Portable Pelvic Examination Table

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Omega (Revision B) Prototype

Designing a Portable Gynecological Examination Table - Improving Access to Maternal Health Care in Rural Ghana

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Abstract – It is important to understand the possible cultural implications of a medical device before it is designed. It is also crucial to follow up with field testing to not only examine the functionality but also the cultural acceptance of the design. The goal of this design project is to diminish the barrier of transportation to secondary and tertiary healthcare facilities and services by developing and constructing a portable gynecology examination table for use by community healthcare and planning services (CHPS) workers in the Sene District, Ghana. This idea was first developed by a group of 12 undergraduates from interdisciplinary backgrounds who traveled to Ghana in Summer 2008. This design will then be introduced to the same field site in Summer 2009. The method of field site observation, prototype design, introduction of prototype to field site, and re-design of the prototype is part of the Global Health Design curriculum which is currently being introduced by Professor Kathleen Sienko and colleagues at the University of Michigan, Ann Arbor. An essential part of this curriculum and of our design is the Co-Creational component. The collaboration between our engineering team and the Ghanaian and American clinicians was and will be essential to developing a final product that is both culturally competent and meets the goal of improving the access to care for women in rural Ghana.

Index Terms – Global health design, Co-creation, Ghana, gynecology, service learning

INTRODUCTION

Regular pelvic examinations and health care visits are important preventative measures for maintaining maternal health. However, in rural settings within the least developed countries, poor traveling conditions, lack of resources, social constraints, lack of educational opportunities, and economic limitations make it difficult for women to receive proper healthcare during a pregnancy. The goal of this design project is to diminish the barrier of transportation to secondary and tertiary healthcare facilities and services by developing and constructing a portable gynecology examination table for use by community healthcare and planning services (CHPS) workers in the Sene District, Ghana.

Design for global health is a topic of increasing importance and places new constraints on the engineering design process. Throughout the design process, Ghanaian and American clinicians were interviewed in order to obtain user requirements for the initial prototype. These requirements were translated into engineering specifications, and brainstorming and functional decomposition were performed in order to generate solution concepts. The highest ranking user requirements were 1) light weight, 2) portable, 3) low in cost, 4) supports the weight of the patient, 5) comfortable for the patient and examiner, 6) easy to clean, 7) non-corrosive/non-absorbent, and 8) adjustable. In agreement with the engineering specifications and the outcomes of our QFD and Pugh charts, we designed a portable gynecology examination table prototype that 1) supports a weight of 313 lbs while only weighing 22 lbs, 2) can be folded into a 7x20x20 inch volume enabling transportation by backpack, 3) costs less than $100, 4) can be cleaned with bleach, and 5) has three adjustable back angles of 0, 30, and 60 degrees.

The middle section base is made out of birch plywood, to which a PVC sheet is adhered to the top. The head and foot section are made aluminum frames with Polyester fabric. Two of the constraints unique to global health design are the use of local materials and local manufacturing. Subsequent prototypes will be manufactured in Ghanaian machine shops using band saws, drill presses, screw drivers, and glue. The proposed materials for in-country manufacturing and assembly are ceiba plywood, PVC, and aluminum. These materials are similar in price, weight, and strength to the birch, PVC, and aluminum that compose the prototype. Local manufacturing processes and an analysis of the functionality, cultural acceptance, and performance of our prototype will be further explored during field testing from June-July 2009.

MOTIVATION

The most current report from World Health Organization says that Maternal Mortality Ratio in Ghana is 560 deaths per 100,000 live births and the Infant Mortality Rate is 76 deaths per 1,000 live births [World Health Organization, 2005]. Many of these deaths could be prevented by regular pelvic examinations and health care check-ups.

One of our team members was part of a Global Intercultural Education for Undergraduates trip to Ghana last summer which had a project goal of studying the issues surrounding maternal mortality. Time was spent in both urban and rural healthcare facilities. While in the Sene District of Ghana, he learned that in the rural areas of the villages women have to sometimes get pelvic exams performed on the hoods of cars.

FIGURE 1
INTERDISCIPLINARY GIEU GROUP IN GHANA – SUMMER 2008

If Ghanaian women in rural areas try to go to a hospital they face a long strenuous trip, sometimes up to a six hour walk. Once they get to the hospital, many times they receive inadequate care and are treated harshly. They then make the long trip back to their village, many times returned in the same or worse condition then when they left. This “vicious cycle” leads to poor health of the women and distrust in the health care system. This is explained in the figure 2 below. These observations from last summer are directly in line with scholarly literature that defines the “Three Delays Model” to receiving maternal health care [Thaddeus and Maine, 1994].

The three delays are: a delay in knowing when to seek care (understanding), a delay in seeking care (transportation), and a delay in receiving care once at the health care facility. The goal of our project is to increase the access to maternal health care by the development of a portable gynecology examination table that health care workers and midwives could take on their motorbikes to the rural areas.

FIGURE 2

VICIOUS CIRCLE OF THE LACK OF ACCESS TO MATERNAL HEALTH CARE IN GHANA

BACKGROUND

In order to develop a portable gynecology table to improve the access to maternal health care in Ghana, both the medically and culturally relevant topics were studied. The areas that we studied are broken up into four main areas: pelvic exam, culture of Ghana, obstetrics/gynecology and midwifery in Ghana, the benchmarking of tables and devices that are currently being used, and patents.

Pelvic Examination

A pelvic examination of a woman is necessary in order to check for infection, complications, and the well being of the woman and her reproductive health. All woman, but especially those that are sexually active should have annual pelvic exams. The exam usually includes five main components: the external exam, the speculum exam, the palpation (bi-manual) exam of the cervix, the anal exam, and the pap smear. [Rathe, 2009]

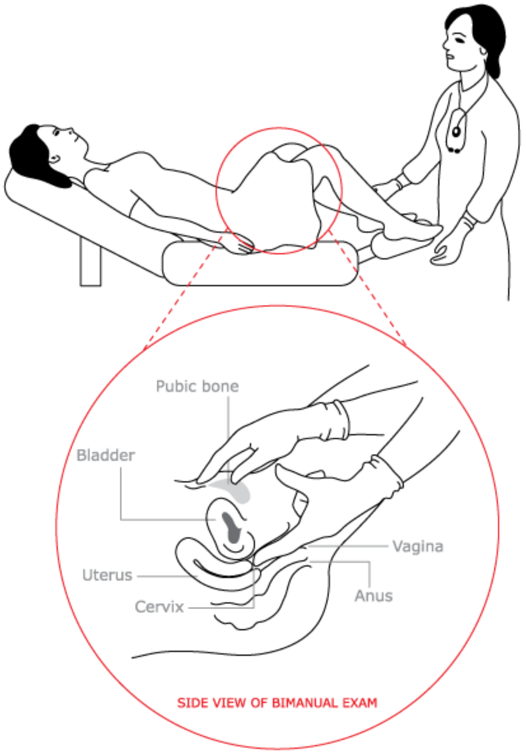

FIGURE 3

DIAGRAM OF BIMANUAL EXAM AND POSITION OF PATIENT (PELVIC EXAM)

The common equipment used in an examination includes a table along with gloves and a speculum. A bright flexible light source, lubricating jelly, and stirrups were also common exam equipments. [Rathe, 2009]

Benchmarking of Current Tables on the Market

To develop an idea of the important components to a gynecology examination table, we benchmarked many different tables that are used in hospitals around the United States. The most basic examination tables included an adjustable bed and a leg separation mechanism. The leg separation mechanisms include simple rubber tips, hanging straps, foot holders, or lower leg holders. Each has its own advantage for ease of use, range of motion, and level of support. We also researched patents for portable beds, stirrups, and gynecology equipment. One of these basic tables by Medical Supplies and Equipment is shown on page 4 [Two in One Examination/Treatment Table, 2009].

FIGURE 4
BASIC GYNECOLOGY EXAMINATION TABLE

Benchmarking of United States Patents

In order to see what devices like the one we were working on had already been designed, we research patents for portable beds, stirrups, and gynecology equipment. One of the portable beds we found is shown below in figure 5 [Torrey, 1974]. This design is only an attachment and not a full examination table.

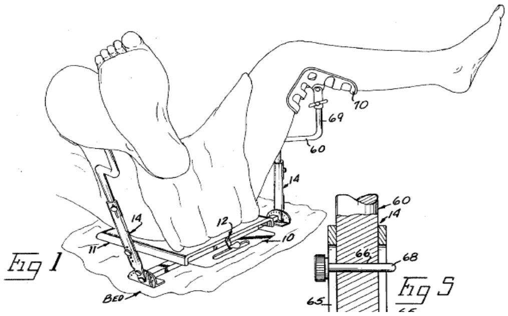

FIGURE 5
PATENT FOR A PORTABLE GYNECOLOGY EXAMINATION ATTACHMENT

Different Classifications of Medical Personnel in Ghana

As identified by our mentor Dr. Ofosu, the end users of our table will be health care workers and midwives who live in the Community-based Health Planning and Services (CHPS) compounds. The different medical personnel in Ghana who deliver maternal care are presented in order to show where the health care workers and midwives fit into the health care system. In Ghana, there are 7 main groups of medical personnel that would attend to women and 4 of these groups are capable of performing a gynecological exam. The first set is medical doctors who normally perform examinations in a hospital or clinic and have access to unlimited specula, gloves, lights, lubricating jelly, and stirrups. Nurses at the hospitals and clinics would never actually perform an exam themselves, only assisting in the procedures. There are also public health midwives that can either operate in the hospitals or in rural communities and are approved by the government to provide maternal health care. There are also “traditional midwives” who have been trained by the government to become traditional birth attendants (TBAs). This was once widely approved of, but there is now a push for public health midwives to provide the care [Geurts, 2001]. The newest group of medical personnel that is being educated to perform exams is community health care workers, who are the targeted end user of our examination table [Nyonator et al, 2005]. Almost 50 percent of births are delivered in the home by a relative, who is not trained for a delivery. Many times this is done because women fear going into the sometimes harsh hospital environment and also don’t want to make the strenuous travel to the facility [Geurts, 2001].

Community-based health planning and services (CHPS) compounds in Ghana

The rural areas of the Ghana health care service are undergoing a change from the current clinical based system to the CHPS community system. CHPS compounds are small healthcare centers manned by a community healthcare worker or midwife. Currently, four-wheel vehicles are used for bi-weekly outreach clinics. In the CHPS based system, a health care worker or midwife would be placed in the communities and would only require a motorbike or bicycle [Nyonator et al, 2005]. The device we are creating is being designed to fit into the new CHPS based system as identified by health care workers and midwives in Dr. Ofosu’s District.

CUSTOMER REQUIREMENTS AND ENGINEERING SPECIFICATIONS

The Co-creation of our design between our engineering team and American and Ghanaian clinicians has been essential to making sure that it is capable of serving the purpose for a gynecology exam as well as being culturally acceptable. To better understand how the table will be used in Ghana, we have been in contact with Dr. Ofosu. Healthcare workers and midwives in Dr. Ofosu’s district will be the end users of our table. In addition, we also spoke with Dr. Tim Johnson, the chair of Obstetrics and Gynecology at the University of Michigan, and Dr. Jody Lori who is a certified nurse-midwife at the University of Michigan hospital. With our many mentors and their customer requirements and background research of current tables and patents, we were able to determine our engineering specifications.

Dr. Ofosu was able to give us the following information [Ofosu, 2009]:

- Useful to have table that can fold-away but still hold patient
- Health care workers are the primary target, and midwives are the secondary target
- Tables are cleaned with a bleach & water solution, or chlorine solution
- Lithotomy or supine position is the best for examination
- Width of table should be no more than 36 in
- Largest pregnant woman weighs about 210lb (Average being 143 lb)
- Largest height of woman is about 72 in (Average about 65.7 in)
- It is possible to have a table of 12-24 in off the ground with a stool included for the healthcare worker
- We can expect the table to be used on a hard dirt surface

Our customer requirements were determined mainly from Dr. Ofosu’s insight [Ofosu, 2009] and other requirements were determined from our other mentors and research. In order to rank these customer requirements, questionnaires were sent to our mentors Dr. Ofosu, Dr. Johnson, and Jodi Lori. We asked them to rank the customer requirements from 1-12 [Ofosu, 2009; Lori, 2009]. From their rankings we created the rankings presented in Table 1.

TABLE I

CUSTOMER REQUIREMENTS RATED FROM MOST IMPORTANT TO LEAST IMPORTANT

Requirement	Rank
Light Weight	1
Portability	2
Low Cost	3
Easy to Use/Assemble	4
Safety	5
Patient Comfort	6
Examiner Comfort	7
Easily Cleaned	8
Manufacturing	9
Maintenance	10
Non-Corrosive	11
Non-Absorbent	12
3 Adjustable Back Angles	13
Adjustable Table Height	14

The next step was to determine our engineering specifications using the customer requirements and a Quality Function Deployment. In order to do this, we discussed what would be necessary to meet this requirement, did research, and asked necessary questions to our contacts. The following sections outline each requirement and how they were translated into engineering specifications. Table 2 presents our final engineering specifications listed in order of most important to least important.

TABLE 2

ENGINEERING SPECIFICATIONS DETERMINED FROM CUSTOMER REQUIREMENTS

Engineering Specification	Target Value
Light Weight	Less than 22 lbs
Support Weight	More than 313 lbs
Non-Absorbent	100%
Non-Corrosive	100%
2 Detachable Stirrups	35-50 Degrees
Cost	$300
3 Adjustable Back Angles	0, 30, 60 Degrees
Travel Pack Water Resistant	100%
Lifetime	Greater than 5 years
Length (unfolded)	More than 62”
Width (unfolded)	No more than 24”
Height (unfolded)	No more than 20”
Length (folded)	Less than 20”
Width (folded)	Less than 20”
Height (folded)	Less than 7”
Bedding Thickness	Less than 1”

High Support Strength

To determine the required support strength, it was necessary to determine the weight of the 95 percentile of women who will be using the table. Anthropometrical data shows us that the average weight of Nigerian women to be 126 lbs (57 kg) [Danborno, 2008]. In addition, Dr. Ofosu stated that the largest woman expected to use the table will weigh approximately 209 lbs (95 kg). In order to determine what the maximum support for the table should be, we agreed on a factor of safety of 1.5. Therefore, the table needs to support no less than 313 lbs (142 kg).

Easy to Clean

A member of our team, Joseph Perosky, spent 4 weeks in Ghana. First hand, he experienced how sanitation and sterilization are performed in the hospitals. Many times when cleaning tables in Ghana, it is only a quick wipe down of the surface. Figure 6 below shows a birthing bed and the unsanitary conditions that may arise.

FIGURE 6

UNSANITARY BED IN CURRENT HOSPITAL WITH BLOOD UNCONTAINED ON THE BED AND FLOOR

Due to sanitation issues, our table needs to be very easy to clean. For the surface in which the woman will be laying, a 100% non-absorbent material is used. Any fluid that is absorbed increases the result of spreading infection or disease to another patient. Since bleach and water or chlorine solutions are the main method of sanitation, Dr. Ofosu has requested a table bed that is non-corrosive. Figure 7 shows a current bed used in Ghana with corrosion and rust on the frames.

FIGURE 7

CORRODED AND RUSTED FRAME OF CURRENT BED IN GHANAIAN HOSPITAL

The pack in which the folded table is carried in must be 100% water resistant. This helps repel dirt, and rain during the travel.

Low Cost

The district in which this bed is being designed for only has an annual budget of $5000 USD [Ofosu, 2009] and is willing to spend 300 US$ on a portable auxiliary table. We want to stay as far under this number as possible. Based off an analysis of the desired materials and in talking to our end user, we set a high end goal of $100 for the production of the table.

Portable

Health care workers or midwives may travel several miles on motor bikes and by foot to get to a patient's home. Many women must travel by foot for up to 5 or 6 hours in order to reach a health care facility [Thaddeus and Maine, 1994]. In order to diminish this barrier to healthcare, the health care worker or midwife must travel on a motor with the gynecology table in a backpack. Figure 8 shows the current roads in rural Ghana today that the healthcare worker will have to travel through.

FIGURE 8

DIRT ROAD IN RURAL GHANA THAT MANY WOMEN HAVE TO TRAVEL ON TO SEEK HEALTHCARE

Due to these reasons, we decided it would best to have a foldable table that could be put inside a water resistant pack and strapped onto the healthcare worker's back. Therefore, we had to come up with dimensions that would make the pack comfortable to wear. It was important to look at anthropological data to determine the size of someone who might be wearing this pack [Danborno, 2008]. We also did benchmarking on sizes of current hiking packs [Hardin and Kelly, 1975]. Combining this data, our table has the following folded dimensions.

Width:	No more than 30 in
Height:	No more than 30 in
Depth:	No more than 12 in

There is an important trade-off between folded size and unfolded size. The bigger we make the unfolded size, the harder it will be to make a smaller folded table. From the same anthropological data mentioned earlier, we were able to look at important body sizes of woman who may be using the table [Danborno, 2008]. Hip width, shoulder width, leg length, and height were recorded as shown in Table 3.

TABLE 3

AVERAGE BODY DIMENSIONS FOR WEST AFRICAN WOMEN

Feature of Woman	Region Where Data was Obtained	Value
Average Height (cm)	Ghana	156.6 ± 7.0
Average Weight (kg)	Ghana	53.0 ± 11.9
Average Height (cm)	Nigeria	162.14 ± 5.95
Average Weight (kg)	Nigeria	57.64 ± 9.52
Hip Circumference (cm)	Nigeria	94.32 ± 7.36
Chest Circumference (cm)	Nigeria	87.69 ± 6.65
Waist Circumference (cm)	Nigeria	73.56 ± 7.39
Thigh Circumference (cm)	Nigeria	52.76 ± 5.52

This data helped us to determine the following dimensions:

• Width:	No more than 20 in
• Length:	No more than 60 in
• Height:	36 in or shorter

We used the recommendation that a backpack load greater than 30% of the user's body weight can be detrimental to their health [Hardin and Kelly, 1975]. We also know that the average Ghanaian woman weights 121 lbs (55 kg); 30% of this weight is 36 lbs (16.5kg) [Cappuccio, 2004]. With a safety factor of 1.5, the total folded weight must be less than 22 lbs (10 kg).

CONCEPT GENERATION AND SELECTION

Once the engineering specifications were finalized, many different ideas were brainstormed by each team member. These ideas were then brought together and discussed to produce over 20 different concepts. A functional decomposition was also performed. In order to select our design, Pugh charts were performed for each component including the legs of the table, the back angle adjustment mechanism, and the leg separating mechanism. After we had decided on the design of each component, we were ready to start developing our Alpha design.

ALPHA DESIGN

The Alpha, our first full design, consists of two main materials: plastic (PVC) and aluminum. The table sections shown as white in the figure 9 were made of plastic. The purpose of the plastic was to provide a sturdy surface that could be easily cleaned. The legs were designed out of aluminum to be strong and lightweight.

The design consisted of three separate sections: foot section, middle section, and head section. The middle section is where the woman will place her buttocks during the exam. The foot section can be stowed away during the exam so that the clinician could have better access to the pelvis. The head section can be inclined to three different positions: 0˚, 30˚, and 60˚. The stirrups are attached to the sides of the middle section and can be adjusted for length and angle. They are constructed from aluminum. The main problem with this design was the cost which was projected to be $300. Therefore, we redesigned our table to create the Beta Design.

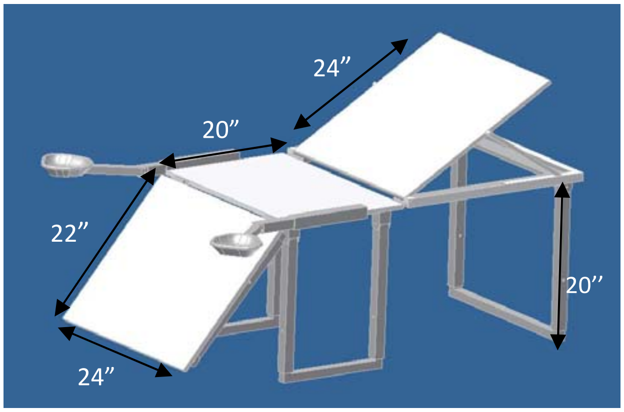

FIGURE 9
CAD DRAWING OF ALPHA DESIGN

BETA DESIGN

The only considerable change between the Alpha and Beta design is that the frame of the Beta design is made of natural birch plywood and birch lumber as shown in figure 10. By switching these components to wood we were able to greatly reduce the cost. The cost for our Beta design dropped to $70. On top of the wooden table sections are thin PVC sections that have been adhered to the wood, which makes it easier to clean.

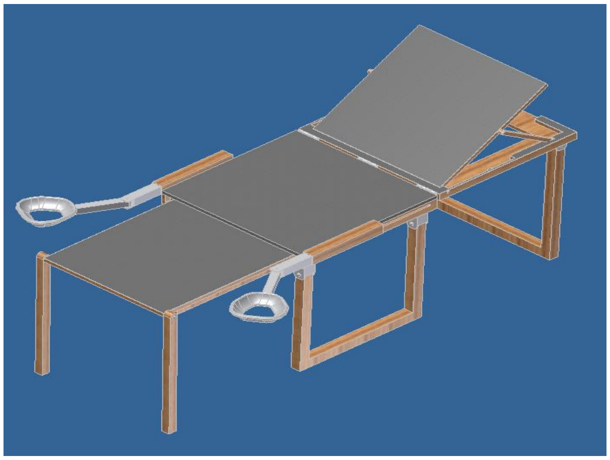

FIGURE 10
CAD DRAWING OF UNFOLDED BETA DESIGN

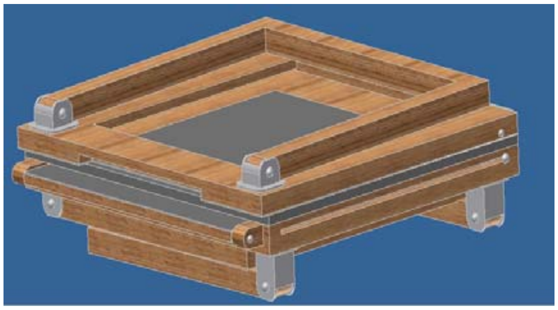

FIGURE 11
CAD DRAWING OF FOLDED BETA DESIGN

OMEGA PROTOTYPE

Many changes took place between the Beta and Omega designs. To save weight, we chose to make our legs, foot section frame, and head section frame out of aluminum from recycled lawn chairs. We made the table's folded dimensions smaller by making the middle section and the head section smaller and we redesigned the foot section to be a removable piece instead of being permanently connected to the table which allowed the middle section to be much skinnier and shorter. Since the head section's dimensions became smaller, we added a removable extension that allows the table to accommodate patients over 72 inches tall. CAD models of the Omega design can be seen in Figures 12 and 13.

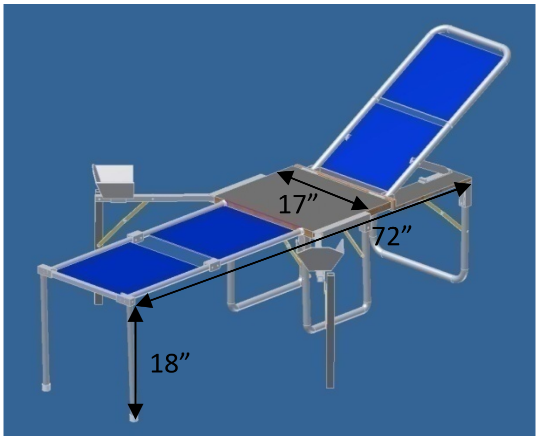

FIGURE 12
CAD DRAWING OF UNFOLDED OMEGA DESIGN

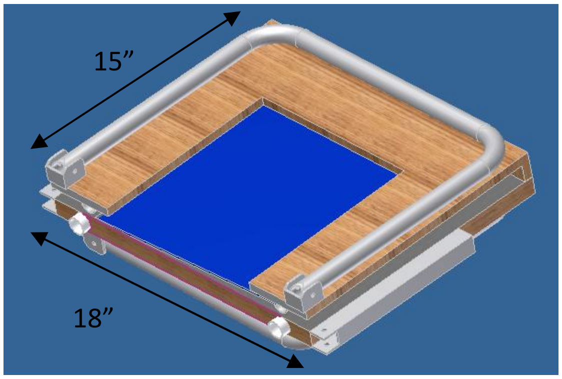

FIGURE 13
CAD DRAWING OF OMEGA DESIGN IN FOLDED POSITION

Once fabricating of the omega prototype had begun, we ran into problems that required us to make modifications to the original design. First, we noticed that the legs were not comfortably stable. To fix this, we added a cross-bar to each leg to prevent torsion and two support struts to steady the legs and make sure they stay open when the table is in use (Figure 14).

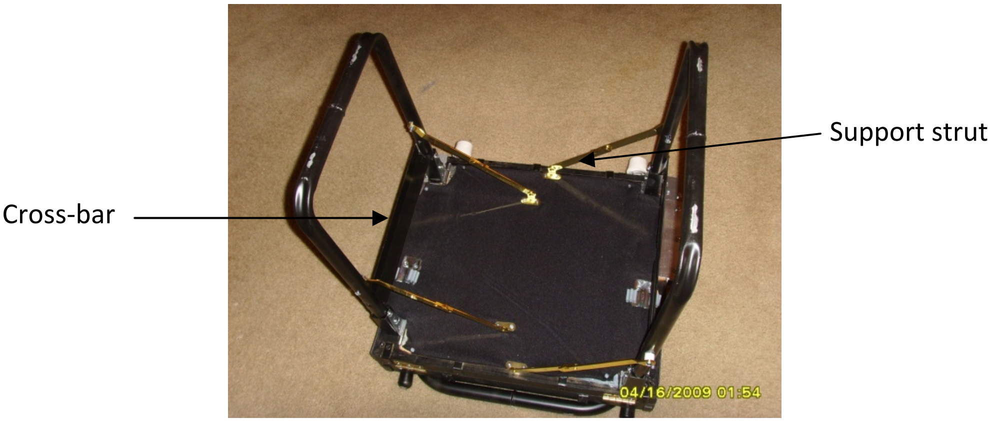

FIGURE 14
ADDITION OF CROSS-BARS AND SUPPORT STRUTS

Since the foot section frame is removable and foldable, it does not keep the fabric of the foot section tight which meant it would not support a patient’s legs. To keep the foot section from collapsing, we added a removable stability bar that rests in brackets on the inside edges of the leg joints (Figure 15). The stability bar keeps the fabric tight and keeps the foot section from collapsing since it keeps the legs straight.

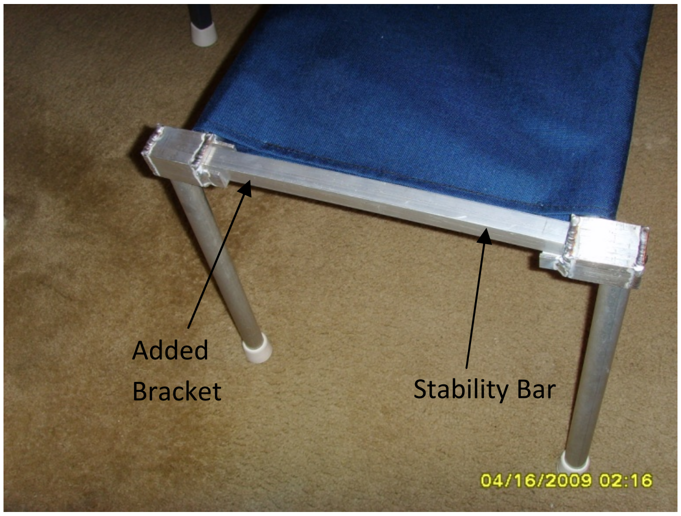

FIGURE 15
ADDITION OF FOOT SECTION STABILIZER BAR

With both stabilizer bars being separate, the back rest was difficult to adjust and would rock side to side. We added a bar connecting the two adjustment rods (Figure 16), which allowed the user to adjust both rods simultaneously and prevented the sideways motion of the back rest.

FIGURE 16
ADDITION OF ADJUSTMENT BAR

ENGINEERING ANALYSIS OF OMEGA DESIGN

To finalize the Omega design, we employed engineering equations to validate the design and material selection as summarized in table 4.

TABLE 4

VALUES OF ENGINEERING ANALYSIS OF OMEGA DESIGN

Analysis	Capable	Maximum	Pass/Fail
Buckling in Legs	805.43 lbs	313 lbs	Pass
Stress in Middle Section	707 lbs	313 lbs	Pass
Buckling in Stirrups Leg	1092 lbs	313 lbs	Pass
Compressive Stress in Adjustment	2.5 kpsi	34 kpsi	Pass
Rod	4163 lbs	313 lbs	Pass
Buckling in Adjustment Rod	0.1 inches	N/A	Pass
Max Deflection	840 psi	20.3 psi	Pass
Bolt Shear			

VALIDATION TESTING OF OMEGA PROTOTYPE

Table 5 lists the engineering specifications that have been validated through experimentation. Due to limited time, we were not able to test for the table's lifetime.

TABLE 5

VALIDATION OF ENGINEERING SPECIFICATIONS FOR THE OMEGA PROTOTYPE

Engineering Specification	Target Value
Support Weight	More than 142 kg
Table Weight	Less than 10 kg
Bedding Thickness	Less than 1"
2 Detachable Stirrups	35-50 Degrees
3 Adjustable Back Angles	0, 30, 60 Degrees
Non-Corrosive	100%
Travel Pack Water Resistant	100%
Length (unfolded)	More than 62"
Width (unfolded)	No more than 24"
Height (unfolded)	No more than 20"
Length (folded)	Less than 20"
Width (folded)	Less than 20"
Height (folded)	Less than 7"

To test our support weight target value of 313lbs, we loaded the table with 320lbs on a flat, indoor surface as well as an uneven, outdoor surface. The table easily supported this weight in both cases. We have not loaded this table to failure because we want to use it for field testing in Ghana this summer and get user feedback to improve the design.

The table was weighed using an eye level physicians scale and weighs a total of 21 lbs (9.5 kg) which is less than our engineering spec of 22lbs (10 kg).

The back angle adjustments and stirrup angles were measured using an electronic protractor. The back angle can be adjusted to 3 different angles of 0˚, 30˚, 60˚ which meets our engineering specification. The stirrups were specified to range from 35 – 50˚. However, since we used a thumb screw as our angle adjustment mechanism, the stirrups angles can range from 0 – 90˚ which covers the 35-50˚ specification.

A corrosion test was completed on wood, aluminum, hinges, and PVC. The materials were soaked in a bleach/water solution, identical to the solution that Ghanaian health care workers use, for 72 hours and then were left to sit and dry for 24 hours. We observed no effects of corrosion on any of the materials.

A water resistant travel pack was bought off the shelf made of 210D antimicrobial nylon / 600D polyester. The bag is specified to be water resistant and the dimensions of the bag are 18'' x 10'' x 18'' which is large enough to fit the Omega design.

The dimensions of the table both folded and unfolded were measured using a hand measuring tape. The unfolded dimensions are: 72'' x 17'' x 18''. The folded dimensions are: 18'' x 17'' x 6''. Both folded and unfolded dimensions meet our specifications.

Ergonomic Testing Of Omega Design

In addition to the validation testing done to the Omega design, we have also performed Ergonomic testing to determine how comfortable and easy it is to use the table. The following sections describe the tests we executed in order to test the ergonomic aspects of our table.

Assembly and disassembly time

We tested the time it takes to assemble and disassemble the table. We wanted to aim for an assembly and disassembly time of 2 minutes. We tested it using experienced members from our own team, members who are familiar with the project but have not contributed, and members who are not familiar with the project and have never seen the table. All participants were given an assembly manual. It took experienced team members an average 2 minutes to assemble and disassemble. It took participants with who are familiar with the project an average 2 minutes and 24 seconds to assemble and 1 minute and 46 seconds to disassemble. It took participants with no experience an average of 4 minutes to assemble and 2 minutes and 30 seconds to disassemble.

Comfort Test

We performed a comfort test where participants laid on the examination table in many different positions and were later asked questions about the comfort of the table in each position.

FUTURE WORK

Although the Omega design is complete we are still facing challenges and improvements that can still be made to the design. The field testing that will take place this summer is also briefly explained.

Stirrup Design

Our major concern with the table is the stirrup design since it is not as stable as we would like it to be. The grounded stirrup is a good start but needs improvement on keeping it stable and sturdy. A different mechanism, other than the thumb screw, should be used to tighten the two stirrup housings together and to adjust the stirrup angle because the thumb screw can loosen making it easier to adjust the stirrup angle by applying a small force and it also takes a long time to remove the thumb screw when detaching the stirrups.

Strengthen Legs

The table legs were made from recycled aluminum pieces and so could not be changed to our ideal shape. As a result, the curved middle section legs roll when the weight is not placed at the center of the middle section. In the future, it would be beneficial to use legs with flat/straight edges instead of round edges. A door stopper can easily be placed at the back of each leg to prevent the legs from rolling up, however it would be ideal to redesign the legs.

Strengthen Leg Hinges

Continuing to strengthen the leg hinges is important because they will support the majority of the weight. In the future, it will be helpful to use stronger hinges to connect the legs to the table.

Decrease Weight/Cost/Components

Portability is the main feature of the table; therefore we should always aim to keep reducing the weight of the table either by changing material, dimensions, or shape. The cost of the table can always be reduced by changing materials or dimensions.

One of the disadvantages of our table is the many separate components that need to be assembled. In the future, it would be more efficient to have a table with fewer components while still keeping the table compact.

Travel Pack

The opening of the travel pack is too small for the table to slip through. The zipper will be removed so that we can create a greater opening and then we will re-attach the zipper. This will allow for the table to be placed in the pack and zipped around the pack as opposed to sliding the table into the pack.

Hand Bars/Securing straps

It would be convenient to add hand bars to the side of the table so that the patient can easily lower themselves, adjust and rise from the table.

It would also be helpful to add straps to the table so that when folded, the straps can aid in keeping the table closed.

Field Testing

The Omega design will be field tested from May- August of 2009 in the Sene District of Ghana with the assistance of a team member (Joseph Perosky). Joseph will receive and utilize any user feedback from the healthcare workers and patients to help improve the design. He will also explore the availability of common materials that can be found in Ghana to help with in country manufacturing.

REFLECTIONS

Ethical Considerations

When designing any medical device, there is always the possibility of a conflict of interest for the inventors. The safety of the team must be put above anything including manufacturing and in-country testing. The design of the table must also never be compromised in so that it would jeopardize the safety of the patient or the clinician using it. There is the possibility for a conflict of interest of the clinicians in Ghana to try to advance the development of the table and take all of their focus off of the health care of their patient. One issue of concern for field testing in Ghana is the informed consent of the patient to have their exam done on the table. It is a concern that the woman will not be given a choice whether or not to take place in the study because of the dire need that she has to get an exam done by the clinician that will be using our table. The privacy and safety of the patient must be put above all other concerns at all times. If at any time during field testing the table looks to be starting to malfunction, no exam can be done on it.

Concerns for Large Scale Implementation

The purpose of designing our table is to increase the amount of women that have access to a skilled attendant and can receive gynecological examinations. The reason a portable gynecology table is necessary in the current situation is due to the lack of infrastructure and access to transportation that many women in rural areas have. If our table were to be implemented on a large scale in Ghana, with the possibility of replication in other countries, one concern is that the entire model of care would change. A worry is that once many of the other barriers to care, such as transportation, education, and economic conditions, were diminished the fact that women had a health care worker or midwife traveling to them would be the status quo and women would not travel to the health care facility. Some ethical questions that must be asked are: “Are we working within the goals of the Ghanaian Ministry of Health?” The quick answer to this question may be “of course not.” In fact we are working with a Ghanaian clinician. The narrowness of our approach and study must be taken into consideration. Close advisement of the Ghanaian Ministry of Health must be undertaken before any large scale implementation was to take place, including local manufacturing.

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We would like to thank Dr. Tim Johnson, Dr. Anthony Ofosu, Dr. Jody Lori, Dr. Kathleen Sienko, Dr. Steve Skerlos, Dr. Brent Gillespie, Dr. Gregory Hulbert and Daniel Johnson for their input on this project. We would also like to thank Mr. Bob Coury for his help in manufacturing the prototypes.

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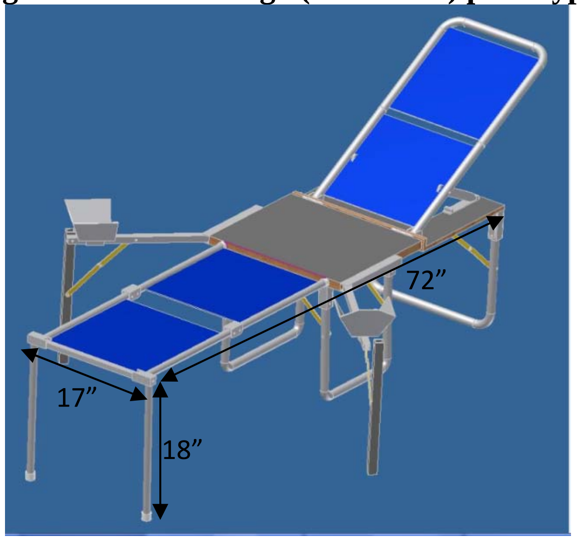
EXECUTIVE SUMMARY

The goal of this design project is to diminish the barrier of transportation to secondary and tertiary healthcare facilities and services by developing and constructing a portable gynecology examination table for use by community healthcare and planning services (CHPS) workers in the Sene District, Ghana. The most important customer requirements, determined using surveys sent to our mentors, are that the table must be portable, light weight, low cost, easy to use/assemble, and safe. The customer requirements translated into the engineering specifications of weighing less than 10 kg, support at least 142 kg, produced for less than $100, and designed with a factor of safety of 1.5.

After many hours of brainstorming, we selected our Alpha design which was presented in Design Review #2. Our Alpha Design evolved into the Beta design which was presented in Design Review #3. We then re-designed to get the Omega (revision A) design which evolved into our final design, Omega (revision B) prototype.

The Omega (revision B) prototype consists of 3 sections as shown in Figure 1 below. The middle section is made of Birch wood covered in a thin sheet of PVC. The head section is made of recycled aluminum frames and polyester fabric and can be adjusted to angles of 0, 30, and 60 degrees. The foot rest section and head attachment are also made of recycled aluminum frames and fabric and can be detached. The stirrups are made from aluminum and can be adjusted from 0 – 90 ˚ and can also be adjusted along their length. They are also detachable.

Figure 1: Final Omega (revision B) prototype



The table can be fabricated using only a drill press, band saw and screw drivers and for under $80. The table weighs 21 lbs and can support more than 313 lbs. The materials are non-corrosive and non-absorbent.

The advantages of the table are that it can be used for more than just a gynecology exam, it is low cost, and easy to manufacture. The disadvantages of the table are that it contains many components for assembly and it is not made from local resources.

1.0 INTRODUCTION

The most current report from World Health Organization says that Maternal Mortality Ratio reported in Ghana is 560 deaths per 100,000 live births and the Infant Mortality Rate is 76 deaths per 100,000 live births. It is very difficult for women to receive the proper healthcare during a pregnancy due to little education, poor traveling, lack of resources, and expenses. Regular pelvic examinations and health care visits are important preventative measures for maintaining maternal health. However, in rural settings within the least developed countries, poor traveling conditions, lack of resources, social constraints, lack of educational opportunities, and economic limitations make it difficult for women to receive proper healthcare during a pregnancy. The goal of this design project is to diminish the barrier of transportation to secondary and tertiary healthcare facilities and services by developing and constructing a portable gynecology examination table for use by community healthcare and planning services (CHPS) workers in the Sene District, Ghana.

Design for global health is a topic of increasing importance and places new constraints on the engineering design process. Throughout the design process, Ghanaian and American clinicians were interviewed in order to obtain user requirements for the initial prototype. These requirements were translated into engineering specifications, and brainstorming and functional decomposition were performed in order to generate solution concepts. The highest ranking user requirements were 1) light weight, 2) portable, 3) low in cost, 4) supports the weight of the patient, 5) comfortable for the patient and examiner, 6) easy to clean, 7) non-corrosive/non-absorbent, and 8) adjustable. In agreement with the engineering specifications and the outcomes of our QFD and Pugh charts, we designed a portable gynecology examination table prototype that 1) supports a weight of 313 lbs while only weighing 21 lbs, 2) can be folded into a 5x19x20 inch volume enabling transportation by backpack, 3) costs less than $70, 4) can be cleaned with bleach, and 5) has three adjustable back angles of 0, 30, and 60 degrees.

2.0 PROJECT DESCRIPTION

The primary goal of our project is to diminish the barrier of transportation of those seeking healthcare in Ghana. By working with Dr. Anthony Ofosu (Head of Sene District Hospital), Dr. Tim Johnson (chair of obstetrics and gynecology at the University of Michigan), and Dr. Jodi Lori (intern nurse-midwifery program coordinator) we will design, develop and construct a reusable portable pelvic examination table that is light weight, small in size, easy to use, and low cost. Attached to the table will be a gynecological kit that will contain all necessary equipment for a pelvic examination including a fetoscope, a fundal height measurement device, and a hands free adjustable light.

3.0 BACKGROUND

The areas that we studied are broken up into four main areas: pelvic exam, culture of Ghana, obstetrics/gynecology and midwifery in Ghana, the benchmarking of tables and devices that are currently being used, and patents.

3.1 Pelvic Exam

A pelvic exam of a woman is necessary in order to check for infection, complications, and the well being of the woman and her reproductive health. All woman, but especially those that are sexually active should have annual pelvic exams. The exam usually includes five main components: the external exam, the speculum exam, the palpation (bi-manual) exam of the cervix, the anal exam, and the pap smear.

To start the exam, the patient should lay down with their head elevated in a comfortable position, usually 30 to 45 degrees. 30-45 degrees is where women feel the most comfortable, elevating the women's head allows for her to feel in control of the situation (Basic Exam Table par. 3). The patient should slides their hips down until their hips reach the bottom or end of the table so that the examiner has easy access to her pelvis. The patient can then use traditional stirrups to separate their legs or they can place their feet together while opening their hips.

The external exam is first performed. The external exam consists of examining the outside of the vulva (encompasses the entire external reproductive anatomy except for the anus) for redness, swelling, lesions, masses or infestations and also inspecting the labia majora and minora. Refer to Figures 2 and 3 on page 3 for anatomy diagrams.

Next an internal exam using a speculum (used to dilate the vagina) is performed. Either a plastic or metal speculum can be used. If it is a metal speculum it should be run under warm water for comfort. The speculum is used to observe the cervix and vaginal walls for lesions and discharge and to obtain specimens for culturing them. (Examination of the Female Pelvis," par. 1-6)

Figure 2: External anatomy of female reproductive system. (Low)

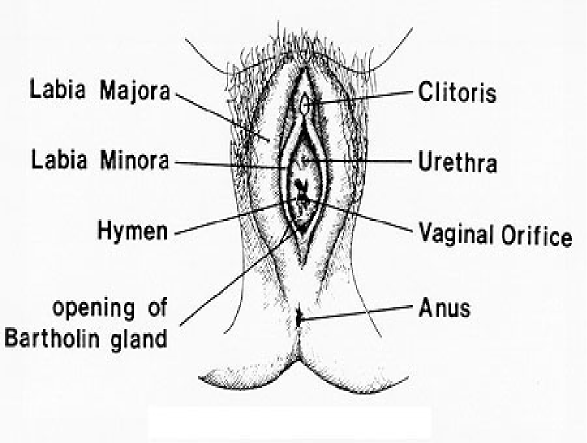
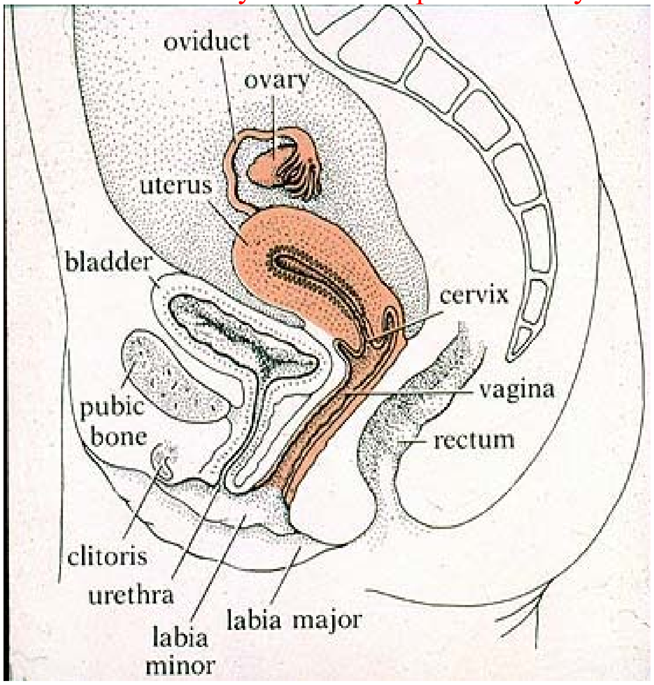


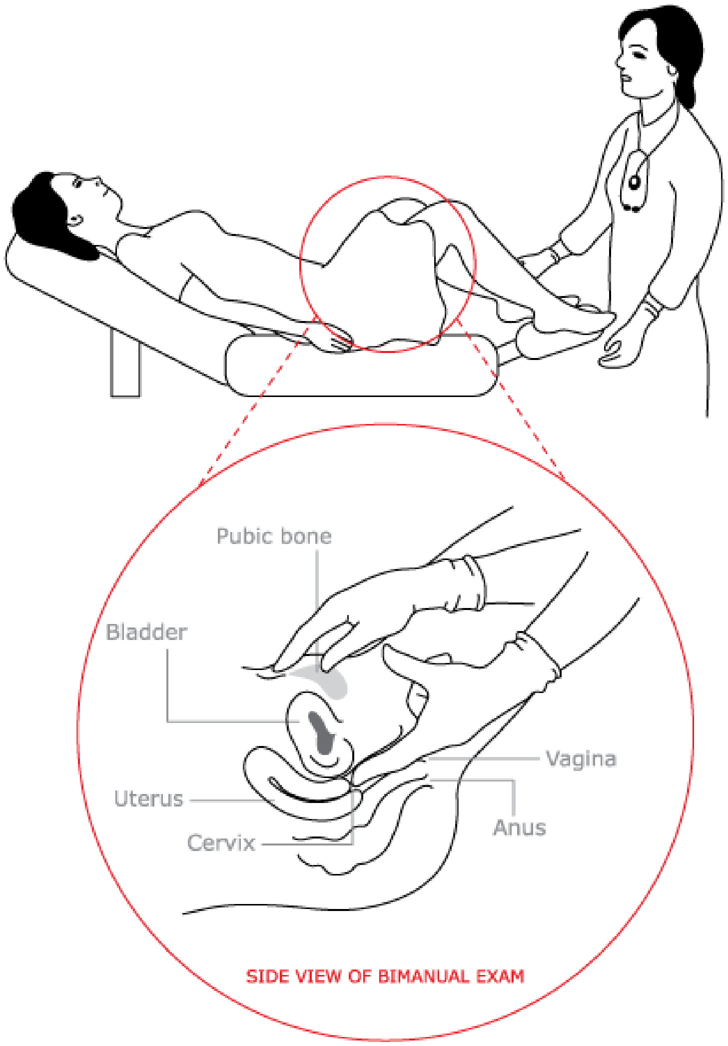
Figure 3: Internal anatomy of female reproductive system. (Low)



Following the speculum exam, using gloves, a bimanual exam of the cervix can be performed. As shown in Figure 4 on page 4, during a bimanual exam the examiner inserts two fingers into the vagina and places the other hand on the abdomen to feel the internal pelvic organs, mainly the uterus and ovaries. Ideally, this is followed with a rectovaginal exam.

Finally, a rectal exam is performed on the woman. In a rectal exam the patient is placed in a position where the anus is accessible and relaxed (lying on the side, squatting on the examination table, bent over the examination table, etc). The examiner inserts a gloved and lubricated finger into the rectum through the anus and palpates the insides for about 60 seconds. A pap smear uses a cotton swab to scrap of the inside of the cervix to collect cells for testing of cervical cancer, infection, or any abnormal cells in the cervix.

Figure 4: Diagram of bimanual exam and position of patient. (Pelvic Exam)

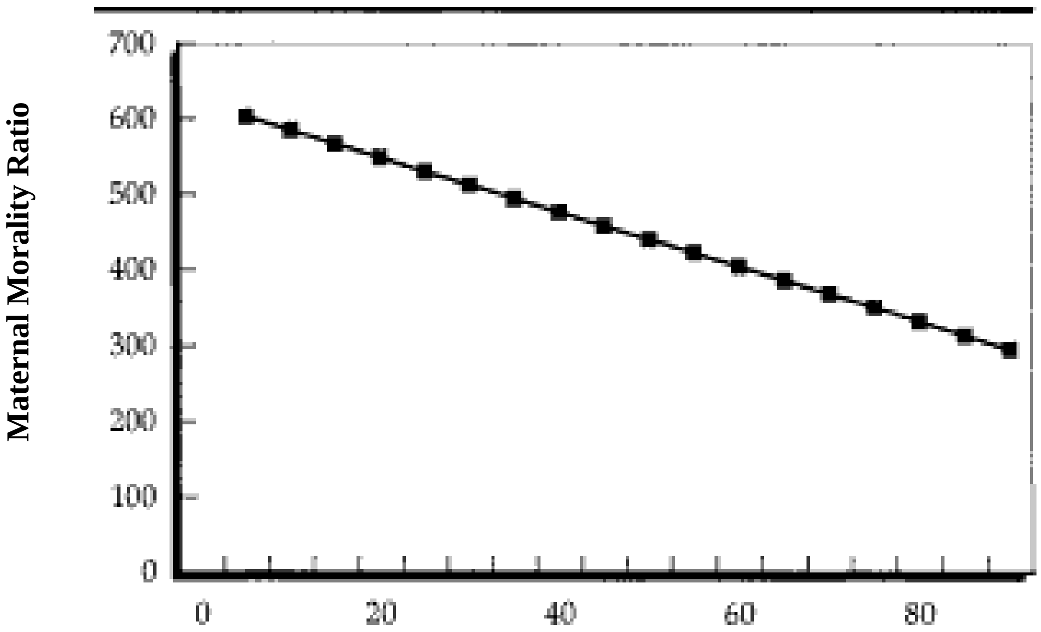


The common equipment used in an examination includes a table along with gloves and a speculum. A bright flexible light source, lubricating jelly, and stirrups were also common exam equipments. ("Examination of the Female Pelvis," par. 1-6)

3.2 Importance of frequent pelvic exams

Figure 5 below shows that greater the percentage of women who receive frequent pelvic exams the smaller the maternal mortality ratio. (Shiffman 284).

Figure 5: Maternal mortality ratio decreases as the percentage of women receiving assistance by a trained health care provider increases.



(Shiffman 284)

With Africa having the highest rates of HIV and AIDS in the world, it is necessary for women to receive antiretroviral treatments during pregnancy which we hope to diminish the transfer of the disease to the neonate. Transmission of HIV or AIDS from mother to child can occur in utero, during labor, or after delivery through breast feeding, but most commonly transmitted during labor. The risk of transmission during the course of pregnancy can be reduced if the mother received monthly antiretroviral treatments throughout her pregnancy excluding the first 3 months. (Petropoulou et al. 536-538). However, because the majority of women do not attend monthly pregnancy exams and receive proper healthcare due to poor travel and lack of resources, they also do not receive antiretroviral treatments which can help lower the maternal mortality rate and infant mortality ratio (World Health Organization). By diminishing these travel barriers with our portable table, these women can receive antiretroviral treatments to help prevent the transmission of virus.

3.3 Different Classifications of Medical Personnel in Ghana

There are 7 main groups of medical personnel that would attend to women and 4 of these groups are capable of performing a gynecological exam. The first set is medical doctors. Medical doctors normally perform examinations in a hospital or clinic and have access to unlimited specula, gloves, lights, lubricating jelly, and stirrups. Nurses at the hospitals and clinics would never actually perform an exam themselves, only assisting in the procedures. There are also public health midwives that can either operate in the hospitals or in rural communities and are approved by the government to provide maternal health care. There are also “traditional midwives” who has been trained by the government to become traditional birth attendants (TBAs). This was once widely approved of, but there is now a push for public health midwives to provide the care (Geurts 383). The newest group of medical personnel that is being educated to perform exams is community health care workers, who are the targeted end user of our examination table. (Nyonator et al. 28) Almost 50 percent of births are delivered in the home by a relative, who is not trained for a delivery. Many times this is done because women fear going into the sometimes harsh hospital environment and also don't want to make the strenuous travel to the facility (Geurts 389).

3.4 Importance of developing medical equipment for midwives in Ghana

"Midwives (no matter how skilled) can seldom save lives with their bare hands. They need appropriate tools as well as an enabling medical and social environment. Conversely, technologies (no matter how ingenious) are effective only if there are skilled and knowledgeable users, communities practicing appropriate health-promoting and care seeking behaviors and functioning health care systems. Technologies encompass equipment, supplies (including medications), procedures and techniques. Appropriate technologies refer to those that have both good functionality (efficacy, effectiveness and safety) and good fit with the environment where they will be used (Tsu 1)." This states the importance of the table we are designing and the potential impact it can have on the health care workers and midwives that it is intended for; it has great potential to decrease the maternal mortality rate.

3.5 Community-based health planning and services (CHPS) compounds in Ghana

The rural areas of the Ghana health care service are undergoing a change from the current clinical based system to the CHPS community system. CHPS compounds are small healthcare centers manned by a community healthcare worker or midwife. Currently, four-wheel vehicles are used for bi-weekly outreach clinics. In the CHPS based system, a health care worker or midwife would be placed in the communities and would only require a motorbike or bicycle (Nyonator et al. 28). The health care workers currently carry a kit with them that includes antiseptics, gauze and bandages, a thermometer, a tape measure, and a few other basic medical equipments (Geurts 389.) The device we are creating is being designed to fit into the new CHPS based system as identified by Dr. Ofosu.

3.6 Transmission of HIV/AIDS

Africa has the highest rates of HIV and AIDS in the world. By allowing these women to receive antiretroviral treatments during pregnancy we hope to diminish the transfer of the disease to the neonate. Transmission of HIV or ADIS from mother to child can occur in utero, during labor, or after delivery through breast feeding, but most commonly transmitted during labor. The risk of transmission during the course of pregnancy can be reduced if the mother received monthly antiretroviral treatments throughout her pregnancy excluding the first 3 months. (Petropoulou et al. 536-538). However, because the majority of women do not attend monthly pregnancy exams and receive proper healthcare due to poor travel and lack of resources, they also do not receive antiretroviral treatments which can help lower the maternal mortality rate and infant mortality ratio (World Health Organization). By diminishing these travel barriers with our portable table, these women can receive antiretroviral treatments to help prevent the transmission of virus.

4.0 BENCHMARKING OF TABLES AND DEVICES

This section outlines what was researched in the current designs of examination tables, designs of foldable chairs, and current patents.

4.1 Current tables on the market

The most basic examination tables included an adjustable bed and a leg separation mechanism. The leg separation mechanisms include simple rubber tips, hanging straps, foot holders, or lower leg holders. Each has its own advantage for ease of use, range of motion, and level of support.

Figure 6a below is a basic pelvic examination table. It has vinyl coated stirrups that are adjustable to 3 lateral positions: 0˚, 10˚, 37˚, and 52˚. The stirrups are adjustable along their lengths and can also rotate to different angles. The adjustable bed sits on a table that is 35'' off the ground and contains side cabinets or drawers for storage. The lengths of the beds vary from 51'' to 72'' when the stirrups are extended and the width of the table is 26.5''. It contains a footstool for the patient to easily climb the table. The foot of the table tilts to allow for pelvic tilt of 0 to 7.5˚.The bed material is made of seamless upholstery for ease of cleaning and has a weight capacity of 325Lbs. The table comes with a plastic tray for debris and costs $1161 with a 3 year warranty. (Basic Exam Table par. 3).

Figure 6b below contains the similar features only it is lower to the ground and has a 450 lbs weight capacity. Pneumatic cylinders are used to adjust the bed angle and table height. It costs $5246 with a 3 year warranty. (Access High-Low Power Exam Table par. 1-4).

Figure 6a: Basic Examination Table. (Basic Exam Table)

Figure 6b: Examination table lower to the ground using pneumatic cylinders. **(**Access High-Low Power Exam Table)

Figure 7 on page 8 is a bare boned examination table. It can be used for all examinations including pelvic exams. The table is 72" long when extended, with a 14" adjustable headrest, a 17" adjustable foot section. Adjustable length stirrups are included and a 2" High-Density urethane foam top for patient comfort. This table costs $760. (Two-in-one Examination/Treatment Table par. 1)

Figure 7: Examination table with minimal features**.** (Two-in-one Examination/Treatment Table par. 1)

Figure 8 shows an examination table made of 3 sections where the middle section elevates to allow for pelvic tilt and a drainage bowl is built in to the bottom section for collecting fluids. The head and stirrups are both manually adjustable. The square cross-sectional legs are mounted on rubber tips for greater friction between the table and ground. (Obstetrics Tables and Examination Tables)

Figure 8: 3 sectioned examination table with manually adjustable stirrups and head rest (Obstetrics Tables and Examination Tables)

Some exam tables contain a drainage bag as seen in Figure 9 on Page 9, which can cost an addition $350. The bag sits underneath the patients pelvic and the bodily fluids drop into the bag which is later disposed of. (Drain Bag Hoop Assembly)

Figure 9: Drainage bag used for pelvic exams to collect fluids at the end of the table. (Drain Bag Hoop Assembly)

4.2 Patent Benchmarking

We researched patents for portable beds, stirrups, and gynecology equipment.

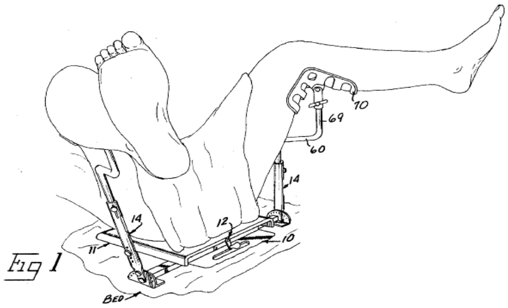
4.2.1 Portable Obstetrical Bed Table (Patent # 1546813)

This patent describes a portable table that allows examinations primarily for purposes of obstetrics. The table is able to be compacted easily enough for an obstetrician to carry it into the home. The dimensions of this table are not given, folded or unfolded, so it is difficult to determine by what means the table will be transported. When unfolded, the table is to be placed onto the patient's bed, or another form of support, to lift them off the ground. To separate and hold the patients legs, there are two rods on either side that extend vertically with straps at the ends. These straps are what hold the patient's legs up and apart and allow for the examination. (Thomsen)

4.2.2 Genito-Urinary Examination Device (Patent # 3817512)

This patent describes a device very similar to the first benchmarked patent. This device, when unfolded, is also designed to be placed on the patient's bed or other form of supports to keep the patient off of the ground. The base of this design, however, is slightly smaller and allows for only the patient's buttocks to be placed onto it. As shown in Figure 10 below, leg supports extend vertically on either side of the patient, and allow for the back of the knees to be placed over them. These devices can be adjusted for height angle. When finished, everything can be folded to allow for easier transportation, but again, actual size is hard to determine for the lack of dimensions. (Torrey)

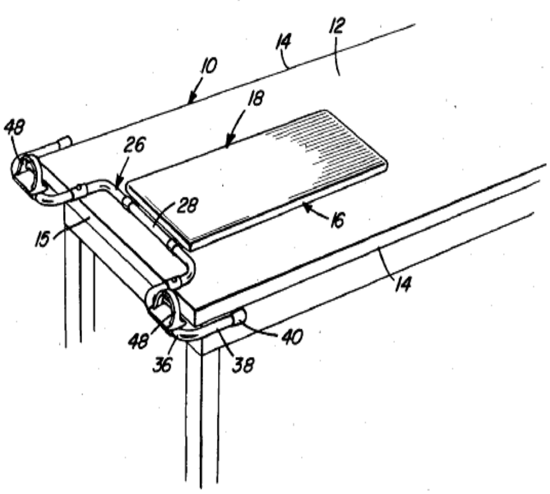
Figure 10: Genito-Urinary Examination Device (Patent # 3817512). (Torrey)



4.2.3 Portable Examining Unit with Stirrups (Patent # 3907270)

This device has a very similar purpose to the device that we are trying to develop. It is a device that will allow for gynecological examinations in under-developed countries. However, this device was designed to be transported in a passenger vehicle, such as a car. Our device will not have this luxury. This device is to be placed onto some sort of support, such as larger, sturdier table. The portion in which the patient will be laying is 30 inches long, by 12 inches wide. For the leg supports, there is a rotating mechanism at the end of the device that rotates out when being use. The foot supports are on the same plane as the back support, but are wider to allow for separation of the legs as shown in Figure 11 below. (Ezzo)

Figure 11: Portable Examining Unit with Stirrups (Patent # 3907270)



4.2.4 Operating-Table Attachment (Patent # 1115794)

This device is an attachment similar to the leg supports on the Portable Examining Unit (Patent # 3907270). However, this device is attached directly to an examination table, or possible any table. After attaching, there are supports that could be adjusted to hold patients legs. This will allow for an obstetrical examination on a table that normally does not accommodate one. (Erikson)

4.2.5 Porta-Zam Gynecological Exam Chair (Patent #6256817)

This device is a chair that allows for a gynecological exam in several positions. There is only enough support for the woman's buttocks up to her head. Her legs are placed onto foot supports that can be extended to different lengths and angles. There are simply two sets of legs that can be adjusted to account for the various positions. Along with this, there are arm rests for added comfort and allows for the woman to adjust herself while in the chair. When not being used, the chair can be folded into a bulky design. (McGuire)

4.2.6 Folding Cot Pack (Patent # 3828992)

The foldable cot is helpful since we were looking at a solution that possibly folds up and can be placed onto healthcare workers back. As shown in Figure 12a and 12b on page 11 this patent holds the whole length of a person's body, but can be folded up and worn on the pack. Along with this, there is a built in pack that could hold various items. In our case, this would be useful for gynecological exam devices. Obvious problems with this device (in relation to our project) is that it is too low to the ground, does not account for leg support, and does not have adjustable back angles. (Cerchion)

Figure 12a: Opened Cot.

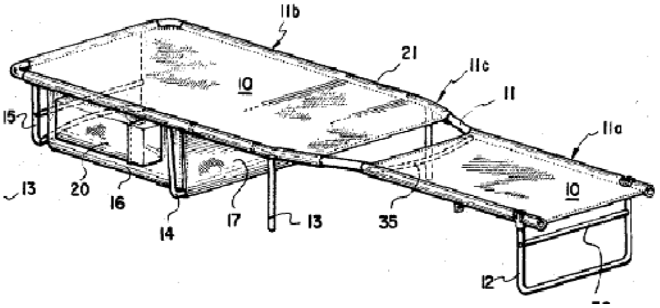
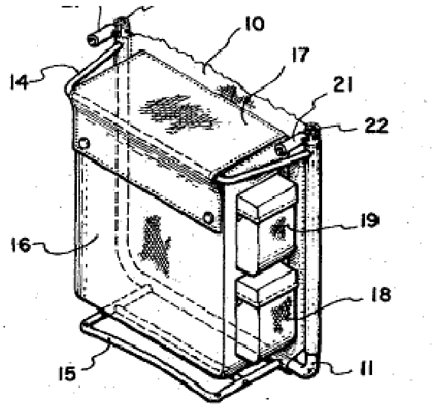


Figure 12b: Folded Cot in pack.



4.2.7 Portable Folding Cot (Patent # 2631303)

This is another example of a cot that could be similar to our design. This cot has a solid bed where the user will lay, as opposed to a stretched cloth material as Patent # 3828992. This has a simple design, one fold in the middle of the cot and two legs on hinges underneath the cot. When folded, the cot forms a small 'box'. Along with this, the cot can fold into a chair where the front leg is folded under and the front half of the cot is placed on the ground. Then the back legs are placed onto the ground at an angle that holds up the back of the cot. (Valentine)

4.2.8 Portable Body Massage Table (Patent #5009170)

This is a slightly more complex design than others we have looked at. However, it folds into a sturdy table that is high enough for the masseuse to give a massage while standing. It is also large enough unfolded to where the person receiving the massage can lay his or her whole body onto it as shown in Figure 13a on page 12. When folded, all of the table supports are folded under the table and the outside of the table encloses everything that is inside of it. Then it is latched, and there are handles that allows the carrier to hold it in one hand as shown in Figure 13b on page 12. When folded the table may be too large to be carried effectively. (Spehar)

Figure 13a: Foldable message table

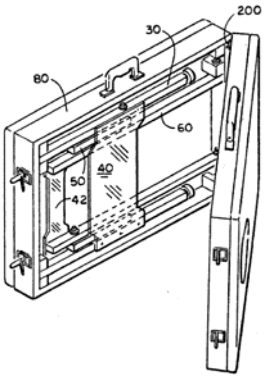
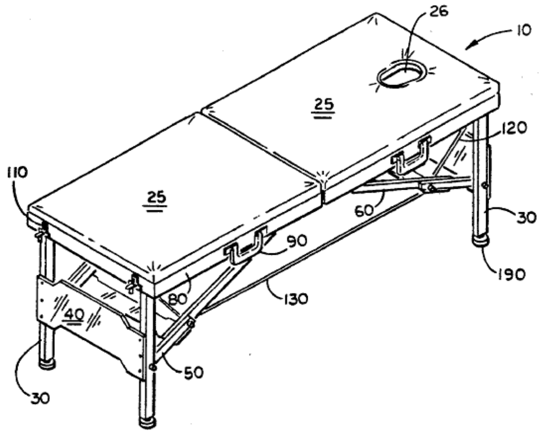


Figure 13b: Foldable message table



5.0 CUSTOMER REQUIREMENTS AND ENGINEERING SPECIFICATIONS

In order to better understand how our table will be used and determine the customer requirements, we used several sources. To better understand how the table will be used in Ghana, we have been in contact with Dr. Ofosu. Healthcare workers in Dr. Ofosu's district will be the end users of our table. We were also able to speak to a nurse from the gynecological ward at the University of Michigan who was able to give us some insight into what an exam consists of. In addition, we also spoke with Dr. Tim Johnson, the chair of Obstetrics and Gynecology at the University of Michigan, and Dr. Jody Lori, a certified nurse-midwife at the University of Michigan Hospital. With our many mentors and their customer requirements and background research of current tables and patents, we were able to determine our engineering specifications.

Dr. Ofosu was able to give us the following information directly about the table (Ofosu):

- Useful to have table that can fold-away but still hold patient
- Health care workers are the primary target, and midwives are the secondary target
- Tables are cleaned with a bleach & water solution, or chlorine solution
- Lithotomy or supine position is the best for examination
- Width of table should be no more than 0.91 m
- Largest pregnant woman weighs about 95 kg (Average being 65 kg)
- Largest height of woman is about 1.83 m (Average about 1.67 m)
- It is possible to have a table of 0.31-0.62 m off the ground with a stool included for the healthcare worker
- We can expect the table to be used on a hard dirt surface

As for the essential gynecology equipment, Dr. Ofosu specifically mentioned the following items

- Fundal Height Measuring device
- Fetal Heart Monitoring
- Free-stand, adjustable light source
- Protection: Gauze, face mask, gloves
- Scalpel
- Speculum

As mentioned before, we were also able to speak with a nurse from the gynecology ward at the University of Michigan hospital, who works in obstetrics and gynecology, which is why we found her insight to be very valuable. During our meeting with her, she told us that the most important items (for examinations) were the stirrups and the adjustable light source.

Our customer requirements were determined mainly from Dr. Ofosu's insight (Ofosu) and other requirements were determine from our other mentors and research. The finished customer requirements list is presented in Table 2 below. To move forward it was necessary to rank the customer requirements in order of importance. This allows us to better determine the final engineering specifications. To rank the customer requirements, we sent questionnaires to Dr. Ofosu, Dr. Johnson, and Jody Lori and asked them to rank the customer requirements from 1-12 (Ofosu; Lori). These filled out questionnaires are presented in Appendix E. From their rankings, and what we found to be the most important through research, we created the rankings presented in Table 2.

Table 2: Customer requirements rated from most important to least important.

Requirement	Rank
Light Weight	1
Portability	2
Low Cost	3
Easy to use/assemble	4
Safety	5
Patient Comfort	6
Examiner Comfort	7
Easily Cleaned	8
Manufacturing	9
Maintenance	10
Non-Corrosive	11
Non-Absorbent	12
3 Adjustable Back Angles	13
Adjustable Table Height	14

The next step was to determine our engineering specifications using the customer requirements and a QFD (See Appendix B for QFD). In order to do this, we started with the most important requirements, discussed what would be necessary to meet this requirement, did research and asked necessary questions to our contacts, then came up with our final specifications. The following sections outline each requirement and how they were translated into engineering specifications. Table 3 on page 14 presents our final engineering specifications listed in order of most important to least important. The only engineering specification that has changed since Design Review #2 is the cost. We originally set a goal of $35 and it was agreed upon with Dr. Ofosu. However, after analyzing the materials and manufacturing costs we determined it impossible to design and build a sufficient table for less than $35. We presented the issue to Dr.

Ofosu and agreed on a higher budget of up to $300 which is what the hospital would be able to spend on the portable table with their given budget of $5000 per year (Ofosu). Although this is a significant increase in our original cost, we do not intend to build the prototype for $300. We built the Beta prototype under $70 and the Omega prototype was built under $80. We would also like the hospital to be able to purchase multiple tables with this budget and will therefore try to minimize the cost as much as possible. Therefore we are aiming to build the prototype for less than $100.

Table 3: Engineering specifications determined from customer requirements.

Engineering Specification	Target Value
Light Weight	Less than 22 lbs
Support Weight	Greater than 313 lbs
Safety Factor	1.5
Non Absorbent	100% Non-Absorbent
Non-Corrosive	100% Non-Corrosive
2 Detachable Stirrups	30- 50˚
Cost	$100
3 Adjustable Back Angles	0, 30, 60 degrees
Travel Pack Water Resistant	100%
Lifetime	Greater than 5 years
Length(unfolded)	Greater than 62’’
Width(unfolded)	Less than 24’’
Height(unfolded)	Less than 20’’
Length(folded)	Less than 20’’
Width(folded)	Less than 20’’
Height(folded)	Less than 7’’
Bedding Thickness	Less than 1’’

5.1 Capable for use of Gynecological Exam

The gynecology exam is the main purpose of the table. So we first wanted to look at stirrups. Some research shows that stirrups are not needed for the exam (Seehusen **1**). This research shows that it is possible for the woman to have an exam simply by placing her legs at the sides of the table and holding them firmly. However, when we spoke to Dr. Ofosu, he specifically asked for stirrups. Therefore, this is something that we would like to include. We would like to have a design that allows for the stirrups to be detached when not in use and stored easily. When they need to be used, they can quickly be attached. In order for the exam to be done properly, we did research on standard stirrup angles in current table designs (Basic Exam Table par. 3; Ofosu; Lori). We also asked which stirrup angles are ideal in the questionnaire. Our final specification we would like to meet is stirrups that open up to 50° and no less than 35°.

5.2 High Support Strength

To determine the required support strength, it was necessary to determine the weight of women who will be using the table. Anthropometrical data shows us that the average weight of women to be 57 kgs (126 lbs) (Danborno). This is the closest region to Ghana that we could find, and are assuming that the data is close to that of Ghanaians. Also, we were able to ask our mentor what weights he might expect. According to Dr. Ofosu, the largest woman to use the table will weigh approximately 95kg (209 lbs). In order to determine what the maximum support for the table should be, we agreed on a factor of safety of 1.5. This means that our table needs to support no less than 142 kg (313 lbs). Our safety factor is determined by the equation 1 below.

$$Safety\ Factor = \frac{Maximum\ weight\ supported\ by\ Bed}{Maximum\ weight\ expected\ to\ be\ placed\ on\ bed} \qquad \text{Eq. 1}$$

5.3 Easy to Clean

A member of our team, Joseph Perosky, spent 4 weeks in Ghana. First hand, he experienced how sanitation and sterilization is done in the hospitals. Many times when cleaning tables in Ghana, it is only a quick wipe down of the surface. Figure 14 below shows a birthing bed and the unsanitary conditions that may arise.

Figure 14: Unsanitary bed in current hospital with blood uncontained on bed and floors.

Due to sanitary issues, our table needs to be very easy to clean. For the surface in which the woman will be laying, we hope to have a 100% non-absorbent material. Any fluid that is absorbed increases the result of spreading infection or disease to another patient. Since bleach and water or chlorine solutions are the main method of sanitation, Dr. Ofosu has requested a table bed that is non-corrosive. Figure 15 on page 16 shows a current bed used in Ghana with corrosion and rust on the frames. When movable parts become rusted and corroded they no longer can perform their functions because they cannot move.

Figure 15: Corrosion and rusted frames of current beds in Ghana.

Along with this, we want the pack in which the folded table is placed in to be 100% water resistant. This helps repel dirt, and possibly rain during the travel. Furthermore, we feel that minimal hinges and minimal corners will help prevent the need for extensive cleaning. This will allow for easier cleaning and maintenance and also help to increase the lifetime of the table.

5.4 Low Cost

From our research, lack of money is a large problem in Ghana as the average income of a resident of Ghana is $376 USD (1999) and the poorest 20% make less than $69 USD (Incomes in Ghana). The district in which this bed is being designed for only has an annual budget in the obstetrics department of about 2000US$ (Ofosu) and is willing to spend 300 US$ on this table. We want to stay as far under this number as possible as to allow them to purchase as many of these beds as they need, but not take up too much of the budget.

It is difficult to make a low cost bed considering that some of the aspects of our project include movable hinges, adjustable back angle, and the specific non corrosive materials. Typical gynecological beds have a price in the range 600-11,000 US$ ((Basic Exam Table, Access High-Low Power Exam Table, Two in One Examination/Treatment Table, Two-in-one Examination/Treatment Table). However, these beds have many more options and can be expected to have high costs. To get a better idea of the cost we can expect, we looked at beach chairs. These chairs have very similar sizes, weights, and support strengths. These chairs typically have a price range between 20-100 US$. The more expensive (greater than $50) have more amenities. Since we are designing a bare bones version of an obstetrics bed that will be similar in design to beach chairs, we are designing for less than $75. Because of this, we created a low end goal of $75, but still would like to minimize this as much as possible.

5.5 Portable

This is one of the most important requirements. Health care workers or midwives may travel several miles on motor bikes and by foot to get to a patient's home. Initially, we planned to have a design that could attach to the bike for easier travel to the houses. This idea may not be the best for our project, because two motorbikes are rarely the exact same, so it may be difficult to design a table that will fit universally onto every bike. Attaching the table to the motorbike may cause a sanitation problem as dirt and soot thrown up from the travelling bike. Figure 16 shows the current roads in rural Ghana today that the healthcare worker will have to travel through.

Figure 16: Dirt road in rural Ghana that many women have to travel on to seek healthcare.

Due to these reasons, we decided it would best to have a foldable table that could be put inside a water resistant pack and strapped onto the healthcare worker. Therefore, we had to come up with dimensions that would make the pack comfortable to wear. It was important to look at anthropological data to determine the size of someone who might be wearing this pack (Danborno). We also did benchmarking on sizes of current hiking packs (Hardin and Kelly 3). Combining this data, our table will have the following folded dimensions.

- Width: No more than 0.76 m
- Height: No more than 0.76 m
- Depth: No more than 0.30 m

There is an important trade-off between folded size and unfolded size. The bigger we make the unfolded size, the harder it will be to make a smaller folded table ("Obstetrics Tables and Examination Tables," par. 3). From the same anthropological data mentioned earlier, we were able to look at important body sizes of woman who may be using the table (Danborno). What we focused on was hip width, shoulder width, leg length, and height as shown in Table 4 below.

Table 4: Average body dimensions for West African women. (Danborno; Cappuccio 1018)

Feature of Woman	Region where data was obtained	Value
Average Height (cm)	Ghana	156.6 ± 7.0
Average Weight (kg)	Ghana	53.0 ± 11.9
Average Height (cm)	Nigeria	162.14 ± 5.95
Average Weight (kg)	Nigeria	57.64 ± 9.52
Hip Circumference (cm)	Nigeria	94.32 ± 7.36
Chest Circumference (cm)	Nigeria	87.69 ± 6.65
Waist Circumference (cm)	Nigeria	73.56 ± 7.39
Thigh Circumference (cm)	Nigeria	52.76 ± 5.52

This data helped us to determine the following dimensions:

- Width: No more than 0.76 m
- Length: No more than 1.52 m
- Height: 0.91 m or shorter

With some research, we determined that packs worn on the users back that are more than 30% of the user's body weight can be detrimental to their health (Hardin and Kelly 3). We also know that the average Ghanaian woman weights 55 kg (121 lbs); 30% of this weight is 16.5 kg (36 lbs) (Cappuccio 1018). With a safety factor of 1.5, the total folded weight will be less than 10 kg (26 lbs).

5.6 Simple Design

We want a simple design for ease of use, sanitation, production, and cost. For instance, minimal hinges will keep the production simple, and even keep the costs down. Also, we mentioned how we would like an adjustable back angle. There is an important trade-off we have to keep in mind here as we make these aspects more adjustable, the design becomes more complex. We would like to keep these aspects adjustable, but need to make sure we still have simple designs.

5.7 Comfortable

The comfort of the woman is important. An adjustable back angle would help aid in the women's comfort. In addition to this, there is research that shows women who lay on their back during exams feel very vulnerable. The inclined positions help them feel more empower (Lori).

From our research on current obstetrics tables, we were able to determine at what angles current back rests can be adjusted to. The range of angles usually is 0°-52°. Because we would like to keep our design simple, we can't have too many angles. Back angles of 0°, 30°, and 60°, are near the angles of current tables and are sufficient for our design.

Another factor we feel is important for comfort is thickness of the table padding. Because this table will have to fold easily, it cannot be too thick. Therefore, there is going to be a trade-off between comfort and portability. For our table padding, we will have a thickness less 1'' to minimize the folded dimensions without sacrificing strength.

5.8 Long Lifetime

To get the most out of the money put into the table, we want to have it last as long as possible. From our research on current gynecological beds, we determined most have a 3-5 year warranty (Basic Exam Table, Access High-Low Power Exam Table, Two in One Examination/Treatment Table, Two-in-one Examination/Treatment Table). We expect that most beds will outlive their warranty. Since most beds in a hospital setting last close to but more than five years, we would expect our table with its use to last slightly shorter. Therefore, we would like it to have a lifetime of greater than 5 years. There are many specifications that play a role in the lifetime of our table. Having non-corrosive material will allow the legs and supports to last longer. Having minimal hinges also allows for less maintenance, because hinges may become defective. The hinges selected were made of steel and it was difficult to find hinges made of non-corrosive materials while still retaining strength. Other material hinges such as plastic hinges would not be strong enough to support the connection between the legs and the table since the largest stress is located in the joints as discussed in Section 19.0.

5.9 Easy to Use

As mentioned before, our teammate Joseph Perosky has been to hospitals in Ghana and witnessed what goes on first hand. From his experience, he knows that in Ghanaian hospitals, when a device loses its usefulness it becomes a doorstop. It is important that our design is easy to use so that it does not become discarded. Also, if it is easy to use, it will require much less time to assemble and disassemble the table for exams, which would allow the user to make more stops in one trip and perform more exams in one day.

Some components of the table may be complicated to use. These parts include the detachable stirrups, adjustable height, and adjustable back angle. We plan to make these as easy to use as possible by doing research on similar designs and what people feel are easiest. We will include a user manual so that anyone can use the table and not just healthcare workers.

5.10 Gynecology Equipment Kit

Attached to the portable table will be the gynecology equipment the healthcare worker will use during the examination. From talking to Dr. Ofosu, we determined that the most important components include a fundal height measuring tape to measure the gestational age, a fetoscope to measure the neonate’s heart rate, and an adjustable handless light for the healthcare worker to use during the examination. Other components may include: gauze, bleach, gloves, a lighter, a face mask, scissors, a washable cloth/drape, and a speculum (Ofosu). The table will come equipped with multiple items that are disposable.

6.0 CONCEPT GENERATION

The main components of the table are the leg separation mechanism, table bed, back angle adjustment, table legs, and packaging. To start our brainstorming process we each took a few minutes and wrote down every thought on each component that came to mind regardless of how impossible it was. We organized our concept ideas by table components and then discussed each. To help generate even more ideas, we searched over 50 different foldable tables, beds, cots, and chairs online and in stores. We examined their connecting and rotation mechanisms and used them to generate ideas of our own. This discussion also led to subsequent concept ideas. Following our brainstorming sessions, we acquired over 20 designs. We then organized all of our concept ideas by component and did a QFD and functional decomposition (See Appendix C for the functional decomposition). It was more practical and useful to evaluate specific components of our table separately rather than complete table designs; therefore we broke each design up into the main components (leg separation mechanism, table, table legs, packaging, and back angle adjustment). (Please refer to the Appendix A.1 for more component designs and complete table designs)

6.1 Leg Separation Mechanism

The leg separation mechanism is used for opening the patient’s pelvis to a sufficient angle to perform a gynecological exam. It is the most important aspect of the design because without it, the examiner cannot get close enough to the pelvis. Figures 17a-c on page 21 show our top three choices for the mechanism.

Figure 17a shows the design that uses traditional stirrups that clamp from underneath the bed and can adjust to different angles and lengths. The advantage of the clamping mechanism is that it is easy to assemble. However, the disadvantages are that the stirrups would not be as sturdy if they were clamped onto the bed and the healthcare worker would have to attach the stirrups.

Figure 17b shows the design of footpads that easily fold out from the table bed. The patient places their feet against the foot pads and they can use the force of their feet on the pads to securely stabilize their feet. The advantages of this mechanism are that it is easy to use and there is no assembly of the stirrups since they are engraved in the table. The footpads are light and small so they do not contribute a great deal of weight to the table. However the disadvantage is that we cannot make the footpads wider than the table. This coupled with the fact that they do not have adjustable angles make them insufficient for a pelvic exam.

Figure 17c shows traditional stirrups attached to the stool that the examiner sits on. The stirrups are adjustable in both length and angle. The advantage of the stirrups on the stool is that they will be stable since the weight of the healthcare worker is securing them. The stirrups also fold into the stool for easy travel and assembly. However, the disadvantage of the stirrups being placed on the stool is that the examiner must remain on the stool to secure the stirrups from moving.

Figure 17d shows the stirrups extending from a housing that is attached to the side of the table. The stirrups would then be adjustable to different lengths using a sliding mechanism. Once extended from the housing, the stirrups can be rotated to different angles. The stirrups and the stirrup housing are both detachable for travel. The advantages of this design are that they do not get in the way of the healthcare worker and they are detachable and adjustable. Another advantage is the extra support provided by the stirrup housing which can help resist a large bending moment. A disadvantage to this design is that it will be more difficult to manufacture since it is made of 3 separate pieces.

Figure 17a: Traditional Stirrups underneath bed

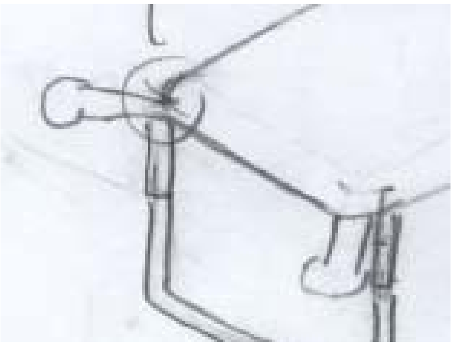


Figure 17b: Fold out footpads

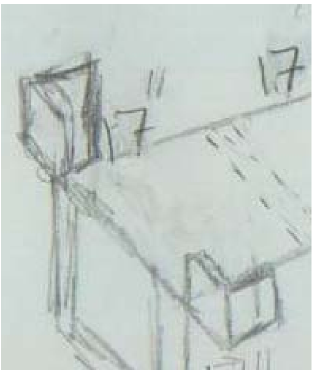


Figure 17c: Stirrups attached to stool

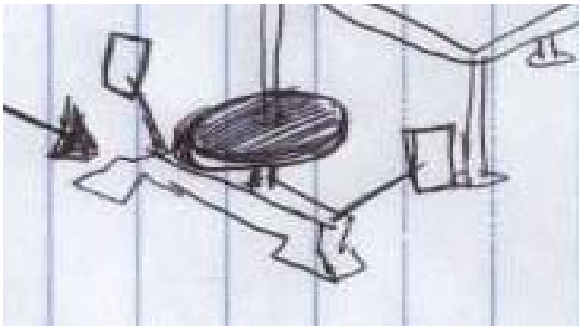


Figure 17d: Stirrups attached to side of table

6.2 Back Angle Adjustments

Our customer requires the table to have an adjustable back angle. Figures 18a-c on page 22 show our top 3 designs for creating an adjustable back angle.

Figure 18a shows a wedge that is detachable using Velcro. It can be positioned behind the patients back on two different edges to allow for 2 different back angles, and then can be removed for the supine position. The advantage of the wedge is that it is easy to manufacture and simple to use. However, the patient has to lift their back in order to reposition the wedge to another angle.

Figure 18b consist of a back frame that securely lifts and fits into notches on the bottom frame. The table can be manufactured to contain multiple notches positioned at different lengths of the bottom frame to allow for multiple angle adjustments. The back frame can lay flat onto the bottom frame to allow for a supine position. The advantages of this design are that it does not contribute extra weight to the table and it is easy to use. However, the disadvantages are that it will be difficult to manufacture and the patient must raise their back to adjust.

Figure 18c shows a design taken off of a current weight bench. The mechanism that is used for adjusting the back angle of the table is a spring loaded pin that is inserted into different holes along the length of the member. The member has two pieces that slide in and out of each other so the length may change, therefore changing the back angle. The main advantage of this design is that it allows the patient’s back to remain on the table while adjusting. However, the disadvantage of this table is that it will also bring in unwanted weight from the extra and thicker frames and the table would be subject to spring failure. It will also be difficult to manufacture, because it has many frames which are all at different angles.

Figure 18a: Wedge used to adjust back angle.

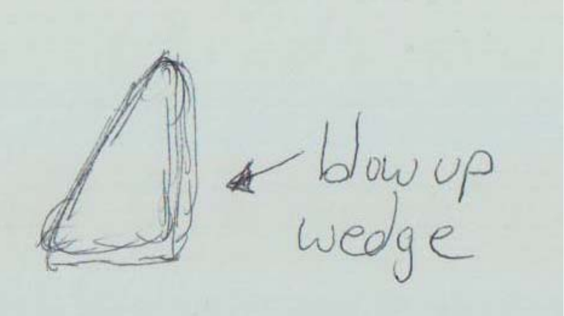


Figure 18b: Back frame secured into notches.

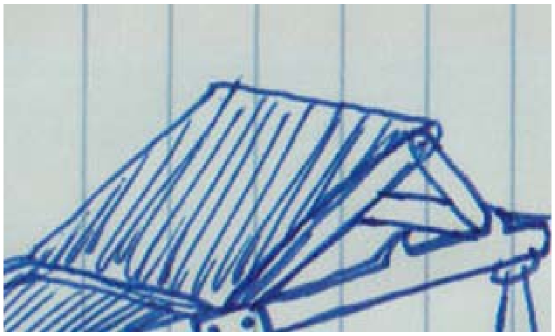
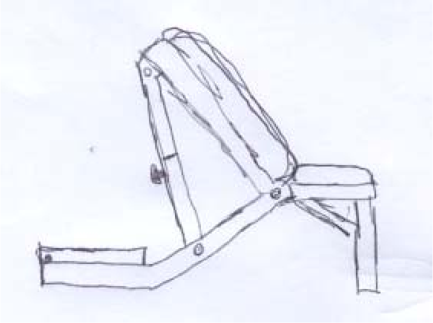


Figure 18c: Back angle using spring loaded pin.



6.3 Table Legs

The average table bed on the market today is approximately 3 ft off the ground. Figures 19a-c below show our top 3 choices of the table legs.

Figure 19a shows a table leg that utilizes a rod for adjustable height. The leg slides up and a rod penetrates through drilled holes in the leg to secure the new height. The rod extends through the entire cross-section of the leg. The rod is attached to a chain so that it does not get misplaced and always remains connected to the table. The advantage is that the table height is easily adjustable. However, the disadvantages of these table legs are that they would be subjected to double shear force and the healthcare worker would have to adjust each leg separately, which could become more of a hassle.

Figure 19b is a simple stiff leg design where the leg twists into the table and locks in. It is not adjustable to different heights but can be detached from the table. Advantages of a stiff leg are that it is sturdy, simple, and easy to manufacture. Some disadvantages are that it has detachable parts, which will cause the healthcare worker to spend extra time assembling it and that the table height would not be adjustable.

Figure 19c is a stackable leg mechanism. Blocks are made to securely stack on top one another and then snap and hold into place. If the table height needs to be adjusted, more blocks can be placed underneath. The advantage of this design is the many ranges of adjustable heights. The disadvantages of this design are the many separate pieces that can be misplaced and the extra hassle of assembling the stackable blocks.

Figure 19d shows another table leg design consisting of 3 rigid stiff legs assembled together to make U-shaped leg. The leg will be attached to the table using hinges. The advantage of this design is its ease of manufacturing and its sturdiness since it has a crossbeam connecting the two vertical legs. The disadvantage of this table leg design is that it cannot be adjusted to different heights.

Figure 19a: Adjustable height leg using a rod.

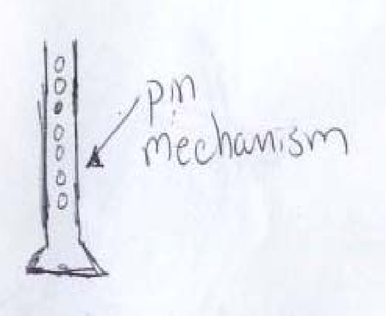


Figure 19b: Stiff Leg

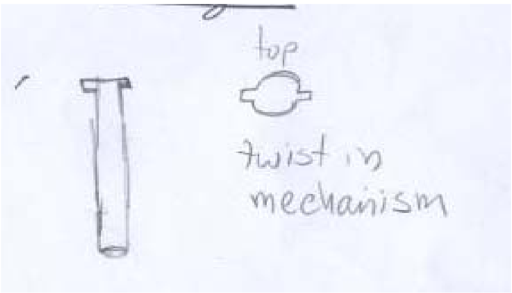


Figure 19d: Stackable Blocks

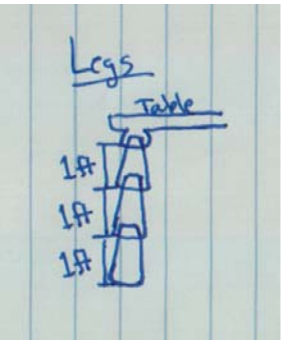
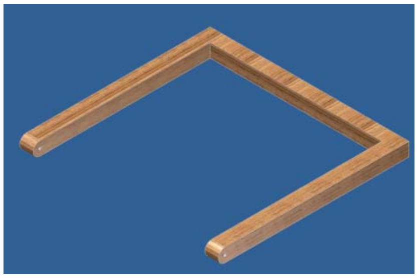


Figure 19d: U-Shaped Legs



6.4 Packaging

Our final useable product will consist of the examination table and essential materials used during a pelvic exam. We must determine a way to combine both the kit and the table in a complete package. Figures 20a-b on the next page show our most common design for packing our product.

Figure 20a below shows how the kit can be strapped onto the table after the table is folded to create one compact system. The table will fold into a thin chair and a pack with the essentials materials will strap onto the table and be placed into a water resistant pack. The advantage to this pack is that since everything is strapped, all the materials will be secured. The disadvantage of the pack is that since it is not symmetrical, it will not sit comfortably on the healthcare workers back and it won't fit neatly in the water resistant pack.

Figure 20a: Materials pack strapped to folded table.

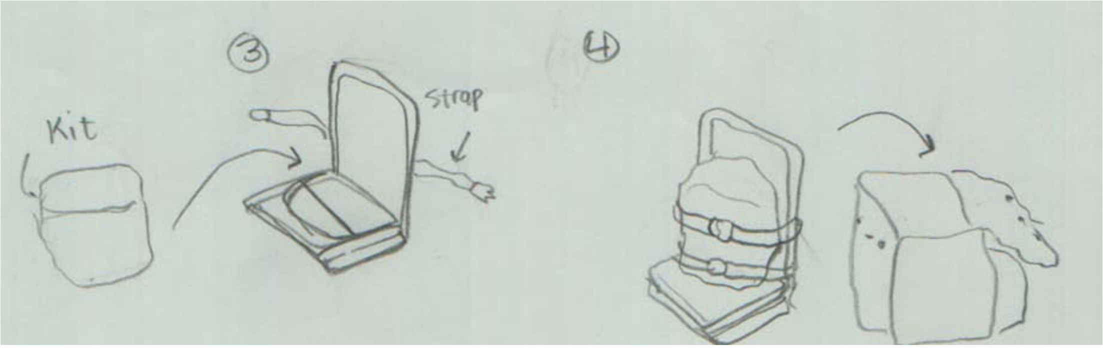
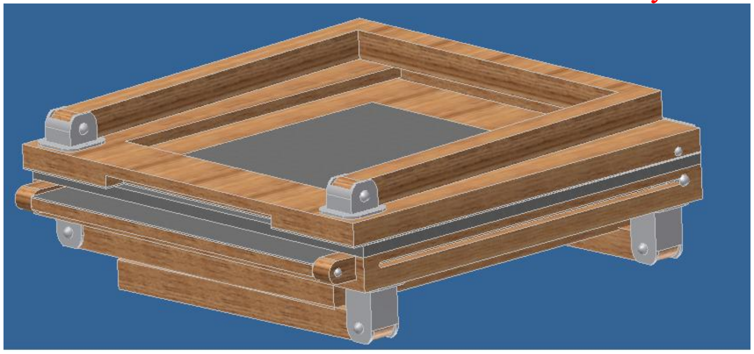


Figure 20b on page 25 shows a folded up table designed that folds using its 3 sections with a slot for the materials in the center. The advantage of this design is that it folds neatly and will allow for straps to be attached so the healthcare worker can carry the table. However, the disadvantage is that the materials will not fit perfectly in the slot so they will not be very secure.

Figure 20b: Materials pack slides into slot created by folded table.

Figure 20c on page 25 shows another folding design where the middle and head rest section legs fold underneath the section and the foot rest section legs swivel to the side of the foot rest. The foot rest with the legs slide into the middle section. The head section folds on top of the middle section. The materials pack will lie on top of the folded table and strap securely. The advantages of this design is that it will lay more comfortably on the healthcare workers back and the materials will be strapped in so they will be secure. However, the disadvantage is that is it thicker and heavier.

Figure 20c: Folded table where middle and head rest sections lay flat on one another.



6.5 Fabric Table Sections

We originally were set on solid rigid table sections because we wanted the table to be as strong as possible and therefore never initially brainstormed for anything else. However, after the production of the Beta prototype we realized that the table was too heavy, so as a trade-off for a lighter table we brainstormed ideas to make lighter table sections without sacrificing strength and low cost. We came to the idea of making the foot and head section of fabric. The fabric will be attached to aluminum frames from recycled lawn chairs. The recycled lawn chairs will aid in the lower cost. The advantage of attaching fabric to recycled frames is that is it light weight, low cost, easy to seam and the fabric can be found in abundance in Ghana. However, the disadvantage of having fabric is that it is not a rigid body and therefore cannot support as much weight as the original wooden sections and will not be as stable. Figure 21-22 shows the foot and head sections made of fabric seamed around recycled aluminum frames.

Figure 21: Foot Section of the Table made of Fabric and aluminum frames.

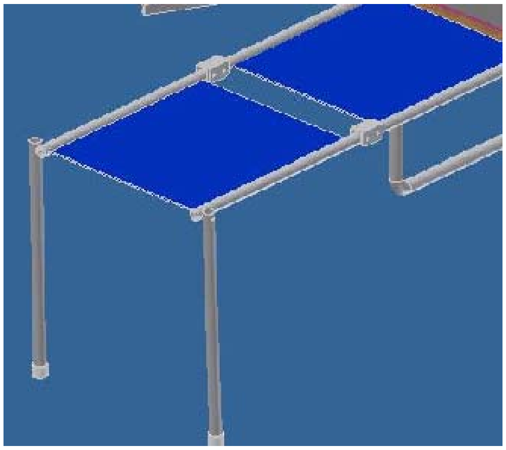
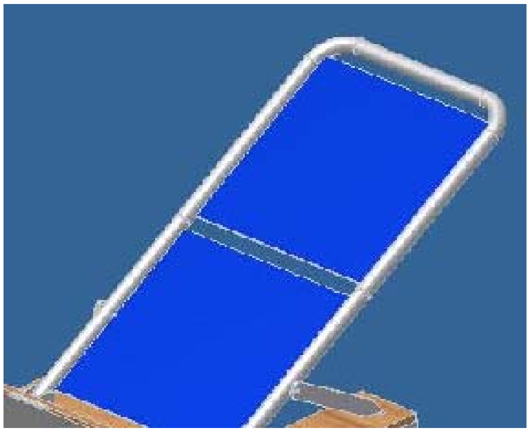


Figure 22: Head section of the table made of Fabric and aluminum frames.



7.0 CONCEPT SELECTION

After many hours of evaluation, we selected the beginnings of our Alpha Design using Pugh Charts.

7.1 Pugh Charts

The table being designed was broken down into three critical components: the legs of the table, the back angle adjustment mechanism, and the leg separating mechanism. From our concept generation, many designs were proposed for each component. Each of these component designs was then put into a Pugh chart. To determine the weight of each feature on the Pugh charts, our team discussed how important each of these was. The weight was based off of talking to our mentors and through surveys that we sent to each of them. Surveys were sent to Dr. Anthony Ofosu, Mrs. Jody Lori, and Dr. Tim Johnson. The surveys were completed by Dr. Ofosu and Mrs. Lori. We are still awaiting response from Dr. Johnson. Our group ranked three of the customer requirements: safety, maintenance, and manufacturing. (Refer to Appendix E for survey and the responses to the survey). We then consulted with our mentors to see that they agreed on the weights. For each component, a datum was chosen to compare the other designs to. Following this, each other design was given a score of a -1, 0, or 1 in comparison to the datum, which represents our advantages and disadvantages. The component designs with the highest scores are the ones that are being used in our Alpha Design.

7.2 Description of each component of analysis

Light Weight: The weight of the table was given a weight of 3. It is important to have a low weight of the exam table so that it will not put strain on the health care worker's back while traveling.

Portability: Portability was given a weight of 3. This was identified by our mentors as one of the most important design criteria in so that the health care workers can reach women in rural areas.

Cost: The cost for each mechanism was based upon manufacturing and potential materials that will be used. Cost was given a weight of 3.

Easy to use/assemble: The ease of use for the health care worker includes maneuverability of each component. Ease of use was given a weight of 3.

Safety: A qualitative analysis was done to address the safety of each component. Ideas taken into consideration were failure due to bending stress and spring failure. A further engineering analysis of each component will be performed in order to meet the desired safety factor of 1.5. A weight of 3 was given to safety due to the risk of a woman or health care worker being injured while using the device.

Patient Comfort: Patient comfort is very important to our design. This was given a weight of 2.

Examiner Comfort: Examiner comfort was given a weight of 2 based upon the surveys.

Easily Cleaned: The table must be easily cleaned to prevent the spread of infection. This was agreed upon by our mentors. Therefore the ease of cleaning was given a weight of 2.
Manufacturing: Each component was analyzed for the ease of manufacturing. Manufacturing includes the option for the pieces to be made of abundantly available resources and the ease of the processes that would be needed to make each component. Manufacturing was given a weighted score of a 2.

Maintenance: Maintenance includes the ease of repairing or replacing parts. Maintenance was given a ranking of 2.

Non-Corrosive: Due to the fact that bleach and water are used to clean the table and the humid environment the table will be used in, the materials used to make the table must be non-corrosive. A non-corrosive table was given a weight of 1.

Non-Absorbent: To stop the spread of infectious disease and allow for ease of cleaning, our table must be made out of non-absorbent materials. A non-absorbent table was given a weight of 1.

Adjustable Table Height: At Design Review #1, an adjustable table height was a high priority. After talking to our mentors and looking at the surveys they filled out, having an adjustable height was determined to be unnecessary and therefore given a weight of 0.

Adjustable Back Angle: The table needs to adjust to 0˚, 30˚, and 60˚ positions. This was a key design criteria identified by Dr. Ofosu. For this reason, the adjustable height was given a weight of 2.

Table 5: Pugh Chart- Legs of Table

Evaluation Criteria	**Weight (Scale Factor)**	**Datum Pin Mechanism**	**Design 1 Adjustable Rod**	**Design 2 Cones**	**Design 3 Stiff Leg**
Light Weight	3	0	0	-1	0
Portability	3	0	0	-1	-1
Low Cost	3	0	0	-1	1
Easy to use/assemble	3	0	0	-1	1
Safety	3	0	0	-1	1
Patient Comfort	2	0	0	0	0
Examiner Comfort	2	0	0	0	0
Easily Cleaned	2	0	0	-1	1
Manufacturing	2	0	0	-1	1
Maintenance	2	0	1	0	1
Non-Corrosive	1	0	0	0	0
Non-Absorbent	1	0	0	0	0
Adjustable Table Height	0	0	0	0	-1
Total		0	2	-19	12

Table 6: Pugh Chart- Leg Separators

Evaluation Criteria	**Weight (Scale Factor)**	**Datum Footpads**	**Design 1 Stirrups**	**Design 2 Calf Holders**	**Design 3 Foot Bar**
Light Weight	3	0	0	0	0
Portability	3	0	-1	-1	-1
Low Cost	3	0	-1	-1	1
Easy to use/assemble	3	0	1	1	0
Safety	3	0	1	1	-1
Patient Comfort	2	0	1	1	-1
Examiner Comfort	2	0	0	0	-1
Easily Cleaned	2	0	0	0	1
Manufacturing	2	0	-1	-1	1
Maintenance	2	0	0	0	1
Non-Corrosive	1	0	0	0	0
Non-Absorbent	1	0	0	0	0
Total		0	0	0	-1

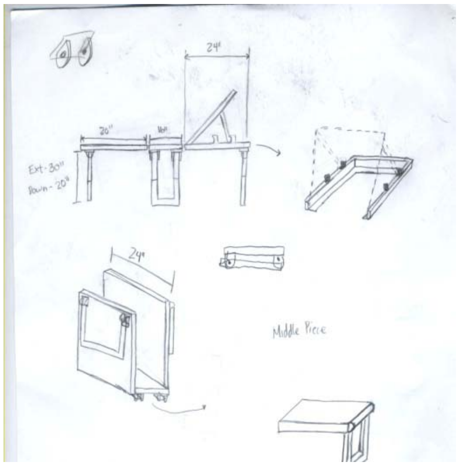
Table 7: Pugh Chart- Back of the Table

Evaluation Criteria	**Weight (Scale Factor)**	**Datum Blow up wedge**	**Design 1 Weight Bench**	**Design 2 Stepping Design**
Light Weight	3	0	-1	-1
Portability	3	0	0	0
Low Cost	3	0	-1	-1
Easy to use/assemble	3	0	1	1
Safety	3	0	1	1
Patient Comfort	2	0	0	0
Examiner Comfort	2	0	0	0
Easily Cleaned	2	0	0	0
Manufacturing	2	0	-1	1
Maintenance	2	0	0	1
Non-Corrosive	1	0	0	0
Non-Absorbent	1	0	1	1
3 Adjustable Back Angles	2	0	1	1
Total		0	1	7

7.3 Alpha Design Sketches Based off of Pugh Charts

Based off of the three Pugh charts above, we developed our final concept sketches. The three main components that were decided upon are a stepping design to achieve the desired back angles, stiff legs to support the table, and stirrups for the women to place their feet in during an exam. Note that in Table 6, stirrups and calf supports were tied at 0. Stirrups were decided upon after a conversation with Dr. Anthony Ofosu, who strongly requested them. Figure 23 below shows our final design sketch.

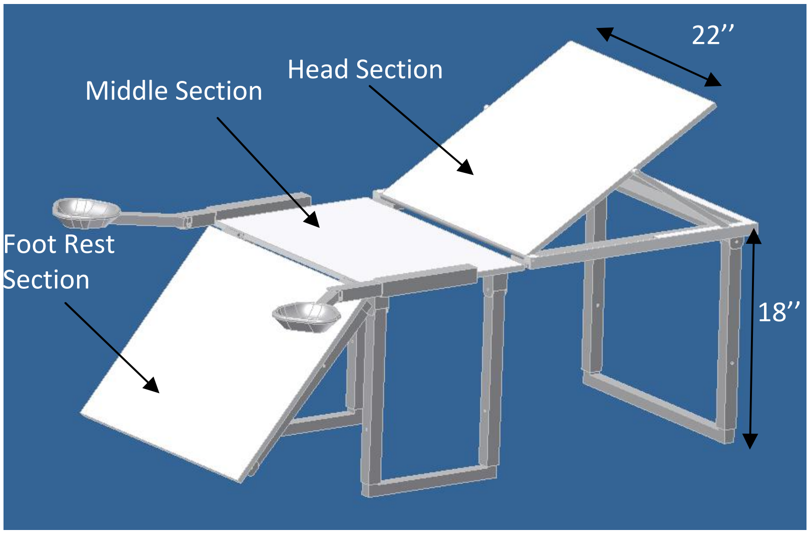
Figure 23: Sketch of Final Concept Based off of Pugh Charts



8.0 ALPHA CONCEPT DESCRIPTION

Our selected Alpha design is presented in Figure 24 below. The following sections describe the three table sections, table hinges, leg systems, back angle adjustment, and stirrups. See Appendix A.4 for detailed engineering drawings.

Figure 24: Alpha Design with 3 table sections



8.1 Table Sections

This describes the three main sections of the table. The table is defined as the area where the patient will be laying. The sections are foot rest, middle, and head.

8.1.1 Foot Rest Section

This section is where the woman will be placing her legs during rest on the bed, and possibly certain portions of the exam, such as measuring the fundal height, where stirrups are not needed. This portion is simply a solid rectangular block, possibly made from sturdy plastic. It is important to note that we have not yet selected our final material for any portion of the Alpha design. It is 0.61 m wide and 0.51 m long.

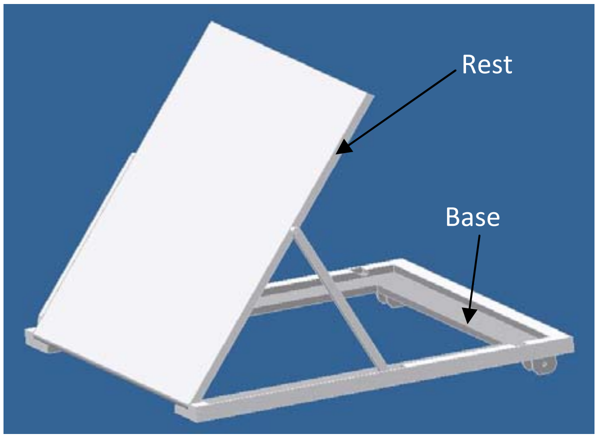
8.1.2 Middle Section

This is the section where the buttocks of the woman will be placed. It is also where most of the woman's weight will be distributed. Therefore, this section will have to hold the most weight. This section has two sets of legs on each side. It is 0.61 m wide and 0.41 m long.

8.1.3 Head Section

The head section is made up of two parts, the base and the rest. Figure 25 on page 31 distinguishes between the two parts. The base allows us to have a more sturdy design with a lower center of gravity. Along with this, the legs attached to the foot rest section are the same as the legs attached to the head base. This allows for compatibility of parts and a reduction in production costs. The rest is where the woman will be laying her upper body. This is adjustable to different angles in respect to the base. The angle adjustment mechanism will be outline in a section 8.5. It is 0.61 m wide and 0.61 m long.

Figure 25: Head Section with Back angle adjustment.



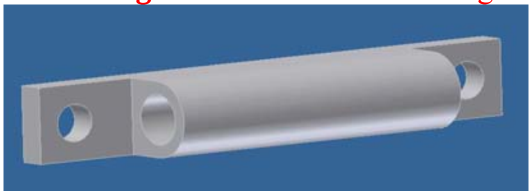
8.2 Table Hinges

The following section describes the hinges that will attach the table sections together. Once the hinges are attached together, the table sections can rotate with respect to the other.

8.2.1 Female Table Hinge

These table hinges allow for a compatible male hinge to be placed inside of them. Two female hinges will be placed on the foot rest section, and two more will be placed on the head section base. Figure 26 below shows the female table hinge.

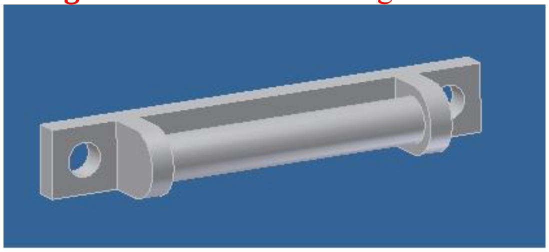
Figure 26: Female table hinge.



8.2.2 Male Table Hinge

There are four male table hinges attached to the middle section. Two at the front edge where the foot rest section will attach to, and two at the back edge where the head section base will attach to. The two at the back edge are further apart to accommodate the design of the head section base. The male table hinge is presented in Figure 27 below.

Figure 27: Male table hinge.



8.3 Leg Joints

The following section describes the leg joints.

8.3.1 Short Leg Joint

These joints are fastened to the bottom of the table. Each joint is attached to the table with two fasteners. There are two rounded extensions that protrude from the base. The table leg itself will be placed between these extensions and a rod/hinge will be slotted through all of them to allow the leg to rotate. Each joint also contains a stop that prevents the leg from rotating past 90 degrees. To make certain the legs do not collapse back into the table, the examiner can tighten the hinge with their finger. This joint is presented below in Figure 28b below.

8.3.2 Extended Leg Joints

A figure of these leg joints is presented Figure 28a below. This leg joint is very similar to the short version; however it has a solid extension from the base. This way, the leg has a solid surface to sit against when it is perpendicular to the table allowing for a more sturdy design.

Figure 28a: Extended leg joint.

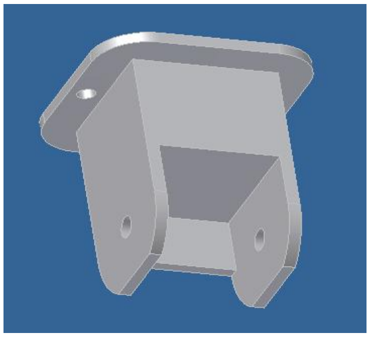
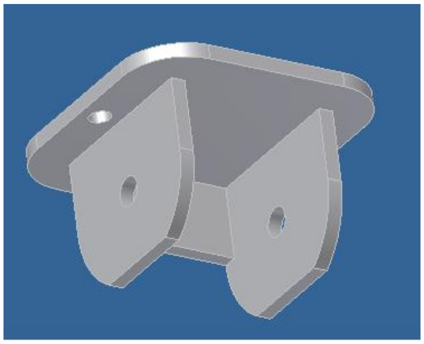


Figure 28b: Leg joint.



8.3.3 Placement of Leg Joints

Figure 27a below outlines where each joint will be placed. Notice the middle section is the only section that requires the extended leg joints. This is because the middle has two sets of legs on each side. In order for these legs to fold in a plane parallel to the middle section, it was necessary for us to design a joint that extends the rotation point of the leg. Therefore, when the first leg folds in, it sits flat against the table. Then the second leg with the extended rotation point is folded in and sits on top of the first leg. This is demonstrated in Figure 29a-b below.

Figure 29a: Placement of leg joint.

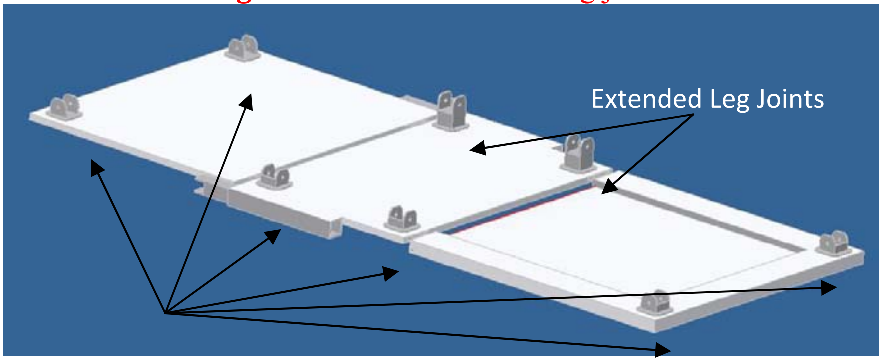
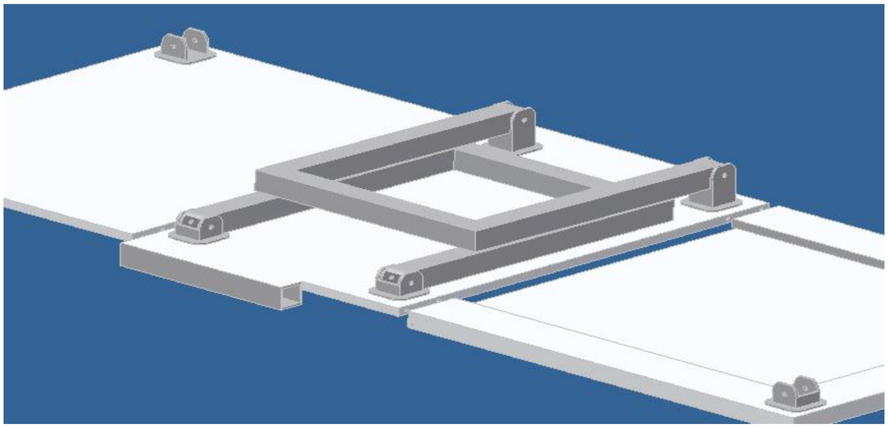


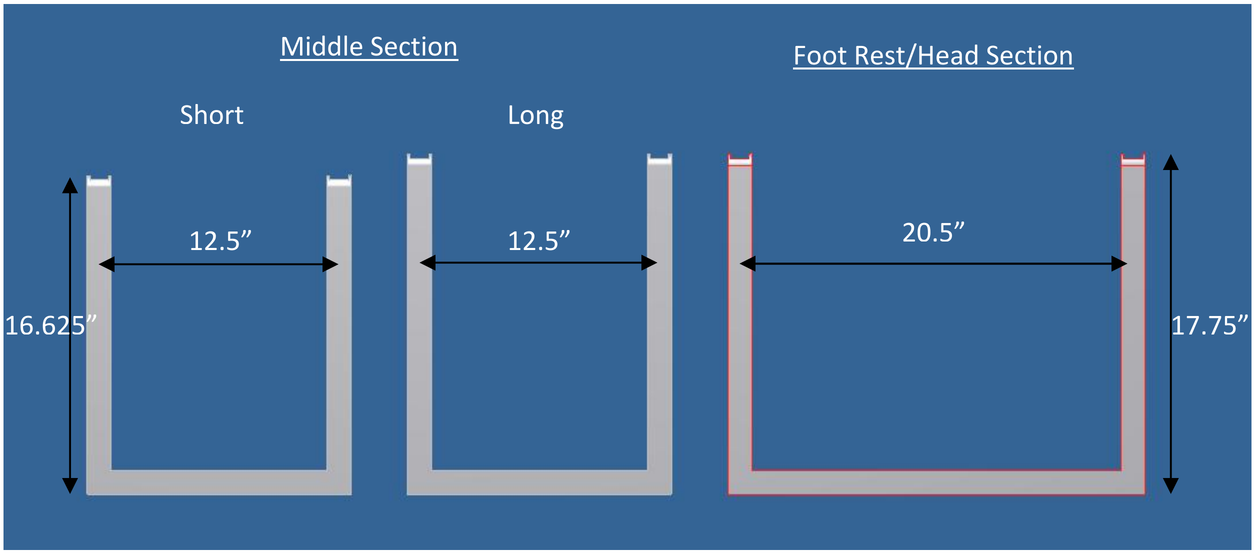
Figure 29b: Folded middle table legs.



8.4 Table Legs

This section outlines the important aspects of the leg supports of the table. Figure 30 below displays the important dimensions in order to distinguish the differences between the legs. Since the height of the table is only 0.51m, we are likely adding a foldable stool for the healthcare worker to position themselves in a comfortable position for the exam.

Figure 30: Dimensions of table legs.



8.4.1 Foot Rest and Head Section Leg

The table legs attached to the foot rest section and head section are the same. From rotation point to rotation point, the legs are 20.5”. Each table leg consists of a ‘U’ shaped rectangular tube section. As mentioned in the section above, the table legs are attached to the leg joints and are allowed to rotate no more than 90 degrees. A rounded top on these sections allows for the legs to rotate, and still allow for contact while the leg is perpendicular to the table.

8.4.2 Middle Section Long Leg

The middle section has two sets of legs. Both sets have the same cross section as the foot rest and head section legs. The first set is the same height as the wide table leg, but is thinner. The distance from rotation point to rotation point is 12.5”.

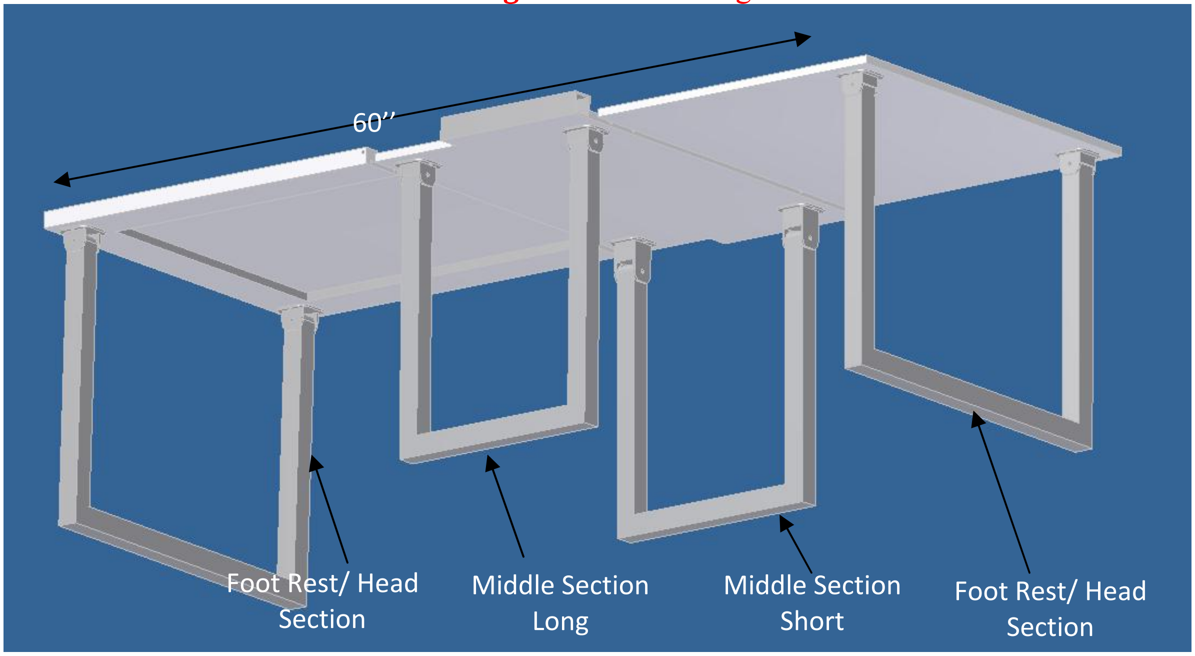
8.4.3 Middle Section Short Leg

The second set of legs on the middle section is slightly shorter than the wide table leg. The total height is reduced 1.125”. This is to account for the change in the extended leg joints. The shorter length allows for the table to sit flat when all legs are perpendicular to the table.

8.4.4 Placement of Table Legs

Figure 31 below demonstrates the placement of each table leg. Notice that the short middle section leg is attached to the longer leg joint. Also, it is important to note that the legs attached to the head and foot rest sections are identical.

Figure 31: Table legs.



8.5 Back Angle Adjustment

This sub-system allows the head rest to be adjusted at different angles. This is achieved by having notches in the head base, at two different positions to allow for angles of 30 degrees or 60 degrees inclined. Adjustment rods that are attached to the head rest extend from the sides into the notches on the head base to securely hold the rest up at an angle. The head base also contains small slots in which the rods are able to sit when the table is in the supine position.

The Law of Cosines was used to determine the position of the notches on the base in order to achieve angles of 30 and 60 degrees. The back angles adjustment sub-system is presented in Figure 32a-b on the next page.

Figure 32a: Back angle adjustment.

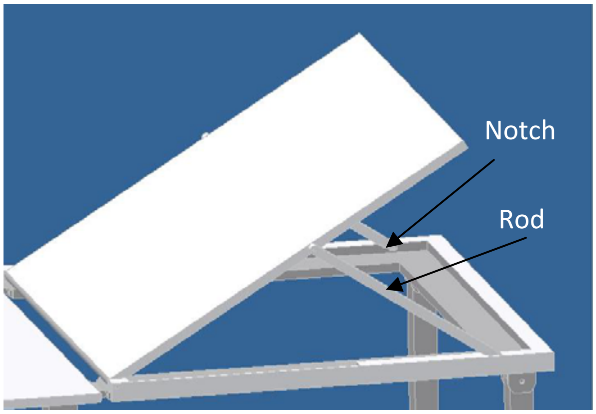
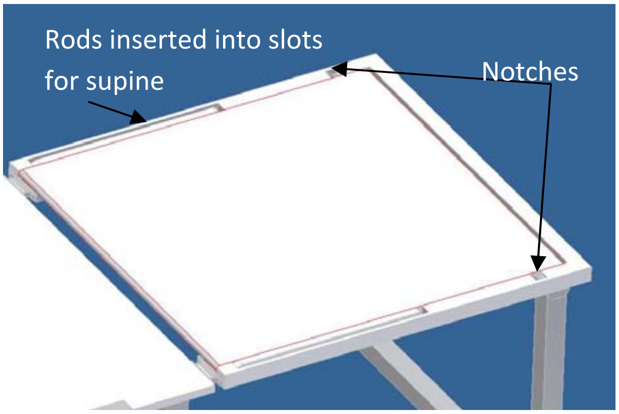


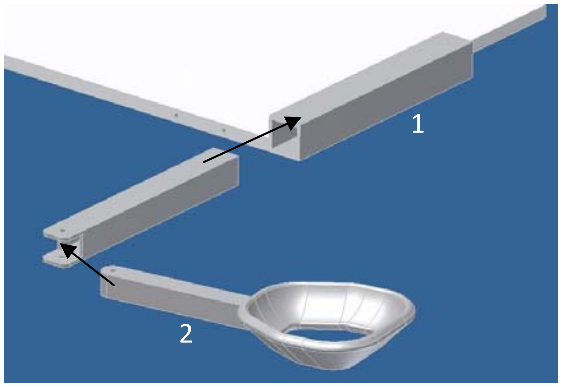
Figure 32b: Table in supine position.



8.6 Stirrups

Our Alpha design has the stirrups being attached to the middle section. Figure 33 below shows how this sub-system is put together. On each side of the middle section there is a rectangular tube (1) that is attached using several fasteners, or possibly even made as part of the middle section. Another straight rectangular tube section (2) will be slid into the tubes on the side of the middle section and somehow fastened. The lengths will also be extendable to allow for different length legs using a rod mechanism. At the end of the extending tube, there is a hole in which a hinge will be inserted. This hinge will also be inserted through the final piece, which is the stirrup (3). The final piece consists of the stirrup, and a short rectangular tube section which is attached to the extended piece (2). The stirrups have 2 degrees of freedom, translation along the length and rotation about the table to allow for stirrups angles.

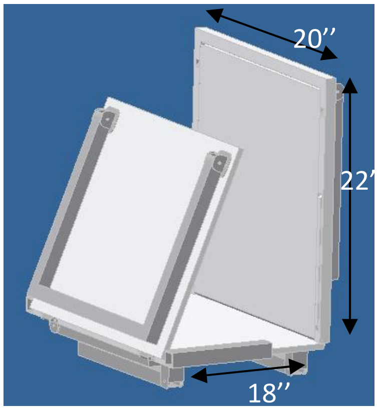
Figure 33: Stirrup assembly on the side of the middle section.



8.7 Folded Alpha Design and Packaging

Figure 34 on page 36 shows our Alpha design as it will appear folded. The leg and head sections are brought up vertically and hooked together. This latching mechanism is something we are still trying to find a better solution for. Initial ideas include a strap that holds the foot and head section together while folded. After these sections are hooked together, and all legs are folded in, the table will be inserted into a water resistant travel pack. This pack will also aid in securing the table when it is folded. Any equipment that is brought with the healthcare worker can also be secured between the head and foot section for added protection during travel.

Figure 34: Alpha design in folded position



8.8 Advantages and Disadvantages of Alpha Design

The advantages of our Alpha design are that it is versatile, in that it can be used for a pelvic exam or standard exam that requires a basic table. Its back is adjustable to allow for patient comfort and the stirrups are adjustable to allow for adequate leg separation. It accomplishes it primary goal of use for a gynecology exam. It is easy to use and portable.

The disadvantages of the table are that is it a somewhat larger when folded, which could be difficult for the healthcare worker to carry. The table could have a high center of gravity which needs to be analyzed further. It works best on flat surfaces, so rough terrain might be difficult.

9.0 MATERIAL SELECTION

A major concern of our design is making sure the legs do not buckle under the weight of a patient. To prevent this from happening, we needed to determine the critical Young's modulus value (the value below which buckling would become a risk) for our leg material. Using the buckling load, we rearranged it to obtain Eq. 2 below.

$$E = \frac{P_{cr}L^2}{\pi^2 I} \qquad \text{Eq. 2}$$

Where P_{cr} is the critical load that will cause failure, L is the length of the leg, and I is the second area moment of inertia. We had already determined the dimensions of the legs to meet the table height requested by our mentors, which gave us the values for L, and I. Next, we determined the value for P_{cr} by determining that the largest load that could be placed on the legs is the patient's entire body weight. Therefore, we used the maximum load value from our engineering specifications as the critical buckling load for the table legs. That maximum load is 142 kg.

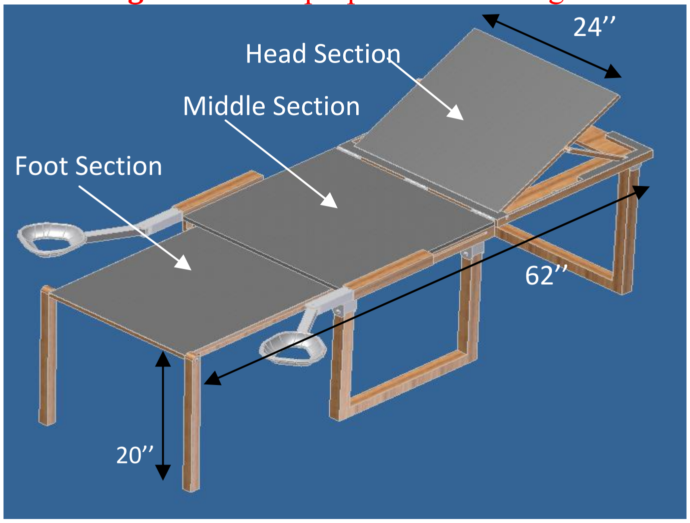
With these values, we used Eq. 13 to solve for our critical Young's modulus value, which came out to be approximately 95 MPa. With this information, we were able to greatly narrow our search for appropriate materials that have Young's Modulus greater than 95 MPa.

Using Cambridge Engineering Selection (CES) we were able to view all the materials that had a Young's Modulus greater than 95 MPa while also viewing other material properties such as shear stress, yield stress, density, and thermal expansion coefficient. After reviewing the material properties we narrowed our material selection down to Aluminum 6061 alloy and Birch Wood. Both materials contained very similar properties in density. However Aluminum was stronger having yield strength of 241 MPa and a Young's Modulus of 68 GPa, while Birch Wood had a yield strength of 3.72 MPa and a Young's Modulus of 790 MPa. However, Birch Wood was significantly cheaper and its Young's Modulus was still greater than the 95 MPa required to resist buckling and so we finalized our Omega design to be made of Birch plywood. Aluminum, and PVC.

10.0 BETA DESIGN DESCRIPTION

The following section describes our Beta design as well as the individual sub-assemblies. A CAD drawing of our Beta design is shown in Figure 35 below. Detailed engineering drawings of each sub component are given in Appendix A.7.

Figure 35: Our proposed final design.



10.1 Evolution of design

This section covers the main reasons behind changes in design from Alpha design to the Beta design. The Beta design consists of 3 sections made of Birch wood covered in a thin sheet of PVC. The U-shaped and stiff legs are also made of Birch wood, while the stirrups and stirrup housing are made of Aluminum. The head section can adjust to 0, 30, 60 ° using an adjustment rod made of Aluminum. The foot section slides into the middle section for easy access to the pelvis and the stirrups are detachable and adjustable to different angles ranging from 35- 50°. The Beta design was fabricated without the stirrups and the travel pack which are likely to change and add more complications. This design does not include any padding.

10.1.1 Materials

The biggest change from the Alpha to Beta design is the materials. When looking up prices for aluminum, which is what our original frame and legs were made of, we realized the prices were much higher than we expected. By using Cambridge Engineering Selector and getting price quotes from various suppliers such as McMaster Carr and Grainger, we determined that wood was much less expensive but still could support the weight that we needed. With a new budget of $300 we still want to fabricate the table for the lowest cost possible so that multiple tables can be purchased with the $300 budget. The decision was made to use birch plywood and birch lumber. This caused minor changes in the actual design of the legs and frame. The legs are now solid as opposed to hollow, and the frame is now wood with a thin sheet layer of PVC on top. The PVC was added to provide extra structural support, to provide the patient with comfort, and protection from the wood. The PVC also allows for easy cleaning.

10.1.2 Width Change

As mentioned in the disadvantages of the Alpha design, our biggest problem was the folded size. By looking at anthropometric research the 95 percentile of women are at most 18’’ wide and therefore our table did not need to be as wide as the Alpha design specified (Danborno). From this, we reduced the table width from 24”to 20”, which is still wide enough for a patient to lie on but reduces its folded size and weight.

10.1.3 Foot Section Changes

In our Alpha design, the foot section rotated. This design was too bulky which prevented it from meeting our engineering specification of 22 lbs. It was also too thick to sit on healthcare workers back comfortably and didn’t meet our folded dimensions specification. Therefore, we had to brainstorm new designs and concepts to decrease its size. One idea that came from this brainstorming was a foot section that could slide in and out of the middle section. This new design allows for both a pelvic exam and a general exam, but reduces the folded size greatly.

10.1.4 Head Section Changes

The biggest section in our Alpha design was the head section. This caused the biggest problem when folding. Since the width had already been reduced, we reduced the length of this section from 24” to 19”. However, this was too short due to the average height of an African women being 61.8’’ (which is longer than the Beta design) and therefore won’t allow the patient to have a support for her head and neck. Therefore we designed a section that would slide out from underneath the head section in which the patient could set her head. When the table is folded, this section slides back underneath the head section. This is described in more detail in section 10.2.3 below.

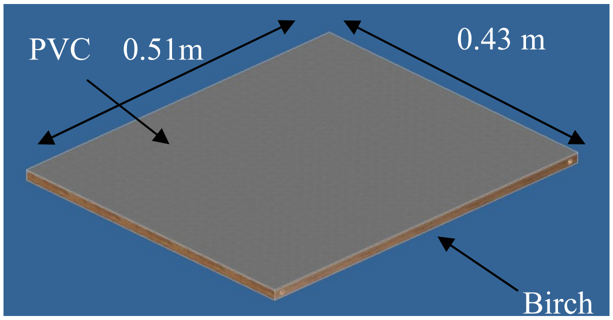
10.2 Table Sections

This section describes the three main sections of the table. The table is defined as the area where the patient will make contact. The sections are foot, middle, and head.

10.2.1 Foot Section

This section is where the woman will be placing her legs during the parts of her exam that do not include examination of the pelvis. This includes breast exam, measuring the fundal height, and other basic tests. The foot section is made out of wood and PVC. The PVC is 1/16” thick and adheres to the top of the wooden section. The PVC is corrosion resistant and the wood is made of birch plywood. Assembled, the section is 0.43 meters wide and 0.51 m long. Figure 36 below presents this table section.

Figure 36: Foot section with plastic and wood portions labeled

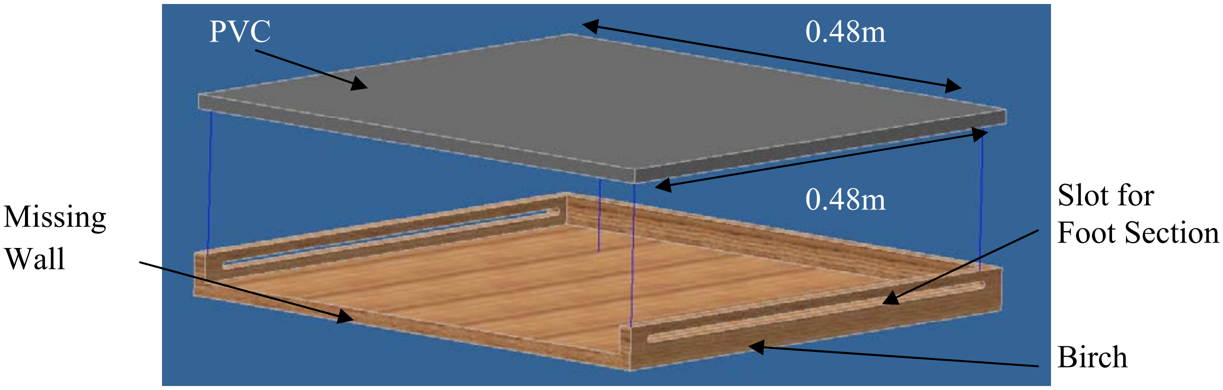


10.2.2 Middle Section

This is the section that the buttocks of the woman will rest upon. Since most of the woman's weight will be distributed through her buttocks, it has to support the most weight. As with the foot section, PVC and birch plywood are the two materials that make up this section. The bottom portion is made of birch plywood, with a thinner PVC portion adhered onto the top in order to create a surface that is easy to clean. The bottom wood section has three walls extending vertically from three of the sides, with the side facing the foot section missing a wall. When the top PVC section is placed onto the top, this creates a 'slot' in the front. This slot is where the foot section will be inserted when the table is folded.

On each side of the wooden section, there is a slot that runs lengthwise. This slot will have a bolt inserted through it and into the foot section. This assures smoother sliding in and out of the middle section. It is 0.48 m wide and 0.48 m long. Figure 37 below shows an exploded view of the middle section with various parts labeled.

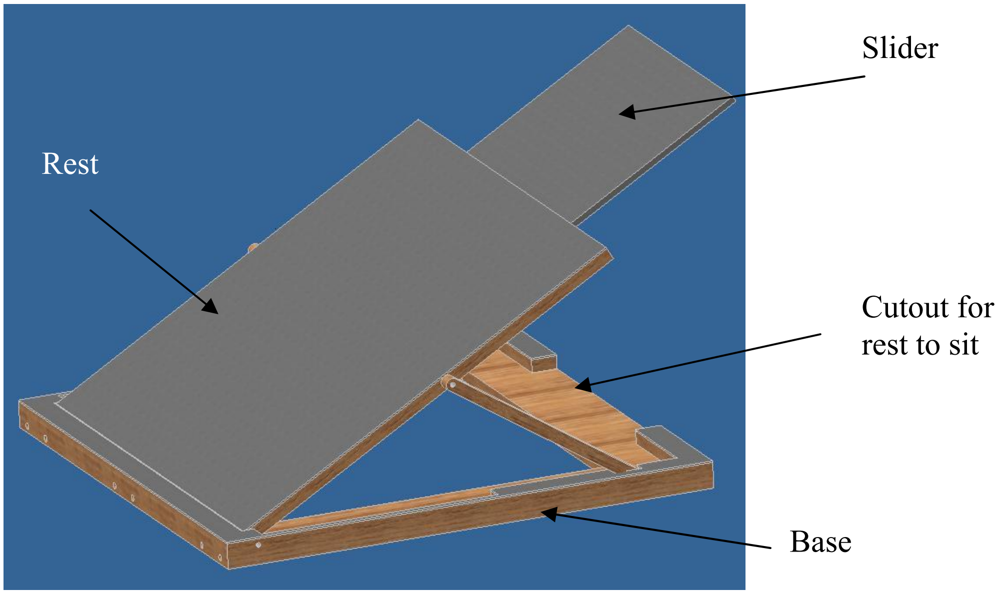
Figure 37: Exploded view of middle section



10.2.3 Head Section

The head section is made up of two parts, the base and the rest. Figure 38 on page 40 distinguishes between the two parts. The base allows us to have a sturdier design with a lower center of gravity. On the base there is a cutout with a ‘ledge’ that allows the head section to sit on when the table is in the supine position. The rest is where the woman will be laying her upper body and head. Underneath the head section, there is a small section that can be slid out in order to support the woman’s head. This design created smaller folded dimensions than the Alpha design. As with the other sections that contact the woman’s body, all parts of the head section are made with a birch base and a PVC top. The rest is adjustable to different angles in respect to the base. The angle adjustment mechanism will be outlined in section 11.5. The head section will be connected to the middle section with store bought hinges. These hinges will allow the head section to rotate 180 degrees.

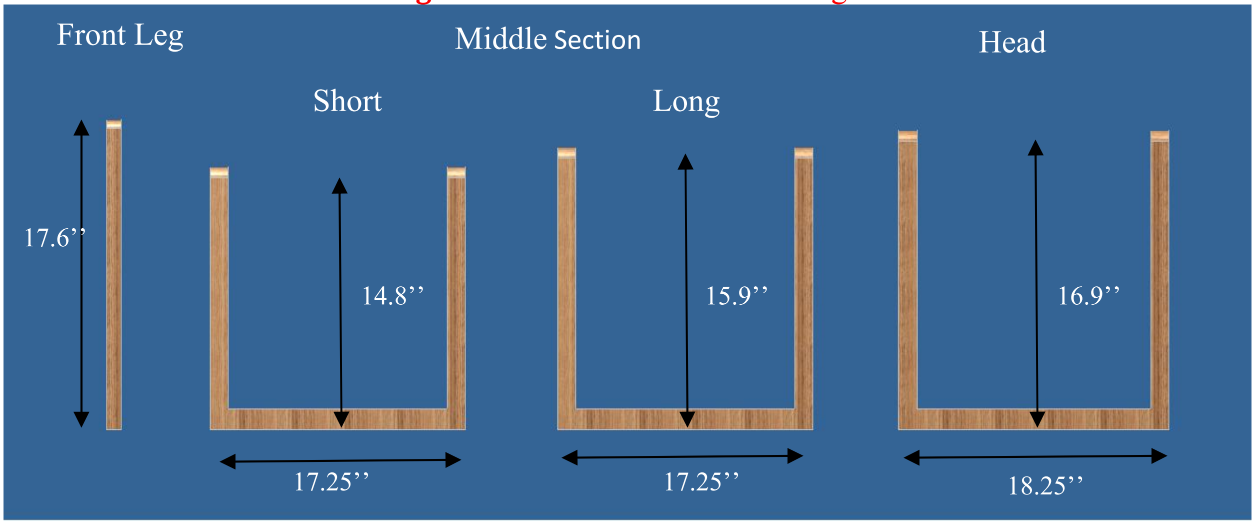
Figure 38: Head Section with labeled parts. Note PVC adheres onto Birch Plywood.



10.3 Legs

This section outlines the various legs of the table. There are four different types of legs on our table: foot rest legs, long middle leg, short middle leg, and head section leg. Figure 39 on page 41 outlines the important difference in dimensions between the various legs. All legs are made from birch wood.

Figure 39: Dimensions of table legs



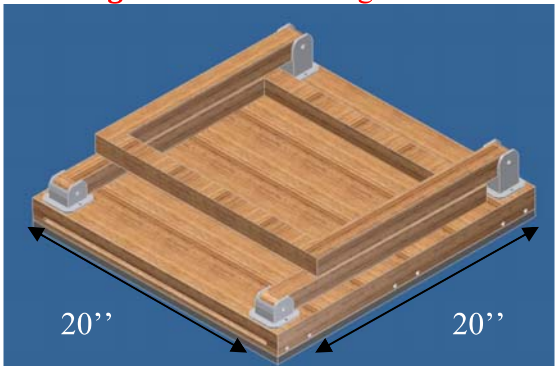
10.3.1 Front Leg

There will be two front legs placed onto both sides of the foot section. When the table is completely unfolded into the supine position, the foot section is pulled out and the front legs are placed down onto the ground. During the exam and folding, the front legs are brought up parallel to the foot section and slid into the middle section. The cross section of the front leg is 1 x 1 inch to ensure that they can fit into the middle section.

10.3.2 Middle Legs

Due to the fact that the legs of the middle section are located on the sides of the middle section, there is interference between the two legs when they fold in. Therefore, it was necessary to design an extension on one side of the table. The shorter of the two middle legs will be placed onto this extension. When the legs are extended, the shorter legs on the extension create a table that sits flat. Also, when the legs fold in, one leg folds in flat against the table, and the other leg folds in on top of the other. This is demonstrated below in Figure 40 below. The middle section legs are both U-shaped with a solid square cross section and made of birch wood. Their cross section is 1.25" x 1.25".

Figure 40: Middle legs folded



10.3.3 Head Section Leg

The head section leg is also U-shaped with a square cross section. The cross section of this leg is 1.25" x 1.25". When folded in, a simple store bought cabinet magnet will secure it from falling open.

10.3.4 Attaching Legs to the Table

In order to attach the legs to the table, we have considered different options. Our Beta design will utilize T-hinges in order to attach the legs to the table. Each leg will require two hinges which are made of steel and have been tested in a bleach/water solution for 72 hours. When removed from the solution no corrosion was observed on the hinges. Table testing will be discussed in more detail in section 20. Figure 41 below displays a T-hinge which we will be using.

Figure 41: T-hinge

10.4 Back Angle Adjustment

This sub-system allows the head rest to be adjusted at different angles and has not changed since the Alpha design. This is achieved by having notches in the head base, at two different positions to allow for angles of 30 degrees or 60 degrees inclined. Adjustment rods that are attached to the head rest extend from its sides into the notches on the head base to securely hold the rest up at an angle. The head base also contains small slots in which the rods are able to sit when the table is in the supine position. The Law of Cosines was used to determine the position of the notches on the base in order to achieve angles of 30 and 60 degrees. The back angle adjustment sub-system is presented in Figures 42a-b below. The adjustment rods will be made from birch wood.

Figure 42a: Inclined back angle

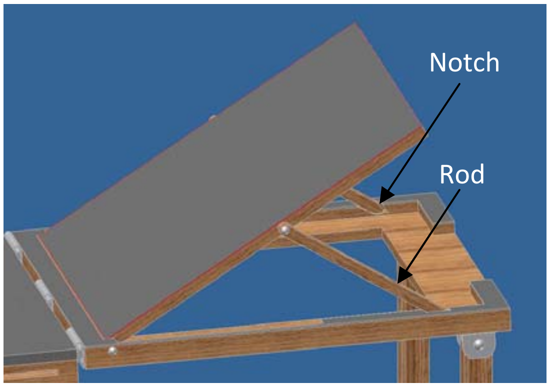
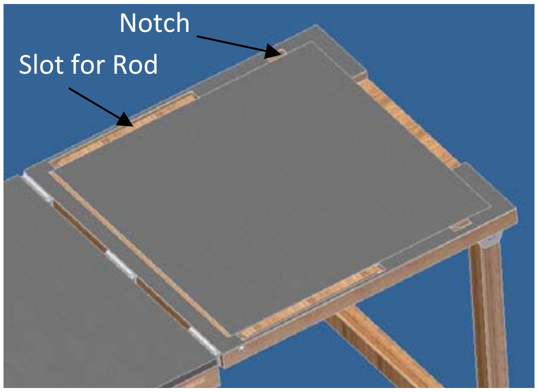


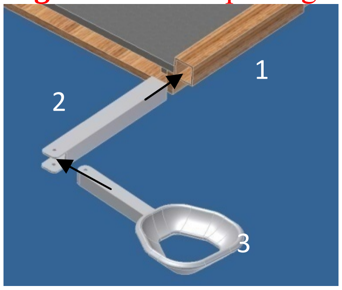
Figure 42b: Back angle in supine



10.5 Stirrups

The stirrups have remained the same since the Alpha design. Our design has the stirrups being attached to the middle section. Figure 43 below shows how this sub-system is put together. On each side of the middle section there is a rectangular tube (1) that is attached using several fasteners, or could possibly even made as part of the middle section. Another straight rectangular tube section (2) will be slid into the tubes on the side of the middle section and fastened using either a thumb screw or wing nut. The lengths will also be extendable to allow for different length legs using a rod mechanism. At the end of the extending tube, there is a hole in which a hinge will be inserted. This hinge will also be inserted through the final piece, which is the stirrup cup (3). The final piece consists of the stirrup, and a short rectangular tube section which is attached to the extended piece (2). The stirrups have 2 degrees of freedom, translation along the length and rotation about the table to allow for different stirrups angles. This component was not fabricated in the Beta prototype because we were still working on how to make the stirrup angles adjustable. However they will require a great deal of attention in the Omega design as they will experience the largest bending forces.

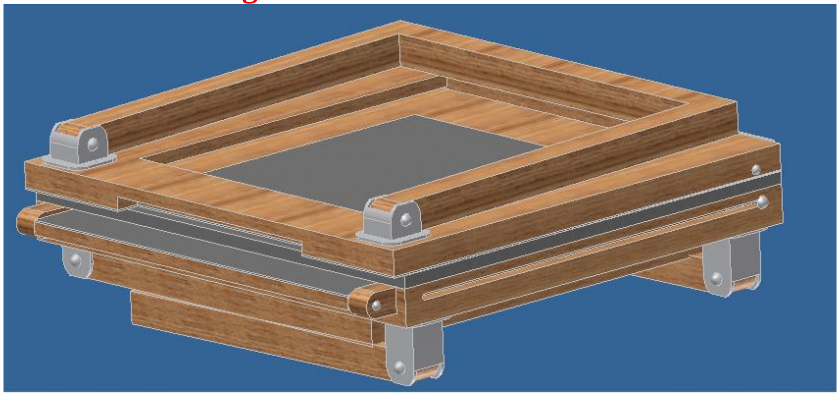
Figure 43: Stirrup design



10.6 Folding Process

The folding process has changed since the Alpha design. The folding process begins by rotating the front legs upwards, so that they are next to the foot section. Once the front legs are put in this position, the foot section and legs can be slid into the middle section. Next, the head section is put into the supine position with the adjustment rods in their slots. The head section legs are then brought up and the head section is rotated so the PVC is lying flat against the PVC of the middle section. Once here, the head and middle sections are locked together with a latch to prevent opening. Then the middle legs are brought in and the folding is completed. Figure 44 below shows a CAD model of our Beta design in its folded position.

Figure 44: Folded CAD model



10.7 Advantages and Disadvantages

There are many advantages of our Beta design and some improvements upon the Alpha design. First, the table is able to accommodate not only a gynecology exam, but also any other type of exam that can be done with the patient lying down in the supine position. Also, the table has the adjustable back angles. This is a big advantage as we have mentioned before that having the women sitting up during exams allows for her to feel empowered. The folded size has been reduced greatly from the Alpha design, allowing it to be more easily transported on the back of the community health care worker. Also, the middle legs are wider, which allows for a sturdier base. Furthermore, since much of the Beta design is wood, it can be manufactured for less than $70 which is much less than the $300 budget, less than then $100 goal and less than if the table were made of Aluminum. Furthermore, wood is readily available in Ghana, especially Ceiba wood which has similar properties to birch wood, making the table easy to manufacture and repair in-country.

These design changes also have a few disadvantages. Because the table is made of wood, it's lifetime will not be as long as a metal table and will potentially be more absorbent than metal. However, we feel that replaceable parts will increase the longevity of the Beta design. Also to solve the problem of absorption, we plan on using a coating and sealant. Another disadvantage is that the table may become too heavy by using wood. However, if this is the case, we are already considering solutions to this problem. We may be able to change sizes of certain pieces, or even make them out of a different material.

For all these reasons, our table will meet all of the engineering specifications and customer requirements. No component or system on our table is too complicated to use or fabricate, and our Beta prototype shows that the systems can support the loads necessary with the exception of the stirrups since they were not fabricated in the Beta prototype. Our engineering analysis and testing on the prototype show that our table shouldn't fail under our determined engineering specifications. Along with this, the table is able to fold up into a size that is easily portable. However, we can always improve on our design which we continue to do every day and is leading us into our Omega design. We will continue to improve on the size and weight of the table.

11.0 ENGINEERING ANALYSIS OF BETA DESIGN

To finalize our Beta design, we employed engineering equations to validate our design and material selection.

11.1 Buckling in Legs

After choosing birch wood for our leg material, we wanted to determine the critical buckling load of our legs. Using Equation 3 below, we entered the Young's modulus of birch and used the dimensions of our design to determine the remaining values.

$$P_{cr} = \frac{\pi^2 EI}{L^2} \qquad \text{Eq. 3}$$

We obtained a critical buckling load of 1335.5 lbs for one leg, a value much greater than the expected extreme maximum 313 lb load. With a factor of safety greater than 4, we are confident that our legs will not buckle under the load of a patient.

11.2 Stress on Middle Section

To make sure that the middle section would not yield under the load of the patient, we analyzed the bending stress caused by a point force equal to 313 lbs (the maximum weight of a patient) located in the middle of the middle section. This configuration yields the highest bending moment on the outer edges of the material, and could be equated to a person standing upright in the middle of the table. Using Equations 4 and 5 below, we set the stress equal to the yield stress of birch wood and solved for the force.

$$\sigma_y = \frac{My}{I} \qquad \text{Eq. 4}$$

$$M = Fr \qquad \text{Eq. 5}$$

This gave us a force of 1149 lbs, which is the weight at which the section will yield. Since the greatest force that could be present is 313 lbs, we concluded that the middle section will not yield.

Along with this we wanted to determine the effect of impact in case the woman doesn't set herself on the table as softly as desired. For this, we determined the energy of a woman falling right before she hit the table, then divided this energy by the distance it takes her to decelerate. For the middle section, we determined the impact force of a 313 lb woman falling from 3 inches. The 3 inch height was determined through deliberation as we figured this would be a general height a woman might drop from if she underestimates how far she has left to go before hitting the table. Using the general kinetic energy equation, Equation 6 below, we were able to determine her kinetic energy just before hitting the table.

$$KE = \frac{1}{2}mv^2 \qquad \text{Eq. 6}$$

Where *m* is the woman's mass and *v* is her velocity just before hitting the table. The velocity was determined by assuming an object starting from rest from three inches. Once we've determined her kinetic energy, we divide that by the distance it takes her to decelerate. The woman's buttock is what will be slowing her down. It was difficult to find data on the thickness of the buttocks, so we assumed a thickness of 1.5 inches including the table bedding. With all this data we determined an impact force of 624.2 lbs. The impact force added with the load force falls within the 1149 lbs of possible support.

11.3 Bending on Stirrups

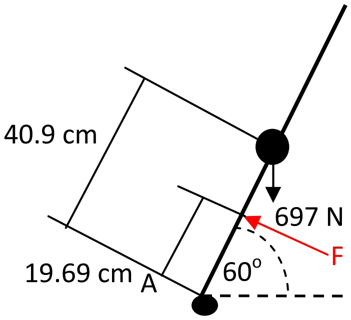
During an exam, the stirrups must support the weight applied by the patient's legs. Also, the patient may adjust them self during the exam which will add an impulse force to the stirrups. We wanted to make sure that the stirrups would not yield under these stresses. Therefore, we analyzed the bending stresses present during an exam. When adjusting themselves, the patient will put a force on the end of the stirrups in order to lift them self off the table so they can reposition them self. Therefore, we equated the maximum force that would be applied to the stirrup to the maximum weight of a patient, 313 lbs (as if she were standing on the stirrups). It should be noted that this is an overestimate, since the patient will most likely distribute half of their weight to each stirrup and other portions of their weight on the table sections.

Using Eq.'s 18 and 19 on page 43 and setting the stress to the yield stress of PVC, we found that the stirrups are each capable of supporting 680 lbs. The stirrups are capable of supporting more than twice as much as our exaggerated projected force. We concluded that the stirrups will not yield under operating conditions.

11.4 Adjustment Rod Compressive Stress

When the back rest is at an angle, the weight of the patient's torso is completely supported by the two adjustment rods. Due to the size of these rods, we weren't sure if birch wood would be a strong enough material to make these out of. Therefore, we analyzed the compressive stress on the adjustment rods when the back rest is at an angle of 60^o, and our maximum-height-and-size patient is resting on the table (when the adjustment rods support the most weight). A model was created in order to quantify the forces on the adjustment rods, and can be seen in Figure 45 below.

Figure 45: Modeled forces on adjustment rods



Using this model, we performed a moment balance about point A. This yielded a force F equal to 1254.2 N, which translates to a reactionary force of 627.1 N for each adjustment rod. Then, using Equation 7 below, we found the compressive stress in each adjustment rod to be 3.89 MPa.

$$\sigma_c = \frac{F}{A} \qquad \text{Eq. 7}$$

Looking at the material properties of birch wood in CES, we found that the minimum compressive strength of birch wood is 9.72 MPa. We then concluded that it was safe to make the adjustment rods out of birch wood, as there is a factor of safety of 2.5 for the compressive stress of the components.

11.5 Adjustment Rod Buckling

Since we determined that the compressive stresses present on the adjustment rods were not a significant concern, we went on to analyze the buckling effects on the adjustment rods. Using the buckling equation (Equation 17), we entered the Young's modulus, the moment of inertia, and the dimensions of the adjustment rods. We found that the adjustment rods were capable of supporting 3200 lbs each, while the greatest load they could bear is 313 lbs (the entire maximum weight of the patient). We used 313 lbs to account for any impulse forces created by the patient shifting their weight or falling back on the back rest.

For this section we also wanted to considered impact force. For this section we again assumed a direct force on the rod being dropped from 3 inches. This was determined through deliberation as we figured this is a height a woman may let up and let her back fall onto the back rest. For this we assumed an object being dropped straight down from 3 inches for ease of calculation. However, it is important to note that this will give us an even greater impact force than a woman leaning back. So if these calculations meet the requirements, it is even better than the actual impact force.

So using the same process as we did before to calculate impact force, we found that her force will be around 926 lbs. This is found with a stopping distance of 0.5 inch. This is assuming a table thickness of 0.4 inches and skin thickness of 0.1 inch. However, this is much smaller than the max force of 3200 lbs, so we are safe from impact forces.

11.6 Effect of Climate Change on Materials

Our design's portability resides in its ability to fold and slide together. Since Ghana's climate is much warmer than that of Michigan, we calculated the effect of thermal expansion to ensure the table will still work in a warmer climate. After doing some research, we found that temperatures in Ghana reach to 32^{o}C ("Ghana," par. 1) in the warmest months and the temperature in the shop is approximately 15.6^{o}C. Also, we used CES to find the thermal expansion coefficient for birch wood (4.29e-5 strain/^{o}C). Next, we decided to analyze the foot rest and foot rest sections first. These sections were chosen due to the fact that they must fit inside of the middle section for the table to fold correctly, thus changes in their dimensions could greatly affect the functionality of our table.

Using Equation 8, we found the strain caused by thermal expansion to be 7.036e-4. Then, we found the change in length, width, and height of the foot section legs and the change in length and width of the foot section using Equation 9. The results can be seen in Table 8 and 9 below.

$$\varepsilon = \alpha(\Delta T)$$ Eq. 8

$$\Delta L = \varepsilon * L$$ Eq. 9

Table 8: Results of thermal expansion analysis on Foot Section

Foot Section			
Length	20"	ΔL	1.41E-02"
Width	17"	ΔW	1.20E-02"
Height	0.5"	ΔH	3.52E-04"

Table 9: Results of thermal expansion analysis on Foot section Legs

Foot Section Legs			
Length	18.125"	ΔL	1.28E-02"
Width	1"	ΔW	7.04E-04"
Height	1"	ΔH	7.04E-04"

Our results showed us that the largest single change in dimensions induced by thermal expansion was 1/71". Also, the total change in width of the entire foot section assembly is equal to 1/75". Therefore, we concluded that the effects of thermal expansion on our design are negligible.

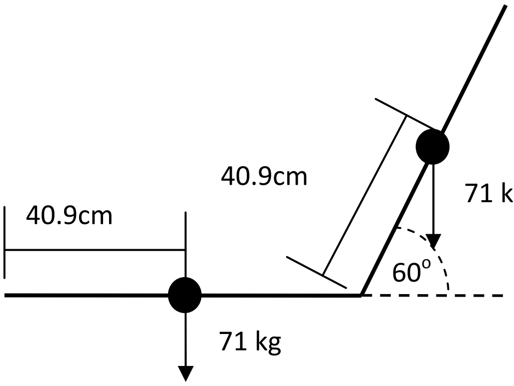
11.7 Center of Gravity/Stability

Another major concern for our design is the stability of the table. This becomes an issue when a patient is lying on the table and the center of gravity (c.g.) height of the patient-table system is highest. In particular, the system's c.g. height will be highest when the head board is at its maximum inclination of 60°. First, we found the c.g. height for the table (17.35 in.) by using Equation 10 below.

$$H_{CG} = \frac{\Sigma(y_{cg} * m_{cg})}{\Sigma m_{cg}} \qquad \text{Eq. 10}$$

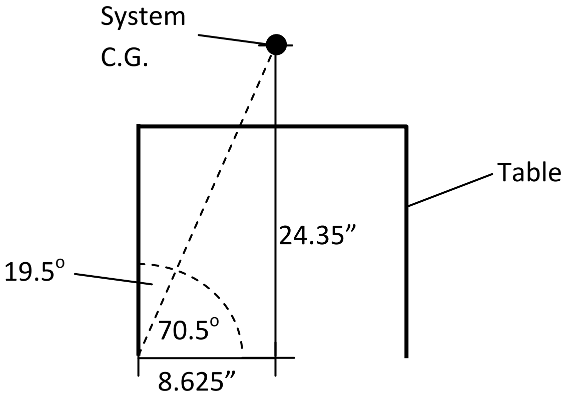
Next, we had to find the center of gravity of the tallest, heaviest patient we are building the table for, which is a 163.6cm tall, 142kg patient. Since this is a gynecology table, our patients will be women. A woman's center of gravity is located around the pelvis due to females' weight distribution ("The Thoren Theory," par. 4-5) so we can approximate that half of her weight is in each half of her body. Next, we made a diagram of the patient sitting on the inclined table (Figure 46 below), approximating that the center of gravity of her legs and torso is half way, and used Equation 10 to find the patient's c.g. height (6.97 in. above the tabletop).

Figure 46: Mathematical model of patient on 60° incline



Next, the center of gravity height of the patient-table system was found to be 24.35 in. With this value, we were then able to see how far the table would have to tip in order for it to fall over. Using the system c.g. height, the width of the middle section legs, and trigonometry, we determined that the table would have to tip beyond 19.5° for it to start to fall over (see Figure. 47 below).

Figure 47: Mathematical model of system c.g. location



11.8 Bolt Shear

The biggest concern with wood is that the wood will fail before any screws, bolts, etc. Therefore, we want to make sure that the bolts do not create a shear stress that is large enough to crack the wood. For this analysis, we focused on the middle section of the table since it will support most of the patient's weight. Of the screws holding the middle section together, 4 of them will be subject to shear forces from the patient's weight. Since the screws are stronger than the wood, they will transfer this force to the wood. We know that each screw goes all the way through the side pieces of the middle section, and so we analyzed the stress with Equation 11 below.

$$\sigma_\tau = \frac{F}{4A} \qquad \text{Eq. 11}$$

For the force, F, we used the weight of the maximum weight of a patient (313 lbs), and the area is the cross-sectional area between the screw and the wood (the area of contact). The results yielded a shear stress of 1.40e5 Pa. Compared to the shear strength of birch (5.79e6 Pa), we see that wood tearing is not a significant risk.

12.0 BETA PROTOTYPE DESCRIPTION

The purpose of this section is to provide a detailed description of the prototype and explain how it will help further our design process.

12.1 Prototype size

The Beta prototype that we have built is a full scale model. Originally we had planned to construct a half-scale model due to budget and material constraints. However, once we decided upon our final materials, it was cheap and easy to purchase our materials at a lumber yard (Fingerle Lumber located in Ann Arbor, MI) and hardware store (Lowe's Home Improvement located in Ann Arbor, MI.) Therefore we decided that it would be more advantageous to build a whole scale model for the purpose of testing.

12.2 Differences from Beta CAD

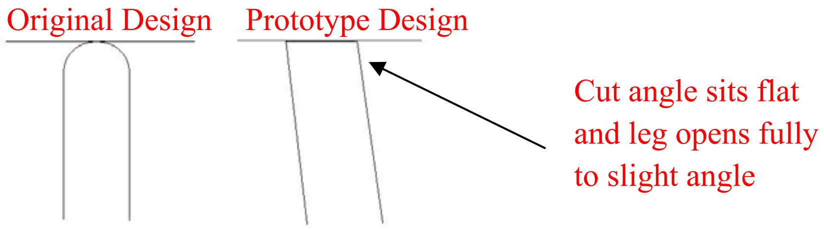
When building the prototype we wanted to keep it as close to the Beta design as possible. Though the main aspects of the table remained the same, there were some changes that arose due to manufacturing and testing reasons.

12.2.1 Leg Changes

Our Alpha design had legs that were rounded at the top. The purpose of the rounded top was to allow for cleaner rotation in the legs. However, while attaching the legs to the bottom of the table with the T-hinges, it was discovered there was no need for the rounded tops as the T-hinge lifted the legs as it rotated it. For this reason, we removed the rounded tops during the manufacturing process. There were actually advantages to this design change. By doing this we removed the need for L-brackets to prevent the leg from rotating past 90 degrees. Also, this adds more contact between the legs and the bottom of the table adding strength and stability.

Even more changes were added to the legs during testing of the device. After putting on the legs and doing a quick test, we realized that the table had a slight instability. We decided that to fix this, we could cut a slight angle at the top of the legs to have them open slightly farther than 90 degrees. By doing this, the weight of the woman will hold the legs open and prevent instability. The downside to this is that it adds a bending stress to the legs. Figure 48 below outlines the changes in the legs.

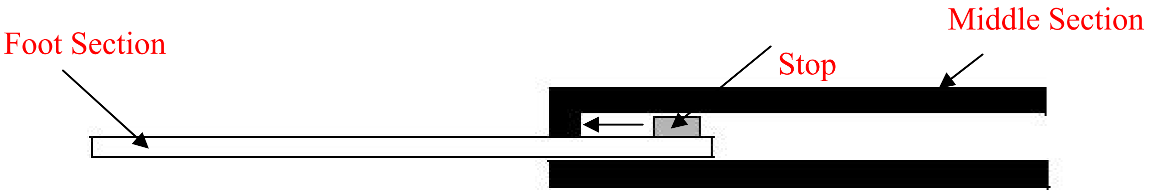
Figure 48: Original and Prototype design of the legs



12.2.2 Middle Section Changes

There were a couple changes made to the middle section during manufacturing. On the Alpha design, there are slots on both sides of the middle section. A bolt was to be put through this slot into the foot section in order to allow it to slide. However, we've decided that this slot creates unnecessary weakness in the middle section. Because of this, we will remove the function of this slot. However, we still needed a way to stop the foot section from sliding all the way out. In order to do this, we added a vertical addition to the end of the foot section and a stop at the opening in the middle section. This vertical addition on the foot section will hit the stop on the middle section to prevent it from sliding out. Figure 49 below displays how this will work.

Figure 49: Stop to prevent foot section from sliding out completely



We tested the middle section by adding weight to it and noticed that there was slight deflection in the middle section when weight was loaded on it. Therefore, we decided it was necessary to add reinforcement to the middle section to prevent deflection. In order to do this we added a rod in the middle of the middle section between the top and bottom pieces. This created another constrained resting point for the top piece of the middle section to help prevent the deflection and help support the loads. Now the load is distributed between 3 constrained points as opposed to 2. Originally the rod would get in the way of the foot section when sliding in. Therefore, we cut a slot into the foot section so that it could slide around this rod.

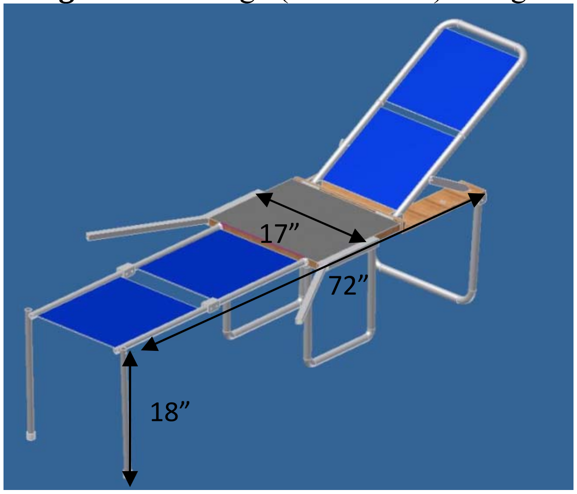
12.3 Beta Prototype Testing

Now that we have a completed Beta design prototype we are able to test the most important specifications of our design. First of all, we will be able to conduct weight bearing tests. The section that will hold the most weight is the middle section, so for purposes of this study, we want to make sure this section alone will be able to hold all the weight we want, 313 lbs.

13.0 OMEGA (REVISION A) DESIGN DESCRIPTION

The following section gives a complete description of our Omega (Revision A) design. The changes between the Omega (Revision A) and Omega (Revision B) are outlined in Appendix C. This design is made of mostly aluminum with some wood added for support as shown in Figure 50 below. All the aluminum in this design is planned to be recycled aluminum to save cost.

Figure 50: Omega (Revision A) Design



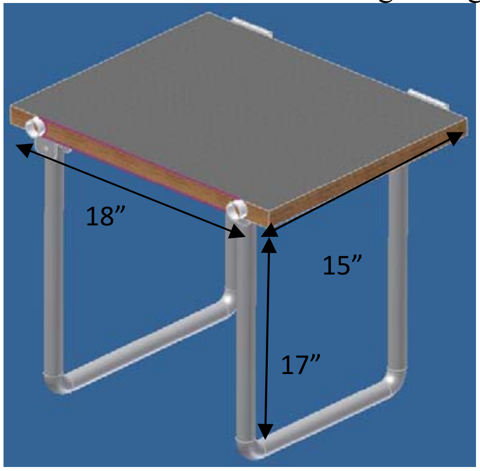
13.1 Table Sections

As in all of our previous designs, the Omega design has three main sections. The foot section, middle section, and head section. This section will describe how each section functions as well as the changes from Beta design.

13.1.1 Middle Section

Any change that is made to this section affects the other two since everything connects to the middle section, so we will describe this section first. The final middle section is presented in Figure 51 on page 53.

Figure 51: Middle section of the Omega design



The middle section provides a base of support for the foot section and the head section. In the Beta design, the middle section was hollow and the foot section slid out from the hollow center.

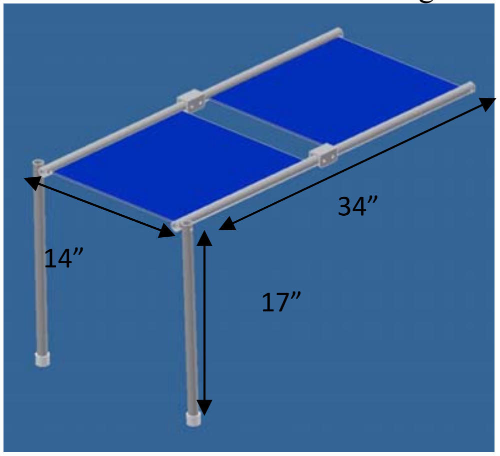
However, for the Omega design, the middle section is a solid piece of wood. The foot section attaches to two pieces that extend out from the front of the middle section. The head section attaches to the middle section the same as it did for the Beta section, using hinges. Three simple hinges will be placed that attach the head section to the middle section, allowing it to rotate freely to open and close.

For ease of cleaning, a thin layer of PVC will still be adhered on top of all wooden sections. This will also give the table a more aesthetically pleasing look and smooth the surfaces. By changing the hollow middle section we are increasing the strength of the middle section.

13.1.2 Foot Section

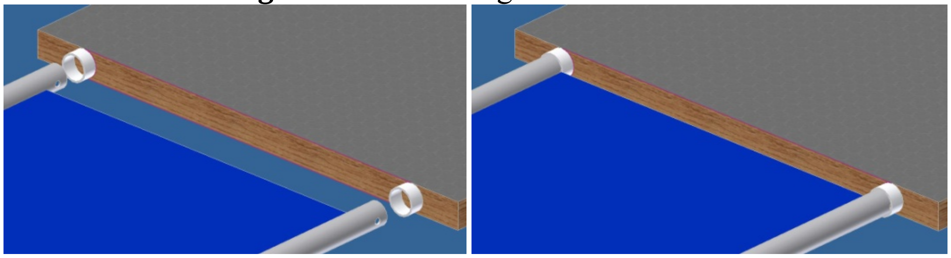
The foot section has undergone some major changes since the Beta design. The final foot section is presented in Figure 52 below.

Figure 52: Foot section of the Omega design



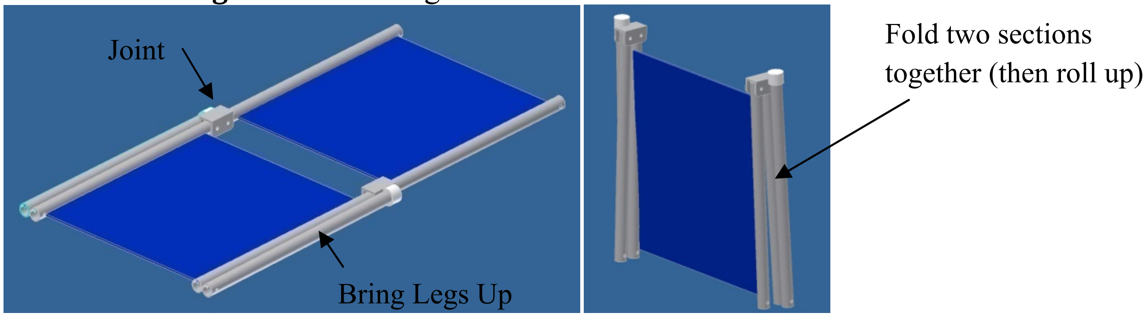
As mentioned before, in the Beta design, the foot section slid out from the middle section and was made of solid wood. Because the length of the middle section was reduced to 15 inches, the sliding design in the Beta design would produce a foot section that was too short in length making the entire length of the table too short. This is the reason for the design change. The Omega design it is made from recycled aluminum frames with fabric stretched between the frame. In the Omega design, the foot section can be attached and detached quickly and folded up separately from the rest of the table. Figure 53 below shows how the foot section is quickly attached to the middle section. There are two rubber slots that extend out from the middle section where the foot section frames can be inserted. The foot section is simply pressed into these rubber slots and held in place with a press fit.

Figure 53: Attaching the foot section



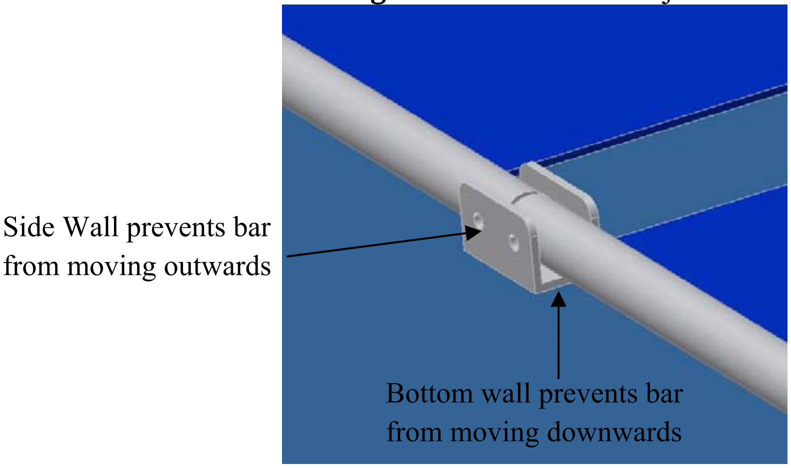
The new foot section design also allows for it to be 'rolled up' into a much smaller folded design. Also, when the foot section extended is 34 inches long, this adds greatly to the length of the table. Therefore, we not only increased the size of our unfolded design, but we decreased the folded dimensions. Figure 54 below displays the folding process involved with the foot section.

Figure 54: Folding the foot section



The joint that attaches the two sets of frame bars together plays a very important role. This joint will prevent the frame from dipping in the middle. Along with this, the joint will prevent a movement from side to side. By having this joint, it allows for a much studier frame while still allowing for the foot section to be rolled up. Figure 55 displays the movement restriction this joint creates.

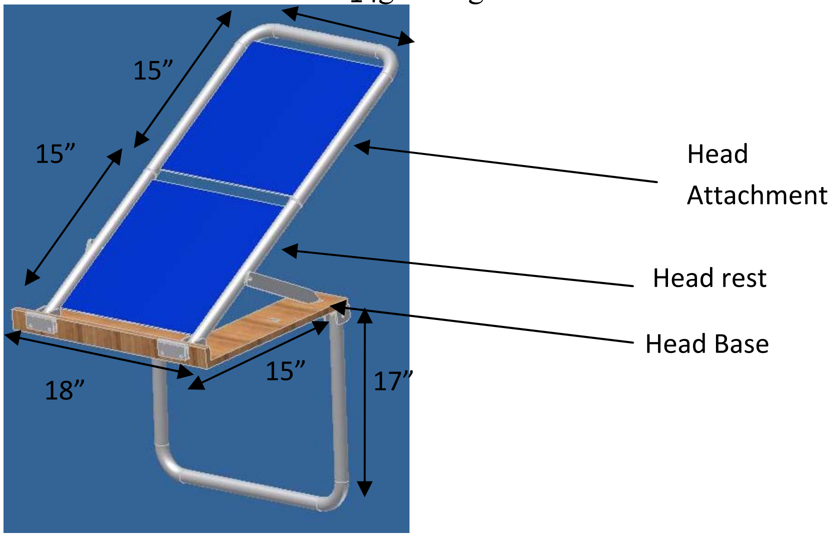
Figure 55: Foot section joint



13.1.3 Head Section

The head section has become much simpler since the Beta design. Our final head section is displayed in Figure 56 below.

Figure 56: Head section of the Omega design.

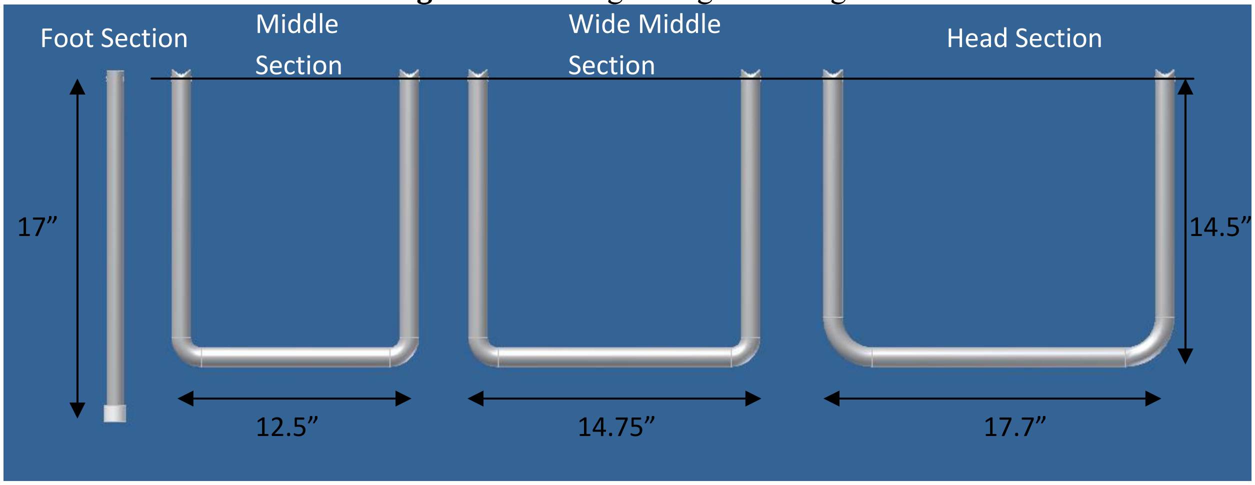


The base has remained wood as in the Beta design. However, we did remove some wood on the design to make it lighter. In the Beta design, the head section and head section base was a wooden section with a piece that slid out from underneath to support the head. However, since the middle section length was reduced, the Omega design would not create a head section that was long enough otherwise the head and middle section would not fold flush. Therefore we had to redesign. Like the foot section, the head rest is now an aluminum frame with fabric stretched between. There is also a head attachment that is a U-shaped aluminum frame with fabric stretched between. This section is removable and can be stored. Because of this, we can have the head section attachment be as long as the middle section, or 15 inches. This will give us a total head section length of 30 inches. The addition will be placed onto the head rest by placing it around an insert that sits inside the hollow frame of the head rest.

13.2 Table Legs

The table legs have gone through some major design changes as well. In the Beta design, the legs were made of solid square sections of wood. The Beta design legs were U-shaped (with exception of the foot section legs), but were square at the corners. The Omega (revision A) legs, as mentioned before, are recycled from lawn chairs. Therefore they will be a hollow, circular cross section and made from corrosion resistant aluminum. This will allow us to save cost and decrease weight. The legs will be U-shaped but the corners of the Omega design legs will be rounded as opposed to square. Figure 57 shows the differences between the legs of different sections.

Figure 57: Omega design table legs



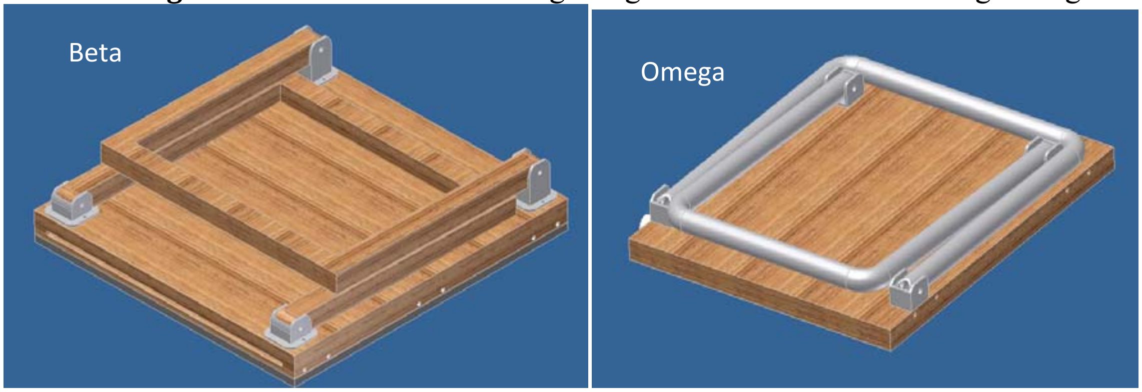
13.2.1 Foot Section Legs

The foot section legs are simply a rigid straight hollow aluminum bar. This bar will be attached to the end of the foot section and provide all of the support of the frame. This is possible by having the foot section joint described above. On the foot section legs, we have attached small rubber caps that will help restrict the motion of these legs. Refer to Figure 57 for table leg dimensions.

13.2.2 Middle Section Legs

Another major change since the Beta design is how the middle section legs close. For the Beta design, we had one leg attached to a joint that was slightly raised from the base of the middle section. This would allow it to close on top of the other. However, we decided that we could reduce the dimensions if we made one leg wider than the other. This way, the wider leg would fold around the narrower leg and reduce the thickness of the middle section when folded. Figure 58 shows the evolution from Beta to Omega design in how the legs fold.

Figure 57: Difference in folding designs between Beta and Omega designs



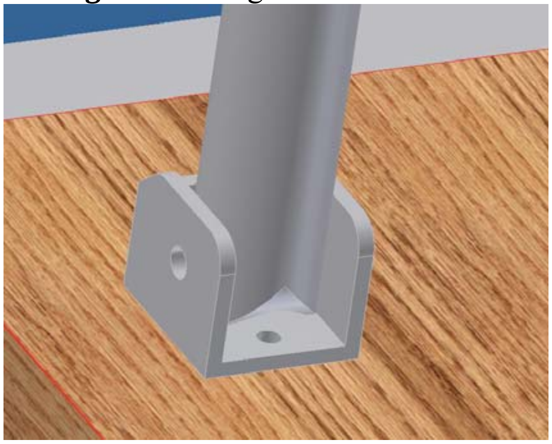
13.2.3 Head Section Leg

The head section leg has the same shape as one of the middle section legs. It is a U shaped circular hollow cross section. As with the middle legs, it will open to 90 degrees and will fold in flat against the table.

13.2.4 Attaching the Legs to the Table

For the Omega (Revision A) design, we will attach the legs to the table with a similar design to the joint presented in Figure 58.

Figure 58: Leg Joint Attachment

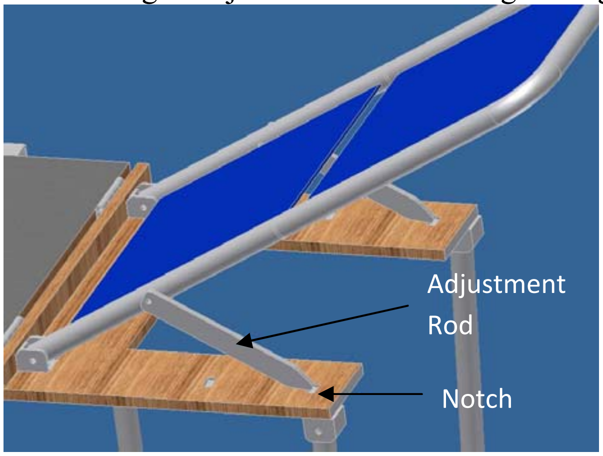


We will fabricate this joint, however, there is the possibility that we may use a joint found on a lawn chair. If we are able to recycle a joint from a lawn chair that works, we will do this as it will save money and time.

13.3 Back Angle Adjustment

As in the previous designs, this sub-system will allow the head rest to be adjusted to the angles of 30 degrees and 60 degrees (with respect to the head base) as well as the supine position. The back angle adjustment for the Omega design follows a very similar design as the Beta design. On the outside edges of the head base frame, there will be two independent adjustment rods that when needed, are inserted into metal lined slots on the head base. The positions of these slots were determined using the Law of Cosines in order to hold the head rest up at the needed angles. The adjustment rods are made of aluminum. When in the supine position, the rods will simply sit next to the head rest frame, not interfering with any other component. Figure 59 below displays how the back angle adjustment system will operate.

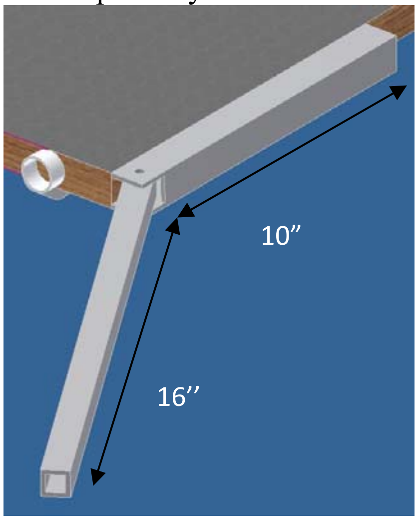
Figure 59: Back Angle Adjustment for the Omega Design



13.4 Stirrups

The stirrups have also had a design change since the Beta design. In the Omega design, there will be a hollow housing on the side of the middle section. However, in this design, the side walls will be cut away at the end of the housing. Along with this, there will be a vertical hole drilled at the end. The second main part of the stirrup design is a 16" hollow, straight square section with a hole at the end. This section will be inserted into the housing on the side of the middle section, and a pin will be inserted through both, holding the insert in place but allowing it to rotate. This will allow us to achieve angles all the way from 0 to 90 degrees. Figure 60 below displays how the stirrup system will work.

Figure 60: Stirrup sub-system for the Omega design



13.5 Folding

The folded design of the Omega (Revision A) design has been reduce since the Beta design, however, the folding process has also become slightly more complicated. The first step involves removing the stirrups. In order to remove the stirrups, the pin that holds the insert in place is removed, and the stirrups are simply folded and set aside. Next, the foot section is removed. To remove the section, the frame is simply pulled out from the rubber inserts on the middle section. Then the legs are folded in parallel to the frame, and the two sections of frames are folded together. This will create two bundles of three bars, held together by fabric. These two bundles are rolled together and fastened. The bundles are set aside with the stirrups.

From there the head addition is removed and also set aside. Then the head rest is placed in the supine position, and the head section is rotated until it is sitting on top of the middle section. Then the head section legs are folded down, the middle section legs are folded in and the folding process is completed. Then this is put into the travel pack along with the stirrups, foot section, and head rest addition. The folding process is presented in Figure 61. The rolling of the foot section cannot be modeled in CAD, but is described above is section 13.1.2.

Figure 61: Omega (Revision A) Design folded

13.6 Advantages and Disadvantages

There are many advantages to our Omega (Revision A) design. Most importantly, the weight has been reduced, by using the hollow aluminum frames and fabric in place of wood. Along with this, the unfolded dimensions have gotten bigger, while decreasing the folded dimensions. Our new foot section and head section designs have allowed for us to greatly increase the length of our table. The width has been decreased; however, it will still be able to accommodate the average women from Ghana. Also, the foot section detachment, as well as the head attachment allowed us to reduce the folded size. The reduced weight and folded size allows for a table that is much easier to carry.

The fabric sections provide comfort to the patient. With the Beta design, we would have needed to buy separate cushioning/bedding to place over the harder wood. However, with the Omega design, the fabric itself already has a certain level of comfort. The fabric is very easy to make in Ghana and similar fabric can be found there to use for in country manufacturing. Along with this, the aluminum frame provides for a stronger frame. The metal frame will create a stronger, longer lasting frame to replace the wood of the Beta design.

Another advantage is that the table will be very easy to manufacture. By keeping the design of the table simple, we will not need any complex machinery to build the table. We plan on using nothing more than a band saw and drill press to construct components of this table. In addition to this, by using recycled parts we greatly reduced the cost it takes to build our model. We are also hoping that this will translate into easier in country manufacturing in Ghana. It is possible that they will be able to use similar recycled parts there to build these models. If not, it is just as possible to make the aluminum frames and seam the fabric. Furthermore, the recycled parts and simple design allow for easy repair of broken parts.

Despite all the advantages, there are some disadvantages to the design. By not using wood, the likelihood that this product will be easy to manufacture in country has decreased. Wood would be the best product to use for in country manufacturing as it is abundant Ghana. Ceiba wood is a common wood found in Ghana and has similar properties to Birch wood. Along with this, the fabric may not be the easiest material to clean, and it may rip or tear easily during travel or exams. However, it should be easy to repair or replace in country. Another disadvantage is that the Omega design has many components including ones that are detachable. This increases the time it takes to assemble the table on site, and makes it a little more difficult to use.

14.0 FINAL OMEGA (REVISION B) PROTOTYPE DESCRIPTION

The purpose of this section is to describe the final Omega (revision B) prototype which is very similar to the Omega (revision A) design. The Omega (revision B) design is the design that was prototyped.

14.1 Omega prototype Size

The final prototype was built to full scale. This is of course so that the table can actually be used and tested in Ghana. The full scale Omega prototype easily holds a woman up to 72 inches in height, and 18 inches in body width.

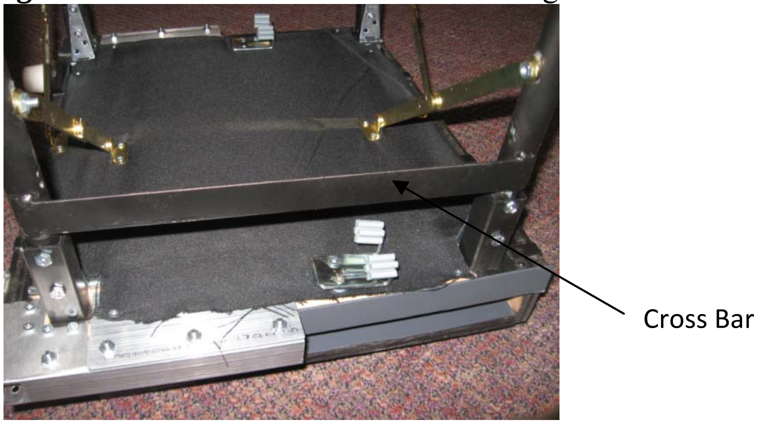
14.2 Adjustments during Building

During the construction of our final Omega prototype, it was necessary to make some adjustments to the final design. These adjustments added on to the Omega (Revision A) design and were mainly for the purposes of stability and to increase table strength. Many of these adjustments are outlined in Appendix C, however the reasoning for each change is outlined in this section.

14.2.1 Cross-Bars on the Middle Section Legs

Because we simply removed legs from lawn chairs and attached them to our table, the legs were U-shaped. When we were experimenting with the legs during building, we noticed that the tops of the 'U' were very easy to bend with respect to the bottom. Therefore we felt it was necessary to strengthen this aspect of the legs. In order to do this, we welded a cross bar to connect the tops of the legs. This would aid in preventing movement and strengthen the overall stability of the legs. Figure 62 displays the cross-bar that was added to the legs.

Figure 62: Cross-bar addition to middle legs

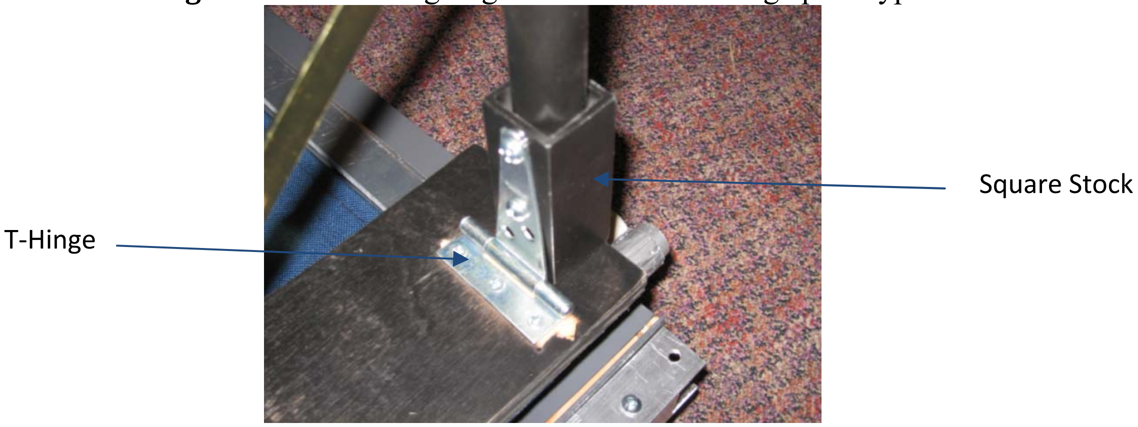


14.2.2 Attaching the legs to the Table

As displayed in the CAD drawings, we had originally planned on creating or recycling a joint that would attach the legs to the table. The legs would be inserted into the joint, a pin would be inserted through both, and the legs would rotate around this joint. However, we had problems coming up with a design for a joint that would be strong enough, and still provide the functionality that we needed without being too bulky or heavy. Therefore we decided to use T-hinges as we did with the prototype. The functionality of the T-hinges worked very well for the

Beta prototype; therefore we decided to use them once again in the Omega. However, the T-hinges are designed for flat surfaces and would have trouble connecting to the round legs.
In order to solve these problems, we found square, hollow steel stock that fit just around the ends of the legs. Then we cut this stock to just fit over the ends of the legs. Holes were drilled through the metal stock, the legs, and the T-hinges so that the three would line up. Once the stock was slid onto the ends of the legs, the T-hinge had a flat surface to be attached to. The ends of our legs were then attached to the table with the T-hinge and allowed to rotate. This design is presented below in Figure 63.

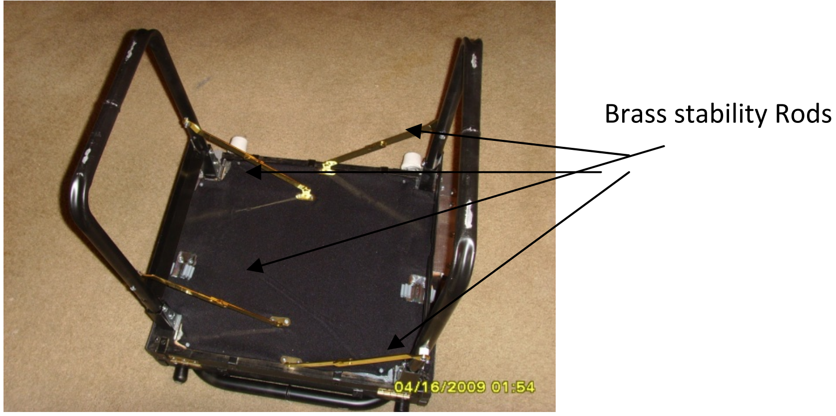
Figure 63: Attaching Legs to the table in Omega prototype



14.2.3 Folding Stability Bars for Legs

We noticed more problems with the stability of the table once the legs were attached. Even with the additions we had already made to the legs, when the table sat up, we noticed it wasn't as stable as it needed to be. Therefore, we purchased some folding chair stability bars from Lowe's Home Improvement. These bars extended from the bottom of the table to the legs. When the legs extend, the bars lock in place and hold the legs in the open position. These bars also share the load of the woman making the table even stronger. When the legs are folded, the stability bars rotate around a rod in the middle and fold flat against the table, and remaining out of the way. Figure 64 displays the stability bars added to the legs of the table.

Figure 64: Folding stability bars for legs

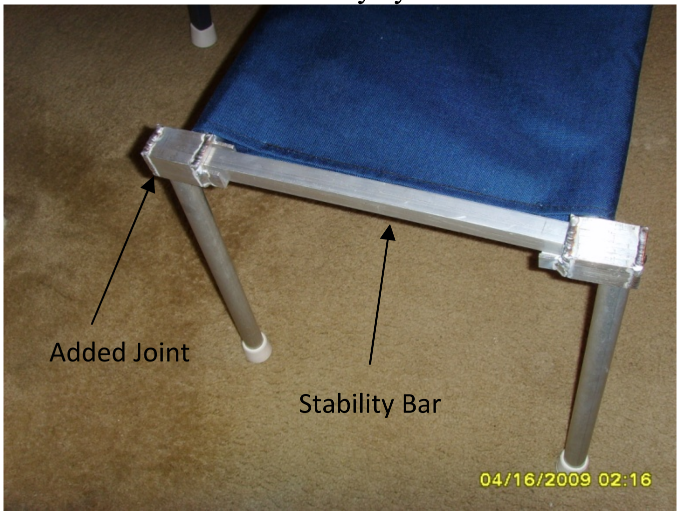


14.2.4 Stability Bars for Foot Section

Once the foot section was complete, we were able to quickly attach it to the middle section to see how it functioned. One immediate problem we noticed is that the ends of the foot section leaned greatly to the inside when any weight was added to the fabric. To solve this problem, it was necessary to have a cross bar that could be added and removed easily. By allowing it to be removed, the foot section wouldn't lose its ability to be rolled up and stored. The Cross-bar could be placed onto the fabric and rolled up inside of the foot section when it needed to be stored.

In order to accomplish this, we added a joint where the end of the foot section connects to the foot section legs. This joint would also add stability and prevent the legs from rotating out to far. On the inside of the joints, we welded a U-shaped metal piece on the inside of each joint that faced upwards. Then we cut a bar to the necessary length that could simply be slid into these U-shaped metal pieces. This bar prevents the ends of the foot section from leaning inwards once it is put into place. Figure 65 displays the stability bar for the foot section

Figure 65: Removable Stability system for the foot section



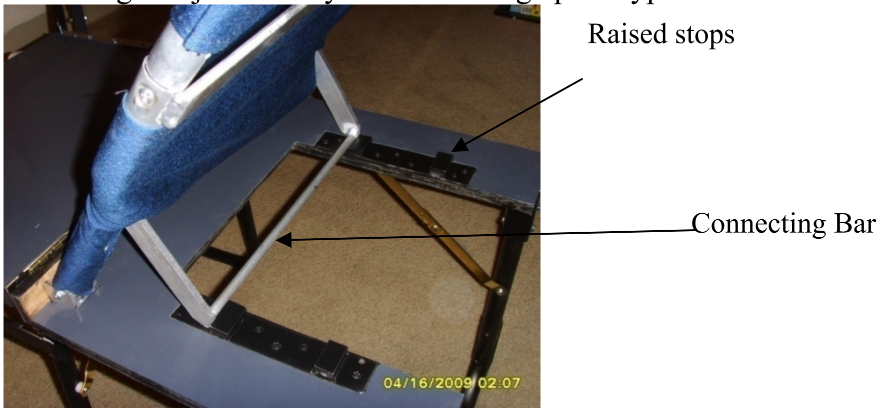
14.2.5 Back Angle Adjustment System

Originally, we had planned to have two independent adjustment rods that were located on the outside of the head rest frame. However, when experimenting with this, we found that this could be awkward to use. Therefore, we decided to create a bar that connected the two adjustment rods. Instead of changing each adjustment rod separately, now it would only take one adjustment. To do this, the adjustment rods needed to be moved to the inside of the head rest frame. This was okay because the fabric holds the back of the woman above these rods. Then we simply welded a bar of correct length between to the adjustment rods.

Another change came in the slots needed to hold the adjustment rods. We originally planned to have metal lined slots cut into the wood. However, over time these slots would become quickly worn and it is possible that the wood may just break or shear. Therefore, we wanted to change the slots to raised bars in which the rod could sit against. We determined where the raised bars needed to be then made the necessary piece by welding small bars on the top of thin aluminum.

These two pieces where then put into place as shown in Figure 66 on page 64. Figure 66 shows how the Omega prototype back angle adjustment system functions.

Figure 66: Back angle adjustment system for Omega prototype



14.3 Advantages and Disadvantages of Omega prototype

The Omega prototype that we have constructed exhibits all of the advantages and disadvantages described in the Omega design section above. However, since some of the changes made during the building, there have been more advantages and disadvantages.

The cross-bars and struts all serve the purpose of adding strength or adding stability. Therefore the prototype has the advantage of being more stable and stronger than the Omega design. Also, the struts prevent the legs from collapsing while the table is in use.

However, some disadvantages came from the additions. The main disadvantage is that the table is slightly heavier than it previously would have been. However, the table remains within our original specification of 22 lbs. Also, the additions add complexity and volume to our table.

15.0 MANUFACTURING & ASSEMBLY OF FINAL DESIGN (OMEGA REVISION B)

In order to create manufacturing and assembly plans it was necessary to create a CAD model of our final design. The changes outlined in the Final Prototype section were incorporated into our original Omega Revision A CAD model to create the Final CAD design (Omega Revision B) shown in Figure 67.

The Final Design is made out of birch wood, PVC, aluminum, polyester webbing, t-hinges, and door hinges. The stock pieces of birch were purchased from Fingerle Lumber in Ann Arbor, MI. The t-hinges and other hinges were purchased from Lowe's Home Improvement in Ann Arbor, MI. The PVC and aluminum were purchased from Grainger from their website. A complete list of these materials can be found in Appendix B. In Figures 68 – 70 are pictures of our Final prototype, with each piece labeled to its corresponding section.

Figure 67: Layout of Final design

Figure 68: Layout of Foot Section

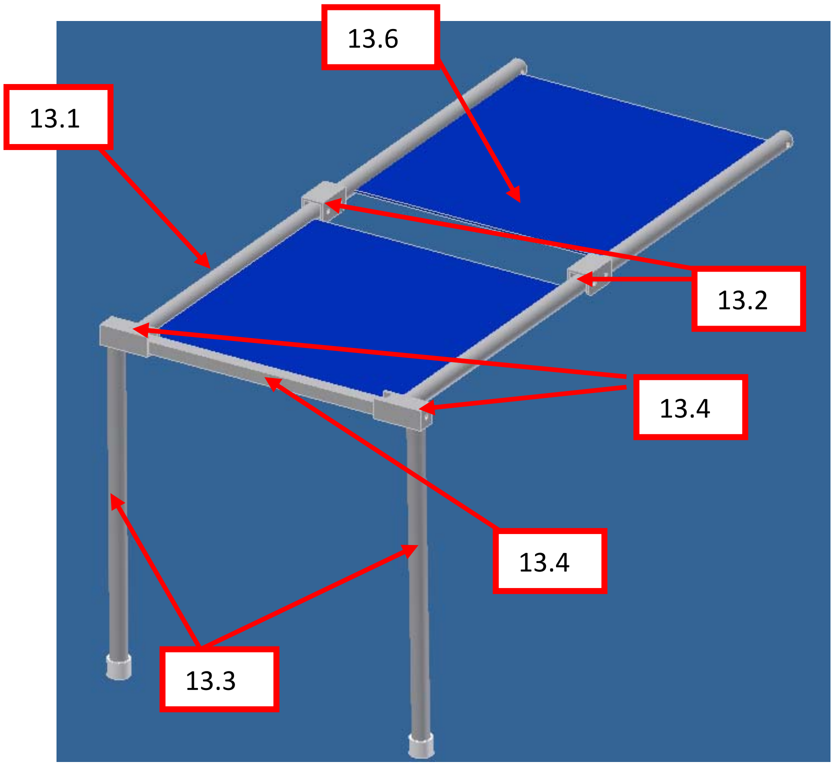


Figure 69: Layout of Middle Section

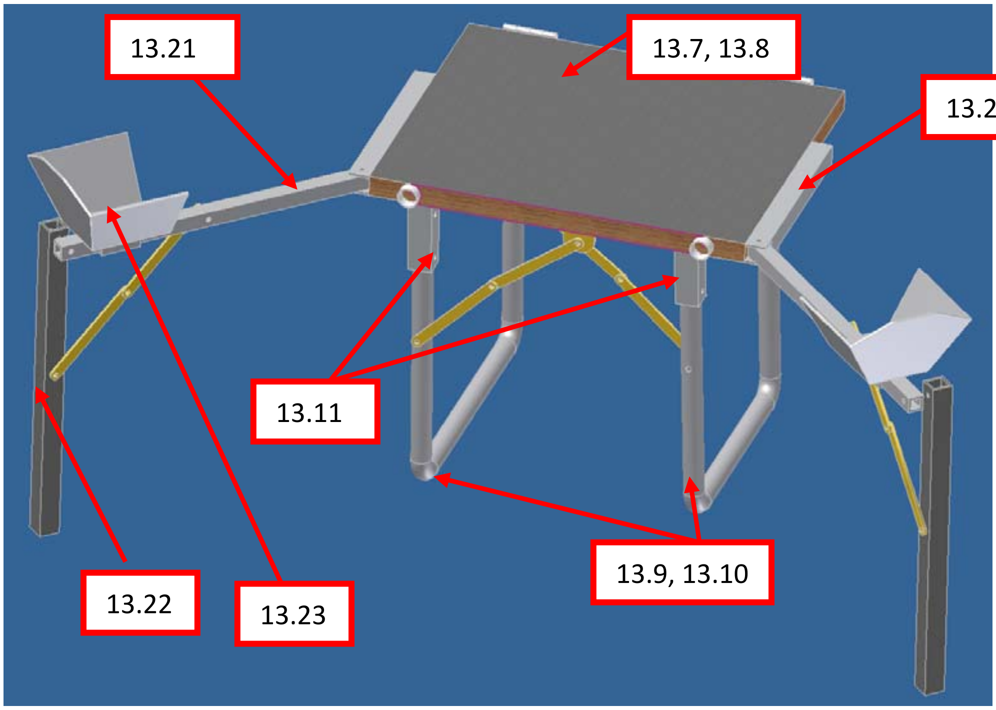
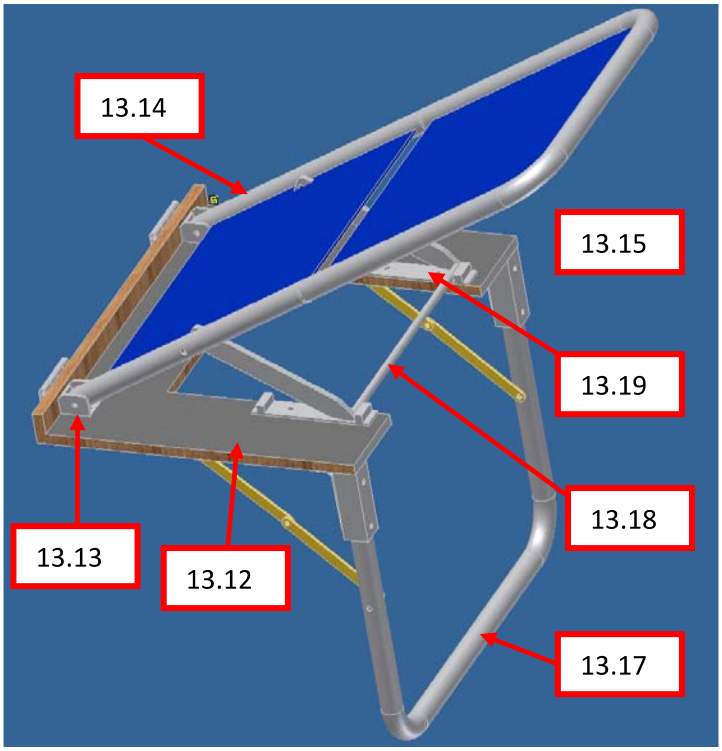


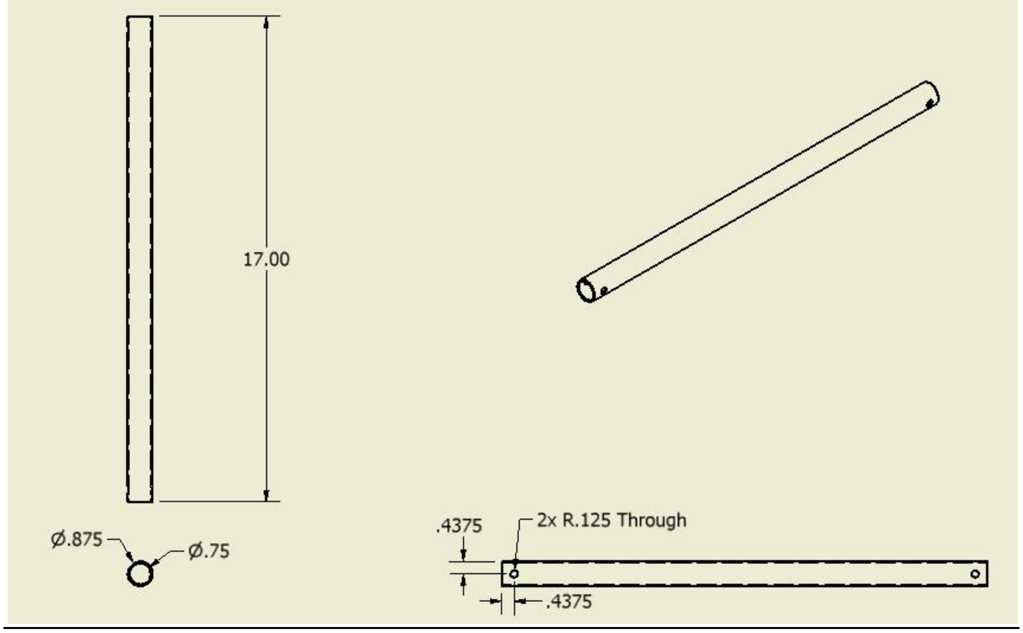
Figure 70: Layout of Head Section



15.1 Foot Section Frame

The foot section frame is made out of four 0.85 inch diameter circular aluminum pieces. A step by step approach to fabricating the foot section frame is shown below.

Figure 71: Manufacturing of foot section frame



15.1.1 Cut 4 aluminum rods with a diameter of 0.85 inches to a length of 17 inches

- Measure out to a length of 17 inches and make a straight line on the rod using a scribe.
- Set the band saw to a speed between 300-350 feet per minute.
- Make a straight cut following the line using the band saw.

15.1.2 Drill a 0.25 diameter hole at each end of the four rods

- Measure out to a distance of 0.4375 inches from the end and side of the rod (see figure 71) and make a mark using a scribe
- Drill a hole with a diameter of 0.25 inches at the marked off spot using the drill press

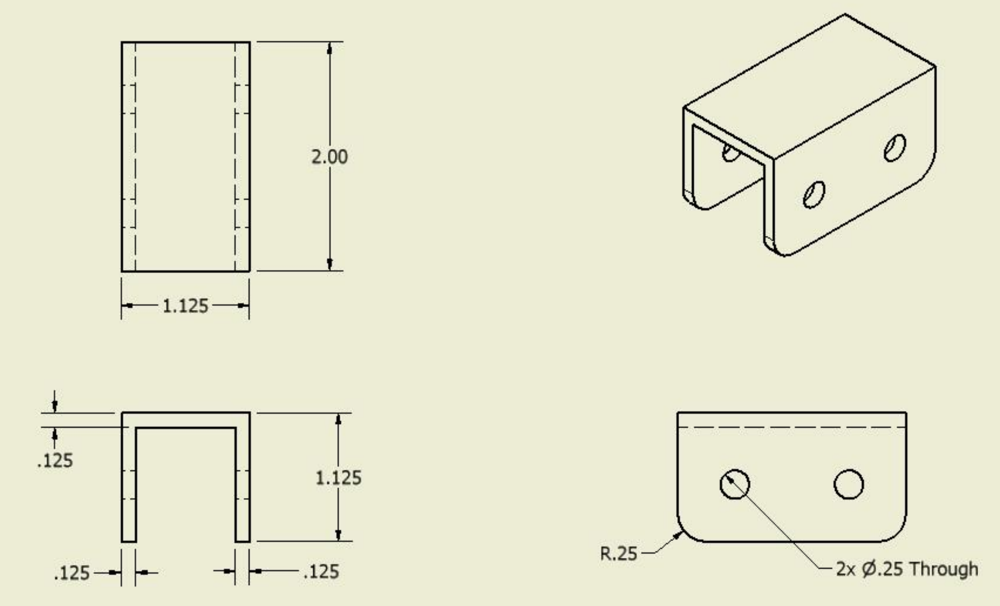
15.1.3 File all rough edges of aluminum

- Using a medium file, smooth all rough surfaces and edges

15.2 Foot Section Joints

The foot section has two joints that connect the four aluminum rods above to make two pieces of the frame. The fabrication of these joints is described in detail below.

Figure 80: Manufacturing of foot section hinge



15.2.1 Cut two pieces (per joint) of aluminum to 1.125x2.0x0.125 inches

- Using 0.125 inch thick stock aluminum, mark off dimensions of 1.125x2 inches using an engineering triangle and a scribe.
- Set the band saw to a speed between 300-350 feet per minute.
- Make a straight cut following the scribe lines using the band saw.

15.2.2 Cut a 0.25 inch radius fillet on each of the bottom corners of the pieces created in 15.2.1 (see figure XX above).

15.2.3 Drill two 0.25 inch diameter holes in each of the pieces from step 15.2.1

- Measure out to a distance of 0.5 inches from each end and side of the piece and make a mark the center using a scribe
- Drill holes with a diameter of 0.25 inches at the marked off spots using the drill press

15.2.4 Cut a piece of aluminum to 0.875x2.0x0.125 inches

15.2.5 Weld the three pieces from steps 15.2.1 and 15.2.2 together

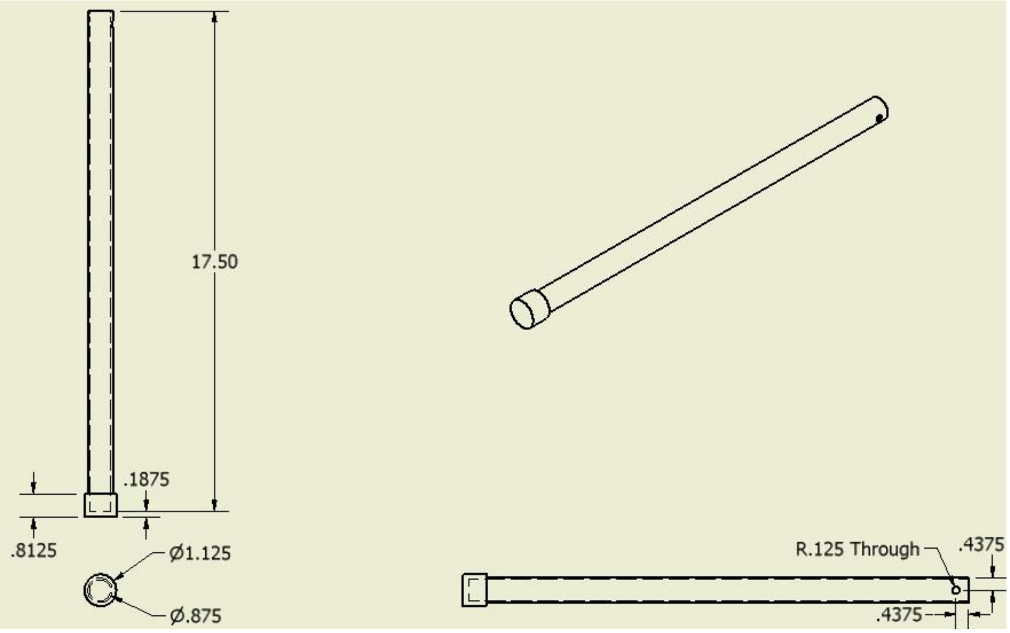
15.2.6 File all rough edges

- Using a medium file, smooth all rough surfaces and edges

15.3 Foot Section Legs

The two foot section legs will be made of 1.125 inch diameter hollow aluminum pipe which has a thickness of 0.25 inches. Each piece will be cut in the band saw and then have a hole drilled at one end for the insertion of a bolt. A step by step approach is shown below.

Figure 81: Manufacturing of foot section legs



15.3.1 Cut length to 17.5 inches using band saw

- Make a straight line using engineering triangle and a pencil for a length of 18.125 inches.
- Set the band saw to a speed between 300-350 feet per minute.
- Make a straight cut following the pencil line using the band saw.

15.3.2 Drill a 0.25 diameter hole at one end that is 0.4375 inches from the end edge using drill press (see Figure 81 above).

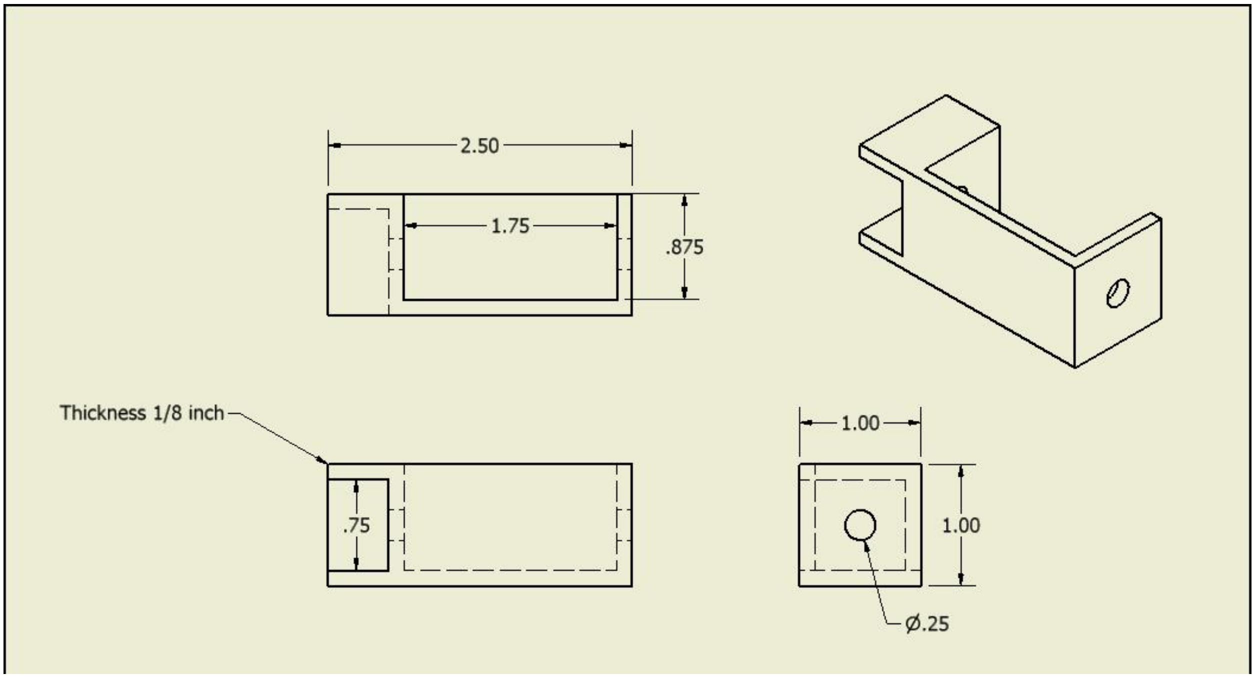
15.3.3 File all rough edges

- Using a medium file, smooth all rough surfaces and edges

15.4 Foot Section Leg Joints

The two foot section legs have joints that connect them better to the foot section frame. The joints also aid in preventing the legs from opening too far. On the insides of the foot section leg joints are U-channels welded. When unfolded, a simple bar is slid into this U-channels to prevent the foot section from sagging. Only one of the leg joints is shown below. To manufacture the other, the U-channel is welded on the other side.

Figure 82: Manufacturing of foot section leg joint



15.4.1 L-shape aluminum stock with 1x1 sides to 1.75 inch length

15.4.2 Cut two 1x1 inch squares that are 0.125 inch thick

15.4.3 Weld 1x1 inch squares onto the ends of the 1.75 length L-shape aluminum stock

15.4.4 Drill 0.25 inch diameter hole through sides

- Follow dimensions in figure above to determine position of hole

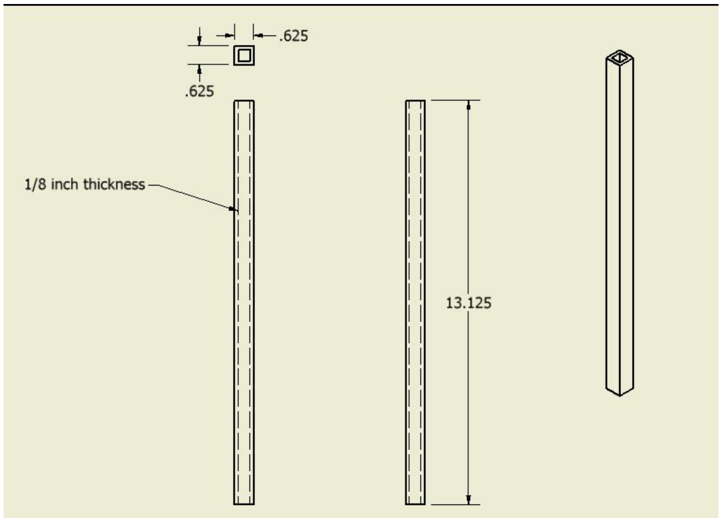
15.4.5 Cut 0.5 inch long U-channel piece using band saw with 1 inch sides

15.4.6 Weld U-channel onto necessary side of part

15.5 Foot Section Cross Bar

The foot section cross bar provides stability at the end of the foot section. By inserting this bar in the U-channels of the leg joints, the foot section cannot lean inwards when weight is put on the fabric.

Figure 83: Manufacturing of foot section cross bar



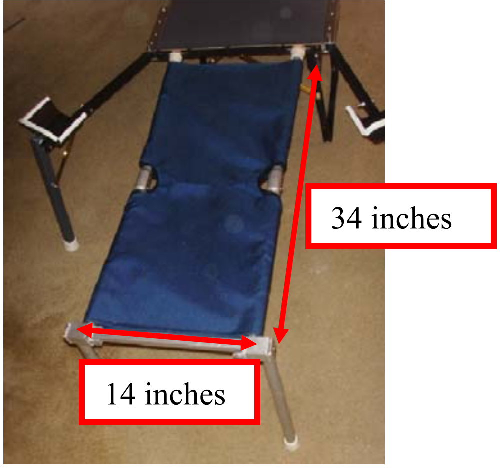
15.5.1 Cut 0.625x0.625 inch stock to 13.125 inches

- Make a straight line using engineering triangle and a pencil for a length of 13.125 inches.
- Set the band saw to a speed between 300-350 feet per minute.
- Make a straight cut following the pencil line using the band saw.

15.6 Foot section fabric

The foot section is made out of polyester webbing. It is made of one solid piece with two semi-circles cut out where the hinges are. The polyester webbing is sewn around the aluminum frame and has dimensions of 34x14 inches. Consultation with a seamstress is what was used to make our prototype and will be essential in future replication.

Figure 84: Foot section fabric



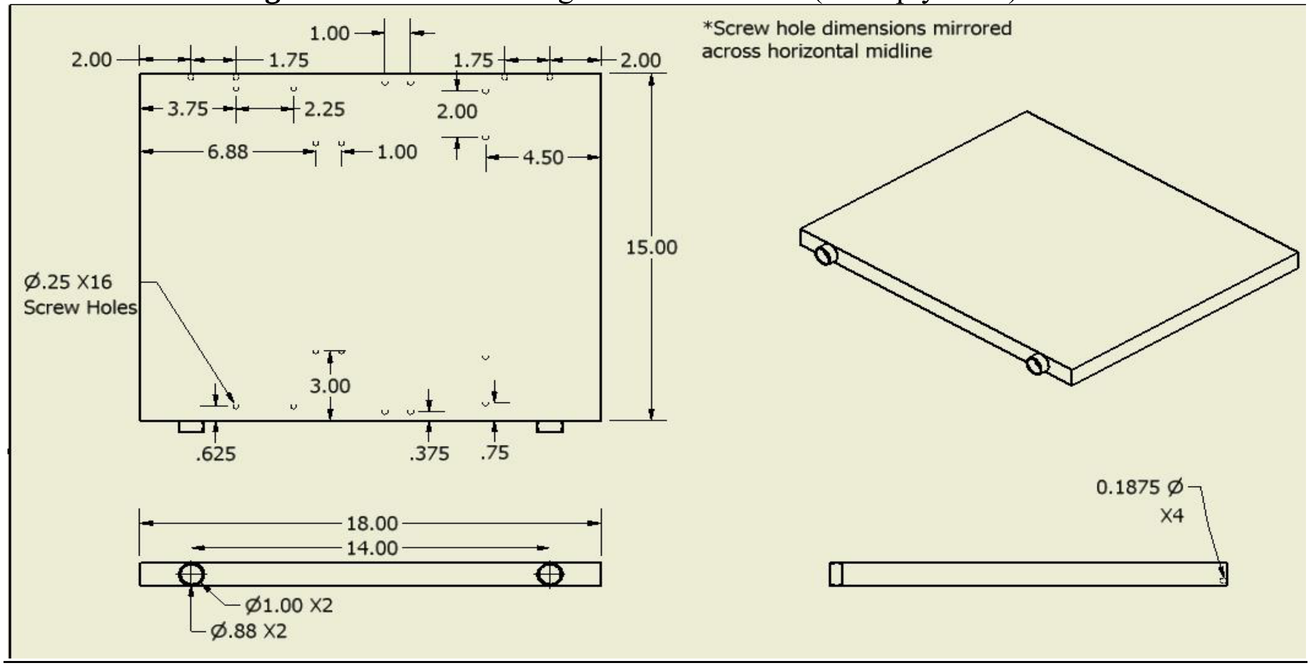
15.6.1 Cut fabric to dimensions of 16x34 inches.

15.6.2 Cut semi-circular slots at 17 inches up the length direction at shown in Figure 84 above.

15.7 Middle Section (Wood)

The middle section will be made out of two pieces 0.5 inch thick natural birch plywood. The middle section of the table will consist of a wooden base and layer of PVC on top of it. The assembly of the PVC top and the two wooden pieces will be described in section 16. The wooden base will consist of 2 different pieces. Their fabrications are described below.

Figure 85: Manufacturing of middle section (birch plywood)



15.7.1 Cut two 15x18x0.5 inch pieces of plywood using band saw using 0.5 inch thick stock birch plywood

15.7.2 Cut length of large piece to 18 inches

- Make a straight line using engineering triangle and a pencil for a length of 18 inches.
- Set the band saw to a speed between 300-350 feet per minute.
- Make a straight cut following the pencil line using the band saw.

15.7.3 Cut width of large piece to 15 inches using band saw

- Make a straight line using engineering triangle and a pencil for a length of 15 inches.
- Set the band saw to a speed between 300-350 feet per minute.
- Make a straight cut following the pencil line using the band saw.

15.7.4 Drill 16 (0.25 in. deep) holes using drill press

- Mark the center of the holes by measuring them using an engineering triangle and referring to Figure 85 for their locations
- Drill 1/8 inch diameter *pilot* holes for screws using drill press

15.7.5 Drill 4 (0.25 in. deep) holes using drill press

- Mark the center of the holes by measuring them using an engineering triangle and referring to Figure 85 for their locations
- Drill 1/8 inch diameter *pilot* holes for screws using drill press

15.7.6 Sand all rough edges

- Using medium grade sandpaper, smooth all rough surfaces and edges

15.7.7 Epoxy two rubber pieces on front of middle section

- Using high strength epoxy, adhere rubber holds onto front of middle section

15.8 Middle Section (PVC)

A sheet of PVC will be attached to the two pieces of birch plywood using epoxy. The fabrication of this piece of PVC is explained in detail.

Figure 86: Manufacturing of the middle section (PVC)

15.8.1 Cut length to 18 inches using band saw
- Make a straight line using engineering triangle and a pencil for a length of 18 inches.
- Set the band saw to a speed between 300-350 feet per minute.
- Make a straight cut following the pencil line using the band saw.

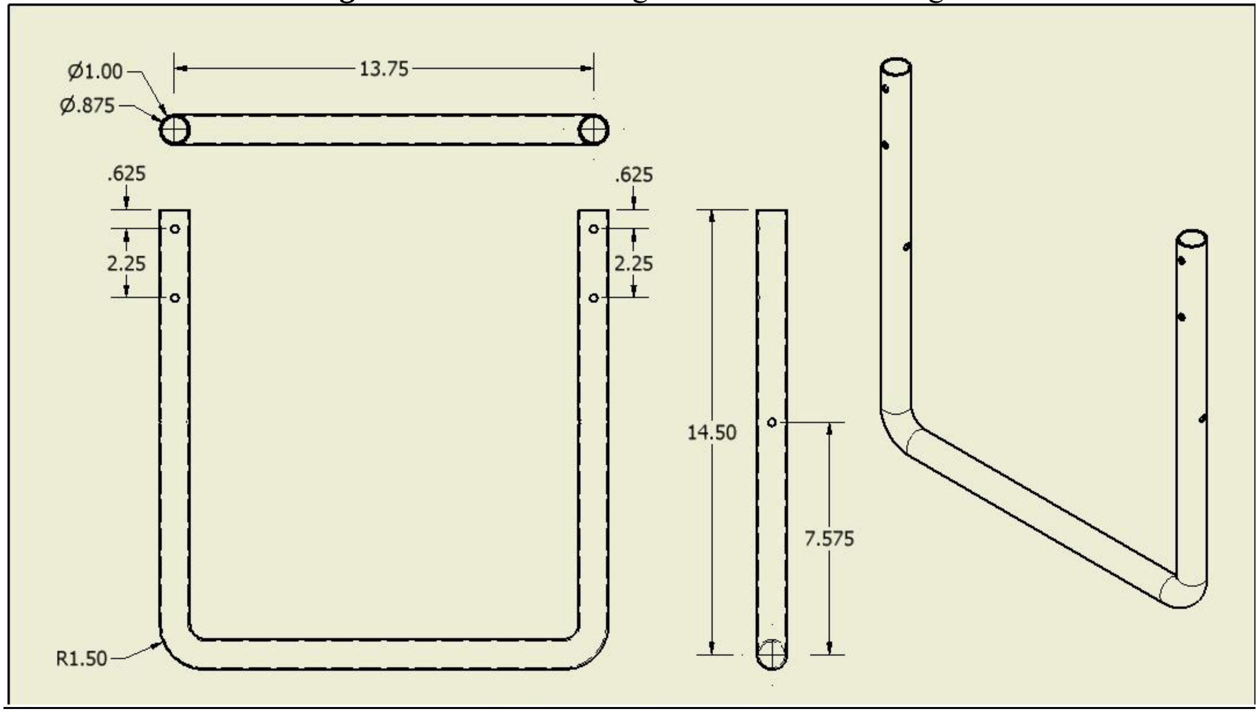
15.8.2 Cut width to 15 inches using band saw
- Make a straight line using engineering triangle and a pencil for a length of 15 inches.
- Set the band saw to a speed between 300-350 feet per minute.
- Make a straight cut following the pencil line using the band saw.

15.8.3 File off any rough edges using a medium file.

15.9 Middle Leg (Wide)

The wider of the two legs for the middle section is made out of hollow aluminum pipe with a diameter of one inch. To cut down on cost, we used recycled lawn chairs and took the legs off of them. See Section 22.0 for our recommendations on the best way to replicate these legs if recycled lawn chairs are not available.

Figure 87: Manufacturing of the wide middle leg



15.9.1 Cut the bottom section to a length of 13.75 inches.

15.9.2 Weld back together in order to make a length of 13.75 inches across the bottom piece.

15.9.3 Cut length of 2 vertical members to 14.5 inches using band saw

- Make a straight line using engineering triangle and a scribe for a length of 15.0 inches.
- Set the band saw to a speed between 300-350 feet per minute.
- Make a straight cut following the scribe line using the band saw.

15.9.4 Drill 6 holes with a diameter of 0.25 inches in the positions shown in Figure 87 above

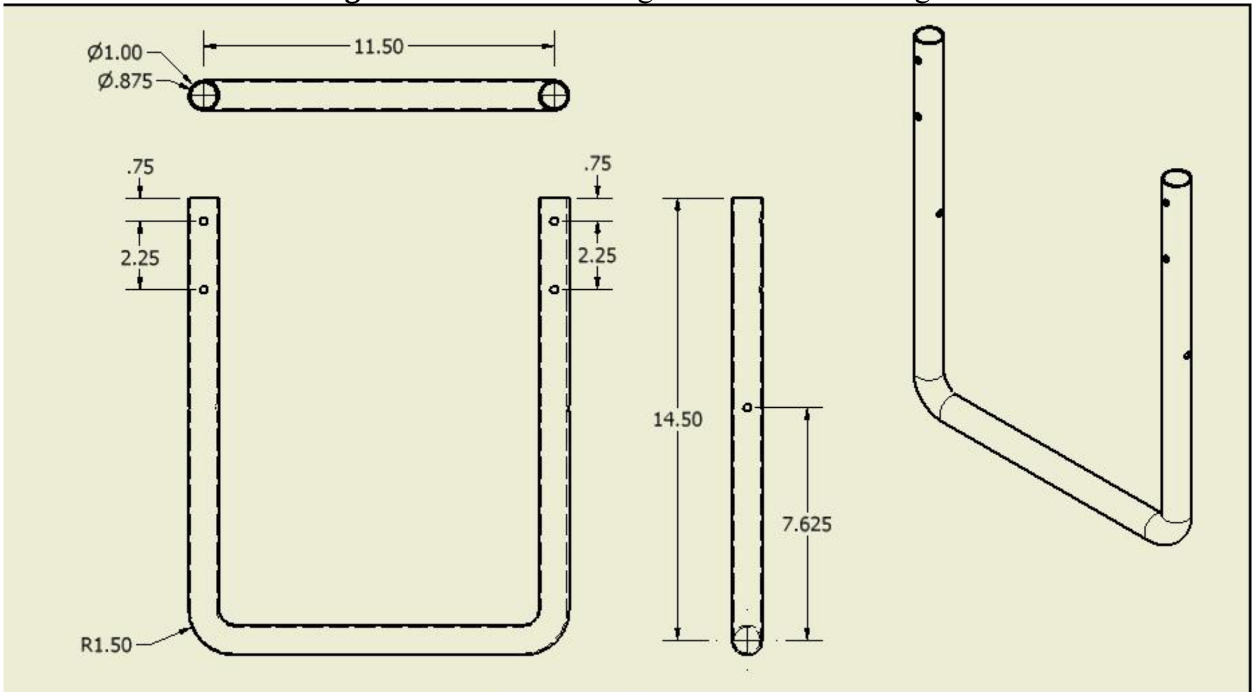
15.9.5 File all rough edges

- Using a medium file smooth all rough surfaces and edges.

15.10 Middle Leg (Narrow)

The narrower of the two legs for the middle section is made out of hollow aluminum pipe with a diameter of one inch. To cut down on cost, we used recycled lawn chairs and took the legs off of them. See Section 22.0 for our recommendations on the best way to replicate these legs if recycled lawn chairs are not available.

Figure 88: Manufacturing of narrow middle leg



15.10.1 Cut the bottom section to a length of 11.50 inches.

15.10.2 Weld back together in order to make a length of 11.50 inches across the bottom piece.

15.10.3 Cut length of 2 vertical members to 14.5 inches using band saw

- Make a straight line using engineering triangle and a scribe for a length of 15.0 inches.
- Set the band saw to a speed between 300-350 feet per minute.
- Make a straight cut following the scribe line using the band saw.

15.10.4 Drill 6 holes with a diameter of 0.25 inches in the positions shown in Figure 88 above

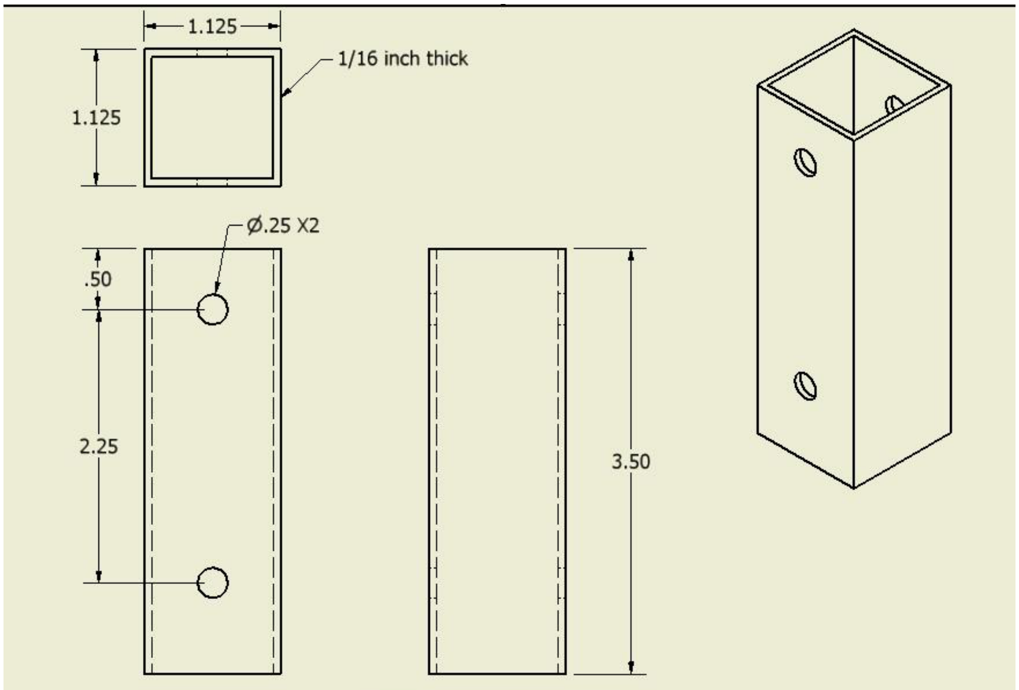
15.10.5 File all rough edges

- Using a medium file smooth all rough surfaces and edges.

15.11 Square Leg Base

This leg base was designed to be attached to the bottom of the two sets of middle legs, and the head section legs. The square shape of the base allows it to be securely attached to the store bought T-hinges. This provides the sturdy base of support we are looking for when the legs are opened.

Figure 89: Manufacturing of square leg base



15.11.1 Cut a square 1/16 inch thick 1.125x1.125 inch square stock to length 3.5

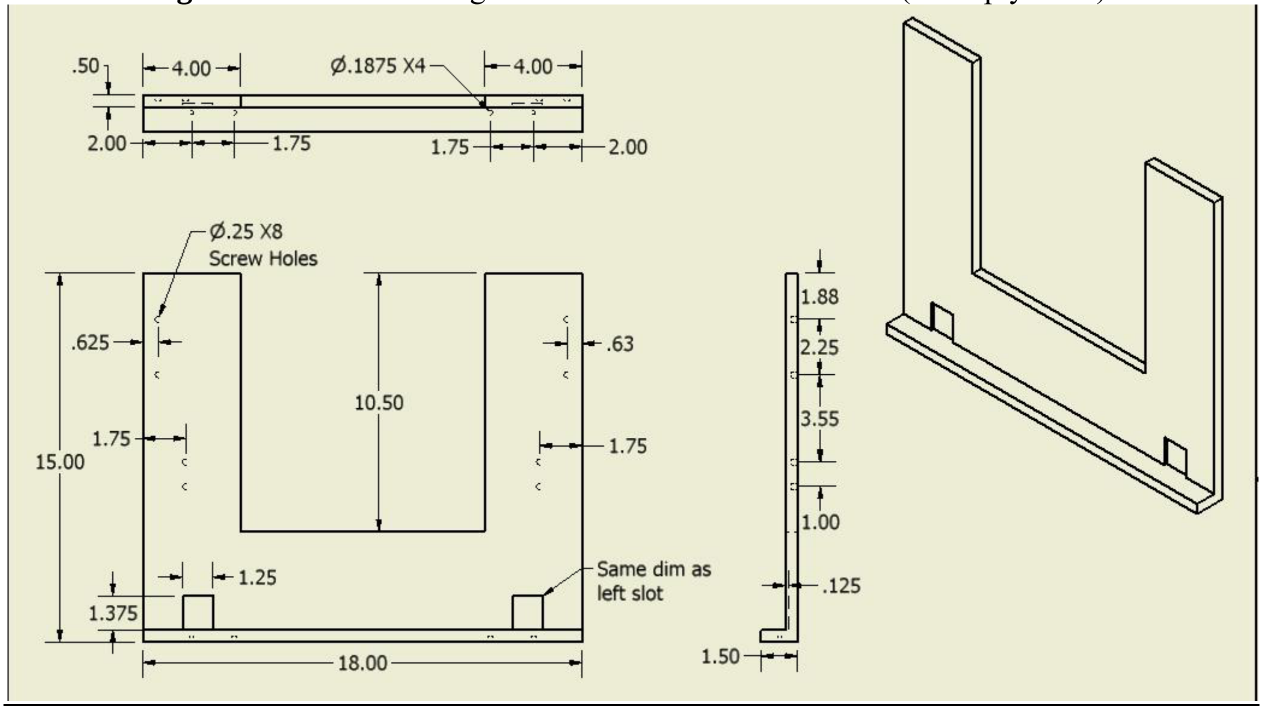
- Make a straight line using engineering triangle and a scribe for a length of 3.5 inches.
- Set the band saw to a speed between 300-350 feet per minute.
- Make a straight cut following the scribe line using the band saw.

15.11.2 Drill 2 0.25 diameter holes in the positions shown in the figure above

15.12 Head Section Base

The head rest will be made out of 0.5 inch thick natural birch. This piece is cut using the bandsaw. The two slots that are 1.25x1.375 inches are chiseled out

Figure 90: Manufacturing of the base for the head section (birch plywood)



15.12.1 Cut solid head base piece with dimensions 18x15x0.5

- Make a straight line using engineering triangle and a pencil for a length of 15, width 18, and thickness 0.5 inches.
- Set the band saw to a speed between 300-350 feet per minute.
- Make a straight cut following the pencil line using the band saw.

15.12.2 Cut out square with dimensions 10.5x10x0.5 as shown in figure above

- Make a straight line using engineering triangle and a pencil for a length of 10.5 and width 10 inches where necessary
- Set the band saw to a speed between 300-350 UNITS.
- Make a straight cut following the pencil line using the band saw.

15.12.3 Drill 8 0.25 in. deep, 1/8 in. diameter pilot holes for screws using drill press as shown in Figure 54 above.

15.12.4 Drill 4 0.25 in. deep, 3/16 in. diameter pilot holes for screws using drill press as shown in Figure 54 above.

15.12.5 Chisel out 1.375x1.25 in. slots for joints and shown in figure about

- Mark with pencil on wood where slots are to be chiseled
- Using hammer and chisel, gently chisel away wood until slot is 0.125 in deep

15.12.6 Cut 0.5 inch extension to be glued at end of head base

- Use tape measure and ruler to measure out 18x1x0.5 piece
- Using either L-brackets or epoxy, attach piece one wider end of the head base as shown
- Piece is necessary to hinge together with middle section

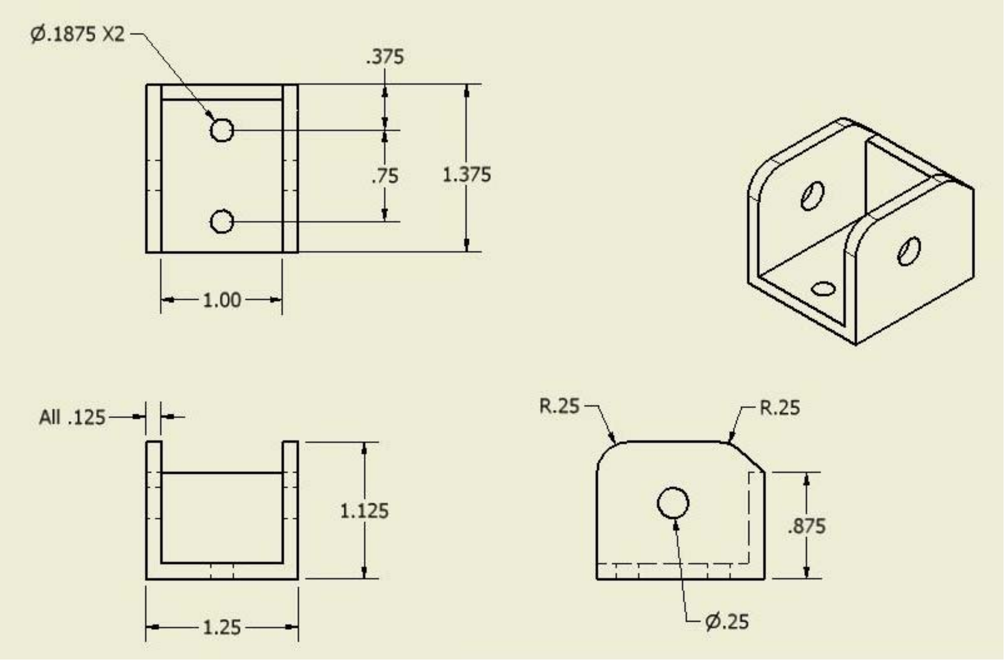
15.12.7 Sand all rough edges

- Using medium grade sandpaper, smooth all rough surfaces and edges

15.13 Head Rest Frame Joints

Two joints will be needed for each of the middle section legs and for the head section leg (total of 6). They consist of the leg rotating around a bolt guided by two through-holes. The fabrication of these joints is shown in detail.

Figure 91: Manufacturing of head rest frame joints



15.13.1 Cut two pieces (per joint) of aluminum to 1.125x1.375x0.125 inches

- Using 0.125 inch thick stock aluminum, mark off dimensions of 1.125x1.375 inches using an engineering triangle and a scribe.
- Set the band saw to a speed between 300-350 feet per minute.
- Make a straight cut following the scribe lines using the band saw.

15.13.2 Cut a 0.25 inch radius fillet on the top left corner of the pieces created in 15.7.1 (see Figure 91 above)

15.13.3 Cut a 0.25 inch corner on the top right corner of the pieces created in 15.7.1 (see Figure 91 above)

15.13.4 Drill two 0.25 inch diameter holes in each of the pieces from step 15.7.1

- Measure out to a distance of 0.6 inches from each end and side of the piece and make a mark the center using a scribe.
- Drill holes with a diameter of 0.25 inches at the marked off spots using the drill press.

15.13.5 Cut a piece of aluminum to 0.875x1.0x0.125 inches using the band saw

- Set the band saw to a speed between 300-350 feet per minute.
- Make a straight cut following the scribe lines using the band saw.

15.13.6 Cut a piece of aluminum to 1.0x1.375x0.125 inches using the band saw and drill two holes with a diameter of 0.1875 inches with their center spaced 0.75 inches apart (see figure XX above)

- Set the band saw to a speed between 300-350 feet per minute.
- Make a straight cut following the scribe lines using the band saw.
- Drill holes with a diameter of 0.1875 inches at the marked off spots using the drill press.

15.13.7 Weld the above pieces together in the orientation shown in Figure 91 and let cool

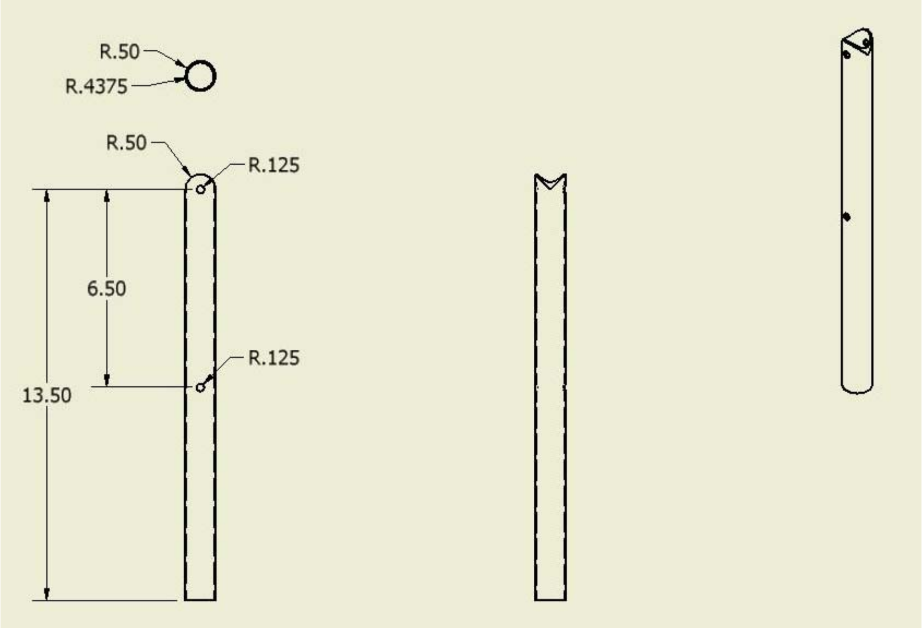
15.13.8 File all rough edges

- Using a medium file, smooth all rough surfaces and edges

15.14 Head Rest Frame

The foot section frame is made out of two 0.50 inch diameter circular aluminum pieces. A step by step approach to fabricating the foot section frame is shown below.

Figure 92: Manufacturing of the middle section (PVC)



15.14.1 Cut 2 aluminum rods with a diameter of 0.5 inches to a length of 14 inches

- Measure out to a length of 14 inches and make a straight line on the rod using a scribe.
- Set the band saw to a speed between 300-350 feet per minute.
- Make a straight cut following the line using the band saw.

15.14.2 Drill a 0.25 diameter hole at one end and also at the center of each rod

- Measure out to a distance of 0.5 inches from one of the ends of the rods and mark with a scribe
- Drill a hole with a diameter of 0.25 inches at the marked off spot using the drill press
- Drill a hole with a diameter of 0.25 inches in the center of each rod (refer to Figure 92).

15.14.3 Round the end with a hole drilled in it to a radius of 0.5 inches

- Measure out to a distance of 0.5 inches from the end of the rod with a hole drilled in it.
- Use a compass and scribe to mark off a semi-circle with a radius of 0.5 inches.
- Set the band saw to a speed between 300-350 feet per minute.
- Follow the semi-circular mark with the band saw to make the cut.

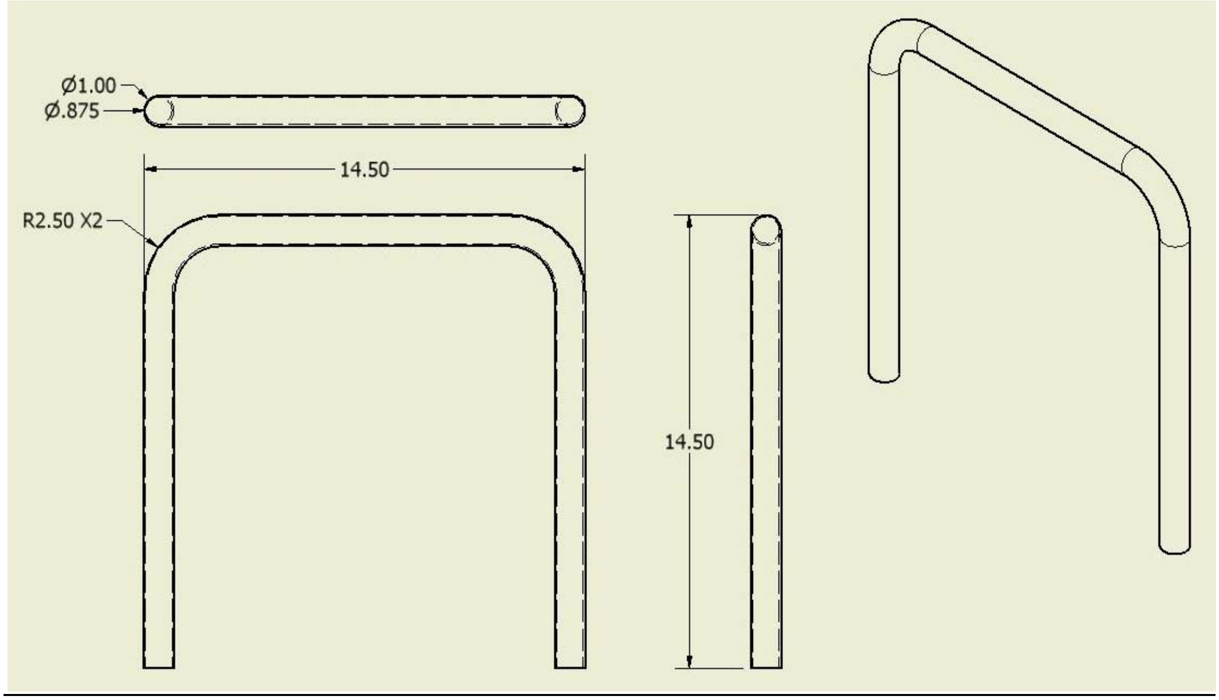
15.14.4 File all rough edges of aluminum

- Using a medium file, smooth all rough surfaces and edges

15.15 Head Rest Addition

The addition to the head rest section will also be made of aluminum pipe with a diameter of 1.0 inches. It will be in the shape of a U with dimensions of 14.5x14.5x14.5 inches. A detailed fabrication of this piece is described.

Figure 93: Manufacturing of the head rest addition



15.15.1 Cut the bottom section to a length of 14.50 inches.

15.15.2 Weld back together in order to make a length of 14.50 inches across the bottom piece.

15.51.3 Cut length of 2 vertical members to 14.5 inches using band saw

- Make a straight line using engineering triangle and a scribe for a length of 14.5 inches.
- Set the band saw to a speed between 300-350 feet per minute.
- Make a straight cut following the scribe line using the band saw.

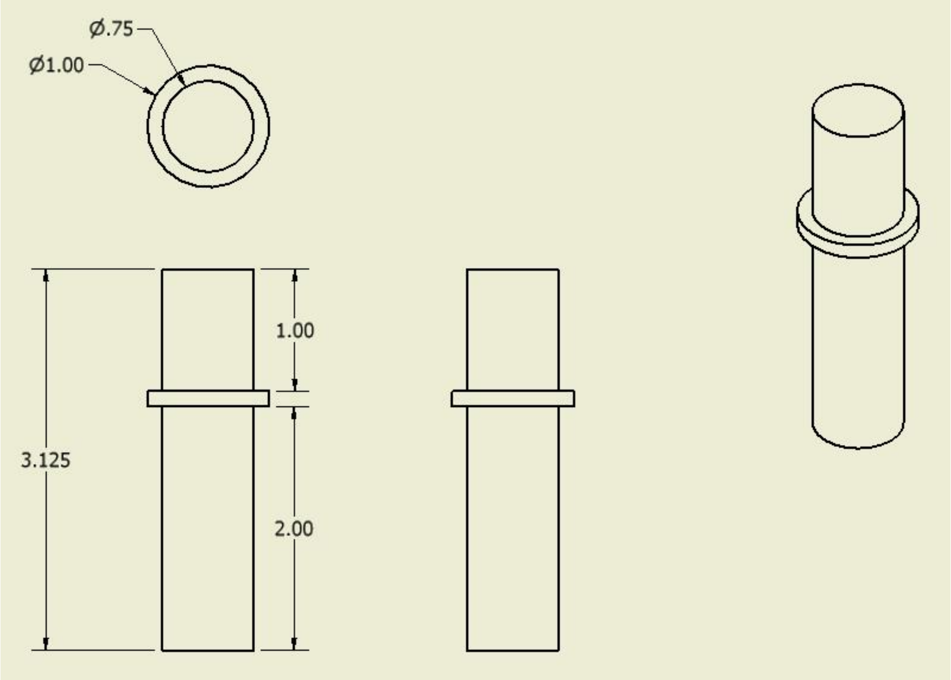
15.15.4 File all rough edges

- Using a medium file smooth all rough surfaces and edges.

15.16 Head Section Insert

The longer end of the insert will be slid into the head rest frames and leave the shorter end protruding out. The head rest addition will be slid onto these protruding ends for a quick addition and removal. They are secured into the head rest frames using epoxy.

Figure 94: Manufacturing of head rest insert



15.16.1 Cut 0.75 diameter aluminum stock to the length of 3.125 inches

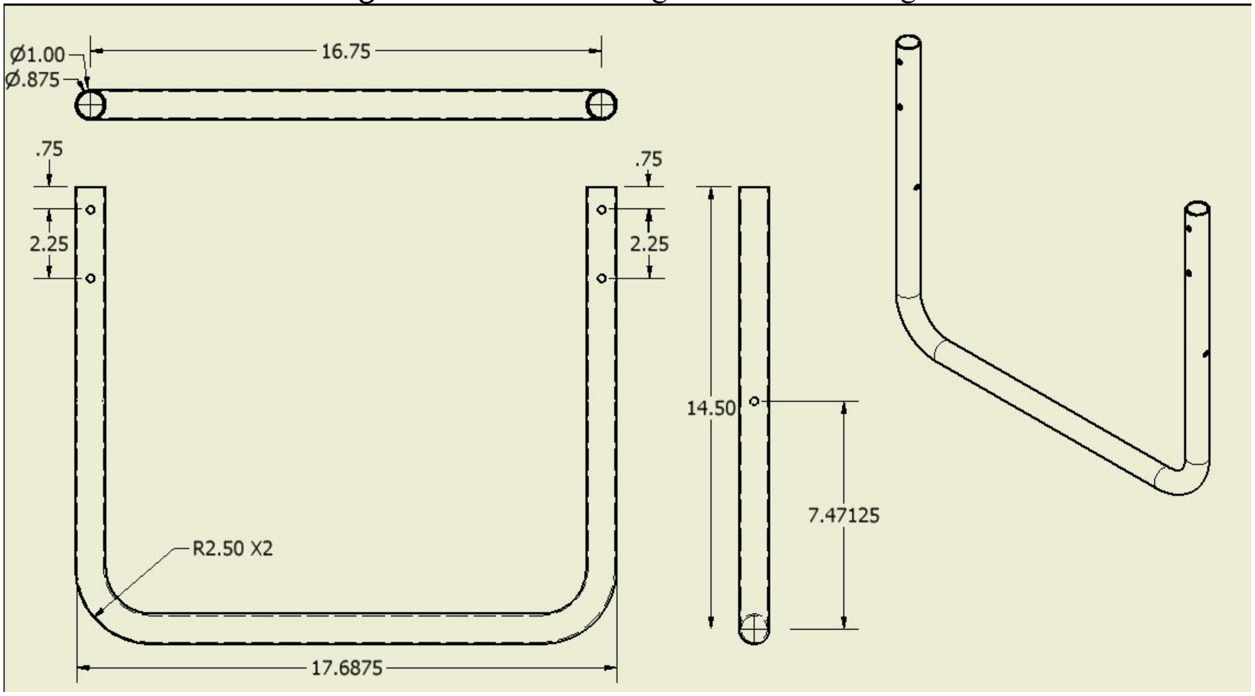
15.16.2 Slide a rubber O-ring over the 3.125 piece at the necessary position

15.16.3 Cover longer end with epoxy and slide into head rest frame. Allow time to set.

15.17 Head Section Leg

The head section leg is made out of hollow aluminum pipe with a diameter of 0.5 inches. To cut down on cost, we used recycled lawn chairs and took the legs off of them. See section 22.0 for our recommendations on the best way to replicate these legs if recycled lawn chairs are not available.

Figure 95: Manufacturing of head section leg



15.17.1 Cut the bottom section to a length of 17.6875 inches using band saw.

15.17.2 Weld back together in order to make a length of 17.6875 inches across the bottom piece.

15.17.3 Cut length of 2 vertical members to 14.5 inches using band saw

- Make a straight line using engineering triangle and a scribe for a length of 15.0 inches.
- Set the band saw to a speed between 300-350 feet per minute.
- Make a straight cut following the scribe line using the band saw.

15.17.4 Drill 6 holes with a diameter of 0.25 inches in the positions in Figure 95 above

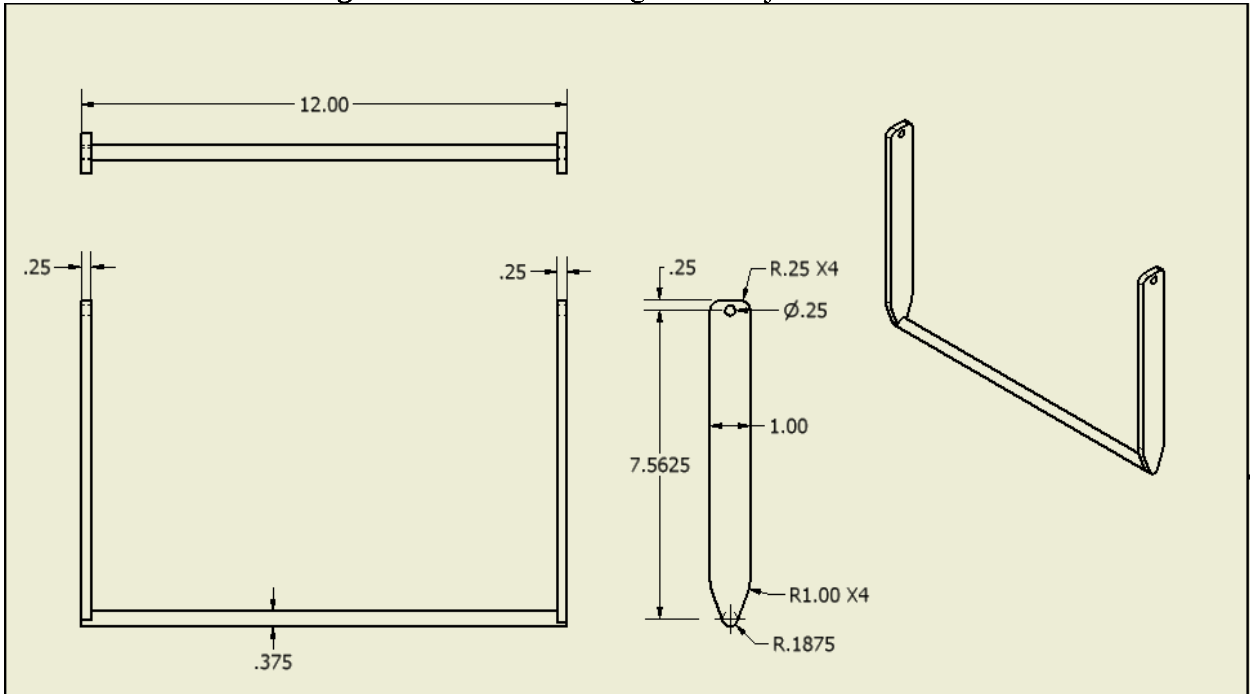
15.17.5 File all rough edges

- Using a medium file smooth all rough surfaces and edges.

15.18 Adjustment Rod

A single adjustment rod will be used to adjust the back angles of the table. The rod is made of aluminum and the design is presented below in Figure 95.

Figure 96: Manufacturing of the adjustment rods



15.18.1 Cut two 0.25 thick pieces of aluminum to the dimensions of 8.0x1.0 using band saw

- Make a straight line using engineering triangle and a scribe for a length of 8.0 and a width of 1.0 inches.
- Set the band saw to a speed between 300-350 feet per minute.
- Make two straight cuts following the scribe lines using the band saw.

15.18.2 Make a cut at the end of the piece from 7 inches to the end (see Figure 96)

15.18.3 Round bottom ends to a radius of 0.1875 inches using band saw

- Draw a half circle with a radius of 0.1875 inches on the bottom end of the piece using a compass and a ruler
- Set the band saw to a speed between 300-350 feet per minute.
- Make a straight cut following the pencil line using the band saw.

15.18.4 Drill a hole with a diameter of 0.25 inches at the end opposite the triangular cut on each piece

15.18.5 Fillet the two corners on the side of the hole to a radius of 0.25 inches using the bandsaw

15.18.6 File all rough edges

- Using a medium file, smooth all rough surfaces and edges

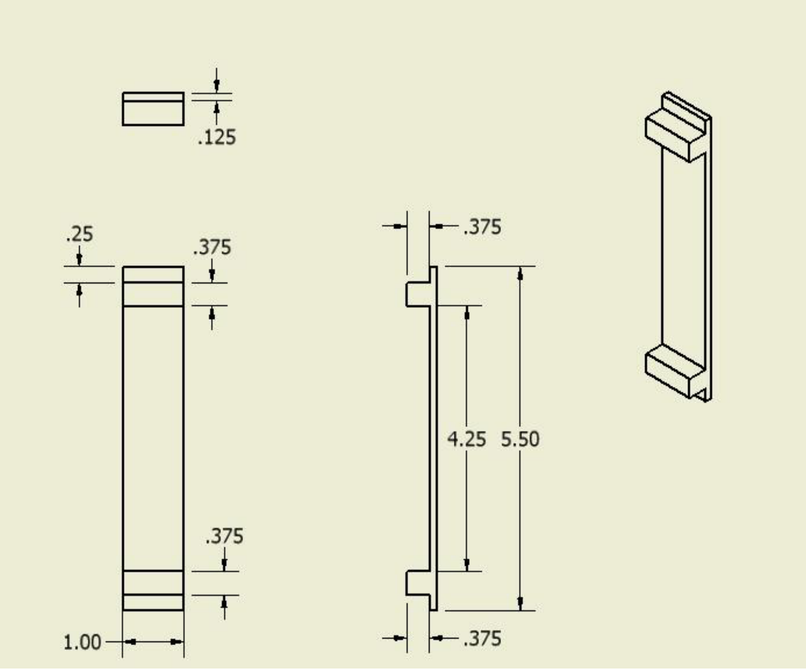
15.18.7 Cut 0.375 in. diameter aluminum stock to 11.5 inches

15.18.8 Weld round stock to the bottom ends of each 0.25 thick piece as shown above

15.19 Back Angle Stopper

The purpose of this device is to stop the adjustment rod and hold the head rest up at the required angles. It is constructed from aluminum and requires some welding.

Figure 97: Manufacturing of the back angle stopper



15.19.1 Cut two 0.125 in. thick pieces of aluminum to the dimensions of 1x5.5 using band saw

- Make a straight line using engineering triangle and a scribe for a length of 5.5 and a width of 1.0 inches.
- Set the band saw to a speed between 300-350 feet per minute.
- Make two straight cuts following the scribe lines using the band saw.

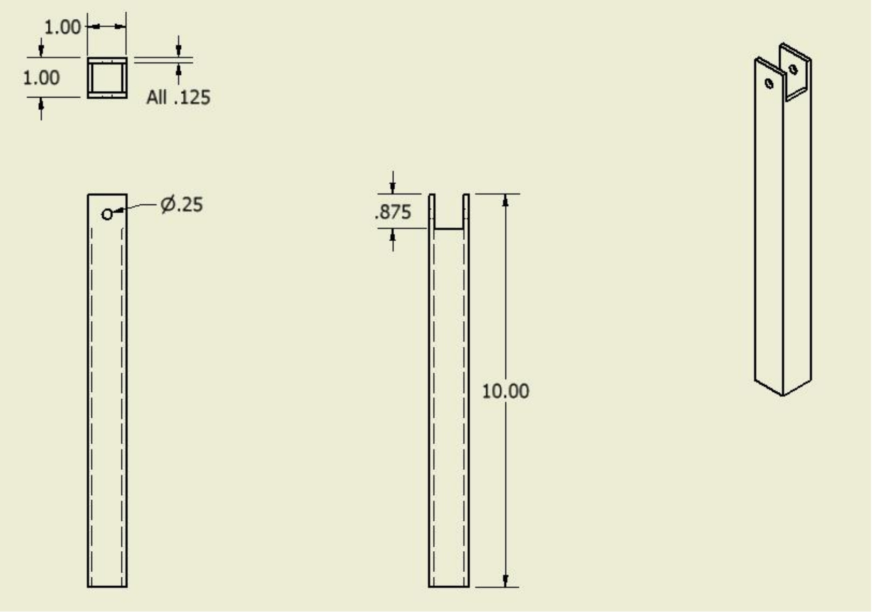
15.19.2 Cut four 0.375 in. thick pieces of aluminum to the dimensions of 1x0.375 using band saw using the same process as above

15.19.3 Weld 0.375 inch pieces to 0.125 inch thick piece in the positions shown above

15.20 Stirrup Housings

The stirrup housings are attached to the middle section. They are made out of hollow aluminum square pipe. They have a cross section of 1.0x1.0 inches and a wall thickness of 0.125 inches.

Figure 98: Manufacturing of the stirrup housings



15.20.1 Cut 2 square aluminum rods with a 1.0x1.0 inch cross section to a length of 10 inches

- Measure out to a length of 10 inches and make a straight line on the rod using a scribe.
- Set the band saw to a speed between 300-350 feet per minute.
- Make a straight cut following the line using the band saw.

15.20.2 Drill a 0.25 diameter hole at one end of the rods

- Measure out to a distance of 0.5 inches from the end and side of the rod (see Figure 98) and make a mark using a scribe.
- Drill a hole with a diameter of 0.25 inches at the marked off spot using the drill press.

15.20.3 Cut a 0.875 inch slot out of the end where the holes are drilled using the bandsaw

- Measure out to a distance of 0.875 inches from the end the rod (see Figure 98) and make a mark using a scribe.
- Set the band saw to a speed between 300-350 feet per minute.
- Make a straight cut following the line using the band saw.

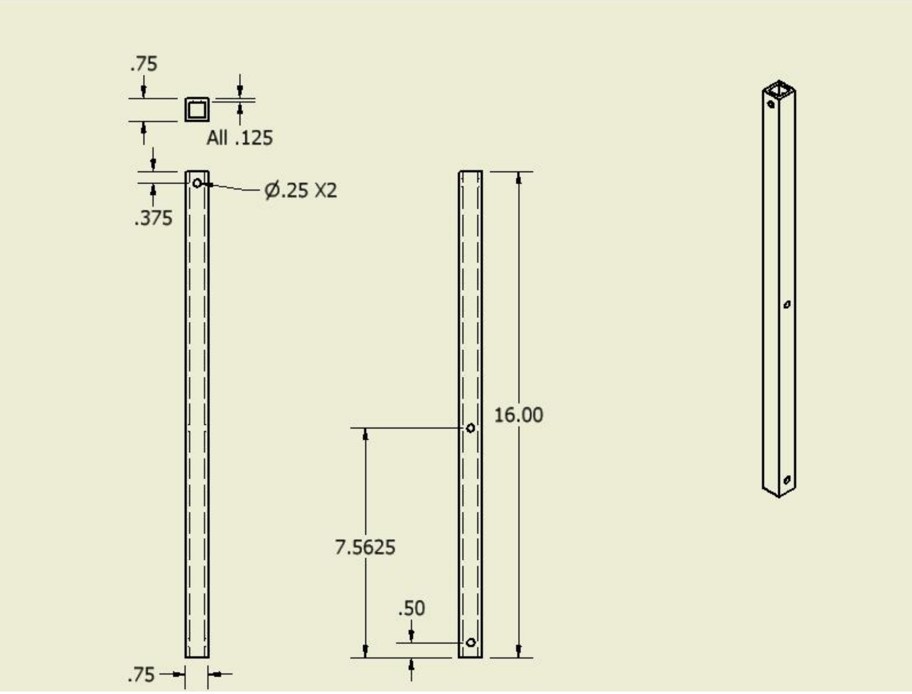
15.20.4 File all rough edges of aluminum

- Using a medium file, smooth all rough surfaces and edges

15.21 Stirrup Extension Rods

Two stirrup extension rods with a 0.75x0.75 inch cross section with a wall thickness of 0.125 inches are attached to the stirrup housing. The stirrups are then attached to the stirrup extension rods.

Figure 99: Manufacturing of the stirrup housing rods



15.21.1 Cut 2 square aluminum rods with a 0.75x0.75 inch cross section to a length of 16 inches

- Measure out to a length of 16 inches and make a straight line on the rod using a scribe.
- Set the band saw to a speed between 300-350 feet per minute.
- Make a straight cut following the line using the band saw.

15.21.2 Drill 6 0.25 diameter holes at positions shown in figure

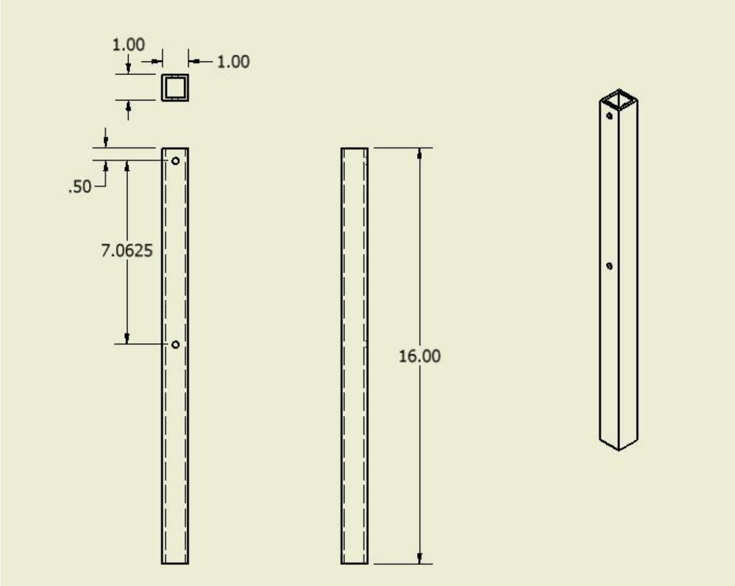
15.21.3 File all rough edges of aluminum

- Using a medium file, smooth all rough surfaces and edges

15.22 Stirrup Legs

Two stirrup legs with a 1x1 inch cross section with a wall thickness of 0.125 inches are attached to the stirrup housing. The stirrup legs are made of PVC and attached to the end of the extension rods.

Figure 100: Manufacturing of the stirrup extension rods



15.22.1 Cut 2 square PVC rods with a 1x1 inch cross section to a length of 16 inches

- Measure out to a length of 16 inches and make a straight line on the rod using a scribe.
- Set the band saw to a speed between 300-350 feet per minute.
- Make a straight cut following the line using the band saw.

15.22.2 Drill 2 0.25 diameter holes at positions shown in figure

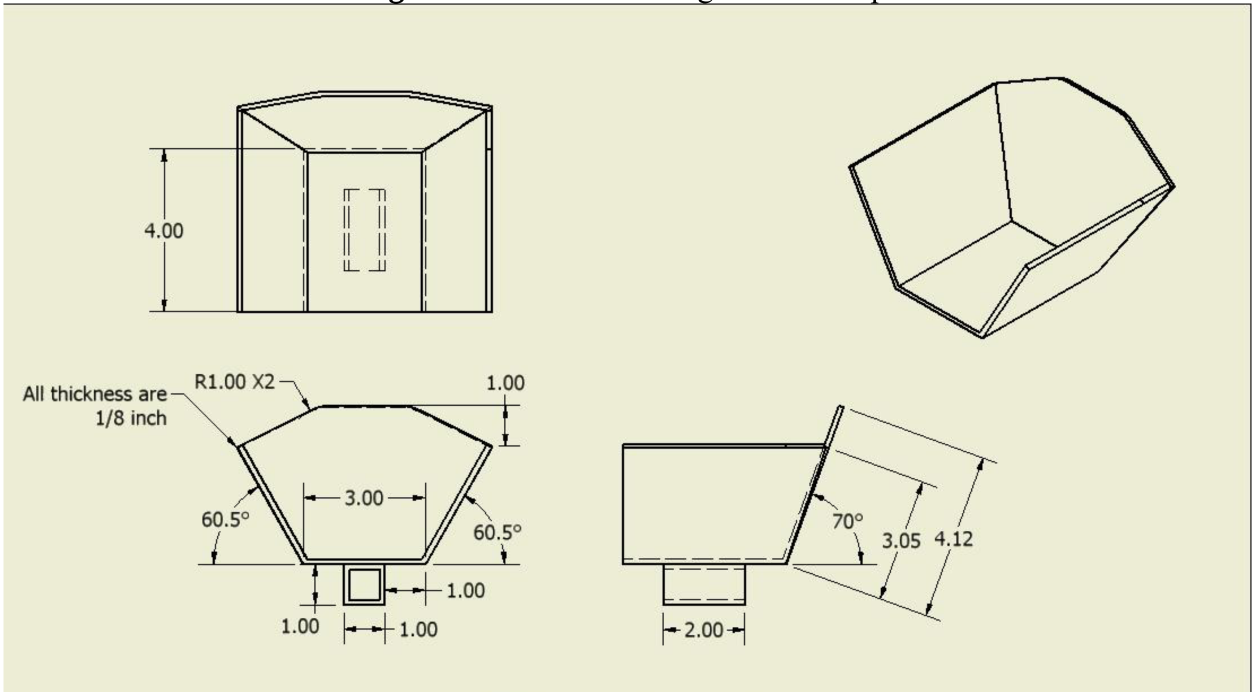
15.22.3 File all rough edges of PVC

- Using a medium file, smooth all rough surfaces and edges

15.23 Stirrups

Two stirrups were constructed using thin pieces of aluminum welded together. The stirrups were later covered with Plasti-Dip for aesthetic look, and the edges were covered with a soft adhesive covering.

Figure 101: Manufacturing of the stirrup



15.23.1 Cut 4 aluminum pieces for the sides of the stirrups

- Measure out the dimensions from the above figure
- Set the band saw to a speed between 300-350 feet per minute.
- Make straight cuts following the lines using the band saw.

15.23.2 Cut 2 aluminum pieces for the backs of the stirrups using the same technique as above

15.23.3 Cut 2 aluminum pieces for the bottoms of the stirrups using the same technique as above

15.23.4 Weld cut pieces together to form shape above

15.23.5 Cut 1x1 inch square aluminum stock to 2 inch in length

- Measure out the dimensions from the above figure
- Set the band saw to a speed between 300-350 feet per minute.
- Make straight cuts following the lines using the band saw.

15.23.6 Weld 2 inch long square stock to bottom of stirrup as shown above

16.0 ASSEMBLY OF OMEGA PROTOTYPE

Using the pieces that were manufactured as explained in Section 15.0 in combination with our purchased parts (see Appendix B for a complete Bill of Materials), we assembled the Omega prototype. First a sub-assembly of each section (foot section, middle section, and head section) was completed. Then each of these sections was assembled to the other two.

16.1 Foot Section Sub-Assembly

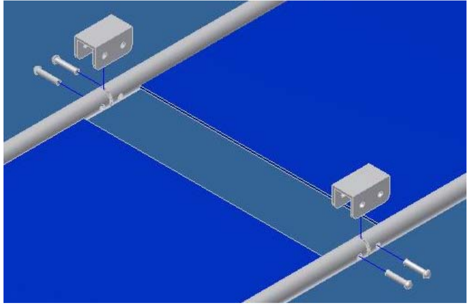
The foot section sub-assembly is the portion of the table that can be extended to create a section where the woman can place her legs. The complete foot section is presented in Figure 102 below.

Figure 102: Complete Foot Section sub-assembly

The following steps were taking to complete this sub-assembly.

16.1.1 The ends of the foot section frames are brought together. Then the foot section hinge is slid over the two frame bars until both holes line up. A ¼ inch bolt is inserted through both holes and a nut is put on the end to hold it in place. Figure 103 below demonstrates this step.

Figure 103: Step 1 in assembly of Foot Section

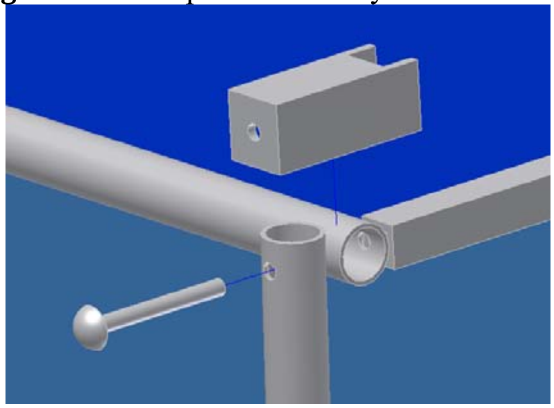


16.1.2 The second step simply involves sliding the fabric over the two connected frame pieces as shown in Figure 104 below. In our cause, there were already screw holes in the frame in which we could insert screws to hold the fabric in place. It may be necessary to create holes in the frame in which to screw the fabric down.

Figure 104: Step 2 in assembly of foot section

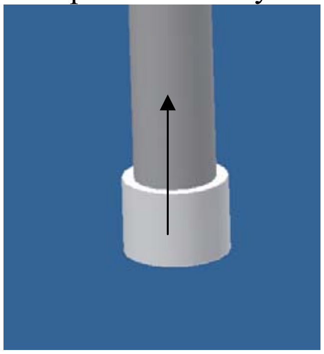
16.1.3 In this step, the legs are lined up to the holes at the end of the foot section frame. Once lined up, the necessary foot section leg joints are put over the frame and legs until all the holes line up. The U-channels on the joints should be facing inwards. A ¼ inch bolt is then slotted through all holes and locked with a nut on the other side. Figure 105 below displays this step in the assembly.

Figure 105: Step 3 in assembly of foot section



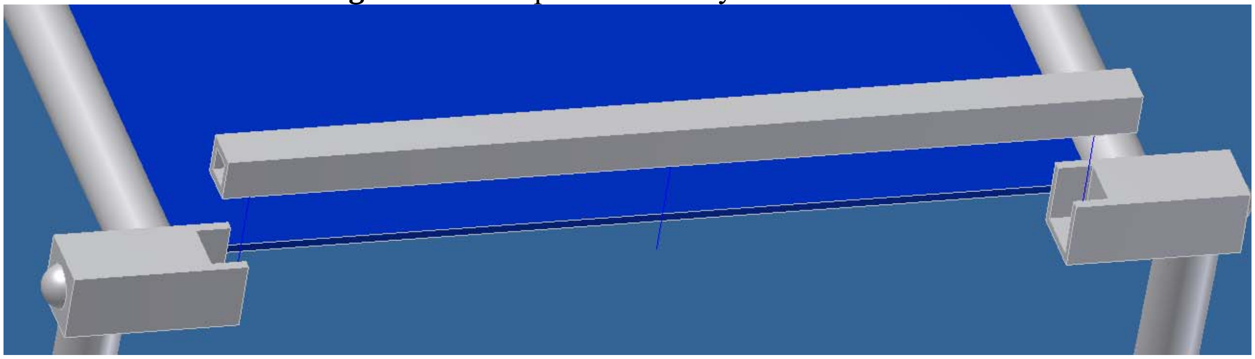
16.1.4 Slid rubber ends on the tips of both foot section legs. This will help prevent sliding and create a sturdier foot section. Figure 106 below displays the result of this step.

Figure 106: Step 4 in assembly of foot section



16.1.5 Insert cross bar two fit in between two foot section leg joints. The cross bar should be sitting on the bottom of the U-channels and pushing against the sides of the joints. Figure 107 below shows this step.

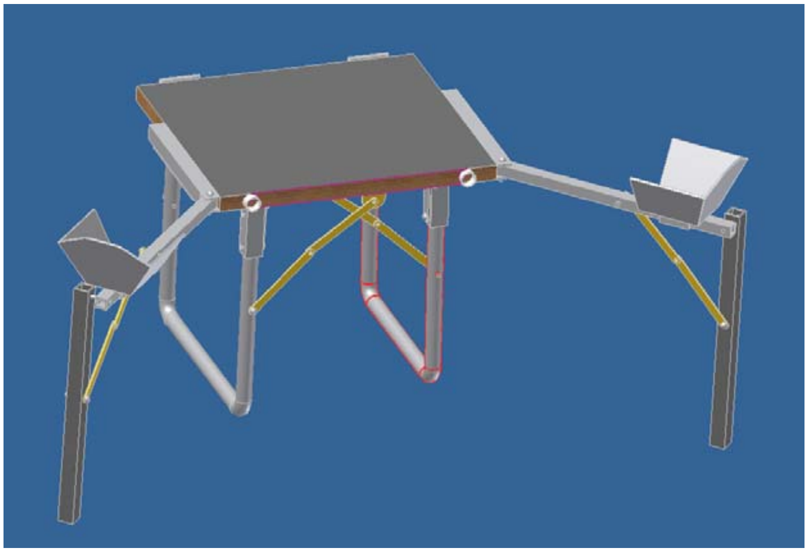
Figure 107: Step 5 in assembly of foot section



16.2 Middle Section Sub-Assembly

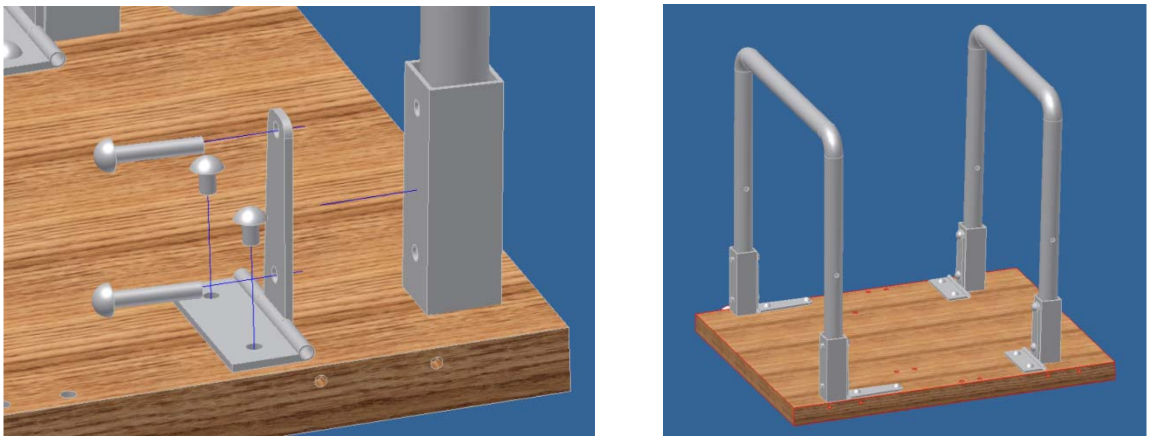
The middle section sub-assembly is where the buttocks of the woman will be placed during the examination. This is the section that will be holding most of the distributed weight. Figure 108 shows the completed middle section.

Figure 108: Completed middle section sub-assembly with stirrups



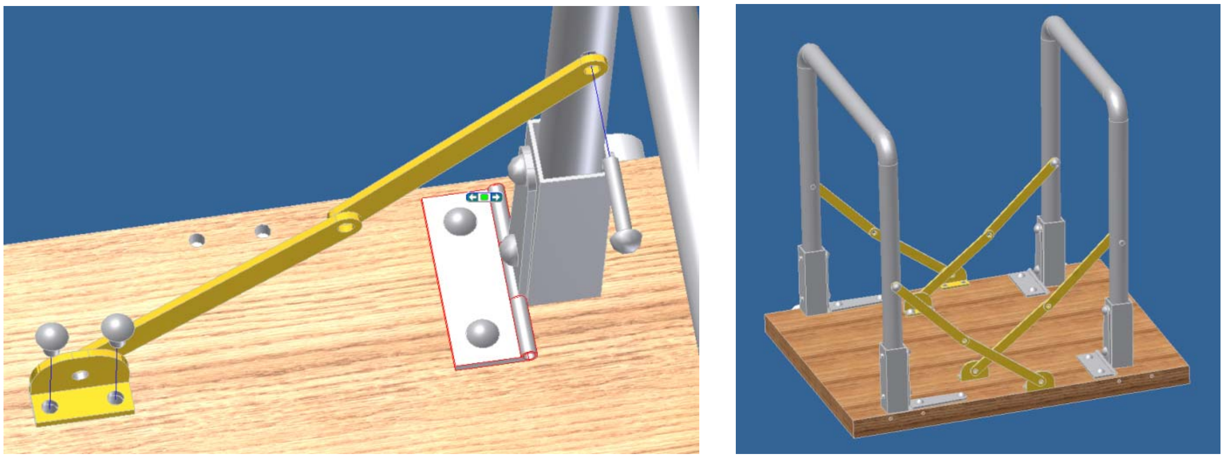
16.2.1 Connect the wide base T-hinges to the table using the necessary screws. Then attach the narrow middle section leg to the T-hinge using the necessary nuts and bolts. Repeat process again for the wider middle section legs.

Figure 109: Connecting middle section legs



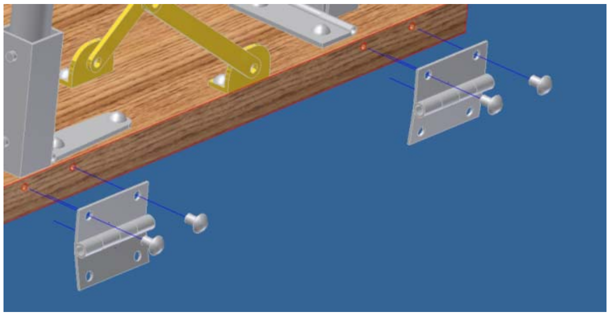
14.2.2 Screw in base of leg support struts using necessary screws. Using ¼ bolts, attach end of supports struts to side holes in the legs. Repeat until all 4 legs support struts have been attached.

Figure 110: Connecting leg support struts



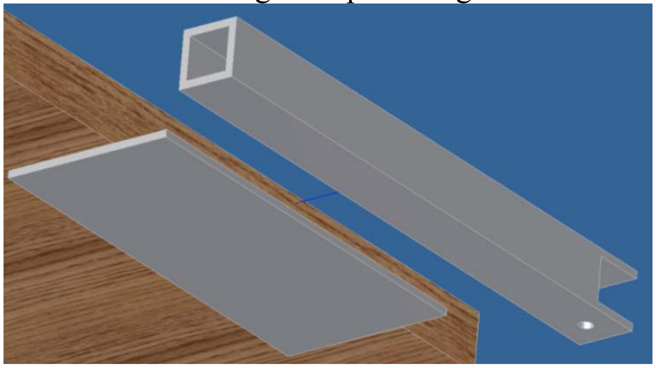
16.2.3 Attach hinge onto back of table using necessary screws. These hinges will attach the head section to the middle section.

Figure 111: Connecting door hinges to middle section



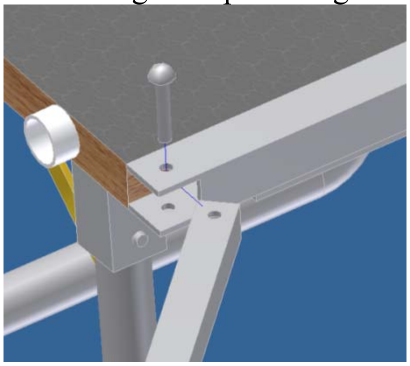
16.2.4 Attach stirrup housing to middle section. In our prototype, we did this by screwing in a flat panel on the bottom of the middle section that protruded out of the side. This housing itself sat on top of this panel and bolted onto it. Figure 112 below shows this panel without the screw holes and bolt holes.

Figure 112: Connecting stirrup housing to middle section



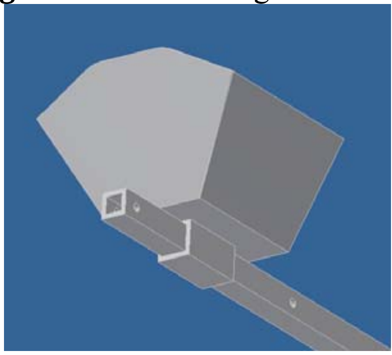
16.2.5 Insert the stirrup extension rod into the stirrup housing. Fit the extension rod into the open end of the housing until the holes line up. Then insert the necessary nut and bolt through all the holes.

Figure 113: Connecting stirrup housing to middle section



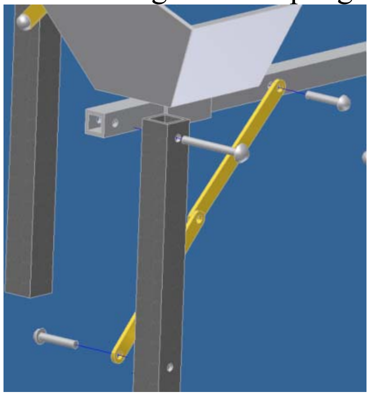
16.2.6 Slide stirrups onto the end of the extension rod. This needs to be done before the stirrup legs are attached or the stirrups will not be able to be put on.

Figure 114: Attaching the stirrups



16.2.7 Attach stirrup legs to extension rod with necessary bolts to allow for rotating. Once legs are attached, put on stirrup struts using necessary ¼ bolts. Struts allow for more stability and help with folding of the stirrups. The stirrups will be completely detachable. Once these struts are put on, the stirrups stay assembled but detached from the table at the stirrup housing.

Figure 115: Attaching the stirrup legs and struts

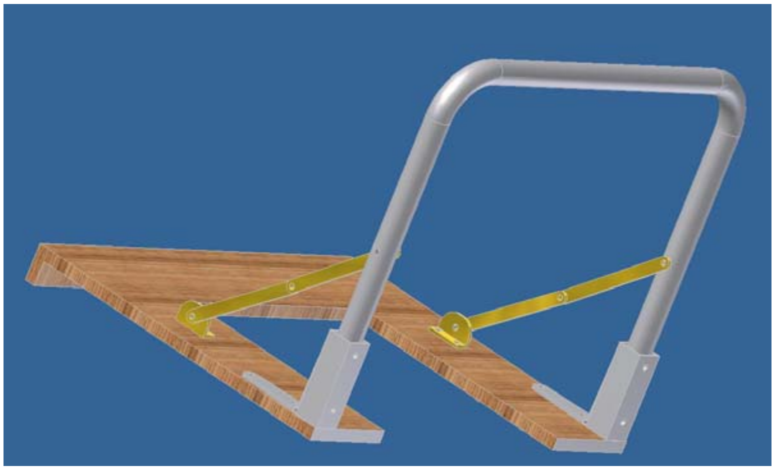


16.3 Head Section Assembly

The head section is where the woman will be resting her upper body. This section is supported by one leg and the hinge attached to the middle section. The head rest is inclinable to 30 degrees and 60 degrees. The following section describes the process when assembling.

16.3.1 Assemble the head section legs (Figure 116) by following the same method as the middle section legs (Section 16.2.1 on pg 90).

Figure 116: Assembled head section legs



16.3.2 Place the joint into the depressed slot in the base. Then use .25” long 3/16” diameter screws to secure it to the table (Figure 117). Repeat the same steps for the other joint. Position the adjustment notches so the holes line up with the holes on the base (Figure 118). Then, secure them to the table using .25” long 3/16” diameter screws.

Figure 117: Assembling the joints

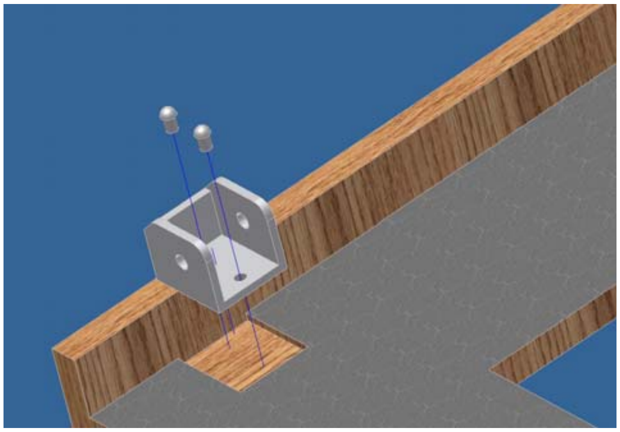
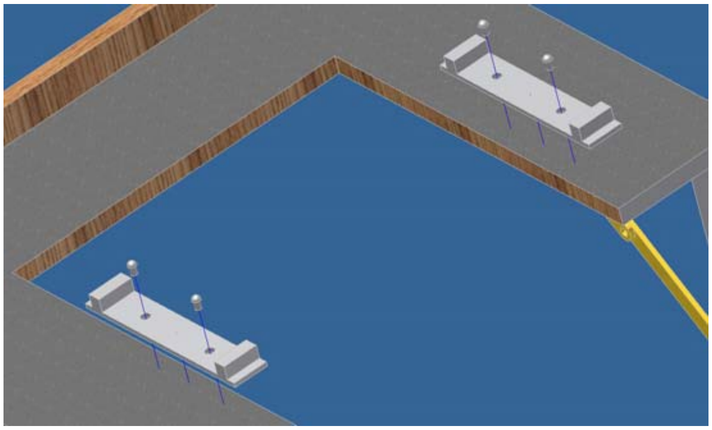
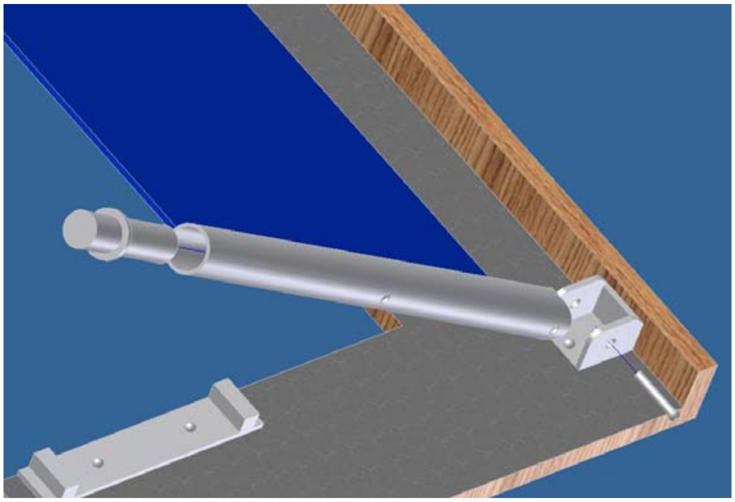


Figure 118: Assembling the adjustment notches



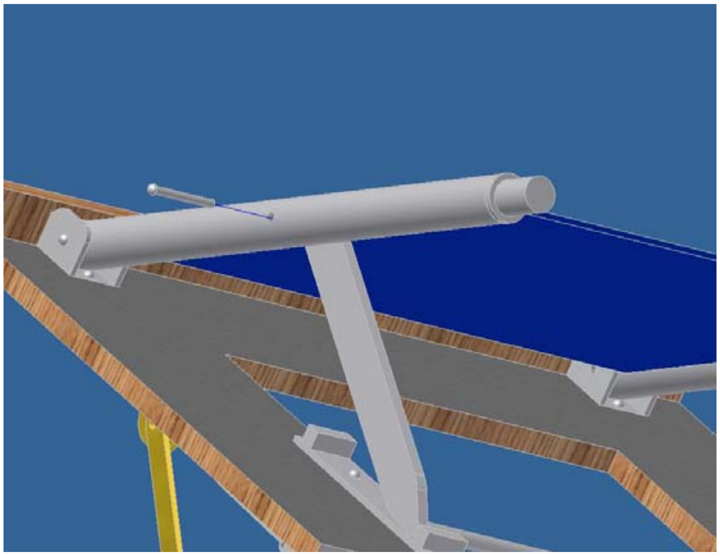
16.3.3 Align the tubes of the head frame in the joints so the holes line up. Then put 1.25" long 3/16" diameter bolts through the joints and secure them with a washer and nut. Then, insert the connectors into the end of the frame tubes (Figure 119).

Figure 119: Assembling the head frame



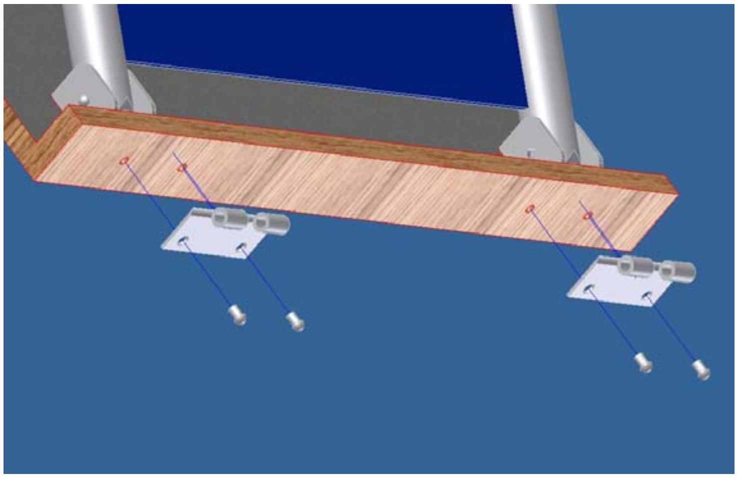
16.3.4 With the head frame assembled, place the adjustment rods behind the fabric, making sure that the holes align with those on the frame. Place the spacers in between the adjustment rods and the head frame, and then put 1.5" long 3/16" diameter bolts through the holes (Figure 120). Then, secure the end with a washer and nut.

Figure 120: Connecting the adjustment rods



16.3.5 To connect the hinges, align the holes with those on the front face of the base and then use .25" long 3/16" diameter screws to secure them to the table (Figure 121).

Figure 121: Connecting the hinges



17.0. FMEA ANALYSIS RESULTS OF PURCHASED COMPONENTS

A FMEA was performed on our purchased components. The only purchased components on our table are the hinges that connect the table sections. The hinges will be subjected to double shear stress because the screws will penetrate through the entire hinge. They will be subjected to everyday wear and tear. A bleach/water solution is the sanitation method used in Ghana, so the hinges will also experience corrosion If they become too rusty, the table will no longer be foldable and therefore useless. We will pick hinges that can withstand weak acid solutions, so that it can resist any corrosion due to the bleach/water solution. If one hinge fails, the leg or table section that it is connected to will no longer function because the component will no longer be able to open or close. However, replacement of the hinge is very simple and the only tool it would require is a screw driver to remove the old hinge and replace it with a new hinge. Any hinge can be used to replace the current T-hinges.

18.0 DESIGN SAFE RESULTS FOR MANUFACTURED COMPONENTS

A Design Safe analysis was performed on the components that we predicted are most likely to fail: hinges that connect the table sections, middle section, stirrups and table legs. (See Appendix G for all Beta design Dimensions). If any of these components were to fail, the table would not be able to serve for a pelvic exam and in most cases it would not be functional for any kind of use.

The hinges will be subjected to double shear stress because the screws will penetrate through the entire hinge. They will be subjected to everyday wear and tear. A bleach/water solution is the sanitation method used. The hinges will also experience corrosion and if they become too rusty the table will no longer be foldable and therefore useless. We will pick hinges that are compatible in weak acid solutions, so that it can resist any corrosion due to the bleach/water solution. If one hinge fails, the leg or table section that it is connected to will no longer function because the component will no longer be able to open or close. However, replacement of the hinge is very simple and the only tool it would require is a screw driver to remove the old hinge and replace it with a new hinge. Any hinge can be used to replace the current T-hinges being used.

The middle section for the Beta prototype is 19’’ long and 20’’ wide. The material selection is crucial for this component because it must be strong enough to support the patient’s weight but also comfortable, because it has the largest table contact with the patients skin. To reduce the risk of the middle section failure we have selected materials with yield strengths greater than the expected applied stress. We have also designed the table with dimensions that can support the patient entire body. Again if this component fails, the entire table fails.

The stirrups will bear the largest bending force due to the patient’s feet bearing down during the exam. If the moment created by the patient is larger than designed for, the stirrups could deform or the stirrup housing could break off the middle section of the table. To prevent this failure, we will design the stirrup housing with extra supports and the housing will be made of Aluminum 6061 alloy.

The table legs are the base and main support of our table. To enhance their strength we have designed the legs with a larger cross-sectional area of 1.56in^2. We have also chosen birch wood for a strong support that will not buckle or yield easily as explained in Section 11.0. If the table legs fail, the table fails to perform its function.

Before and after each exam the healthcare worker should perform a 30 second inspection of the table examining for fractures, cracks, unsteadiness, corrosion, etc.

19.0 ENGINEERING ANALYSIS OF OMEGA (REVISION B) PROTOTYPE

To finalize the Omega (revision B) design, we employed engineering equations and performed finite element models to validate the design and material selection. Table 10 below summarizes our engineering analysis.

Table 10: Summary of Engineering Analysis of Omega (Revision B) Prototype

Analysis	Capable	Maximum	Pass/Fail
Buckling in Legs	**805 lbs**	**313 lbs**	**PASS**
Stress in Middle Section	**707 lbs**	**313 lbs**	**PASS**
Compressive Stress in Adjustment Rod	**2.5 kpsi**	**34 kpsi**	**PASS**
Buckling in Adjustment Rod	**4163 lbs**	**313 lbs**	**PASS**
Buckling in Stirrup Leg	**1092 lbs**	**313 lbs**	**PASS**
Max Deflection	**0.1 in**	**NA**	**PASS**

19.1 Buckling in Legs

After choosing recycled aluminum frames for the table legs, we determined the critical buckling load of the legs. Using Equation 12 below, we entered the Young's modulus of Aluminum (9862 kpsi) and used the dimensions of our design to determine the moment of inertia and length of the table legs (16 in).

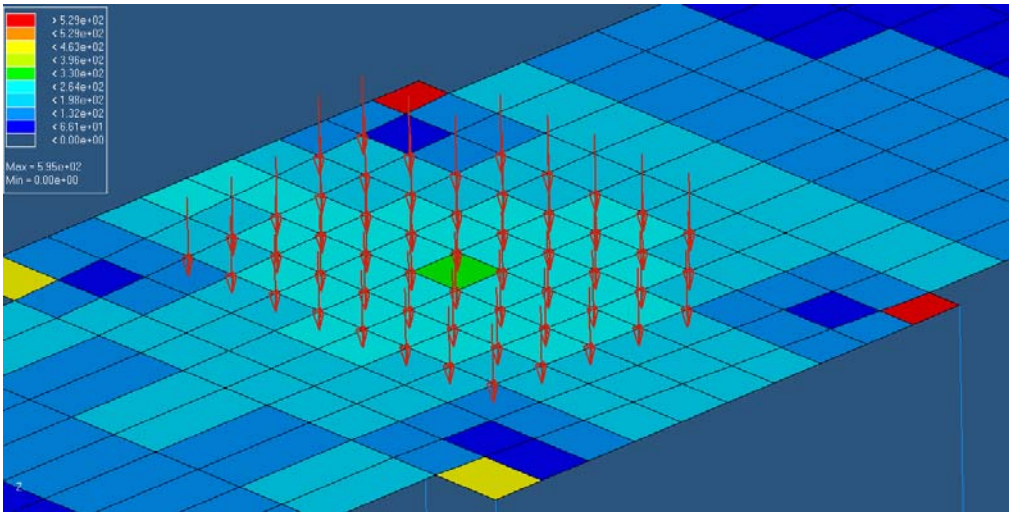
$$P_{cr} = \frac{\pi^2 EI}{L^2} \qquad \text{Eq. 12}$$

We obtained a critical buckling load of 805.43 lbs for one leg, a value much greater than the expected extreme maximum 313 lb load. With a factor of safety greater than 2, we are confident that our legs will not buckle under the load of a patient.

19.2 Stress on Middle Section

To make sure that the middle section would not yield under the load of the patient, we analyzed the bending stress caused by a pressure load. Using Hypermesh solver, we performed a finite element model to determine the maximum pressure load the middle section can hold before yielding. This was conducted by adjusting the pressure load until the maximum stress was just under the yield stress of aluminum (600 psi). With a distributed pressure of 3.4 psi the maximum stress converges to 595 psi which is less than the yield stress of aluminum. Therefore, using Equation 13, 3.4 psi (distributed over the area of the middle section) comes to an applied load of 707 lbs which is more than double our expected weight of 313 lbs. Also, notice the largest stress and largest bending moment is located at the corners of middle section (shaded in red and yellow) in the hinges that connect the table section to the legs as shown in Figure 122.

Figure 122: Location of stress and bending moment of middle section are greatest at the corner hinges.



$$P = \frac{F}{A} \qquad \text{Eq. 13}$$

Along with this we wanted to determine the effect of impact in case the woman doesn't set herself on the table as softly as desired. For this, we determined the energy of a woman falling right before she hit the table, then divided this energy by the distance it takes her to decelerate. For the middle section, we determined the impact force of a 313 lb woman falling from 3 inches. The 3 inch height was determined through deliberation as we figured this would be a general height a woman might drop from if she underestimates how far she has left to go before hitting the table. Using the general kinetic energy equation, Equation 14, we were able to determine her kinetic energy just before hitting the table.

$$KE = \frac{1}{2}mv^2 \qquad \text{Eq. 14}$$

Where *m* is the woman's mass and *v* is her velocity just before hitting the table. The velocity was determined by assuming an object starting from rest from three inches. Once we've determined her kinetic energy, we divide that by the distance it takes her to decelerate. The woman's buttock is what will be slowing her down. It was difficult to find data on the thickness of the buttocks, so we assumed a thickness of 1.5 inches including the table bedding. With all this data we determined an impact force of 624.2 lbs which is less than the capable 707 lbs.

19.3 Buckling on Stirrup Legs

During an exam, the stirrups must support the weight applied by the patient's legs. Also, the patient may adjust themselves during the exam which will add an impulse force to the stirrups. We wanted to make sure that the stirrup legs would not buckle under these loads. Therefore, we analyzed the critical buckling load present during an exam. When adjusting themselves, the patient will put a force on the end of the stirrups in order to lift them self off the table so they can reposition them self. Therefore, we equated the maximum force that would be applied to the stirrup to the maximum weight of a patient, 313 lbs (as if the patient were standing on the stirrups). It should be noted that this is an overestimate, since the patient will most likely distribute half of their weight to each stirrup and other portions of their weight on the table sections.

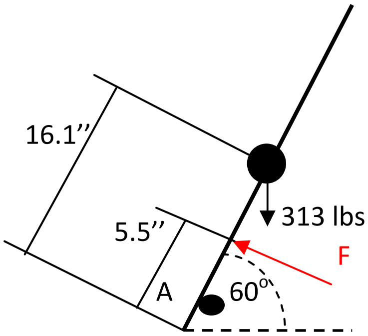
Using Equation 15 and setting the Young's Modulus to that of PVC (340 kpsi), we found that the stirrup legs are each capable of supporting 1092 lbs before buckling. The stirrups are capable of supporting more than three times as much as our exaggerated projected force. We concluded that the stirrups will not yield under operating conditions.

$$P_{cr} = \frac{\pi^2 EI}{L^2} \qquad \text{Eq. 15}$$

19.4 Adjustment Rod Compressive Stress

When the back rest is at an angle, the weight of the patient's torso is completely supported by the two adjustment rods. Due to the size of these rods, we weren't sure if aluminum would be a strong enough material to make these out of. Therefore, we analyzed the compressive stress on the adjustment rods when the back rest is at an angle of 60^o, and our maximum-height-and-size patient is resting on the table (when the adjustment rods support the most weight). A model was created in order to quantify the forces on the adjustment rods, and can be seen in Figure 123 below, where F is the force exerted on the Adjustment rod.

Figure 123: Modeled forces on adjustment rods



Using this model, we performed a moment balance about point A. This yielded an adjustment rod reactionary force F equal to 1251.6 lbs for both adjustment rods and 625.8 lbs for one adjustment rod. Distributed over an area of 0.25 in^2 and using Equation 16 the compressive stress on one adjustment rod is 2.5 kpsi.

$$\sigma_c = \frac{F}{A} \qquad \text{Eq. 16}$$

Looking at the material properties of aluminum in CES, we found that the minimum compressive strength of aluminum is 34 kpsi. We then concluded that it was safe to make the adjustment rods out of aluminum, as there is a factor of safety of greater than 13 for the compressive stress of the adjustment rods.

19.5 Adjustment Rod Buckling

Since we determined that the compressive stresses present on the adjustment rods were not a significant concern, we went on to analyze the buckling effects on the adjustment rods. Using the buckling equation (Equation 15), we entered the Young's modulus of aluminum (9862 kpsi), the moment of inertia, and the dimensions of the adjustment rods. We found that each adjustment rod was capable of supporting 4163.3 lbs, while the greatest load we have specified them to bear is 313 lbs (the entire maximum weight of the patient on one adjustment rod). We used 313 lbs to account for any impulse forces created by the patient shifting their weight or falling back on the back rest.

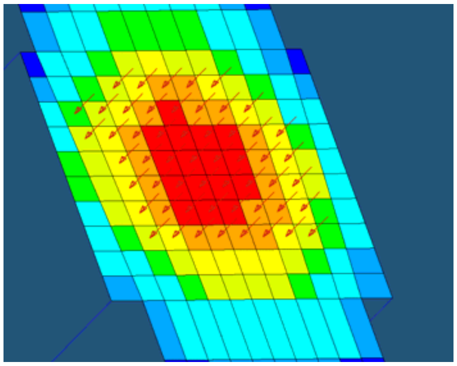
For this section we also wanted to considered impact force. We again assumed a direct force on the rod being dropped from 3 inches. This was determined through deliberation as we figured this is a height a woman may let up and let her back fall onto the back rest. For this we assumed an object being dropped straight down from 3 inches for ease of calculation. However, it is important to note that this will give us an even greater impact force than a woman leaning back. So if these calculations meet the requirements, it is even better than the actual impact force.

Using the same process as we did before to calculate impact force, we found that her force will be around 926 lbs. This is found with a stopping distance of 0.5 inch. This is assuming a table thickness of 0.4 inches and skin thickness of 0.1 inch. However, this is much smaller than the capable force of 4163.3 lbs, so we are safe from impact forces.

19.6 Deflection of Middle Section

Using Hypermesh, we performed a finite element model to determine the amount the middle section will deflection due to the applied pressure load of 3.4 psi (707 lbs). Figure 124 shows the greatest deformation will occur in the center of the table (shaded red and yellow elements). The maximum deflection will be 0.1 in at the center of the table.

Figure 124: Finite element model of the middle section deflection.



19.8 Bolt Shear

The biggest concern with wood is that the wood will fail before any screws, bolts, etc. Therefore, we want to make sure that the bolts do not create a shear stress that is large enough to crack the wood. For this analysis, we focused on the middle section of the table since it will support most of the patient's weight. Of the screws holding the middle section together, 4 of them will be subject to shear forces from the patient's weight. Since the screws are stronger than the wood, they will transfer this force to the wood. We know that each screw goes all the way through the side pieces of the middle section, and so we analyzed the stress with Equation 17 below.

$$\sigma_\tau = \frac{F}{4A} \qquad \text{Eq. 17}$$

For the force, F, we used the weight of the maximum weight of a patient (313 lbs), and the area is the cross-sectional area between the screw and the wood (the area of contact). The results yielded a shear stress of 20.3 psi. Compared to the shear strength of birch (839.7 psi), we see that wood tearing is not a significant risk.

20.0 VALIDATION TESTING OF OMEGA (REVISION B) PROTOTYPE

We will test the majority of our engineering specifications, however due to limited resources and time we cannot test every engineering specification. Table 11 below lists the engineering specifications that have been validated through experimentation. Due to limited time, we were not able to test for the table's lifetime.

Table 11: Validated Engineering Specifications.

Engineering Specification	Target Value
Support Weight	More than 313lbs
Table Weight	Less than 22lbs
Bedding Thickness	Less than 1''
2 Detachable Stirrups	35-50 Degrees
3 Adjustable Back Angles	0, 30, 60 Degrees
Non-Corrosive	100%
Travel Pack Water Resistant	100%
Length(unfolded)	More than 62''
Width(unfolded)	Less than 24''
Height(unfolded)	Less than 20''
Length(folded)	Less than 20''
Width(folded)	Less than 20''
Height(folded)	Less than 7''

To determine the amount of weight the table is able to support, we loaded it with 313 lbs to observe if it will fail and the table was able to support the specified 313 lbs. We also did the load test on an uneven surface and a soft (grass/dirt) surface and the table did not fail with 313 lbs meeting our specification. We have not loaded this table to failure because we want to use it for field testing in Ghana this summer and get user feedback to improve the design.

The table was weighed using an eye level beam scale and the table weighs a total of 21lbs which is less than our engineering spec of 22 lbs.

The back angle adjustments and stirrup angles were measured using an electronic protractor. The back angle can be adjusted to 3 different angles of 0°, 30°, 60° which meets our engineering specification. The stirrups were specified to range from 35 – 50°. However, since we used a thumb screw as our angle adjustment mechanism, the stirrups angles can range from 0 – 90° which covers the 35-50° specification. However, the thumb screw that allows for the angle adjustment is sensitive and so a small force can cause the stirrups to move to a different angle easily.

A corrosion test was completed on wood, aluminum, hinges, and PVC. The materials were soaked in a bleach/water solution for 72 hours and then were left to sit for 24 hours. We visually inspected no effects of corrosion on any of the materials. All rotating and adjustable components were still able to move.

A water resistant travel pack was bought off the shelf made of 210D antimicrobial nylon / 600D polyester. The bag is specified to be water resistant and the dimensions of the bag are 18'' x 10'' x 18'' which is large enough to fit the Omega design.

The dimensions of both the folded and unfolded were measured using a hand measuring tape. The unfolded dimensions are: 72'' x 17'' x 18''. The folded dimensions are: 18'' x 17'' x 6''. Both folded and unfolded dimensions meet our specifications.

21.0 ERGONOMIC TESTING OF OMEGA (REVISION B) PROTOTYPE

In addition to the validation testing done to the Omega design, we have also performed Ergonomic testing to determine how comfortable and easy it is to use the table. The following sections describe the tests we executed in order to test the ergonomic aspects of our table.

21.1 Assembly and disassembly time

We tested the time it takes to assemble and disassemble the table. We wanted to aim for an assembly and dis-assembly time of 2 minutes. We tested it using experienced members from our own team, members who are familiar with the project but have not contributed, and members who are not familiar with the project and have never seen the table. All participants were given an assembly manual. It took experienced team members an average 2 minutes to assemble and disassemble. It took participants with who are familiar with the project an average 2 minutes and 24 seconds to assemble and 1 minute and 46 seconds to disassemble. It took participants with no experience an average of 4 minutes to assemble and 2 minutes and 30 seconds to disassemble.

For each group, the components that required the greatest assemble/dis-assembly time was the stirrups, an issue we address in the Section 24.0.

It is important to note that there is no hurry when assembling and disassembling the table. The examiner will have as much time as they need. We would like the times to be as small as possible. However, it is not detrimental if the assembly time takes longer than 2 minutes.

21.3 Mock Exam

In order to see how comfortable the table is for the patient, and healthcare worker, we imitated a mock exam. For this test, we had a mock patient lay on the table with their legs in the stirrups and on the foot section, and with their backs elevated in all 3 angle positions. The patient was asked about comfort, security, and ease of adjustment. Refer to Appendix A.5 for survey responses.

The mock healthcare worker was positioned on a stool 10’’ off the ground and asked to try and enter the pelvic region of the patient. The healthcare worker was asked questions about the stability of the table, if they expected it to tip, the comfort of the stool, ease of use of the stirrups and back angle adjustment, ease of access to the pelvic region. Refer to Appendix A.5 for survey responses.

22.0 MAINTENANCE OF OMEGA (REVISION B) PROTOTYPE

We want to make maintenance of the Omega (Revision B) prototype an easy and smooth process to prevent any delays.

22.1 Table Sections

For our design to be successful, it must be easily maintained. Despite our engineering analysis, unforeseen circumstances may cause pieces to break, rendering the table unusable. Instead of the table being cast aside, however, it can be fixed in Ghana. One of Ghana’s natural resources is ceiba wood. This wood is similar to birch, which makes it a suitable candidate for replacement of the middle section and head section base. Therefore, if any wood components break, they will be able to make replacement parts using local resources.

The head and foot section can be also be replaced from recycled aluminum or light steel parts (from chairs, tables etc.) as long as they are cut to the right dimensions or they can be bought from various vendors. Replacing the table sections will require the table to be out of service for a few days based upon availability and deliver time of parts.

22.2 Joints

The hinges we selected are not design specific, meaning that the hinges we picked out are not the only hinges that will work. As long as the hinges can rotate at least 180 degrees, they are suitable for our design. If any of the hinges become damaged or broken, they can be replaced by a similar type of hinge.

22.3 Adjustment Rod

If the adjustment rods fail, there are multiple options. Ghana does have steel resources if they want them to be made of metal; however, steel will be much heavier and will cost more to make. They also have plenty of wood resources, and could make the adjustment rods out of wood if they so desire. Lastly, they could simply not replace the adjustment rods. The back incline is not a necessary feature for a pelvic exam, and the table will lose no functionality without an adjustable back rest.

22.4 Stirrups

If the stirrups fail, they can be replaced using aluminum or other light steels which may be difficult to find in country. However, the table can still be used for general purpose exams if the stirrups do fail.

22.5 Fabric

A tear in the fabric can be easily sown up in the country of Ghana or the entire fabric can be replaced if needed for a cost of $2-5 plus the cost of fabric ($8-10) (Kofi).

22.6 Cleaning

Due to bodily fluids possibly leaking during a pelvic exam and to help prevent the spread of infection the table must be cleaned after each use. The table can be cleaned using the common bleach/water solution since the materials selected are not corrosive in weak acids environments. All components should be wiped completely dry otherwise the chance of corrosion increases. The fabric does not need to be removed before cleaning.

23.0 CURRENT CHALLENGES

Due to the nature of the problem we are aiming to solve, there are constraints on our design that will create challenges that we must overcome.

23.1 Cost/Materials Selection

Our initial budget was $35, however after reviewing material and manufacturing costs we realized that this budget was out of reach. After speaking with Dr. Ofosu we came to an agreement that the hospital would be willing to spend up to $300 on the portable pelvic examination table. We built the Beta design under $70 and our Omega design under $80. This new budget is more than enough to build our design, however we still want to make it as low cost as possible so that many tables can be purchased with the $300 budget, therefore we want to set a high end goal of fabricating the table for under $100 but still want to minimize this cost as much as possible. Therefore, we are still facing the cost issue of selecting strong but low cost materials for every component. Components that will support the greatest load such as the middle section and the adjustment rod will be made of stronger materials that are relatively more expansive than materials selected for the foot section which will not bear as much load.

23.2 In-country manufacturing

Ultimately we want the table to be manufactured in Ghana. But for this version of the design we want to the materials to be accessible in Ghana. Therefore, we are constantly battling with material selection so that all the materials or even similar materials can be found in country. The second design version of the table will address the issue of in-country manufacturing.

23.3 Stirrups

Only one prototype of the stirrup was fabricated, so we only have one design to analyze. The stirrup design is not stable and a disadvantage to the design is that it takes a long time to detach the stirrups due to the thumb screw that connects the inner housing to the outer housing. The re-design of the stirrups will be discussed in detail in Section 24.0.

23.4 Travel Pack

The travel pack was purchased off the shelf and although we did find a water-resistant pack that does fit the table, the opening to the pack is too small and so must therefore be adjusted so that it is wider and so that table can enter the pack. Section 24.0 discusses the future work of the travel pack to address this issue in more detail.

24.0 FUTURE WORK

Although the Omega design is complete we are still facing challenges and improvements can still be made.

24.1 Stirrup Design

Our major concern with the table is the stirrup design since it is not as stable as we would like it to be. The grounded stirrup is a good start but needs improvement on keeping it stable and sturdy. A different mechanism, other than the thumb screw, should be used to tighten the two stirrup housings together and to adjust the stirrup angle because the thumb screw can loosen making it easier to adjust the stirrup angle by applying a small force and it also takes a long time to remove the thumb screw when detaching the stirrups.

24.2 Strengthen Legs

The table legs were made from recycled aluminum pieces and so could not be changed to our ideal shape. As a result, the curved middle section legs will roll when the weight is not placed at the center of the middle section. In the future, it would be beneficial to use legs with flat/straight edges instead of round edges. A door stopper can easily be placed at the back of each leg to prevent the legs from rolling up, however it would be ideal to redesign the legs.

24.3 Strengthen Leg Hinges

Continuing to strengthen the leg hinges is important because they will support the majority of the weight. In the future, it will be helpful to use stronger hinges to connect the legs to the table.

24.4 Decrease Weight/Cost/Components

Portability is the main feature of the table; therefore we should always aim to keep reducing the weight of the table either by changing material, dimensions, or shape. The cost of the table can always be reduced by changing materials or dimensions.

One of the disadvantages of our table is the many separate components that need to be assembled. In the future, it would be more efficient to have a table with fewer components while still keeping the table compact.

24.5 Travel Pack

The opening of the travel pack is too small for the table to slip through. The zipper will be removed so that we can create a greater opening and then we will re-attach the zipper. This will allow for the table to be placed in the pack and zipped around the pack as opposed to sliding the table into the pack.

24.6 Carrying Test

It is important to determine the ease of portability and comfort of the examination table while in the pack. Therefore, it would be very beneficial to test the comfort of the pack for a healthcare worker while walking and while riding a bike. Ask the participants to carry the pack for a specified distance and then have them compare it to a standard backpack loaded with the same amount of weight. Ask about strain on back and comfort of the pack.

24.7 Field Testing

The Omega design will be field tested from May- August of 2009 in the Sene District of Ghana with the assistance of a team member (Joseph Persoky). Joseph will receive and utilize any user feedback from the healthcare workers and patients to help improve the design. He will also explore common materials that can be found in Ghana to help with in country manufacturing.

24.8 Hand Bars/Securing straps

It would be convenient to add hand bars to the side of the table so that the patient can easily lower themselves, adjust and rise from the table.

It would also be helpful to add straps to the table so that when folded, the straps can aid in keeping the table closed.

25.0 PROJECT PLAN

In order to have a fully functionally working prototype by April 16, we developed a project plan that set us up for success. Our strategy was to always plan ahead and pad our time. We devoted double the predicted time for meetings, manufacturing, research, etc then anticipated to allow for any emergencies or back tracks. We planned to have all assignments completed a few days before they are due to allow for clear revisions. Each team member took part and contributed in every phase of our project plan. With the help of each team member and the detailed project plan we were able to complete the Omega prototype by April 16 and complete all validation on the Omega prototype by April 20.

- Phase I (January 7 – January 28)
    - Develop design criteria
    - Determine engineering specifications
    - Design review 1 presentation and paper
- Phase II (January 28 –February 20)
    - Create at least 20 design concepts
    - Create sketches and CAD models for design concepts
    - Determine Alpha design
    - Design review 2 presentation and paper
- Phase III (February 20 – March 27)
    - Refine Alpha Design to Beta design
    - Clinic Visit
    - Complete FEA
    - Choose Materials
    - Determine Manufacturing Process
    - Fabrication and hardware testing
    - Build Beta prototype
    - Begin to order materials for Omega design
    - Design review 3 presentation and paper
- Phase IV (March 24 – April 21)
    - Complete Omega design (March 24 – March 29)
    - Test and validate Beta design (March 24 – 28)
    - Finish ordering materials of Omega design (completed March 30)
    - Build Omega design with stirrups (March 30 – April 7)

    - Design travel pack (March 30 – April 4)
    - Seam the travel pack with straps (April 5 – April 20)
    - Test and validate Omega design with travel pack (April 8 – April 20)
    - Design review 4 presentation (April 10)
    - Design Expo Poster (April 10 – April 15)
    - Design expo (April 16)
    - Final paper (completed April 20)
- Phase V (April 28 – August 1)
    - Test in Sene District of Ghana (May 19 – August 6)

A detailed schedule of our project plan can be found in Appendix A.2. Using our QFD, functional decomposition, customer requirements, engineering specifications, and Pugh charts we have chosen our preliminary Alpha design, evolved it into our Beta design and are continuing to improve our design to transform into our Omega design. Even the Omega will continue to improve as we encounter more challenges and make new improvements.

The team roles are specified below. The team roles were determined by each team member's strengths, weakness, and preferences.

- James Bradshaw
    - CAD designer
    - Design researcher

- Adam Gienapp
    - CAD designer
    - Secretary

- Rebecca Rabban
    - Treasurer
    - FEA analyst
    - Materials analyst

- Joseph Perosky
    - Team contact
    - FEA analyst
    - Cultural Research

The Omega design is completed and prototyped and is ready to be field tested in the Sene District of Ghana. A team member of ours (Joseph Perosky) will be in Ghana this summer receiving user feedback on the Omega prototype. The feedback will be used in a second version design.

26.0 CONCLUSION

The problem our team is resolving is to design and build a portable pelvic examination that includes all necessary gynecology equipment. The most important customer requirements, determined from our mentors are it must be portable, light weight, low cost, easy to use/assemble and safe. The engineering specifications were determined using the customer requirements. Using both our customer requirements, engineering specifications, QFD, and functional decomposition we were able to determine over 20 design concepts which were then broken down into their main components. We selected the best design for each component using Pugh charts to come to our Alpha Design. Our Alpha design has evolved into our Beta design which has been prototyped and evaluated. Using our pros and cons we came to our final Omega design which was also prototyped and validated. The Omega design meets every engineering specification except for bedding thickness on the middle section.

Our next step from here is to make changes discussed in Section 24.0 so that we can begin field testing in the Sene District of Ghana. The field testing will provide user feedback that we can use to re-design for a new and improved table.

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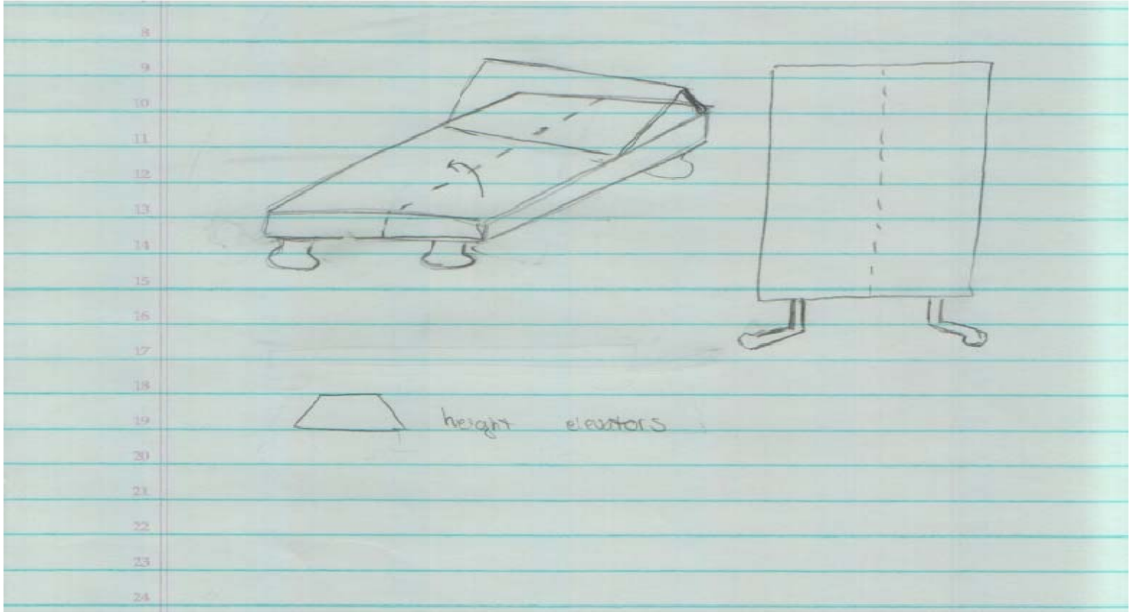
APPENDIX A.1 CONCEPT DESIGNS

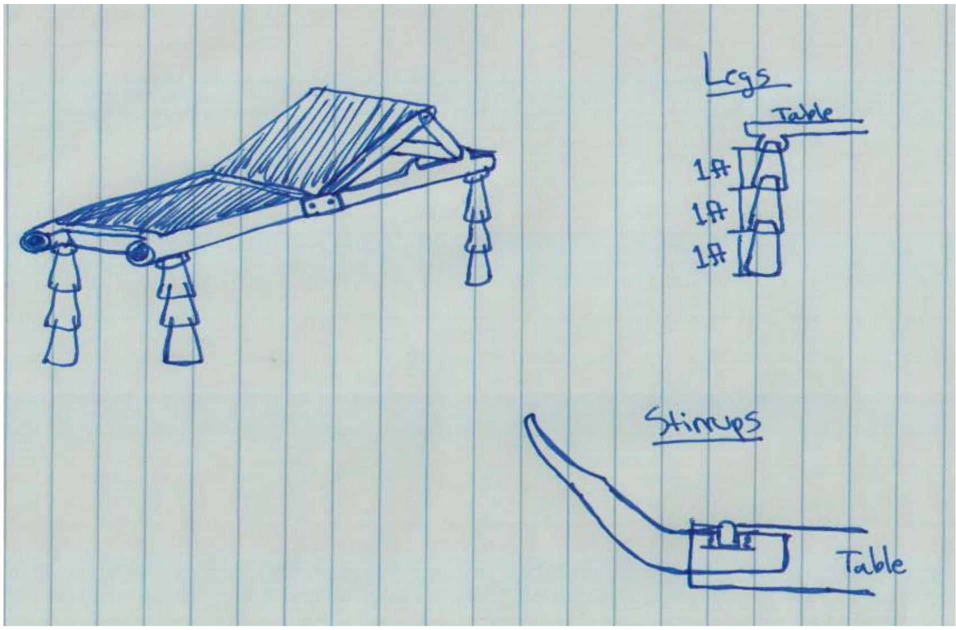
A.1.1 Concept Design 1

This shows a complete table concept design. It consists of a table those first folds in half width wise and then length wise. Underneath the table, there will be tracks where the legs slide in. A wedge is placed at the head using velcro for back angle adjustment. Blocks can snap into the table legs to allow for table elevation. The stirrups slide out of tracks from underneath the table.



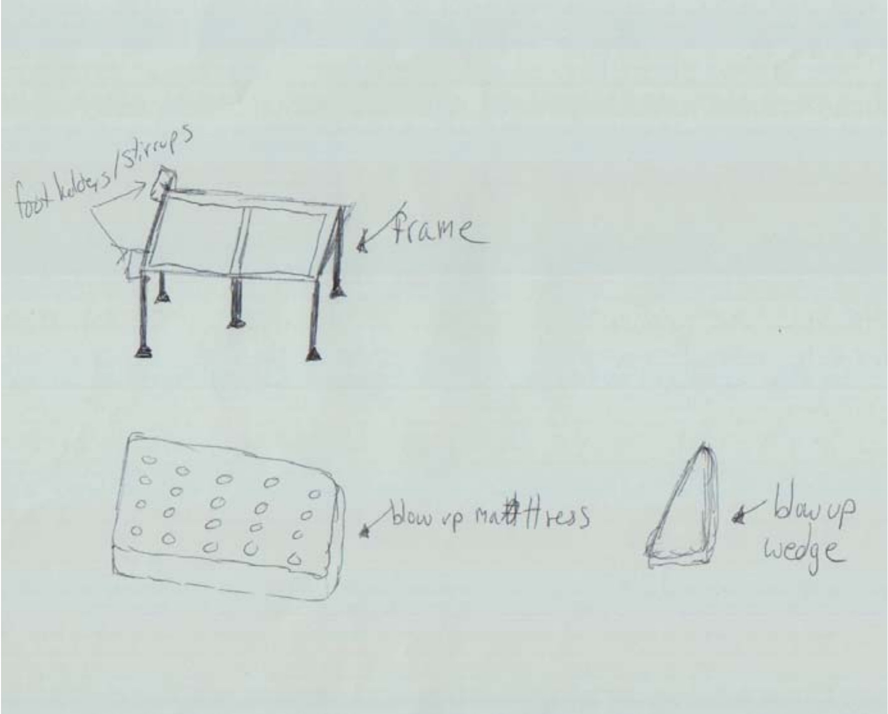
A.1.2 Concept Design 2

This shows a design where the table is made of a frame that elevates at the top to adjust the back angle, using notches that the frame slides into. The table height can change due to cones that can be added underneath the legs. And the stirrups slide out of the table frame at the bottom.



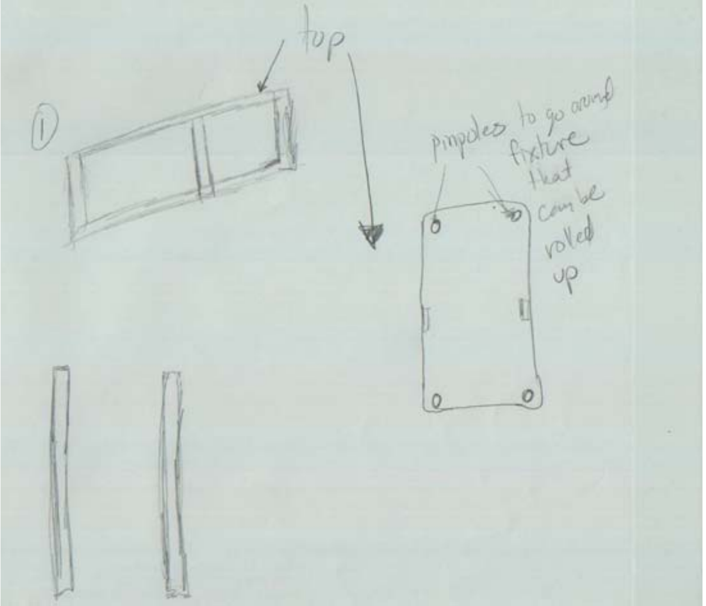
A.1.3 Concept Design 3

This shows a design concept where the table bed is inflatable and sits on the table frame. The table legs fold underneath the table as does the stirrups. It uses an inflatable wedge for back angle adjustment.



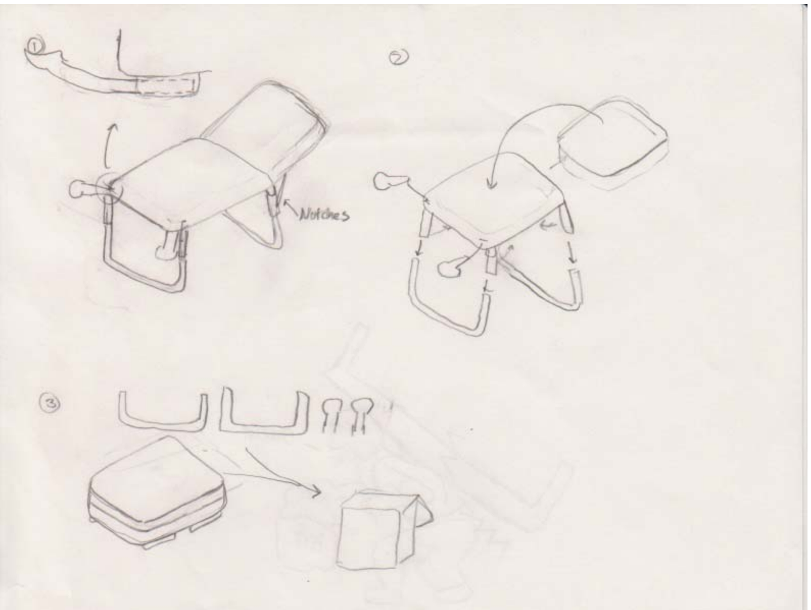
A.1.4 Concept Design 4

This shows a complete design concept where every piece of the table is detachable. The table bed and table legs lock into the table frame.



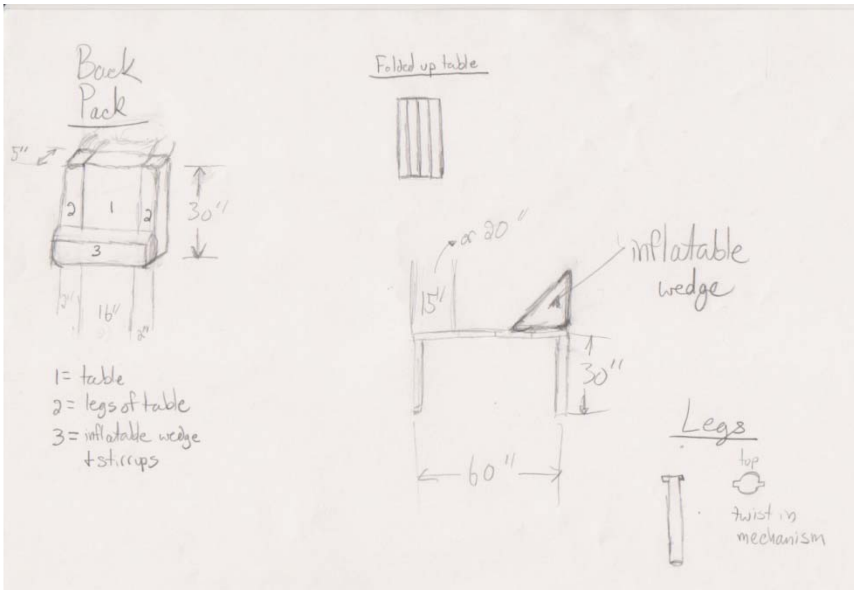
A.1.5 Concept Design 5

This design depicts legs that can be removed from the bottom. This is to aid in storage. There are also slots underneath the front section of the table in which the stirrups could be inserted when they are to be used. To fold, the bottom legs are removed, and the upper sections are folded in. Then the two sections are placed next to each other, and everything is placed in a pack.



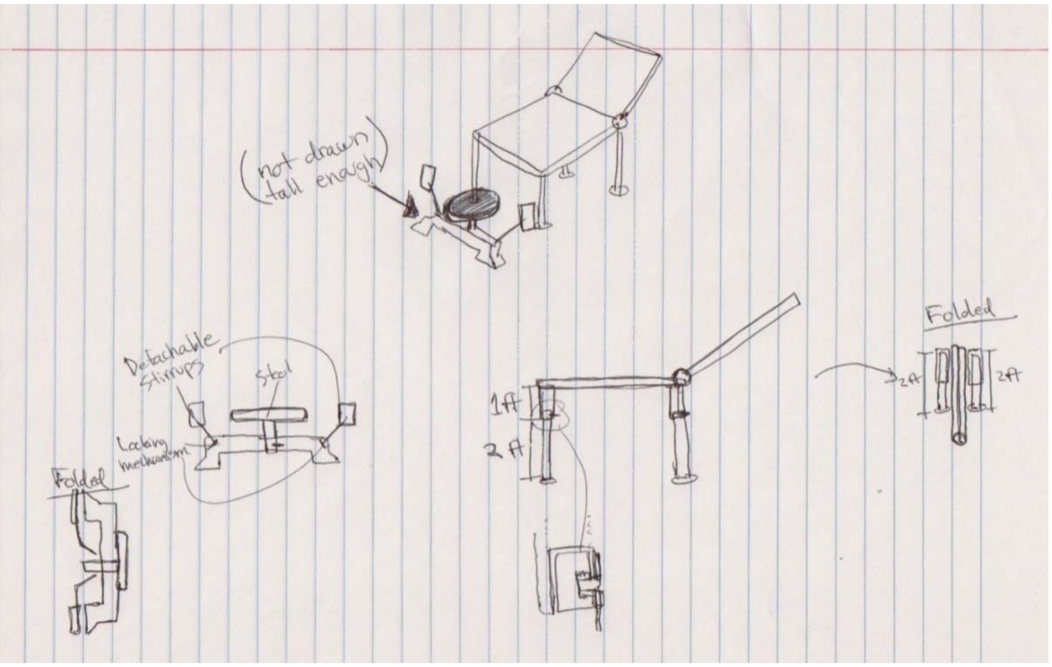
A.1.6 Concept Design 6

This design is a simple, flat table frame with an inflatable wedge for the patient to lean on. This wedge is what creates the adjusted back angle. The legs can be removed, and are placed onto the table with a twist in mechanism where they are locked by inserting and twisting. When folded, the pack itself has different sections for each separate part of the table.



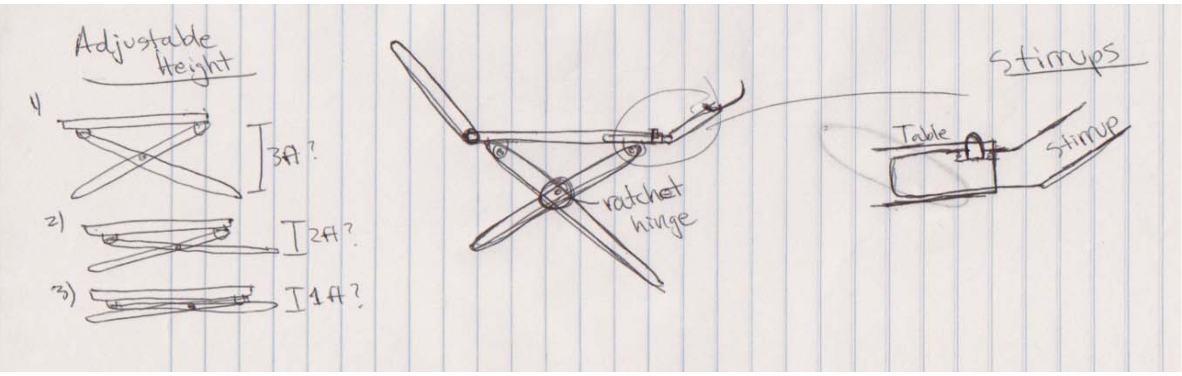
A.1.7 Concept Design 7

The most important aspect of this design was the stool. We considered including a stool in which the stirrups were actually a part of. We figured this may be a problem however as whenever the doctor needed to adjust the stool, it would move the woman's legs. However, it created an idea in our heads that maybe the stirrups could be separate from the table. The table design, like many, is a simple two sections.



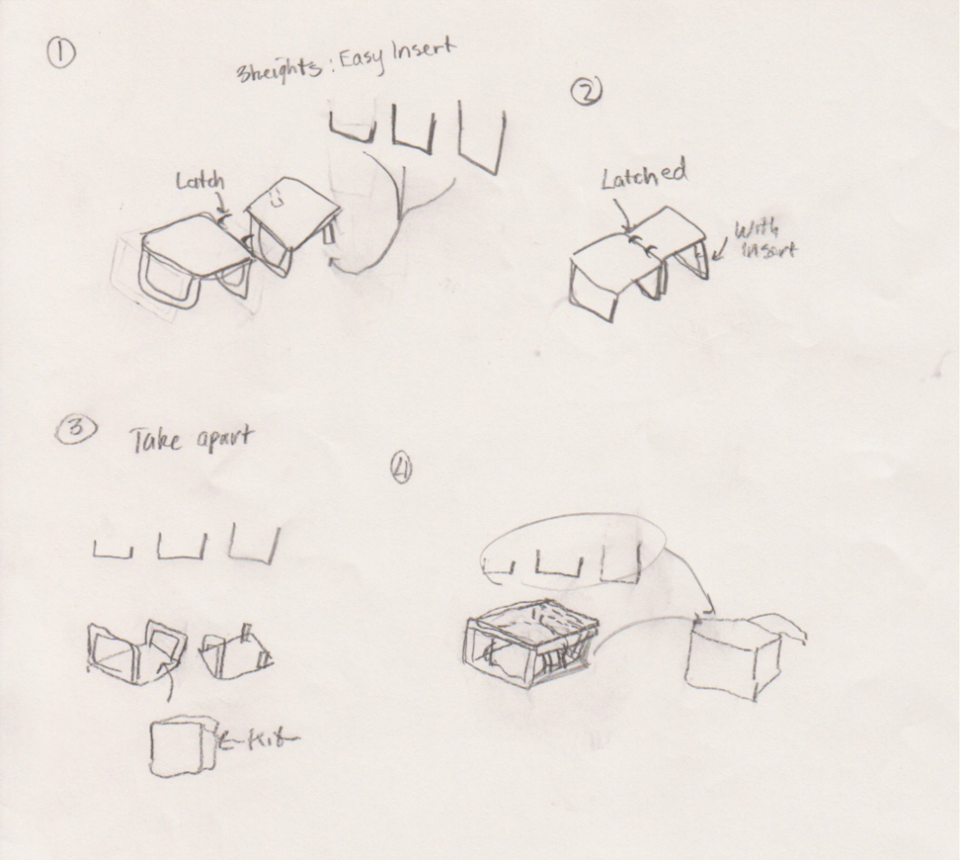
A.1.8 Concept Design 8

The main aspects of this table to be looked at are the legs. The legs create an X-shape underneath the table like many beach/lounge chairs we had researched. The hinge where the legs cross would lock the legs at different angles and allow the height to sit at different angles. This was before we concluded the adjustable height legs were not needed. The stirrups again slide into a slot on the bottom of the table and protrude out the front.



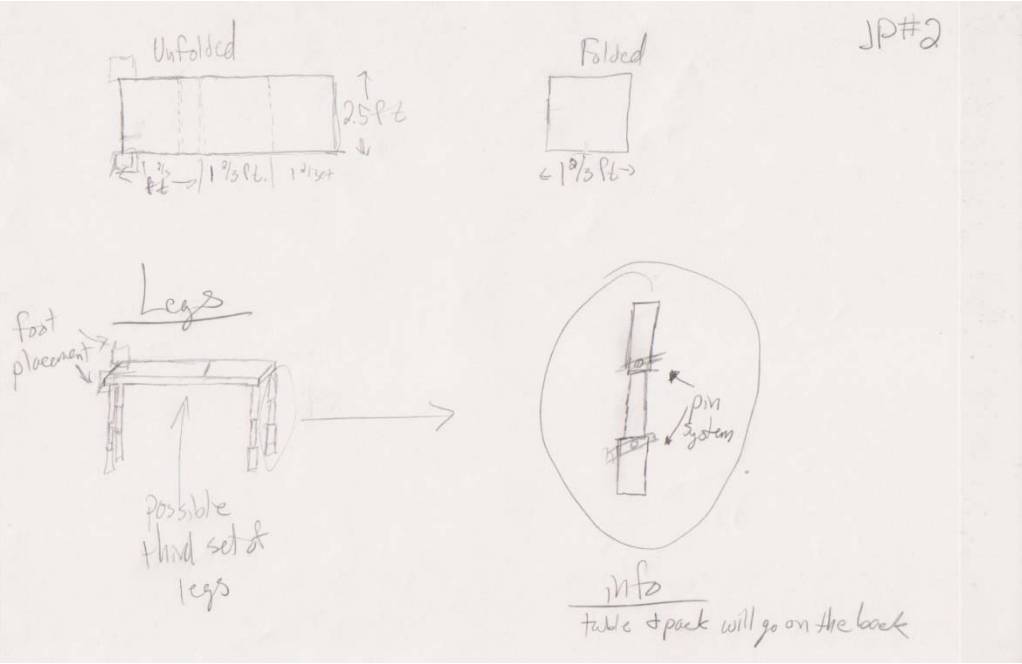
A.1.9 Concept Design 9

This is another two section, solid top table. The legs on the front section stay on and are only about a foot off the ground. However, on the back section, the farthest leg back can be removed. Brought along with the table are different height inserts. Depending on which insert is put in, the table back will sit at different angles. OF course, everything can be disassembled, and the two table sections are put together. During travel, any extra equipment can be put between these table sections.



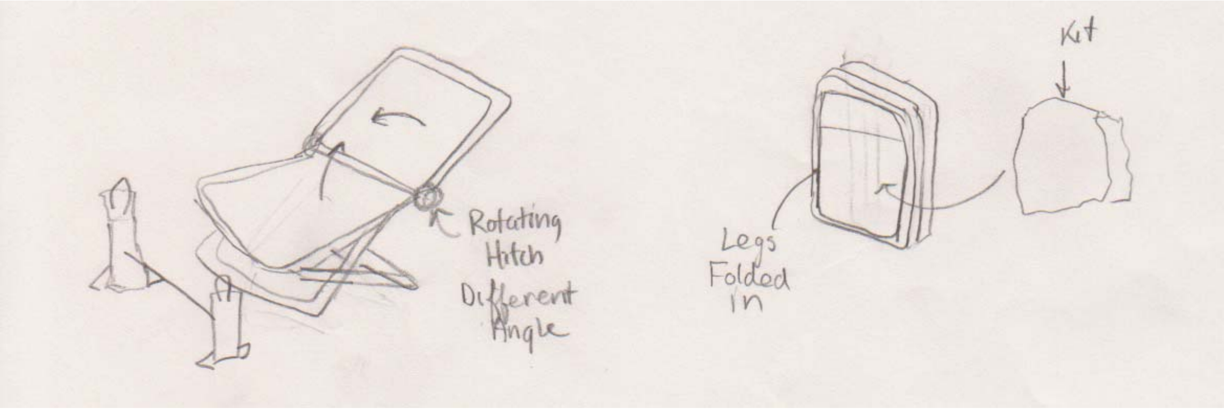
A.1.10 Concept Design 10

This table is a three section, folded top. The main aspect of this table was an adjustable leg system. Again, we concluded we no longer needed this leg system. However, by dividing the table into three sections, it is able to fold into a smaller space.



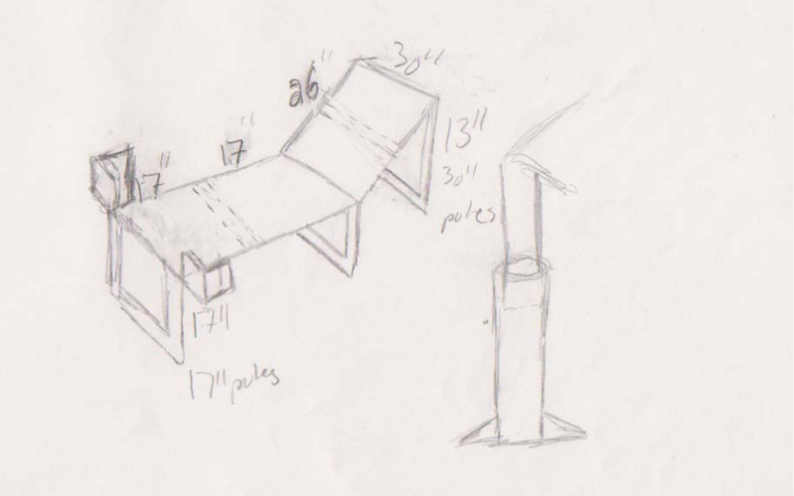
A.1.11 Concept Design 11

This table/chair is very similar to concept design A.4 as it features the X-crossed leg system. It is made in two sections, and between the two sections is a hinge that is able to adjust the back and hold it at different angles. The stirrups are free-standing objects that are placed in front of the chair. This was a bad option because they would be easily toppled. The material of the chair is a cloth material stretched between the frames, like many of our benchmarked beach chairs. The kit is secured to the chair when it is folded with straps and placed into a pack.



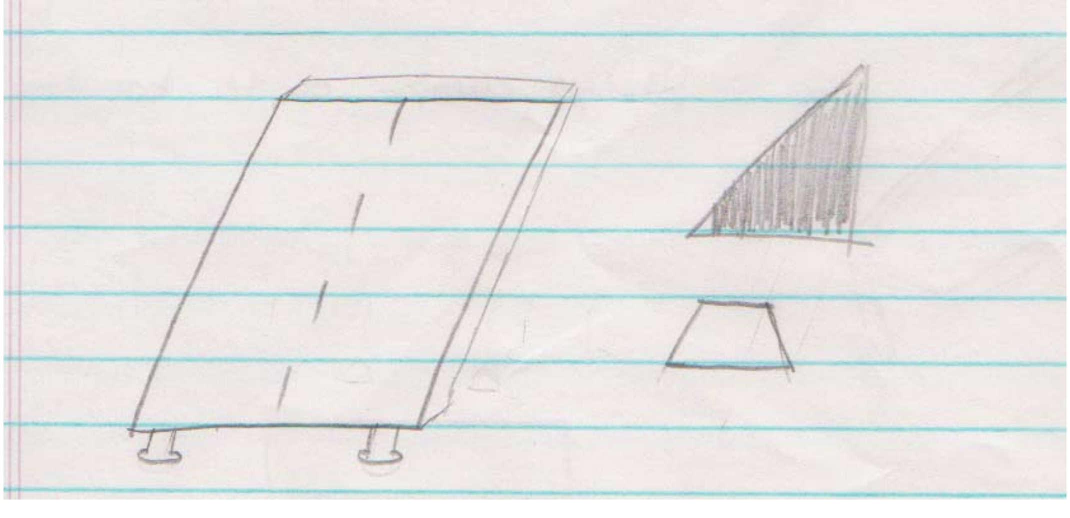
A.1.12 Concept Design 12

This table is two sections, each of which folds into smaller sections (folding creases represented by dotted lines). The foot holders are just simple L-shaped vertical extensions at the corners of the table. The woman could just push against these with her feet during the exam to keep her legs separated.



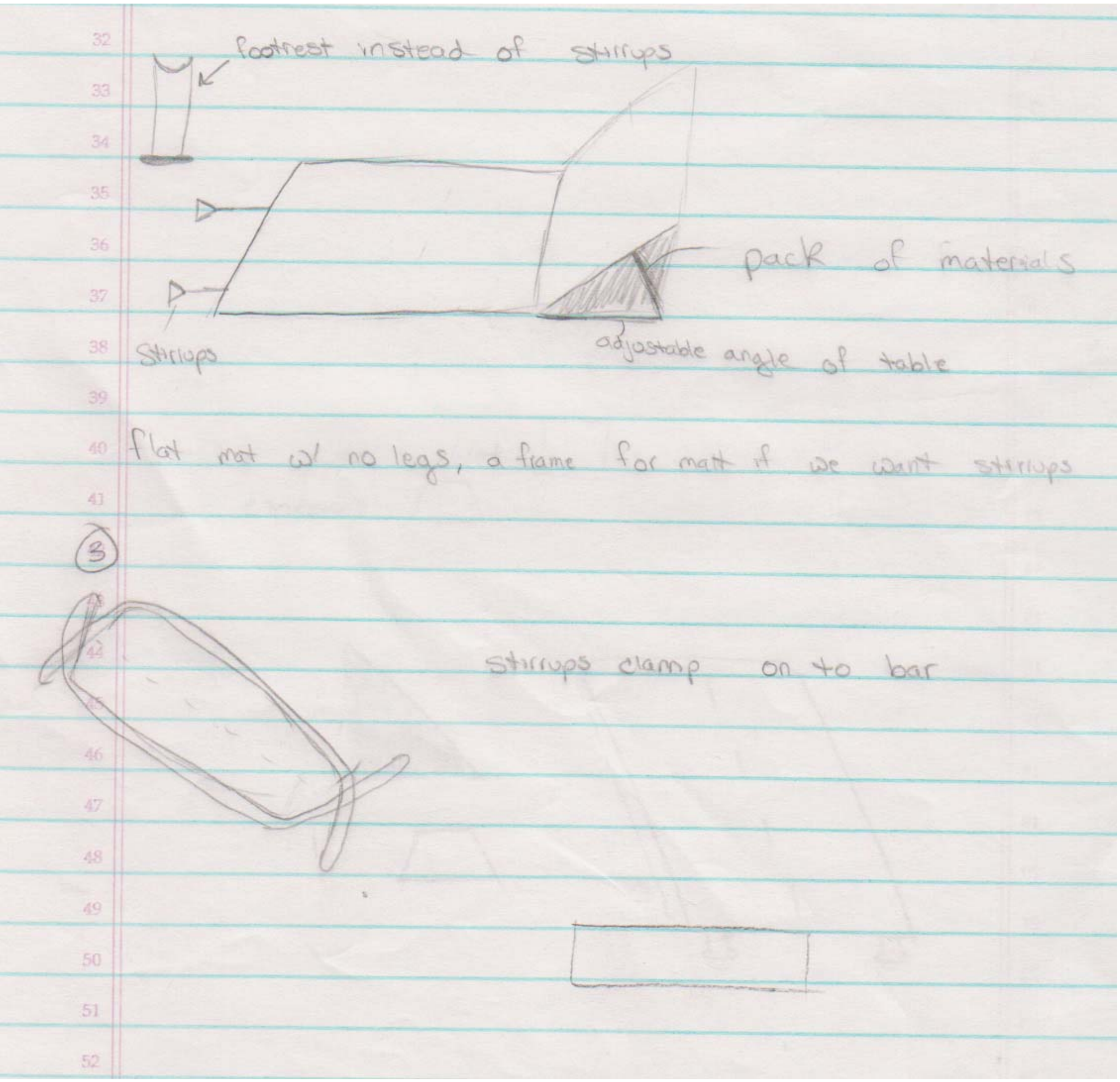
A.1.13 Concept Design 13

This design is much a futon. It is a simple bedding material with legs underneath. To fold, the table can be folded along the dotted line, and once more so it will not be as long. The back angle is adjusted with a simple wedge design. The legs also have 'elevators' that would raise the height of the table.



A.1.14 Concept Design 14

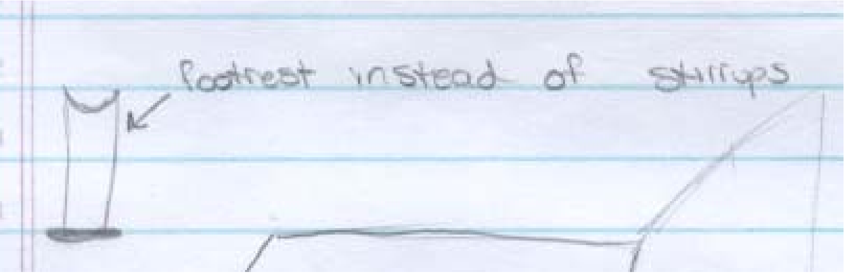
This page shows two designs. The first is simply a mat that is placed on the ground, and a wedge to adjust the back. This design did not get the woman up off the ground, and therefore was not used. The second design is two large U-frames with a cloth material stretched between them. This design was scratched because it was too bulky.



flat mat w/ no legs, a frame for matt if we want stirrups

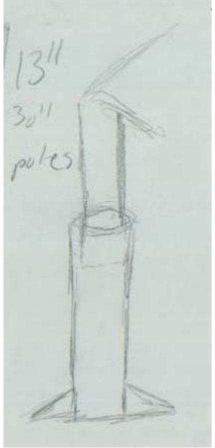
A.1.15 Concept Design 15

This picture shows another leg separation mechanism that consists of foot sections that sit on the floor and can be moved to any length needed.

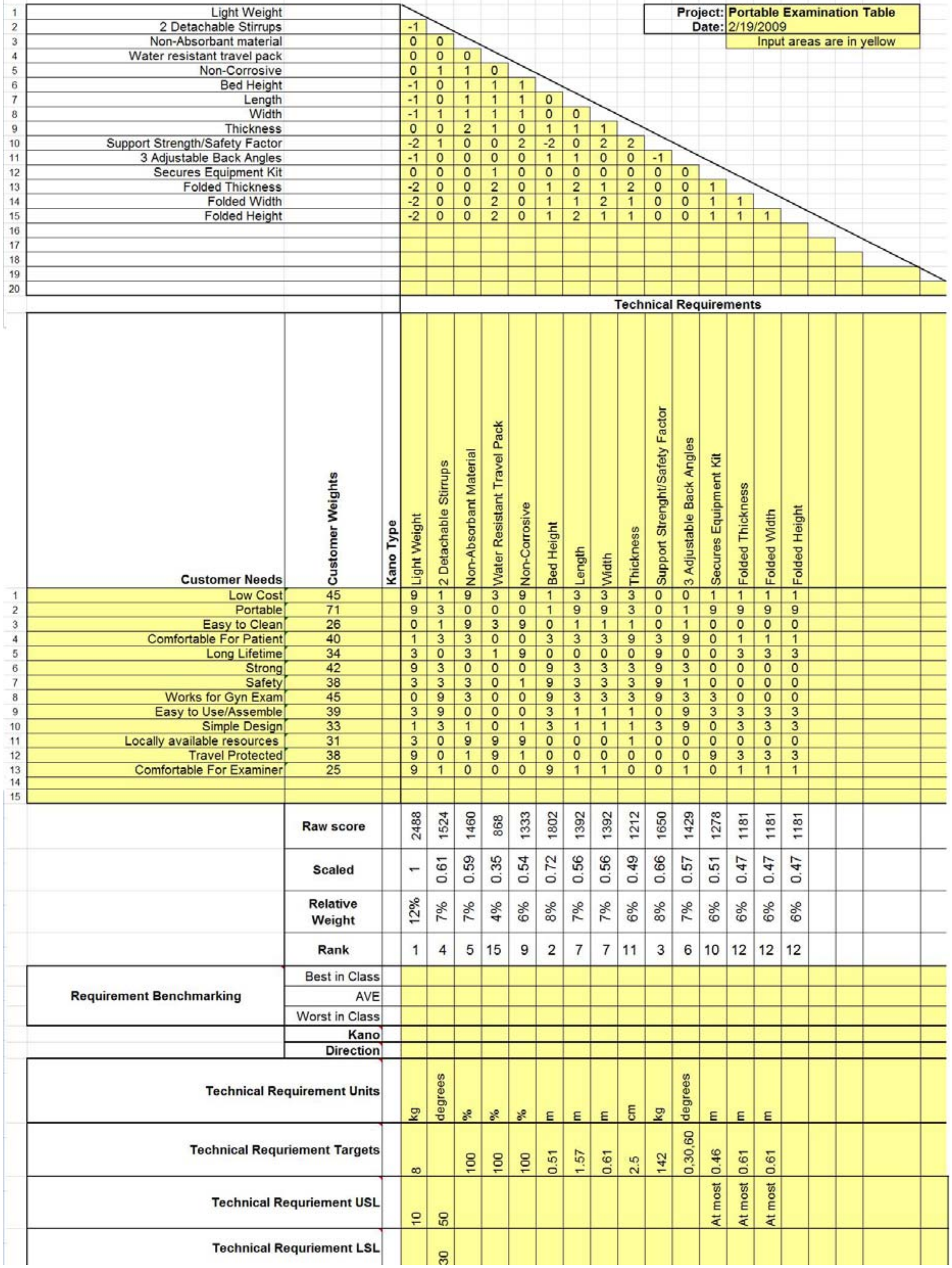


A.1.16 Concept Design 16

This drawing is another table leg design that consists of a pole that slides in and out of another pole to allow for height adjustment and it uses a rod mechanism to secure it.



APPENDIX A.2 QFD

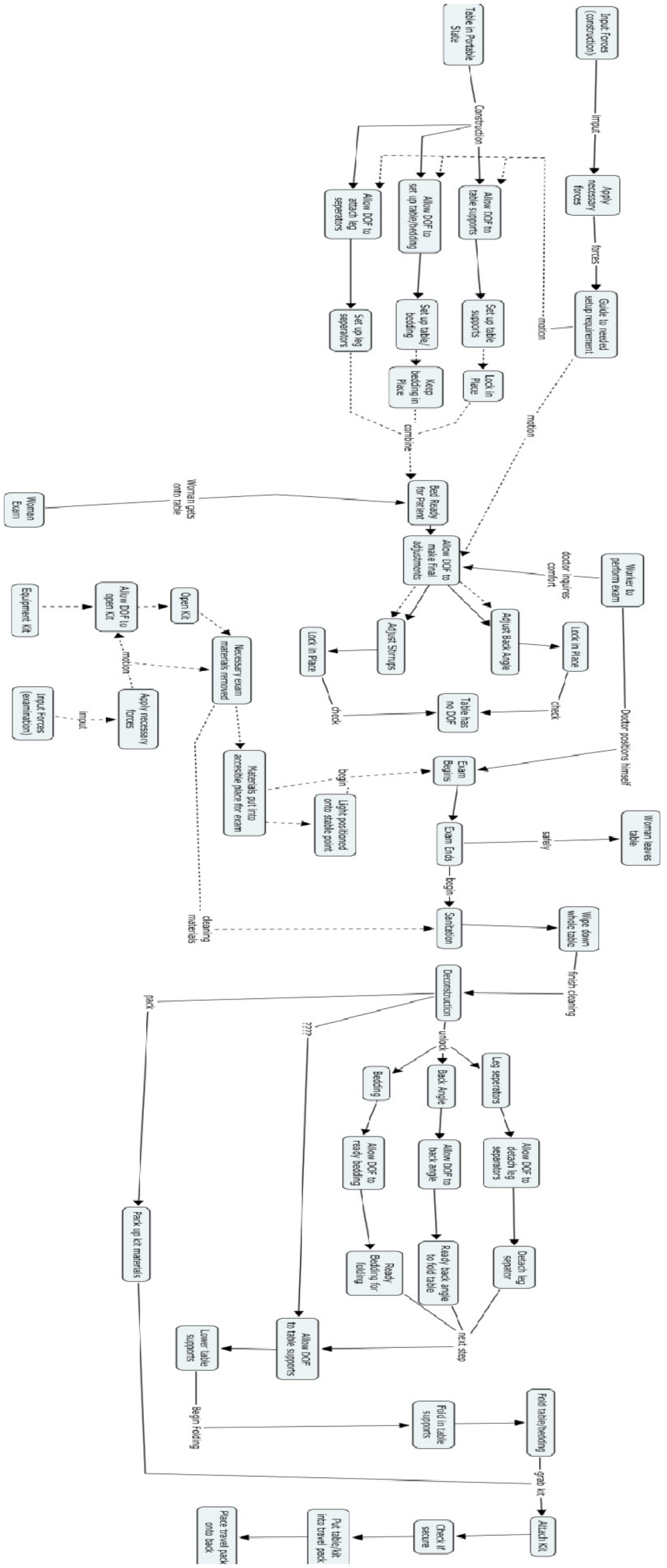


Project: **Portable Examination Table**
Date: 2/19/2009
Input areas are in yellow

1	Light Weight														
2	2 Detachable Stirrups	-1													
3	Non-Absorbant material	0	0												
4	Water resistant travel pack	0	0	0											
5	Non-Corrosive	0	1	1	0										
6	Bed Height	-1	0	1	1	1									
7	Length	-1	0	1	1	1	0								
8	Width	-1	1	1	1	1	0	0							
9	Thickness	0	0	2	1	0	1	1	1						
10	Support Strength/Safety Factor	-2	1	0	0	2	-2	0	2	2					
11	3 Adjustable Back Angles	-1	0	0	0	0	1	1	0	0	-1				
12	Secures Equipment Kit	0	0	0	1	0	0	0	0	0	0	0			
13	Folded Thickness	-2	0	0	2	0	1	2	1	2	0	0	1		
14	Folded Width	-2	0	0	2	0	1	1	2	1	0	0	1	1	
15	Folded Height	-2	0	0	2	0	1	2	1	1	0	0	1	1	1
16															
17															
18															
19															
20															

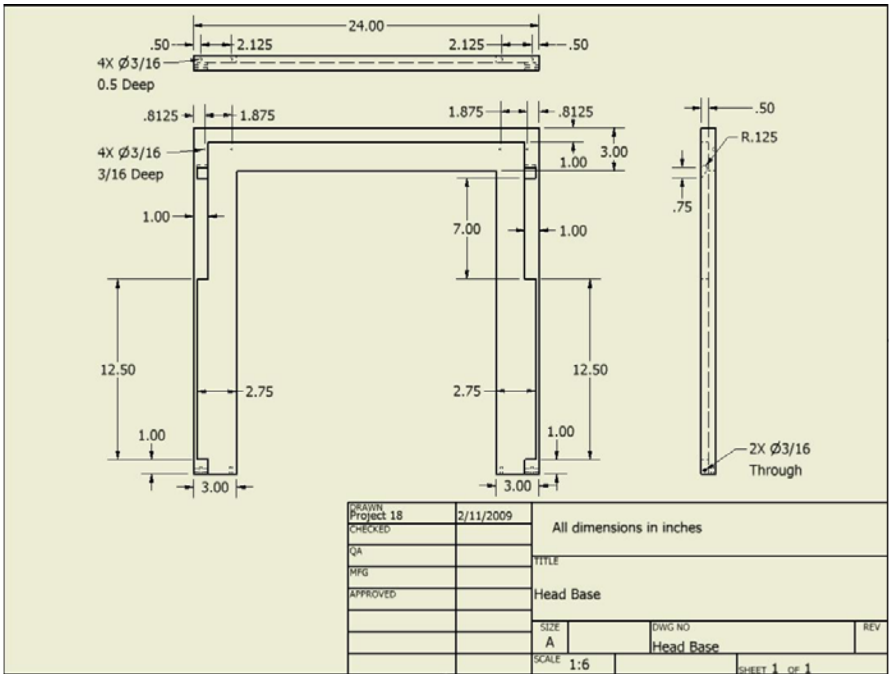
				Technical Requirements														
	Customer Needs	**Customer Weights**	**Kano Type**	Light Weight	2 Detachable Stirrups	Non-Absorbant Material	Water Resistant Travel Pack	Non-Corrosive	Bed Height	Length	Width	Thickness	Support Strenght/Safety Factor	3 Adjustable Back Angles	Secures Equipment Kit	Folded Thickness	Folded Width	Folded Height
1	Low Cost	45		9	1	9	3	9	1	3	3	3	0	0	1	1	1	1
2	Portable	71		9	3	0	0	0	1	9	9	3	0	1	9	9	9	9
3	Easy to Clean	26		0	1	9	3	9	0	1	1	1	0	1	0	0	0	0
4	Comfortable For Patient	40		1	3	3	0	0	3	3	3	9	3	9	0	1	1	1
5	Long Lifetime	34		3	0	3	1	9	0	0	0	0	9	0	0	3	3	3
6	Strong	42		9	3	0	0	0	9	3	3	3	9	3	0	0	0	0
7	Safety	38		3	3	3	0	1	9	3	3	3	9	1	0	0	0	0
8	Works for Gyn Exam	45		0	9	3	0	0	9	3	3	3	9	3	3	0	0	0
9	Easy to Use/Assemble	39		3	9	0	0	0	3	1	1	1	0	9	3	3	3	3
10	Simple Design	33		1	3	1	0	1	3	1	1	1	3	9	0	3	3	3
11	Locally available resources	31		3	0	9	9	9	0	0	0	1	0	0	0	0	0	0
12	Travel Protected	38		9	0	1	9	1	0	0	0	0	0	0	9	3	3	3
13	Comfortable For Examiner	25		9	1	0	0	0	9	1	1	0	0	1	0	1	1	1
14																		
15																		
		Raw score		2488	1524	1460	868	1333	1802	1392	1392	1212	1650	1429	1278	1181	1181	1181
		Scaled		1	0.61	0.59	0.35	0.54	0.72	0.56	0.56	0.49	0.66	0.57	0.51	0.47	0.47	0.47
		Relative Weight		12%	7%	7%	4%	6%	8%	7%	7%	6%	8%	7%	6%	6%	6%	6%
		Rank		1	4	5	15	9	2	7	7	11	3	6	10	12	12	12
	Requirement Benchmarking	Best in Class																
		AVE																
		Worst in Class																
		Kano																
		Direction																
	Technical Requirement Units			kg	degrees	%	%	%	m	m	m	cm	kg	degrees	m	m	m	
	Technical Requriement Targets			8		100	100	100	0.51	1.57	0.61	2.5	142	0,30,60	0.46	0.61	0.61	
	Technical Requriement USL			10	50										At most	At most	At most	
	Technical Requriement LSL				30													

APPENDIX A.3 FUNCTIONAL DECOMPOSITION

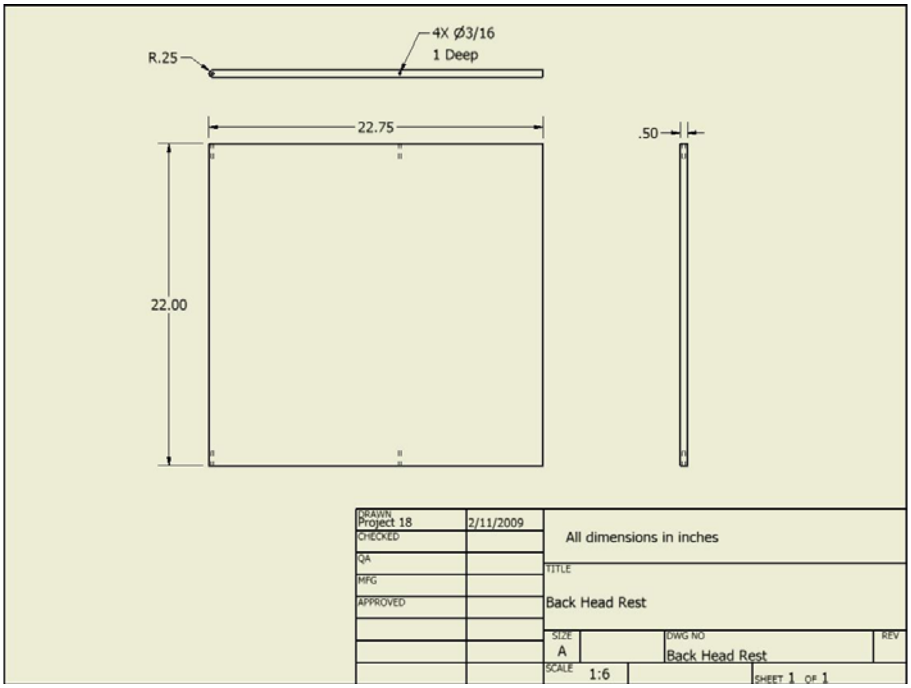


APPENDIX A.4 ALPHA DESIGN ENGINEERING DRAWINGS

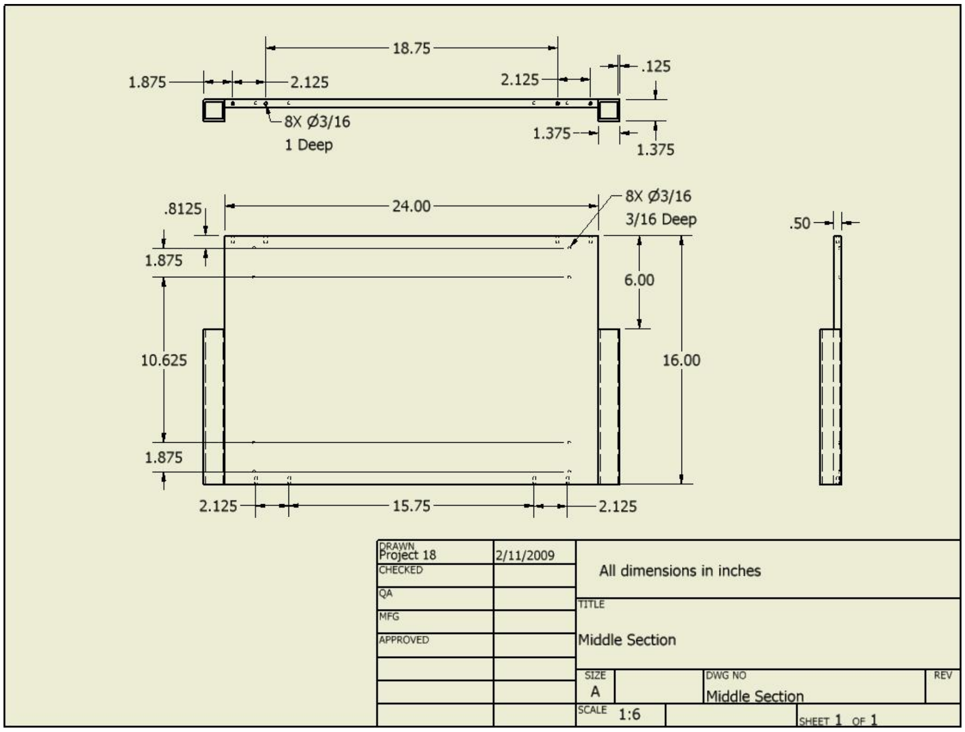
A.4.1 Head Base



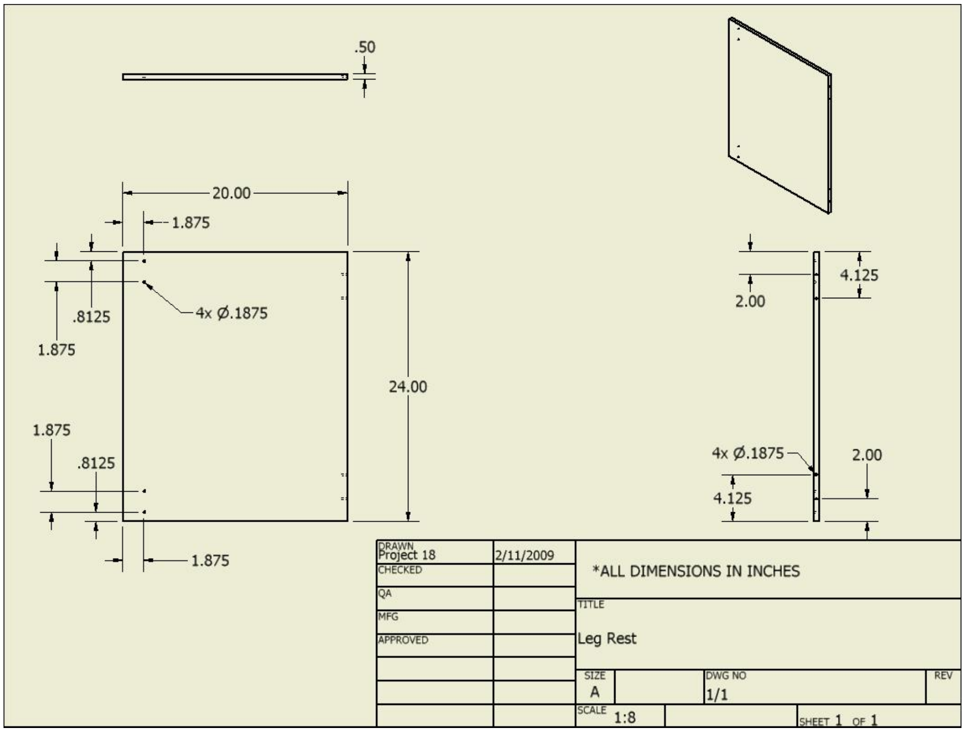
A.4.2 Head Rest



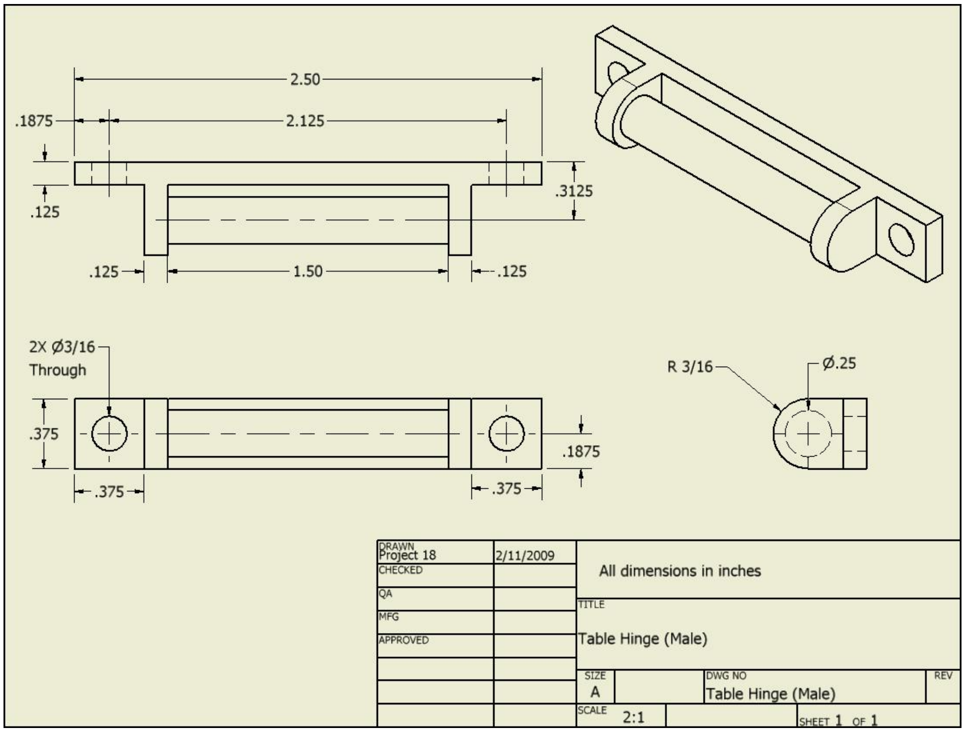
A.4.3 Middle Section



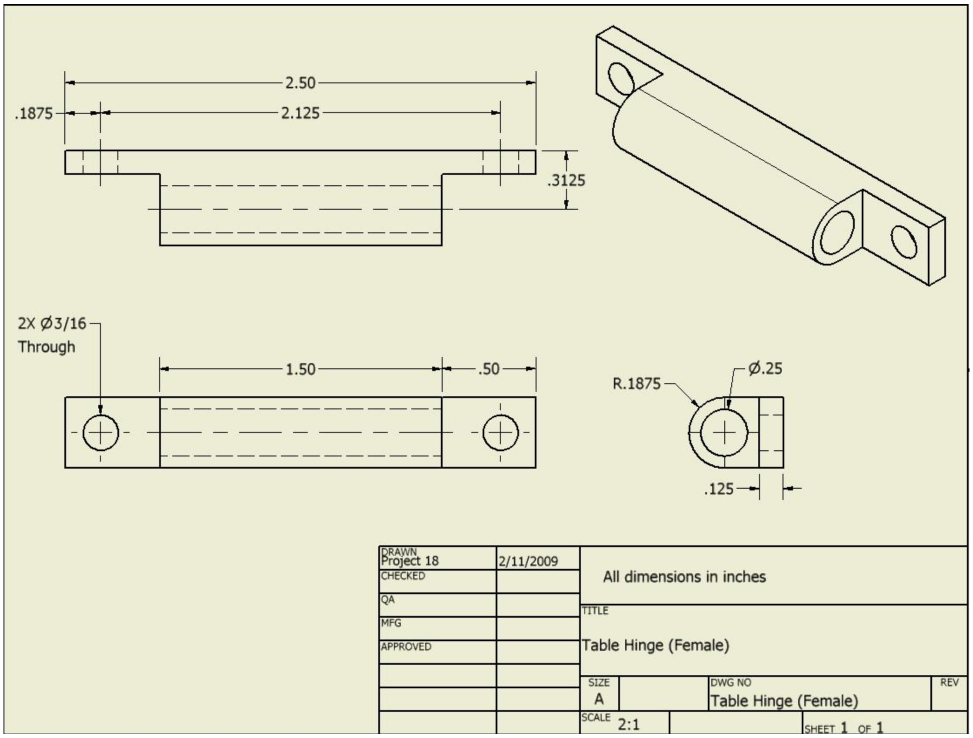
A.4.4 Leg Rest



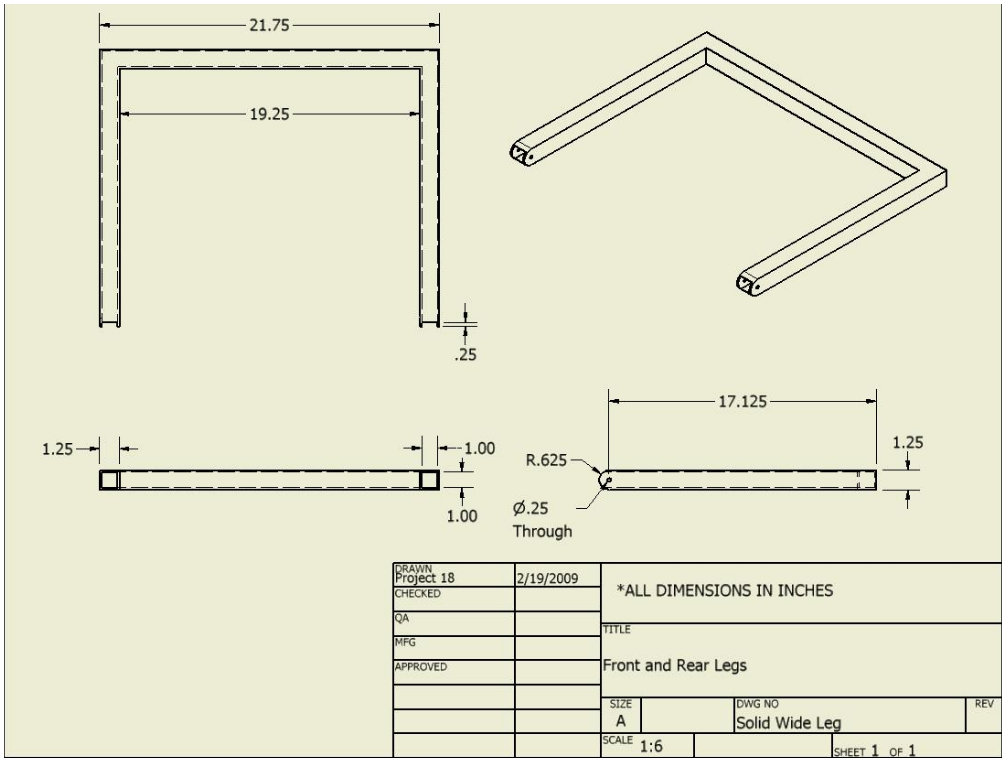
A.4.5 Male Hinge



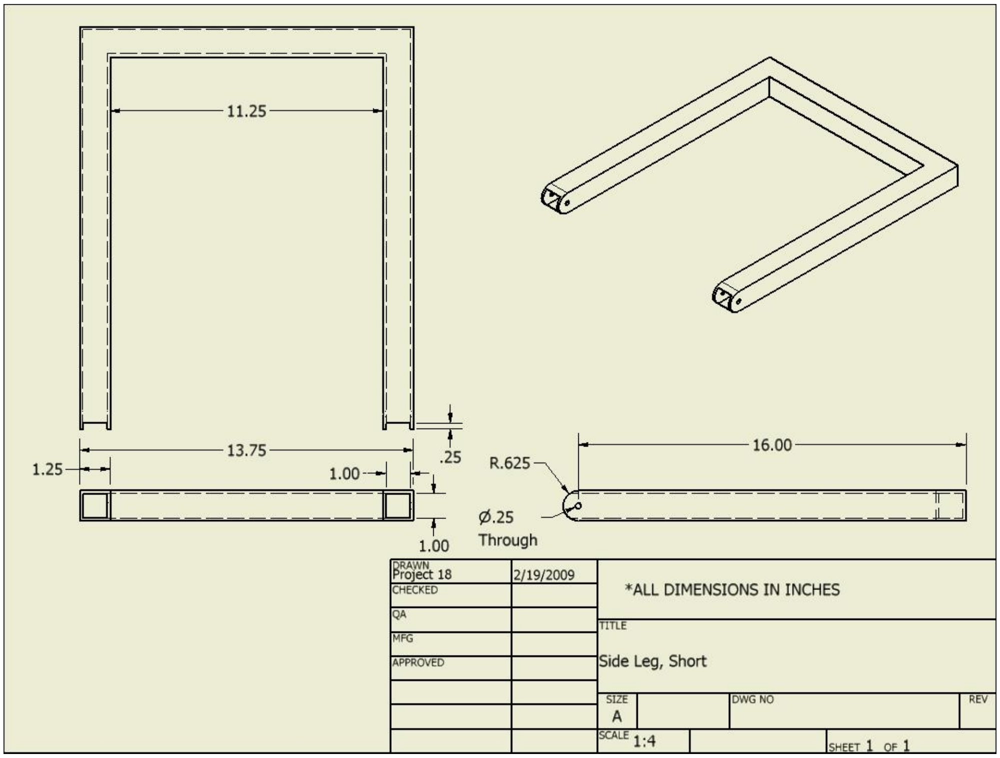
A.4.6 Female Hinge



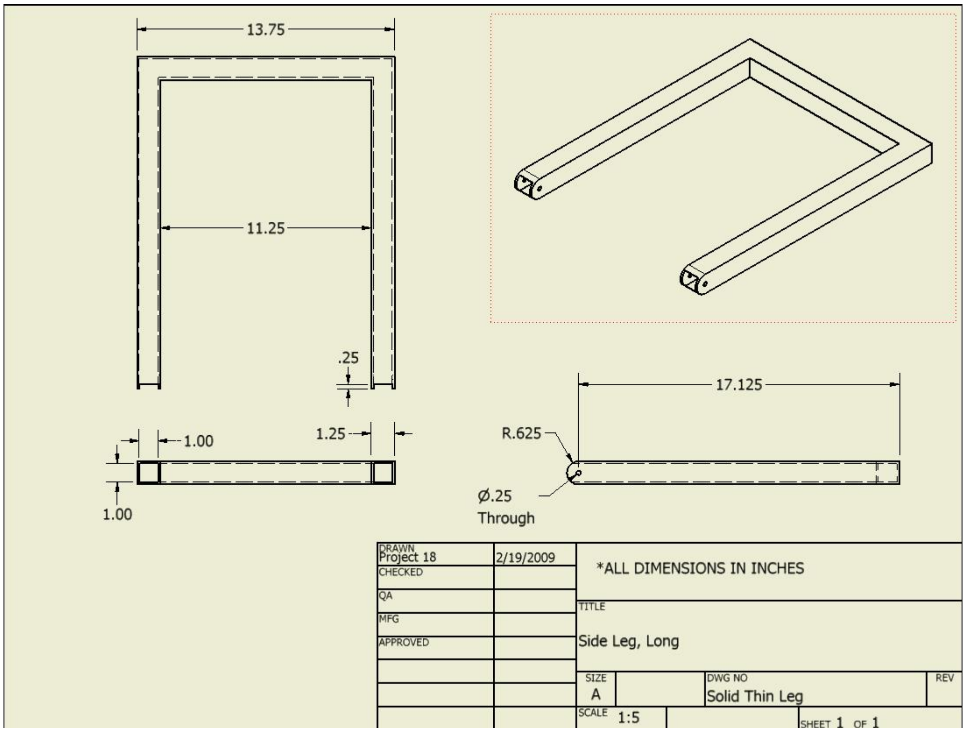
A.4.7 Front and Rear Legs



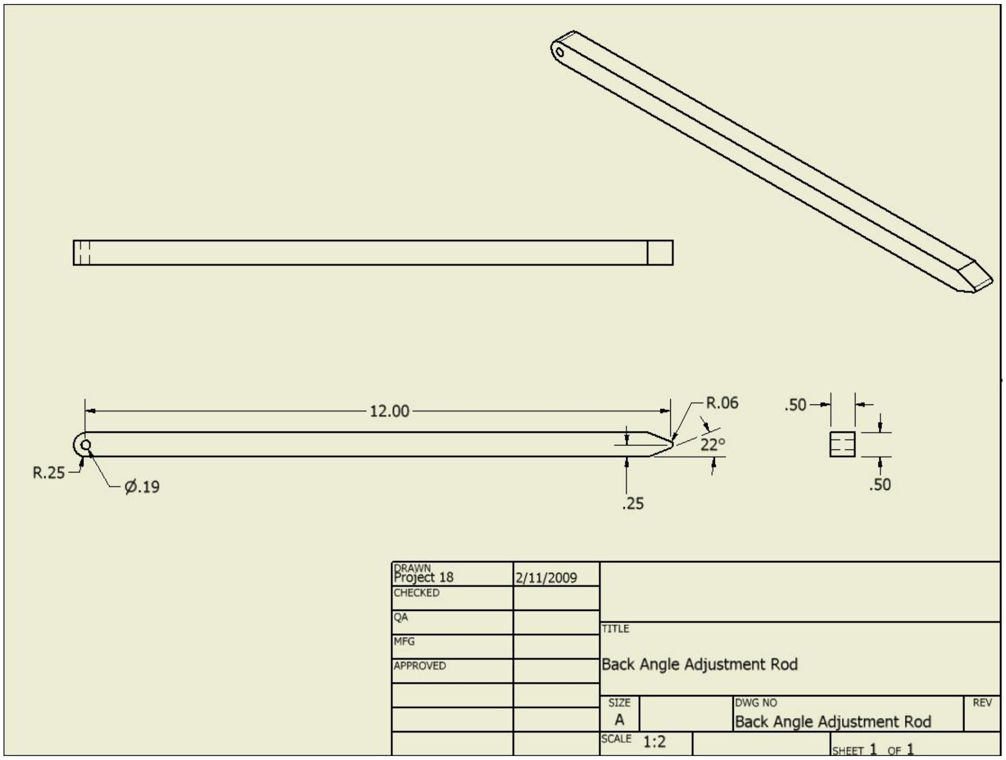
A.4.8 Side Leg, Short



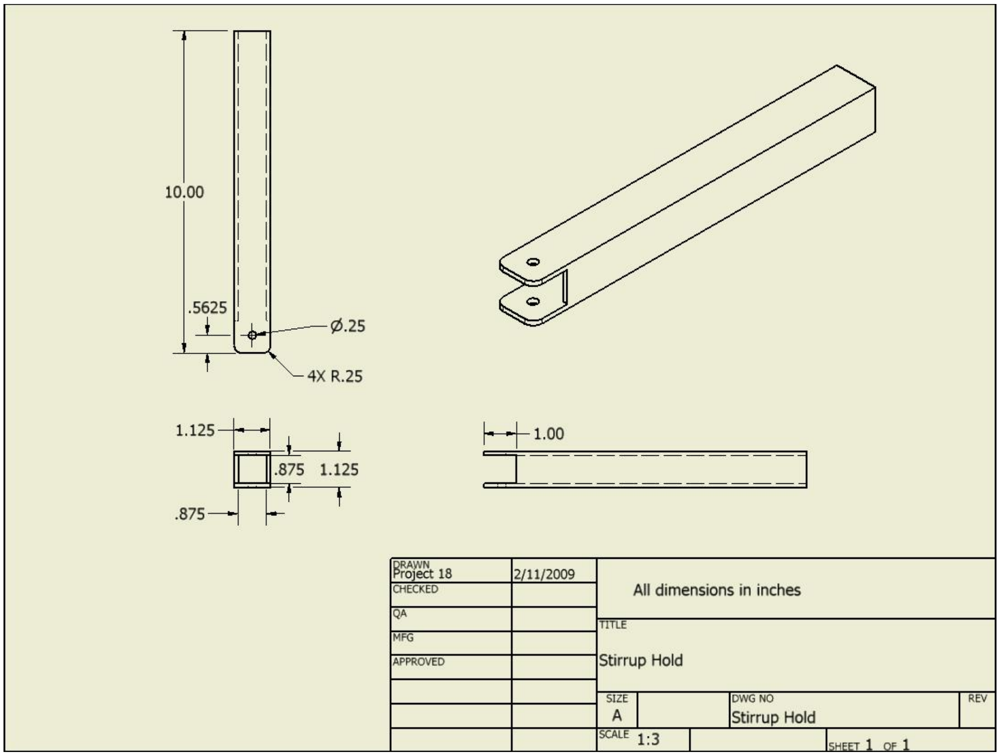
A.4.9 Side Leg, Long



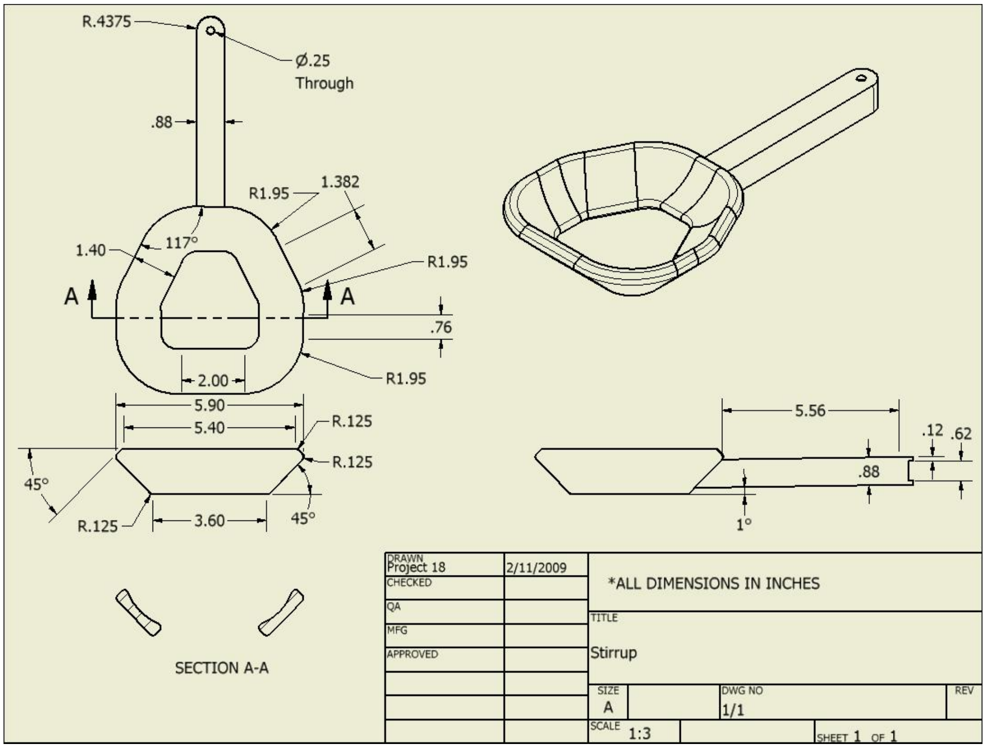
A.4.10 Back Angle Adjustment Rod



A.4.13 Stirrup Hold



A.4.14 Stirrup



APPENDIX A.5 SURVEY

A.5.1 Blank Survey

Please rate the table features of our portable pelvic examination table. Rank in order of importance. Please rank the specifications 1-12.

Engineering Specification	Ranking
Light Weight	
Low cost	
Portability	
Easy to use/assemble	
Adjustable Table Height	
Patient comfort	
Examiner comfort	
3 Adjustable Back Angles	
Stirrups	
Easily Cleaned	
Non-Corrosive	
Non-Absorbent	

Comments on the rankings (if necessary):

Additional Questions:

- Would it be acceptable to have a stool for the health care worker or midwife to sit on and have the table only be 1-2 feet off the ground?
- What are the most common distances in between a women's legs for an exam?(heel to heel horizontal with knee joint and hip joint flexed _____
    - i.e. what are the most common angles or stirrups to open up to?
    - How far does a woman's pelvis have to be opened up? Above answers this question
- What are the desired back angles of the table?
    - Why? (Are the current back angles that are used because it has been the protocol for so long or do you find certain positions easier for the patient and you?).

A.5.2 Returned Survey – Dr. Ofosu

Please rate the table features of our portable pelvic examination table. Rank in order of importance. Please rank the specifications 1-12.

Engineering Specification	Ranking
Light Weight	1
Low cost	5
Portability	7
Easy to use/assemble	2
Adjustable Table Height	11
Patient comfort	8
Examiner comfort	9
3 Adjustable Back Angles	10
Stirrups	12
Easily Cleaned	3
Non-Corrosive	4
Non-Absorbent	6

Comments on the rankings (if necessary):

Additional Questions:

- Would it be acceptable to have a stool for the health care worker or midwife to sit on and have the table only be 1-2 feet off the ground? Yes it is possible
- What are the most common distances in between a women's legs for an exam?(heel to heel horizontal with knee joint and hip joint flexed __3ft ___
    - i.e. what are the most common angles or stirrups to open up to?
    - How far does a woman's pelvis have to be opened up? Above answers this question
- What are the desired back angles of the table?____________25 -45 degrees ok_____
    - Why? (Are the current back angles that are used because it has been the protocol for so long or do you find certain positions easier for the patient and you?). Most now have adjustment – grooved that you can change by moving into grooves. Patients can push better when angle is increased – helps the bearing down and it is comfortable than lying flat.

A.5.3 Returned Survey – Jody Lori

Please rate the table features of our portable pelvic examination table. Rank in order of importance. Please rank the specifications 1-12.

Engineering Specification	Ranking
Light Weight	2
Low cost	3
Portability	1
Easy to use/assemble	4
Adjustable Table Height	11
Patient comfort	5
Examiner comfort	6
3 Adjustable Back Angles	10
Stirrups	12
Easily Cleaned	7
Non-Corrosive	8
Non-Absorbent	9

Comments on the rankings (if necessary): Is this a portable exam table for use in a clinic or in the community/home? Will it be carried from one place to another? Is it for pelvic exams only or delivery as well?

Additional Questions:

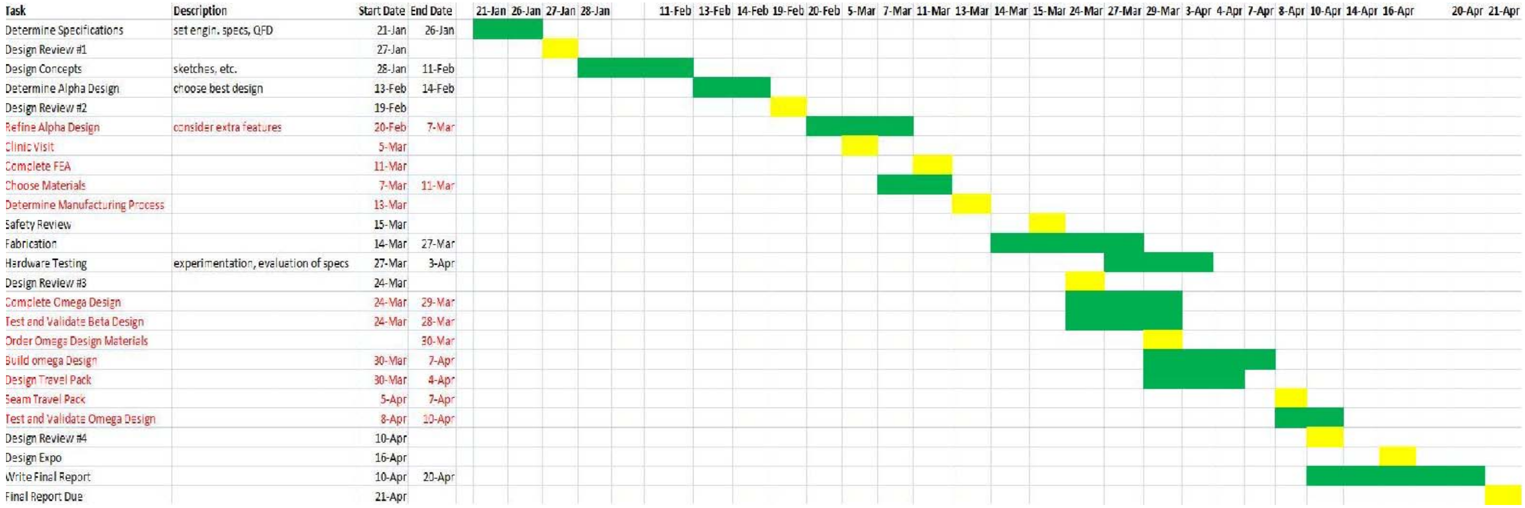
- Would it be acceptable to have a stool for the health care worker or midwife to sit on and have the table only be 1-2 feet off the ground? Yes

- What are the most common distances in between a woman's legs for an exam? _about 30 degrees_
  - i.e. what are the most common angles or stirrups to open up to? same

  - How far does a woman's pelvis have to be opened up? Not sure what you mean

- What are the desired back angles of the table?____30-45 degrees_______
  - Why? (Are the current back angles that are used because it has been the protocol for so long or do you find certain positions easier for the patient and you?) The angles used are so the provider can engage with the woman and she does not feel vulnerable during a pelvic exam. It helps to empower her (the patient). Laying a woman flat on her back for an exam or for childbirth is often done but it is definitely not optimal.

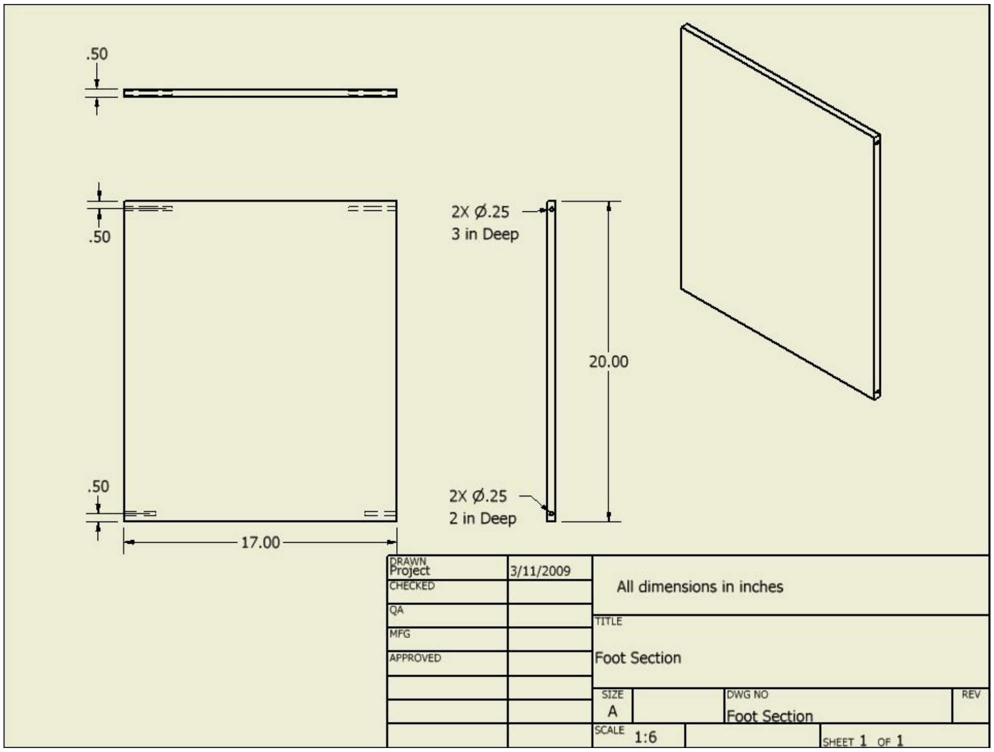
APPENDIX A.6 GANTT CHART



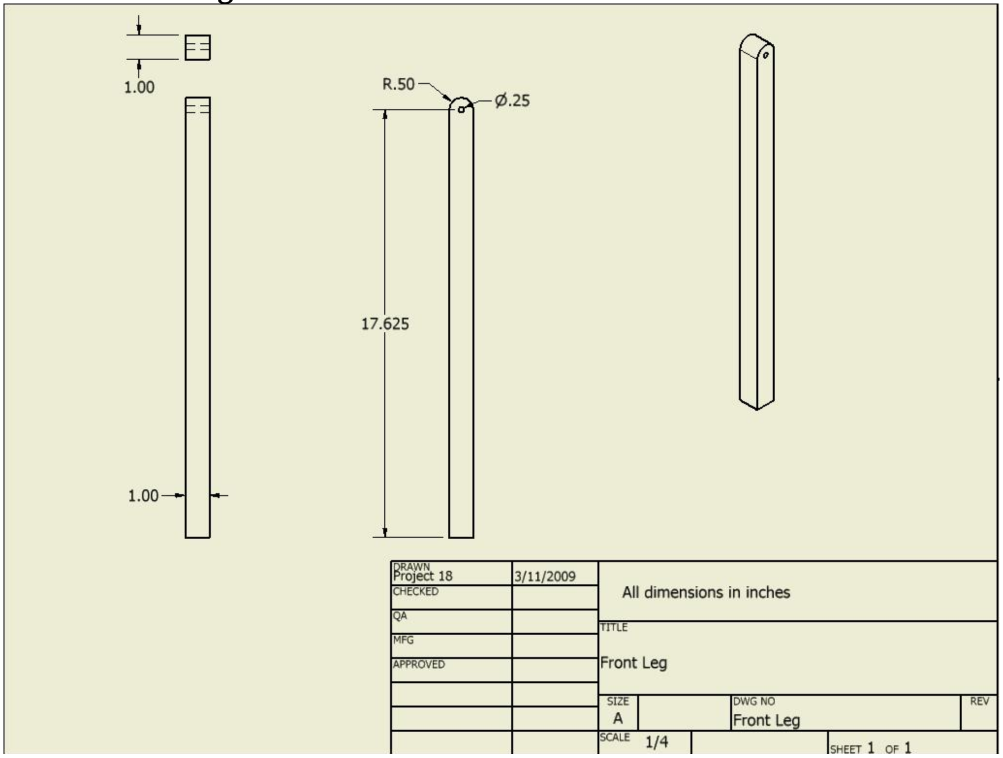
Task	Description	Start Date	End Date	21-Jan	26-Jan	27-Jan	28-Jan		11-Feb	13-Feb	14-Feb	19-Feb	20-Feb	5-Mar	7-Mar	11-Mar	13-Mar	14-Mar	15-Mar	24-Mar	27-Mar	29-Mar	3-Apr	4-Apr	7-Apr	8-Apr	10-Apr	14-Apr	16-Apr		20-Apr	21-Apr
Determine Specifications	set engin. specs, QFD	21-Jan	26-Jan	🟩	🟩																											
Design Review #1		27-Jan				🟨																										
Design Concepts	sketches, etc.	28-Jan	11-Feb				🟩	🟩	🟩																							
Determine Alpha Design	choose best design	13-Feb	14-Feb							🟩	🟩																					
Design Review #2		19-Feb										🟨																				
Refine Alpha Design	consider extra features	20-Feb	7-Mar										🟩	🟩	🟩																	
Clinic Visit		5-Mar												🟨																		
Complete FEA		11-Mar														🟨																
Choose Materials		7-Mar	11-Mar												🟩	🟩																
Determine Manufacturing Process		13-Mar															🟨															
Safety Review		15-Mar																	🟨													
Fabrication		14-Mar	27-Mar															🟩	🟩	🟩	🟩											
Hardware Testing	experimentation, evaluation of specs	27-Mar	3-Apr																		🟩	🟩	🟩									
Design Review #3		24-Mar																		🟨												
Complete Omega Design		24-Mar	29-Mar																	🟩	🟩	🟩										
Test and Validate Beta Design		24-Mar	28-Mar																	🟩	🟩	🟩										
Order Omega Design Materials			30-Mar																			🟨										
Build omega Design		30-Mar	7-Apr																			🟩	🟩	🟩	🟩							
Design Travel Pack		30-Mar	4-Apr																			🟩	🟩	🟩								
Seam Travel Pack		5-Apr	7-Apr																							🟨						
Test and Validate Omega Design		8-Apr	10-Apr																							🟩	🟩					
Design Review #4		10-Apr																									🟨					
Design Expo		16-Apr																											🟨			
Write Final Report		10-Apr	20-Apr																								🟩	🟩	🟩	🟩	🟩	
Final Report Due		21-Apr																														🟨

APPENDIX A.7 BETA DESIGN ENGINEERING DRAWINGS

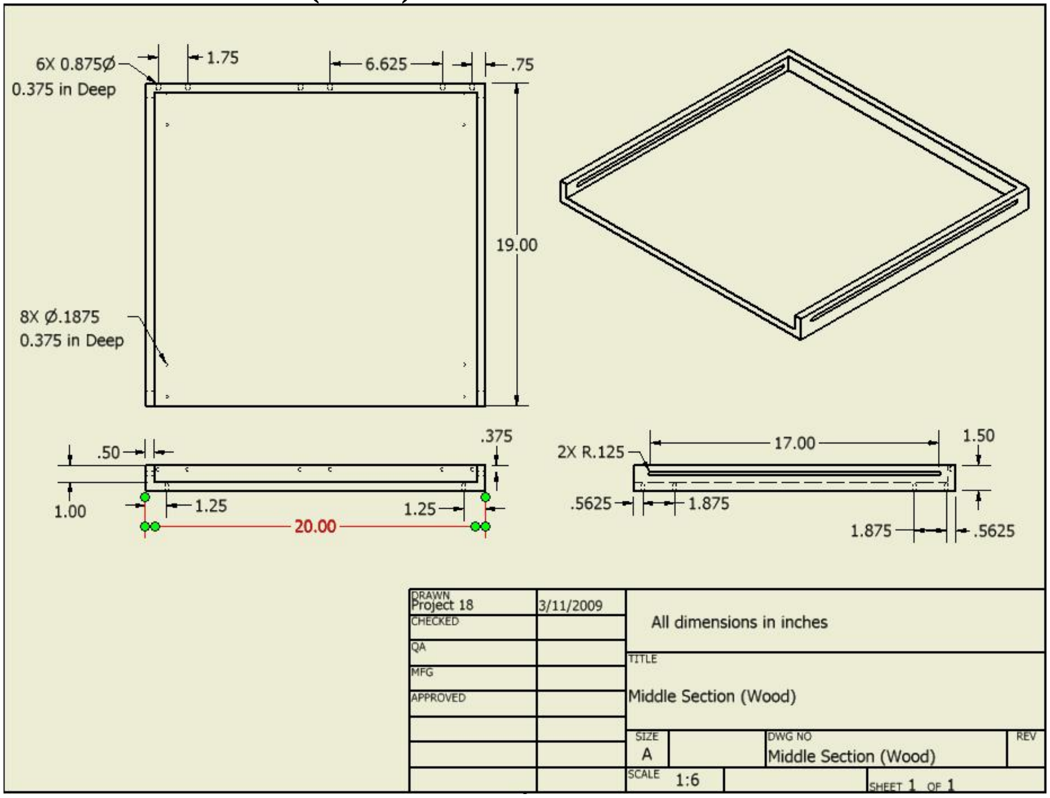
A.7.1 Foot Section



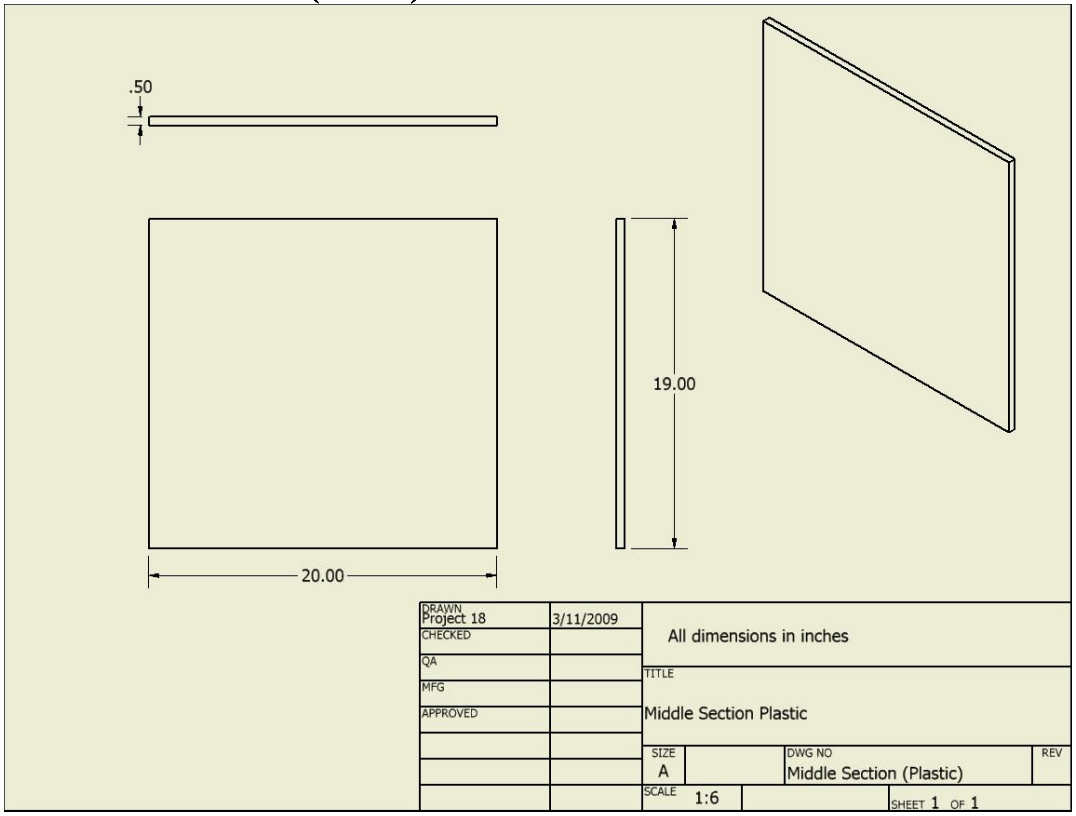
A.7.2 Front Leg



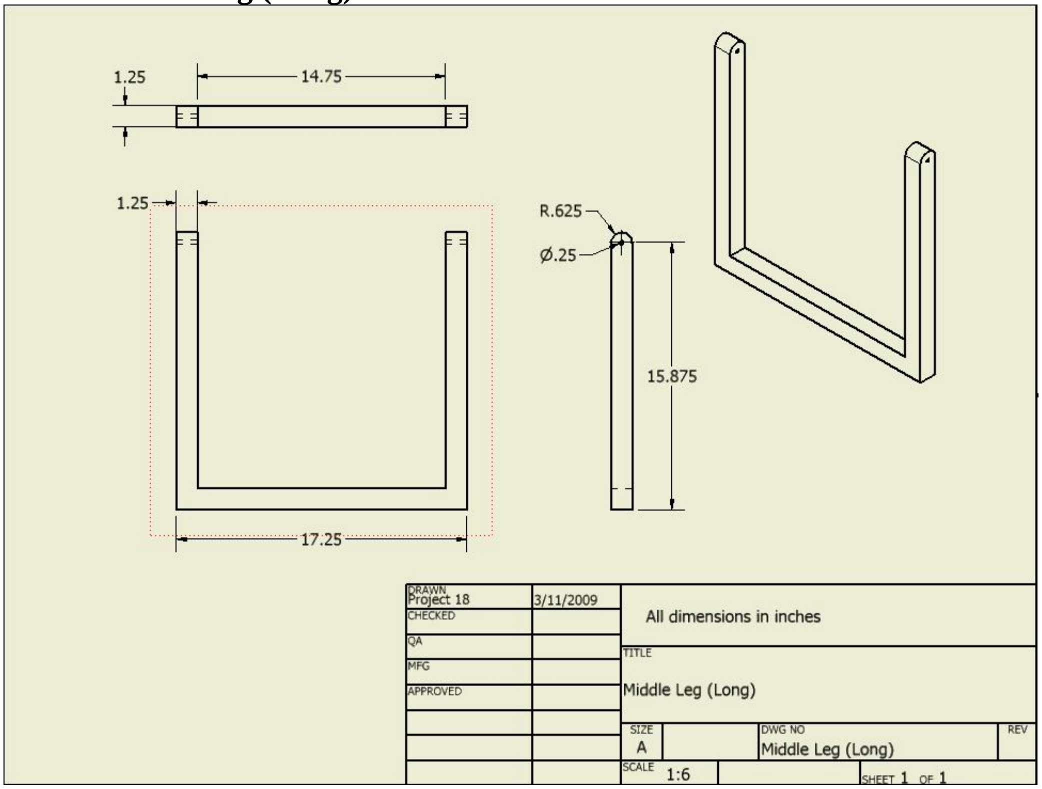
A.7.3 Middle Section (Wood)



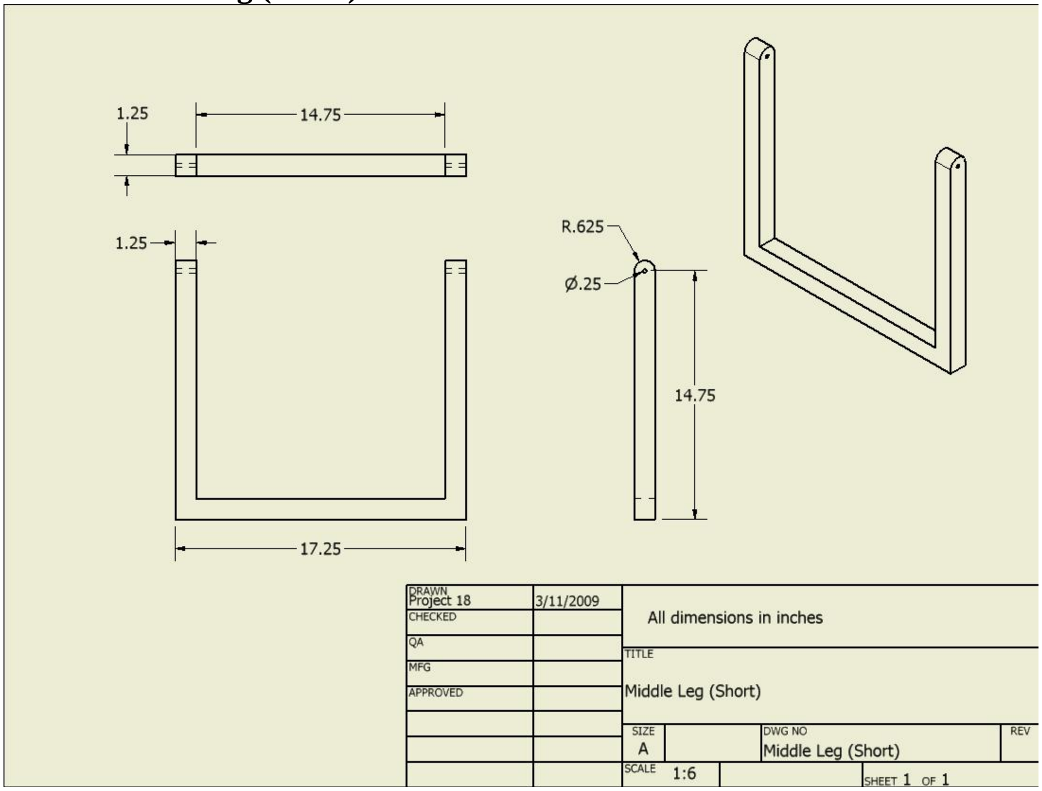
A.7.4 Middle Section (Plastic)



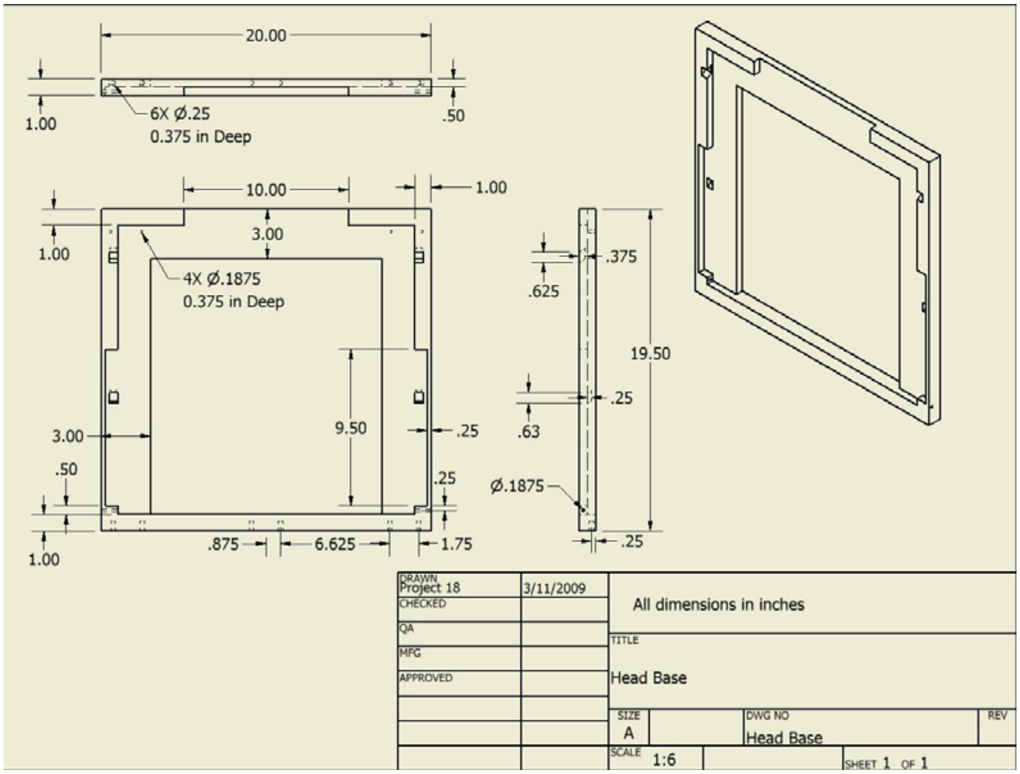
A.7.5 Middle Leg (Long)



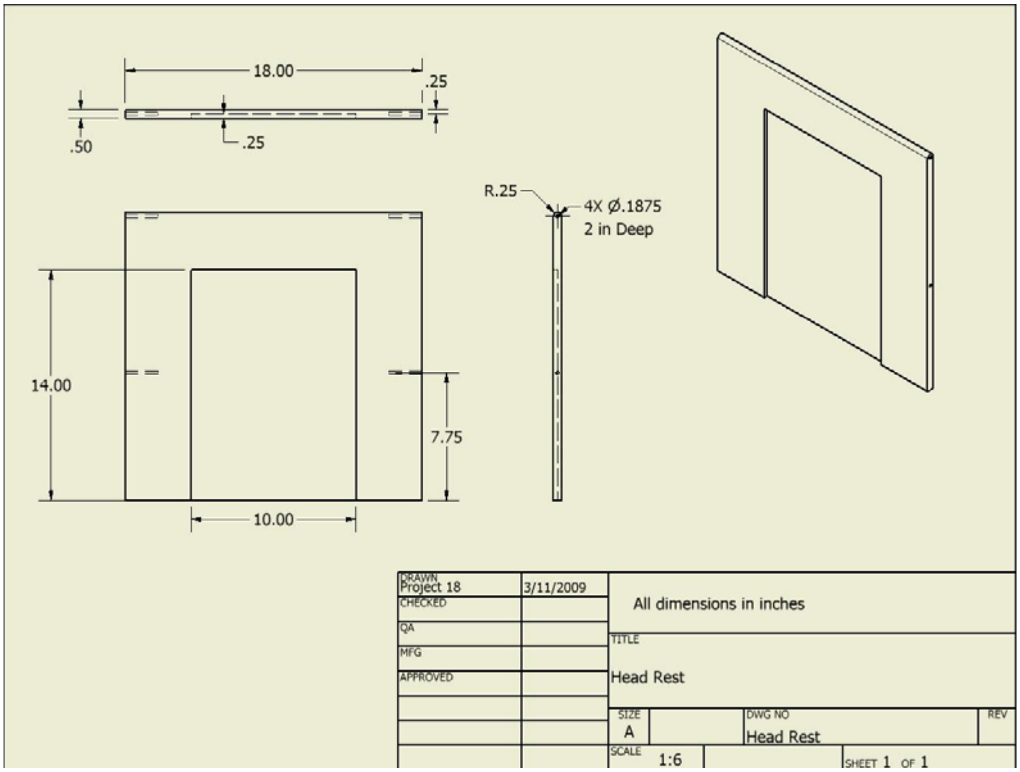
A.7.6 Middle Leg (Short)



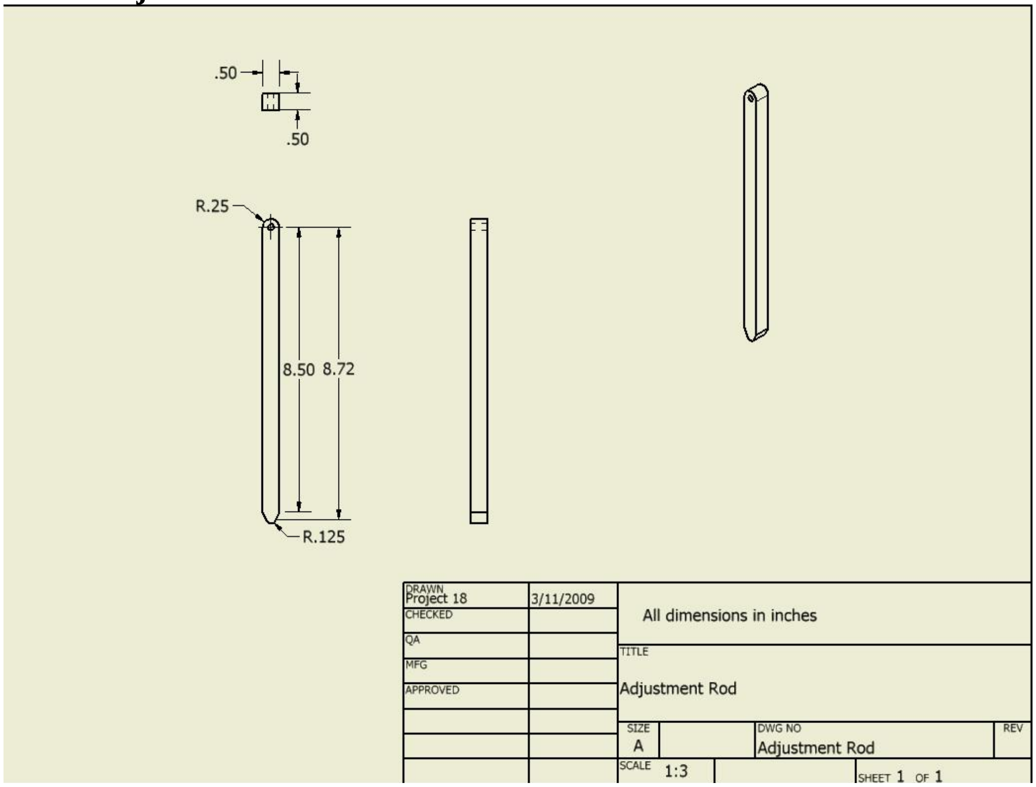
A.7.7 Head Base



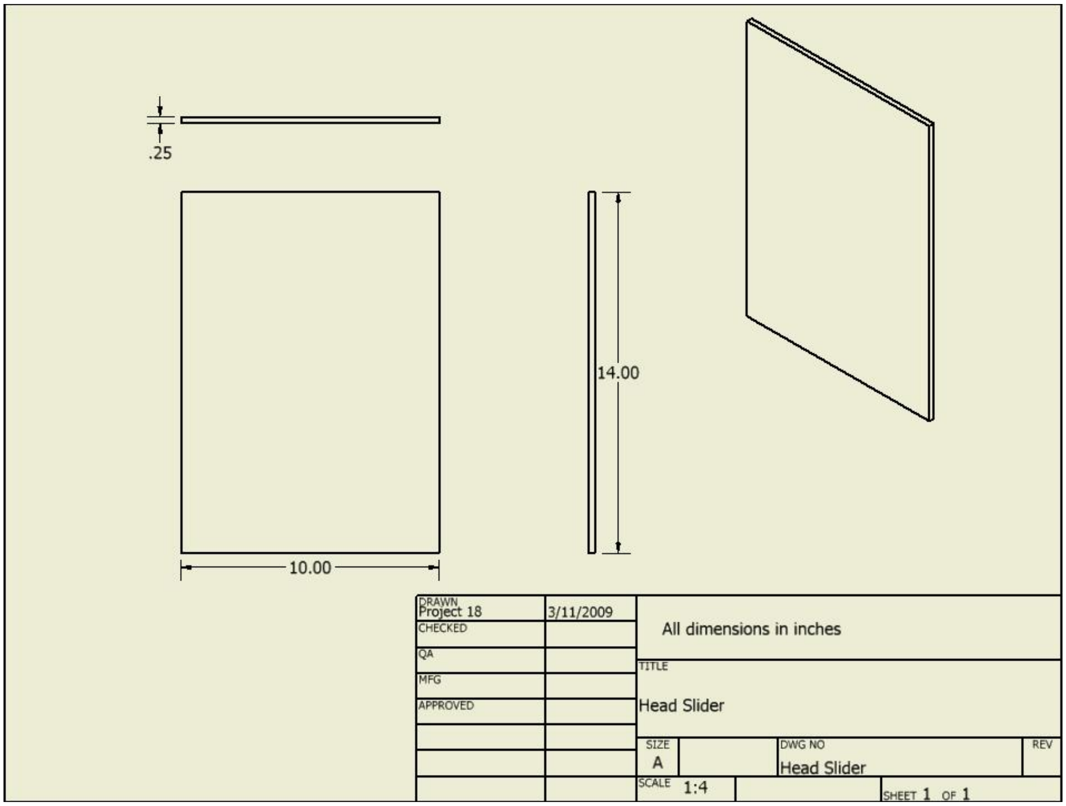
A.7.8 Head Rest



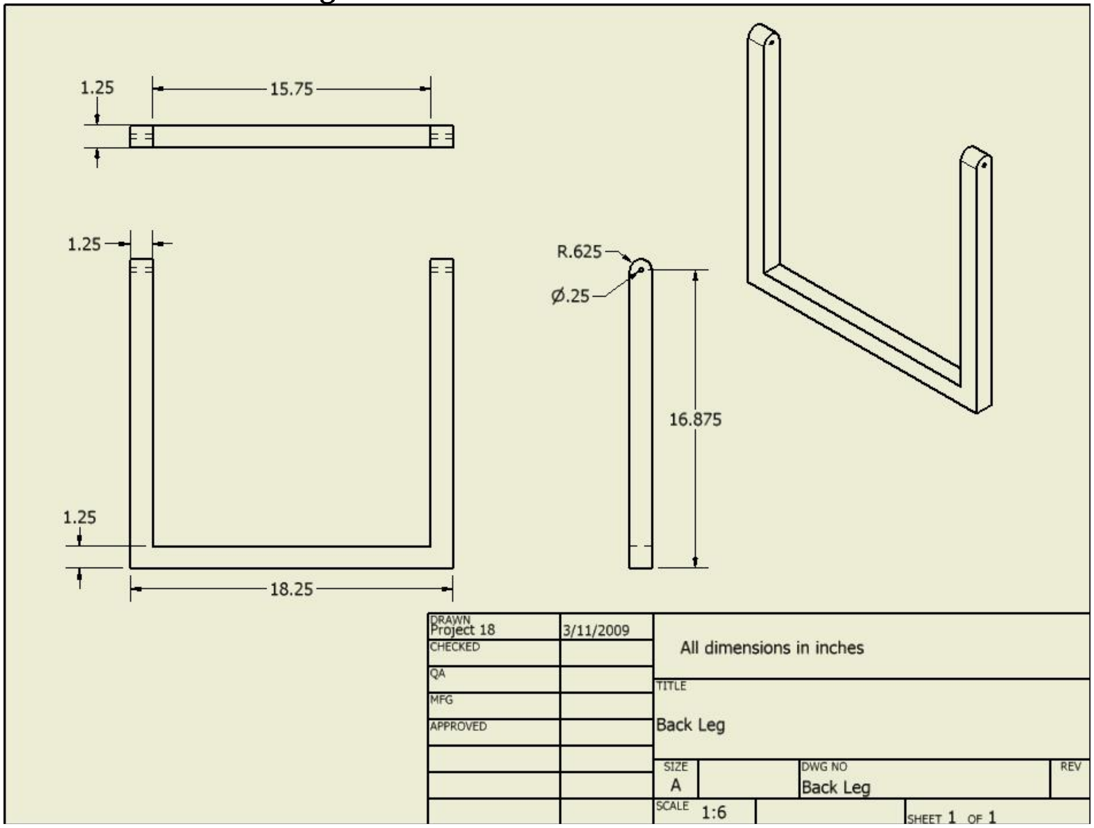
A.7.8 Adjustment Rod



A.7.9 Head Slider Insert



A.7.10 Head Section Leg



DRAWN Project 18 3/11/2009
CHECKED
QA
MFG
APPROVED

All dimensions in inches

TITLE
Back Leg

SIZE A
DWG NO Back Leg
REV
SCALE 1:6
SHEET 1 OF 1

APPENDIX A.8 VALIDATION SURVEYS

A.8.1 Walking Test Survey

For each bodily region, rate the amount of strain caused by the backpack (circle one):

Backpack with Table

Neck	Nonexistent	Small	Moderate	Large
Shoulders	Nonexistent	Small	Moderate	Large
Upper back	Nonexistent	Small	Moderate	Large
Lower back	Nonexistent	Small	Moderate	Large

Weighted Backpack

Neck	Nonexistent	Small	Moderate	Large
Shoulders	Nonexistent	Small	Moderate	Large
Upper back	Nonexistent	Small	Moderate	Large
Lower back	Nonexistent	Small	Moderate	Large

Did either backpack noticeably affect your balance? (If so, please be sure to indicate which one.)

Did either backpack noticeably affect your posture? (If so, please be sure to indicate which one.)

When wearing the backpack containing the table, were any pressure points created by the contents of the pack?

Please write any additional comments/concerns/suggestions on the back. Thank you for taking the time to aid us in our testing!

A.8.2 Biking Test Survey

For each bodily region, rate the amount of strain caused by the backpack (circle one):

Backpack with Table

Neck	Nonexistent	Small	Moderate	Large
Shoulders	Nonexistent	Small	Moderate	Large
Upper back	Nonexistent	Small	Moderate	Large
Lower back	Nonexistent	Small	Moderate	Large

Weighted Backpack

Neck	Nonexistent	Small	Moderate	Large
Shoulders	Nonexistent	Small	Moderate	Large
Upper back	Nonexistent	Small	Moderate	Large
Lower back	Nonexistent	Small	Moderate	Large

Did either backpack noticeably affect your balance? (If so, please be sure to indicate which one.)

Did either backpack noticeably affect your posture? (If so, please be sure to indicate which one.)

When wearing the backpack containing the table, were any pressure points created by the contents of the pack?

Please write any additional comments/concerns/suggestions on the back. Thank you for taking the time to aid us in our testing!

A.8.3 Patient Comfort Survey

Please indicate the comfort level of each configuration:

Legs on foot section, supine	Very Comfortable	Comfortable	Neutral	Uncomfortable	Very Uncomfortable
Legs on foot section, 30°	Very Comfortable	Comfortable	Neutral	Uncomfortable	Very Uncomfortable
Legs on foot section, 60°	Very Comfortable	Comfortable	Neutral	Uncomfortable	Very Uncomfortable
Legs on stirrups, supine	Very Comfortable	Comfortable	Neutral	Uncomfortable	Very Uncomfortable
Legs on stirrups, 30°	Very Comfortable	Comfortable	Neutral	Uncomfortable	Very Uncomfortable
Legs on stirrups, 60°	Very Comfortable	Comfortable	Neutral	Uncomfortable	Very Uncomfortable

Were there any protrusions/design flaws that lead to your discomfort?

Did the table feel sturdy? If it did not feel sturdy, was there any particular reason?

Did you have any trouble getting on the table? If so, why?

Did you have any trouble getting off of the table? If so, why?

Please write any additional comments/concerns/suggestions on the back. Thank you for taking the time to aid us in our testing!

A.8.4 Mock Exam Survey

Did you experience any difficulty or discomfort while examining the patient? If so, why?

Did you experience any difficulty in setting up the table? If so, why?

Did you experience any difficulty in adjusting the back angle? If so, why?

Did you experience any difficulty in setting up/adjusting the stirrups? If so, why?

Please write any additional comments/concerns/suggestions on the back. Thank you for taking the time to aid us in our testing!

APPENDIX A.9 COMPLETED VALIDATION SURVEYS

A.9.2 Patient Comfort Survey

Please indicate the comfort level of each configuration:

Legs on foot section, supine	[✓ Very Comfortable]	Comfortable	Neutral	Uncomfortable	Very Uncomfortable
Legs on foot section, 30^o	[✓ Very Comfortable]	Comfortable	Neutral	Uncomfortable	Very Uncomfortable
Legs on foot section, 60^o	[✓ Very Comfortable]	Comfortable	Neutral	Uncomfortable	Very Uncomfortable
Legs on stirrups, supine	Very Comfortable	[✓ Comfortable]	Neutral	Uncomfortable	Very Uncomfortable
Legs on stirrups, 30^o	Very Comfortable	Comfortable	Neutral	Uncomfortable	Very Uncomfortable
Legs on stirrups, 60^o	Very Comfortable	[✓ Comfortable]	Neutral	Uncomfortable	Very Uncomfortable

Were there any protrusions/design flaws that lead to your discomfort?

Metal stirrup housing

Did the table feel sturdy? If it did not feel sturdy, was there any particular reason?

Very sturdy

Did you have any trouble getting on the table? If so, why?

No, very easy. Good height.

Did you have any trouble getting off of the table? If so, why?

No. It’s very sturdy and you just turn and your legs are on the floor.

Please write any additional comments/concerns/suggestions on the back. Thank you for taking the time to aid us in our testing!

Great design, very comfortable (relative to its use).

A.9.2 Patient Comfort Survey

Please indicate the comfort level of each configuration:

Legs on foot section, supine	[✓ Very Comfortable]	Comfortable	Neutral	Uncomfortable	Very Uncomfortable
Legs on foot section, 30°	[✓ Very Comfortable]	Comfortable	Neutral	Uncomfortable	Very Uncomfortable
Legs on foot section, 60°	[✓ Very Comfortable]	Comfortable	Neutral	Uncomfortable	Very Uncomfortable
Legs on stirrups, supine	Very Comfortable	[✓ Comfortable]	Neutral	Uncomfortable	Very Uncomfortable
Legs on stirrups, 30°	Very Comfortable	[✓ Comfortable]	Neutral	Uncomfortable	Very Uncomfortable
Legs on stirrups, 60°	Very Comfortable	Comfortable	[✓ Neutral]	Uncomfortable	Very Uncomfortable

Were there any protrusions/design flaws that lead to your discomfort?

Thumb screws were slightly in the way when I went to get off the table.

Did the table feel sturdy? If it did not feel sturdy, was there any particular reason?

The table felt very sturdy.

Did you have any trouble getting on the table? If so, why?

No.

Did you have any trouble getting off of the table? If so, why?

No trouble. I was close to scraping on the thumb screws, though.

Please write any additional comments/concerns/suggestions on the back. Thank you for taking the time to aid us in our testing!

A.9.3 Patient Comfort Survey

Please indicate the comfort level of each configuration:

Legs on foot section, supine	[✓ Very Comfortable]	Comfortable	Neutral	Uncomfortable	Very Uncomfortable
Legs on foot section, 30°	[✓ Very Comfortable]	Comfortable	Neutral	Uncomfortable	Very Uncomfortable
Legs on foot section, 60°	[✓ Very Comfortable]	Comfortable	Neutral	Uncomfortable	Very Uncomfortable
Legs on stirrups, supine	Very Comfortable	Comfortable	[✓ Neutral]	Uncomfortable	Very Uncomfortable
Legs on stirrups, 30°	Very Comfortable	Comfortable	[✓ Neutral]	Uncomfortable	Very Uncomfortable
Legs on stirrups, 60°	Very Comfortable	Comfortable	[✓ Neutral]	Uncomfortable	Very Uncomfortable

Were there any protrusions/design flaws that lead to your discomfort?

No, being in stirrups is just naturally uncomfortable.

Did the table feel sturdy? If it did not feel sturdy, was there any particular reason?

Very sturdy. I was surprised that such a small table was so sturdy.

Did you have any trouble getting on the table? If so, why?

No trouble.

Did you have any trouble getting off of the table? If so, why?

No trouble.

Please write any additional comments/concerns/suggestions on the back. Thank you for taking the time to aid us in our testing!

Impressive design!

A.9.4 Patient Comfort Survey

Please indicate the comfort level of each configuration:

Legs on foot section, supine	[✓ Very Comfortable]	Comfortable	Neutral	Uncomfortable	Very Uncomfortable
Legs on foot section, 30°	[✓ Very Comfortable]	Comfortable	Neutral	Uncomfortable	Very Uncomfortable
Legs on foot section, 60°	[✓ Very Comfortable]	Comfortable	Neutral	Uncomfortable	Very Uncomfortable
Legs on stirrups, supine	Very Comfortable	[✓ Comfortable]	Neutral	Uncomfortable	Very Uncomfortable
Legs on stirrups, 30°	Very Comfortable	[✓ Comfortable]	Neutral	Uncomfortable	Very Uncomfortable
Legs on stirrups, 60°	Very Comfortable	[✓ Comfortable]	Neutral	Uncomfortable	Very Uncomfortable

Were there any protrusions/design flaws that lead to your discomfort?

The stirrup housings were placed where I wanted to put my hands.

Did the table feel sturdy? If it did not feel sturdy, was there any particular reason?

The table was quite sturdy.

Did you have any trouble getting on the table? If so, why?

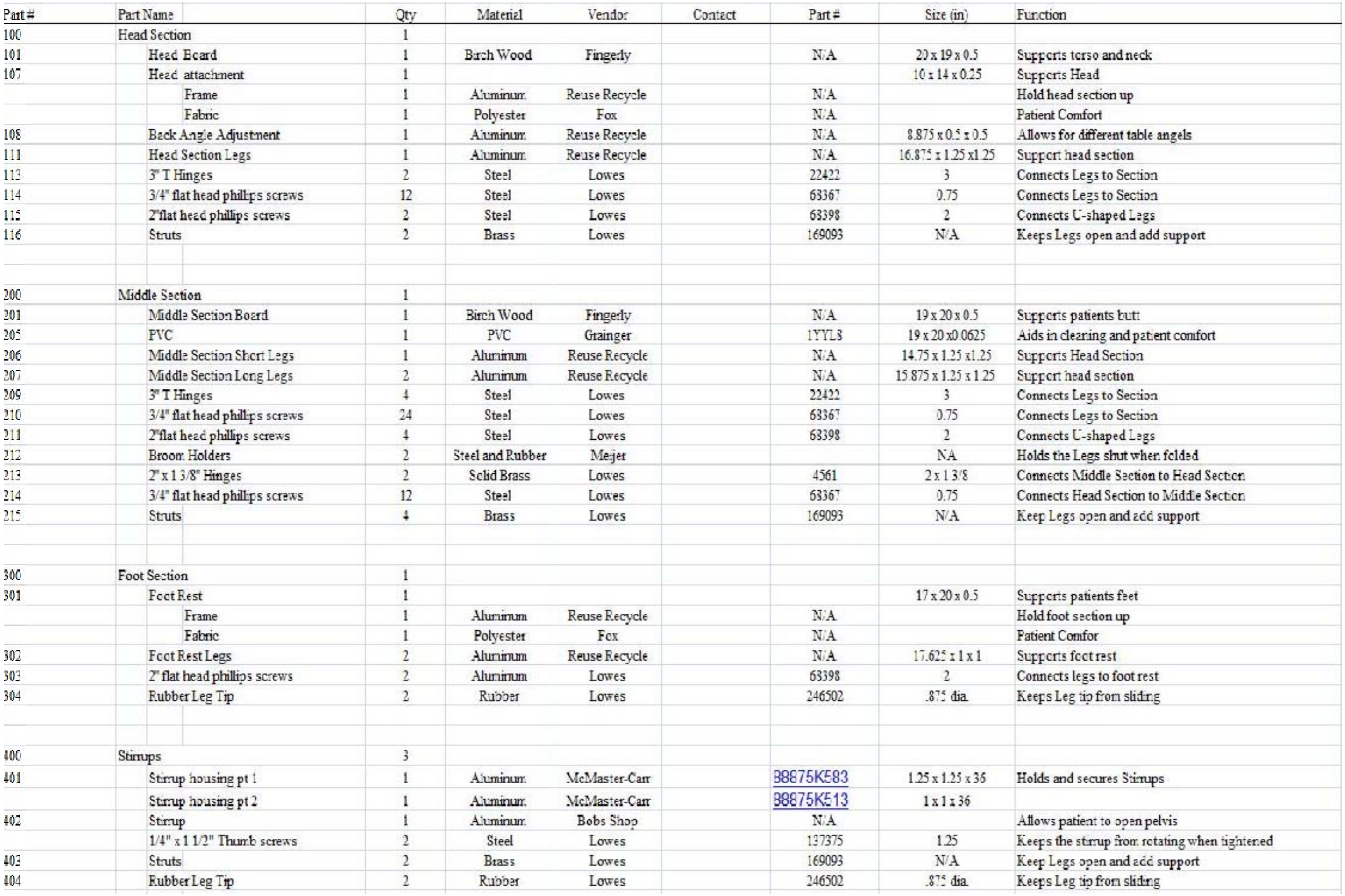
No. The table is at a good height.

Did you have any trouble getting off of the table? If so, why?

No. Again, the table is at a good height.

Please write any additional comments/concerns/suggestions on the back. Thank you for taking the time to aid us in our testing!

APPENDIX B BILL OF MATERIALS



Part #	Part Name	Qty	Material	Vendor	Contact	Part #	Size (in)	Function
100	Head Section	1						
101	Head Board	1	Birch Wood	Fingerly		N/A	20 x 19 x 0.5	Supports torso and neck
107	Head attachment	1					10 x 14 x 0.25	Supports Head
	Frame	1	Aluminum	Reuse Recycle		N/A		Hold head section up
	Fabric	1	Polyester	Fox		N/A		Patient Comfort
108	Back Angle Adjustment	1	Aluminum	Reuse Recycle		N/A	8.875 x 0.5 x 0.5	Allows for different table angels
111	Head Section Legs	1	Aluminum	Reuse Recycle		N/A	16.875 x 1.25 x1.25	Support head section
113	3" T Hinges	2	Steel	Lowes		22422	3	Connects Legs to Section
114	3/4" flat head phillips screws	12	Steel	Lowes		63367	0.75	Connects Legs to Section
115	2"flat head phillips screws	2	Steel	Lowes		63398	2	Connects U-shaped Legs
116	Struts	2	Brass	Lowes		169093	N/A	Keeps Legs open and add support
200	Middle Section	1						
201	Middle Section Board	1	Birch Wood	Fingerly		N/A	19 x 20 x 0.5	Supports patients butt
205	PVC	1	PVC	Grainger		1YYL8	19 x 20 x0.0625	Aids in clearing and patient comfort
206	Middle Section Short Legs	1	Aluminum	Reuse Recycle		N/A	14.75 x 1.25 x1.25	Supports Head Section
207	Middle Section Long Legs	2	Aluminum	Reuse Recycle		N/A	15.875 x 1.25 x 1.25	Support head section
209	3" T Hinges	4	Steel	Lowes		22422	3	Connects Legs to Section
210	3/4" flat head phillips screws	24	Steel	Lowes		63367	0.75	Connects Legs to Section
211	2"flat head phillips screws	4	Steel	Lowes		63398	2	Connects U-shaped Legs
212	Broom Holders	2	Steel and Rubber	Meijer			NA	Holds the Legs shut when folded
213	2" x 1 3/8" Hinges	2	Solid Brass	Lowes		4561	2 x 1 3/8	Connects Middle Section to Head Section
214	3/4" flat head phillips screws	12	Steel	Lowes		63367	0.75	Connects Head Section to Middle Section
215	Struts	4	Brass	Lowes		169093	N/A	Keep Legs open and add support
300	Foot Section	1						
301	Foot Rest	1					17 x 20 x 0.5	Supports patients feet
	Frame	1	Aluminum	Reuse Recycle		N/A		Hold foot section up
	Fabric	1	Polyester	Fox		N/A		Patient Comfor
302	Foot Rest Legs	2	Aluminum	Reuse Recycle		N/A	17.625 x 1 x 1	Supports foot rest
303	2" flat head phillips screws	2	Aluminum	Lowes		63398	2	Connects legs to foot rest
304	Rubber Leg Tip	2	Rubber	Lowes		246502	.875 dia.	Keeps Leg tip from sliding
400	Stirrups	3						
401	Stirrup housing pt 1	1	Aluminum	McMaster-Carr		88875K583	1.25 x 1.25 x 36	Holds and secures Stirrups
	Stirrup housing pt 2	1	Aluminum	McMaster-Carr		88875K513	1 x 1 x 36	
402	Stirrup	1	Aluminum	Bobs Shop		N/A		Allows patient to open pelvis
	1/4" x 1 1/2" Thumb screws	2	Steel	Lowes		137375	1.25	Keeps the stirrup from rotating when tightened
403	Struts	2	Brass	Lowes		169093	N/A	Keep Legs open and add support
404	Rubber Leg Tip	2	Rubber	Lowes		246502	.875 dia.	Keeps Leg tip from sliding

APPENDIX C ENGINEERING CHANGES

There were 7 changes between the Omega final design and the Omega final prototype.

C.1 Foot Section Legs

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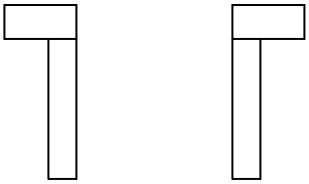

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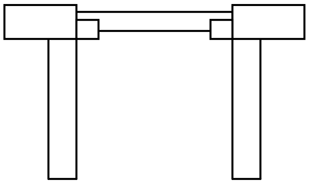


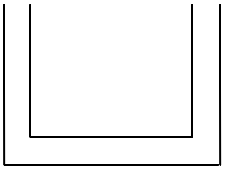
A removable cross bar was added in between the foot section legs in order to keep the fabric tight when a patient is resting their legs. The cross bar also made the legs much more stable by preventing the foot section from collapsing due to side motion.

C.2 Middle Section Legs

The table legs are a major concern because they are at the highest risk of failure due to buckling, therefore we spent a large portion of the manufacturing time strengthen the table legs.

C.2.1 Leg Stability

WAS:



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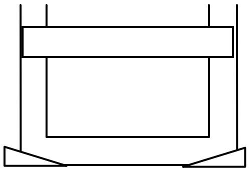
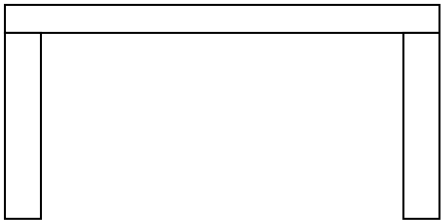


A cross bar was added to both middle section legs in order to strengthen them against torsion and bending. Also, we noticed that the rounded corners of the legs allowed them to rotate on the ground when weight was not placed at the center of the section, which could cause the table to tip over forwards/backwards. Therefore, rubber stops were placed at the rounded corners in the legs to prevent them from rotating.

WAS:



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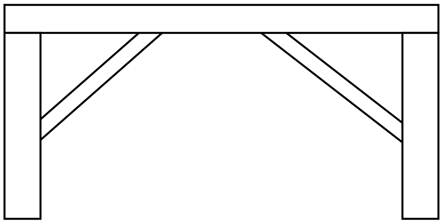


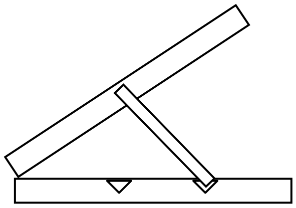
We noticed after its construction that the middle section was not very stable. After some investigation, we found that the hinges allowed motion of the legs. Therefore, two support struts were added to each leg to keep the legs in place while the table is being used. This greatly enhanced the stability and safety of the table. These support struts also keep the legs from collapsing back in and required a significant force to close them.

C.3 Head Section

The angle adjustment and the head section legs varied from the final design to the prototype.

C.3.1 Angle Adjustment

WAS:



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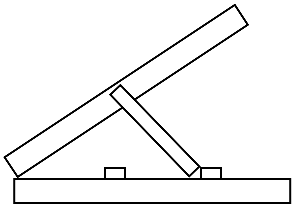


Instead of having notches in the table section for the adjustment rods to sit in, we made elevated stops for the adjustment rod to stop against. The notches would require drilling holes in the wooden section (for the rod to sit into) which meant that there was less material in the base of the head section, thus making it weaker in those areas. We also determined that over time the adjustments rods would dig into the wood, causing cracks and shearing the wood. The elevated stops made of aluminum allow for a stronger back angle adjustment.

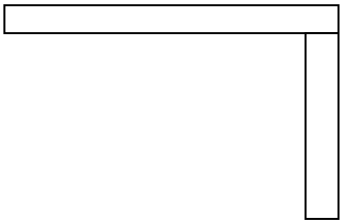
WAS:

IS:

We added a cross bar connecting the two adjustment rods in order to make them sturdier. The cross bar also make the back angle much easier to adjust, since each rod does not have to be adjusted independently.

C.3.2 Leg Stability

WAS:



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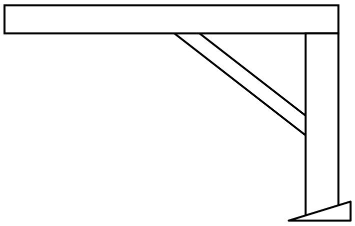

A support strut was added to each side of the legs in order to ensure they stay open while the table is in use. These supports made the legs much sturdier. Also, we noticed that the legs would sometimes slide back, which allowed the middle and head sections to fold in while the table was in use. We added a rubber stop to the head section legs, effectively preventing this sliding motion. Both of these changes made the table much sturdier and safer.

C.4 Stirrups

The stirrups were only manufactured once and as a result proposed problems we had not seen in the final Omega design.

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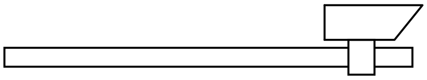

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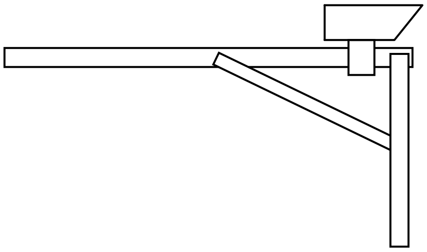


Originally, the stirrups were supported entirely by the stirrup housing on the side of the table. Realizing that this was not sufficient, we connected a leg to the end of the stirrups, and then added a support strut between the leg and the stirrup housing. This prevented the stirrup from transmitting a destructive moment to the stirrup housing, and helped steady the stirrups when in use.

APPENDIX D DESIGN ANALYSIS ASSIGNMENT

D.1 Material Selection Assignment (Functional Performance)

Component #1: Body panels

Function:	A supportive base that the legs, head frame, etc. will attach to.
Objective:	Provide a supporting base for the middle and head sections of the table.
Constraints:	The body panels must be lightweight, strong, and low cost.

Material Indices

- Young's Modulus greater than 95MPa
- Cost/mass ratio less than $2/kg
- Very good resistance to weak acids

Top Five Material Choices

1. Birch wood
2. Wrought Aluminum 7075, T651
3. PVC
4. Ni-Cr white cast iron
5. Styrene Foam

Final Choice + Reasoning: Birch wood was chosen for its low cost and the fact that it can be easily acquired from a local lumber yard. While birch wood is heavier than aluminum or PVC, it's weight is offset by its cost, which is more important for the body panels since they are the largest components of our design.

Component #2: Table legs

Function:	To elevate the table to the correct height.
Objective:	Provide a sturdy, effective means of elevating the table.
Constraints:	The table legs must be lightweight, strong, and low cost.

Material Indices

- Young's Modulus greater than 95MPa
- Cost/mass ratio less than $2/kg
- Very good resistance to weak acids

Top Five Material Choices

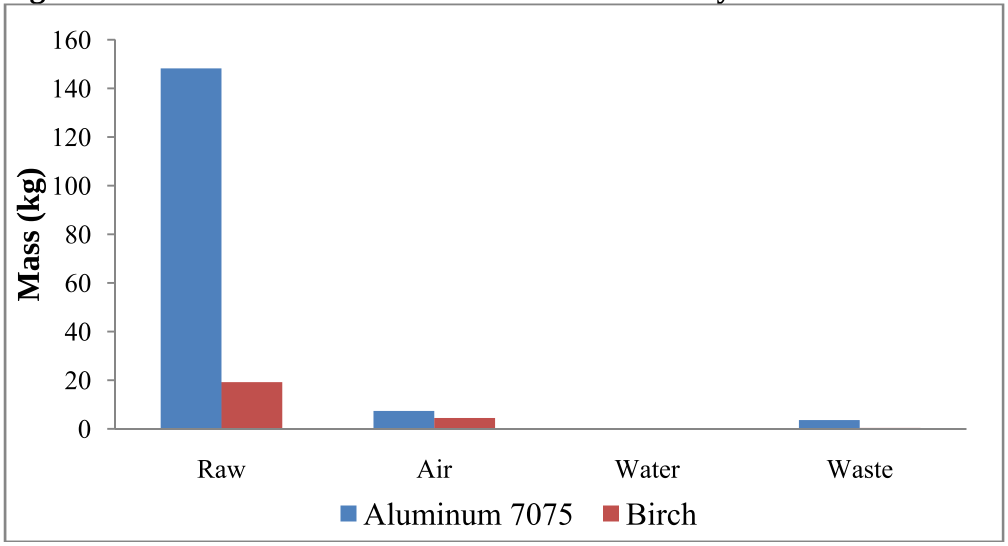
1. Birch wood
2. Wrought Aluminum 7075, T651
3. PVC
4. Ni-Cr white cast iron
5. Styrene Foam

Final Choice + Reasoning: The wrought aluminum alloy was chosen to save weight, still be relatively cheap, and because it is very strong. We wanted to make sure the legs were made out of a particularly strong material to avoid leg buckling. While the cast iron is stronger than aluminum, it is several times heavier, which made it unsuitable for our design.

D.2 Material Selection Assignment (Environmental Performance)

Mass of birch wood: 3.643 kg Mass of aluminum alloy: .8734 kg

Figure D.1 – Total emissions of 7075 Aluminum Alloy and Birch Wood



From the results of our environmental analysis, it is clear that the aluminum alloy used for our design will have a much bigger impact on the environment than the birch wood. The aluminum creates more total emissions (Figure D.1) and has a higher overall damage impact (Figure D.2 on pg D3 and Figure D.4 on pg D5) than birch wood.

However, over the life cycle of a table the two materials may have a similar impact on the environment. While the aluminum needs far more resources to be manufactured, it is stronger and more durable than the birch wood as the wood is much more susceptible to cracks. The aluminum would survive an accidental drop of the table, but after time the wood may not, requiring those pieces to be replaced. Thus over time the aluminum's environmental impact would become lower, while the environmental impact of the birch wood may increase. Therefore, while we could manufacture the aluminum pieces out of birch, the long-term environmental effects could become much greater, making the initial environmental impact of the aluminum seem much more reasonable.

For our design and materials, the important damage meta-categories are ecosystem quality and resources (Figure D.3 on pg D4). The aluminum has a large impact on resources, and the wood has a sizable impact on ecosystem quality.

Figure D.2 – Relative Impacts in Disaggregated Damage Categories of 7075 Aluminum Alloy and Birch Wood

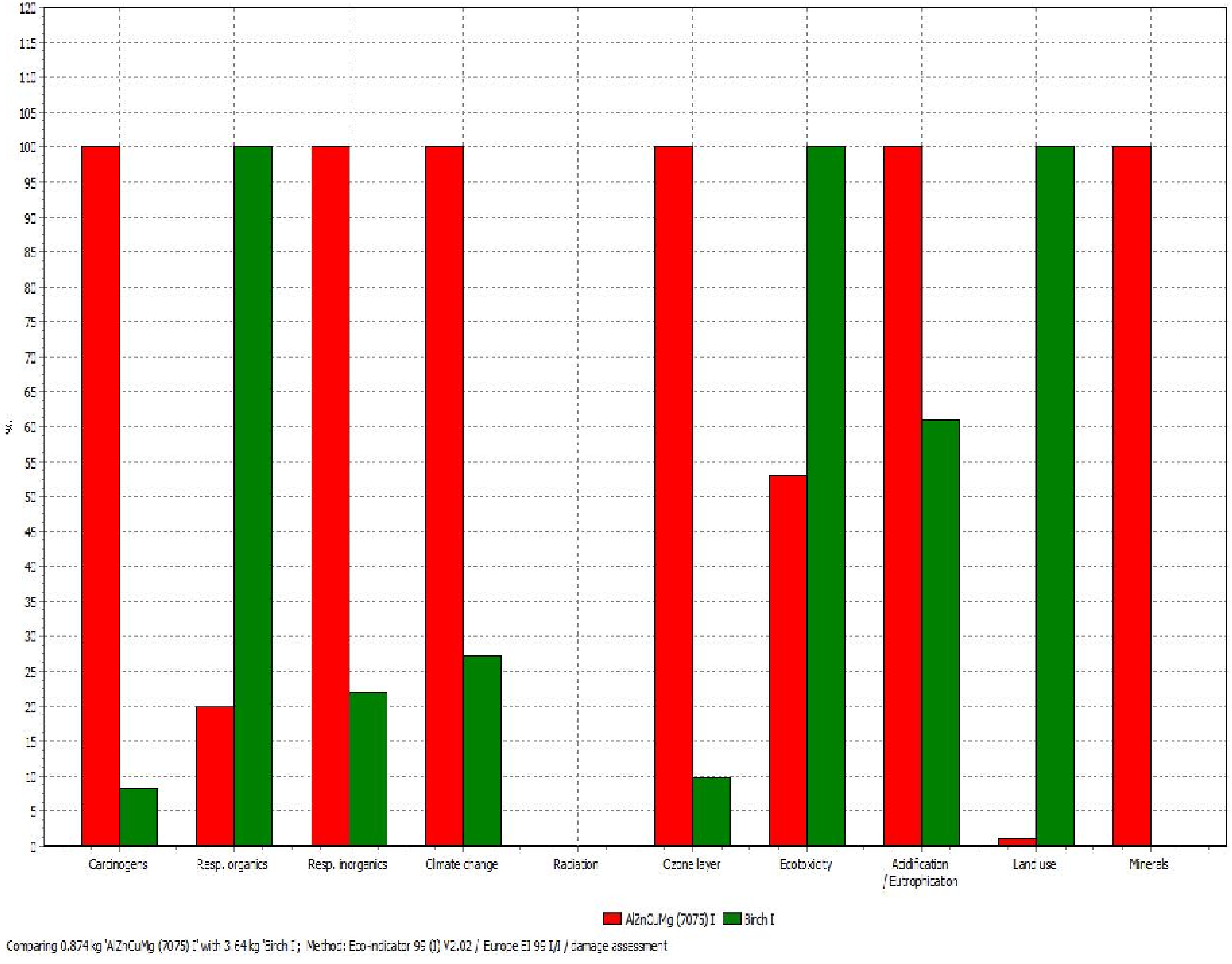


Figure D.3 – Normalized Damage Score of 7075 Aluminum Alloy and Birch Wood

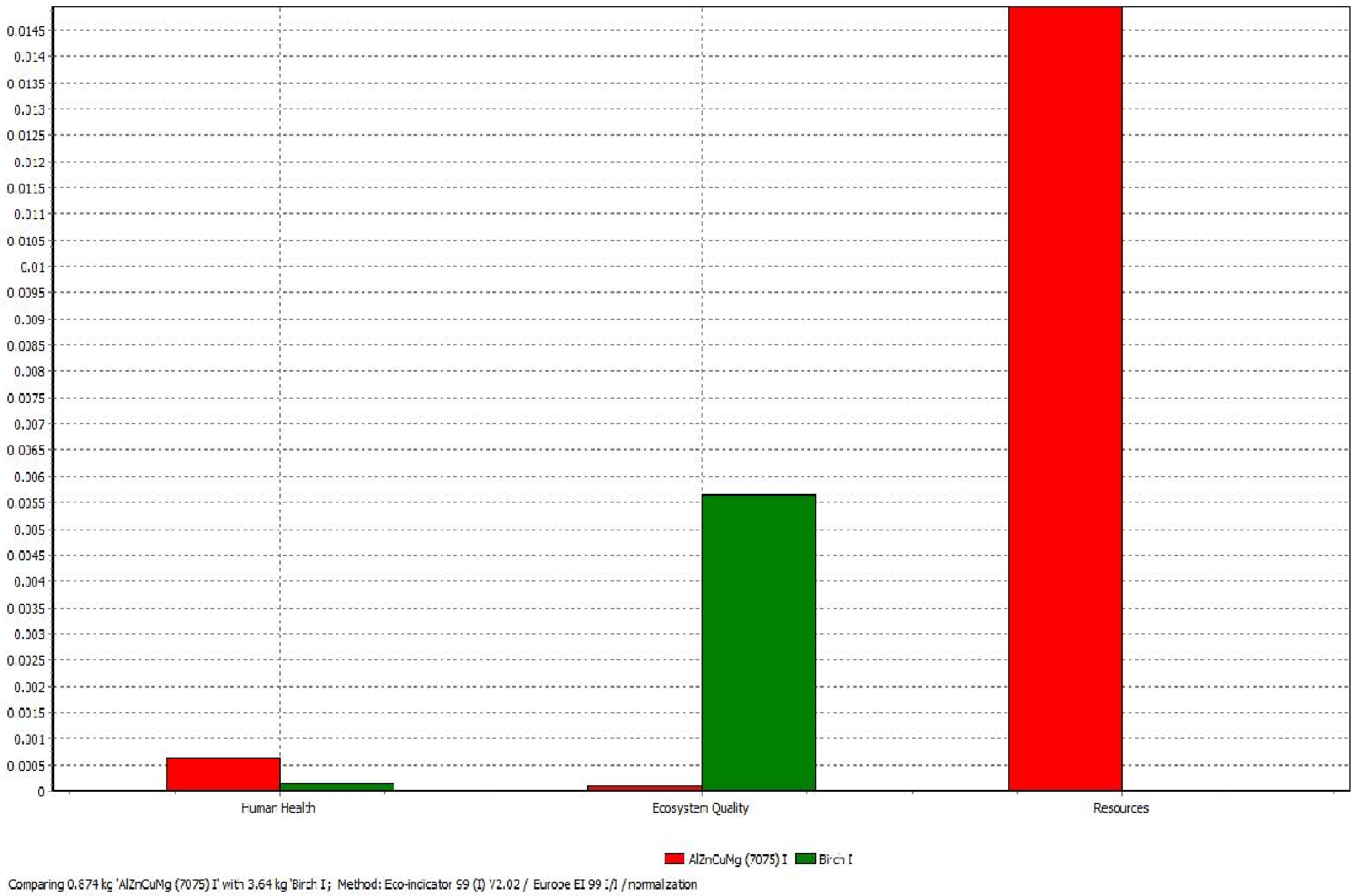
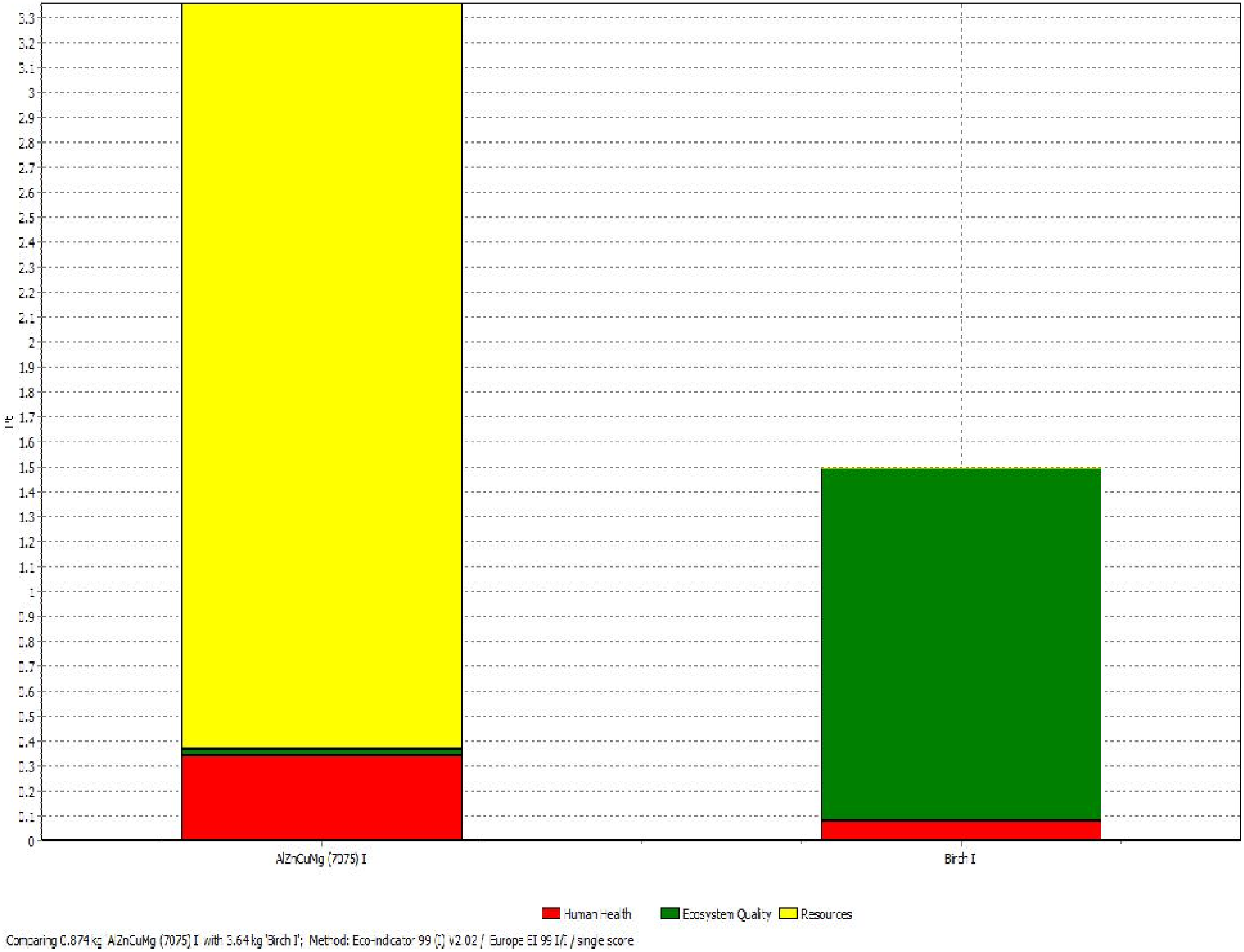


Figure D.4 – Single Score Point Comparison of 7075 Aluminum Alloy and Birch Wood



D.3 Manufacturing Process Selection Assignment

Our prototype is scheduled for use in the Brong Ahafo region of Ghana. This region contains 220 health care facilities. (http://www.ghanahealthservice.org/healthstats.php?dd=6&region=Brong%20Ahafo%20Region) If our design becomes widely accepted in the region and localized production begins, we would expect that they would produce 220 tables, one for each facility. By using the CES Manufacturing process selector, we determined the optimal manufacturing processes involving each material.

To cut the aluminum and the wood, a band saw is best. Band saws are capable of making larger cuts involved with the wood table sections as well as smaller, more accurate cuts involving the aluminum legs and brackets. Also, band saws have low equipment and tooling costs relative to other machinery. Since both tools are quite economical, it is reasonable that they are available in Ghana.

To drill the holes in both the wood and aluminum, a drill press is optimal. Initial cost of a drill press is slightly higher relative to the band saw, but saves a lot of time and effort as it is far more accurate and capable than a hand drill.

Lastly, bends need to be made in the aluminum to form the legs. A manual tube bender is the best choice. Manual benders are the cheapest metal benders available. While manual benders are generally harder to work with than automated ones, there are not many pieces on our design that need to be bent. Also, manual benders are the simplest to operate and do not require an experienced machinist.