# RECONFIGURABLE TABLE FOR TWO

TABLE4TWO
JENNIFER FLACHS
TINA LIAO
LIN-LIN LIOU
REBECCA MACKLEM
JOSE MAINARDI

SECTION 002
GROUP 1
TABLE4TWO@UMICH.EDU

FINAL DESIGN REVIEW
NOVEMBER 2007

REPORT DATE – 11 DECEMBER 2007

PREPARED FOR
YORAM KOREN & APRIL BRYAN

## TABLE OF CONTENTS

**ABSTRACT**
Tables are used daily in almost every situation and setting. One table, however, cannot satisfy the various needs that each situation may require. This project's purpose is to design and build a table that can be used for a business meeting between two people sitting 180 degrees from each other, and can be changed to an intimate table for a couple who is sitting very close to each other. The table must also satisfy all configurations in between these two extreme positions. Our target market was college students and young professionals. We wanted to maximize usable space but accommodate to small living quarters. We generated multiple design concepts, evaluated each design, and refined our concepts to one. This report summarizes our information search, user requirements, engineering specifications, generated concepts, and explains our engineering analysis that ultimately led to the final design. Furthermore, the prototype manufacturing and testing plan is detailed and manufacturing of a working prototype is completed.

## INTRODUCTION

Our project is to design and build a table that can be used in a business setting with two people sitting opposite one another, and then reconfigured for a more intimate setting with two people in love. The user should be able to change the table into different configurations between the given extremes. Our motivation is to create a table that is adaptable to these different settings, so one table would be able to replace many different ones. The basic requirements for our project are the table must seat two people in the settings given, it must be reconfigurable, and it must cost less than $400 to prototype. The explicit user requirements are given in Table 3. This project is sponsored by Professor Yoram Koren and the NSF Engineering Research Center for Reconfigurable Manufacturing Systems.

## INFORMATION SEARCH

Research was done to begin the design process in order to discover any existing ideas and requirements that would be beneficial to our table design. We did research in aesthetics, ergonomics, literature, and patents to get a general overview of table designs. From our research, it was proven that there is a need for a single table that can be transformed to fit in different settings.

### Aesthetics

We interviewed Professor Allen Samuels and Professor Vince Castagnacci of the Art and Design College at the University of Michigan on 13 September 2007 and 17 September 2007, respectively to begin our research on aesthetics. Professor Samuels specializes in industrial design and explained creative ways to approach the problem without having any restraints. He recommended we start developing ideas without determining if they were actually possible or not. This would allow our imagination and creativity to be the driver of our design instead of our restrictive engineering rules. The limitations of the design would be overcome at a later stage when our engineering knowledge could solve the problems that the table design first encounters. Professor Castagnacci teaches an advanced art studio in color and taught us the different effects that colors have when placed next to one another. For example, if one strip of a color is placed on a light surface and another strip of the same color is placed on a dark surface; those two strips would appear to be different colors based on the background. Information from both professors helped us in the aesthetic consideration of our table design.

More research on preferred shapes and forms was done to determine which table shape would be the most desirable to the average customer. It was found that various artists and architects in history based their designs on the golden ratio. The golden ratio occurs when the ratio between the sum of two quantities and the larger quantity is the same as the ratio between the larger quantity and the smaller quantity. This ratio has the value of approximately 1.618 which is phi. This ratio can be applied to shapes to produce the most “visually satisfying” forms. Some examples of these geometric forms are shown in Figure 1. Our table designs will attempt to fit the aesthetically pleasing criteria by basing the tabletop forms on this information. Each different table configuration will attempt to utilize the golden ratio to satisfy the user’s eyes.

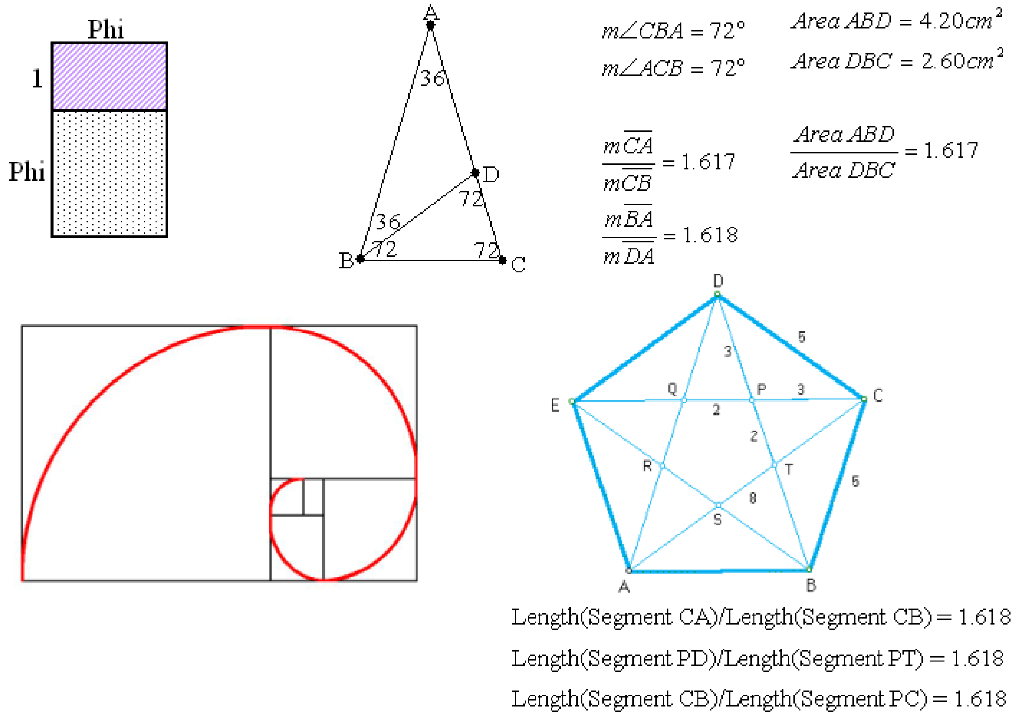



**Figure 1: Most Visually Appealing Geometric Shapes Based on the Golden Ratio [1]**

Throughout our own team discussions, we have discovered preferences based on symmetry. Some of our group members prefer the table to be symmetrical and produce common shapes, while other members do not mind shapes and surfaces that are unconventional. This also comes into consideration when designing for various environments because a business setting may not have the same requirements as an intimate setting. For example, most people may prefer a table for a business setting to have a rectangular shape, while for an intimate setting they may prefer a round table that encloses the couple. These preferences will affect our table design because we are trying to create a table that can adapt to every environment and appeal to the preferences of most users.

**Ergonomics**

To determine the height of our table and the extent to which it should be adjustable, we contacted Thomas J. Armstrong, Professor and Director of the Center for Ergonomics at the University of Michigan, College of Engineering. He sent us a publication of his titled “Biomechanical Aspects of Hand Work” [2]. A section of this reading discusses the body as a series of links and gives results about the length of certain links in the body as a fraction of a person’s stature from research done by R. Drillis and R. Contini. A portion of the results are in Table 1 and Figure 2.

| Link | Fraction of Stature (1) |
|---|---|
| Floor-knee (2) | 0.285 |
| Floor-hip (3) | 0.530 |
| Knee-hip | 0.245 |
| Floor-elbow (4) | 0.630 |
| Floor-elbow when seated, hip & knee level | 0.385 |

*Average link proportions (from: Drillis R, Contini R, 1966)

**Table 1: Link Length as a Fraction of Stature [2]**

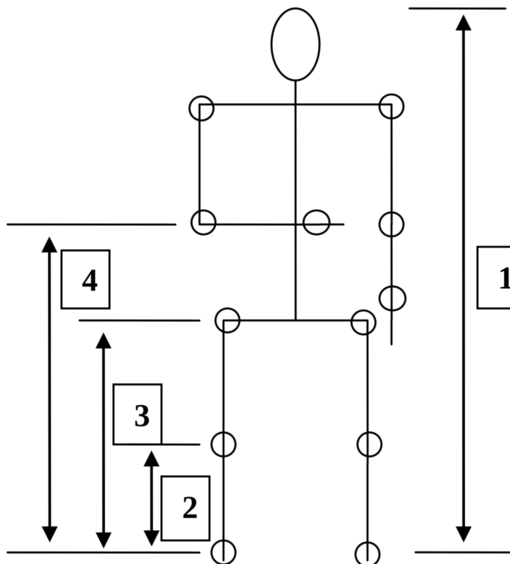



**Figure 2: Links of the Body [2]**

When this data is coupled with statistics regarding the statures of women and men over the age of 18 in the US [2] and seating suggestions from the Spine Universe website and Cornell University Ergonomics Web, we can determine the range of heights our table should have to accommodate a majority of the US population over 18. The article from Spine Universe suggests sitting with hips and knees at right angles and feet flat on the floor to reduce low back pain. The Cornell University Ergonomics Web suggests that a computer user have their wrists flat and the angle of their elbows greater than or equal to 90 degrees to avoid nerve compression at the elbow. The data regarding computer use is important because computers are very common in the workplace and are likely to be a part of most business meetings. Results regarding table height are in Table 2. To insure comfortable table height for the majority of the population, the table height should be adjustable from the 5$^{th}$ percentile for women to the 95$^{th}$ percentile for men. To accommodate persons using an elbow angle greater than 90 degrees, the table should be capable of adjusting below the women's 5$^{th}$ percentile. From these measurements, our table should be adjustable from about 1.8 ft tall to 2.4 ft tall. To fulfill these guidelines the chairs used at our table should have an adjustable seat height and possibly a footrest.

| | Female | | | | Male | | | |
|---|---|---|---|---|---|---|---|---|
| (Percentiles) | **Av** | **5%** | **50%** | **95%** | **Av** | **5%** | **50%** | **95%** |
| **Stature, m** | 1.618 | 1.504 | 1.618 | 1.73 | 1.755 | 1.636 | 1.755 | 1.880 |
| **Weight, kg** | 69.2 | 48.0 | 65.6 | 102.5 | 82.1 | 59.7 | 80.0 | 110.8 |
| **Table height, m** | 0.6229 | **0.5790** | 0.6229 | 0.6660 | 0.6757 | 0.6299 | 0.6757 | **0.7238** |
| | | | | | | | | |
| (Percentiles) | **Av** | **5%** | **50%** | **95%** | **Av** | **5%** | **50%** | **95%** |
| **Stature, ft** | 5.308 | 4.934 | 5.308 | 5.676 | 5.758 | 5.367 | 5.758 | 6.168 |
| **Weight, lb** | 152.6 | 105.8 | 144.6 | 226.0 | 181.0 | 131.6 | 176.4 | 244.3 |
| **Table height, ft** | 2.044 | **1.900** | 2.044 | 2.185 | 2.217 | 2.067 | 2.217 | **2.375** |

*National Health Survey data for Statures and Weight Statures (m) and body masses (kg) for males and females age 18 and over from National Center for Health statistics (from CDC 2003).

**Table height – distance from the floor to the elbow when seated with hips and knees at 90 degree angles

**Table 2: Optimum Table Height for Men & Women in the US [2]**

**Patent Search**

To ensure that our designs were original, we performed a US patent search. We also reviewed previous patents to see if we could use them, especially in the area of reconfiguration mechanisms. We found that our designs were not previously patented, although there were designs that were aesthetically similar to our designs. The following are a few patents that we could use or modify to fit our specifications.

Patent number 5458070, as shown in Figure 3, was an extendible table with two rotating elements [5]. The two flat circular surfaces lie on top of one another in two parallel and adjacent planes but can also slide apart. Each circular surface is supported by its own arm, which rotates the respective surface simultaneously with the other arm using a chain transmission. This patent gave us an idea for surfaces moving on top of one another to produce various table configurations. If we were to change the shape of the tabletop piece, the general mechanism could be used in our designs.

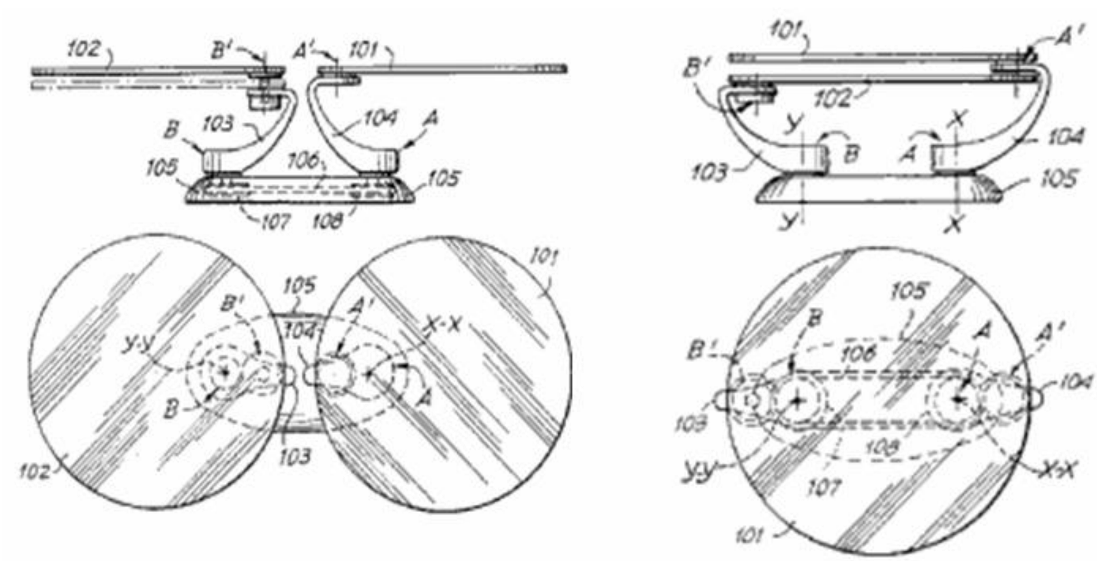



**Figure 3: One Design of Patent 5458070 [5]**

Patent 5375514 (Figure 4) is an adjustable height table support mechanism that lifts and pivots upward and outward on links[6]. This patent uses a simple pivot-locking link ‘system’ to move the tabletop to different heights. This mechanism would be helpful in placing small pieces of the table underneath the main piece. Also, if we can find and modify the mechanism to stop at selected heights, rather than just two heights, as well as at various angles, it would be very useful in the individual user/laptop portion of our designs when different elevations or angles are necessary.

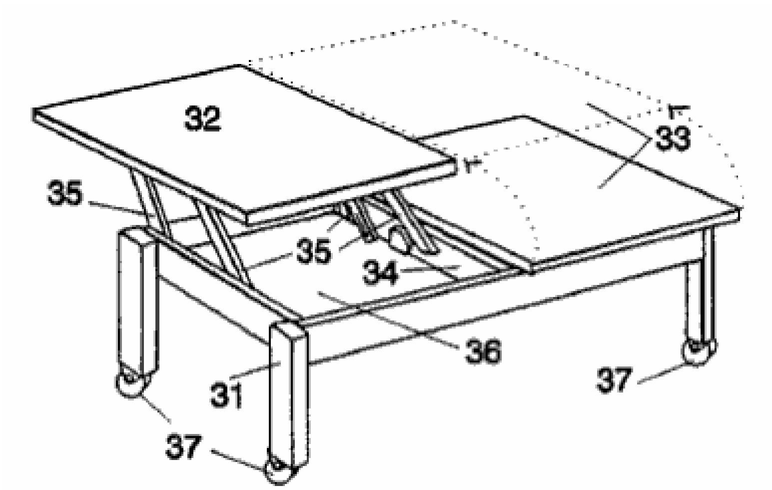



**Figure 4: Patent 5375514 – Adjustable Height Table Support Mechanism [6]**

Patent 5562049 is a table with surfaces that can extend and rotate [7]. The design is shown in Figure 5 while the mechanism in use is shown in Figure 6. The tabletop can extend in size after it shifts to the higher level. This design is mainly used in adjacent seating units so users can have a support surface when seated in attached units. This design is helpful because we want our table to have an adjustable height, and this is an example of how it can be accomplished. The link-locking apparatus can be utilized in many reconfigurable designs. This mechanism allows the user to vary the table height and change the surface area. The design has more than one piece that can lie on top of another which changes the surface area more significantly than other patented designs.

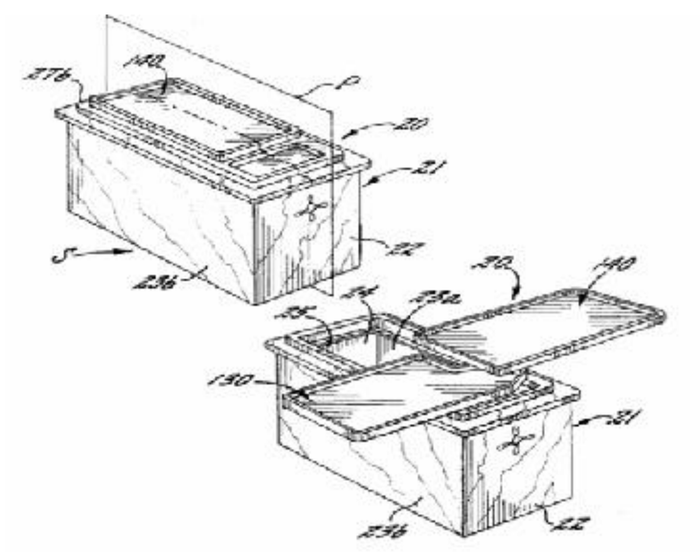


**Figure 5: Design of Patent 5562049 [7]**

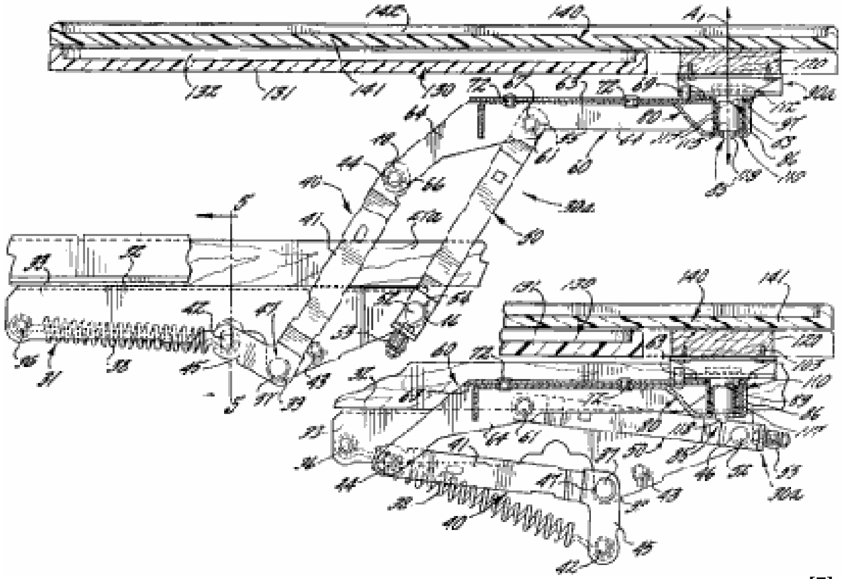


**Figure 6: Moving/Locking Mechanism of Patent 5562049 [7]**

**Literature Search**

A literary search was performed at the University of Michigan in the Art, Architecture and Engineering Library. The main goal of the literature search was to gather ideas regarding existing designs. Many interesting concepts were discovered that would assist us with the creation of our design, but a number of concepts were unconventional and impractical. Nevertheless, these designs helped spark our creative processes.

Figure 7 displays a reconfigurable table consisting of many different smaller tables. Each table has a different shape and can be used separate from the rest of the table. Each of the smaller tables can be combined in a number of different ways to form a bigger table of different shapes depending on the combination.

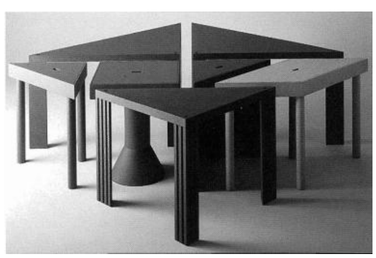


**Figure 7: Smaller Connecting Tables [8]**

Although it does fully satisfy the requirement of having multiple configurations, the table is impractical in use because it could cause confusion when setting up and the amount of smaller tables could prove unsteady when put together as a bigger table.

We found many books relevant to our project, such as <u>50 Tables: Innovation in Design and Materials</u> [4]. The reference displayed 50 different table designs with detailed manufacturing processes. The text explained, in depth, the process of designing and manufacturing unique tables that have multiple methods for reconfiguration, such as rotation and extension. The table in Figure 8 exhibits the ability to stretch out with linkages like an accordion. The seating bench and tabletop are made of a number of wooden tongues that overlap as the table is contracted.

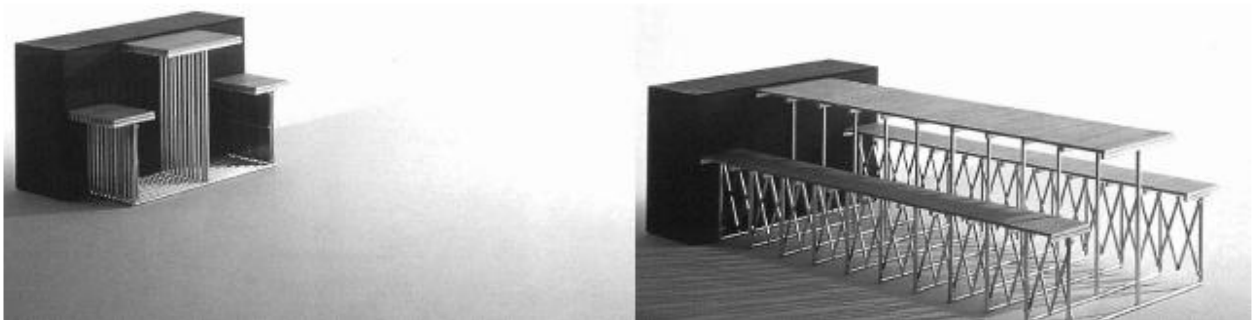


**Figure 8: Stretching Table [9]**

The most impressive feature of the table is its ability to increase almost tenfold in tabletop area but the design and the amount of pieces could prove cumbersome and the design is not very aesthetically pleasing. The amount of force required to stretch the table as it rasps on the ground and moves every linkage could be too great for the average user to exert. A more practical table that extends and increases its tabletop area substantially was found in the reference entitled Expomueble, Annual of Furniture Innovations [10]. The table (Figure 9) extends to almost twice its length by the use of a roller, under the middle section of the table, which moves a belt of linked wooden pieces outwards. While the surface area changes the legs remain motionless unlike the table in Figure 8. The table has a modern design and is aesthetically pleasing.

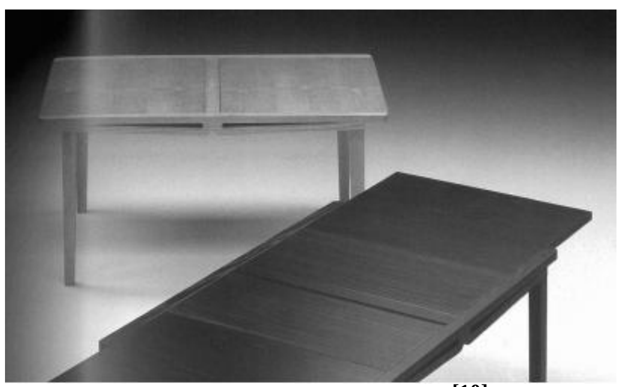


**Figure 9: Rolling Table [10]**

Although it is more aesthetically pleasing and practical than the previous designs, it looks susceptible to jamming. Also, having so many parts and linkages in the tabletop might affect the balance of objects put on top of the table. These extending designs, while interesting, didn’t seem as practical as having using hinges to fold parts of the table. Most of our designs make use of hinges. An office table with hinged flaps from the book, Prototypes for the Designer [11], has two foldable flaps on either side. The far flap is folded up and the near one down, while the rest of the table is static.

**Figure 10: Hinged Flaps in Office Table [11]**

This is a simple concept but the flaps in this table are too small and don't utilize the possibilities hinges can provide when attempting to increase the surface area. The table shown in Figure 11 from American Tables [12] has a greater change in surface area than the one mentioned previously while also employing hinges as the mechanism of reconfiguration. The table changes from a small rectangular table to a bigger circular table by means of hinged flaps on the sides.

**Figure 11: Antique Foldable Table [12]**

While this design has a greater increase in surface area it sacrifices leg room when the large flaps are in the closed configuration. This table also has an antique look that would not appeal to the majority of users. The table in Figure 12 from Expomueble, Annual of Furniture Innovations [10] has flaps on hinges. The flaps fold below the center of the table, perpendicular to the tabletop, providing ample leg room. The two possible surface shapes of the table are a circle and an oval.

**Figure 12: Modern Foldable Table [10]**

This table changes surface area without sacrificing leg room and with a modern aesthetically pleasing design. The change in surface area is also significant. These attributes make this table design an ideal one and a balance of form and function that should be achieved in this project.

Most of our concepts for our designs paralleled the ones we found in our literature search. The challenges each table faced or the concept that they tried to establish were addressed in their designs. The smaller connecting table had a large number of possible shapes. The stretching table increased surface area by more than tenfold and the modern foldable table could hide its tabletop flaps and become smaller without complicated mechanisms and without sacrificing leg room. However none of these tables addressed our complete list of user requirements. It is with these separate concepts gathered from the existing designs and with the future concepts left to be devised that our design can be tied together and our user requirements completed.

### USER REQUIREMENTS AND ENGINEERING SPECIFICATIONS

The original problem statement and customer requirements for our table were determined by Professor Yoram Koren. To better define the project at hand, a more detailed set of customer requirements was determined, and the specific users for the table were identified. A customer base of adults aged sixteen and older was considered when defining specific user requirements. Safety related features were included in the product design to eliminate hazards if younger people are in the vicinity of the table. We also considered different environments where our table could be used. Some settings we considered were business meetings, libraries, coffee shops, apartments, homes, and intimate dinners for two.

User requirements were determined by conducting customer/focus group interviews, and a study of similar products that were currently on the market, such as reconfigurable dining tables, study desks, and conference room tables. By combining the requirements given by Professor Koren and expanding them to reach a broad range of consumers and their preferences, the final list of user requirements was formed. The list of requirements is located in Table 3.

**User Requirements:**

- Seats two people
- Reconfigurable (ability to change form)
- 180 degree seating for business setting
- Close seating for intimate setting
- Costs < $400 to prototype
- Safe for all ages
- Comfortable
- Multiple configurations (large number of configuration options)
- Adjustable height range
- Inexpensive manufacturing costs
- Long lifetime
- Able to hold a large amount of weight
- Varying surface area
- Changes settings quickly
- Aesthetically pleasing
- Electrical transformations
- Used in multiple environments
- Environmentally friendly materials

**Table 3: User Requirements**

The weight of each user requirement was determined by comparing each requirement with an individualized list of every other requirement presented. The order of importance of the requirements was determined by its dominance over the other factors in the individual comparisons. In each comparison of requirement pairs, the more important factors were given a "1" and the less important factors were given a "0." After summing the results for each requirement, a final order of importance was determined. The weights of the user requirements were defined using a scale of 1-10, with 1 being the least important factors, and 10 being factors that are mandatory for the design. Individual comparisons and relative weight measurements are located in Appendix A: Weight Chart.

To reveal areas of improvement in our design specifications, "benchmark" products that served similar purposes were included in the QFD. Each existing product was evaluated against each user requirement and rated on a 1-5 scale. In this scale, 1 represented a product that did not satisfy the requirement at all, and 5 represented a product that satisfied all means of the requirement. The conference room table, dining room table, and study desk shown in Figure 13 were used in our comparison.

**Figure 13: Benchmark products used for QFD Comparison [13]**

Each of our benchmark tables satisfies different user requirements. However, none of them can reconfigure into another type of table. Thus, each of these tables lacks one of the most important user requirements – the ability to reconfigure. Our goal is to design a table that will incorporate the different requirements that each of these tables satisfy. The benchmark portion of the QFD will help us determine what needs to be improved in each design.

The customer requirements were translated into engineering specifications by defining them as quantifiable parameters. The set of specifications satisfies every user requirement shown in Table 4. The specification along with its target value and unit are presented in the QFD (Figure 14, pg 12). These target quantities were determined by the user requirements, analyzing present tables, and determining what was convenient for the user to do. Compatibility in different environments, numbers of configurations, seats available and cost were taken directly from the user requirements. The table height range, surface area range, weight, failure load, and surface defects were determined by researching the different tables that are used in each environment. The reconfiguration steps and time, exposed electronics, lifetime of the table, and number of colors were determined by what would be the most convenient for the user. A cross-correlation between the individual engineering specifications was determined to reveal indirect dependencies of customer requirements on engineering specifications. The relationships are displayed by using a "- -" representing a strong negative relationship, a "-" representing a negative relationship, a "+" representing a positive relationship, and a "+ +" representing a strong positive relationship in the upper triangle of the QFD.

**Engineering Specifications:**

- Compatible in Different Environments ≥ 3
- Configurations ≥ 3
- Seats Available ≥ 2 people
- Cost ≤ $400
- Range of Table Height ≥ 6 inches (0.15 m)
- Surface Area Range ≥ 5 $ft^2$ (0.46 $m^2$)
- Weight ≤ 150 lbs (68 kg)
- Static Failure Load ≥ 200 lbs (90.72 kg)
- Surface Defects ≤ 0.5 defects/$ft^2$ (5.38 def/$m^2$)
- Reconfiguration Steps ≤ 4 steps
- Reconfiguration Time ≤ 15 seconds
- Exposed Electronics ≤ 1 unit
- Material Lifetime ≥ 10 years
- Colors Available ≥ 2

**Table 4: Engineering Specifications**

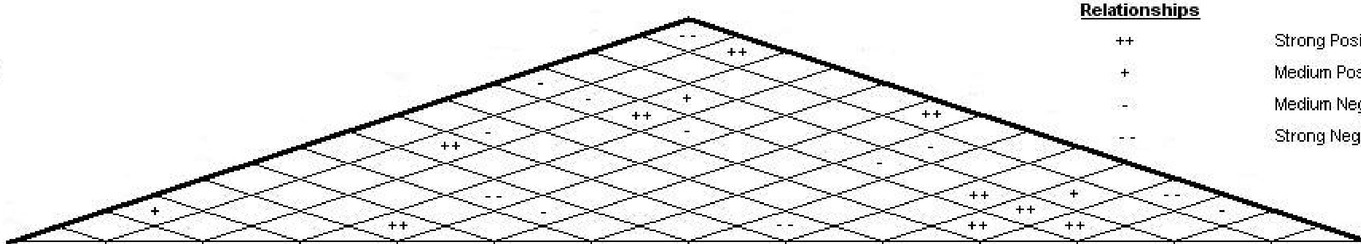
For each individual specification and requirement combination a correlation was made using a scale of 0, 1, 3, and 9 which is described below.

9 = strongly related
3 = somewhat related
1 = weakly related
0 = totally unrelated

After each respective correlation was made, the rank of the relationship was included with the weight of the user requirement being evaluated to determine the overall impact of the specification on the design. These values were summed and normalized to give a final ranking to the importance of the defined engineering specification. The finalized QFD was then determined from the rankings. The QFD for the design is presented in Figure 14.

The QFD shows that the most important engineering specifications for the project are the compatibility of the table in different environments, the number of available configurations and the height adjustment range of the table. Throughout the design process, all of our design choices will be based on these specifications. The QFD that was created gives the designers a guideline to follow with respect to the order of importance for how the table is designed.

Quality Function Development (QFD)



**Relationships**

| | |
|---|---|
| ++ | Strong Positive |
| + | Medium Positive |
| - | Medium Negative |
| - - | Strong Negative |

(+) => more is better
(-) => less is better

| | Weight* | Failure Load (+) | Reconfiguration Time (-) | Seats Available (+) | Surface Defects (-) | Material Lifetime (+) | Exposed Electronics (-) | Cost (-) | Reconfiguration Steps (-) | Range of Table Height (+) | Compatable in Different Environments (+) | Surface Area Range (+) | Configurations (+) | Colors available (+) | Weight (-) | Benchmarks: *Conference Room Tables* | *Dining Room Tables* | *Study Desks* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Seats 2 People | 10 | | | 9 | | | | | | | 1 | | 1 | | | 4 | 4 | 5 |
| Able to Reconfigure | 10 | | 9 | | | | | | 9 | | | 3 | 3 | | 3 | 1 | 1 | 2 |
| Business Meeting Appropriate | 10 | | | 3 | | | 1 | | | 1 | 9 | 9 | 3 | 1 | | 5 | 1 | 2 |
| Intimate Setting Appropriate | 10 | | | 3 | | | 1 | | | 1 | 9 | 9 | 3 | 1 | | 1 | 5 | 2 |
| Costs < $400 to Prototype | 10 | | | | | | | 9 | | | | | | | 1 | 4 | 4 | 4 |
| Aesthetically Pleasing | 3 | | | | 9 | | 3 | | | | | | | 9 | | 4 | 4 | 4 |
| Adjustable Height Range | 6 | | 1 | | | | | | | 9 | | | 1 | | | 1 | 1 | 1 |
| Used in Multiple Environments | 2 | | | 3 | | 1 | | | | 3 | 9 | 1 | 3 | | | 4 | 4 | 4 |
| Varying Surface Area | 4 | | | 3 | | | | | | | | 9 | 9 | | 9 | 2 | 2 | 3 |
| Changes Settings Quickly | 4 | | 9 | | | | | 3 | 9 | 3 | | | 1 | | 9 | 1 | 1 | 2 |
| Electrical Transformations | 3 | | 9 | | | | 9 | 9 | 1 | 1 | | | | | 9 | 1 | 1 | 1 |
| Safe for all Ages | 9 | 3 | | | 1 | 1 | 3 | | | 1 | 3 | | 1 | | | 2 | 1 | 3 |
| Multiple Configurations | 7 | | 1 | 3 | | | | | 3 | 3 | 3 | 3 | 9 | | 3 | 5 | 5 | 5 |
| Environmentally Friendly Materials | 1 | | | | 3 | 3 | | 3 | | | | | | | | 3 | 4 | 4 |
| Long Lifetime | 5 | 3 | | | 9 | 9 | | | | | | | | | | 1 | 1 | 2 |
| Inexpensive manufacturing costs | 6 | | | | | 1 | 3 | 9 | | | | | | | 1 | 3 | 3 | 3 |
| Able to hold a large amount of weight | 5 | 9 | | | | 1 | | 1 | | | | | | | 9 | 5 | 5 | 5 |
| Comfortable | 8 | | | | | | | | | 9 | | 3 | | | | 4 | 4 | 4 |
| **Measurement Unit** | | lbs (kg) | sec | # | defect/$ft^2$ (defect/$m^2$) | years | # | $ | # | inches (m) | # | $ft^2$ ($m^2$) | # | # | lbs (kg) | | | |
| **Target Value** | | 200 (90.72) | 15 | 2 | 0.5 (5.38) | 10 | 1 | 400 | <=5 | 6 (0.15) | 3 | 5 (0.46) | 3 | 2 | 150 (68) | | | |
| **Importance Rating** | | **4** | **5** | **6** | **4** | **3** | **4** | **6** | **5** | **7** | **9** | **10** | **8** | **2** | **7** | | | |
| **Total** | | 87 | 166 | 189 | 84 | 70 | 101 | 191 | 150 | 197 | 256 | 293 | 224 | 47 | 211 | | | |
| **Normalized** | | 0.04 | 0.07 | 0.08 | 0.04 | 0.03 | 0.04 | 0.08 | 0.07 | 0.09 | 0.11 | 0.13 | 0.10 | 0.02 | 0.09 | | | |

***Weights: scale of 1 to 10**
*(ten being most important)*

**Key:**
9 => Strong Relationship
3 => Medium Relationship
1 => Small Relationship
*(blank)* => Not Related

**Figure 14: Quality Function Development (QFD)**

## Concept Generation

Our team used the FAST diagram shown in Figure 15 to analyze the task function, primary basic functions, and basic functions of our table. We reviewed the project description and concluded that the task function of our table was to support loads. Then we considered what the table was required to do in order to support loads to decide on our primary basic functions. These are to reconfigure structure, ensure stability, maintain durability and ensure safety. Each primary basic function was then analyzed to determine how it could be satisfied in order to establish its defined function. The basic functions for reconfiguring structure are to adjust height, change surface area and alter the shape of the table. Stability can be ensured by balancing the loads of the table. Maintaining durability is satisfied by designing a table that is able to withstand impact and resist elements. In order to ensure safety, it would be preferable if the table corners are slightly rounded and no areas can pinch fingers. If we were to use the jack as the base, we would need to focus on safety as there is potential for serious injury.

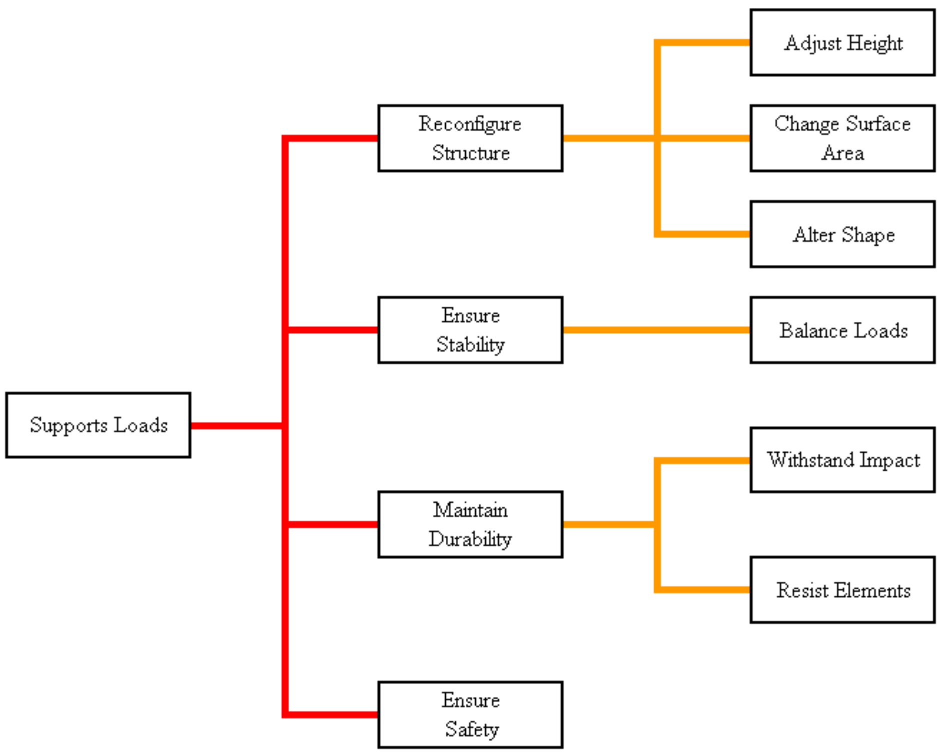



**Figure 15: FAST Diagram**

A morphological chart was used to generate concept ideas for our basic functions. It gives the team a sense of what needs to be accomplished and also provides an approachable and visual map of our designs. In the chart (Figure 16, pg 16), we give design options for each of the defined basic functions. A high-level design was created by combining concepts for every basic function.

The first function of our FAST diagram is to adjust height. In the morphological chart, we describe six concepts that fulfilled this function. The first one was a simple pin system. The pin could either be spring-loaded, where the pin is attached to the inner bar and the user pushes the pin in and moves the leg to the next hole, or it could be completely unattached, where the user has to completely pull out the pin to adjust the height. Height adjustment would be incremental.

As this concept is manual, height adjustment could be difficult for a single person to accomplish. The next concept was a jack system. Adjustment could occur via a lever or a foot pump. The range of adjustment is continuous with a jack. This concept can be motorized for the convenience of the user. Another concept is a screw system where the entire table is rotated to alter the height. Depending on the shape of the tabletop, this system's range can be continuous and also motorized but may be impractical with large configurations. This system is easier to operate manually. The fourth concept is the rack and pinion in which gears are utilized to adjust the height. This system has a continuous range and may also be motorized. A more unique concept was the linkage system. This system has bars that open to lower the height or close up to increase the height. The ends of the bar would slide in rails attached to the underside of the tabletop. This system is more creative but may be less feasible with larger, heavier tabletops but could be motorized to solve this. The last concept was a linkage system between a small portion of the tabletop and the tabletop. This would result in an individual height adjustment allowing for different heights to be achieved simultaneously. This concept could easily be altered to be motorized but is easily operated manually.

The second function to be fulfilled was changing surface area. We had three concepts that accomplished this. The first one was hinges. Hinges would enable us to fold pieces of the table over or under another part. A second concept was the use of rotating parts. A portion of the table could be rotated under or over another part using a pivot. This concept could be motorized and/or incorporated with gears and chains to make separate parts rotate simultaneously. This would decrease reconfiguration effort and time. The last concept was to completely remove a piece of the tabletop. This concept is very common in designs where the surface area changes significantly.

The next function was altering shape which tied into the function of changing surface area. Once again, hinges could be used to fold pieces underneath the tabletop surface to create a different shape. Another concept would be to rotate pieces around each other to form other shapes with pivots. And like with changing surface area the last concept we came up with was to remove a piece of the table entirely.

The fourth function required was to balance loads, both internal and external. The first concept was simply to have more than one leg. Three legs would ensure the absence of wobble and four legs will easily support any external off-centered loads. If we wanted to have only one leg, we could design the table with a large base and large connecting surface to the underside of the table which would distribute loads more evenly. A third concept was to have a symmetrical base to ensure balance. The last concept is to have a heavy base. This would support any offset loads.

The fifth function of our project was withstanding impact. The fourth function covered static loads but the table has to also be able to remain upright and undamaged when subjected to large dynamic forces. Our first concept to achieve this function was material selection. Glass, metal, or Plexiglas are examples of materials that could withstand large forces. Reinforcement around the edges and on the surface would also help the table to endure impact. The last concept was to have an internal shock system that would damp out large forces but not move the tabletop.

Another required function was resistance to the elements. This includes everything in the environment from the humidity in the air to changes in temperature. The choice of material could easily satisfy this function. Metal with a rust resistant coating would do well to repel the elements. A second option was to cover the table in a water/scratch resistant coating. The last concept was to cover the tabletop with a water/scratch resistant material.

The last function of our table was that it had to be safe for the users, whether or not they were in the age range of our intended consumers. We came up with five concepts that would increase the safety of our project. The first concept was to round the edges or have a protective border along the edge. This would protect users from possible injury if they ran into the edge of the table. Another concept was to design a raised edge along the exterior of the table to keep objects from falling or rolling off and landing on a person's foot or a child's head. A smooth, finished surface would decrease the chances of injury from splinters or sharp edges that might arise from an uneven surface. A fourth concept was to refrain from having gaps or small spaces in which the user might pinch their fingers or skin. This was especially important due to the concepts of rotating, moving, and folding parts that are necessary to accomplish our other functions. The last concept we came up with to ensure safety was to have electrical grounding, if there was a motor or any electrical device involved to prevent the possibility of electric shock.

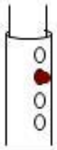
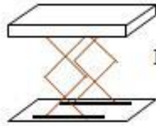
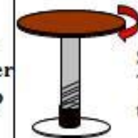
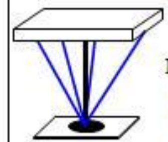
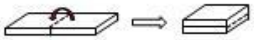
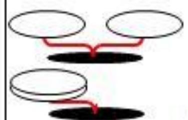
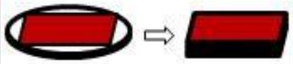
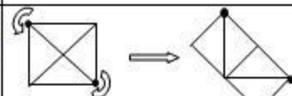
| Function | Concept 1 | Concept 2 | Concept 3 | Concept 4 | Concept 5 | Concept 6 |
|---|---|---|---|---|---|---|
| Adjust Height |  Pin System: Push in the pin to raise table and pin will pop out at the next hole |  Jack System: Lift with a lever or a footpump |  Screw System: Turn whole table to raise or lower |  Rack & Pinion System: Gears raise and lower table |  Linkage System: Exterior bars move in and out to adjust |  Separate surface that can lift/tilt depending on preference |
| Change Surface Area |  Hinges to fold corners or edges under each other |  Rotating tabletops that move on top of each other | Pieces of the table that can be removed and stored away | Slide and roller to move table sections | Accordian folds to collapse sections together | |
| Alter Shape |  Hinges to fold corners or edges under each other |  Rotating pieces that move to create different shapes | Pieces of the table that can be removed and stored away | | | |
| Balance Loads | More than 1 leg (3 or 4) |  Large base and connection point to the table (if only 1 leg) | Symmetrical base | Heavy Base | | |
| Withstand Impact | Material selection (glass, plexiglass, metal) | Reinforcement around edges or surface |  Shock system that can damp out large impacts | | | |
| Resist Elements | Material selection (glass, plexiglass, metal) | Water resistant coating | Scratch resistant material/coating | Sealed grooves and holes to prevent material or moisture collection | Covered joints to protect wear and rust | |
| Ensure Safety | Rounded edges or protective border | Slightly raised exterior edge to prevent objects from rolling off the table | Smooth/finished surface | No gaps or small spaces that can pinch fingers | Electrical grounding if necessary | |

**Figure 16: Morphological Chart**

From the results of the morphological chart, several design options were developed. Different concepts from each function were combined to contribute to a complete table design. From the many concepts we came up with for each function, we were able to produce fifteen possible designs. There were concepts, from each function, that were recurrently used in many of the designs we generated. For height adjustment, the jack and pin system were prevalent. Hinges and rotation were incorporated into many of the designs for both altering shapes and changing the surface area. Most of the designs used one leg due to the aesthetic appeal and ease in altering the height and therefore utilized the large base. Although the morphological chart drove us to think of many solutions for every function, some concepts were too complicated or unfeasible to place into our actual designs.

## CONCEPT EVALUATION AND SELECTION

In order to narrow down the number of concept choices, an initial feasibility analysis was completed. Each design was analyzed in terms of its ability to function and be manufactured. Several designs that had been conceived were eliminated at this stage due to complexity and/or difficulty in reconfiguration. Designs that did not satisfy all of the user requirements or engineering specifications, shown in Table 3 (pg 9) and Table 4 (pg 11) respectively, were also eliminated from consideration. These designs consisted mostly of concepts that did not have enough (at least three) reconfiguration arrangements, and concepts that did not have a height adjustment option. Specific design faults are included with the description of each individual table in Appendix B for the designs that were initially eliminated.

After these designs were taken out of consideration, the three remaining concepts were further analyzed using lists of merits and limitations for each design of overcoming limitations. The final design concepts were chosen using a Pugh chart.

### Concept 1: The Lotus

The first selected concept, shown in Figure 17, is the Lotus Table. This design focuses on only using hinges as the primary joint between sections. The table has two different shapes that it can be reconfigured into, and changes surface area three times. The table has a small circle configuration that is appropriate for an intimate situation, a small square configuration that is appropriate for a range of intrapersonal interactions, and a large square configuration that doubles the surface area of the table and makes it suitable for a business meeting between at least two people. The table also has a jack base that allows it to have at least six inches of vertical travel. The jack is activated by using a hydraulically powered foot pedal. The jack is a separate part of the design and can be used on multiple table designs that have one leg.

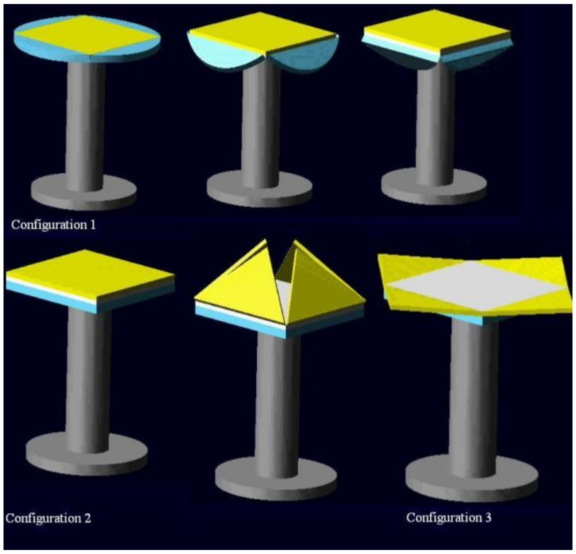



**Figure 17: The Lotus Table Design**

The merits and limitations that were found for this table along with the design choices to overcome the limitations are shown in Table 5 and Table 6, respectively.

- ✓ Doubles surface area
- ✓ Different shapes (circle & square)
- ✓ Very few extra moving parts
- ✓ Aesthetic
- ✓ Easy to manufacture
- ✓ Conservative look
- ✓ Multiple material options
- ✓ Simple design/Clean lines
- ✓ Easy to reconfigure - only need to fold
- ✓ Symmetrical

**Table 5: Concept 1 Merits**

The main merits for this table design are due to the fact that it has a large change in surface area and is very straightforward. The concept uses only hinges to reconfigure and therefore has increased simplicity in its design. With the simplicity of the concept, we are also able to incorporate multiple material options in the design without reconfiguration issues such as requiring a metal component for rotation. The conservative look, symmetry, and simple shapes of the table can also appeal to many different consumers.

| LIMITATION | SOLUTION TO LIMITATION |
|---|---|
| Only 1 leg, stability issues | Wide base and connection to table |
| Exposed Hinges (comfort) | Special flat hinge |
| Difficult to unfold, edges meet in center | Round corners and add gripping material |
| Conservative | Use a post-manufacturing aesthetic design |
| Bending load may be to great | Cross beam support under flaps |
| Heavy to lift | Lightweight and durable material |

**Table 6: Concept 1 Limitations and Solutions**

All of the major limitations found for this design were found to have simple solutions and ways to overcome them. The major limitation that was focused on was the stability issues that were present because the table has only one leg. These issues were overcome by ensuring a wide connection where the leg contacts the table and where the leg contacts the floor, or grounding surface. The other limitations are also overcome by simple solutions such as buying special flat hinges to ensure comfort, an increase in aesthetics after the table is manufactured to increase its uniqueness, and cross beams under the flaps to add extra support to the extended edges.

**Concept 2: Shapely**

The second selected concept, shown in Figure 18, is the Shapely Table. This design uses both rotating mechanisms and hinges as the primary joints between linkages. The table has three different shapes that it can be reconfigured into, and changes surface area three times. The table has a circular configuration that is appropriate for various general uses, a smaller oval like shape for a close intimate setting, and a larger rectangular configuration that is appropriate for intrapersonal interactions. The track on the underside of the table will allow the two ends to slide and rotate in order to move into another configuration. The table will also have a jack base that allows it to have at least six inches of vertical travel. The jack uses a hydraulically powered foot pedal to raise the table and a release valve to lower the table.

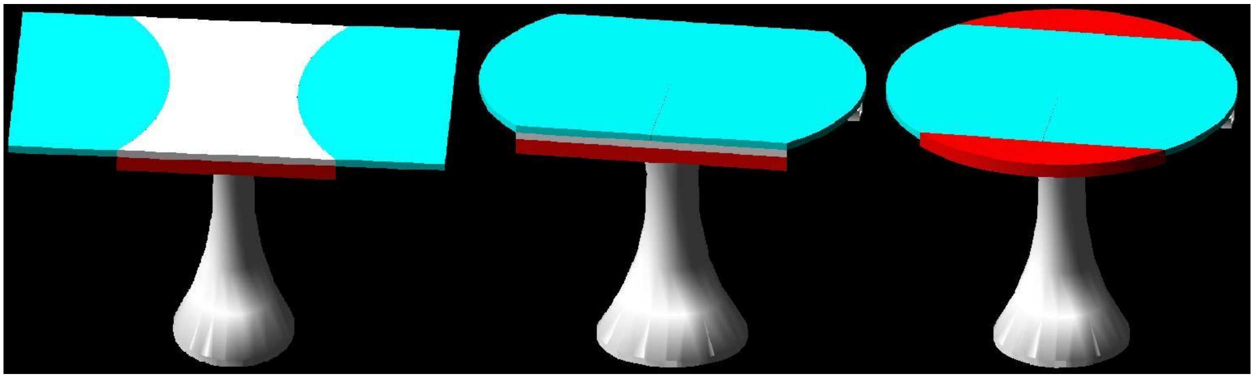


**Figure 18: Shapely Table Design**

The merits and limitations that were found for this table along with the design choices to overcome the limitations are shown in Table 7 and Table 8 respectively.

| |
|---|
| ✓ Easy to reconfigure |
| ✓ 3 different shapes |
| ✓ Large change in surface |
| ✓ Symmetrical |
| ✓ Conservative look |
| ✓ Easy to manufacture |
| ✓ Mechanical advantage (jack) |
| ✓ Intermediate heights |

**Table 7: Concept 2 Merits**

The main merits for this table design are due to the fact that it is simple to reconfigure and manufacture and has a measurable change in surface area. The concept uses both rotating mechanisms and hinges to reconfigure and therefore has simplicity in its design. The conservative look, symmetry, and multiple shapes of the table can also appeal to many different consumers in many different environments. The use of the mechanical jack also incorporates a mechanical advantage into the system which allows the user to exert less force and energy in adjusting the table to their level of comfort.

| LIMITATION | SOLUTION TO LIMITATION |
|---|---|
| Only 1 leg, stability issues | Wide base and connection to table |
| Sharp Edges | Round/chamfer edges of table |
| Conservative | Use a post-manufacturing aesthetic design |
| Jack placement within base and safety | Place on ground with cover over scissors parts |
| Heavy to lift | Lightweight and durable material |

**Table 8: Concept 2 Limitations and Solutions**

All of the major limitations found for this design were found to have simple solutions and ways to overcome them. The major limitation that was focused on was the stability issues that were present because the table has only one leg. These issues were overcome by ensuring a wide connection where the leg contacts the table and where the leg contacts the floor, or grounding surface. Also, the base can be made heavier in order to offset any weight that is placed on the ends of the table. The other limitations are also overcome by simple solutions such as rounding the edges of the table to ensure safety, an increase in aesthetics after the table is manufactured to increase is uniqueness, and a cover for the scissor jack for safety.

**Concept 3: Rotate Me**

The third selected concept, shown in Figure 19, is the Rotate Me Table. This design focuses on using cylindrical fittings as the primary joint between linkages. The table has three different shapes that it can be reconfigured into, and changes surface area three times. The table has a small circle configuration that is appropriate for an intimate situation, a configuration with two separate circles which is appropriate for a range of intrapersonal interactions, and a large configuration, shaped like a rectangle with rounded ends that doubles the surface area of the table and makes it suitable for a business meeting between two people. The table also has a pin adjustable base that allows it to have at least six inches of vertical travel. Table height must be manually adjusted.

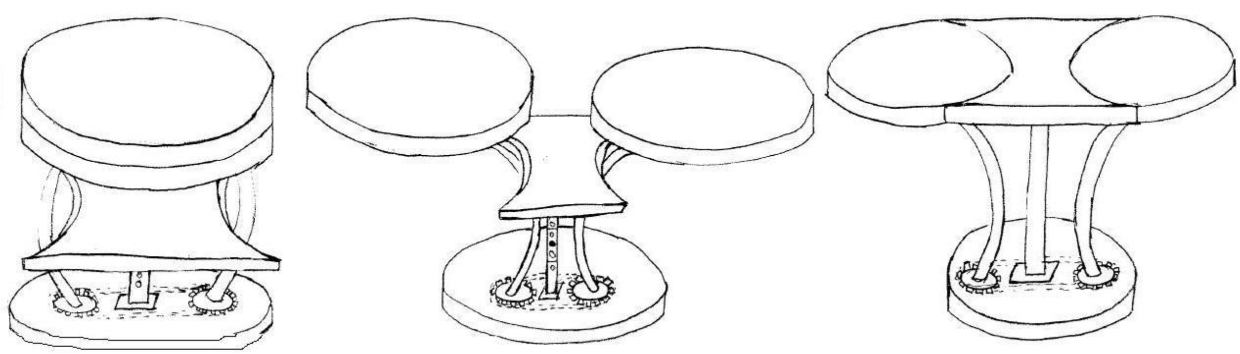


**Figure 19: Rotate Me**

The merits and limitations that were found for this design, along with modifications to overcome the limitations, are shown in Table 9 and Table 10 respectively.

- ✓ Mechanical advantage (gears)
- ✓ 3 different shapes
- ✓ Sides move together
- ✓ Creative/interesting appearance
- ✓ Large increase in surface area

**Table 9: Concept 3 Merits**

The main merit of this table design that sets it apart from the other concepts is its creative appearance and function. This ingenuity allows the design to have many interesting features such as having three very different shapes. The table also includes a sprocket and chain assembly in its base which allows the user to turn both table surfaces at the same time with minimal effort. Another distinguishing merit awarded to this design was the large increase in surface area. The table surface area increases by more than a factor of two between the smallest and largest configurations.

| LIMITATION | SOLUTION TO LIMITATION |
|---|---|
| Unbalanced Loads | Thicker legs, wider base connections |
| Sharp Edges | Round/chamfer edges of table |
| Minimal leg room | Remove middle section and store elsewhere |
| Jack placement within base and safety | Place on ground with cover over scissors parts |
| Table legs will jab user in closed configuration | A wide and flat connection for more comfort |

**Table 10: Concept 3 Limitations and Solutions**

All of the major limitations found in this design were found to have simple solutions that could overcome them. The major limitation was the compromised stability due to the small rotating legs. These issues are overcome by ensuring a wide connection where the leg contacts the table and where the leg contacts the floor, or grounded surface, and by increasing the diameter of the legs. The other limitations of sharp edges and insufficient leg room are also overcome by simple solutions such as rounding the edges of the table to ensure safety and redesigning the shapes and the locations in which un-used pieces are stored.

In order to choose the best design from our three concepts, we selected the Concept 1, the Lotus, as the baseline for our Pugh chart (Figure 20, pg 22). The other two designs were evaluated against this one to decide which of the three is best to continue with.

| Customer Requirement | Weight | Concept 1: "The Lotus" | Concept 2: "Shapely" | Concept 3: "Rotate Me" |
|---|---|---|---|---|
| Seats 2 People | 10 | 0 | 0 | -- |
| Reconfigurable | 10 | 0 | + | 0 |
| Business Meeting Appropriate | 10 | 0 | 0 | 0 |
| Intimate Setting Appropriate | 10 | 0 | 0 | 0 |
| Costs < $400 to Prototype | 10 | 0 | 0 | 0 |
| Safe for all Ages | 9 | 0 | + | -- |
| Comfortable | 8 | 0 | 0 | -- |
| Multiple Configurations | 7 | 0 | + | 0 |
| Adjustable Height Range | 6 | 0 | 0 | -- |
| Cheap manufacturing costs | 6 | 0 | -- | -- |
| Long Lifetime | 5 | 0 | 0 | 0 |
| Able to hold a large amount of weight | 5 | 0 | 0 | -- |
| Varying Surface Area | 4 | 0 | -- | + |
| Changes Settings Quickly | 4 | 0 | + | + |
| Aesthetically Pleasing | 3 | 0 | 0 | 0 |
| Electrical Transformations | 3 | 0 | 0 | -- |
| Used in Multiple Environments | 2 | 0 | 0 | 0 |
| Environmentally Friendly Materials | 1 | 0 | 0 | 0 |
| **Total (+)** | | | (+)30 | (+)8 |
| **Total (--)** | | | (-)10 | (-)47 |
| **Net Total** | 113 | 113 | 133 | 74 |
| **Weighted Total** | | 100% | **118%** | 66% |

**Figure 20: Pugh Chart to Compare Our Three Concepts**

Concept 1 was chosen because it seemed the simplest in design and function. Concept 2, Shapely, rates higher in the following requirements: being reconfigurable, being safe, having multiple configurations, and changing between different arrangements quickly. It is easier to change configuration in the Shapely Table than in the Lotus Table, as there are more steps to unfolding the small square into the bigger square. This ease of use also enables quick reconfiguration time. There is also less chance of injury in Shapely than the Lotus. When the Lotus is being unfolded into the big square, there is a large possibility of pinching a finger in a hinge, especially if the outer piece were to fall into place. The movements in reconfiguring Shapely are mostly horizontal since the outer table tops only need to be lifted 2 inches to reconfigure and thus more controlled due to the track and pin system underneath the tabletop. The variety in configurations for the second concept is also greater than those in the first. The Lotus only has a square and a circle while Shapely has a rectangular, a circular, and an oval configuration. In the requirements of minimal manufacturing costs and varying surface area, Shapely lost points. The second concept has significantly more complex shapes and mechanisms, which would increase costs. Its range of surface area, from the smallest to the largest configuration, was the least of the three. The largest configuration did not double the area of the smallest one.

The Rotate Me table fared significantly worse than the other two concepts. It was better than the Lotus in varying surface area and changing settings quickly. Rotate Me more than doubles in surface area between the smallest and largest arrangements. The chain and sprocket system made reconfiguring the table easy and quick because both circular parts rotate simultaneously.

However, in the areas of seating 2 people, safety, comfort, height range, weight support, and electrical transformations, it was sub-par to the Lotus. When seating 2 people in the smallest configuration, the leg room underneath the table was very limited due to the extra table piece stored in the center. The protruding portions of the legs when connected to the tabletops and the adjustable middle portion intrude on the leg room and comfort of the person sitting at the smallest configuration. The design also has a greater possibility of causing injury due the sharp corners of the middle piece that is suspended underneath the table and the moving mechanism of the two circular pieces. The shape and structure of the legs that allows the table pieces to rotate on top of one another also inhibit height adjustment and large weight support. All parts and pieces that make this design creative and interesting also increase difficulty and costs in manufacturing. Overall, with the Lotus set at 100%, Shapely received 118% while Rotate Me earned 66%. This clearly shows that Shapely was the best design according to our customer requirements.

### SELECTED CONCEPT

After additional review of Concept 1 and Concept 2 with our extended team of engineers and sponsor during our presentation on 23 October 2007, it was noted that Concept 1, The Lotus, is a table that has been seen before and does not have three very different table shapes. On the other hand, Concept 2, Shapely, produced three very different shapes for the user to be able to use and was an innovative configuration. The vote within our extended team of engineers was unanimous for Concept 2, Shapely.

Concept 2 is a rectangular table in its largest form, configuration 'A' in Figure 21. From this, the two far ends will slide upward and away from the center portion of the table on a track underneath the table (configuration 'B' and 'C'). Then in configuration 'D', the end pieces will rotate 180° so the two flat edges are facing each other. This allows the ends to slide together over the center portion of the table to create the oval-like configuration 'E'. Finally, to make the circular configuration 'F', two table flaps flip up on the flat sides of the oval.

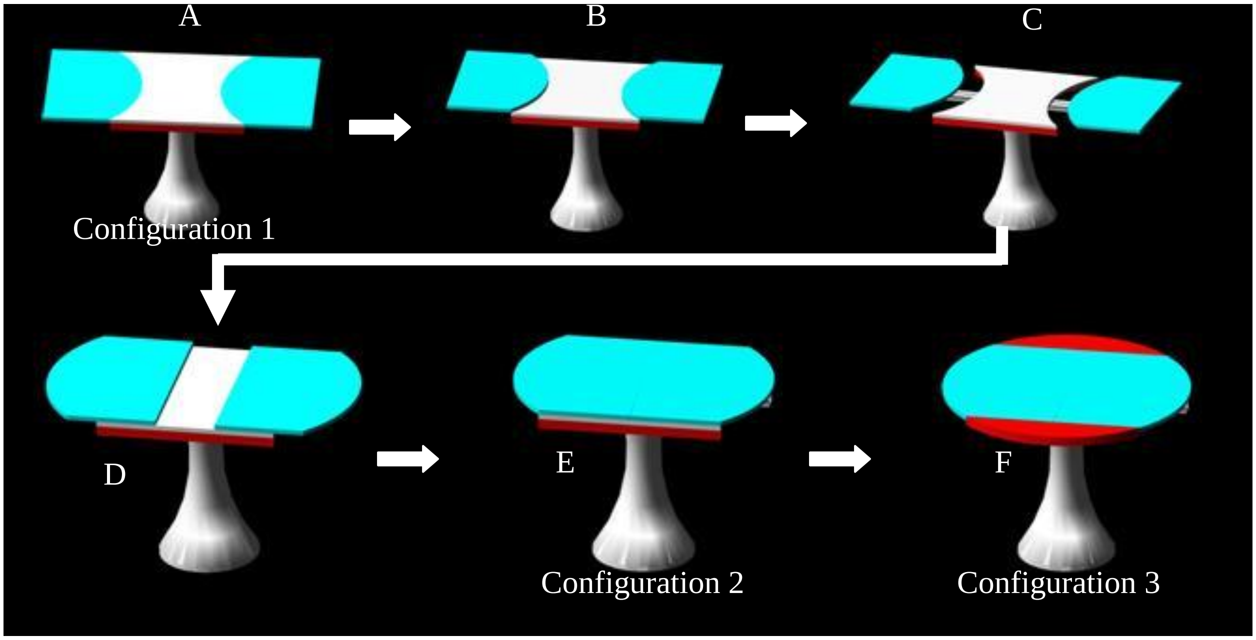



**Figure 21: Configuration Steps for Concept 1: Shapely**

The dimension of the rectangular table is 6 ft (1.83 m) by 3 ft (0.91 m), the dimension of the oval shape table is 3 ft (0.91 m) by 4.24 ft (1.29 m), and the diameter of the circular table is 4.24 ft (1.29 m). A rough engineering drawing of the rectangular table with the circular flaps is shown in Figure 22. General dimensions of the main pieces are labeled in inches on the drawing. The base of the table is an approximate model of the jack we will be purchasing. The jack will have an additional section on top of the jack to provide extra height so the jack does not have to be fully extended to obtain optimal height. We are also considering a wider base covering with a slit for the jack foot pedal. A wider wooden cover around the crude jack base will increase aesthetics as well as increase the stability of the table. The track system for the bottom of the table will be manufactured if we cannot purchase one that will fit our needs.

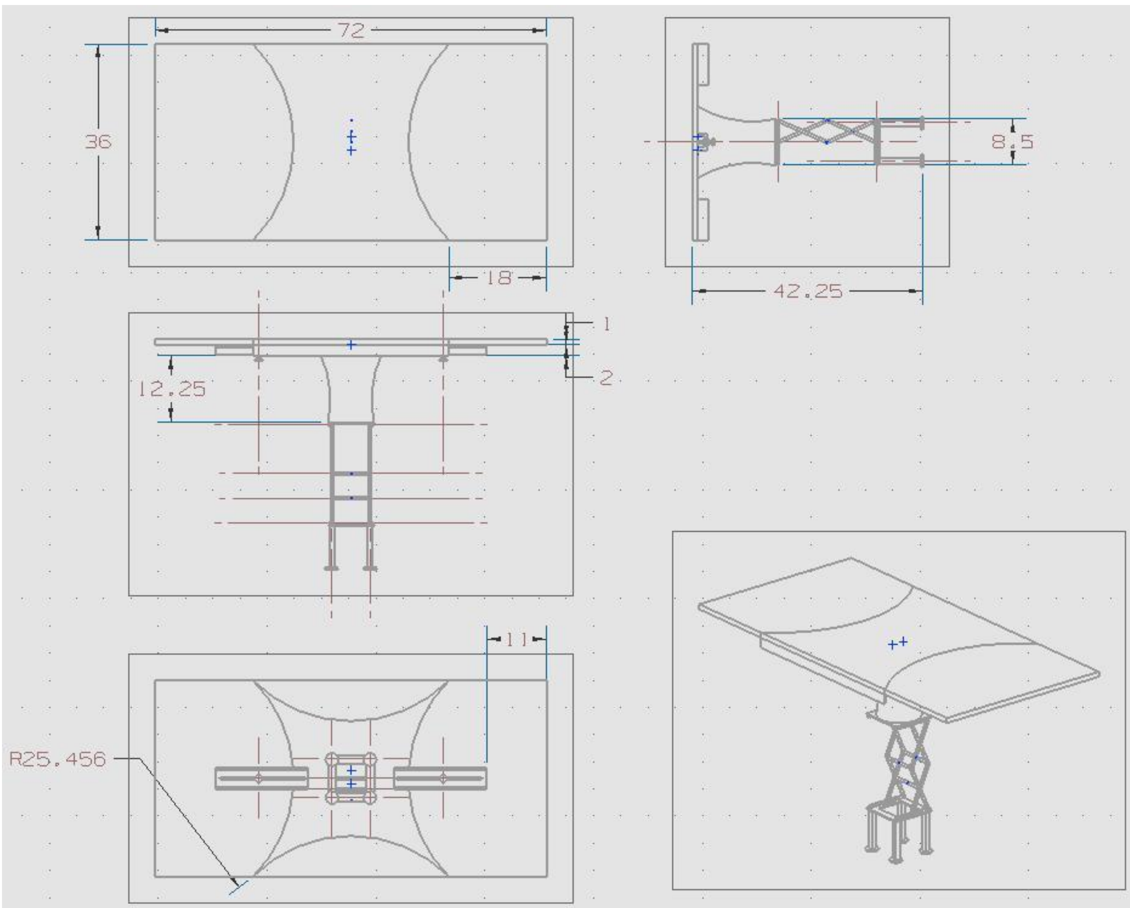


**Figure 22: Engineering Drawing for Concept 1: Shapely (Dimensions are in inches)**

The track underneath the table will have a sliding pin system to translate and rotate the end pieces. A top view and side view of the pin location within the track system are shown in Figure 23 (pg 25) as the table is being transformed. The simple pin shown in the drawing will be connected to the underside of each end piece. The track itself will be connected to the center portion of the table leaving a space for the jack base.

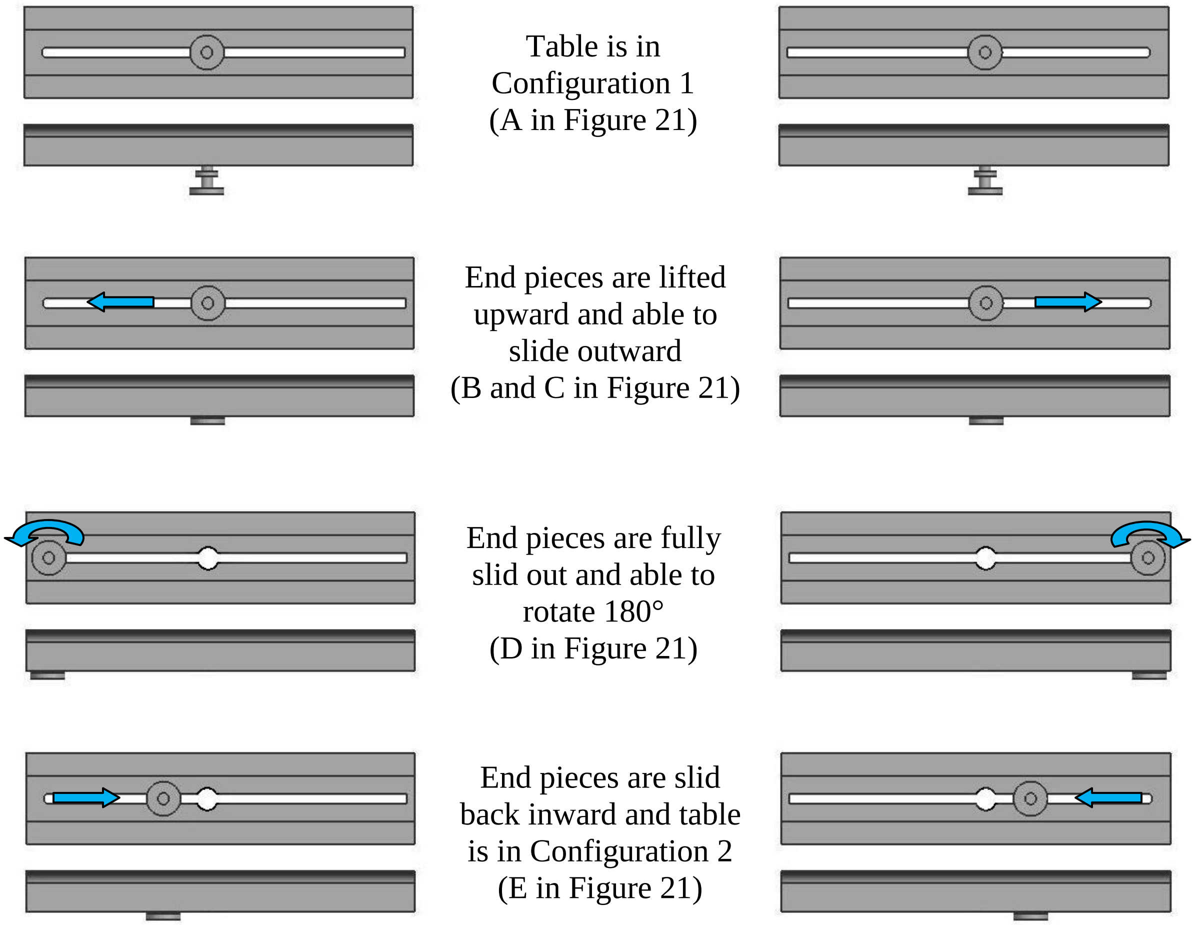



**Figure 23: Track System for the End Pieces**

A close up of the track and pin under the table is shown in Figure 24. When the table is in the rectangular configuration, the end pieces will be resting on the track itself. The end will move upward and backward to begin the reconfiguration. The smaller circular nut on the pin will be able to translate above the track through the hole and slide backward. The end pieces will be held up by the smaller circular nut connected to the track. From here, the table ends are free to rotate around without much effort from the user. When the ends are slid inward, they will be resting above the center portion of the table.

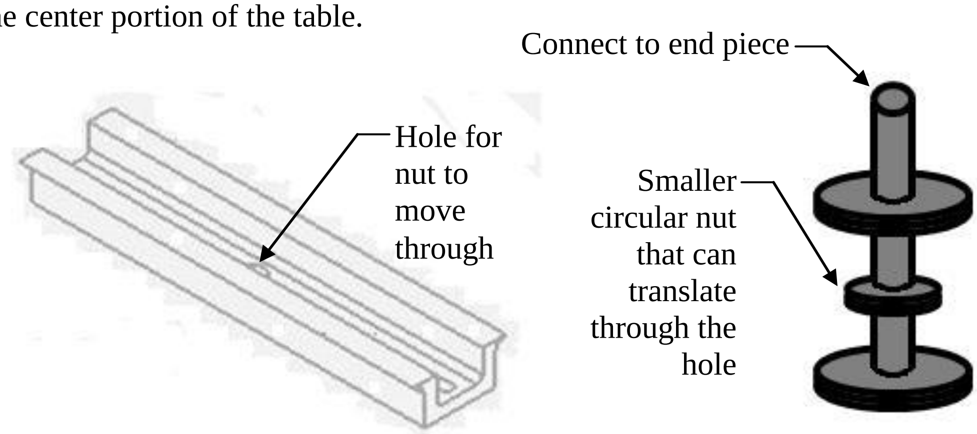



**Figure 24: Pieces of the Underside Track System**

We have researched different types of jacks, hinges, and tracks to see what is available for purchase. This has led to the conclusion that our team will purchase a jack for our base and hinges for our circular flaps. Our team may manufacture the track system, but we may purchase one if we can find a system available that fulfills all of our needs. Power sources are not necessary in our design because we will have a foot pump-operated jack system. The power-operated jacks that were considered require a power source. This would require the table to have a 12 V battery within the base or always be near an electrical outlet. That requirement seemed impractical when a simple mechanical system could be used for lifting the table.

The jack being considered for use in our project is the ATLAS Motocross Lift [14], which is shown in Figure 25. The jack is hydraulically operated by a small foot pump located at the base of the lift. The base is 14 inches (0.36 m) by 16 inches (0.41 m) and the minimum height is 13.5 inches (0.34 m). The jack has a lifting capability of 35 inches (0.89 m) at a 300 lb (136.08 kg) capacity and has three predetermined locking locations. For our table the jack will be modified in size to meet the necessary attachment size. The height adjustment range is also larger than necessary and will be restricted to the 6 inch (0.15 m) desired travel. Because of the safety hazard that is introduced by the intersecting links on the jack in compression and decompression, a clear, thick safety skirt will be placed around the base of the mechanism. A clear telescoping Plexiglas covering is ideal to cover the scissors. The jack will then serve as a functional part of the table design as well as an aesthetically pleasing component. A wider base covering with a slit for the foot pump is also a possibility for extra stability and a nicer finished look.


**Figure 25: ATLAS Motocross Lift [14]**

When considering the choice of materials, we would like a material with a larger yield strength and smaller density. Materials with larger yield strength are more resistant to bending when loads are applied and by choosing a material with a smaller density, we minimize the load that is applied as part of the table's structure, so that it has a greater ability to support extra loads added to its surface. We reviewed data from the CES EduPack for a general type of material choice because we are able to view a graph of Young's modulus versus density for many different types of materials. From our initial review we believe that our material of choice will be some sort of wood because of the group's location in the graph.

## QUANTITATIVE ENGINEERING ANALYSIS

To identify key components, dimensions, tolerances, and materials in the final design, a complete engineering analysis was performed for the table. To completely define the table design the system was broken down into its three separate configurations. In each configuration, the maximum load of 60 lbs is applied at the location that would create the largest stress on the connection points of the table. The overall maximum stresses and most opportunities for failure occur in the extended position. Therefore once the extended configuration is proven stable, the other two configurations can be assumed stable as well.

For the extended configuration a general list of assumptions was utilized in order to define parameters and simplify analysis. The following list will define all assumptions being made to complete the quantitative engineering analysis for the table:

Assumption 1: The wood is Southern Pine and has a density of 0.0213 lb/in$^3$.
Assumption 2: All components of table design are rigid bodies.
Assumption 3: All purchased components will function as described at defined capacity ratings.
Assumption 4: Applied load is split across both support bars, the offset is considered negligible.

### Extended Configuration

The extended configuration shown in Step A of Figure 21 (pg 23) was analyzed for the engineering calculations because it has the largest stress values. Figure 26 (pg 28) shows a diagram with a load applied at the furthest edge of the table along the centerline in order to calculate the possibility of tipping, along with the analysis for end deflection, and support beam stresses. Figure 26 shows the exact location where the force is being applied for maximum stress. It also shows where the other important engineering factors will be calculated.

### Analysis 1: Tipping Force

The first step, that was made in the engineering analysis, was calculating that the maximum applied force that would not cause tipping. We define "tipping" as any time when not all four legs of the jack are in contact with the ground. In order to calculate this, the tipping moment caused by the applied force was calculated and compared to the stabilizing moment caused by the weight of the table (150 lbs) and the base length. In our calculations we assumed that the center of gravity would be located at the center of the top of the base. We know this is not exactly the case because the weight of the table due to the scissor is off-center and unknown, but because the scissor moves as the table height changes, the location of the center of gravity will depend on the height of the table. The rotating static joint between the scissor and the base is located on the right side of the jack, so as the table height is increased, the center of gravity will move to the right and upward. As the height is decreased, the center of gravity will move to the left and downward. We assumed the height of the center of gravity to be at the top of the base of the jack (12 in from the ground) because it is a static point and reasonably close to the actual location. The jack weight is 75 lbs and wood, beams and crossbar combined weight is 60 lbs. The calculations in Figure 27 (pg 29) show that 75 lbs can be applied to the edge of the table before it begins to tip. This load is 37.5% of our failure load of 200 lbs given by our engineering specifications. The applied load is determined to be 60 lbs due to having to satisfy the yield criterion of the supporting beams. Because of the yield stress in the beams, the table would break before it tips over. The failure load could be increased by using larger support beams with greater yield strength and widening the section of the base where it meets the ground.

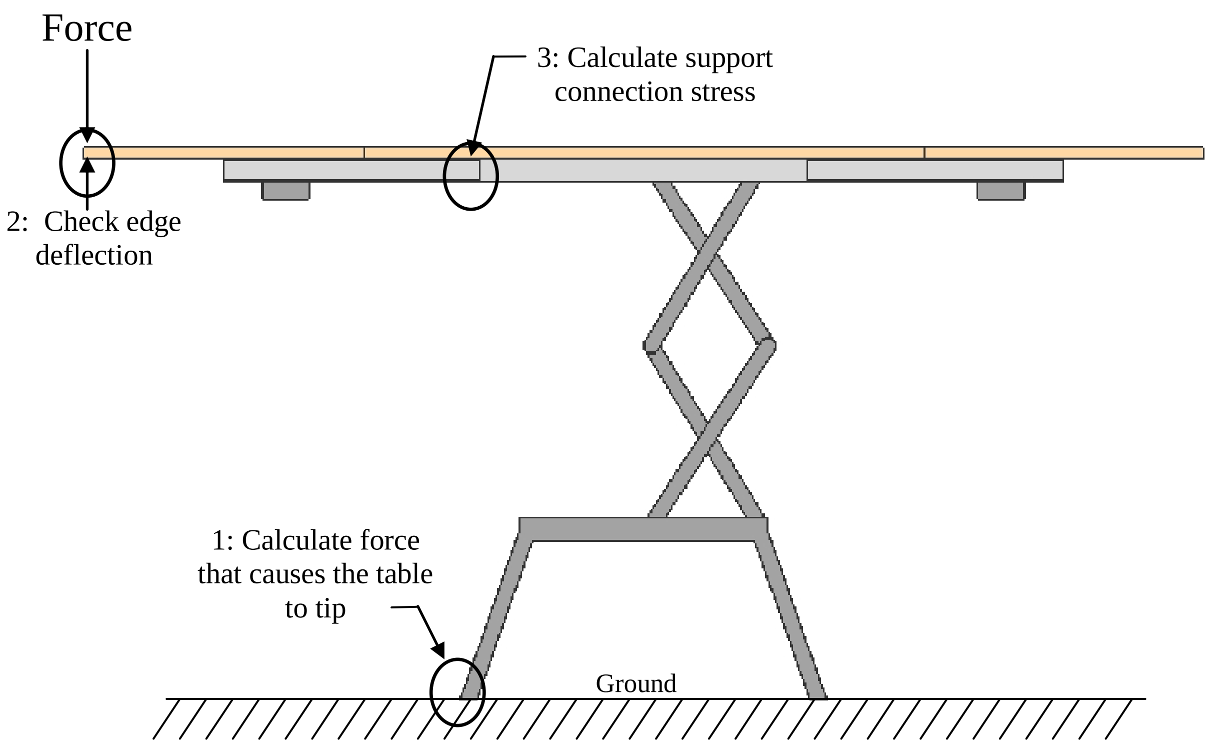



**Figure 26: Engineering Analysis for Extended Configuration**

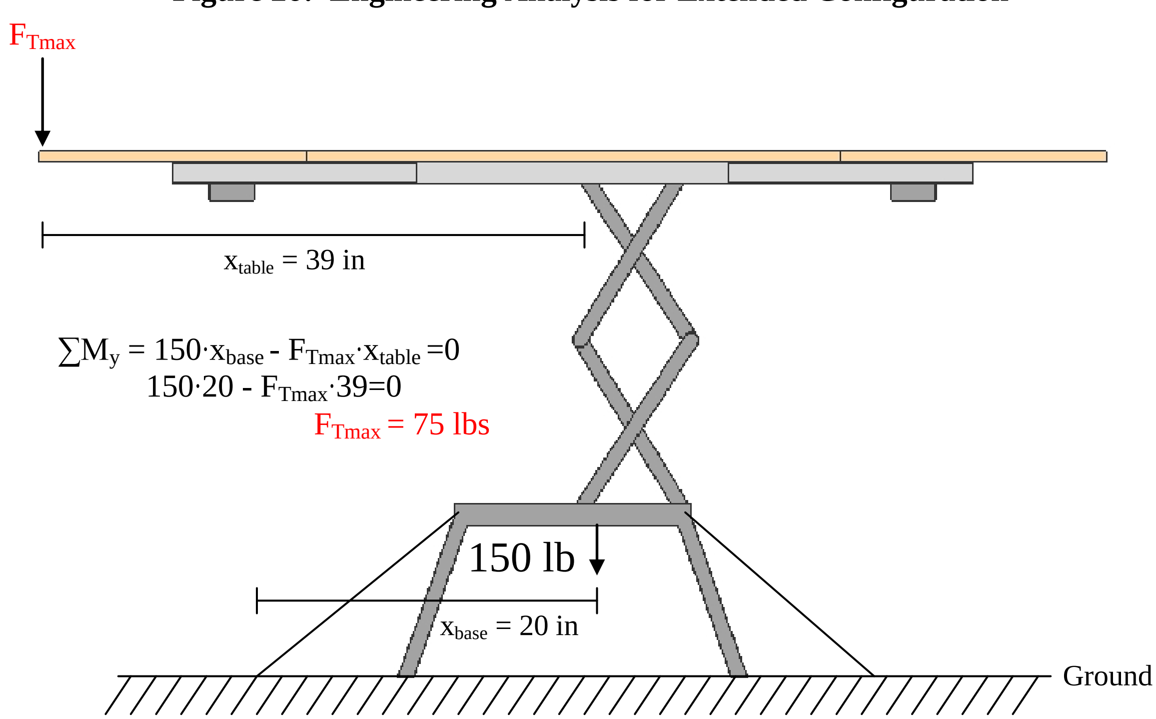
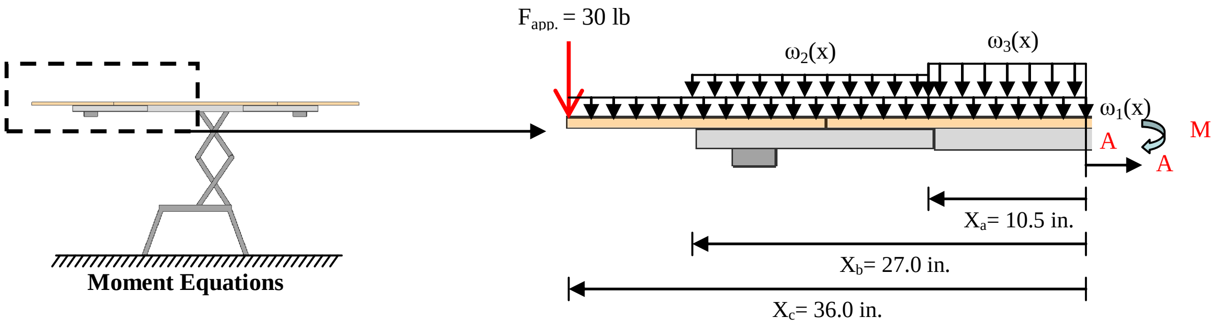



**Figure 27: Tipping Force Calculation**

**Analysis 2: Edge Deflection**

Appendix C shows the calculations made to determine the reaction forces at the location where the table connects to the jack. From these values, the equations for the moment on the table and the deflection of the wood are determined. Figure 28 also shows the calculations made for the moment and the table deflection assuming static loading. Figure 28 shows the free body diagram that was set up to calculate the deflection of the table as a function of the distance from the origin. The assumptions made for the set of calculations are also shown in the same figure. The maximum deflection is 0.66 inches. The plots of the deflection of the wood and the moment distribution are provided in Appendix C.

The square tubing will be manufactured from 6063 Aluminum, which has a yield stress of 16 ksi. The applied load for the table was decreased from 75 lbs to 60 lbs in order to satisfy the yield requirement of the metal. This lower yield strength metal was used because the cost of the higher strength aluminum (6061) was up to double that of 6063 aluminum and the cost of the prototype would not be within our allotted budget.




**Moment Equations**

**Assumptions:**

1: The distributed weight of the supports is negligibly small and was not included in the calculation of the moments or deflections.

2: The Deflection is modeled as though the wood is not supported by the metal outer beams and is only supported by the connection to the middle of the table (at x=0). This means that the max deflection calculated would never be reached by the table edge.

3: The deflection was calculated using the entire weight of the wood, and the total applied force of 60 lbs (the maximum force before yielding).

$$M(x) = M_A - \int x \cdot \omega_1(x) \cdot dx$$

$$M(x) = 1458 - \int x \cdot 0.57 \cdot dx$$

$$M(x) = 1458 - 0.29 \cdot x^2$$

Distributed Weight of Wood
$\omega_1(x)$=0.57 lb/in.
Distributed Weight of Inner Pipe
$\omega_2(x)$=0.023 lb/in.
Distributed Weight of Outer Pipe
$\omega_3(x)$=0.029 lb/in.

E=1.4 MPa
I=1.26 $in^4$

$$v(x)_{force} = \frac{Fx^2}{6EI}(3L - x)$$

$$v(x)_{distributed} = \frac{\omega x^2}{24EI}(6L^2 - 4Lx + x^2)$$

$$v(x)_{woodonly} = \frac{Fx^2}{6EI}(3L - x) + \frac{\omega x^2}{24EI}(6L^2 - 4Lx + x^2)$$

$v_{max}$ = 0.66 in.

**Figure 28: Moment Distribution and Deflection Distribution Calculations**

The stress is calculated at the connection point between the sliding square tubing support and the larger square anchored support. The maximum stress at that point is 15.73 ksi. This will give a safety factor of 1.02 for the sliding tubing.

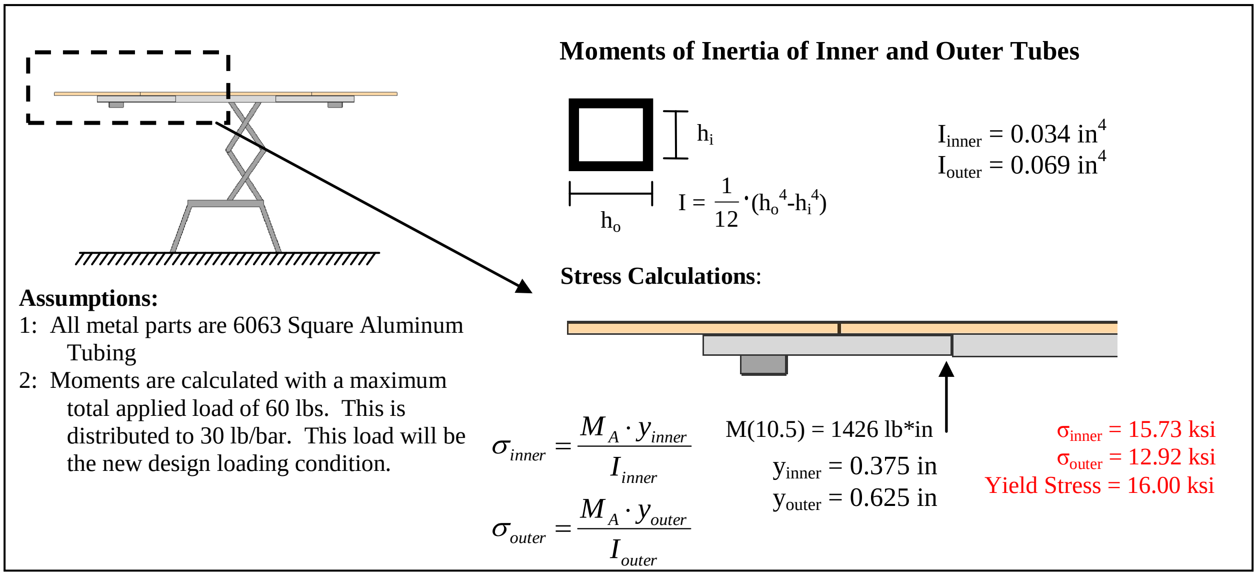



**Figure 29: Stress Calculations in Extended Configuration**

Due to the results of the quantitative engineering analysis we have determined that all of the selected components have been designed and accurately toleranced. With an applied maximum load of 60 lbs anywhere on the table, no failure modes should be present. We did not design for impact loading, only for the static loading that would be applied in everyday use.

The jack is designed to have a maximum load of 297 lbs. The weight of the table above the jack (60 lbs) and the applied load (60 lbs) combine to a total of 120 lbs, which is well under the maximum allowable load. Therefore the jack is sufficient in providing the needs for the table. The jack itself weighs 75 lbs and the parts above the jack weigh about 60 lbs for a combined weight of 135 lbs, which is below our engineering specification of 150 lbs maximum total weight. A smaller jack, if available, may have been used because we do not use the entire height adjustment available or approach the maximum allowable load given by the jack manufacturer. This, however, decreases the weight of the table itself and will in turn decrease the counter acting force that makes the table stay in place when an external outside force is pushing on it.

### QUALITATIVE ENGINEERING ANALYSIS

The Design for Manufacturing and Assembly (DFMA), the Design for the Environment (DFE), and Failure Modes and Effect Analysis (FMEA) guidelines were used to examine our design qualitatively.

### Design for Manufacturing and Assembly

When transferring ideas from paper into a prototype, manufacturing and assembly need to be considered to ensure successful construction. Design for manufacturing and assembly provide guidelines for this process. These guidelines aid the designer so that the product has the best cost, quality, reliability, regulatory compliance, safety, time-to-market, and customer satisfaction. Our group considered five major guidelines in our design: designing for assembly, part handling, joining, part insertion, and machining.

Design for assembly focuses on minimizing part counts, modularizing multiple parts into single subassemblies, permitting assembly in open spaces, and standardizing to reduce part variety. To minimize part counts, we are using fewer brackets to support the outer tubes than originally planned. The original plan was to use three or four brackets to support the outer tubes, but because of interference with the jack we are going to use fewer brackets to secure the outer tubes to the underside of the table. We are also using the jack for the height adjustment and as the main leg of the table, instead of having a separate leg on top of the jack.

We plan to mount the inner tubes and the cylinder to the crossbar before installing this subassembly to our table.

Our table does not have any “enclosing” parts except for the acrylic sections that enclose the scissors of the jack; these will be assembled last to allow for assembly in an open space.

We plan to use screws that are the same size to reduce variety. The bolts we use are also going to be of the same dimensions to reduce variety.

Design for part handling reduces the mistakes made in assembly by workers by employing the following four guidelines: maximizing part symmetry, adding features to facilitate orientation, avoiding parts that are easy to tangle or nest, and color coding different parts that are shaped similarly. All of our outer and inner tubes are symmetric, as well as the tabletop pieces. Because of the side-to-side offset on the tubing in reference to the table, the cross-bars are asymmetric. Our cross-bar cylinder has a notch milled out (Figure 30) so the rotatable table ends could be removed, this notch helps determine its orientation.

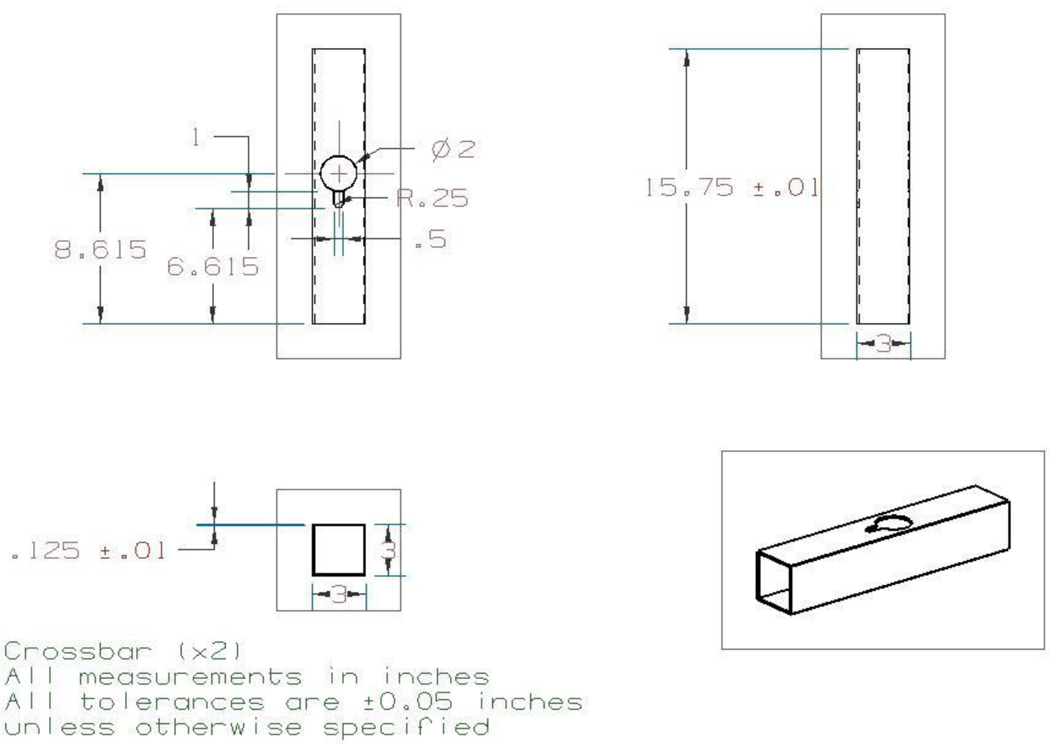



**Figure 30: Drawing of Crossbar with Notch**

The assembly and insertion of our project does not contain parts that can tangle or nest.

Because of the asymmetry of our cross-bars, one of the ends could be painted or marked so that its orientation could be easily determined for assembly.

In designing for joining, we considered 3 major components: eliminating fasteners, allowing access of tools and avoiding over-constraining. We are minimizing the number of screws and bolts used to save assembly time, without compromising the structural integrity of our table. The tubes are attached to the underside of the table using adjusted metal-strip brackets and because the brackets have been bent upward they contain the tubes without adding extra fasteners. Assembly is performed from the center of the table outward and the underside of the table is exposed, except for the jack, which is covered last, so there is easy access for tools. We did not over-constrain the elements of our table to make the joining process easier.

Design for part insertion emphasizes combining the smaller parts into the finished product of our table. It has three guidelines: adding features for easy insertion, adding alignment features, and using z-assembly that never requires turning the product over. The inside of our outer tubing and the outside of our inner tubing is tapered at the ends so that it can be easily assembled. When the sliding bars are welded to the crossbar, they will be easy to align with the outer bars during insertion. Our table is assembled from the top and the bottom at the same time using bolts, after the tubing is attached to the side of the jack, so it does not need to be turned over.

Design for machining has fourteen elements (Table 11, pg 33). It is important to consider the capabilities of the equipment used to machine our product to avoid creating a design that would be difficult or impossible to machine.

Design for manufacturing and assembly is an important part of the design process because it aids the designer in creating a product that is easy to manufacture and assemble, improving cost, quality, reliability, regulatory compliance, safety, time-to-market, and customer satisfaction.

1. Pre-shape by casting, forging and welding
    a. Our tubes are extruded, so they only need to be sawed to length before being welded to the cross-bar.
2. Use standard materials shapes and range of sizes
    a. The square tubing that we use for the sliding bars are standard sizes (3/4” and 1.25” edge lengths with 1/8” wall thickness) to avoid extra machining.
3. Use standard dimensions
    a. The dimensions of our table are standard; we cannot use random sizes because of the availability of tools in the shop.
4. Design holes to tool shape, add space for tapping
    a. All of our holes are through-holes that can be machined with the equipment available, and do not require tapping.
5. Avoid overhangs
    a. Our table does not contain overhangs that are almost impossible to machine.
6. Avoid long, narrow holes
    a. Our table does not contain long, narrow holes.
7. Give radius to internal corners
    a. Our tubing and L-brackets have a radius in the internal corners, which decreases the onset of crack propagation at these high-stress locations.
8. Avoid drilling inclined surfaces
    a. All drilling operations are done to the top of the table or the jack, at a 90° angle to the material, for ease of drilling.
9. Avoid interferences
    a. Tool sizes were considered during design to avoid interferences during machining and assembly. All of the holes drilled into the jack can be done without interference and the acrylic sheet can be assembled without interferences from other parts.
10. Place holes away from corners and edges
    a. The holes in our L-brackets are a sufficient distance from the corners and edges (3” on an edge with holes at 1” and 2” from the bend).
11. Avoid long, thin sections
    a. Our table is not very long, and the table-top pieces are not thin, which reduces deflection during assembly and use.
12. Avoid long, bent holes
    a. Our table design does not contain any long, bent holes.
13. Add features to facilitate fixturing
    a. All of our parts are easy to hold and fixture because of their size and shape, none of the parts we use are extremely small or sharp.
14. Minimize tool changes and setups
    a. Our parts do not require many machining operations which reduces tool changes and set-up time.

**Table 11: Design for Machining Guidelines**

## Design for the Environment

Design for the environment is an approach to the design of a product that considers the environmental impact of the product during its procurement, construction, distribution, use, and at the end of its life. It incorporates many guidelines, five of which were considered in our design. These guidelines are physical optimization, optimize material use, optimize production techniques, optimize distribution and optimize end of life systems.

Physical optimization is accomplished for our product in several ways. We integrate product functions by designing a table that adapts for different settings, combining the needs of many tables into one. Our table is made of strong materials to increase its reliability and durability. All of the moveable parts are easily detached for maintenance and repair, except for the jack because it is covered to prevent user injury. Our table has a strong user-product relationship because it looks and “feels” like a table, the user will not be uncertain over the product’s function.

Material use is optimized by using cleaner materials, avoiding halons, CFCs, HCFCs, VOCs, cadmium, lead, mercury and brominated flame retardants. The wood and aluminum used in our table can also be recycled, and for bulk production other recycled material could be used as the major material of the tabletop, with a cover layer added to improve appearance. Material usage could be reduced by purchasing in bulk and reducing waste.

We can optimize production techniques in three major ways. Reducing the number of production steps would make assembly easier and can be done by integrating components. Our table tops would be simple to manufacture given their simple shapes and the fact that both sets of moving table tops are symmetrical with each other. Cleaner energy could be used to power the manufacturing and assembly lines. Waste could be reduced by using optimal shapes that reduce the amount of cut-off scrap material that then becomes waste by carefully dividing the bulk pieces of wood.

The distribution process of our product focuses on packaging, transportation and logistics. Recyclable packaging with biodegradable stuffing would reduce the amount of waste associated with our product. The transportation and logistics processes could be made more efficient. Using a delivery service that would deliver other products along with ours in the same trip would reduce costs and be more energy efficient. By using electronic documentation, the amount of paper waste can also be reduced. Other steps can be taken in the manufacturing line like eliminating Cathode Ray screen displays that have been proven to be environmentally unfriendly.

The end-of-life system helps to reduce the negative impact of our product. Our product is designed to be easily assembled and disassembled. The parts can then be separated between those that must be incinerated and the recyclables, such as wood and metal. Implementing these guidelines reduces the waste created by our product and any side effects that may cause harm to the environment.

## Failure Mode and Effect Analysis

In order to analyze the potential failures of the table we have implemented the Failure Mode Effects Analysis (FMEA). In the FMEA (Table 12, pg 36) every part of our table was analyzed for any potential or past failures and the effects it would have on the whole design was noted. Every failure includes a brief description and a number rating the severity of the failure under the column *Severity*. The rating ranges from 0, having no effect on the design, to 10, where the table and its main functions become inoperable. For every possible failure we determined a cause, the causes can range from the expected in our settings for the table to the more improbable. We also quantify from 1 to 10 the probability of failure under the column *Occurrence*, 1 being very improbable and 10 expected. Possible tests for each failure are enumerated that could help determine if our table is robust enough not to fail. Detection of failures is an issue especially if the table undergoes these preliminary tests, to quantify ability of a failure to be detected a range of ratings was also assigned under the column of *Detection*, where 1 is easily detected and a 10 would almost certainly not. The product of these 3 ratings results in the Risk Priority Number for that particular failure possibility. The RPNs show which failures should have a higher priority over the others. The higher the RPN the more effort will need to be made to counteract the failure possibility. Simple parts usually result in a low RPN but the geometrically complicated rotating cylinder gives the highest RPN in our FMEA.

For example, the outer tubes will be supporting the inner tubes.  These will be holding the crossbar which will be supporting the rotating outer pieces. The outer tubes will be subject to strong bending loads. The outer, rotating parts are a key part to some of the main functions of the table, which is to change shapes and support loads. That is why if the outer tube fails, the severity is ranked 9 out of 10. Failure of this part will result in this main function not being accomplished. Since the outer tubes are made of 6063 aluminum and the proper force analysis has been completed, an occurrence rating of 2 was given, meaning that the outer tubes will not likely fail. Since the outer tubes hold most of the table together, their failure will be evident. The functions of the table will not be possible, which is the reason that a detection number of 2 is given. The severity, occurrence and detection numbers are all multiplied to give the Risk Priority Number of 36, which falls right around the middle of the ranges of all the RPNs calculated. Since the FMEA was made when our final design was finalized the RPN only went through a small change. The only significant change we made on the table was the choice of size for the inner tubes. Our inner tunes were too big (cross section of 1'' x 1'') for sliding and would have caused too much friction and unnecessary forces on the sliding mechanism. These inner tubes had an *occurrence* rating of 6. When they were changed to a cross section of ¾'' x ¾'' they slid more easily and did not take the same amount of effort to move. A new *occurrence* rating of 2 was calculated. This changed our total from 385 to our final total RPN of 349.

Each separate part that will be manufactured or purchased is listed in the FMEA. From the table tops and the sliding tubes to the hinges and bolts most of the possible failures would come from heavy and unbalanced loads and poor manufacturing. It is interesting to note some possible failures might be outside of the manufacturing scope like possible locking of the jack or the breaking of purchased pieces like bolts and hinges. Using a FMEA will help enable a more robust design to be achieved.

| Item/Function | Potential Failure | Potential Effects of Failure | Severity | Potential Causes | Occurrence | Current Design Tests | Detection | Recommended Actions | RPN |
|---|---|---|---|---|---|---|---|---|---|
| Table Tops: provides support to the contents being put on the table | Breaking | Table will not reconfigure properly and may become instable. Table will be uncomfortable for the user. Objects on the table will not remain there. Stability will be affected. May hurt the user. | 10 | Too much weight is added to the table. Material is not strong enough. Force from the user is too large. | 2 | Adding weights in the similar fashion of failure tests as well as mock manual use. | 1 | Take into account another type of wood. Minimize bending loads within the design. | 20 |
| | Bending, Shearing | | 7 | | 3 | Adding weights in the similar fashion of failure tests as well as mock manual use. | 2 | Take into account another type of wood. Minimize bending loads within the design. | 42 |
| Plexiglas cover: covers the jack in all configurable heights by sliding open. | Breaking, locking. | Stability of the table may be affected. Jack could be exposed. | 5 | Improper choice of materials. Not properly built. | 3 | Opening and closing at the speed of the jack or faster. Kicking as to emulate damage from legs of users. | 3 | Better the design of the sliding acrylic. | 45 |
| Hinges: Allow table tops to connect and fold on top of each other. | Breaking | Table tops will no longer be connected and possibly fall apart. Table tops won't be able to change configuration. | 10 | Loads are not evenly distributed. Too much weight is added to the hinges. Material is not strong enough. Force from the user is too large. | 2 | Bend and load the areas of connection to observe if hinges yield or break. | 2 | Look into another type of hinge. Minimize bending loads. | 40 |
| Jack (ATLAS Motocross Lift): Changes height with links connected to a pedal. Will allow the table to change height. | Breaking | Table will not be able to change height. Table might lose balance or fall apart. | 8 | Loads are not evenly distributed. Too much weight is added to the Jack. Force from the user is too large. Connection to the table top is flimsy. Linkages not robust enough. Connection to the leg is poor. | 3 | Adding weights and unsymmetrical loads while static and while being elevated. | 2 | Fix or reinforce in the machine shop. | 48 |
| Bolts | Breaking | Pieces of the table may no longer be connected. | 7 | Material not strong enough. Poor bolting. | 1 | Bend and load the areas of connection to observe if bolts yield or break. | 2 | Look into another type of bolt. Minimize bending loads. | 14 |
| Rotating Cylinder: Holds and changes configuration of the outer flap by means of a track and a pin in the tube attached to the flap. Will be attached to a hollow tube with a fitting hole. | Bending, Buckling | Table top will shift sideways. Table will not be able to change height. Table might lose balance or fall apart. | 9 | Loads are not evenly distributed. Force from the user is too large. | 3 | Adding weights in the similar fashion of failure tests as well as mock manual use. | 2 | Look into another type of material. Machine another type of channel where bending moments won't be as large. | 54 |
| Inner and Outer Hollow Tubes: The Outer tube will allow the inner tube to slide in and out extending the outer flaps of the table. | Bending, Breaking | Table top will shift sideways. Table will not be able to change height. Table might lose balance or fall apart. | 9 | Loads are not evenly distributed. Force from the user is too large. | 2 | Adding weights in the similar fashion of failure tests as well as mock manual use. | 2 | Look for larger tubes. Design a locking mechanism and minimize bending loads especially when open. | 36 |
| Hollow Tube with Hole: This tube will be attached to the inner tubes as they slide in and out and will hold the outer flaps through the drowning cylinder. | Bending, Breaking and inability to slide | Table top will shift sideways. Table will not be able to change height. Table might lose balance or fall apart. | 9 | Loads are not evenly distributed. Force from the user is too large. Material is not strong enough | 2 | Adding weights in the similar fashion of failure tests as well as mock manual use. | 2 | Look for a larger, stronger tube. | 36 |
| L-Brackets: Will hold the outer tubes onto the center table top. | Breaking | Table top will lose rigidity. The set off tubes might fall completely off the table. | 7 | Loads are not evenly distributed. Force from the user is too large. L-Brackets not properly bolted. Material is not strong enough. | 1 | Bend and load the areas of connection to observe if brackets yield or break. | 2 | Look into another bracket. Minimize bending loads. | 14 |

**Table 12: Failure Mode and Effect Analysis Chart**

## FINAL DESIGN

The Shapely design was modified and chosen for manufacturing. It proved to be the optimal design to satisfy the user requirements. The design of Shapely is broken down and explained in the following sections and a full scale prototype will be manufactured.

### Primary Table Parts

The actual table itself consists of a center stationary piece, two movable end pieces, and two flaps that can flip up. These pieces will be made from a ¾" thickness 4x8 foot (1.22 x 2.44 m) sheet of sanded pine plywood. The CAD drawing of the primary table parts is in Figure 31, and dimensions of each piece are shown in Appendix D. Each piece will be individually sanded, stained, and varnished.

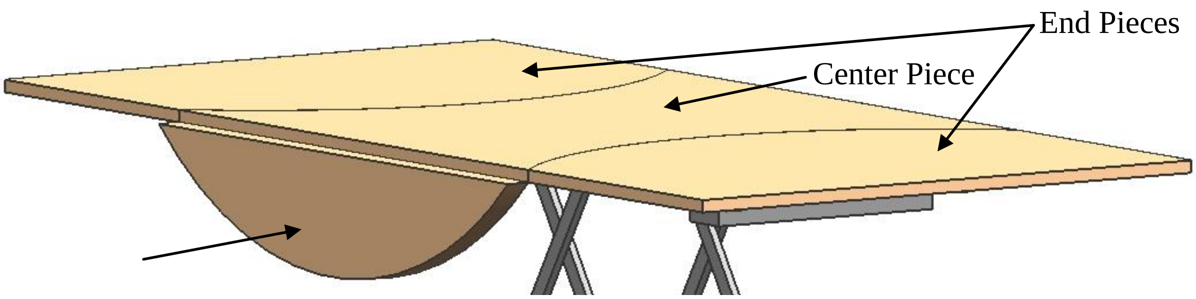



**Figure 31: Primary Table Parts**

### Track System for Reconfiguration

The track system we decided to use for the table design is different from the original system. Although the original design was simpler, there were many issues that were likely to cause failure in the entire concept. These support issues were mainly a result of only having one bar supporting the underside of each end piece. Utilizing a double-bar supported track system increases stability for both when the piece is in motion and when it is stationary. We also didn't have room in the underside of the table without having to modify the jack, which would have been occupying the same space.

The new track system located under the table, to aid in table transformation, was modified to have two sliding arms per end piece. The arms will be able to slide inside a larger square hollow tube attached to the underside of the stationary center table section. A hollow rectangular cross bar connecting the two arms will have a center cylindrical hole that will act as a pivot point for the rotation of the end pieces. The cylinder protruding from the two rotatable end pieces will fit into the hole in the crossbar. Figure 32 (pg 38) shows the assembled track system. All pieces will be manufactured out of 6063 Aluminum.

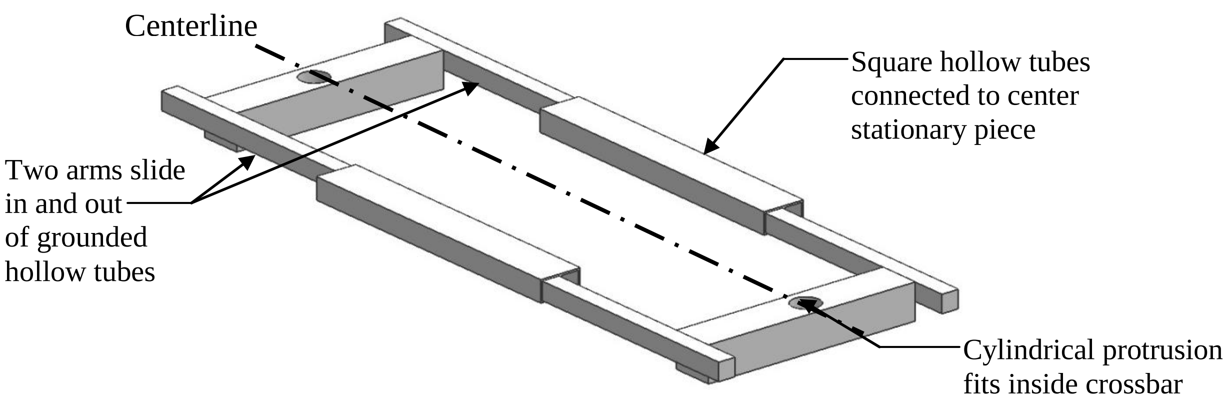



**Figure 32: Sliding Track System**

Dimensions for the main parts of the track system are shown in Appendix E. The track system is a combination of the three parts and the same for each end, thus, manufacturing will be simpler. The manufacturer will just have to be sure the holes in the crossbar line up with the centerline.

The cross bar's center cylindrical hole will have a pipe inside of it that has a milled path for the complementary post to travel. A model and drawing of the rotation cylinder are shown in Figure 33. The path allows the table to transform from configuration 1 (full rectangular table) to configuration 2 (oval shaped table) by lifting the end piece up one inch and rotating it. The end piece will fall back down on top of the center portion after the 180° turn to complete the transformation. The dipped portions of the path also hold the table ends in place when it is in the different configurations. All pieces will be manufactured from 6063 Aluminum.

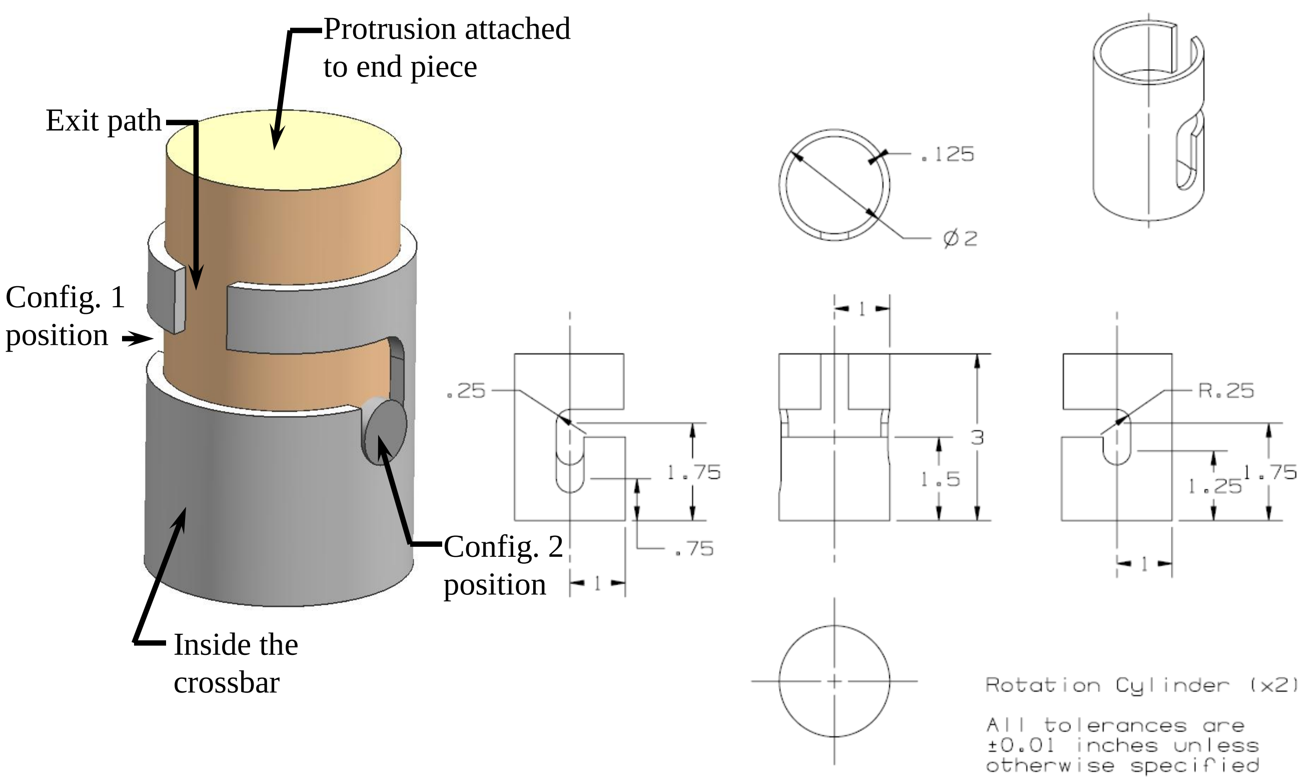



**Figure 33: Model and Drawing for the Rotation Cylinder**

**Jack Base**
The ATLAS Motorcross Bike Lift [14] will be attached to the bottom of our table and will be its full base. The 14” by 16” connection point will fit exactly underneath the center portion of the table. The integrated jack and tabletop system is shown in Figure 34.

**Figure 34: Tabletop with Lift Base**

The protective covering around the scissor links of the jack will be made of acrylic sheets. The covering on the lift is shown in Figure 35. One rectangular casing covering the bottom half of the scissor links will be connected to the lower platform of the lift. Another acrylic casing will be connected to the top platform of the lift and overlap the bottom casing. This telescoping design will allow the table to move up and down the required 6 inches (0.15 m) and not have the protective covering interfere.

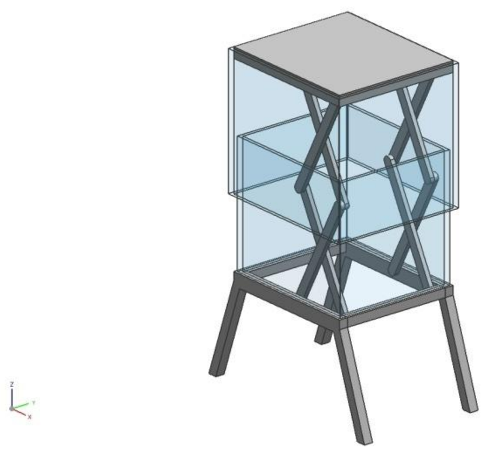


**Figure 35: Acrylic Casing over Scissor Links of Lift**

**Bill of Materials**
All the materials required to build our prototype are listed in Table 13. The most expensive part of the table was the lift for the base.  It was almost 35% of our total funds. We ordered this component from Greg Smith Equipment Co. We also ordered the folding leaf hinges from Rockler Companies, Inc. The square tubes and the hollow cylinder were purchased from McMaster-Carr. We bought the large plywood sheets of pine from Home Depot as well as paint, tack cloth and acrylic sheets. We were able to acquire the metal strips, wood glue, paintbrushes, screws, and sandpaper from the machine shop.

| Quantity | Part Description | Purchased From | Part Number | Price (per unit) | Total Price (incl. shipping and tax) |
|---|---|---|---|---|---|
| 2 | 0.75" 4x8 Pine Plywood Sheet | Home Depot | | $21.97 | $46.58 |
| 2 | Optix .093-36 x 30 Acrylic Sheet | Home Depot | | $13.29 | $28.17 |
| 1 | Glidden Semi-Gloss Paint | Home Depot | 421766 | $9.99 | $10.59 |
| 1 | Glidden Primer | Home Depot | | $8.97 | $9.51 |
| 3 | 3" Foam Brushes | Home Depot | | $0.73 | $2.32 |
| 2 | 2" Foam Brushes | Home Depot | | $0.56 | $1.18 |
| 1 | Clear Caulk | Home Depot | | $2.97 | $3.15 |
| 1 | EZ-One 3pk Tack Cloths | Home Depot | 42-TC3BB | $2.08 | $2.20 |
| 2 | Locking Bolts | Home Depot | | $5.27 | $10.54 |
| 4 | 1.25"x1.25" alum hollow square tube (27") | McMaster-Carr | 88875K36 | $38.36 | $46.78 |
| 2 | 3"x3" hollow rectangular tube (15.75") | McMaster-Carr | 88875K733 | $28.48 | $36.31 |
| 4 | 3/4"x3/4" alum hollow square tube (21") | McMaster-Carr | 88875K31 | $10.89 | $32.78 |
| 2 | 2" OD hollow cylinder (2.5") | McMaster-Carr | 9056K131 | $8.53 | $15.95 |
| 2 | Pair of Folding Leaf Hinge | Rockler | 28928 | $9.99 | $28.59 |
| 1 | Gray ATLAS Motorcross Lift | Greg Smith Equipment | HT1007 | $99.00 | $136.95 |
| | Scoring Blade for Acrylic Sheeting | University of Michigan | | $0.00 | $0.00 |
| | Bolts, Nuts and Lock Washers | University of Michigan | | $0.00 | $0.00 |
| | Wood Glue | University of Michigan | | $0.00 | $0.00 |
| | Plastic Wood | University of Michigan | | $0.00 | $0.00 |
| | Screws | University of Michigan | | $0.00 | $0.00 |
| | Sandpaper | University of Michigan | | $0.00 | $0.00 |
| | Hot Glue Gun & Glue | Jennifer Flachs | | $0.00 | $0.00 |
| | | | | TOTAL | $411.61 |
| | | | | BUDGET | $400.00 |
| | | | | DIFFERENCE | -$11.61 |

**Table 13: Bill of Materials**

All the products had a shipping and delivery period of 5 days or less. We ordered all the products we required for the prototype at least 3 weeks prior to the date the prototype is due. For products that we were unsure of how they would fit with our design, like the hinges, we ordered far in advance, almost 6 weeks ahead of the prototype due date. Ordering the products earlier gives us a larger buffer time period in case we have any problems with them.

**Satisfaction of Engineering Requirements**

After reviewing the engineering requirements set at the beginning of our design process, we discovered that we have met all but two of the requirements, the maximum applicable load and the prototype cost. Table 14 lists the targeted engineering specification values with the actual values in the corresponding column.

| Desired Engineering Specifications: | Final Design Specifications |
|---|---|
| • Compatible in Different Environments ≥ 3 | • Compatible in all environments |
| • Configurations ≥ 3 | • 3 different configurations |
| • Seats Available ≥ 2 people | • Up to 8 seats available |
| • Cost ≤ \$400 | • \$411.61 to prototype |
| • Range of Table Height ≥ 6 inches (0.15 m) | • 6 inches table height range |
| • Surface Area Range ≥ 5 $ft^2$ (0.46 $m^2$) | • 6.43 $ft^2$ (0.6 $m^2$) surface area range |

| | |
|---|---|
| • Weight ≤ 150 lbs (68 kg)<br>• Failure Load ≥ 200 lbs (90.72 kg)<br>• Surface Defects ≤ 0.5 defects/$ft^2$ (5.38 def/$m^2$)<br>• Reconfiguration Steps ≤ 4 steps<br>• Reconfiguration Time ≤ 15 seconds<br>• Exposed Electronics ≤ 1 unit<br>• Material Lifetime ≥ 10 years<br>• Colors Available ≥ 2 | • 135 lbs (61.23 kg) weight<br>• 60 lbs (27.22 kg) failure load<br>• 0.5 defects/$ft^2$<br>• 4 steps to reconfigure<br>• ≅ 15 seconds reconfiguration time<br>• No electronics<br>• 10 years<br>• 2+ colors available |

**Table 14: Satisfaction of Engineering Specification**

Our final design does well to satisfy the most important engineering specifications according to our QFD in Figure 14. We exceeded the range of surface area by more than a square foot, hit the target goal of 3 different configurations, exceeded the number of environments the table can be placed in, and produced the prototype within budget.

The only engineering specifications we did not satisfy was the failure load, which is evident from our quantitative engineering analysis calculations, and the total prototype cost, which exceeded the maximum budget by $11.61. The 6063 Aluminum used for the track system was not an adequate type of aluminum to satisfy the stresses incurred at the edge of the table. Thus, a failure load of 60 lbs (27.22 kg) was all that the design could handle. We did, however, discover that 6061 Aluminum would be a material that could withstand the 200 lbs (90.72 kg) load. This aluminum was not used for our prototype due to the substantial increase in cost it would take to buy the material. Our QFD has the cost of the prototype ranked higher in importance than the failure load so we chose to lower the acceptable failure load. In reality, a point load of 200 lbs (90.72 kg) load at the very edge of a table is improbable and would rarely occur.

## MANUFACTURING PLAN

In order to ensure a smooth manufacturing process for our prototype, a plan has been developed detailing the procedure in which the manufactured parts will be created and assembled.

### Primary Wood Pieces

The primary wood pieces for the table are made from two sheets of ¾” 4’ x 8’ (1.22 m x 2.44 m) sanded pine plywood. In order to create a tight fit between the rounded end pieces and the center, one sheet of pine plywood will be cut to a 3’ x 6’ (0.91 x 1.83 m) rectangle with a table saw. The separate pieces will be constructed from that same rectangle using a jigsaw to make the rounded edges. After completion of the center and end pieces, the flaps will be cut from 3’ (0.91 m) pieces of plywood. The required arc will be drawn on the plywood and a jigsaw will be used to make the curve. Two circular flaps will have to be made for each side of the table and attached on top of each other to compensate for the height variation in the different configurations. An ordered manufacturing plan for the primary wood pieces is shown in Table 15.

### Sliding Aluminum Track Pieces

The inner and outer hollow tubes and hollow cylinder were cut to length with the band saw. The rotational pathway was milled. All of the tubes are 6063 Aluminum which are easy to machine, the specifications are easily verifiable in the Machinery's Handbook provided by the university. A detailed manufacturing plan is shown in Table 16.

**Acrylic Encasing**
Eight sheets will be cut for the entire encasing. Four sheets will be 16" x 13" for the bottom portion and 16.5" x 13" for the upper portion.

**Center and End Wood Pieces**

Material: ¾" 4'x8' Sanded Pine Plywood (Purchased)

| Step | Manufacture | Tool |
|---|---|---|
| 1) | Cut full sheet of plywood to 3'x6' with grains running parallel to the longer side | Table Saw 80 teeth/in |
| 2) | Draw 25.46" radius arc for the two end pieces. | Pencil, Dry Line, Pin |
| 3) | Cut along the arc line to create end piece. | Downward Jigsaw 20 teeth/in |
| 4) | Repeat cut on opposite arc. | Downward Jigsaw 20 teeth/in |

**Circular Flaps**

Material: ¾" 4'x8' Sanded Pine Plywood (Purchased)

| Step | Manufacture | Tool |
|---|---|---|
| 1) | Cut scrap plywood into 3' sections with grains running parallel to the 3' side | Table Saw 80 teeth/in |
| 2) | Draw 25.46" radius arc starting on one corner of the 3' side. | Pencil, Dry Line, Pin |
| 3) | Cut along the arc line to create circular flap. | Downward Jigsaw 20 teeth/in |
| 4) | Repeat steps for a total of 4 flaps. | Downward Jigsaw 20 teeth/in |

**Table 15: Primary Wood Manufacturing Plan**

**Outer Tube (x4)**

Material : 6061 Aluminum

1.25" x 1.25" Cross Sectional Dimensions, 1/8" Thickness

| Step | Manufacture | Tool |
|---|---|---|
| 1) | Cut into length of 21 inches | Band saw, 500 ft/min, feed: 8 $in^2$/min |

**Inner Tube (x4)**

Material : 6061 Aluminum

3/4" x 3/4" Cross Sectional Dimensions, 1/8" Thickness

| Step | Manufacture | Tool |
|---|---|---|
| 1) | Cut into length of 27 inches | Band saw, 500 ft/min, |

**Crossbar (x2)**

Material : 6061 Aluminum

3" x 3" Cross Sectional Dimensions, 1/8" Thickness

| Step | Manufacture | Tool |
|---|---|---|
| 1) | Cut into length of 15.75 inches | Band saw, 500 ft/min, feed: 8 $in^2$/min |
| 2) | Drill hole of 2" in diameter in the center point of both faces of 3" by 15.75" | 2" diameter Bore, 620 ft/min, feed: .008 in/rev Carbide tip. |

**Rotation Cylinder (x2)**

Material : 6061 Aluminum

2" outer diameter, 1/8" thickness

| Step | Manufacture | Tool |
|---|---|---|
| 1) | Cut into length of 3 inches | Band saw, 320 ft/min, feed: 8 $in^2$/min |
| 2) | Place flat(not standing) and drill across the shaft 1.75" from the bottom of the cylinder | 0.25" Drill Bit, 365ft/min, .016 in/rev. Carbide tip |
| 3) | Place flat(not standing) and drill from the end of the first channel and drill down .75" towards the bottom | 0.25" Drill Bit, 365ft/min, .016 in/rev. Carbide tip |
| 4) | Place flat(not standing) and drill from the other end of the first channel and drill down .25" towards the bottom | 0.25" Drill Bit, 365ft/min, .016 in/rev. Carbide tip |

**Table 16: Manufacturing Plan for Aluminum Track Pieces**

**Assembly**

First the outer tubes of the tracks system will be attached to the underside of the center tabletop piece. Using precut metals strips, we will form them into brackets and attach the tubes by encasing in the brackets and attaching them using half-inch #4 screws. The inner sides of this setup will be fastened 14" apart to allow for the jack to be fit in between. The two tubes of each side will be placed flush against one another. At this point, 4 tubes will have been attached. Four countersunk holes will be drilled through the tabletop surface. Four inch-and-a-half long bolts will attach the table to the jack flush to the outer tubes. Two hinges will first be screwed into the underside of each hinged round pieces that have double thickness of the rest of the table, using four 1" #4 screws. The hinges will be centered and placed 10 inches apart. The other half of the hinge will then be attached to the center piece by four 1" #4 screws.

For the rest of the track system, the cylinder will first need to be inserted into the hole drilled into the crossbar. The cylinder needs to be placed precisely to ensure its function will be accomplished. The one inch milled path on the cylinder needs to be furthest from the center and in line with the length of the table. The notch in the crossbar will face to the right, when facing the center of the table. The exit pathway in the aluminum cylinder must line up with the botch in the cylinder. After the cylinder is welded to the crossbar, attach the crossbar to both inner bars using L-brackets. The inner bars then need to be placed inside the outer bars already attached to the centerpiece.

For the acrylic sheet encasing, each set of similar 4 squares will be glued together into a cube with 2 opposite open ends. The smaller dimensioned one, 16", will fit into the larger, 16.5" one. These will then be attached to the lower and upper ends, respectively, of the actual jack, not the base, using #4 screws.

The entire table will then be sanded down. The countersunk holes will need to be filled with wood putty and the entire upper surface will be painted with a water-resistant, scratch-resistant lacquer.

If our product were to be mass produced, a few changes would have to be made to the manufacturing process to satisfy engineering, cost, and environmental requirements. The metal and wood pieces would be purchased in bulk reducing the waste due to sizing constraints that we needed to work around while building our prototype. Tubing sizes could be adjusted to give a better sliding fit for mass production. We were required to make do with the general sizes that could be purchased from a few different companies, rather than having it made to our specifications. The environmental impact of our product could be decreased by implementing all of the ideas discussed in design for environment.

**ENGINEERING CHANGE NOTICES**

There were a large number of changes that differed from the finalized design. Many were adjustments that were deemed necessary in the process of building the prototype. First, we routered the area of the outer tubes into the underside of the table and directly screwed the tubes to the table rather than using the metal tape brackets. This was an easier method of attaching the tubes and diminished the possibility of the tubes moving side to side. The tubes needed to be sunk to minimize the difference in height between the center piece and the two end pieces. Due to the decreased thickness of the table, we decided not to drill countersunk holes as it would have diminished the strength of the entire tabletop. We had to let the bottom of the heads of the bolts sit on top of the surface. In turn, we had to create divots in the underside of the two rotatable end pieces to ensure they lay flat, on top of the middle piece. We also ended up using a square cross beam since there were not any rectangular tubes available in the desired dimensions. The cross beam was welded to the ends of the inner tubes rather than a two-and-a-half inches from the end. This change was not intentional. The PVC cylinders were attached to the rotatable piece through the wood from the surface causing another uneven surface. Similarly, countersunk holes were not drilled for the same reasons that the holes for the bolts in the center piece were not countersunk. The pin that traveled along the milled path of the aluminum outer cylinder was attached by drilling a hole in the PVC and threading a bolt to the desired depth. We also attached latches to the underside of the rotatable end pieces for the extended configuration. This ensured that the inside, rounded edge would not rise when a weight was placed on the outer edge. This latch alleviated some of the stress that would otherwise be placed on the pin and cylinder. The acrylic sheets had to be cut to accommodate the tubes that were flush against the jack's upper surface. The upper, larger "cube" was attached to the upper surface of the jack using 2 L-brackets each, on two of the sheets. The other two top acrylic sheets had to be shortened to 12" and were attached to these two sheets also using L-brackets. These two other sheets could not be attached to the jack because of the outer tubes. The bottom "cube" was attached to the jack by attaching 2 small panels of pine to the base of the jack. Two sheets were screwed into the wood and the other two sheets were attached to these two sheets all using L-brackets. Lastly, we built a base to increase the surface area resting on the ground. This was necessary for the balance of the entire assembly and to enable the specified maximum applied load with a larger factor of safety. The base was an isosceles trapezoid extending from the top of the base of the jack.

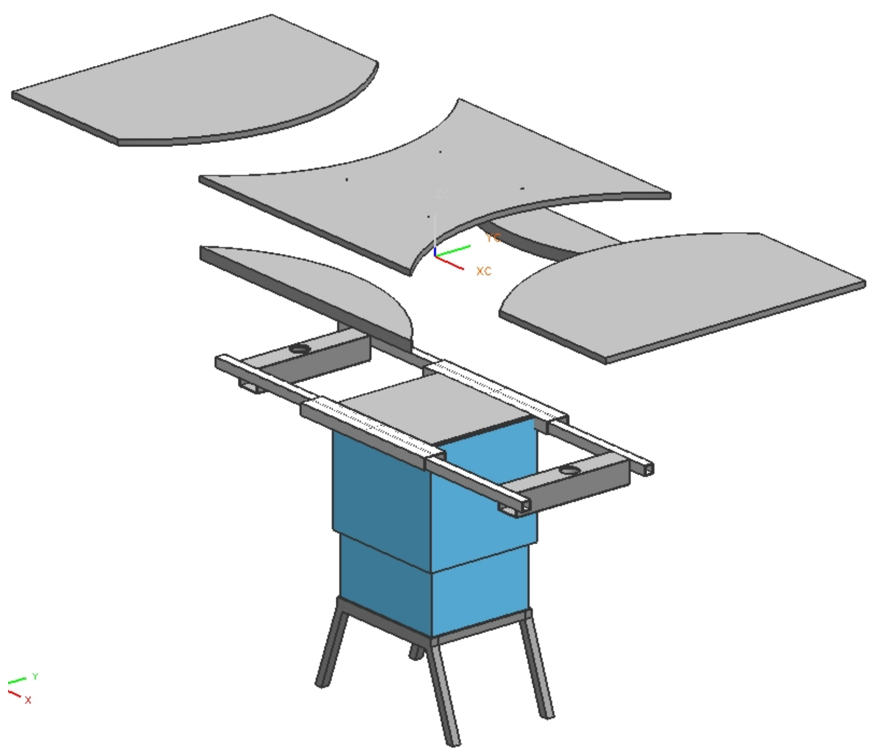


**Figure 36: Exploded View of Tabletop System**

## DESIGN TESTING

The first test performed on the prototype was for the jack. We had to make sure that the minimum and maximum height could be attained and that the operation of the jack was simple and convenient for the user. We also had to ensure that the use of the jack was safe for all users by encompassing it completely with an acrylic sheet cover.

A test was also performed to ensure that all configurations were met with ease. The user requirements specify that the user must be able to reconfigure the table in less than or equal to 15 seconds. Following testing performed on the prototype, not only can the table be reconfigured into each arrangement in less than 15 seconds, but all three configurations including the height adjustment can be achieved by 1 user in 15 seconds. In this process, it was confirmed that all three configurations were easily converted, stable, and they were able to maintain the maximum load of 60 pounds on the end of the table. The pieces of wood that were selected had a preload deflection of approximately 1 inch. When the 60 pound load was added to the end of the table a total deflection of 3 inches was observed. This deflection is much larger than the deflection predicted in the engineering analysis and further design improvements should be made to address this issue.

Tests were also performed on to ensure the safety of the user when using the hinges on the side flaps of the table. Several users and conditions were tested and it was determined that the hinges were safe when reconfiguring the table.

Balance of the entire table was tested with the largest configuration when the end pieces were pulled out. When only one end piece was moved at a time, we ensured that the entire assembly would not tip over due to the offset weight. This test was the performed incorporating the maximum applied load of 60 pounds. With the load applied the table continued to resist tipping.

## DISCUSSION FOR FUTURE IMPROVEMENT

As with any design, there is always room for improvement. For our design, the main improvement would be to improve on the wood material to ensure a higher strength, less bending, and a more even surface. Other improvements can be seen in the list below.

**Future improvement of our final design.**

- Increase the thickness of the table for higher strength and less warping of the wood. A higher quality of wood should be chosen for the same reasons.
- Increase aesthetic appeal by smoothing out the angled base and using an opaque material for the jack encasing.
- Cover the outer ends of the inner tubes for safety.
- Increase stability of the rotatable end pieces when they are rotated on top of the middle stationary piece by attaching a sunken latch to the underside of the rectangular ends.
- Increase surface wear resistance by using a stain and lacquer.
- Ensure all tabletop surfaces are flat and that no screws or bolts extend above the surface.

In terms of aesthetics, we received a variety of input from the participants of the Design Expo on December 4th, 2007. Many of the viewers favored our design and thought it could be a future mass-produced manufactured good. The clear encasing on our prototype was to facilitate comprehension of how our table was able to adjust height, but would be modified as an aesthetic aspect.

For future improvements on our project, the main concern would be to design a track system that would support higher loads. An idea that could improve our design would be to purchase pre-made telescoping arms that are stronger in material. This would make the sliding a lot smoother as well as increase the load that the table could handle. Other future improvements for the re-design of our project can be seen below.

**Future improvements for the redesign of our project.**

- Redesign track mechanism to be able to support larger user applied loading at the points that experience the maximum stress.
- Increase structural support and rigidity of table base and jack assembly.
- Increase the amount of support provided by the outer stationary tubes on the sliding track mechanism by introducing a new way to attach them to the main table structure.
- Increase the ease for which the tubes in the sliding track mechanism telescope.
- Decrease the cost of the table by manufacturing the jack for the base in house
- Decrease the cost of the table by optimizing the amount of wood being used for manufacturing.

Most of the improvements suggested for the reconfigurable table are necessary because of design cost restraints. Many of the problems such as the sliding track and structural support of the table were introduced due to insufficient funds. Because of this, the applicable applied load on the table is low (only 60 lbs) and not very feasible for optimal table use. Many of these issues can be resolved in mass production of the design because of reduced part costs due to bulk orders the in house manufacturing of several components. All of the future improvements noted above are both feasible and practical and will increase the demand and functionality of the reconfigurable table design.

## CONCLUSION

The initial design process procedure that has been followed and the final design of the reconfigurable table are completed. In the pursuit of a design of a reconfigurable table that could change according to different settings between two people, it was beneficial to conduct a thorough information search. Different professors in the University of Michigan have taught us the importance of aesthetics and ergonomics to the users of our table. Before we began designing we searched books and documents for existing patents and designs. This aided our information search as well as our creative process. After we completed our information search and with the help of our sponsor Yoram Koren, a list of user requirements could be determined. These requirements were translated into engineering specifications and a QFD diagram was used to determine the most important engineering specifications we should consider in our design. The main functions of the table were broken down in a FAST chart that would lay the way to a morphological chart. The morphological chart allowed us to create concepts for the primary functions, clarify our design needs, and combine multiple functions to create a high-level table concept. Our high level concept choices came down to three described in the concept evaluation and selection. A Pugh chart was used as a tool to choose between these three design concepts as well as the votes of the students in the ME 450 discussion, section 2, we presented the designs to. The evaluation and the class votes led to Concept 2, Shapely, as the preferred design. Quantitative engineering analyses were performed on our final design to obtain results of stability, strength, and overall feasibility. Qualitative engineering analyses were done with the DFMA, DFE, and FMEA to ensure design for manufacturability, design for the environment, and predict failures that may occur with use. The final design of Shapely was documented with computer aided design models and engineering drawings. A manufacturing plan was developed for the construction of our full scale prototype. Lastly, tests were performed to ensure the engineering satisfactions set forth in the beginning of the design process were met. The final step was to construct the prototype. All deadlines have been met and the final design and prototype were presented at the University of Michigan Design EXPO held 4 December 2007 at the Michigan State Capitol Building in East Lansing, MI.

**ACKNOWLEDGEMENTS**

The authors would like to thank Professor Yoram Koren and Ms. April Bryan for guidance in the design process and lending their expertise in the practical aspects of team dynamics and leadership. They also provided us with a place to store and work on our prototype, and enabled us to come in on the weekend to work on the table. We would also like to thank the ME 495 section 002 discussion class for giving user input to the practicality of our final design. The guidance in the machine shop of Mr. Steve Emmanuel, Mr. Steve Erskine and Mr. Bob Coury is also appreciated in the manufacturing of our table design. A thank you is reserved for the rest of the ME 450 faculty and staff for aiding our team through the design process and organizing all events planned in the semester. Finally, we would like to thank the legislators and representatives at the Michigan State Capitol for allowing us to present our design at the capitol building.

## Bill Of Materials

| Quantity | Part Description | Purchased From | Part Number | Price (per unit) | Total Price (incl. shipping and tax) |
|---|---|---|---|---|---|
| 2 | 0.75" 4x8 Pine Plywood Sheet | Home Depot | | $21.97 | $46.58 |
| 2 | Optix .093-36 x 30 Acrylic Sheet | Home Depot | | $13.29 | $28.17 |
| 1 | Glidden Semi-Gloss Paint | Home Depot | 421766 | $9.99 | $10.59 |
| 1 | Glidden Primer | Home Depot | | $8.97 | $9.51 |
| 3 | 3" Foam Brushes | Home Depot | | $0.73 | $2.32 |
| 2 | 2" Foam Brushes | Home Depot | | $0.56 | $1.18 |
| 1 | Clear Caulk | Home Depot | | $2.97 | $3.15 |
| 1 | EZ-One 3pk Tack Cloths | Home Depot | 42-TC3BB | $2.08 | $2.20 |
| 2 | Locking Bolts | Home Depot | | $5.27 | $10.54 |
| 4 | 1.25"x1.25" alum hollow square tube (27") | McMaster-Carr | 88875K36 | $38.36 | $46.78 |
| 2 | 3"x3" hollow rectangular tube (15.75") | McMaster-Carr | 88875K733 | $28.48 | $36.31 |
| 4 | 3/4"x3/4" alum hollow square tube (21") | McMaster-Carr | 88875K31 | $10.89 | $32.78 |
| 2 | 2" OD hollow cylinder (2.5") | McMaster-Carr | 9056K131 | $8.53 | $15.95 |
| 2 | Pair of Folding Leaf Hinge | Rockler | 28928 | $9.99 | $28.59 |
| 1 | Gray ATLAS Motorcross Lift | Greg Smith Equipment | HT1007 | $99.00 | $136.95 |
| | | | | | |
| | Scoring Blade for Acrylic Sheeting | University of Michigan | | $0.00 | $0.00 |
| | Bolts, Nuts and Lock Washers | University of Michigan | | $0.00 | $0.00 |
| | Wood Glue | University of Michigan | | $0.00 | $0.00 |
| | Plastic Wood | University of Michigan | | $0.00 | $0.00 |
| | Screws | University of Michigan | | $0.00 | $0.00 |
| | Sandpaper | University of Michigan | | $0.00 | $0.00 |
| | Hot Glue Gun & Glue | Jennifer Flachs | | $0.00 | $0.00 |
| | | | | TOTAL | $411.61 |
| | | | | BUDGET | $400.00 |
| | | | | DIFFERENCE | -$11.61 |

## References

[1] Obara, S., 2000, "Golden Ratio in Art and Architecture," University of Georgia, Athens, GA, cited 26 September 2007, from Department of Mathematics Education <http://jwilson.coe.uga.edu/EMT668/EMAT6680.2000/Obara/Emat6690/Golden%20Ratio/golden.html>

[2] Armstrong, T. J., "Biomechanical Aspects of Hand Work," University of Michigan, Ann Arbor, MI, cited 26 September 2007, from Department of Industrial and Operations Engineering <http://www.engin.umich.edu/class/ioe433/Biomechanics/Biomech.pdf>

[3] Foley, K. T., Haid, R. W. Jr., and Zdeblick, T. A., et al., 2006,"How to Cope When You Have Low Back Pain: Sitting, Driving, Standing, Stooping, Squatting, Kneeling," SpineUniverse.com, cited25 September 2007, from <http://www.spineuniverse.com/displayarticle.php/article2028.html>

[4] Hedge, A., 2007, "CUergo: Computer Workstation Ergonomics Guidelines," CUergo, Cornell University, Ithaca, NY, from <http://ergo.human.cornell.edu/ergoguide.html>

[5] Gamba, A., and Guerra, A. L., 1995, "Extendible table with two rotating elements, for use as a piece of furniture," United States Patent Application 5458070.

[6] Dann, H. I., 1994, "Adjustable height table support mechanism," United States Patent Application 5375514.

[7] Hoffman, S. D., and Helton, S. J., 1996, "Table with extendable and rotatable surfaces and mechanism for same," United States Patent Application 5562049.

[8] Habegger, J., *Sourcebook Of Modern Furniture 3rd Ed.*, Milano, Italy

[9] Bryars, M., *50 Tables: Innovations in Design and Materials*, New York, NY,

[10] Magistretti, V., *Expomueble, Annual of Furniture Innovations 3rd Ed.*, Mexico City, Mexico

[11] Borngraber, C., *Prototypes for the Designer*, Frankfurt, Germany.

[12] Garvan, M., *American Tables 2nd Ed*., Yale University, New Haven, CT.

[13] Everything Furniture, Inc., 2007, cited 10 October 2007, from <http://www.everythingfurniture.com>

[14] Greg Smith Equipment, 2007, cited 21 October 2007, from <http://www.gregsmithequipment.com>

## BIOS

**Tina Liao**
I was born in Virginia but have lived in Rockville, Maryland since I can remember. When I was young, my parents used to get really angry with me since I would take different toys or appliances apart but couldn't always put them back together afterward. I started building houses with Habitat for Humanity in high school and haven't stopped building since. I love seeing the result of a hard day's work and the effect that it has on the families who work so hard to earn their house. I came to Michigan because of its engineering reputation…and of its football team of course. I chose mechanical engineering over the other disciplines because I wanted a broader scope of knowledge and more flexibility in the future. I graduate this December and am currently looking for a job. I preferably want a career in design because I enjoy the creativity and problem solving skills required to create a product.

**Rebecca (Beka) Macklem**
I have lived in Michigan my entire life until recently. In May 2007 I moved my life down to Annapolis, MD to begin work for a Marine Engineering company where I am currently employed as a naval architect, marine engineer, and a mechanical engineer. I am now back in Michigan finishing my dual degree program and plan to move back down to Maryland at the end of December to continue working. I have always had what some people call "the knack." I tend to be able to fix different devices, or know how different things work when I have never seen them before. I have also always been curious to learn how everything I use worked. I tend to avoid using apparatuses when I do not yet know how they function. My family gets annoyed sometimes because of all of the questions I ask about the way things work. They kid and tell me I am going to become a life-long learner since I can never seem to stay away from school for long periods of time. Because of this, and a strong interest in math, I felt that engineering would be a good fit for me. I came to

the University of Michigan, because I was brought up by my father (who graduated from UofM) to love everything related to the university. As long as I can remember I have wanted to attend. My future plans include finishing my degree, and continuing my new career, and eventually (hopefully) making a difference in the world of engineering.

**Jennifer Flachs**

I am from Laingsburg, MI – Where the city and country meet. When I was in high school I attended a summer camp at Michigan Technological University about Women in Engineering. I had a great time, and that's when I decided I wanted to be an engineer. Both of my parents have engineering degrees, so I may be following in their footsteps somewhat. I chose mechanical engineering because I wanted to design and build roller coasters, motorcycles or automobiles. I like to know how things work, so ME seemed like a natural choice for me. I am a member of the SAE Baja Racing Team and the Vice President of Collegiate Affairs for my sorority, Phi Sigma Rho. My future plans include earning a master's degree in engineering or business administration, finding a job that I enjoy and that is a challenge, and traveling all over the world.

**Lin-Lin Liou**

I was born in Taiwan. I came to the United States when I was almost 3 and have lived my entire life in New Jersey until I went to the University of Rochester for two years. I decided to become a mechanical engineer despite Mathematics and Physics being significantly weaker subjects for me than Chemistry and Biology. I chose this path partially to follow in the footsteps of my father and partially to challenge myself. I was originally going to join the Air Force Reserves to be an Aircraft Maintenance Technician prior to college but decided to join the Reserve Officer Training Corps after my freshman year to still be a part the Air Force and serve my country. I transferred to the University of Michigan my junior year. Although I did obtain an internship with Lockheed Martin and thoroughly enjoyed my job as a designing engineer, I did not want that type of career at this time in my life. I already have a job for me when I graduate and commission as an Officer of the USAF which does not have direct relation to my degree.  I hope one day I will be able to use my degree while in a position that satisfies me.

**Jose Mainardi**

I was born and raised in Puerto Rico. Since an early age I have had an interest in how things work and was amazed by anything related to architecture and construction. As I got older, traveled the world and met new people this interest developed and it became my belief that the most brilliant people in the world are engineers and that I would like to be one someday. In high school I enrolled in a program for college credits at the Pennsylvania State University, it was then and there that I decided to apply to the best engineering colleges in the United States, where I could find the best opportunities and the most academically stimulating lifestyles for a student. I decided to attend the University of Michigan not only because of its prestigious engineering program but also because it's located in the most beautiful and fun college town in the world, Ann Arbor, Michigan. I am graduating in May 2008 and will probably continue working on the pharmaceutical industry where I've had extensive experience before. My interests besides engineering include fitness and health, following Michigan athletics, world issues, watching movies and striving to live up to the Michigan axiom of "leaders and best".

# APPENDIX A: WEIGHT CHART

**Weights***

| | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Seats 2 People | * | must haves | | | | | | | | | | | | | | | | | | | | | | | | |
| Reconfigurable | * | | | | | | | | | | | | | | | | | | | | | | | | | |
| Business Meeting Appropriate | * | | | | | | | | | | | | | | | | | | | | | | | | | |
| Intimate Setting Appropriate | * | | | | | | | | | | | | | | | | | | | | | | | | | |
| Costs < $400 to Prototype | * | | | | | | | | | | | | | | | | | | | | | | | Total | Percentage | Ranking |
| Aesthetically Pleasing | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | | | | | | | | | | | | 4 | 5% | 3 |
| Adjustable Height Range | 1 | | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | | | | | | | | | | | 7 | 9% | 6 |
| Used in Multiple Environments | | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | | | | | | | | | | 2 | 3% | 2 |
| Varying Surface Area | | | 0 | 1 | 1 | | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | | | | | | | | | 5 | 6% | 4 |
| Changes Settings Quickly | | | | 1 | 0 | 1 | 0 | | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | | | | | | | | 5 | 6% | 4 |
| Electrical Transformations | | | | | 0 | 0 | 1 | 1 | 0 | | 0 | 0 | 1 | 0 | 0 | 0 | 1 | | | | | | | 4 | 5% | 3 |
| Safe for all Ages | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | 12 | 15% | 9 |
| Multiple Configurations | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 0 | | 1 | 1 | 1 | 0 | 0 | | | | | 9 | 11% | 7 |
| Environmentally Friendly Materials | | | | | | | | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | | | | 1 | 1% | 1 |
| Long Lifetime | | | | | | | | | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | | 1 | 1 | 0 | | | 6 | 8% | 5 |
| Inexpensive manufacturing costs | | | | | | | | | | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | | 1 | 0 | | 7 | 9% | 6 |
| Able to hold a large amount of weight | | | | | | | | | | | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | | 0 | 6 | 8% | 5 |
| Comfortable | | | | | | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 11 | 14% | 8 |
| | | | | | | | | | | | | | | | | | | | | | | | **Overall total** | 79 | | |

**APPENDIX B: GENERATED CONCEPTS**

**Fold and Slide (Figure 37)**

In its largest configuration, the table is a large rectangle with semi-circular ends. There are 2 rectangular-shaped sections in the middle of the table that fold down and hang to reconfigure the table surface, when the tabletops are slid together. The sections are connected by hinges and when they are part of the tabletop surface, support poles are slid out on the underside of the table between 2 different sections for support. When the sections are folded the support poles are slid back under the table and the remaining surfaces are brought together, with the folded piece hanging vertically under the table. In its smallest reconfiguration the table has one rectangular section of the table under which the folded sections hang, which keeps the table from becoming truly circular when in its smallest configuration. It is supported by six legs. This table was not chosen because the un-used sections of tabletop hang down and may be in the way of a user's feet or legs. The table also does not have a variety of different shapes, it is one shape that has a center section compressed and expanded to change surface area.

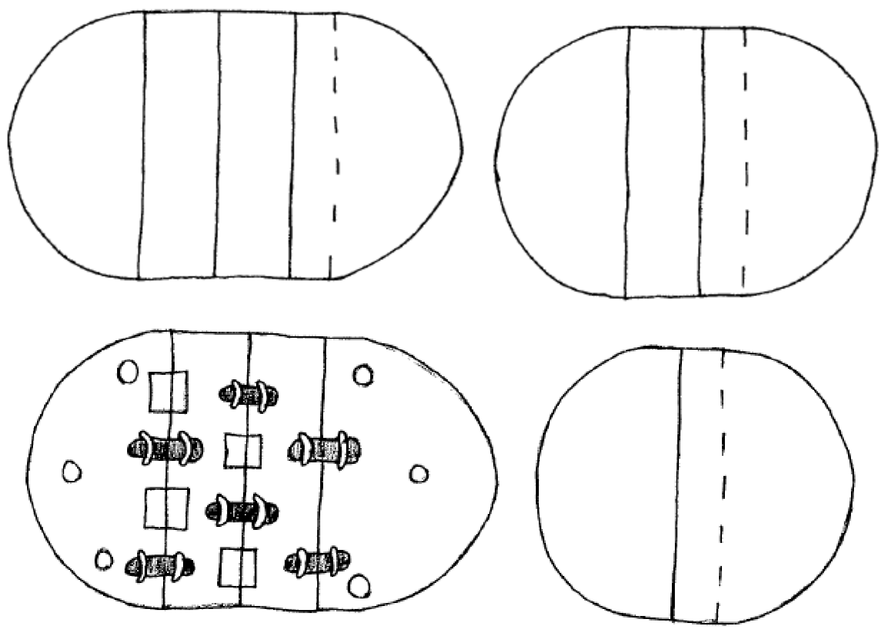


**Figure 37: Fold and Slide Concept Drawing**

**Computer Opposites (Figure 38)**

The table is rectangular-shaped in its largest configuration. To reconfigure it, two square sections can be rotated about different points to create a more interesting shape. The table would be supported by six legs. In the largest configuration a user has a large amount of table space, and is seated reasonably far from any other persons seated at the table. When reconfigured, two people can sit close to one another, separated only by a small section of tabletop. The square sections of table could be used with computer screens that have rotating bases so the users can have a face-to-face interaction while being able to refer to two different computer screens, by rotating their chairs. This concept was discarded because it has two reconfigurations, which does not meet our minimum of three, as given in or Engineering Specifications and it would be difficult to adjust the height because it has 6 legs.

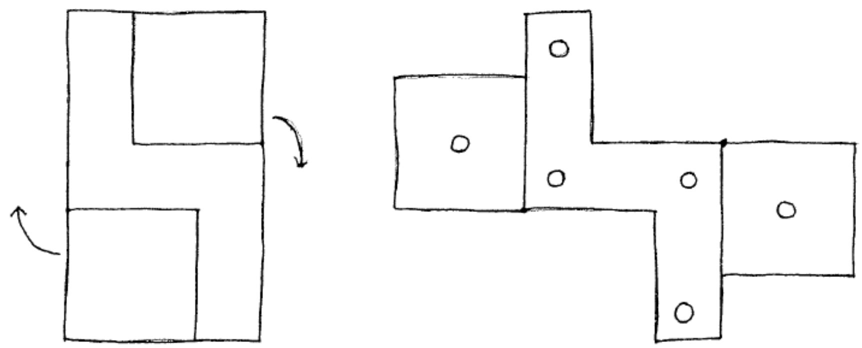


**Figure 38: Computer Opposites Concept Drawing**

**Three-Shape (Figure 39)**
The first configuration of the table is shaped as a square, with one half that can be split and rotated in two different ways. The two sections can rotate 270 degrees to form a large rectangle, or the corners could be folded down and the table could be pushed down and rotated 45 degrees further to form a triangle. These three different shapes allow the users to have a variety of seating situations, from across the square configuration, to double the distance in the rectangular configuration, to sitting side-by-side or at 90 degrees from one another in the triangle configuration. This table was discarded because we decided that in the intimate setting with the smallest configuration that the users would be able to sit 180 degrees from one another. It was also not chosen because of the multiple number of legs which would cause any height changes to be very cumbersome and time-consuming.

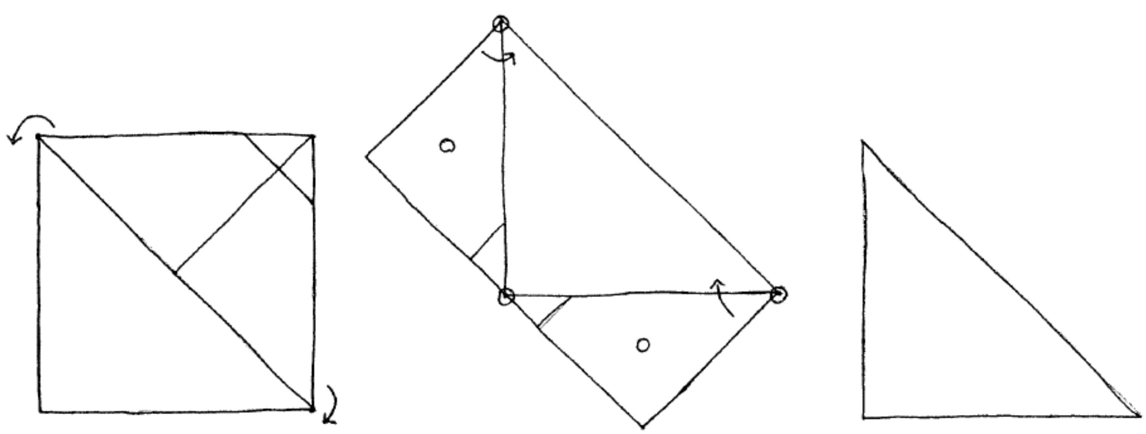


**Figure 39: Three-Shape Concept Drawing**

**Small to Really Big (Figure 40)**
This design enables a large range of surface area. It can be a small circular table for a romantic setting for two and also adjusted to a bar height or increased slightly to over twice the surface area for more usable area. It can also be increased to almost 2.5 times this area to create a professional setting for a business meeting or large dinner. This largest surface area is achieved with three leaves which means anything in between can also be created. The pin setting allows

for adjusting the height so that this table can go from a bar table, to a dining table or a business table to a coffee table allowing for a large number of situations. The pin system and two-leg system would make large height adjustment difficult. This design is very similar to current dining table designs making it a unappealing concept to prototype for the project.

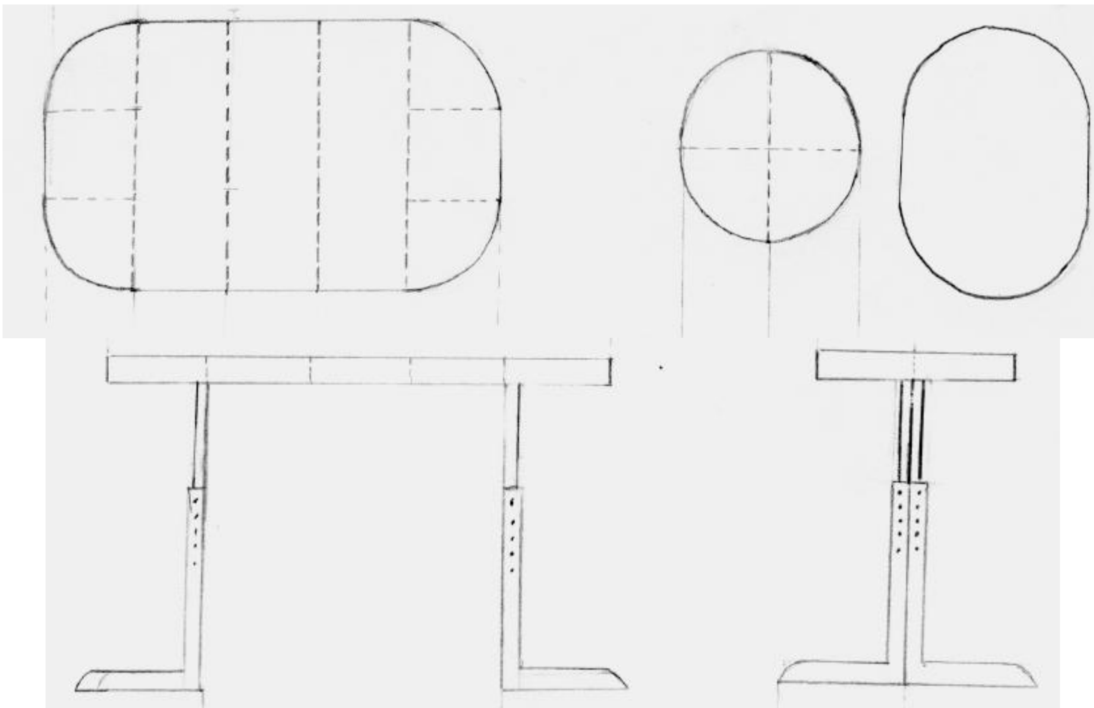


**Figure 40: Small to Really Big Concept Drawing**

**Double Triangles (Figure 41)**

This design has only 2 configurations however it allows for more than just the romantic setting and business meeting. The larger configuration can also allow for studying. By sitting 90 degrees from the side that two people at a business meeting would sit at, a person studying would increase the table area around them allowing for easier access to all their study items. The increase in surface area is minor and there are only two configurations. There would also need to be a large number of mechanical devices to make the design useful and was not chosen as one of three final concepts.

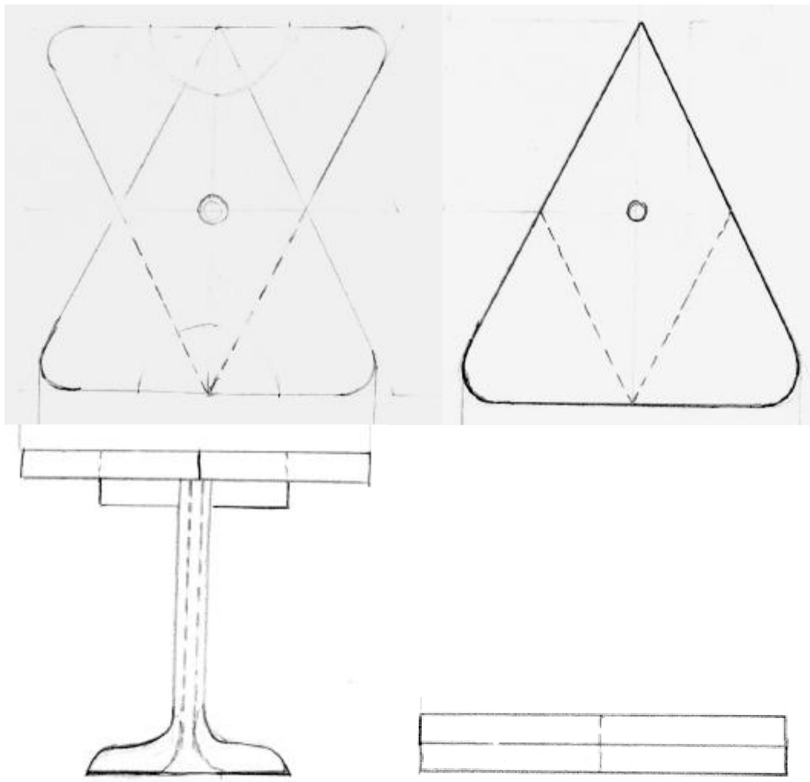


**Figure 41: Double Triangles Concept Drawing**

**Quarters (Figure 42)**
This design is simplistic yet useful in rooms with corners.  The single isosceles right triangle can be placed into a corner.  It can be doubled in surface area and placed flat against a wall for the romantic setting so that the couple will be facing towards each other.  The third piece can be added to make a wall that juts out with a 90-degree angle, useful or all four pieces can be used to make a large square table for a business meeting and a larger dining situation.  Two of the triangles would be removable so that the pieces would not inhibit leg space in the smallest configuration.  This design would require the table base to fold into itself.  This mechanism, even if manufacturable, would have a decreased stability in all the configurations making this design infeasible.

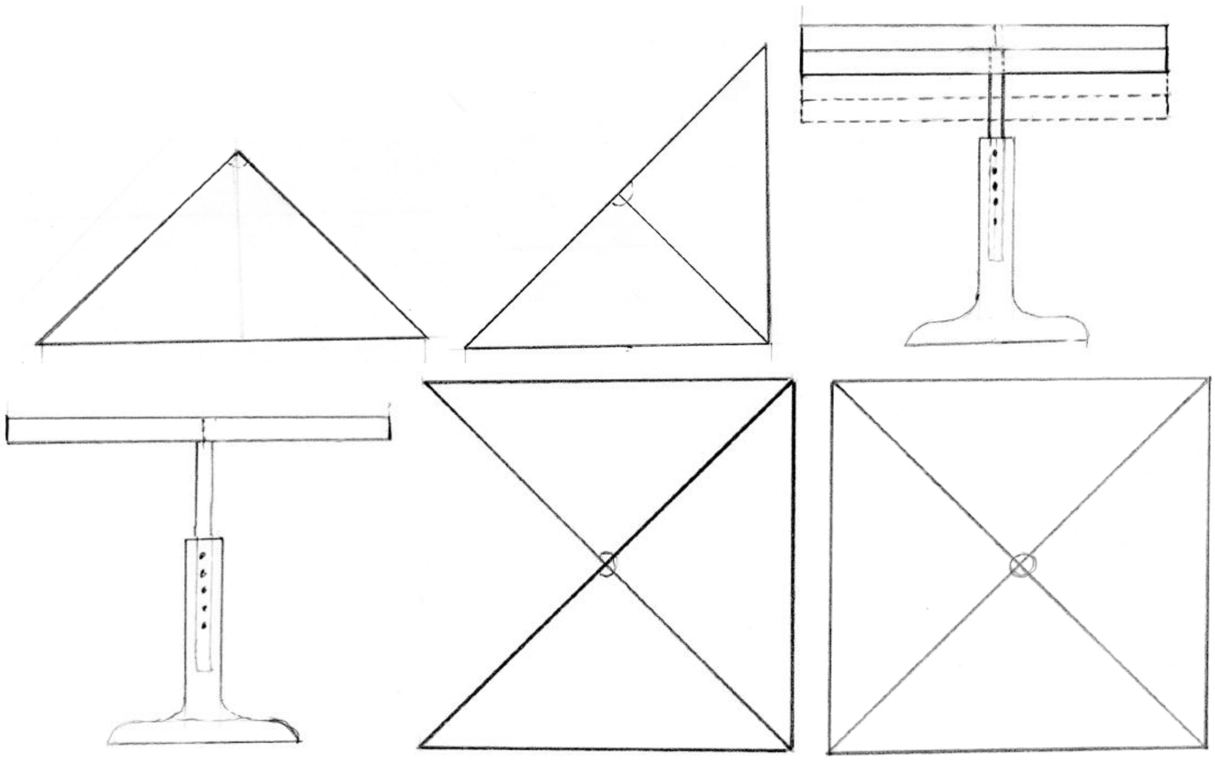


**Figure 42: Quarters Table Concept Drawing**

**Isosceles Square (Figure 43)**
On the top left of the picture we have a closed table. Four triangular flaps are hinged on the four sides of the table and fit as the square we see from the top view. On the bottom left we can see all four flaps open, doubling the surface area of the table. On the top right a 3dimensional view of the open table is shown. This early design served as the basis of our first final concept. The design is easy to build and practical however it had the need to be elaborated upon.

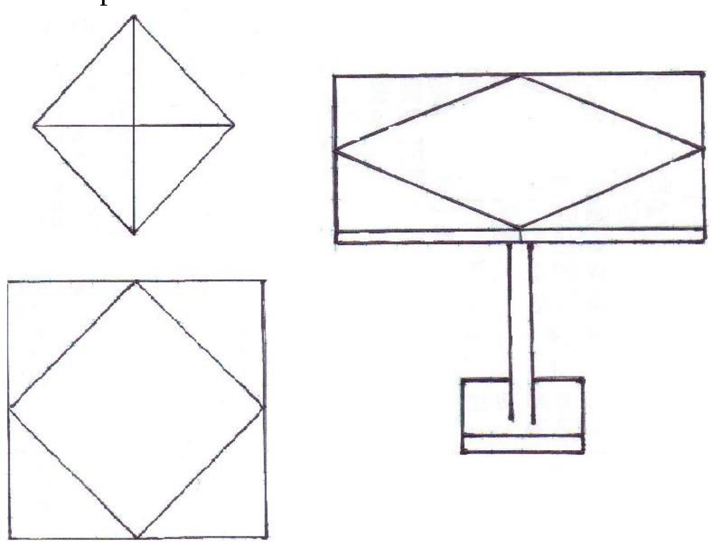


**Figure 43: Isosceles Square Drawing**

**Puzzle Table (Figure 44)**

This designs appeal comes from the fact that it can be reconfigured many times. The table consists of four triangular table tops of exactly the same surface area. Each of the table tops has its own leg. The table tops can be reconfigured and joined in any way the user desires. For this purpose the tables should be lightweight and easy to move. Figure 31 shows a top view of three different configurations with the four tabletops. The first joins on the symmetrical sides to form a square. The second flips two tables 90 degrees clockwise and counterclockwise to form an arrow shape with a ridge that could be appropriate for a person addressing others. The third design shows the tables joining at the edge points and leaving a big space in the center. This configuration can be observed in small classrooms and could be useful. While this design provided a chance to be creative with the surface shape and area it could lead to confusion as to which shape to use for what. Also as the tabletops become lightweight they lose stability, and the wobbling can create a safety hazard between the spaces where the tables meet.

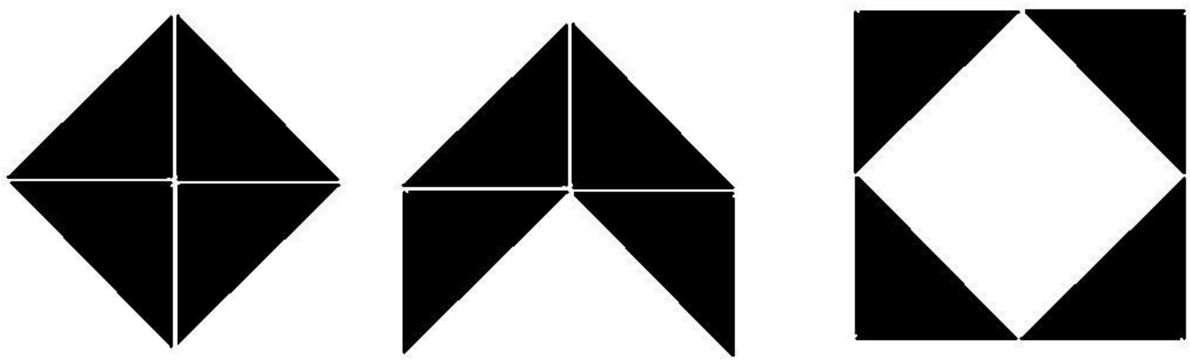


**Figure 44: Puzzle Table Drawing**

**The Sammich (Figure 45)**

This design shows a foldable table. The closed table on the top left and bottom left show the hinged flap closed on top of the bottom one. The hinges are located to the right of the table. Another set of legs are hinged along the left legs and will turn clockwise if viewed from the top. Ultimately this design was discarded because of its simplicity and because it was not innovative in any way.

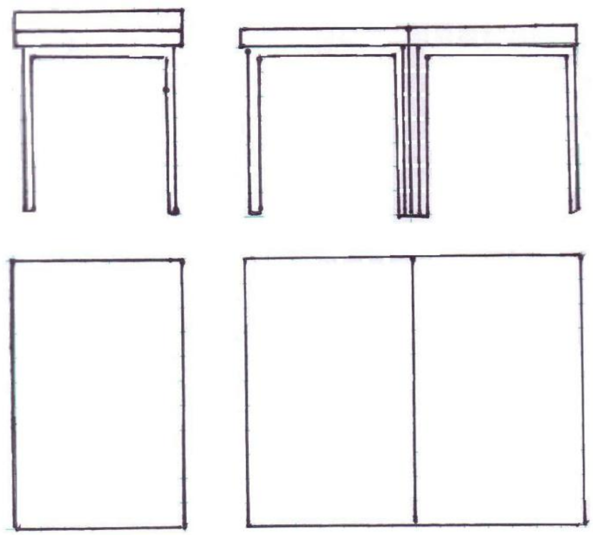


**Figure 45: The Sammich Drawing**

**Shapely (Figure 46)**
This table transforms from a rectangle to an oval like shape to a circle. The large rectangle is good for bigger business meetings or when more than 2 people are using the table. In order to shift from the rectangle to the oval, the two ends are slide away from the center portion, rotated 180 degrees, and then slide back over the center of the table. The oval table is convenient for 2 people who want to sit comfortably close to each other in an intimate setting. Finally, to make the circular table, two flaps on the flat side of the oval are lifted from their folded positions to complete the circular shape. This table formation can be used for 2 people who would like more space to have a business meeting. This “Shapely” table has one leg that will be able to adjust height using a scissor jack with a foot pump.

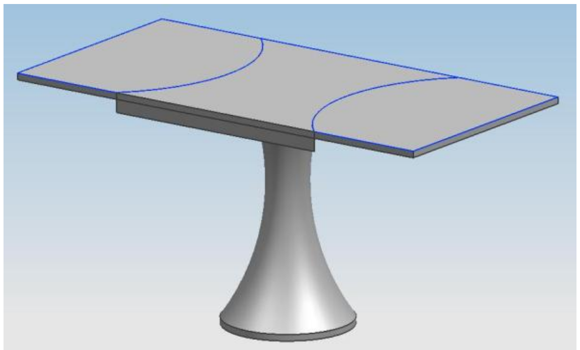


**Figure 46: Shapely Design**

**Chain Gang (Figure 47)**
This table has an infinite amount of configurations but the surface area of the table will always remain constant. The rim of the table consists of a chain that is moldable to whatever the users preference is. The surface of the table is a rubber material that can adjust to the changing shape of the outer rim. The four legs of the table will have wheels on the bottom that can lock so they can also adjust to the various shapes of the table. This design was not used because the idea of having varied surface area was very desirable in satisfying the requirement for multiple settings.

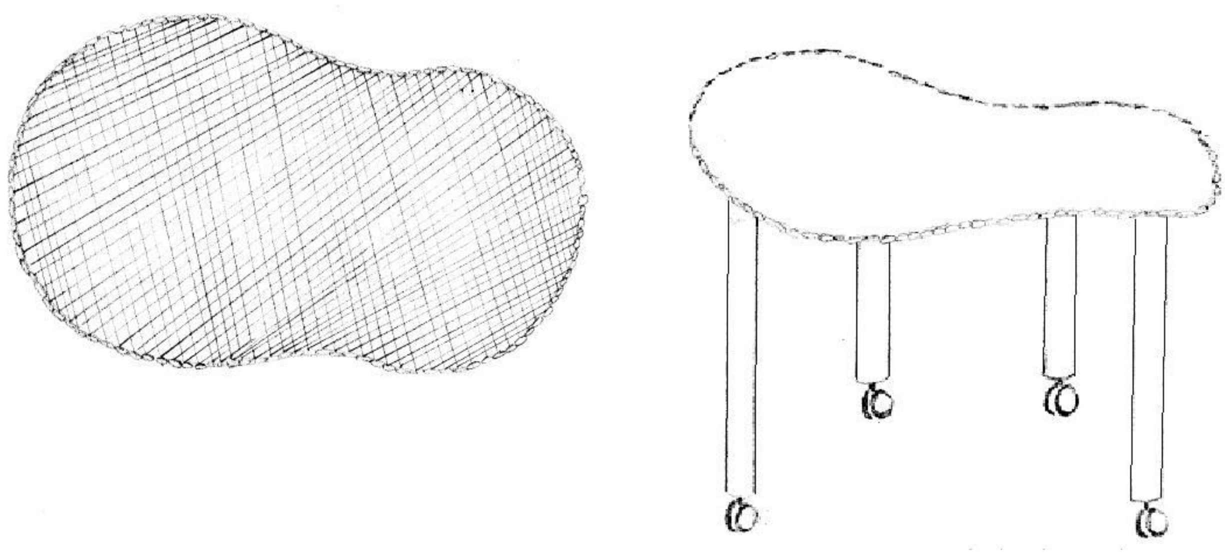


**Figure 47: Chain Gang Design**

**High Flyer (Figure 48)**
This design consists of a circle, a rectangle, and an octagon shaped table. The center pole has arms that extend out and contain cables to lift sections of the table. To remove the octagon shape, the cables are hooked on the table portion and then lifted up to the arms above the heads of the users. To get the small circular table, the same process is repeated but the octagon and rectangular sections are latched together. This table gives the user a lot of variation in table shape and size. However, this design is not stable when the sections are connected to the arms so it was not used.

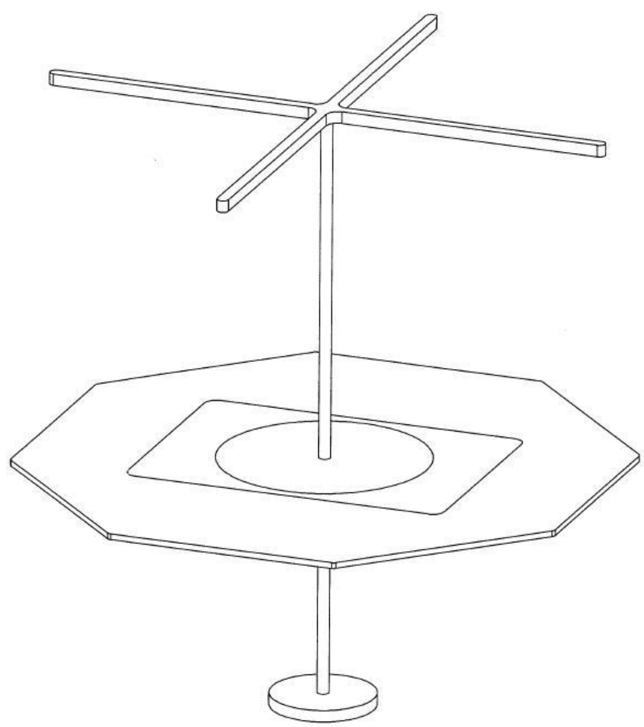
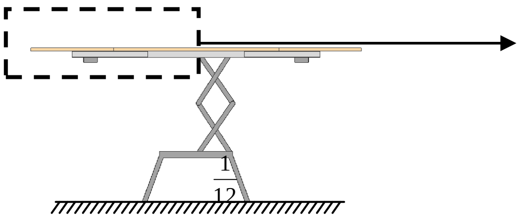
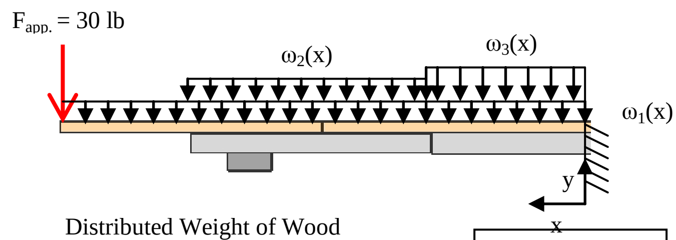


**Figure 48: High Flyer Design**

## Appendix C: Engineering Analysis Calculations




**Assumptions:**

1.) Outer Support is assumed to be grounded.
2.) All metal parts are 6063 Square Aluminum Tubing
3.) Distributed weights are for ½ of the total table weight. It is assumed that the total load is distributed equally between the two side supports.
4.) The applied load of 60 lb. is distributed evenly to the two supports. Therefore the model is shown with having a 30 lb load on each support.
5.) The weights of the supports are considered negligible.

Distributed Weight of Wood

$\omega_1(x)$=0.57 lb/in.

Distributed Weight of Inner Pipe

$\omega_2(x)$=0.023 lb/in.

Distributed Weight of Outer Pipe

$\omega_3(x)$=0.029 lb/in.

E=1.4 MPA
I = 1.26 in$^4$

**Equilibrium of Forces and Moments:**

$\sum F_x = 0 = A_x$ $\qquad A_x = 0$ lbs

$\sum F_y = F_{app.} + F_1 - A_y = 0$

$30+21-F_A = 0$ $\qquad A_y = 51$ lbs

$\sum My = (F_{app.} \cdot x_{app.}) + (F_1 \cdot x_1) - M_A = 0$

$(30 \cdot 36)+(21 \cdot 18)-M_A = 0$

$M_A = 1458$ lb·in

**Figure 49: Reaction Forces Calculations**

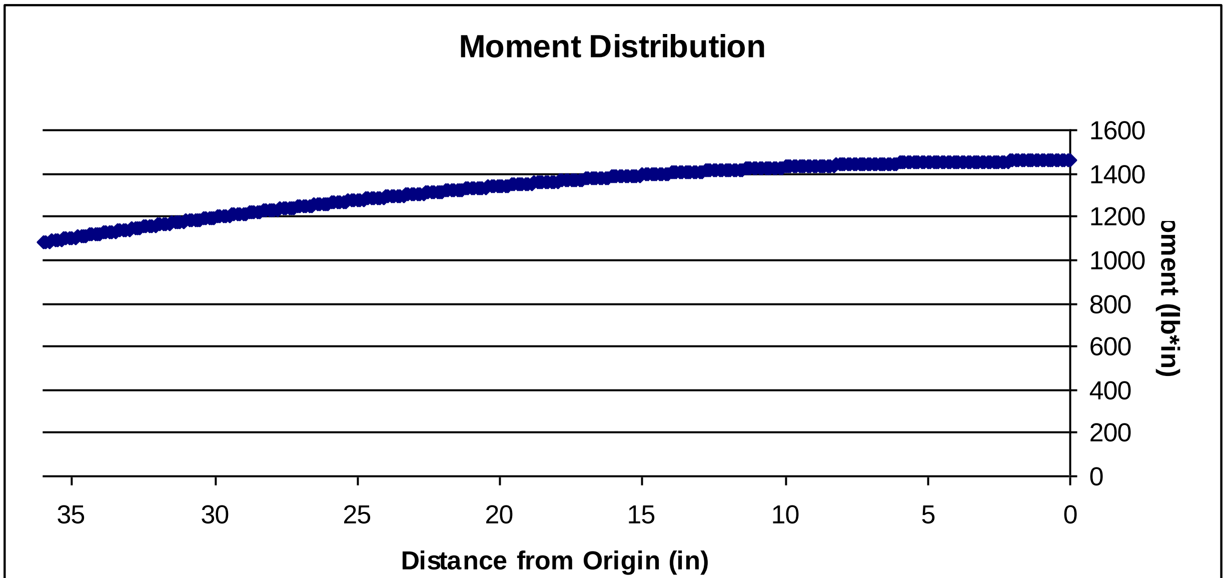



**Figure 50: Moment Distribution**

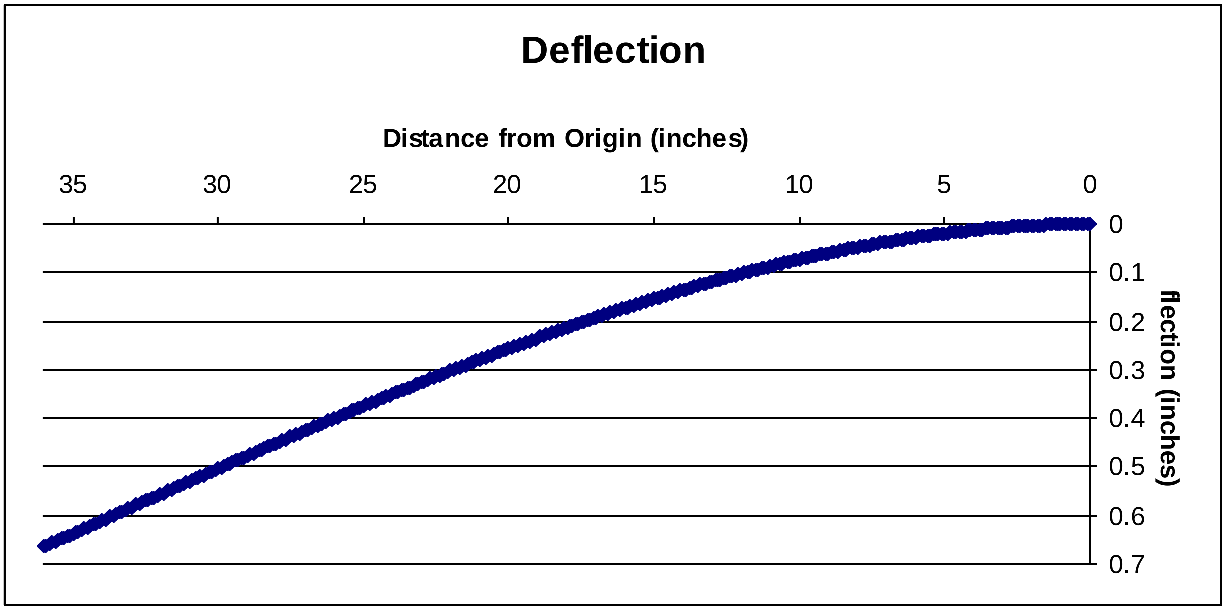
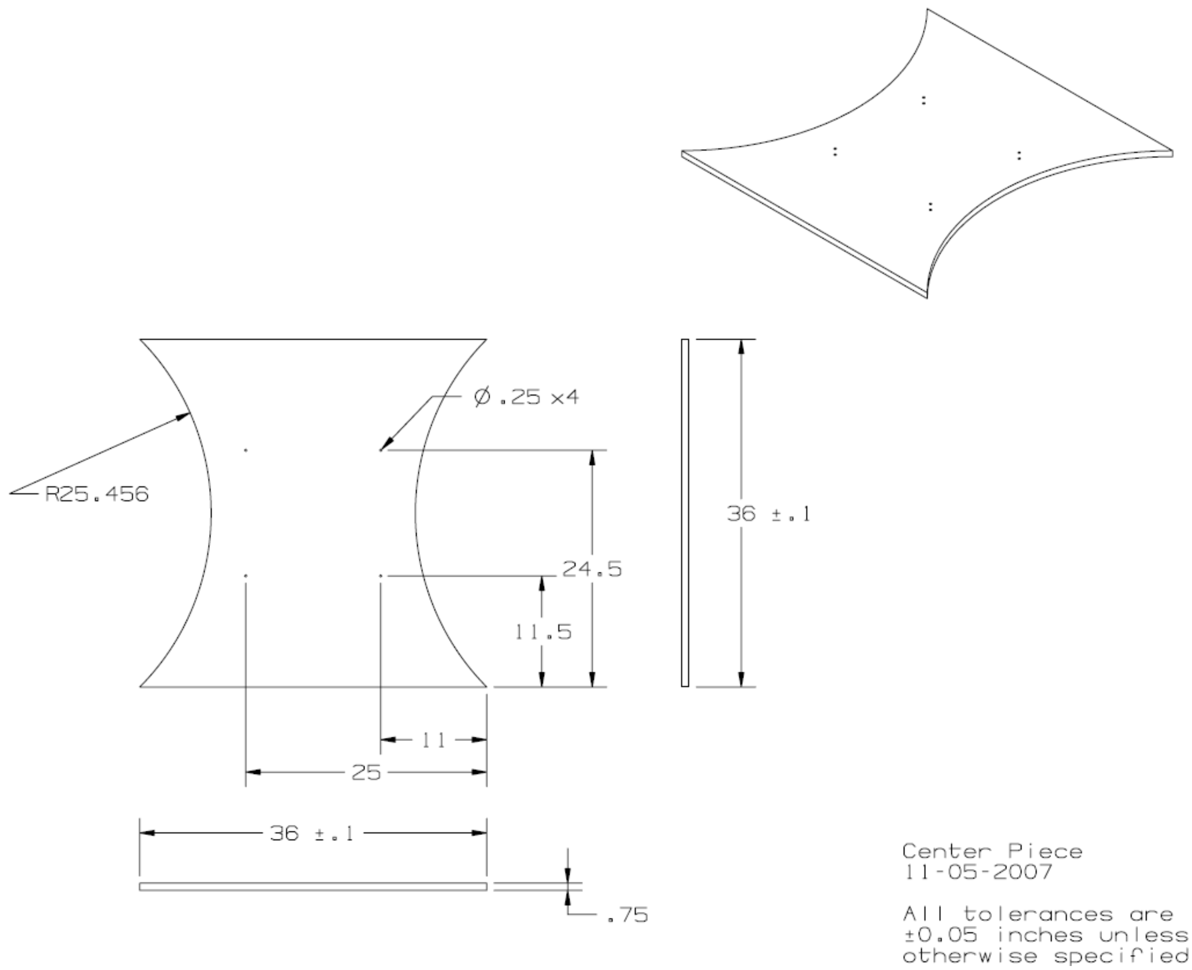
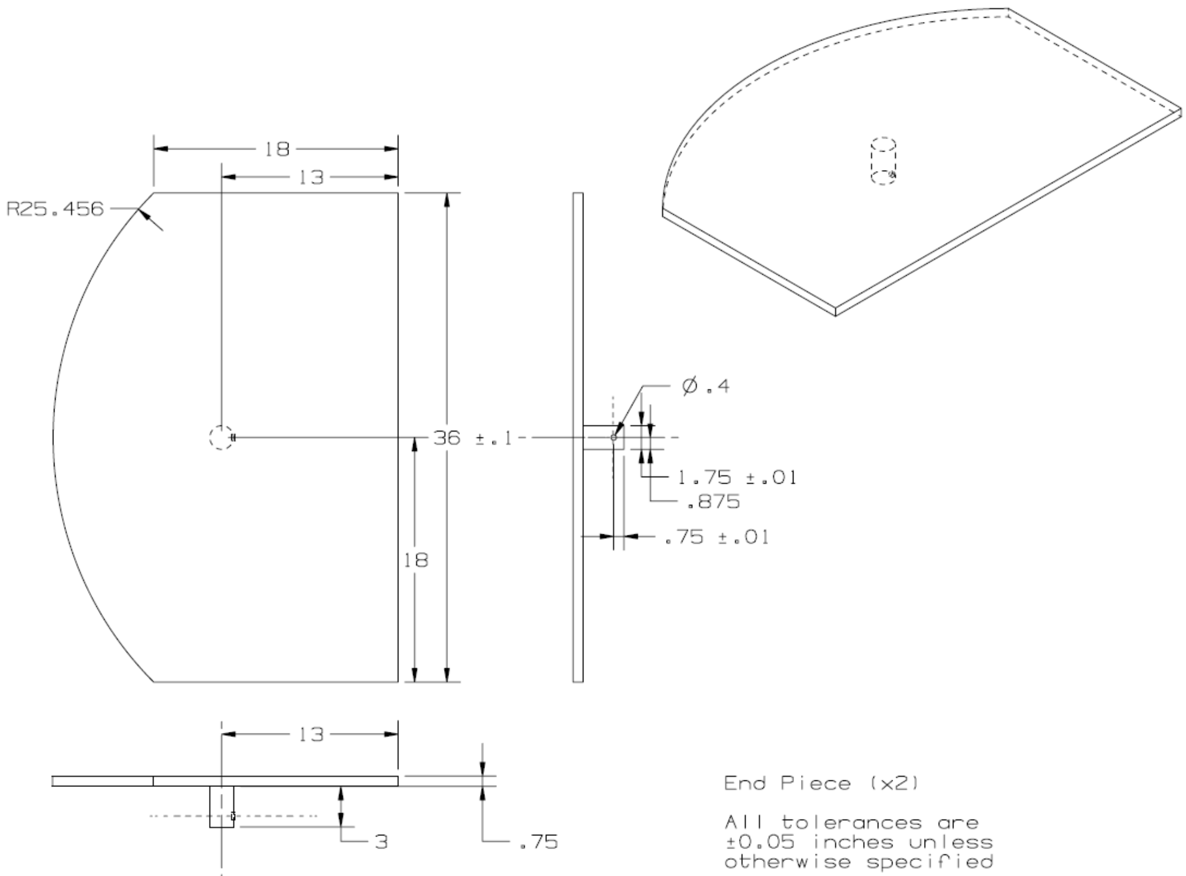
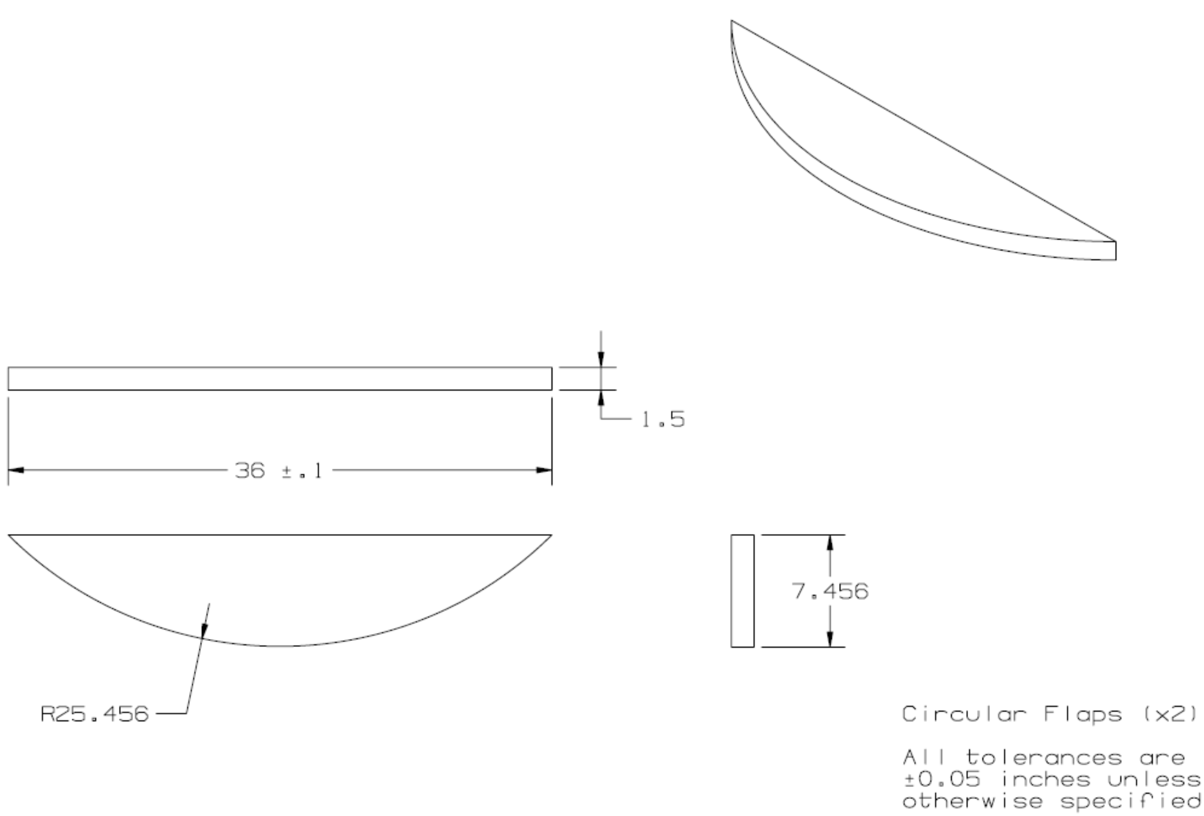



**Figure 51: Deflection Distribution**

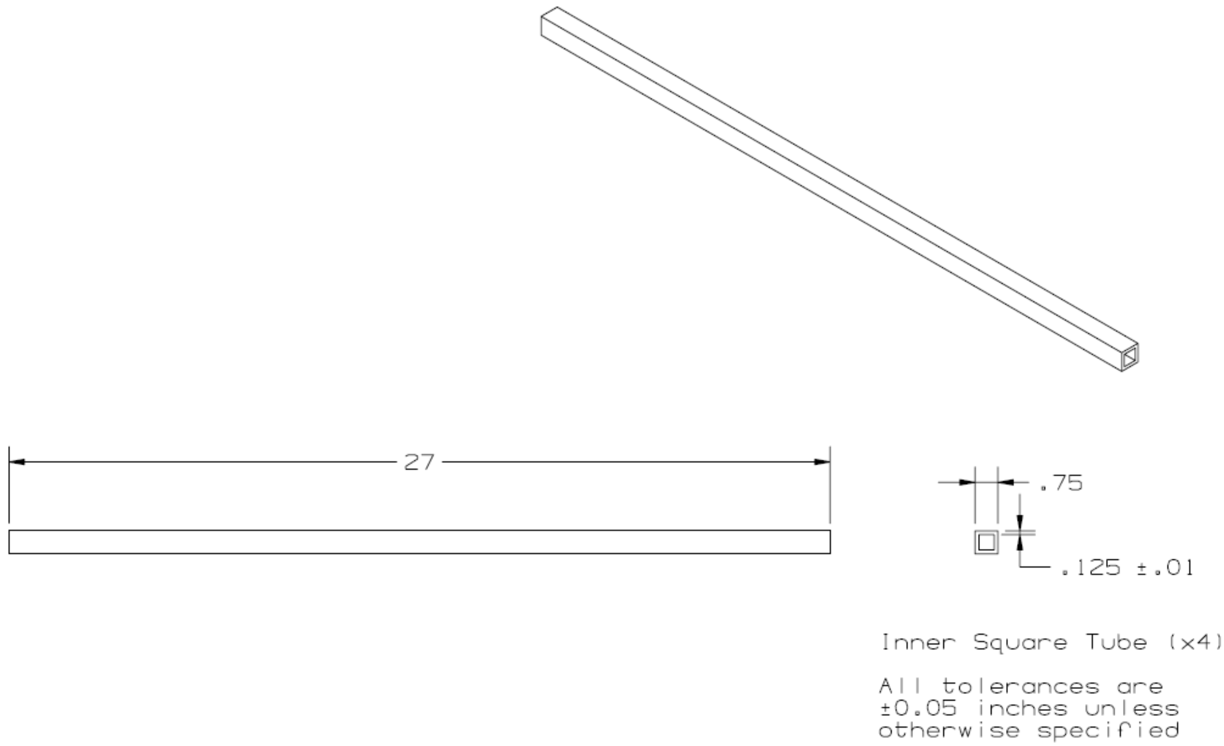
**Appendix D: Engineering Drawings for Shapely Main Parts (Dimensions in inches)**

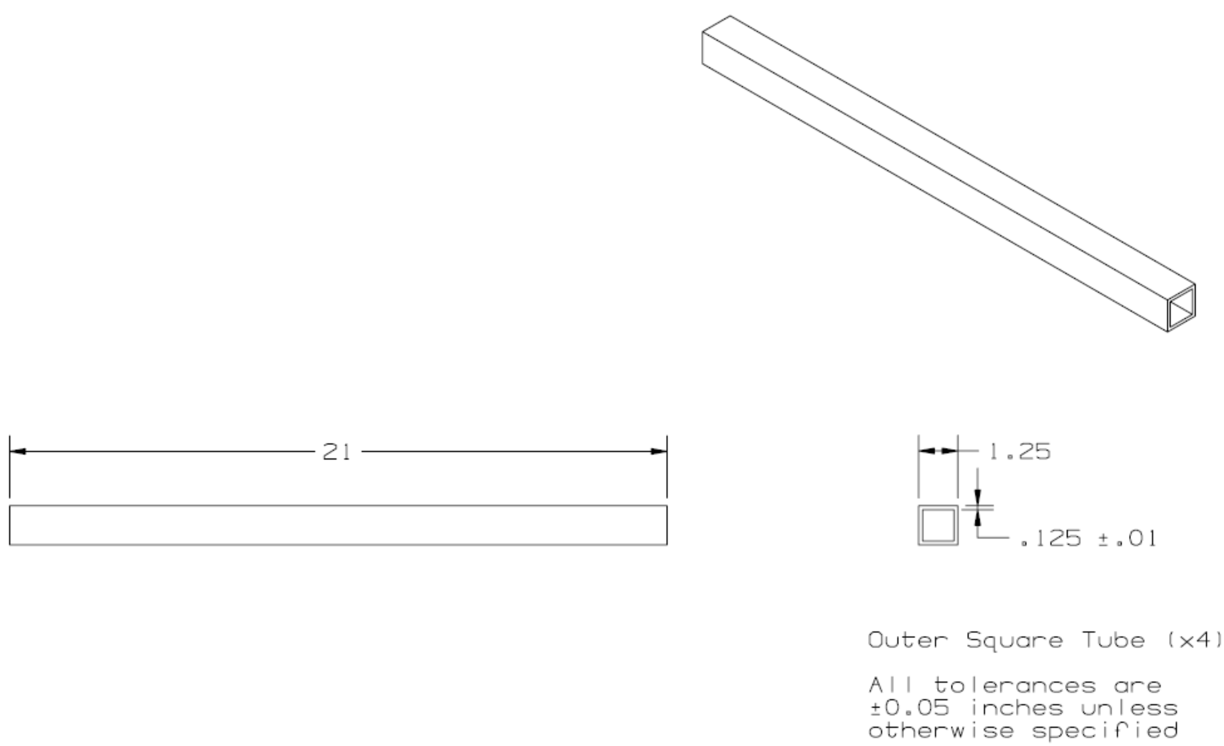


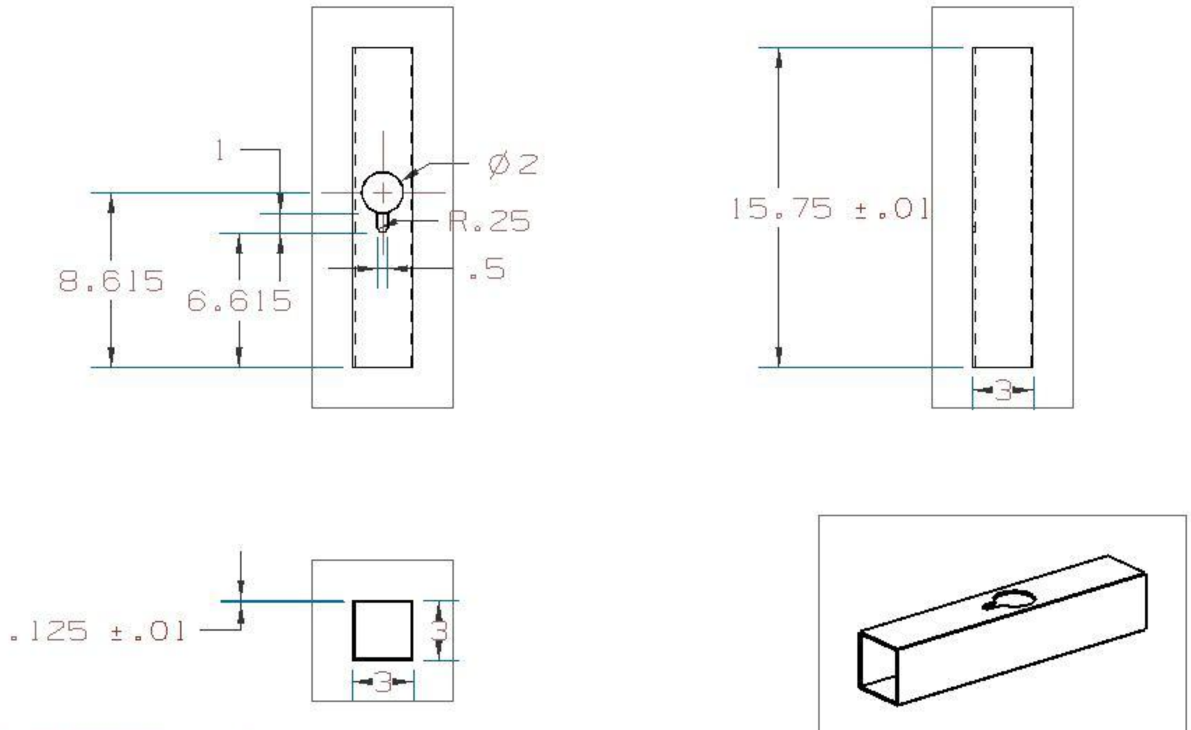

18
13
R25.456
36 ±.1
18
Ø.4
1.75 ±.01
.875
.75 ±.01
13
3
.75
End Piece (x2)
All tolerances are ±0.05 inches unless otherwise specified


1.5
36 ±.1
7.456
R25.456
Circular Flaps (x2)
All tolerances are ±0.05 inches unless otherwise specified

**Appendix E: Engineering Drawings for Shapely Track Parts (Dimensions in inches)**






Crossbar (x2)
All measurements in inches
All tolerances are ±0.05 inches
unless otherwise specified