Engineering Design Report

Reconfigurable Obstetrics Delivery Bed

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Team 16
Navdeep Kaur
Leah Miller
Diane Njindam
Nick Rubis
Frances Sennett

Sponsor
Prof. Kathleen Sienko
Global Health Design Minor
Professor of Mechanical Engineering
Professor of Biomedical Engineering

Mentors
Dr. Timothy Johnson
Chair of the Department of Obstetrics and Gynecology, University of Michigan Health System

Jody Lori
CNM Lecturer and Interim Nurse Midwifery Program Coordinator, University of Michigan, School of Nursing

Consultant
Dr. Anthony Ofosu
Sene District Hospital Director, Ghana

EXECUTIVE SUMMARY

This report details an engineering design project undertaken by Mechanical Engineering undergraduate students at the University of Michigan. The goal of the project is to design and manufacture a reconfigurable obstetrics delivery bed that is easy to clean and maneuver, robust, low cost and usable for all the stages of labor for patients in the labor and delivery ward at Komfo Anokye Teaching Hospital (KATH) in Kumasi, Ghana. This project stems from the Global Intercultural Experience for Undergraduates (GIEU) Program where twelve University of Michigan students went to Ghana and gained field site experience while completing clinical observations in Obstetrics and Gynecology at KATH.

The labor and delivery ward is currently equipped with eight supine beds for the initial stages of labor and two delivery chairs for the end of the second stage of labor. Near the end of the second stage of labor, when delivery is imminent, the women walk from the supine bed to the delivery chair. A reconfigurable obstetric delivery bed would allow women to remain in one bed throughout delivery, improve patient flow, increase patient and newborn safety during delivery, increase the quality of patient care, and provide more birthing stations.

To facilitate an effective and successful design, a comprehensive list of customer requirements was transformed into quantitative engineering specifications. For the sake of the design process, the entire hospital staff has been defined as the customer while the delivering mothers have been defined as the end users. Utilizing a simple scale, the customer requirements were evaluated and ranked. The resulting critical requirements for the end product are as follows: robust, safe, affordable, be reconfigurable, and easy to sanitize. Throughout the design process, both the requirements and their corresponding specifications have been reevaluated and redefined

The design process in its entirety is detailed throughout this report, including methodology, procedures, analyses, and end results. A detailed description, including finalized CAD models of all components is provided as well. The design has evolved throughout the process and the current design is the result of intense engineering efforts and analysis. This report serves to document the entire process from initial background research to final recommendations for improvement to the final design.

This report documents the entire design process including the final manufacturing plan, the measures taken to ensure that all established customer requirements and engineering specifications have been validated and satisfied in the final prototype, a detailed description and analysis of every major component, an in depth critique of the functionality of the these components, and finally, our recommendations concerning improving the final design and suggested future work.

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Reconfigurable Obstetrics Delivery Bed for Komfo Anoyke Teaching Hospital in Kumasi, Ghana

Navdeep Kaur
Senior, Department of Mechanical Engineering
University of Michigan
Ann Arbor, MI 48104
navdeepk@umich.edu

Leah Miller
Senior, Department of Mechanical Engineering
University of Michigan
Ann Arbor, MI 48104
lnmiller@umich.edu

Diane Njindam
Senior, Department of Mechanical Engineering
University of Michigan
Ann Arbor, MI 48104
dianjind@umich.edu

Nick Rubis
Senior, Department of Mechanical Engineering
University of Michigan
Ann Arbor, MI 48104
nrubis@umich.edu

Frances Sennett
Senior, Department of Mechanical Engineering
University of Michigan
Ann Arbor, MI 48104
fsennett@umich.edu

***Abstract* – This report details the conception and design of a reconfigurable obstetrics delivery bed intended for the Labor and Delivery Ward of the Komfo Anokye Teaching Hospital (KATH) in Kumasi, Ghana. After extensive clinical observations in KATH, a group of multidisciplinary University of Michigan students involved with the Global Intercultural Experience for Undergraduates Program initially identified the problem. The ward is currently equipped with eight supine beds and two delivery chairs. As delivery begins nearing the end of the second stage of labor, the patients walk from a supine bed to a delivery chair across the ward. The engineering team was asked to design and manufacture a reconfigurable obstetrics delivery bed that patients can use during all three stages of labor, which could potentially improve patient flow, increase patient and newborn safety during delivery, increase the quality of patient care, and increase the number of delivery stations. This report documents the design process including the measures taken to ensure that all established customer requirements and engineering specifications have been validated, a detailed description and critique of the functionality of the final design, and recommendations concerning improving the final design and suggested future work.**

Index Terms – Obstetrics bed, Patient Health, Reconfigurable

Introduction

The Labor and Delivery Ward at the Komfo Anokye Teaching Hospital (KATH) in Kumasi, Ghana is equipped with eight supine beds and two delivery chairs. Due to equipment shortages and an often overwhelming patient flow, delivering mothers are not guaranteed a supine bed at the onset of labor nor a delivery chair for birthing. Patients are required to wait in the hallway until they reach a dilation of five centimeters when they are provide a supine bed if one is available. If and when they are given access to a supine bed, the women must remain on the bed until they are dilated 9-10cm, which marks the end of the second stage of labor. At this stage in the birthing process, the woman is prepared to deliver and must walk from the supine bed to one of the delivery chairs if one should be available. Oftentimes mothers deliver on the supine bed or even outside in the hallway. Delivering in the supine position is the most taxing and strenuous position for a woman. As such, the ultimate goal is to replace all the supine beds in the ward with reconfigurable delivery beds to improve patient care, safety, and health. The layout of the concerned ward can be seen in Figure 1 below with the green boxes representing the supine beds and the orange boxes representing the delivery chairs. Pictures of the supine beds and delivery chairs currently used in KATH can be seen in Figures 2 and 3 below.

While reconfigurable labor and delivery beds have been designed, the critical aspect of this project is to tailor these designs to fit within the current Ghanaian medical culture so that they will be accepted and fully utilized. The ultimate goal is to design a product that can be completely manufactured with available materials in country. The final prototype will be shipped to Ghana so that further design critique and analysis can be performed.

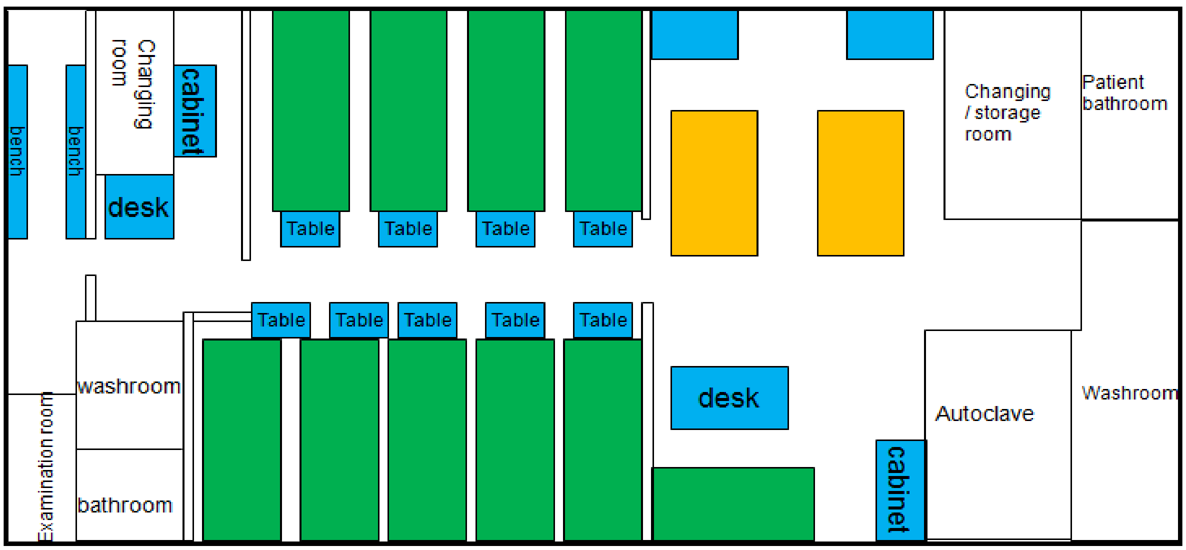


FIGURE 1

LAYOUT OF THE LABOR AND DELIVERY WARD AT KATH

FIGURE 2
KATH SUPINE BED

FIGURE 3
KATH DELIVERY CHAIR

BACKGROUND

Improving the quality of obstetric care is an urgent priority in developing countries due to high maternal mortality rates (Ansong-Tornui, Armar-Klemesu, Arhinful, Penfold, & Hussein, Hospital Based Maternity Care in Ghana - Findings of a Confidential Enquiry into Maternal Deaths, 2007).[i] Ghana has one of the highest maternal mortality rates with 540 maternal deaths for every 100,000 live births. "It is [also] estimated that for every maternal death, another 20 women will develop some form of life-long morbidity related to pregnancy and/or childbirth" (D'Ambruoso, Abbey, & Hussein, 2005).[ii]

In Ghana, a universal, free policy was implemented to provide payment-free delivery care in health facilities. This new policy has ultimately resulted in deterioration in the quality of care due to the increased patient utilization without a simultaneous increase in resources such as personnel and equipment[iii]. The World Health Organization's *World Health Statistics* 2008 details information regarding disease control, health care systems and discrepancies, and mortality rates. The following facts relate to Ghana and further validate the need to make obstetric improvements in Ghanaian medical culture (World Health Organization, 2008).[iv]

- 50% of overall births by skilled health personnel
- 79.7% of births attended by skilled health personnel in urban area (2.6 times higher than rural areas)
- 20.6% of poor women have births attended by skilled health personnel as opposed to 90.4% of wealthy
- 9 midwives per 10,000 people
- 9 hospital beds per 10,000 people
- 18 million: the estimated number of additional hospital beds the WHO African Region would need to match the bed density in the rest of the world

With these staggering statistics, it is necessary to maximize resources and design functional beds that can be easily adopted into the established medical system, serving more than one function.

Cultural Background of Birthing in Ghana

Childbirth in Ghana has deep social, religious, and cultural influences. The ability to bear children is highly revered within the Ghanaian culture; it is an act that commands respect. In Ghana, a woman who is unable to bear children is not believed to be a woman (Bazzano, Kirkwood, Tawiah-Agyemang, Owusu-Agyei, & Adongo, 2008).[v] Childbirth is also considered a very natural process, making hospital birth unnecessary and frowned upon. Women gain respect through home births, considering it ideal to deliver with "minimum assistance and maximum secrecy" so as not to bother anyone. [vi] Difficult labors are often attributed to the mother's past mistakes. This deeply rooted desire to keep pregnancy a secret and not seek assistance or care results in many women not seeking appropriate medical care.

Another factor influencing child birthing decisions in Ghana is the quality of healthcare.[vii] Women often recount harsh treatment from midwifes or even are turned away if they arrive before active labor. In the hospital, the women are also alone, without support from family, without pain medication, and expected to remain silent throughout the labor and delivery process. While one medical design cannot change the cultural norms associated with medical care, the goal of the reconfigurable labor and delivery bed is to begin taking the steps to change the medical culture in Ghana to enhance respect and quality of care.

Stages of Labor and Delivery

The process of labor is divided into three stages, differentiated by physical changes of the uterine cervix and location of the baby. Delivery describes the action of bringing the baby to the outside world (ACOG, 2007).

The first stage of labor is the early labor, active labor and transition (Mayo Clinic, 2007). It "begins when the uterus contracts and the cervix starts to open," which allows the baby to move to the birth canal.[viii] The cervix dilates from 0cm to 3cm during early labor and contractions begin, occurring every five to twenty minutes. After early labor within the first stage of labor is active labor, during which the cervix dilates to approximately 7cm and contractions increase. Transition is the last phase of the first stage of labor and the cervix dilates to 10cm.[ix] By the end of this stage, the cervix is completely open and contractions become longer and stronger as the body prepares for the baby to move. The longest stage of labor is usually the first stage. In the second stage of labor, the mother begins pushing during each contraction until the baby is delivered. The second stage may last several hours and ends with the birth of the baby. [x] The third stage of labor is characterized by uterine contractions, usually less painful, that continue until the placenta is delivered. [xi] The final stage may last up to thirty minutes.

The aforementioned stages of labor are characteristic of vaginal delivery. [xii] If there are complications during an attempted vaginal delivery, the baby may have to be delivered via Cesarean delivery, which is "delivery of the baby through a cut made in the women's abdomen and uterus." Cesarean delivery is utilized when the baby may be too large to fit through the pelvis, the baby is in distress, or there are complications with the mother. [xiii]

Birthing Positions

For the purpose of improving patient care and health, we chose to focus on designing a bed that would accommodate two birthing positions: semi-recumbent and lateral. The semi-recumbent position and lateral position are shown in Figure 4 and Figure 5 respectively. The semi-recumbent position has lower rates of episiotomy (a surgical incision to enlarge the vagina) and tearing and is the mostly widely used birthing position. It is also the position currently utilized at KATH. The lateral birthing position has the lowest rates of episiotomy and tearing and is most highly recommended by our mentor, Dr. Lori.

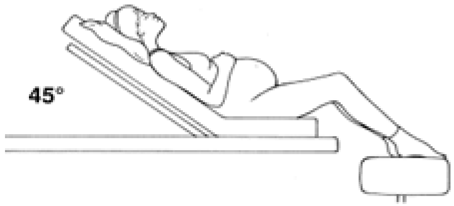


FIGURE 4
SEMI-RECUMBENT BIRTHING POSITION

FIGURE 5
LATERAL BIRTHING POSITION

Benchmarking Current Products: Hill-Rom Affinity 4 Birthing Bed

We researched many current market products as well as several delivery bed patents. The Hill-Rom Affinity Bed (shown in Figure 4) is the bed currently used at the University of Michigan hospitals and is a high quality labor and delivery bed. While the standard bed contains many technological features beyond the scope of our project design and budget, we utilized the main technical specifications for our benchmarking as seen below.

TABLE 1
AFFINITY 4 BIRTHING BED TECHNICAL SPECIFICATIONS[xiv]

Feature	Dimension
Bed Length	229cm
Bed Width	99cm
Bed Height	58-99cm
Mattress Thickness	12.7cm
Max Head Elevation	63°
Max Bed Lift Capacity	227kg

FIGURE 4
HILL-ROM AFFINITY 4 BIRTHING BED USED AT THE UNIVERSITY OF MICHIGAN HOSPITALS

CRITICAL DESIGN SPECIFICATIONS

To effectively design the requested obstetrics delivery bed, a comprehensive list of customer expectations for the final product was produced. Critical to the generation of this expectation list was determining who constituted the project's customer. Ultimately, it was determined that the hospital staff (midwives, doctors, maintenance personnel, etc) is the customer, while the delivering patients are the end users of the product. Based on discussions with our mentors and contacts regarding medical personnel requirements for the bed, ideal birthing conditions, and Ghanaian medical culture, we were able to determine the following list of customer specifications, which are shown in order of importance from 5 (most important) to 1 (least important). Table 2 also includes the target values for the corresponding engineering specifications.

TABLE 2
CUSTOMER REQUIREMENTS WITH CORRESPONDING ENGINEERING SPECIFICATIONS

Customer Requirement	**Importance (1 low, 5 high)**	**Engineering Specification**	**Target Value**
Robust	5	Upward Support Force (N)	3000
Safety	5	Safety Factor (#)	1.5
Affordable	5	Manufacturing Cost ($)	≤500
Reconfigurable	5	Back Support Inclinable (°)	180, 150, 130
		Foot Support Adjustable (°)	90 x-dir and 90 z-dir
Easy to clean/sanitize	5	Cleaning Time	2
Longevity	4	Service Lifetime (Years)	10
Easy to maneuver/ adjust	4	Adjustment Hand Force (N)	200-300
Comfortable	3	Comfortable Usage Time (hrs)	12
Collects bodily fluids	2	Percentage Collected (%)	≥90
Privacy *	1	Coverage (% of bed)	50
Holds examination/delivery materials	1	Upward Support Force (N)	75

Robust (5)

Continual bed use and the possible improper use of the bed resulted in a critical importance ranking. The assumption is made that the average Ghanaian woman is comparable in weight to the average American woman and the average age of pregnancy in Ghana is 20 years old (MNPI Maternal and Neonatal Program Effort Index Ghana). Using the NHANES III Survey (95^{th} Percentile), the heaviest weight of the delivering mother can be estimated at 100kg. If two women use the bed and a safety factor of 1.5 is included, the requirement specifies that the bed must maintain 3000N.

Safety (5)

As the final product may be improperly used and patient safety is paramount to bed functionality, a safety factor of 1.5 was factored into all calculations.

Affordable (5)

With an annual budget of roughly $2,000 for all capital investments, the Labor and Delivery Ward of KATH cannot afford a bed that costs over $500. Our team hopes to further reduce this cost with in-country materials and manufacturing.

Reconfigurable (5)

The demands of this project absolutely require the final bed to be reconfigurable. The back support must have positions at 180° (supine), 150°, and 130° to facilitate birthing positions and to allow for patient comfort. The foot support must also be rotatable from supine position to a position removed from the front of the bed to accommodate the midwives for the birthing process.

Easy to Clean/Sanitize (5)

With the rampant spread of infection and to improve overall sanitation, the bed must be easy to clean with the liberally applied bleach and water solution. With high patient flow, equipment shortages, and a small staff, the turnover of the bed must be quick, resulting in a specified clean time of less than 2 minutes.

Longevity (4)

Longevity is directly linked to the bed robustness. Understanding the continual use of the current beds, the use of bleach and water as a cleaning solution, and the longevity of current hospital equipment, the service lifetime is specified to be 10 years.

Collects Bodily Fluids (4)

As we do not know whether every bed will be cleaned between every patient, our goal was to limit the amount of fluid that might contaminate the ward between cleanings. This will help to greatly improve the sanitation and health for the patients. Bodily fluids are expelled throughout the birth, specifically the final delivery of the placenta. These fluids need to be contained to fight the spread of infections and ensure a sanitary delivery ward. To be successful in containing fluids, the bed design must collect 90% of the bodily fluids. The patients in the ward currently must urinate/defecate in a bucket next to the bed, so an added goal would be to incorporate urination/defecation into the fluid collection system.

Easy to Maneuver/Adjust (4)

As only two midwives run the ward and control patient care, we realize that unless the bed is easy to operate and improves the current system, it will likely not be used. Thus, if the bed is reconfigurable but the process to do so is unintuitive or physically challenging, the design is a failure. Assuming the majority of the birthing staff are women and the maximum hand grip strength of a woman ranges from 235-418 N (Humanscale, Henry Dreyfuss Associates, MIT Press), we specified that the adjustable elements can require anywhere from 200N to 300N of force.

Comfortable (3)

The birthing process is particularly strenuous, particularly without pain medication or a family member for support. The average labor length is 12 hours. As the women remain in bed for the majority of this period, a comfortable bed will ultimately improve their birthing experience. Thus, the beds, specifically the padding, must be comfortable for the usage time of 12 hours.

Privacy (1)

Privacy would greatly improve the respect of patients and their modesty within the ward. We originally aimed to establish a privacy screen that could cover up 50% of the patient. As childbirth is a private matter, integrating privacy in the ward would hopefully encourage more patients to deliver in a hospital setting.

Holds Examination/Delivery Materials (1)

Charts and other medical equipment are currently placed on the beds and we would like to maintain this capability. The maximum weight of materials anticipated is 5kg, making the corresponding engineering specification a support force of 75N. This specification is not rated highly as there are tables that could be utilized in the current ward which would reduce design costs.

DESIGN EVOLUTION

There were many steps and iterations to our design evolution. Design generation began with a design breakdown to the following functional components: back support, seat support, foot support, frame, stirrups, fluid collection system, privacy, and locking mechanisms. For each component, designs were generated, rated for performance with the use of Pugh charts, and iterated based on mentor feedback. Throughout this process, we created several Alpha designs.

The First Alpha Design

The first Alpha design was composed of the top-rated components from the initial functional decomposition breakdown. The back support is a solid piece that can be adjusted to incline angles of 180˚, 130˚ or 100˚ with a rotating bar that rests against three different hooks. The seat support is rectangular in shape with a semi-circular opening that is connected to a fluid drainage system. This system will channel the birthing fluids into the fluid collection bucket and can be used for urination and defecation. The foot support will be composed of two separate pieces that will be supported by a foldable leg, allowing the foot support to decline from the supine position to a vertical angle. The frame of the bed is rectangular in shape with a break in the structure to accommodate the fluid collection system. The frame has six legs to support the weight of the patient safely. The stirrups, which are not pictured below, will be stored under the foot supports of the bed and will be full, indented foot rests. The stirrups will rotate and lock at 45° from the horizontal. Privacy will be considered with the use of a cloth screen that can be in an upright position or rotated to a position flush with the frame. The padding for the bed will be made in three separate pieces; it will be made by wrapping foam with vinyl to prevent the absorption of bodily and cleaning fluids.

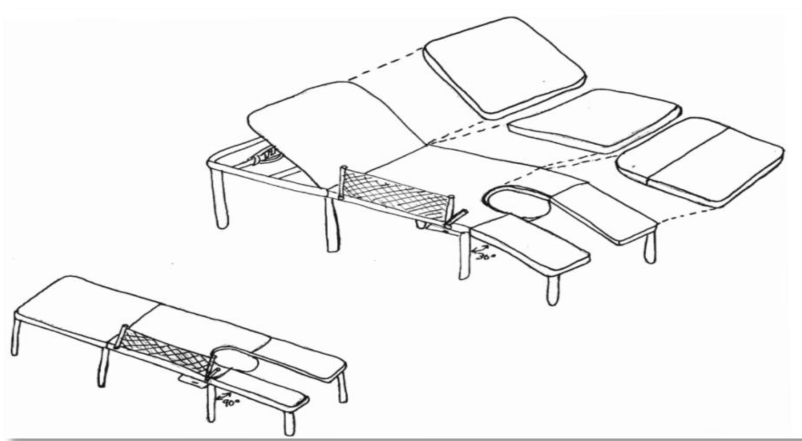


FIGURE 5
FIRST ALPHA DESIGN

Design Evolution Leading the Final Design

There have been many iterations of this design throughout our design and manufacturing process. Two of the main factors that guided our re-designs were material cost and our limited budget. With the understanding that our prototype would be integrated into the Labor and Delivery Ward at KATH, we chose to minimize material rather than sacrifice aluminum as our material selection. One change based on budget concerns was the evolution of the back support from a plate of metal to a simpler frame that will be further discussed in our Final Design Description.

Additionally, upon further consideration and discussion with our mentors, privacy and the use of the fluid collection system for urination and defecation were ultimately removed from our design. While privacy would help hospital care to more closely fit the cultural privacy standards regarding childbirth, the current ward has built in curtains that are not used, leading us to believe that privacy within the bed would also be disregarded. Though we want to improve patient care, we ultimately determined that this aspect would be an overdesign. We would hope that this could eventually be implemented into the design in future work. The functionality of the fluid collection system was also altered due to concerns about the sanitation of such a system for the patient. Thus, the fluid collection system now focuses solely on funneling the birthing fluids. After clinical observations in the delivery ward at the University of Michigan hospital to better understand the fluids associated with childbirth, the team chose to replicate a funnel slide, as this design would contain fluid splash as well as serve as a liquid tight system.

Another major design evolution was the foot support rotation and locations. Upon further discussion with doctors at the University of Michigan and Dr. Lori, it was determine that an ideal foot support would be able to be completely removed from the front edge of the frame. With this functionality, the midwife would not be hindered in her positioning during delivery.

Based on the foot support evolution, the stirrups became another focal design area. We continued discussions with mentors and sponsors to finalize the functionality of the stirrups as an anchoring system for the patient at a position 45° from vertical. Several different scenarios for a stirrup stemming from the bottom of the leg or ground were discussed; however, these stirrups were disregarded due to the added joint complexity and the associated manufacturing processes. We also received feedback expressing a desire for the stirrups to maintain the full weight of one patient. All of these new considerations led to the final design described below.

Finally, the back support bar was shortened in order to full accommodate the supine position. This made the 100° inclinable position impossible. Thus, this angle of configurability was removed from the design.

FINAL DESIGN DESCRIPTION

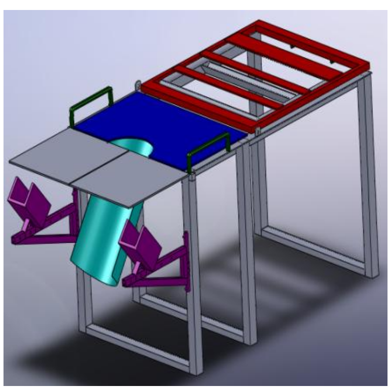


FIGURE 6
SUPINE POSITION

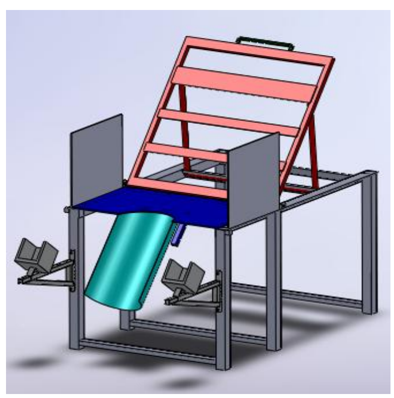


FIGURE 7
TRANSITION FROM SUPINE TO DELIVERY POSITION

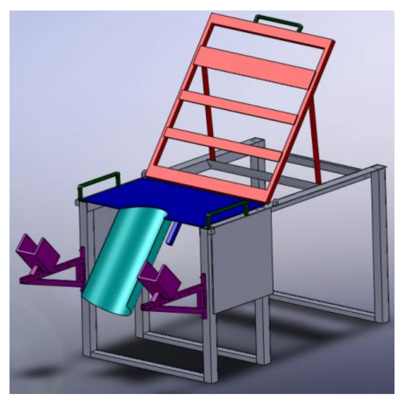


FIGURE 8
DELIVERY POSITION

Frame

The purpose of the frame is to provide the stability and strength required to support the patient during active labor and delivery. The seat and back support sections of the bed will be supported on the frame. Four legs will be used to support the seat of the bed while the final two will be placed under the end of the back support. The crossbars are meant to prevent tipping. The two back support stop bars are made of the L-shaped bars and are used to cradle the back support bar and provide the different angles of configurability. The frame crossbar located above the central legs is meant to further provide support and stability for the seat.

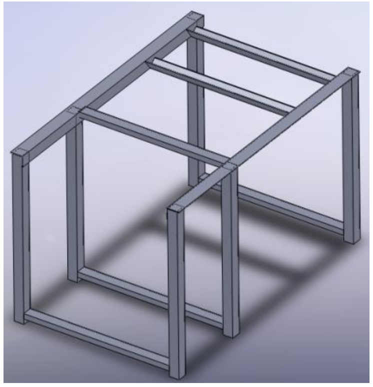


FIGURE 9
FINAL FRAME DESIGN

Back Support System

The purpose of the back support is to support the patient's back, neck, and head when the bed is reconfigured to the 180°, 150°, or 130° positions. It is not ideal for a patient to remain station for a long period of time; thus, the different back support angles help to facilitate some patient movement throughout the process. The back support bar rotates within two collars to adjust for different configurations.

FIGURE 10
FINAL FRAME DESIGN

Seat Support

The seat support serves as the main support platform for the patient's weight during delivery. This piece does not reconfigure; it is bolted to the frame. The semi-circular opening is centered on the piece and is meant to facilitate fluid collection during the birthing process.

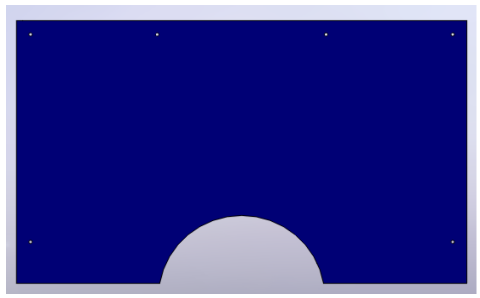


FIGURE 11
SEAT SUPPORT

Foot Supports

The foot supports are meant to support the patient's legs and feet while the bed is in a supine position. The engineering specification for configurability calls on the foot supports to lie flat in the supine position for active labor and to be completely removed from the front of the bed for the delivery process. This will be achieved through the use of a table arm joint. The positioning of the foot supports can be seen in Figures 6, representing the supine position, Figure 7, representing the translation of the support, and Figure 8, representing the support position in the delivery position.

Fluid Collection System

The fluid collection system is meant to facilitate the collection of birthing fluids. The system is meant to be detachable so it can easily be cleaned along with the bucket that collects fluids. The fluid collection system is shown in Figure 12. The system will be support by a bar angle at 45° below the seat support. The system will hook onto this bar, allowing gravity to assist in fluid flow. To contain and properly filter birthing fluid, the system starts at a diameter larger than the seat semi-circular opening and narrows in width to fit within the bucket. Thus, the system should be able to account for splashing and dripping fluids.

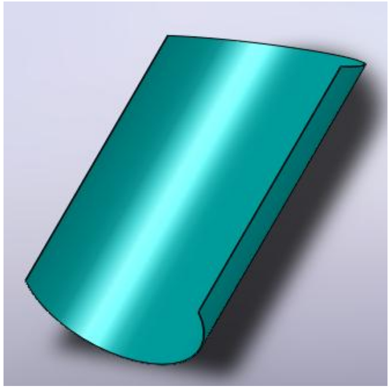


FIGURE 12
FLUID COLLECTION SYSTEM

Stirrups

The stirrups are designed to provide the patient with support during delivery and to widen the cervix to assist in delivery. The system can be adjusted vertically and horizontally in order to account for women of different heights with simple pin joints. While the ideal stirrup holds the patient's legs at approximately 30° from the straight position, the overall width of the bed accounted for this angle.

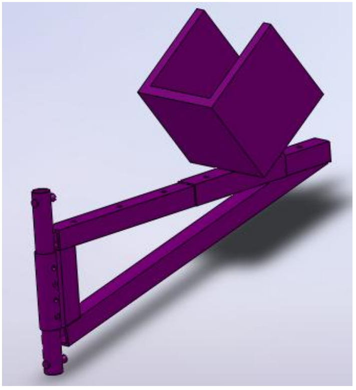


FIGURE 13
STIRRUP ASSEMBLY

Padding

Padding will be composed of three different pieces for back support, seat support, and foot support. The purpose of the padding is to provide the patient with comfort throughout the use of the bed. The foam will be glued to wood before being wrapped in vinyl in order to maintain shape. Also, the padding will be attached to the frame with Velcro so that it can be removed for cleaning.

PROTOTYPE CRITIQUE

In reviewing the final manufactured prototype, it quickly becomes evident that several areas of the reconfigurable delivery bed need further analysis and improvement in order to help to improve Ghanaian healthcare. While we do feel that in our design we have made small improvements that will ultimately improve patient health, the following aspects have been identified as focal points for design considerations.

Foot Support and Tablet Arm Joint

We believe no element is more ne is more critical than the conjunction of the stirrups and the foot support at the front of the frame. While the functionality of this design is beneficial for the delivery process, the system does not have an ease of maneuverability desired. One major concern for the foot support and table arm joint system is how much weight can be supported without compromising the supine position. The two foot support and two tablet arm system was not fully prototyped; thus, we believe that further analysis would be extremely beneficial in analyzing a two foot support system to ensure that the load and stresses associated with use are acceptable. Once fully prototyped, the feedback from hospital personnel at KATH with respect to ease of use and functionality will be critical to determining possible future design considerations.

Padding

In order for the padding to be a beneficial aspect of the design, it must be able to withstand the bleach, keep fluid away from the foam, and provide comfort. From our prototype, we found that the Velcro attachment mechanism resulted in issues with the staple strength. This loosened the vinyl and allowed for possible fluid intake into the foam. The Velcro also made the padding difficult to remove, which might hinder the hospital personnel from removing it for cleaning.

Seat

One design change that should be considered for the frame is the size of the semi-circular opening to facilitate fluid collection. Testing of the prototype, we realized the inherent difficulty that the large size of the opening would cause in allowing the patient to sit at the front edge of the seat for delivery. We believe that simply reducing the diameter of the opening will greatly improve the functionality of this component.

Stirrups System

One major consideration for the stirrup system would be improving the pin joints or possibly replacing them with pressure joints. We would also like to incorporate stirrup rotation in the stirrup assembly so that depending on patient height, leg separation can be more tailored. Likewise the functionality of the stirrups needs to be improved to allow multiple adjustments to ensure a wide range of accommodating leg separation angles.

Fluid Collection System

The fluid collection system could greatly be improved from our current design. While we feel that the general design makes sense for its function, the execution and material choices can be improved. One relatively easy way to improve the fluid collection system would be to make the fluid collection system of thin aluminum plate that could be molded to the desired shape. This would ensure a large enough initial and final diameter to maximize fluid collection. Another aspect of the design that needs to be addressed is the way in which the system was made detachable. The attachment mechanism for the prototype was difficult to use and might hinder use in Ghana.

FINAL RECOMMENDATIONS

The focus of any potential future design teams must be directed at improving the aforementioned critical area. It is our recommendation that the Mechanical Department of the University of Michigan's College of Engineering retain the current prototype's jointed frame and back support and ensure that a new design team is tasked with attaching both a robust, yet storable foot support in addition to creating an innovative adjustable stirrup attachment system. Possible improvements to the foot support may include separating the foot support into two separate pieces with two rotating joints to enable final birthing storage on each side of the bed. With regards to improving upon the stirrup attachment system, we believe the engineering effort should focus on the adjustable nature of the attachment. Throughout our conversations with medical personnel worldwide, there currently seems to be very little effort being focused on this potentially beneficial innovation.

ACKNOWLEDGMENTS

We would like to thank Professor Kathleen Sienko of the University of Michigan for all of her guidance throughout this process. We would also like to thank Dr. Johnson of University of Michigan Hospital, Dr. Jody Lori of the University of Michigan Nursing School, and Dr. Ofosu of the Sene District Hospital in Ghana for their mentorship and insight.

[i] Ansong-Tornui, J., Armar-Klemesu, M., Arhinful, D., Penfold, S., & Hussein, J. (2007). Hospital Based Maternity Care in Ghana - Findings of a Confidential Enquiry into Maternal Deaths. *Ghana Medical Journal, 41* (3), 125-132.
[ii] D'Ambruoso, L., Abbey, M., & Hussein, J. (2005). Please understand when I cry out in pain: women's accounts of maternity services during labour and delivery in Ghana. *BMC Public Health*, 140.
[iii] Ansong-Tornui, J., Armar-Klemesu, M., Arhinful, D., Penfold, S., & Hussein, J. (2007). Hospital Based Maternity Care in Ghana - Findings of a Confidential Enquiry into Maternal Deaths. *Ghana Medical Journal, 41* (3), 125-132.
[iv] World Health Organization. (2008). *World Health Statistics*. Geneva: World Health Organization Press.
[v] Bazzano, A. N., Kirkwood, B., Tawiah-Agyemang, C., Owusu-Agyei, S., & Adongo, P. (2008). Social costs of skilled attendance at birth in rural Ghana. *International Journal of Gynecology and Obstetrics*, 91-94.
[vi] Bazzano, A. N., Kirkwood, B., Tawiah-Agyemang, C., Owusu-Agyei, S., & Adongo, P. (2008). Social costs of skilled attendance at birth in rural Ghana. *International Journal of Gynecology and Obstetrics*, 91-94.
[vii] Bazzano, A. N., Kirkwood, B., Tawiah-Agyemang, C., Owusu-Agyei, S., & Adongo, P. (2008). Social costs of skilled attendance at birth in rural Ghana. *International Journal of Gynecology and Obstetrics*, 91-94.
[viii] ACOG. (2007, January). You and Your Baby: Prenatal Care, Labor and Delivery, and Postpartum Care. *The Patient Education Pamphlet*. Washington, D.C.: American College of Obstetricians and Gynecologists.
[ix] Mayo Clinic. (2007, April 13). *Stages of Labor: Baby, It's Time!* Retrieved January 25, 2009, from MayoClinic.com: http://www.mayoclinic.com/health/stages-of-labor/PR00106
[x] Mayo Clinic. (2007, April 13). *Stages of Labor: Baby, It's Time!* Retrieved January 25, 2009, from MayoClinic.com: http://www.mayoclinic.com/health/stages-of-labor/PR00106
[xi] ACOG. (2007, January). You and Your Baby: Prenatal Care, Labor and Delivery, and Postpartum Care. *The Patient Education Pamphlet*. Washington, D.C.: American College of Obstetricians and Gynecologists.
[xii] ACOG. (2007, January). You and Your Baby: Prenatal Care, Labor and Delivery, and Postpartum Care. *The Patient Education Pamphlet*. Washington, D.C.: American College of Obstetricians and Gynecologists.
[xiii] ACOG. (2007, January). You and Your Baby: Prenatal Care, Labor and Delivery, and Postpartum Care. *The Patient Education Pamphlet*. Washington, D.C.: American College of Obstetricians and Gynecologists.
[xiv] Hill-Rom Affinity 4 Birthing Bed. *Hill-Rom Enhancing Outcomes for Patients and Their Caregivers*. http://www.hill-rom.com/USA/Affinity.htm

APPENDIX A

INTRODUCTION

A group of twelve multidisciplinary University of Michigan undergraduate students traveled to Ghana as part of the Global Intercultural Experience for Undergraduates Program (GIEU) during May 2008. During this month, the group gained extensive field site experience and completed clinical observations in Obstetrics & Gynecology at the Komfo Anokye Teaching Hospital (KATH) in Kumasi and in the rural Sene District Hospital in the Brong-Ahafo Region. The project described in this paper addresses one of the problems observed by the GIEU students; the problem is based in the Labor and Delivery Ward at KATH. The ward is equipped with eight supine beds and two delivery chairs. The supine beds are used by patients during the first and second stages of labor. Towards the end of the second stage of labor, when patients are ready to deliver, the women must walk from the supine bed to one of the two delivery chairs at the other end of the room. Our team has been assigned the task of designing and building a reconfigurable obstetrics delivery bed for the Labor and Delivery Ward at KATH that will serve patients during all three stages of labor, improve patient flow, increase patient safety during delivery, increase the quality of patient care, and increase the number of delivery stations.

Problem Description

The labor and delivery ward at the Komfo Anokye Teaching Hospital (KATH) in Kumasi, Ghana is equipped with eight supine beds and two delivery chairs. Due to equipment shortages and large patient flow, not all expecting mothers are guaranteed a bed at KATH when they begin laboring or are ready to deliver. The patients must sit and wait in the hallway outside the delivery ward until they are five centimeters dilated (Sienko, GIEU). Once they reach that dilation, they are able to enter the labor and delivery ward and have access to one of the supine beds if one is available. If and when they are given access to a supine bed, the women must remain on that bed until they are dilated 9-10cm, which is near the end of the second stage of labor. The end of the second stage of labor is when the baby is delivered. When this dilation is reached, the women must walk from their supine bed to one of the two delivery chairs at the end of the room (Sienko, GEIU). The team’s task is to design and build a reconfigurable obstetrics delivery bed for the labor and delivery ward of Komfo Anokye Teaching Hospital in Kumasi, Ghana that will serve patients for all three stages of labor, improve patient flow, increase patient safety during delivery, increase the quality of patient care, and provide more birthing stations

Problem Origin and Sponsor

This problem was observed first hand by University of Michigan (UM) students who traveled to Ghana in May 2008 as part of the Global Intercultural Experience for Undergraduates Program under the supervision of Professor Kathleen Sienko. She is a professor in the Departments of Mechanical Engineering and Biomedical Engineering at UM and is the sponsor for this project. The mentors for this project are Dr. Timothy Johnson (Chair of the Department of Obstetrics and Gynecology, University of Michigan) and Jody Lori (CNM Lecturer and Interim Nurse Midwifery Program Coordinator, University of Michigan). The international consultant for this project is Dr. Anthony Ofosu, the Director of the Sene District Hospital in Ghana.

BACKGROUND AND INFORMATION SOURCES

KATH Hospital Layout and Hospital Beds

Currently, the labor and delivery ward at KATH has eight supine beds and two delivery chairs. The layout of this room can be seen in Figure 1 below with the green boxes representing the supine beds and the orange boxes representing the delivery chairs. Pictures of the supine beds and delivery chairs currently used at KATH can be seen in Figures 2 and 3 below.

Figure 1: Layout of the Labor and Delivery Ward at KATH

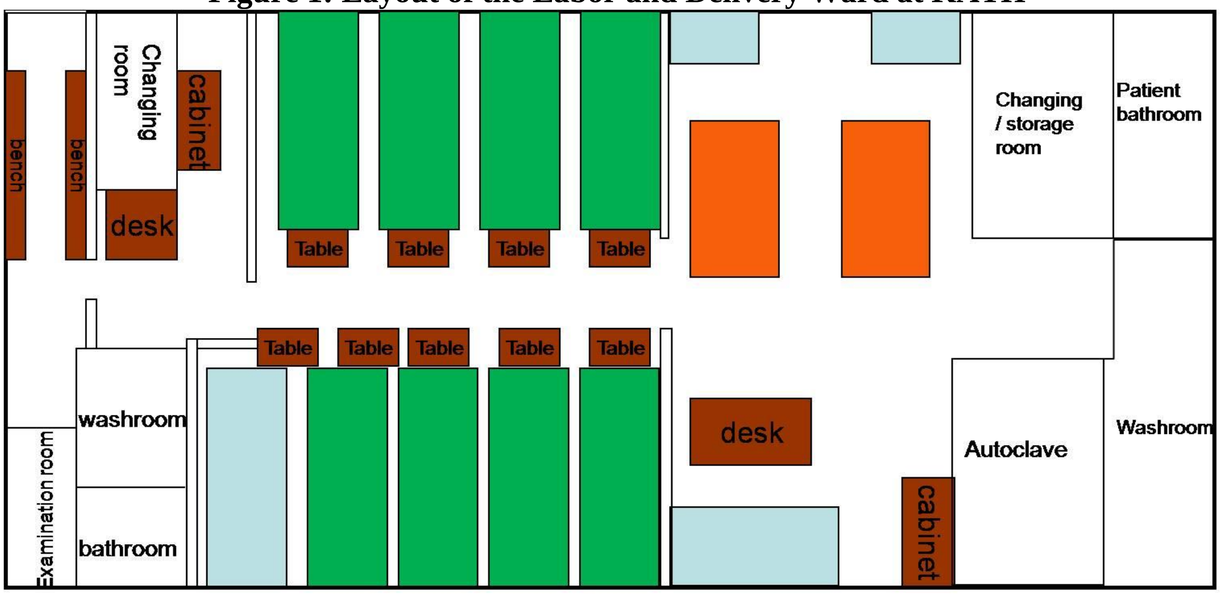


Figure 2: Current Supine Bed

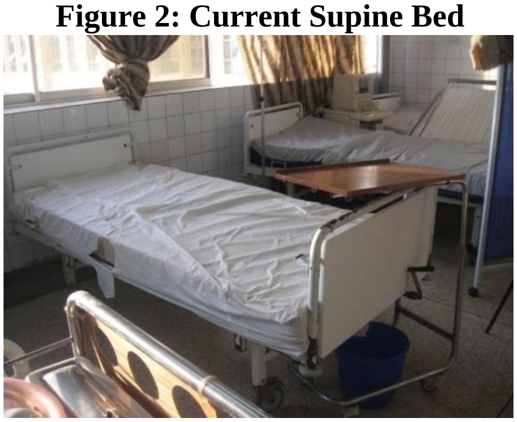


Figure 3: Current Delivery Chair

General Ghana Healthcare Facts

The World Health Organization's *World Health Statistics* 2008 details information regarding disease control, health care systems and discrepancies, and mortality rates. The following facts relate to Ghana and provide a basic understanding of the medical culture (World Health Organization, 2008).

- 540 maternal deaths/ 100,000 live births
- 50% of overall births by skilled health personnel

- 79.7% of births attended by skilled health personnel if in urban area (2.6 times higher than rural areas)
- 20.6% of poor women have births attended by skilled health personnel as opposed to 90.4% of wealth
- 9 midwives per 10,000 people
- 9 hospital beds per 10,000 people
- 18 million: the estimated number of additional hospital beds the WHO African Region would need to match the bed density in the rest of the world

Stages of Labor and Delivery

Labor is defined as the process through which a baby is born. The process of labor is divided into three stages, differentiated by physical changes of the uterine cervix and location of the baby. Delivery describes the action of bringing the baby to the outside world (ACOG, 2007).

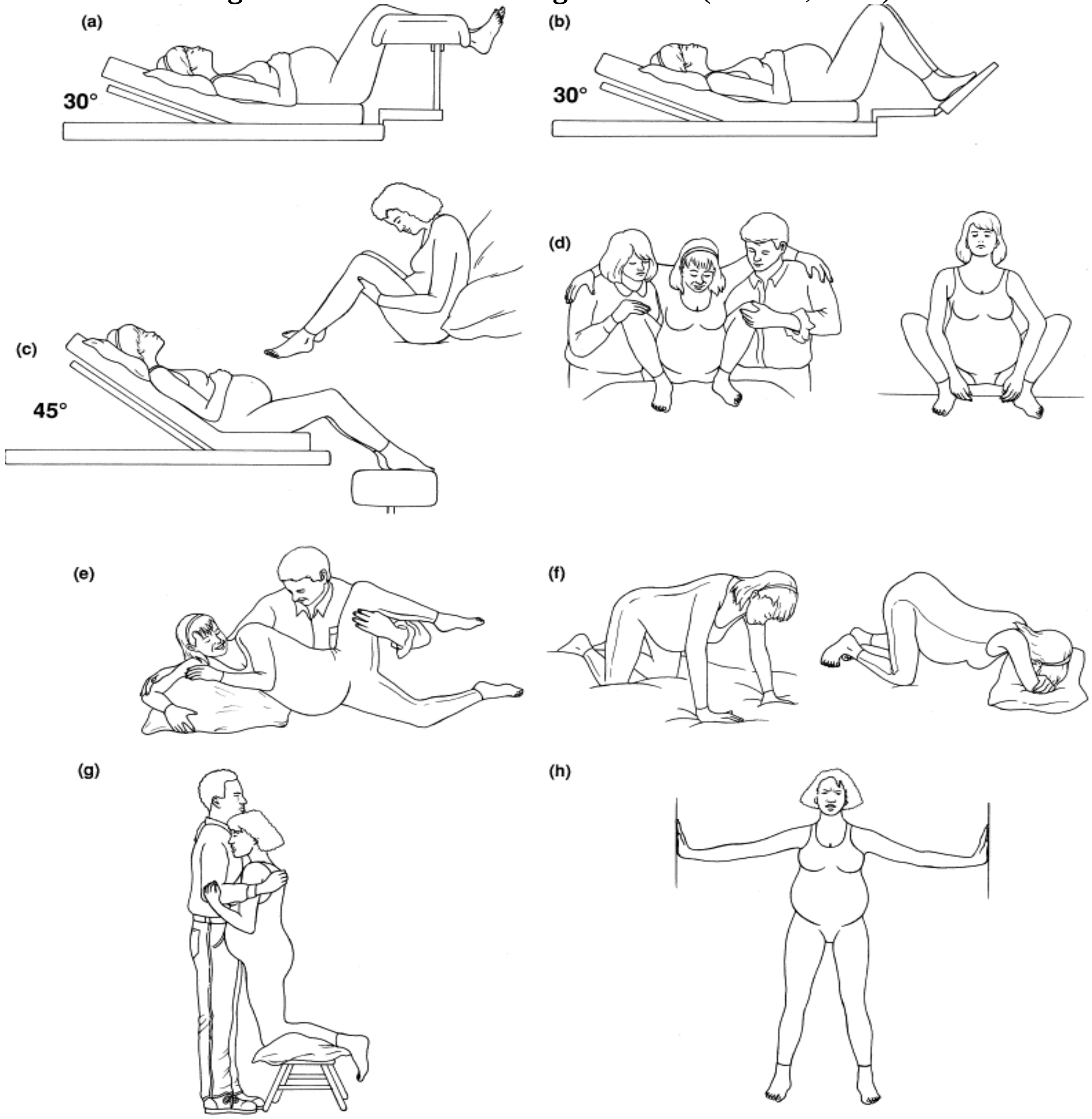
The first stage of labor is the early labor, active labor and transition (Mayo Clinic, 2007). It "begins when the uterus contracts and the cervix starts to open," which allows the baby to move to the birth canal (ACOG, 2007). The cervix dilates from 0cm to 3cm during early labor and contractions begin, occurring every five to twenty minutes. After early labor within the first stage of labor is active labor, during which the cervix dilates to approximately 7cm and contraction increase. Transition is the last phase of the first stage of labor and is the time when the cervix dilates to 10cm (Mayo Clinic, 2007). By the end of this stage, the cervix is completely open and contractions become longer and stronger as the body prepares for the baby to move. The longest stage of labor is usually the first stage. In the second stage of labor, the mother begins pushing during each contraction until the baby is delivered. The second stage may last several hours and ends with the birth of the baby. The third stage of labor is characterized by uterine contractions, usually less painful, that continue until the placenta is delivered (ACOG, 2007). The final stage may last up to thirty minutes (Mayo Clinic, 2007).

The aforementioned stages of labor are characteristic of vaginal delivery (ACOG, 2007). If there are complications during an attempted vaginal delivery, the baby may have to be delivered via Cesarean delivery, which is "delivery of the baby through a cut made in the women's abdomen and uterus." Cesarean delivery is utilized when the baby may be too large to fit through the pelvis, the baby is in distress, or there are complications with the mother (ACOG, 2007).

Birthing Positions

The choice of birthing position has a huge impact on the comfort level of the mother during labor. An effective birthing position is one that speeds up the labor and reduces discomfort by perfectly aligning the baby and reducing specific pressures and unnecessary muscular efforts (Lauren Dundes, 1987). The most common birthing positions are pictured below in Figure 4. KATH currently only uses the semi-recumbent birthing position, due mainly to the birthing chairs which facilitate this type of birth.

Figure 4: Common Birthing Positions (Hanson, 1998)



(a) Lithotomy (lying on back with legs at 90°)
(b) Dorsal (legs at angle less than 90°)
(c) Semi-Recumbent/Semi-sitting
(d) Squatting
(e) Lateral (lying on the side)
(f) All-fours (hands and knees)
(g) Kneeling
(h) Standing

Based on a study in New South Wales, Australia, the most commonly used birthing position is semi-recumbent (56%) (Shorten, Donsante, & Shorten, 2002). All-fours was used for 18.9% of births, lateral was used for 12.2% of births, standing was used for 9.5% of births, squatting was used for 2.1% of births, and kneeling was used for only 1.3% of births. Part of the commonality of the lithotomy and semi-recumbent positions is due to convenience for doctors (Lauren Dundes, 1987). However, as gravity is a factor that facilitates the progression of labor, lithotomy often leads to a slower and more strenuous labor. Midwives in the United States encourage birthing positions in the following order: side-lying (88.8%), squatting (82.2%), sitting (73.5%), standing (34.5%), kneeling (27.6%), dorsal (25.3%), all fours (7.1%), and lithotomy (7.1%) (Hanson, 1998).

One method of evaluating the quality of birthing positions is based on its affect on the perineum, the area between the "pubic symphysis and the coccyx" (Perineum). The lower the rate of episiotomy (the surgical incision through the perineum made to enlarge the vagina and assist in childbirth and the less the number of tears requiring suture, the better the birthing position (Shorten, Donsante, & Shorten, 2002). The lateral birthing position, which is optimal for relaxation during labor, has low episiotomy and tear requiring suture rates, producing the most favorable perineal outcome [(Shorten, Donsante, & Shorten, 2002)]. The squatting position, which helps open the pelvis to help the baby find the correct position, has the highest tear requiring suture rates (>53%) and the lowest intact perineum rate (<42%) as well as the highest rate of the most severe degree trauma (third degree tear) (Lauren Dundes, 1987). Positions such as all-fours, standing, and semi-recumbent have approximately the same average results for episiotomy and tear needing sutures. The use of the birthing chair has been found to increase the risk of postpartum blood loss for the mother (Hanson, 1998).

The birthing positions that will be considered for the bed design are: semi-recumbent, lateral, and squatting. Semi-recumbent has lower rates of episiotomy and tearing, is the mostly widely used birthing position, and is also the position currently utilized at KATH. The lateral birthing position has the lowest rates of episiotomy and tearing and is most highly recommended by Dr. Lori. Although squatting has higher rates of tearing and episiotomy, this birthing position is useful during difficult labors to widen the cervix and is highly encouraged by midwives.

Maternal Mortality Rate

Improving the quality of obstetric care is an urgent priority in developing countries due to high maternal mortality rates (Ansong-Tornui, Armar-Klemesu, Arhinful, Penfold, & Hussein, Hospital Based Maternity Care in Ghana - Findings of a Confidential Enquiry into Maternal Deaths, 2007). Ghana has one of the highest maternal mortality rates with 540 maternal deaths for every 100,000 live births. "It is [also] estimated that for every maternal death, another 20 women will develop some form of life-long morbidity related to pregnancy and/or childbirth" (D'Ambruoso, Abbey, & Hussein, 2005). In Ghana, a universal, free policy was implemented to provide payment free delivery care in health facilities. This new policy has deteriorated the quality of care due to the increase of utilization without an increase in resources such as personnel and equipment (Ansong-Tornui, Armar-Klemesu, Arhinful, Penfold, & Hussein, Hospital Based Maternity Care in Ghana - Findings of a Confidential Enquiry into Maternal Deaths, 2007). However, women's neglect in returning to the hospital for postnatal care when in deteriorating health must also be considered in regard to the maternal mortality rate (Ansong-Tornui, Armar-Klemesu, Arhinful, Penfold, & Hussein, Hospital Based Maternity Care in Ghana - Findings of a Confidential Enquiry into Maternal Deaths, 2007).

Cultural Background of Birthing in Ghana

Childbirth in Ghana has deep social, religious, and cultural influences. Culturally, the ability to have children is highly revered within the Ghanaian culture. A woman who is unable to bear children is believed to not be a 'woman' (I., 2006). Additionally, childbirth is considered a very natural process, making hospital birth unnecessary. Women gain respect from home births, considering it ideal to deliver with "minimum assistance and maximum secrecy" so as not to bother anyone (Bazzano, Kirkwood, Tawiah-Agyemang, Owusu-Agyei, & Adongo, 2008). A woman who requires a hospital birth is weak or has a difficult labor, which is considered the fault of the mother's mistakes. This deeply rooted desire to keep pregnancy a secret and not seek assistance or care results in many women not seeking appropriate medical care. Additionally, the placenta, which is respected and buried with the respect of a person, is not returned to the mother if they deliver in the hospital, which deters some mothers (I., 2006).

Another factor influencing childbirth decisions in Ghana is the quality of healthcare (Bazzano, Kirkwood, Tawiah-Agyemang, Owusu-Agyei, & Adongo, 2008). Women often recount harsh treatment from midwifes and are turned away if they arrive before active labor. The advice of other women who have received care at certain hospitals greatly affects whether other women will seek care at that hospital.

Many economic factors also influence the choice for a supervised delivery. Aside from the cost of traveling to the hospital on the bad transportation system, women also must provide certain mandatory supplies for their delivery such as disinfectant and napkins. In order to afford a supervised delivery, women are often forced to sell food, jeopardizing their health, which often results in harsh treatment from the midwives (I., 2006). Additionally, despite the universal payment exemption, women are sometimes still charged out of pocket (Perosky, 2009). On larger scales, the poor economy results in fewer hospitals; hence, women often deliver before reaching the hospital or get into accidents during rainy seasons (I., 2006).

Socially, the childbirth decisions are made by older female relative, traditional birth attendants, and the woman's husband (Bazzano, Kirkwood, Tawiah-Agyemang, Owusu-Agyei, & Adongo, 2008). Women are forced to respect and follow their decisions regarding when to seek medical attention. As the cost for deliveries with serious maternal and fetal risk is more expensive than normal delivery, often the husband, who is in charge financially, will avoid hospital care even in cases of emergency (I., 2006)

Contacts

We have many contacts for this project from Ghana and the University of Michigan community. Our most important contact is our mentor, Dr. Anthony Ofosu, the Sene District Hospital Director in Ghana. At the University of Michigan, our primary contact is our supervisor, Professor Sienko as well as the GIEU Ghana team – Joey Perosky, Sherrita McClain, Kara Goodrich, Kelsey Wright, and Desiree McLain. Other contacts we have found for this project are Dr. Lori, CNM Lecturer and Interim Nurse Midwifery Program Coordinator for the University of Michigan, who is currently working on midwife education in Ghana. We have also spoken with Dr. Johnson, Chair of the Department of Obstetrics and Gynecology at the University of Michigan.

Information Gaps

The following is a list of questions we still must address in regards to our project:

- What are the exact dimensions of the current beds?

- What material is available for manufacturing in Ghana?
- What do midwives and doctors expect of their patients?
- Can the midwives deliver when the mothers are not in the semi-recumbent position?
- Would women be allowed to position the bed without assistance?

Where will this information come from?

We are waiting to gather some of this information, regarding the current bed and room dimensions, from members of the GIEU team. In regards to manufacturing and material selection, we plan to contact Professor Asibu in the Department of Mechanical Engineering who has manufacturing experience in Ghana.

Benchmarking Current Labor and Delivery Beds

The purpose of birthing beds is to allow for the mother to remain in the same bed throughout the labor, birthing, and recovery process and receive all necessary care (Healthcare Products Comparison System, 2004). There are several consistent aspects of birthing beds. Typically, there are three adjustable sections: the backrest, the seat, and the footrest with each section consisting of the bed support covered by a mattress. The adjustability of the backrest and footrest allows for many different birthing positions while maintaining access to the mother's perineal area. It is recommended that a bed has leg supports and removable foot support to facilitate the birthing process as well as to comfortably accommodate all sizes of women. Birthing beds also usually have a removable drain pan for the collection of bodily fluids through the birthing process. Other considerations are adjustable bed heights, ranging from 50.8cm – 101.6cm. Current materials used for birthing beds are materials such as iron, steel, aluminum, and wrought iron which can be coated with epoxy or polyester (Healthcare Products Comparison System, 2004).

Current Product: Hill-Rom Affinity 4 Birthing Bed

The Hill-Rom Affinity Bed is a top of the line labor and delivery bed currently utilized at the University of Michigan hospital. While the bed standard features and accessories are beyond the scope of our project design and budget, we can use the main technical specifications for labor and delivery bed benchmarking.

Table 1: Affinity 4 Birthing Bed Technical Specifications (Affinity 4 Birthing Bed)

Feature	Dimension
Bed Length	229cm
Bed Width	99cm
Bed Height	58-99cm
Mattress Thickness	12.7cm
Max Head Elevation	63°
Max Bed Lift Capacity	227kg

Figure 5: Hill-Rom Affinity 4 Birthing Bed

United Surgical Industries Obstetric Delivery Table

The Obstetric Delivery Table is a more basic design with dimensions of 182cm x 56cm x 76.2cm. The frame is made from PVC and pre-treated and coated with epoxy powder (United Surgical Industries). This design encompassed foot supports and a small bodily fluid collection bowl, which slides into position when the footrest is lowered.

Figure 6: Obstetric Delivery Table

United Surgical Industries Obstetric Delivery Bed in 2 parts

The Obstetric Delivery Bed in 2 parts is an example of a bed in which the footrest separates for the delivery process (United Surgical Industries). The bed dimensions are 180cm x 55 cm x 82 cm, and the base is made of steel. The leg removable leg section is on moveable castors with brakes.

Figure 7: Obstetric Delivery Bed in 2 parts

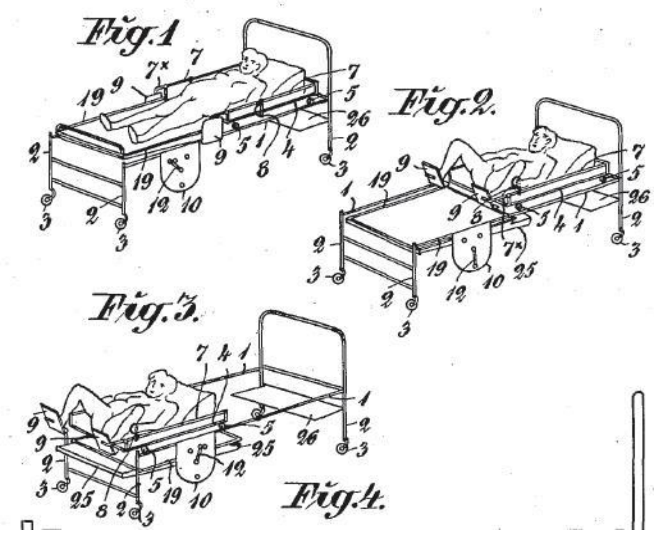
Patents

The following patents from 1942 to 1987 have several common features while taking very different approaches to the childbirth process. The common features include segments for the upper and lower body, and upper body segment that articulate from 180 degrees to an inclined angle greater than 90 degrees, and stirrups or some type of leg support.

US Patent #2,290,191

The “Delivery Bed” (Karlson, 1942) shown below in Fig. 8 includes a lower body segment that drops down mechanically so that the upper body segment can slide forward towards the foot of the bed frame. This reconfiguration facilitates doctor/midwife access to the patient.

Fig. 8: “Delivery Bed” by Karlson



US Patent #4,411,035

The “Maternity Care Bed” (Fenwick, 1983), shown in Fig. 9 below, has three segments: a head section, a seat section and a foot section. Both the head section and the foot section can be adjusted independently from the seat section. The foot section can be raised to provide additional support to the patient or it can be lowered and retracted. The surfaces of between the seat and foot section is shaped almost like a V to facilitate fluid collection. A top view of the bed is shown in Fig. 10 below.

Fig. 9: "Maternity Care Bed" Side View

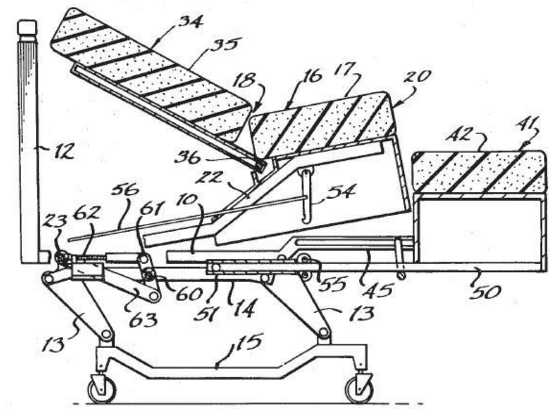
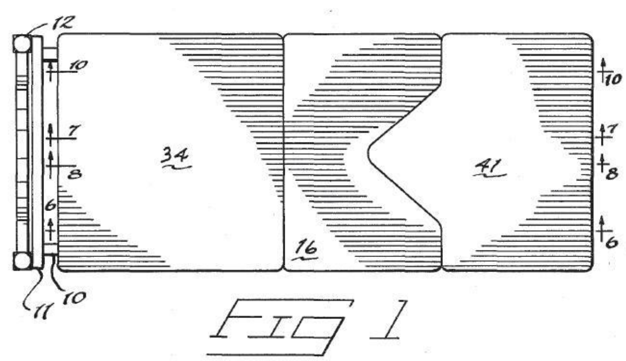


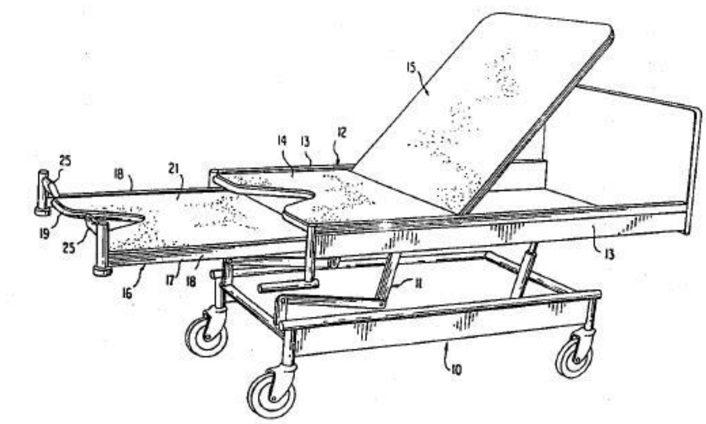
Fig. 10: "Maternity Care Bed" Top View



US Patent #4,682,376

The "Delivery Bed" (Feldt, 1987) shown below in Fig. 11 is also divided into three sections. Similar to the patents above, the head section rotates up independently from the rest of the bed. The foot section can slide out from underneath the seat section to different lengths between fully stowed and fully extended. This design was created to simplify the foot support section so as to reduce manufacturing cost, maintenance and make cleaning easier.

Fig. 11: "Delivery Bed" by M. Feldt



US Patent #4,356,578

The fourth bed, "Obstetrics Bed," is shown below in Figures 12-13 (Clark, 1982). This bed is considerably different from the other three, but still has the common feature of multiple sections and a seat section that is curved at one end to facilitate fluid collection. The bed is large enough that one or more people can recline on it and the different sections of the bed can be separated to form a delivery station. The mattress of the foot section is removable and the frame can be used as a seat for the doctor/midwife. In addition the sections of the bed have storage space and there are built-in, adjustable stirrups.

Fig. 12: “Obstetrics Bed” Isometric View, Supine and Inclined Positions

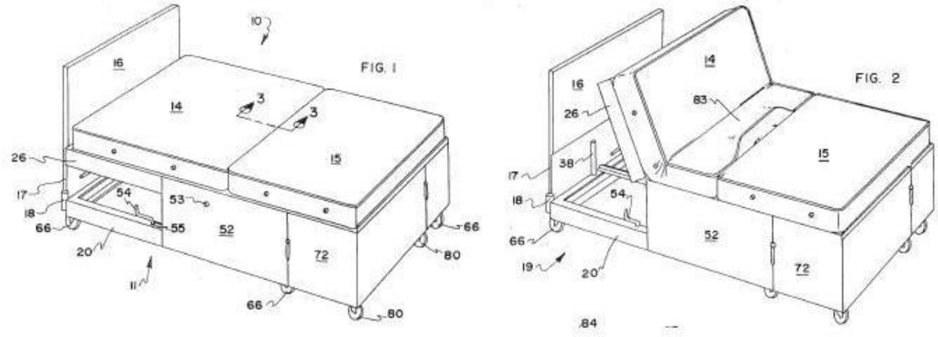
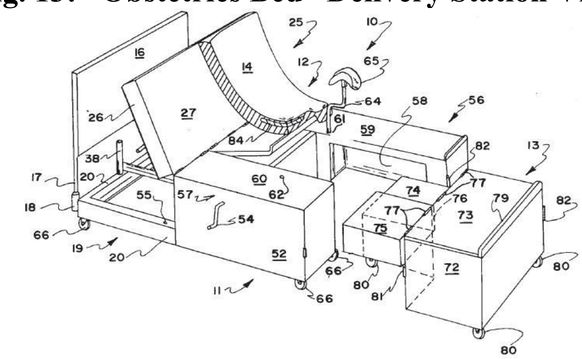


Fig. 13: “Obstetrics Bed” Delivery Station View



CUSTOMER REQUIREMENTS AND ENGINEERING SPECIFICATIONS

This section explains the derivation of the customer requirement importance rankings and the correlating engineering specifications for those requirements as established by discussions with Dr. Johnson, Dr. Lori, Professor Sienko, and Team Ghana. These requirements have been reevaluated during the design process, selection of the alpha design, and discussion of the alpha design with mentors.

Customer requirements and engineering specifications were initially developed and weighted for importance by the team. Adjustments and improvements to the importance and parameters of these requirements and specifications were made after multiple interviews with the mentors and several extended contacts in Ghana. These sessions addressed medical personnel requirements, ideal birthing conditions, Ghanaian medical culture etc. In order to evaluate both the customer requirements and the corresponding engineering specifications, which were established through product benchmarking and understanding Ghanaian needs, the team chose to create a Quality Function Deployment (QFD), which facilitated the ranking and the allocation of money, engineering efforts, time, and budget. These critical engineering specifications will be the focus of the redesign process.

To effectively design the requested obstetrics delivery bed/chair, a comprehensive list of customer expectations for the final product was produced. Critical to the generation of this expectation list was determining who constituted the project’s customer. Ultimately, it was determined that the hospital staff (midwives, doctors, maintenance personnel, etc) is the customer, while the delivering patients are the end users of the product. The goal was to effectively meet both the customer and end user requests. The importance of customer requirements is evaluated on a scale from 1 to 5. Table 2 below explains the rating correlation to importance level. The customer requirements are discussed below, and the customer requirements and their corresponding engineering specifications are summarized in Table 3 on Page 18.

Table 2: Scaling system to evaluate the importance of the customer request

Scaled Rating	Importance
5	Critical
2-4	Moderate
1	Bonus Requirement

Robust

Robustness was rated 5 (critical) due to the possibility of more than one pregnant woman using the bed at a time and the high patient flow resulting in continual bed use [Joey]. The engineering requirement is that the bed supports 3000N, based on an assumption that the end user, the average African woman, is comparable in size to the average black American woman. Very little accurate information concerning the average weight of Ghanaian women is published. Therefore, the assumption in size comparability to average black American woman is made, noting that if inaccurate, the assumption is most likely an overestimate. The average age a woman gets pregnant in Ghana is 20 years old (MNPI Maternal and Neonatal Program Effort Index Ghana). Using these assumptions and the NHANES III Survey conducted from 1988-1994, the heaviest (95^{th} Percentile) weight of a delivering mother can be estimated to be 100 kg. Assuming a maximum of two women utilizing one bed, a force of 2000N will act downward on the supporting legs. This force was calculated using Newton's First Law (Eq. 1), where *m* is the total mass of the pregnant mothers and *g* is the gravitation acceleration. Assuming, the design has six legs, and factoring in the 1.5 safety factor, each leg must support 750N.

$$F = mg \qquad \text{(Eq. 1)}$$

Achieving a robust design will mainly focus on the material selection for the bed frame. Current designs use steel, iron, aluminum, wrought iron, and PVC, which have high values of Young's modulus and overall strength. Considerations as to material availability and strength will be critical in material selection after a final design has been selected.

Longevity

With a service lifetime of 10 years, which is based on understanding the continual use of the current beds, the use of bleach and chlorine as cleaning products, and the longevity of the current hospital equipment, the rating for longevity has been reevaluated to an importance of 4 (moderate). Based on discussions with team mentors, it was determined that the longevity is a function of robustness and material selection. Since the robust requirement is critical, decreasing longevity to a moderate requirement, will allow the use of a less expensive material. Longevity is still highly rated due to the budget constraints of the labor and delivery ward at KATH and the limited on-site maintenance personnel. Longevity as a requirement is directly linked to the requirement for a robust design.

Safety

The safety customer requirement was rated at an importance level of 5 or critical. As the ultimate use of the product cannot be directly monitored and more women may use the bed that the design calls for, a safety factor of 1.5 is used in the engineering specification calculations. The setting of the final product in regard to the safety of the mother and unborn child also contributes to the high importance rating.

Affordable

The customer requirement of affordability was rated at an importance level of 5 or critical. The obstetrics ward of the Komfo Anokye Teaching Hospital has an annual budget of roughly $2,000 for capital investments. From current product benchmarking, the low end of cost for delivery chairs is approximately $425. Based on these figures, the goal for the cost of the end product is less than $500, but the hope is to reduce this cost with scrap, bicycle, and Ghanaian manufactured parts as well as few manufacturing costs. Additionally decisions to neglect privacy and urination/defecation system in the system due to discussions with Team Ghana and the sponsors have reduced the overall cost of the bed.

Reconfigurable

The customer requirement for a reconfigurable bed, functional for labor and delivery, was rated at an importance level of 5 or critical. The team aims to design the bed to reconfigure in two ways. These two reconfigurable aspects ranked most highly as aspects of the design. First, the back pad should be able to rotate from the standard supine position (180°) to 100° in order to facilitate several birthing positions, as well as examinations. Second, the bottom foot pad of the bed must rotate downward to an angle of -90° to allow the doctor easy access in the birthing process. A declinable foot pad will also help to contain bodily fluids released during the birth by serving as a funnel to a waste collector placed at the foot of the bed.

Easy to Clean/Sanitize

The customer requirement of a bed that is easy to clean and sanitize was rated an importance of 5. This requirement has been increased in importance after discussions with team sponsors. With the rampant spread of infections like HIV throughout Africa sanitization is a key in the design. The current cleaning solution used in KATH is a simple combination of chlorine or bleach and water and is liberally applied after the birthing process. With the high patient flow and equipment shortage, the turnover of the bed between births must be done quickly. Therefore, the entire bed must be able to be cleaned in less than two minutes. Choosing a waterproof, durable, and nonporous material for the mattress cover on the bed is crucial in achieving this time specification.

Collects Bodily Fluids

Due to discussions with Dr. Johnson and Jody Lori, it has been established that a comprehensive fluid collection device will more than likely hinder midwives during the birthing process. The collection of bodily fluids was thus redefined as a channeling system that directs the fluid from the patient to a container. It was rated as an importance of 4. This partial fluid collection system that will not extend past the edge of the bed, will effectively direct most of the fluids to the separate container while providing no hindrance to the hospital staff during the delivery process.

The original bodily fluid collection system incorporated urination/defecation and birthing fluids, while the new system will only channel fluids during birthing. By reducing the collection system, the amount of material needed to manufacture the new system is reduced and therefore, the manufacturing cost will decrease.

Body fluids are expelled throughout the birth, but specifically during the final delivery of the placenta. These fluids need to be contained to fight the spread of infections and ensure a sanitary delivery ward. To be successful in containing fluids, the bed design must collect 90% of the bodily fluids. If 90% fluid collection can be achieved, the post birthing clean up will be shortened.

Easy to Maneuver/Adjust
The customer requirement for the ease of maneuverability and adjustability was rated an importance of 4. This requirement has been increased from an initial value of 3 as maneuverability directly correlates to the reconfigurable aspect of the bed. If the bed is reconfigurable but the process is unintuitive or physically challenging, the design is unsuccessful. The main assumption used to derive the corresponding engineering specification for this requirement is that the majority of the birthing staff in the ward is female. Accordingly, the bed needs to be able to be adjusted by the staff or pregnant women. The max hand grip strength of a woman ranges from 235-418 N (Humanscale, Henry Dreyfuss Associates, MIT Press), so the adjustable elements can require anywhere from 200N to 300N of force. This range will ensure that both the hospital staff and the delivering mothers can adjust the bed.

Comfortable
Comfort as a customer requirement was rated at an importance of 3. This requirement stems from the average labor length of 12 hours. As the women remain in bed for the main portion of this labor, the goal is for the end use to remain comfortable throughout the entire birthing process. Thus, the beds, specifically the padding, must be comfortable for the usage time of 12 hours.

Privacy
The customer requirement of privacy was rated as only a 1 or bonus consideration. This requirement is specific to the end users, the delivering mothers. In Ghana, women gain respect from home births, considering it ideal to deliver with “minimum assistance and maximum secrecy” so as not to bother anyone (I., 2006). For Ghanaian women, a woman who requires a hospital birth is weak or has a difficult labor, which is considered the fault of the mother’s mistakes. This deeply rooted desire to keep pregnancy a secret and not seek assistance or care results in many women not seeking appropriate medical care. The effect of privacy on Ghanaian women’s decision for or against hospital deliveries must be considered. The goal for increasing privacy is to cover 50% of the bed from view to allow for privacy throughout the childbirth process as well as when the woman defecates or urinates. However, the medical culture in Ghana strongly points to privacy not being utilized; thus, making this requirement less important.

Holds Examination/Delivery Materials
The customer requirement of bed holding examination equipment and delivery materials was rated as an importance of 1. Currently, charts and other medical equipment are sometimes placed

on the beds; thus, the new design should maintain this capability. The maximum weight of materials anticipated is 5kg, making the corresponding engineering specification a support force of 75N. This force was calculated using Equation 1 on page 15.

Importance and Engineering Effort

The purpose of determining customer requirements and deriving corresponding engineering specifications is to enable complete understanding of the current problem and the critical aspects of the new design. By ranking customer requirements and engineering specifications, certain requirements are identified as critical, allowing the team to focus on those specific aspects of the design.

Quality Function Deployment (QFD)

The final step in developing the customer requirements and their corresponding engineering specifications was to combine the collected information detailed above in a Quality Function Deployment (QFD), which can be seen in Appendix E. The QFD assigns individual weights to each engineering specification and then ranks the specifications based on their importance to the overall project. The reevaluation of the project requirements has been factored into the QFD. With this information, time can be effectively budgeted to the most critical requirements.

Table 3: Customer Requirements with Corresponding Satisfying Engineering Specifications and Values

Customer Requirement	Importance (1 low, 5 high)	Engineering Specification	Target Value	Engineering Effort (1=most effort, 13=least effort)
Robust	5	Upward Support Force (N per leg)	750	11
		Number of Supporting Legs (#)	≥4	9
Longevity	4	Service Lifetime (Years)	10	4
Safety	5	Safety Factor (#)	1.5	5
Affordable	5	Manufacturing Cost ($)	≤500	3
Reconfigurable	5	Back Support Inclinable (°)	180, 150, 130	1
		Foot Support Adjustable (°)	90 x-dir & 90 z-dir	2
Easy to clean/sanitize	5	Cleaning Time (Min.)	2	5
Easy to maneuver/ adjust	4	Adjustment Hand Force (N)	200-300	8
Comfortable	3	Comfortable Usage Time (hrs)	12	10
Collects bodily fluids	2	Percentage Collected (%)	≥90	7

DESIGN EVOLUTION (GENERATION AND SELECTION)

Initial Concept Generation

The first concept generation was accomplished by generating a breakdown of the design into the following functional components: back support, seat support, foot support, frame, stirrups or leg supports, privacy, and locking mechanisms. Each team member independently sketched designs for each functional component for 15 minutes. At the end of the allotted time, each team member explained their concepts to the rest of the team. All the concepts from the initial brainstorming session are shown in Appendices B – F.

Back support designs: Figure 14 and Figure 15 are two of the back pad designs. Figure 14 is an indented pad that would essentially enclose the patient with the outer edges of the back support rising higher than the center. Figure 15 is a simple back support structure, similar to the basic supine structure. In addition to this base structure, there is a small, attached pillow with two movable pieces on either side of the pillow, similar to that of an airplane head support.

Figure 14

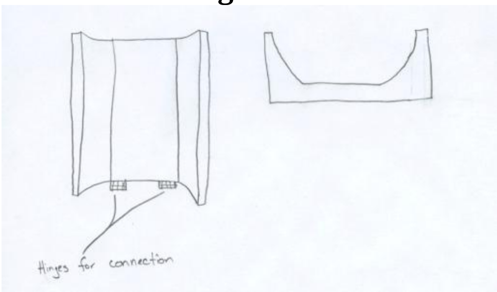
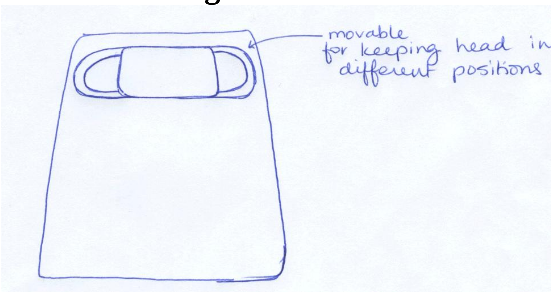


Figure 15



Seat support designs: Figure 16 is a molar shaped seat pad. The semi-circular opening on the seat pad functions as an opening for the fluid collection system for urination/defacation and birthing fluids. As the molar shaped seat pad does not provide a large seating area, the outlined rectangular section will be indented so that the patient will not slide out during the birthing process.

Figure 16

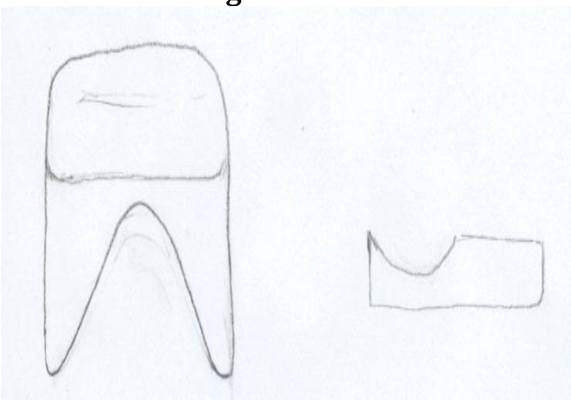
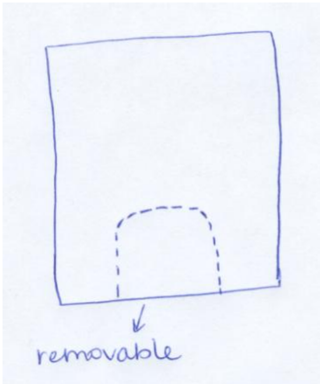


Figure 17



Foot support designs: Figure 18 and Figure 19 represent two different footpad designs, which incorporate a fluid collection system. Figure 18 is composed of a mattress pad that can be separated from a bottom, collection bin. The separation of the two pieces would allow for the fluid to be filtered more efficiently and with less contamination. Figure 19 consists of two foot rests that are separated by a trough to filter the birthing fluids. The external foot rests are padded for support.

Figure 18

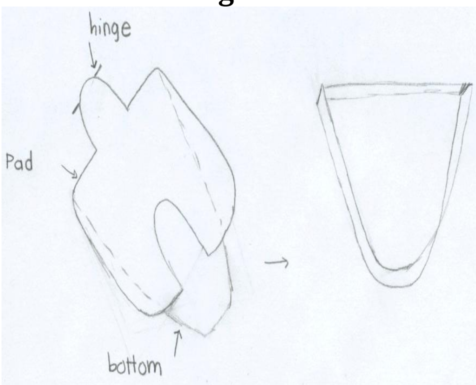
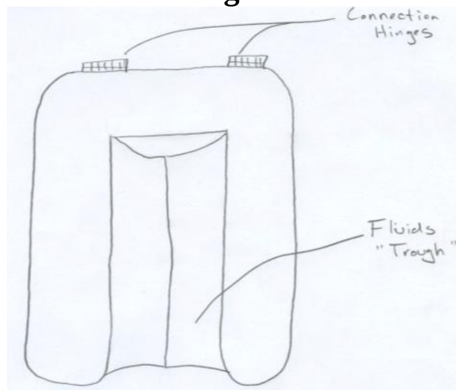


Figure 19



Frame designs: Figure 20 and Figure 21 are two different frame support designs generated in the brainstorming session. Figure 20 is a box shaped solid design. In this design, the frame supports the back pad and seat pad with the foot pad being separate from the solid frame. In the frame support, the box frame has built in shelves for storage. Figure 21 is a more basic frame with leg supports at the rear and front of the back support, front of the seat support, and front of the leg support. The frame also has a built in shelf that flips out from under the bed. The foot support also can fold down to 90°.

Figure 20

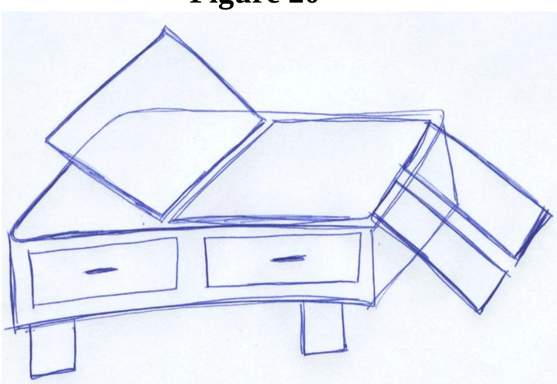
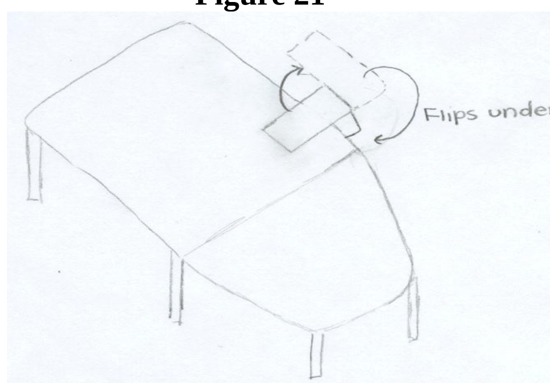


Figure 21



Stirrups or leg support designs: Figure 22 and Figure 23 represent two different sitrrups or leg supports. Figure 22 is a more traditional stirrup that are based on the frame of the bed. They are initially flush with the frame but can be folded out to position when needed. Figure 23 are leg supports that are solid footrests that are initially held under the footpad. When needed, they can be slid out from under the footpad and adjusted to positive 45°. The idea behind this design is to provide a stable foot rest for the patient to provide stability and support.

Figure 22

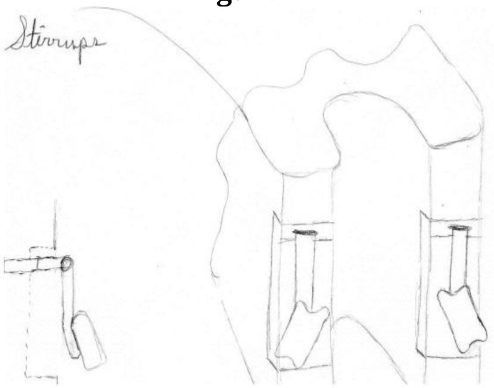
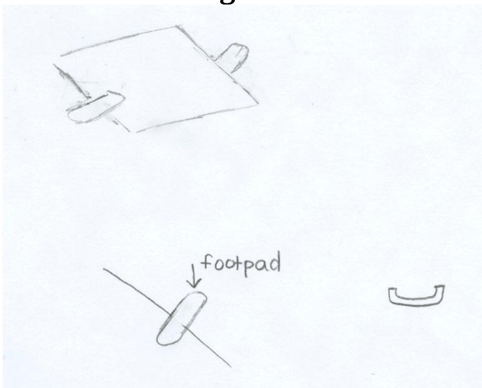


Figure 23



Privacy concept designs: Figure 24 and Figure 24 are two different approaches to privacy. Figure 24 is rod mechanism that will extend from the back frame of the bed, along the side, and to the front of the bed. The rod mechanism that covers the front portion of the bed will be able to bend back into line with the side rod. A curtain will be pulled along the rod to provide privacy. Figure 25 is a pull up screen. The screen would roll down to the bottom of the frame. Then it will pull up and latch onto two, rod pieces that will extend up from the frame.

Figure 24

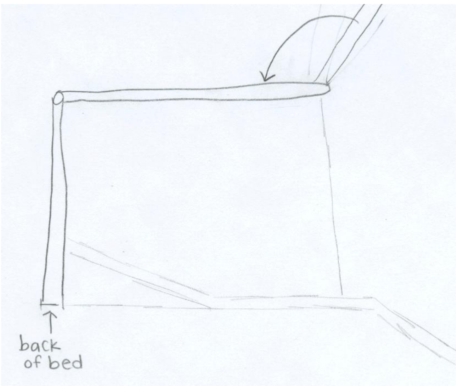
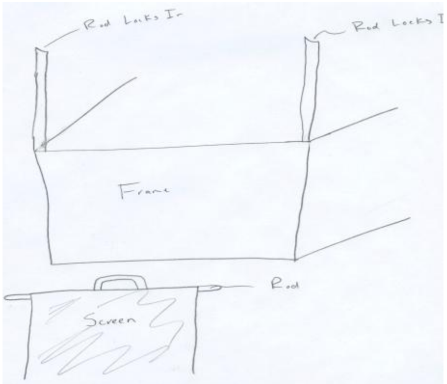
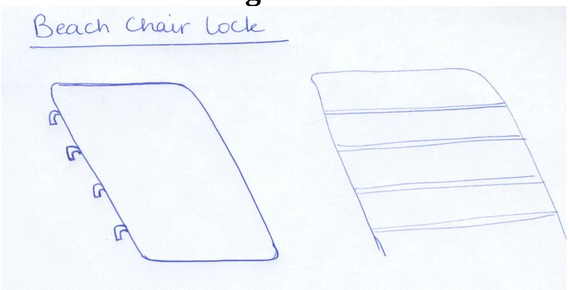


Figure 25



Locking mechanism designs: The locking mechanism designed for the back support is similar to a beach chair locking mechanism. The back support in this design has notches which catch on the rods on the frame shown on the right.

Figure 26



Once the designs for each functional component were completed, each functional component was evaluated on a Pugh chart to determine whether it met, exceeded, or did not meet the project engineering specifications. The Pugh charts for all of the concepts generated from the initial brainstorming session are provided in Appendix K.

Generation after Pugh Analysis and Informal Presentation

Considering only the top rated designs for each functional component, the team held a second brainstorming session to develop an "alpha" design. The team first discussed which components rated most highly and why designs previously considered ideal were not longer viable. The main reason for concepts fairing badly was cost of materials for the more sturdy designs or difficulty in manufacturability. Then focusing on top design components, the team discussed options for creating one design. The main focus of this brainstorming session became the issues of the fluid collection system and somehow sanitarily including birthing fluid collection and urination/defecation. The design shown in Figure 28 was the resulting "alpha" design. This design was the "alpha" design was finalized with the understanding that there was still a design issue regarding the functionality of the fluid collection system.

Generation after Mentor Feedback before DR2

After discussing the design issue of the fluid collection system with Dr. Johnson and Dr. Lori, it was decided that the concept of integrating a fluid collection system to incorporate urination and defecation would be removed. This decision changed the outline of the fluid collection system and foot support design challenges. Thus, the team met again to focus solely on these design aspects. The main discussion centered on the ability to simplify the fluid collection system to a filter or funnel for the fluid. The developed final design can be seen in Figure 61. This design is explained in detail in the 'Final Design Description' section later in the report.

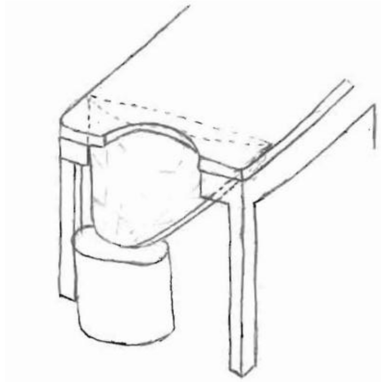
Mockup Fabrication to Assist Further Generation

In order to facilitate the manufacturing plan and to visualize current design challenges for the final prototype, the team decided to mock-up the prototype. This wood mockup was not built to scale and was only intended to give us a physical representation of the CAD model for the final prototype. The mockup was created so that the team could experiment with different attachments for the stirrups and fluid collection system and also assisted in visualizing the frame edge and leg dimensions. It is important to note that the mockup was built with simple hinges that will not be used on the final prototype. The mockup further helped to identify the foot support joint and leg connections as potentially important areas.

Fluid Collection System Development

After observing in the delivery ward to better understand the fluid associated with childbirth and taking into consideration the disposable design utilized at the University of Michigan hospital, the team chose to replicate a funnel slide. The shape of a slide was logical in terms of containing splashing due to high edges of the system. To utilize the current bucket collection system at KATH, the slide would start at the width of the bed and funnels down to a width that will fit within a standard bucket. The sketch of this design is shown below in Figure 27.

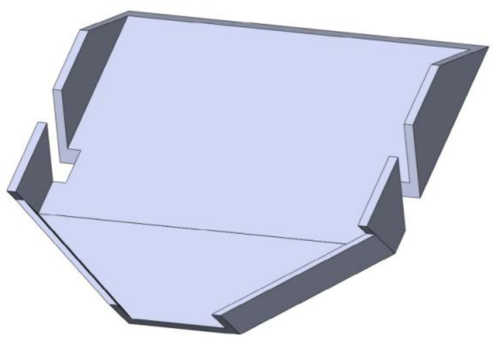
Figure 27: Slide Fluid Collection Concept



Evolution of the Slide Fluid Collection System

The idea behind the slide fluid collection system remains constant. However, due to discussions about the feasibility of manufacturing a concave system that would decrease in width, the system was changed to a flat piece of material with raised edges to contain fluid. This system started at the width of the bed and maintained width until passing the front legs of the frame. At this point, the system would funnel to a width of less than 1ft. This design is shown in Figure 28 below.

Figure 28: Flat Slide Fluid Collection System



Generation Based on Material Cost

With the completed CAD model, the team discussed ways to reduce materials costs. The basic structures and functionality of all components was maintained but excess waste was removed or simplified.

Back support reduction: The "alpha" back support and final design back support are shown in Figure 29 and Figure 30 below respectively. The "alpha" back support was very simple in design; however, the material cost for a solid back support was not justified by the forces that would be acting on the back support. The first decision was to maintain the dimensions by cutting out the majority of the middle material and leaving an external frame. To reinforce the support of the back support, the team chose to use three cross beams that would be welded to the outer frame. Additionally, the issue of achieving the supine position with the back support bar was addressed. Rather than cutting out depth from the frame to accommodate the depth of the back support bar, the team decided to shorten and thin out the bar. By shortening and thinning out the back support bar, the bar was designed to fold within the back support frame. Thus, the bottom of the back support frame is the pieces that lie on the frame, creating the desired supine position. However, due to shortening the back support bar, the angle of 100° was no longer achievable. The team decided the material cost reduction and functionality outweighed the loss of one configurable angle.

Figure 29: Alpha Back Support Design

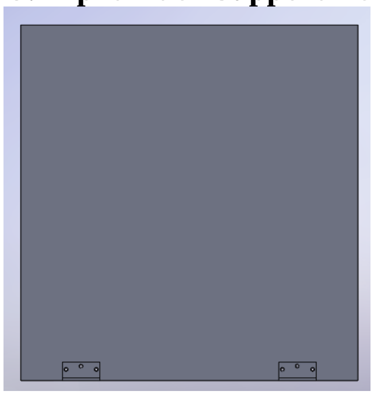
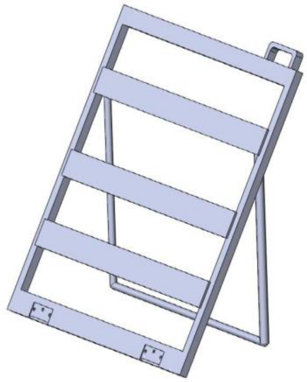


Figure 30: Final Design Back Support



Frame reduction: The "alpha" frame design was also modified mainly due to the cost of the large metal pieces. Dimensions, which had been randomly selected, were also more carefully discussed and most dimensions were reduced due to unnecessary material. Originally, the back support bar was meant to be stopped on hooks that extruded from the frame. After discussion, these pieces were removed and it was decided to indent into the frame to lock the back support positions. It was additionally decided to repeat the seat support piece on the frame to add extra support as well as to extend the edges above and below the plate of the frame.

Figure 31: Alpha Design Frame

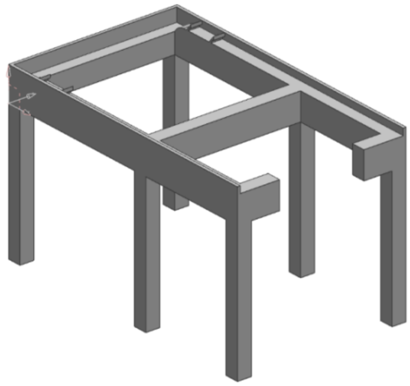
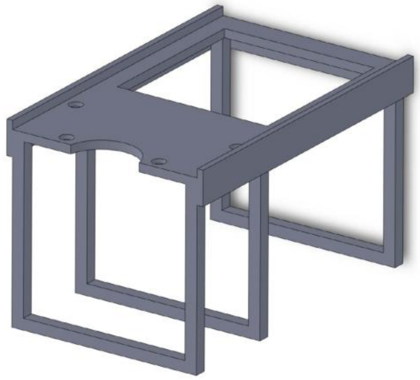


Figure 32: Final Concept Frame



Stirrup Generation

Stirrup design has been the most difficult component in this project. A design was not completed for the "alpha" design and therefore the most important task was a stirrups concept generation meeting. The meeting was held in a study room equipped with a white board that was used to draw and discuss different ideas. The main issues were how to make the stirrups adjustable for women of different heights and how to adjust for different angles of rotation without interfering with the functionality of the foot supports. Interference would mainly be due to the foot support in the stored position, lying flush against the outer edge of the frame. The basic idea was to extend the stirrup from the outer edge of the frame so it would not interfere with the fluid collection system. A telescoping arm was considered to adjust for different heights, as well as a sliding arm with a kickstand, and a stirrup arm that adjusted height and length with a pin system. Some of the ideas discussed are shown below in Figures 33-35 and all of the others are shown in Appendix M.

Figure 33: Telescoping Stirrup Arm

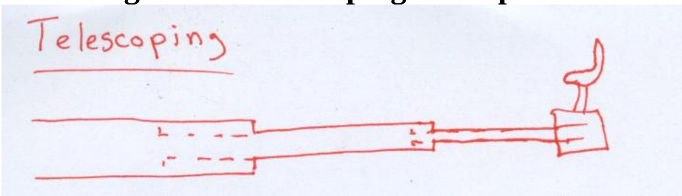


Figure 34: Kick Stand Stirrup Arm Support

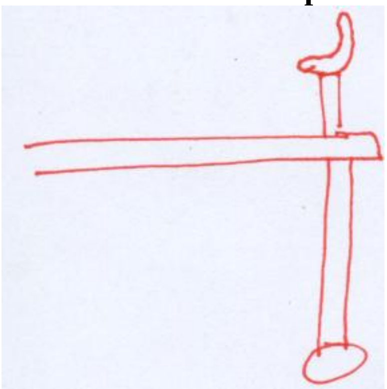
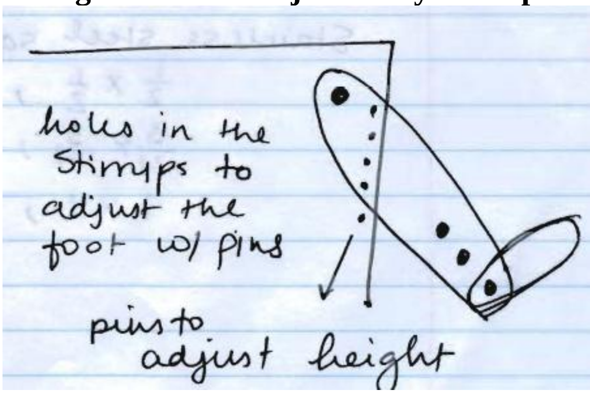


Figure 35: Pin Adjustability Stirrup



After presenting these stirrup designs and discussing the functionality of the stirrups with our mentor, we considered anchoring the stirrup system from the ground. Several different designs for stirrup attachment to the bottom of the leg were discussed; however, these stirrups were disregarded due to the additional joint complexity and manufacturing processes. After researching more options for stirrup designs, the team found a design pictured on Amazon.com that was simple and provided the required degrees of freedom and adjustability; this design is shown in Figure 36 below. This led to a final stirrup design shown in Figure 37 below, which is explained in detail in the Final Design Description Section.

Figure 36: Simple Design on Web

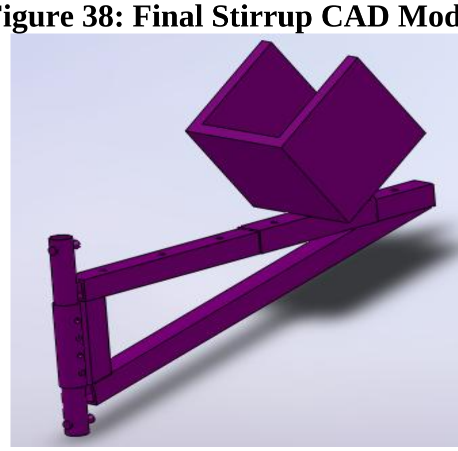
Figure 37: Team's Final Stirrup Design

Generation Based on DR3 Feedback

Based on class feedback from the DR3 presentation, there were several design alterations. The first adjustment was to the fluid collection system. Issues were brought up regarding fluid getting stuck in places (such as behind the front legs) as well as the difficulty in manufacturing plastic to fit around the front legs. The team decided simply to reduce the width of the fluid collection system to 28in. so that the entire system fits within the front legs. This change reduces the manufacturing challenge and the issue of fluid collecting within the system rather than filtering.

Following DR3, our team had to organize another brainstorming meeting to discuss additional changes for the stirrups design. We needed to reevaluate the stirrups again because we received feedback that the set screw design might not perform very well and we faced challenges of attaching the foot rest to the rest of the structure. From the brainstorming meeting we developed a concept that was inspired by the study desks in our campus media union. The idea consisted of a concentric bar design that could be locked in place with a pin. The system geometry is triangular and has two degrees of freedom, one in the vertical direction and one that is parallel with the top surface of the bed. An image of this design is shown below in Figure 38. This final concept was generated in CAD, fabricated, and attached to our final prototype.

Figure 38: Final Stirrup CAD Model



Generation Based on DR3 Feedback

Based on class feedback from the DR3 presentation, there were several quick design alterations. The first adjustment was to the fluid collection system. Issues were brought up regarding fluid getting stuck in places (such as behind the front legs) as well as the difficulty in manufacturing plastic to fit around the front legs. The team decided simply to reduce the width of the fluid collection system to 28in. so that the entire system fits within the front legs. This change reduces the manufacturing challenge and the issue of fluid collecting within the system rather than filtering.

Alpha Design Concept Selection

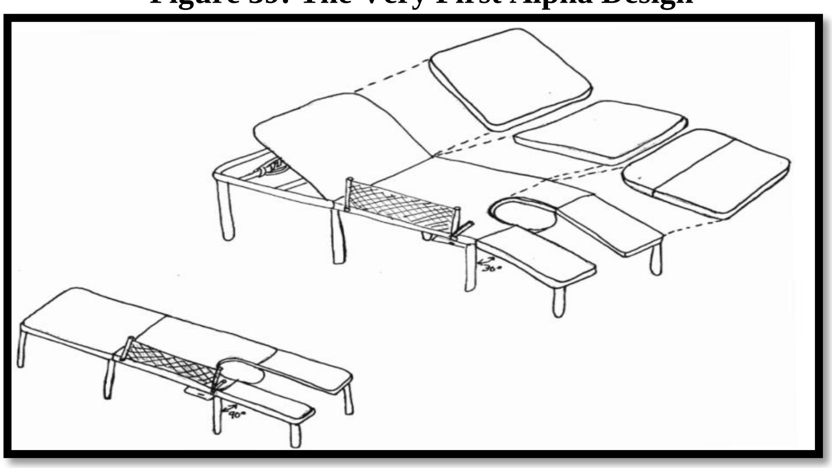
Concept selection was accomplished by generating Pugh charts. Separate pugh charts were created and analyzed for every component of the bed as follows: back pad, seat pad, foot pad, frame support, stirrup or leg support, privacy, and locking mechanisms. The pugh charts can all be found in Appendix K.

The analysis of pugh charts was accomplished by scoring on the following scale: **0**, **+**, **-**, or **NA**. A score of 0 was given if the a concept met the engineering specification, + was given if the concept exceeded the engineering specification, - was given if the concept did not meet the engineering specification, and NA was given if that particular engineering specification did not apply to the concept. Then, from the resulted top functions, the team generated four complete designs and a pugh chart of the completed designs was developed. The completed designs were each drawn individually by different members of the team and evaluated. The resulting top features from the pugh chart led to a discussion of the advantages and disadvantages of each of the designs which in turn led the creation of the first alpha design. The first alpha design is shown below in Table 4 and the four competing designs can be found in Appendix L.

Table 4: Alpha Design vs. 4 Individual Members' Designs

Complete Designs					
Specifications	**Alpha**	**1**	**2**	**3**	**4**
Longevity	+	+	+	+	0
Safety	0	0	0	0	0
Robust	+	+	+	+	0
Affordable	+	-	-	-	+
Reconfigurable	+	0	0	0	0
Easily Sanitized	0	-	0	0	0
Maneuverability	0	-	-	-	0
Privacy	+	0	0	-	-
Comfort	0	0	+	+	0
Fluid Collection	+	+	+	0	+
Holds Materials	-	0	0	+	0
Score:	+5	0	+2	+1	+1

Figure 39: The Very First Alpha Design



After a discussion with the mentors, the team realized that features such as privacy screen, bathroom/defecation area were not recommended. The team then decided to eliminate those features and the elimination of those features created the alpha seen on Figure 39 and discussed in further details in the next section of this paper.

ALPHA DESIGN

The following section details the alpha design for the reconfigurable obstetrics delivery bed. Each component/function of the bed will be described.

Alpha Design Components

The alpha design has the following components:

- Back support
- Locking mechanism
- Back pad
- Seat support
- Fluid drainage system
- Seat pad
- Foot support
- Foot pad
- Frame
- Stirrups

The dimensions of the bed in the supine position are 180cm (70.86inches) long by 75cm (29.52inches) high by 75cm wide. All the dimensions of the bed were determined from anthropometric measurements of a 95th percentile American female over the age of 20, with the assumption that the 95th percentile Ghanaian woman would be of similar size.

The back support, shown in Figure 40, is linked to the frame, shown in Figure 41, of the bed by bar that can be adjusted. This bar can be positioned so that the angle θ equals 180˚, 130˚ or 100˚. The bar rests against one of three different hooks on the frame of the bed to achieve the three different angles.

The locking mechanism of the back support is similar to that of a beach chaise. Where small hooks (3 corresponding to each angle of configuration) are designed on a bar pin jointed to the back support; this bar is secured on the main frame of the bed by the hooks. The different hooks are setup so to position the back support at different angles.

The back pad is a cushion for the back support section of the bed. It is a simple rectangular shaped pad with rounded corners. The back pad is composed of a foam-like material to provide comfort. It is covered with vinyl to prevent the absorption of bodily and cleaning fluids. The back pad is 70 cm (27.55inches) wide and 96.52 cm (38inches) long.

The fluid drainage system will be integrated into the semi-circle cut out of the seat support. The fluid drainage will channel the birthing fluids to the fluid collection bucket. The bucket will be located on the floor directly under the semi circle cut out.

The seat pad has a rectangular shape with a semi-circle cut out on the front center of the pad to match the shape of the seat support. Like the back pad, it is made of a foam-like material and is covered with vinyl. The seat pad is 70 cm wide and 30.48cm (12inches) long.

The foot support, shown in Figure 40, section will be composed of two parts. The width of each foot support will be about half the width of the frame 37.5 cm (14.76 inches). The foot support will have no legs but instead it will operate in a manner similar to the swivel desk top of high school chairs. It will rotate up and over to support the pregnant woman's leg when lying, down and on the side during the birthing process to give room to the midwife or doctor.

The foot pad is also made of a foam-like material and is covered with vinyl. The pad is composed of two rectangular sections that are each 30cm (11.81inches) wide and 50.8 cm (20inches) long.

The frame of the bed is rectangular in shape with a break in the structure to accommodate the fluid collection system. The support system sits in the frame and has limited attachment points to allow for configurability. The frame has six sturdy legs to support the weight of the bed and the patient safely.

The stirrups for the bed will be full, indented foot rests. Due to space limitations, the stirrups will be stored on the underside of the frame. When needed, they can be slid out from underneath the bed and adjusted to an angle of positive 45°. The purpose of the stirrups is to provide the patient with the appropriate leg support during delivery.

Potential Areas for Design Change

The alpha design for the delivery bed has some functions and characteristics that may change with further design evaluation. Adjustments to the alpha design are expected, especially as the project approaches the prototyping stage.

The fluid drainage system will require further design updates and analysis for collecting the birthing fluids. There are physical constraints intrinsic to the structure of the bed that inhibits successful fluid drainage.

The dimensions of the alpha design were based on the anthropometric measurements of a 95^{th} percentile American woman over the age of 20. The dimensions of the supine beds at KATH are not known and therefore comparable dimensions could not be chosen. It is also unknown whether the dimensions of the supine beds and delivery chairs are preferred by the medical personnel and patients at KATH. The bed dimensions are extremely important due to the lack of space in the delivery ward.

Figure 40: Alpha design back, seat and foot support

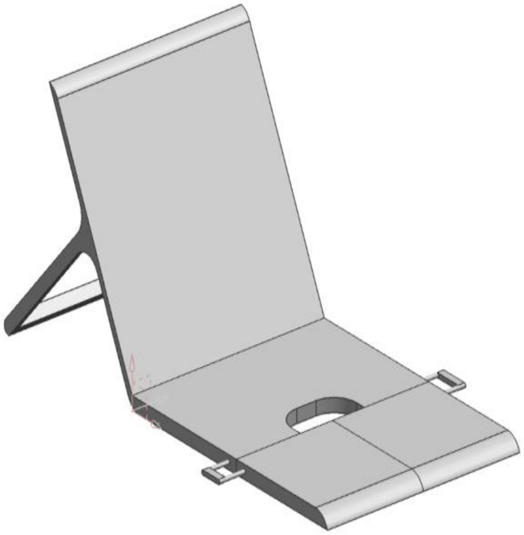
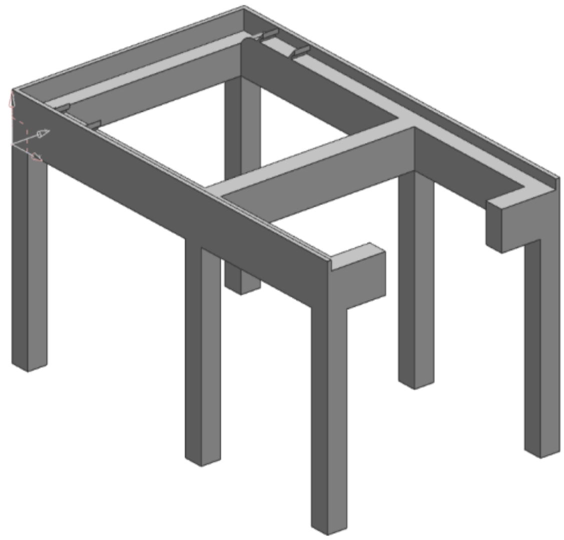


Figure 41: Alpha design frame



ENGINEERING ANALYSIS

The following section will cover the engineering fundamentals relevant to the prototype.

The engineering fields that are relevant to the prototype are statics, dynamics and materials. The applicable fundamentals and concepts from statics and dynamics are Newton's law, bending moments, torque and friction. For materials, the applicable properties are: fracture toughness, Young's modulus, corrosion, yield strength and ultimate tensile strength.

Newton's law, Eqn. 2 below, was necessary to calculate the forces that will be applied to the bed due to its own weight plus the weight of the patient. The bending moments, Eqn. 2 below, of the bed frame was determined to make sure that the frame shape will not degrade over the lifetime of the bed and reduce functionality or safety. Since the most important feature of the bed is the configurability, the amount of applied torque, Eqn. 3, to the configurable sections was determined. The required torque to move the back support of the bed must not exceed the average strength of the users and the joints and links of the bed must be able to withstand the forces. When these calculations were made, a safety factor of 1.5 was applied to ensure safety and reliability of the bed.

$$Force = mass * acceleration \qquad \text{(Eq. 2)}$$

$$Moment/Torque = force * moment\ arm \qquad \text{(Eq. 3)}$$

Friction was also considered for the design because it will affect the torques required to configure the bed in the different positions. The joints should require minimal lubrication to meet joint wear/lifetime requirements.

The engineering fundamentals mentioned above directly influenced material selection for the bed. In order to determine the optimal materials for the bed, the following material properties were considered: fracture toughness, fatigue strength, yield strength, Young's modulus, corrosion resistance and porosity. The first four material properties are applicable to the bed frame and the back, seat and leg supports. The last two material properties are applicable to the bed pads, the frame and the supports because of the corrosive cleaning solution.

The driver of the design is configurability. As a consequence, a large focus was placed on making sure that this function is designed well because it determined the utility of the bed. Configurability would have failed if the joints and links did not withstand the operational forces or wear prematurely due to frictional forces or the corrosive cleaning solution. The configurability would also have failed if the bending forces exceeded the strength of the support structure material and geometry.

CONCEPT DESCRIPTION

Figure 42 and Figure 43 below show the final design in supine and delivery position. This design meets the engineering requirements and specifications established for this project. Each design component will be explained in more detail below.

Figure 42: Supine Position

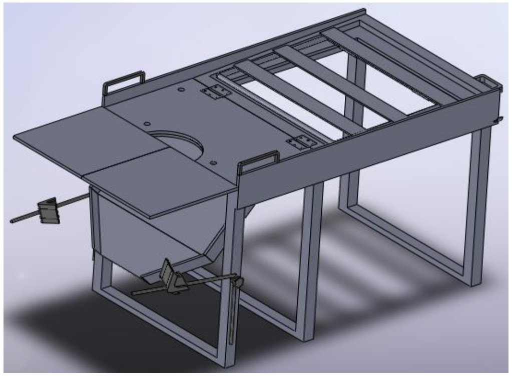


Figure 43: Delivery Position

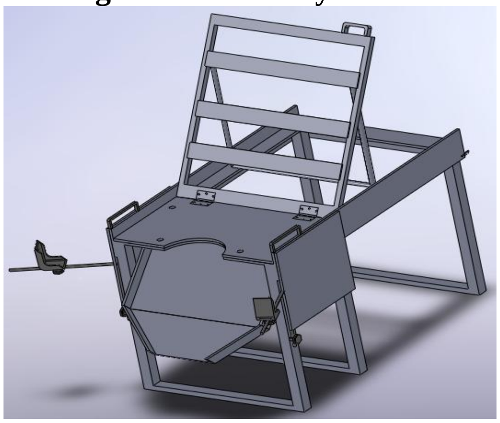


Figure 44: Frame

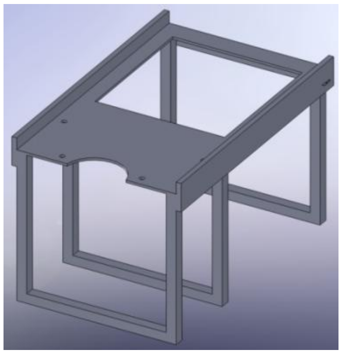


Figure 45a: Frame Top View Drawing

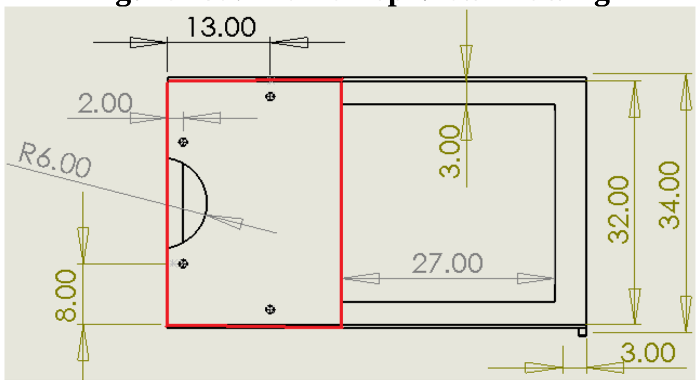


Figure 45b: Frame Side View Dwg.

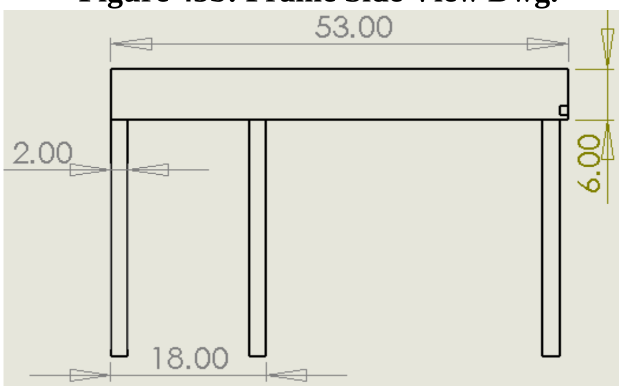
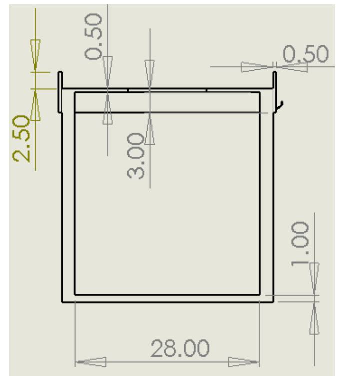


Figure 45c: Frame Front View Dwg.



The final design for the frame is shown above in Figure 44. This frame has outer dimension of 4.5ft. long by 2.8ft. wide and will be made of A36 steel. The purpose of the frame is to provide the stability and strength to support the patient during active labor and delivery and during bed reconfiguration. For support, the bed has 6 legs made of 2in. by 2in steel rods that are 31in high. Because the seat support will be the location that handles the most force in supine position and particularly in delivery, the front four legs sit on the four edge of the seat section. The 6in. plates shown in Figure 45b act as an edge for the bed on the left and right sides. There is a 4in. plate located on the back of the frame that acts as an edge but is shorter to accommodate the handle on the back support.

The seat section of the frame is outlined in red in Figure 45a above. Due to support issues with this piece, this section of the frame will be made of a 0.5in. thick piece identical to the seat support explained below. During labor, the woman will be loading all of her weight onto the very front of the frame, making that support system, the most critical for design functionality. Creating the frame base with a piece identical to the seat support shape will add more stability to the seat support, particularly the inner edges of the semi-circular opening. The seat support design is explained further in this section. The locations of the bolt holes that will be used to insure a secure connection to the seat support are illustrated out Figure 45a above. The semi-circular opening meant to facilitate fluid collection has a diameter of 1ft. and is center on the frame.

The back support section of the frame has two important elements. First is the 27in. by 26in. cutout. This cutout was added in an effort to reduce material costs for the frame. The removal of this size piece of material reduced the material cost by approximately 30%. The second important aspect is the 3in. plates that surround the cutout. These plates function as the shelf on which the back support will rest in supine position. Additionally, the indents for the configurability of the back support will be cut into these pieces. These indents will serve as the locking mechanism for the back support bar and thus the different back support positions. These indents are not pictured above but are designed to be >0.5in deep. They will likely be a last element added to the design upon manufacture to ensure accuracy in angling of the back support.

There are several special features added to the frame for the patient. The first addition is the two handles shown in the final design on the front end of the frame edges. The purpose of these handles is to address patient comfort during delivery. As Ghanaian culture expects women to be silent during delivery and does not include a typically include having a birthing partner, the handles will provide the woman with something to station herself with for delivery and also something to grab to release pain. The handle design and dimensions are shown below in Figure 46. The handles will most likely be made from steel and possibly wrapped in padding to provide comfort.

Figure 46: Handle

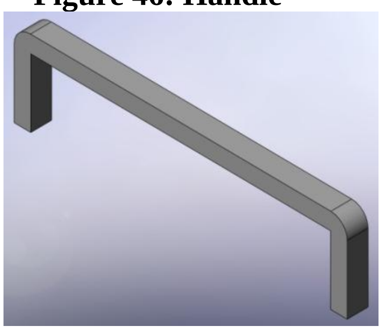
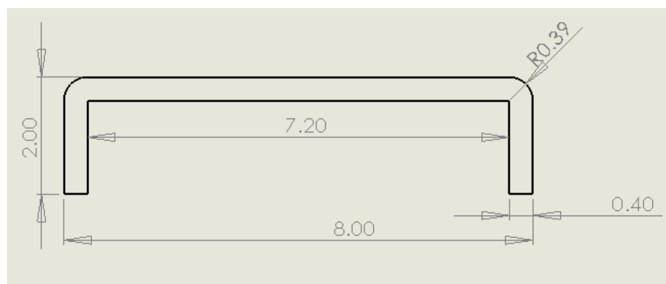


Figure 46a: Handle Front View Drawing



Another feature is the hook, which is shown on the back right frame edge. The purpose of the hook is to provide the women with a way to hang their belongings up and keep them off the floor. This is purely an extra consideration for the patient.

Back Support System

Figure 47a: Front View Back Support

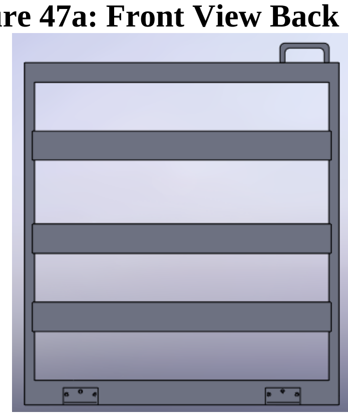


Figure 47b: Back View Back Support

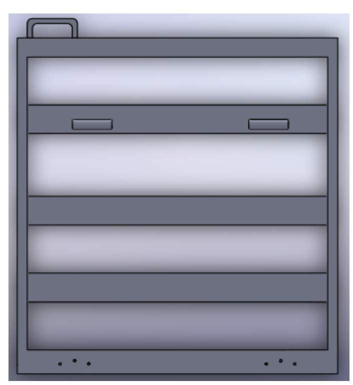


Figure 47c: Side View Back Support Dwg.

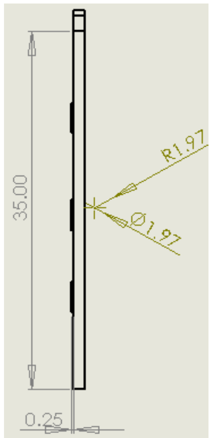


Figure 47d: Front View Back Support Dwg.

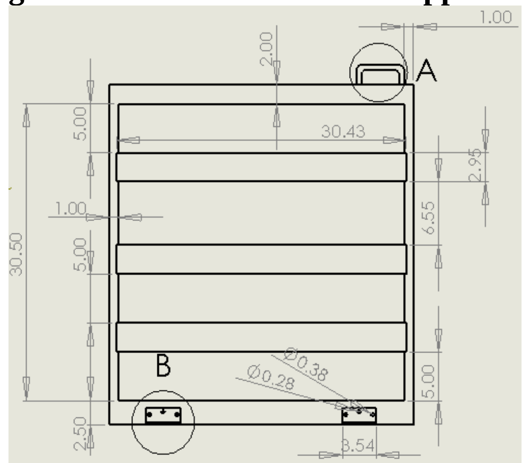


Figure 47e: Bottom View Back Support Dwg.

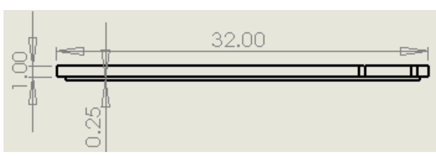


Figure 47f: Back View Back Support Dwg.

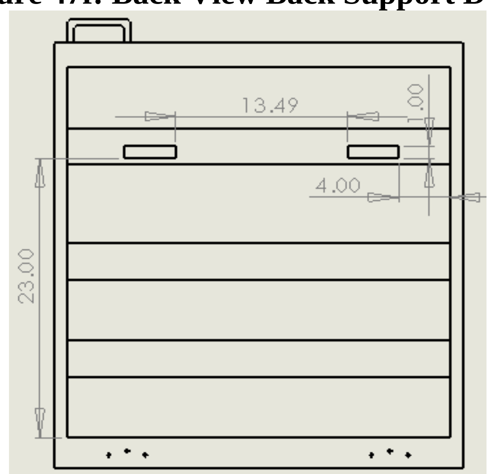


Figure 47g: Detail B Drawing (from 47d)

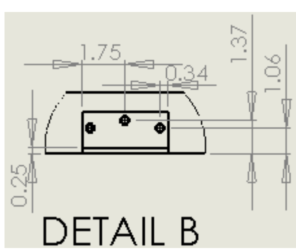
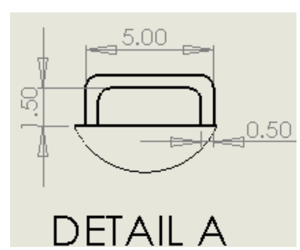


Figure 47h: Detail A Drawing (from 47d)

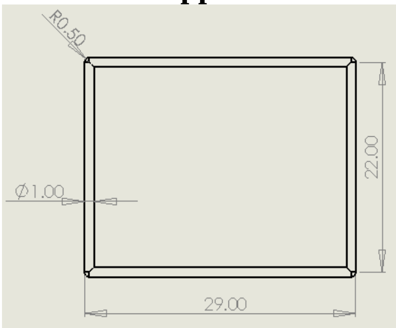


The purpose of the back support is to support the patient's back, neck, and head when the bed is reconfigured to 180°, 150°, and 130°. Reducing material costs in this element was achieved in eliminating a solid back support. Instead, the piece is made up of a frame with three cross beams that will bridge the cutout. This entire piece will be hinged onto the seat support piece, which requires a slightly wider bottom edge of the frame.

In order to satisfy the requirement for ease of maneuverability, there is a handle located at the top of the back support (dimensions shown in Figure 49). As noted previously, there is no raised edge at the back of the frame, which accommodates the location of the handle.

Figure 48: Back Support Bar

Figure 49: Back Support Bar Drawing



The back support will be adjusted with the use of a back support bar shown in Figure 50 below. This bar will run through the two collars that are located on the highest back support crossbeam. One issue with the entire back support system was to allow the entire system to lie completely flat to generate the desired supine position. The back support frame has a depth of 1in. With the crossbeams welded to the top of the frame, there is a 1in. depth within which the back support bar can be stored. The height and width of the back support bar was adjusted so that it could fit within the back support frame. However, due to this adjustment, the collars were placed on the top crossbeam rather than the center beam and the bar was shortened. This bar shortening eliminated the 100° incline from the possible reconfigurable angles. The tradeoff was deemed acceptable as the storage consideration was considered more important than that incline level. The positioning options of the entire back support system are shown below in Figure 50 and Figure 51.

Figure 50: Back Support Bar

Figure 51: Back Support Bar Drawing

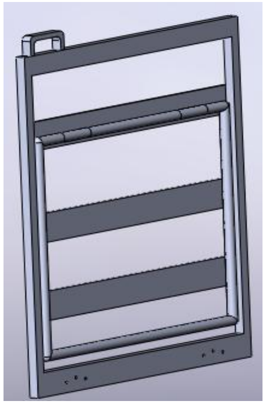


Figure 52: Seat Support

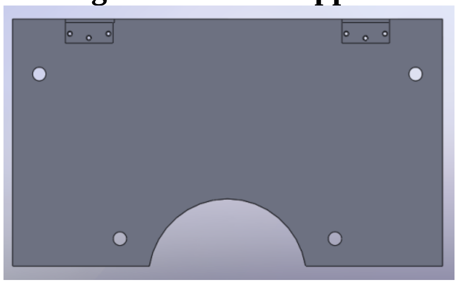


Figure 53a: Seat Support Top Drawing

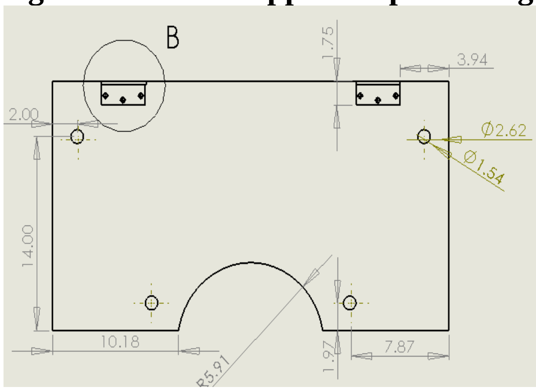


Figure 53b: Seat Support Side Drawing

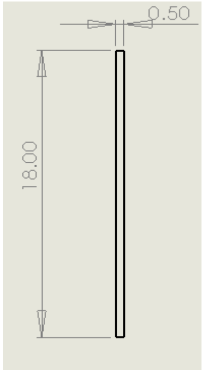
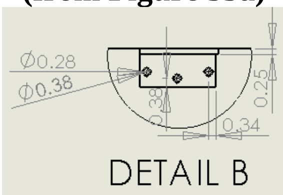


Figure 53c: Seat Support Front View

Figure 53d: Detail B Drawing (from Figure 53a)



The seat support functions as part of supine bed and as the part of the bed where the woman sits during labor. This piece does not reconfigure; it is bolted to the frame and is the piece that the back support is hinged to. The semi-circular opening is identical to the opening on the frame describe above with a 12in. diameter, centered on the seat support piece.

Foot Support

Figure 54: Foot Support

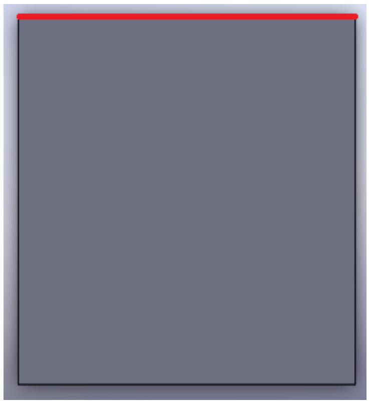


Figure 55a: Foot Support Top View Drawing

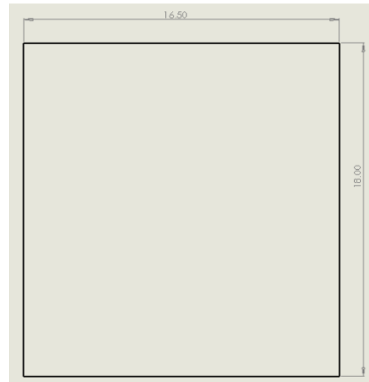
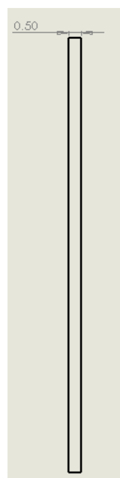


Figure 55b: Foot Support Side View Drawing



The foot supports are meant to support the patient's legs and feet while the bed is in supine position. The engineering specification for reconfigurability calls on the foot supports to lie flat in the supine position for active labor and to be completely removed from the front of the bed for the delivery process. The foot support system of the bed consists of two foot supports of the design and dimensions shown above. These two foot supports lie next to one another in the supine position with the front edge (represented by the red line in Figure 54) lies flush with the seat support. Each foot support rotates about its own tablet arm hinge that is based on the outer edge of the frame. The table arm hinge allows the foot supports to lie horizontally and then rotate to be stored vertically next to the outer edge of the frame. These two positions are shown in Figure 56 and Figure 57 below, which are taken from Ferco Seating, the joint manufacturers.

Figure 56: Side View of Stored Foot Rests

Figure 57: Side View of Foot Supports in Use

Fluid Collection System

Figure 58: Fluid Collection System

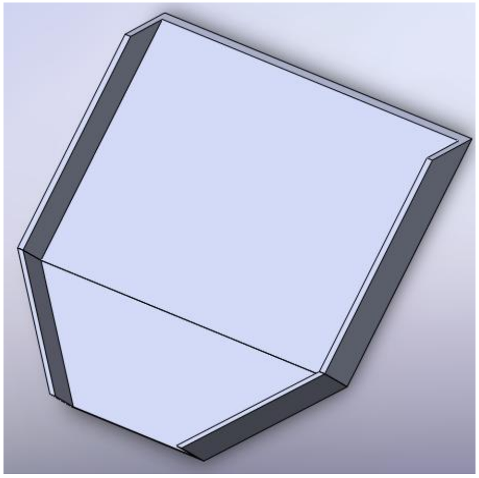


Figure 59a: Front View Fluid Collection System

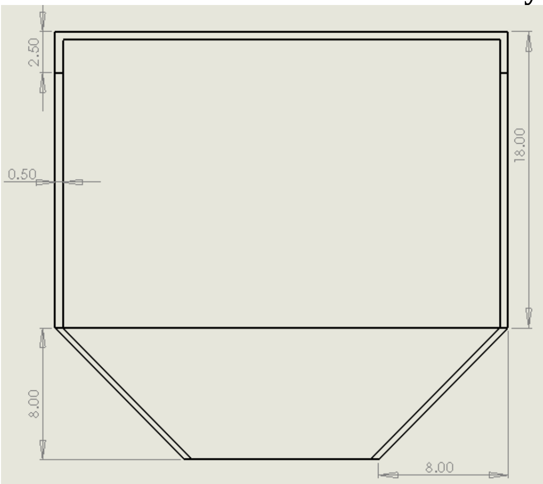


Figure 59b: Side View of System

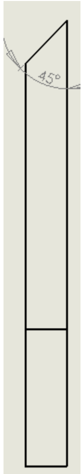
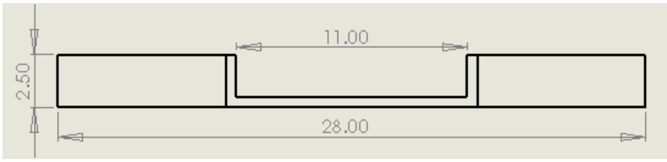


Figure 59c: Bottom View of System



The fluid collection system is meant to assist in the collection of birthing fluids. The system will be bolted underneath the frame behind the semi-circular seat opening. This system angles downwards at a 45° angle to allow gravity to direct fluid. The system has a width of 28in., which makes it fit directly inside the frame legs. The system remains at that width until it extends beyond the frame of the bed. While observing a delivery, it was noted that fluid does drips but also can splash forward. The width is meant to account for as much of this fluid splash as possible. The fluid collection system then filters the fluid by narrowing to a width of 11in. The fluid will be collected by a bucket currently used by the hospital that will be placed at the bottom of the system. The system has 2.5in. edges (a height chosen to contain fluid while not making the system too bulky) to contain the fluid, and the system will be liquid tight to ensure that no fluid collects in the edges of the system. Liquid tight is defined as not allowing any liquid to escape the system through the edge and flat piece connection or any other connections.

Stirrups

Figure 60: Stirrup Assembly

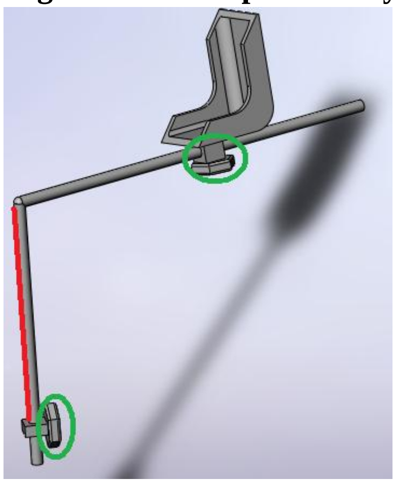


Figure 61a: Stirrup Arm Side View Drawing

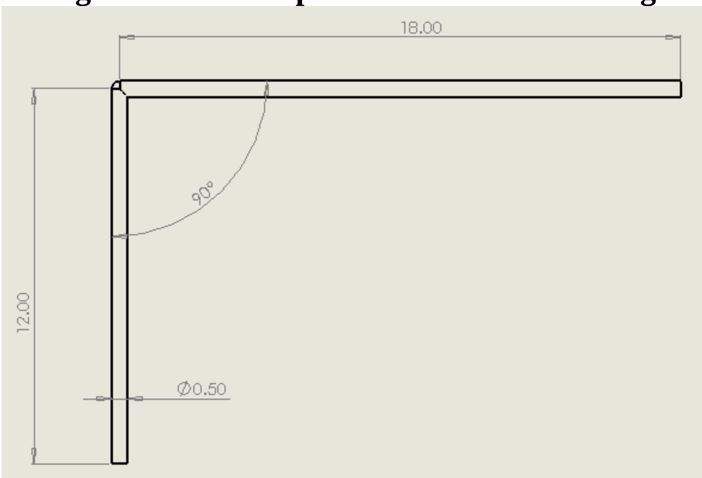


Figure 61b: Stirrup Foot Rest Front View Drawing

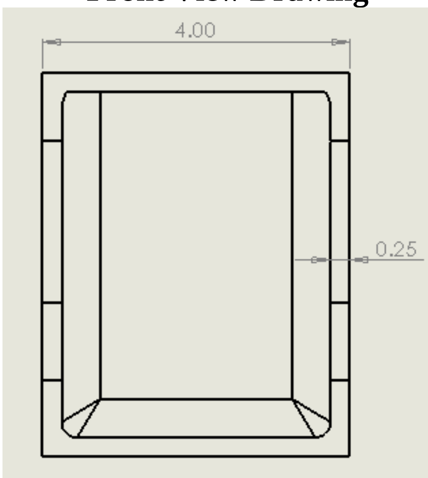
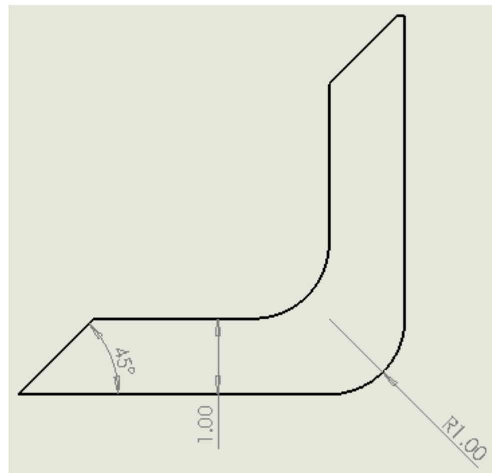


Figure 61c: Stirrup Foot Rest Side View Drawing



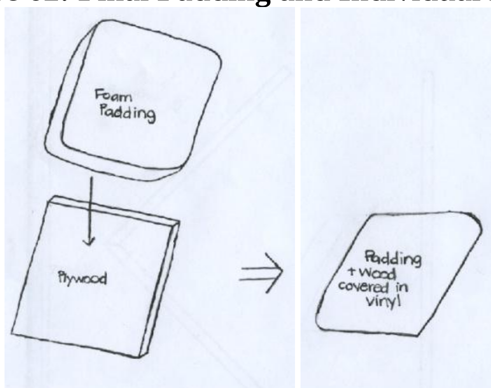
The stirrups fulfill the normal functionality of stirrups. There were two main design issues that led to this final stirrup design. The first issue was creating stirrups that could adjust for women of different heights. This adjustment would need to be made in stirrup height from the ground and stirrup rotation from the edge of the frame. Dr. Jody Lori, a team mentor, recommended that the stirrups raise the patient's legs to approximately 45° from the vertical position. The reason for stirrups at this angle, which is lower than traditional setups, was to allow the stirrups to act more as an anchoring system for the woman during delivery. It also helped facilitate the semi-recumbent delivery position, which research has shown is one of the safest delivery positions for the mother.

The stirrup arm is made of 0.5in steel tube. The red line shown in Figure 60 represents the side of the arm that will run parallel to the front legs of the frame. The non-highlighted leg will extend forward from the frame and rotate. The stirrup movement is facilitated by two set screws, which are circled in green in Figure 60 above. The lower set screw will attach the stirrup arm to the outer edge of the front frame legs, while the second set screw will allow the stirrup to be adjusted for length along the second portion of the arm. The set screw is an easy and simple design option that allows for the circular stirrup arms to be adjusted for height and angles of rotation and can be altered for women of different sizes.

The stirrup foot rest, which is shown in Figure 61b and 61c, will be made of plastic to reduce weight. The concept for the foot rest was to mimic the heel of a shoe, to allow comfort for the woman. The foot rests will be covered with padding on the inner surfaces to add more patient comfort.

Padding

Figure 62: Final Padding and Individual Pieces



Padding will be placed over the foot supports, seat support, and back support. The purpose of the padding is to provide the patient with comfort throughout the use of the bed. The padding will be made to identically fit each piece and will most likely be made of strong foam. Navdeep also has access to couch cushions and the viability of the cushion padding is being considered.

To ensure the padding maintains its shape and lies flat along the supports, the foam will be placed on top of a thin piece of plywood. The plywood and foam will then be covered with a non-porous vinyl material, which will either be sewn together or stapled. The purpose of the plywood is to help the padding maintain its shape and to create a flat surface so that the padding can be perfectly mated to the supports. The entire padding will be attached to the support with Velcro, allowing for easy removal of the padding for cleaning.

PARAMETER ANALYSIS

Moving forward from DR 2, we reevaluated and analyzed the original Alpha design to identify critical areas for improvement and evolution. This section discusses how engineering parameters and specifications were derived or analyzed in order to progress to the initial fabrication of the final prototype. Several areas were also identified as possible failure locations and were evaluated using engineering analyses to determine the likelihood of such a failure.

Shape

In determining the shape of the bed in the final prototype, we considered benchmarking results, ease of manufacturing, and space constraints in the Labor and Delivery ward in KATH.

In today's global gynecological market, the majority of beds have a rectangular shape. A rectangular shape is easier to manufacture than something with curved edges as the majority of viable materials are provided as straight stock. Thus, extra manufacturing steps would be required to alter the bed frame to any other shape. Two possible options for bed frames that would not alter the original stock material would be a rectangular or square shape. A square shape was disregarded based on anthropometric data collected for women, which indicated a square shape would result in wasted material or not enough material depending on the driving dimension (length or width). Anthropomorphically, women have profiles more closely resembling a rectangular shape than a square shape. Another reason for selecting a rectangular frame is that current beds used in KATH all have rectangular frames. Since the ultimate goal of this project is implementation in the ward, we chose to create a prototype that would not alter the current layout in the ward. Space is a precious commodity in the hospital and any variation from the current standard concerning shape might negatively affect the final implementation as well as general design acceptance. With this analysis, we chose to move forward with a rectangular bed frame.

In regard to individual pieces such as back, seat, and foot supports, logic dictated that these supplementary pieces fit within the frame. This was critical to space conservation and the strength support of the frame.

Dimensions

Benchmarking and anthropometric data were critical in the determination in the final dimensioning of the frame and its auxiliary pieces. Conversations with the head of the Biomedical Engineering Unit Business Administrator in KATH produced dimensions for the beds in the ward. These dimensions were a length of 54 inches and a width of 34 inches. However, the team determined these results were more than likely for one of the delivery chairs rather than the supine beds as a total length of 54 inches would mean any woman taller than 4' 6'' would have a large portion of her body hanging off of the bed. From anthropometric research, the average height of a woman was determined to be 1.687m or approximately 66inches (Dined). The average width of a woman was determined to be 0.44m which is approximately 17 inches. The width value is deceiving because the anthropometric data did not supply information for pregnant women. With this consideration in mind, we chose to dimension the bed as follows: a total length of 72 inches and a width of 34 inches. The increase in the length will accommodate a greater range of women and match the dimensions of benchmark beds. The increased width allows pregnant mothers to lie in both a supine and fetal position comfortably. The total length of the bed includes the length of the foot supports when they are deployed in the supine configuration. In the inclined or delivery positions of the bed, the foot supports are stored to the side and the overall length of the bed drops to 54 inches, which matches the dimensions supplied from the hospital staff (assumed delivery bed dimensions).

Dimensions for individual pieces were determined with regard to two considerations: anthropometric estimations and the constraint that all pieces be contained within the frame of the final design. These dimensions are discussed and shown in the Final Design Description section.

Material

Conversations with Professor Asibu detailed the availability of pure aluminum and mahogany wood in Ghana; the wood could then furthermore be treated to increase strength and impermeability. Treated wood was dismissed in an attempt to modernize the hospital ward and gain design acceptance. For cost purposes, aluminum was chosen because mahogany is very expensive in the United States and also because wood treatment is an expensive chemical process.

In order to determine the materials for each component of the final prototype, we reexamined the engineering specifications in order to determine particular constraints. The frame will ultimately bear the vast majority of the load throughout the birthing process, so several constraints exist. A high Young's modulus is critical to prevent leg buckling and a high yield stress is necessary to ensure that no failure will occur at the joints (welded or fastened). With these constraints established, we used the CES Selector software to narrow down possibly materials. The resulting CES material results are shown in Appendix D. As expected, the majority of viable materials were metals. The two metals we chose to further investigate were common steel and certain aluminum alloys. The tradeoffs between the two are fairly simple. Steel is much cheaper, but roughly three times as heavy and requires additional coating to prevent corrosion. Aluminum is lighter though much more expensive requires no additional coating. Even though steel was much cheaper than aluminum, the team decided to proceed with aluminum because of its non-corrosive properties because coating steel proved to be more expensive than aluminum. Furthermore since aluminum is available in Ghana, the team prototype would be a closer representation to the final design.

Comfort is another engineering specification and in order to ensure comfort for a patient that may use the bed for up to 12 hours, padding must be used to supplement the frame. The cleaning procedure currently used in KATH dictates that the outer material of the padding be nonporous and resistant to corrosion. We have chosen to cover the padding with a vinyl material very similar to the mattress used currently in KATH but tailored to dimensions of the final design.

Robust

A safety factor of 1.5 was included in every calculation of the final design. The engineering specification of robustness entailed a frame that could support at least 2000N based on the weight of two pregnant women lying on the bed at the same time; though the likelihood of having more than one woman on a bed at a time is very slim considering the fact that the bed only allows room for one delivery at a time. With the safety factor of 1.5 the team determined that the final design could hold 3000N which is well above the customer requirement.

The Frame of the bed being made of aluminum will be able to withstand the water bleach solution that is currently used at KATH for cleaning purposes; therefore eliminating corrosion and increasing bed robustness.

Longevity

The longevity of the bed cannot be directly evaluated for this to be possible, the team will require a period of 10 years of use of the bed to determine whether it met the engineering specification. Since longevity is not measurable, the team decided instead to evaluate longevity as a factor of robustness because a robust bed has a lesser chance of failure. If failure is prevented then the bed will last long.

Safety

As mention in robust section, a safety factor of 1.5 was included in engineering specification calculation therefore the bed can be safely used at maximum load. Also for final design considerations, sharp edges of the bed were covered with plastic paint and all bolt ends are facing the inside of the frame rather than the outside to eliminate potential pinching or cutting hazards to user. Rubber stopper, though not used on the prototype, will be used on the legs of the final design to provide more stability and friction between the legs and the ground.

Affordable
Affordability of the bed is a factor of material cost. The team projects the cost of the bed to come to a grand total of $500. This is determined based on the price of material in the United States. This price is likely to change due to the difference in material availability in Ghana. Aluminum is abundantly available in Ghana thus it is safe to assume that the price of the bed will drop and the bed will be affordable.

Reconfigurable
The Engineering specification for a reconfigurable bed is that the back support stand at 150˚, 130 ˚and 180˚ it also require the foot support to rotate downward to an angle of -90˚. The team analyzed the configurability of the bed by measuring the angle of configuration of the back support. The angle of configuration of the foot support is not necessary to be measured since the foot support is completely taken out of the doctor's way during birth.

Easy to clean / sanitize
Easy to clean was analyzed through the foam material cover; the final design of the bed will be covered in vinyl, a non-porous material therefore allowing the rapid wipe down of the bed with bleach water solution after use. The padding can easily be taken off the bed for a more thorough wash with a water hose at another location. Padding is composed of 4 smaller pieces attached to the bed with industrial Velcro; this facilitates its removal for cleaning.

Easy to maneuver adjust
The bed is a stationary object and does not need to be moved; so maneuverability is analyzed as a factor of configurability.

Comfortable
Comfort was analyzed through the firmness of the foam material used. The higher the firmness, the more softness is provided and the more comfortable the bed is.

Collects bodily fluids
The collection of bodily fluids can be analyzed by determining the amount of ejected fluid that ends us inside the bucket. For these purposes, a semi circle cut out is included on the seat pad and support of the final design as well as a fluid channeling system directly under the semi circle cut out.

Attachment Methods
Manufacturing the final prototype required a great deal of assembly and the methods of attachment for the various pieces have been analyzed to maximize configurability and lifetime.

Welding: The majority of the bed's frame was welded. Welding provided a stable connection and is also an available process in Ghana. Weld calculations have been performed on all critical welded components including back support collars and back support crossbeams and are discussed later in this section.
Bolting: To attach the legs to the bed, we chose to mechanically fasten them with bolts. The bolted joints will provide the necessary strength and can be removed to aid in the shipment of the bed to Ghana. Bolt calculations have been conducted to analyze the strength of the joint and will

be discussed later in this section. Bolting will also be utilized to bolt the seat support onto the frame.

Tablet arm joint: The foot supports will be attached through the use of a table arm joint similar to desk joints utilized at the University of Michigan. In order to not impede the delivery process, the foot supports must be able to be completely removed from the front of the bed. These joints will accomplish this required movement from supine to outside of the front of the bed. Through research, the team was able to obtain one of the joints and was able to replicate the joint. It is thus safe to assume that the replication of the join will be possible in Ghana.

Analysis from Alpha to Final Design

Rigorous engineering analysis was not performed to make design changes from the Alpha design to the current final design. All concept evolution decisions were based on mentor feedback, predicted material costs, and basic engineering logic. These decisions are outlined in the Design Evolution section. Engineering analysis was performed on the final design to ensure it met design specifications and had design aspects failed to meet specification, changes would have been considered.

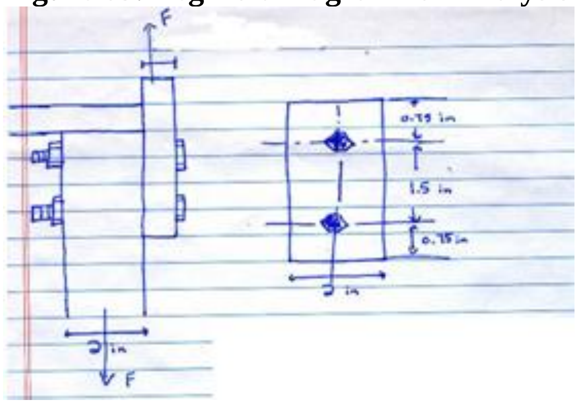
Critical Locations

With the general outline of the bed completed, we were able to identify several key locations that failure would be most likely occur.

Leg bolt analysis: Since the legs of the bed will bear the majority of the load, we analyzed the legs extensively. The legs directly underneath the bed will bear the most loads and were the focal point of the analysis. The diagram for the bolt analysis is shown in Figure 63 below. First, we performed several calculations to ensure that the bolted joints would not fail. The shear in the bolts, bearing on the bolts, bearing on the leg members, and the tension of the bed members were analyzed using Eq. 4 below, where A is the area, S is the tensile strength, and n is a safety factor of 2.

$$F_{FAILURE} = \frac{A*S}{n} \qquad \text{(Eq. 4)}$$

Figure 63: Leg Bolt Diagram for Analysis



A summary of the results can be seen below in Table 5. The full calculations are shown in Appendix O.

Table 5: Leg Bolt Analysis

Consideration	Area (in^2)	Strength (kpsi)	Force (kips)
Shear in Bolts	0.884	40.7	17.99
Bearing on Bolts	0.75	92	34.5
Bearing on Member	0.75	35.05	13.14
Tension of Members	0.625	35.05	10.95

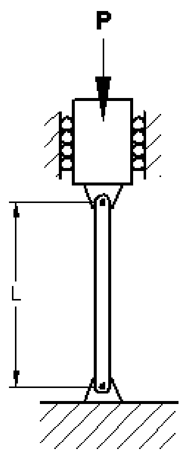
From these calculations, the minimum force required for the failure of the bolted joints is dependent on the tension of the members with a failure force of 10.95 kips. From engineering specifications, the max load distributed to each leg is anticipated to be 750 N or approximately 0.2 kips. Thus, 10.95 is over 50 orders of magnitude greater than 0.2, validating that the leg joints will not fail.

Leg buckling analysis: We next identified the buckling of the legs as a possible failure method due to the large loads. To calculate the force required causing buckling of the legs, Eq. 5 shown below was used, where *E* is the Young's modulus of the steel, *I* is the moment of inertia, and *L* is the length of the leg. The full calculations can be found in Appendix O.

$$F_{BUCKLE} = \frac{\pi^2 * EI}{L^2} \qquad \text{(Eq. 5)}$$

Using the appropriate values for 6061-T6, a buckling force of 1.59 kips was derived. From the engineering specifications, no load greater than 0.2 kips is expected, so the legs will not buckle. The leg buckling free body diagram is shown below in Figure 64.

Figure 64: Leg Buckling Free Body Diagram

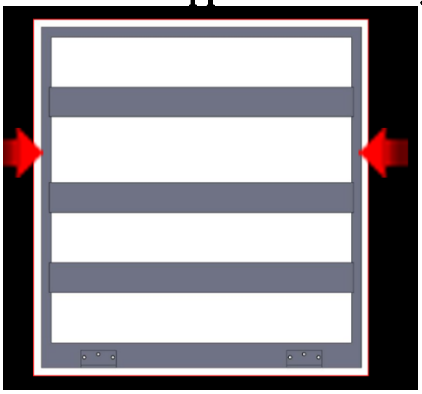


Back support frame analysis: Examining the prototypes final design also pointed the back support as a possible failure area. The back support side frames were identified and analyzed using Eq. 6 below, where *M* is the max anticipated moment, *y* is the distance from the centroid, and *I* is the moment of inertia of the side frames.

$$\sigma_x = \frac{-M*y}{I} \qquad \text{(Eq. 6)}$$

The full calculations can be found in Appendix O, and the frame diagram. The resulting stress was calculated at 6000 psi, which is approximately 60 times less than the material yield stress of 36000 psi. Thus, the side frames will not yield.

Figure 65: Back Support Frame Diagram

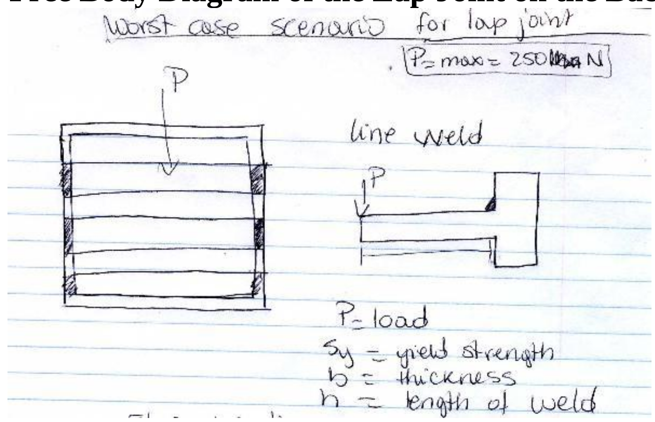


Back support weld analysis: The cross beams attached to the back support will be welded, so a welding calculation was used to identify the moment of failure. This was analyzed by assuming the worst case scenario of a maximum load being applied at the center of the welded crossbeams rather than a distributed load. The welding calculation used in the analysis is represented in Eq. 7 below, with *S* being the material strength and *b* and *h* being weld geometric properties:

$$M_{FAILURE} = \frac{S*bh}{2} \quad \text{(Eq. 7)}$$

The associated moment of failure was calculated to be 61.3 kips*in and from the analysis of the back support, no moment greater than 1.165 kips*in is expected. Therefore, the welded joints of the back support will not fail. The full calculations can be found in Appendix O, and the free body diagram is shown below in Figure 66.

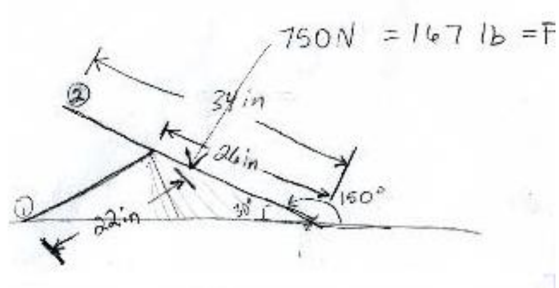
Figure 66: Free Body Diagram of the Lap Joint on the Back Support



Back support bar buckling analysis: Finally, the inclining locking bar is susceptible to buckling. The maximum intended load is considered to be half of the woman's body weight with a safety factor of 2. Half of the weight was intended because approximately half of the body is resting on the back support. This performed analysis proves that the design of the final prototype is strong enough to support the maximum load and thus this test validates the design of the support bar.

Using the buckling equation shown above (Eq. 5), a minimum buckling force of 6.02kips was calculated. This force is much greater than the anticipated specified load, so the support bar will not fail. The diagram for this analysis is shown in Figure 67 below, and the calculations are shown in Appendix O.

Figure 67: Support Bar Analysis Diagram



We believe that this analysis more than validates the final design. All of the calculated failure forces are orders of magnitude greater than any expected load. Excessive safety factors were used throughout the analysis as well to further insure a safe and valid design. The analysis was done using accurate material properties and relationships expected in the final design, so this analysis will directly correlate to the final design. Further areas of analysis include examining the hinge joints of the bed this will be done through testing of the bed at maximum load. Testing has also been performed on the fluid collection system as well as the stirrups these will be explained in further details in the testing and validation section of this report.

The design was analyzed using rigorous static engineering analysis to determine the critical loads and forces. The team considered utilizing ADAMS simulation software to analyze the stresses and forces throughout the design but was guided by Dan Johnson to use simple engineering equations. It was determined ADAMS was not required because the overall design is stationary and doesn’t involve dynamics. The analysis was rigorous on the aspects that were deemed most critical such as the leg bolting.

Design for environmental sustainability
A SIMAPro analysis is attached in Appendix D of this report.

FINAL DESIGN AND PROTOTYPE DESCRIPTION

This section explains in details the different components of the final design accompanied with CAD and engineering drawings; it also explains how those components relate to engineering specifications and customer requirements.

Figure 68 and Figure 69 below show the final design for the obstetrics reconfigurable delivery bed in supine and delivery positions respectively. This design meets the engineering requirements and specifications established for this project. The detailed engineering drawings for these two positions are show in Figure 70 a-c below.

Figure 68: Supine Position

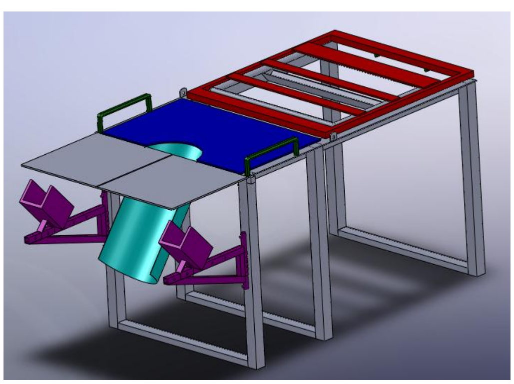


Figure 69: Delivery Position

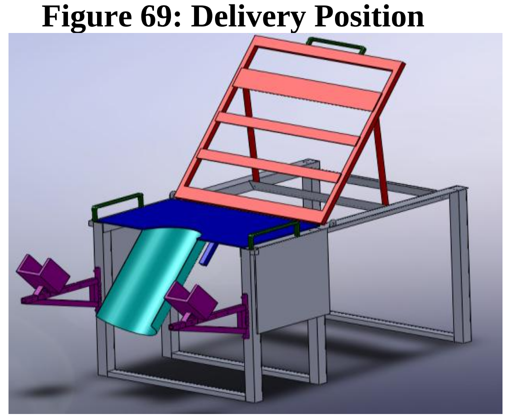


Figure 70a: Side View Delivery Position Drawing

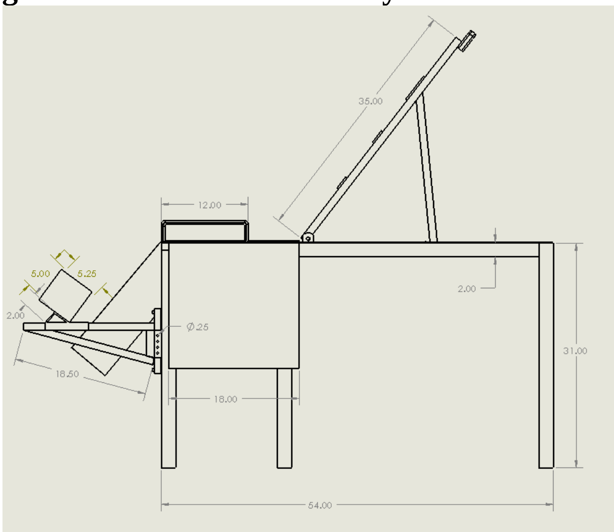


Figure 70b: Top View Delivery Position Drawing

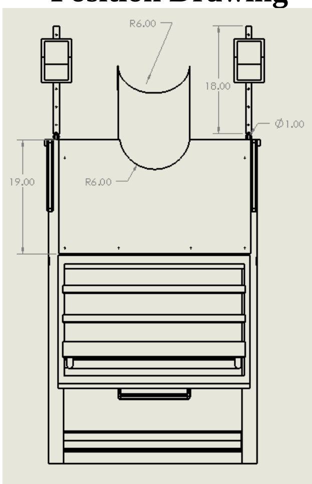


Figure 70c: Back View Delivery Position Drawing

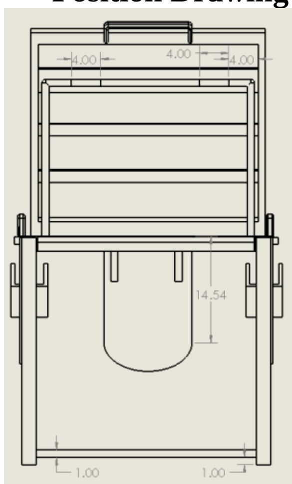


Figure 71: Frame

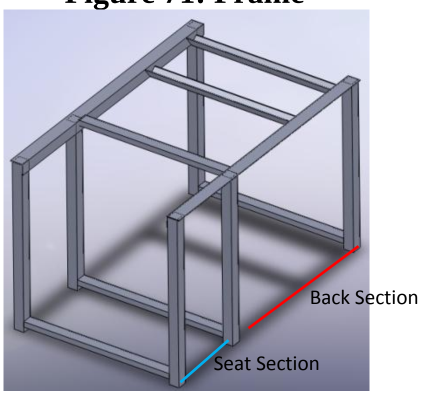


Figure 72a: Frame Top View Drawing

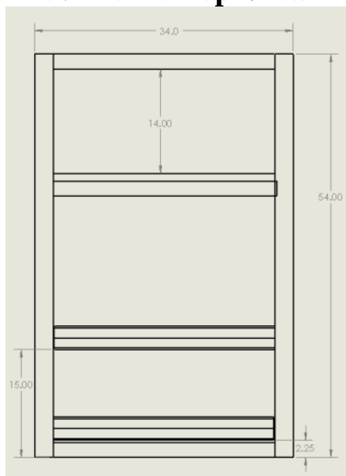


Figure 72b: Frame Side View Dwg.

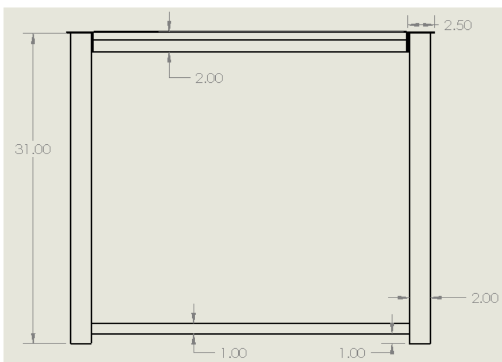
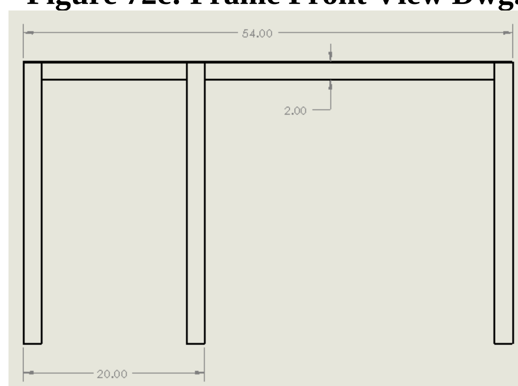


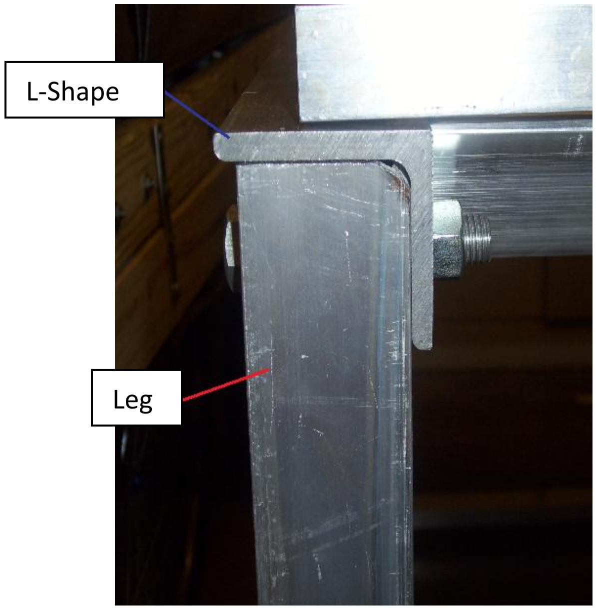
Figure 72c: Frame Front View Dwg.



The prototype design for the frame is shown above in Figure 72. Differences between this design and the final design are explained below. This frame has outer dimension of 4.5ft long by 2.8ft wide and was made out of 6060-T6 aluminum. The purpose of the frame is to provide stability and strength to support the patient during active labor and delivery and during bed reconfiguration. For support, the bed has 6 legs made of 2in by 2in steel rods that are 31in high. Each set of legs has a crossbar of 2in long by 1in high by 31 in wide of 6061-T6 aluminum stock to connect bars in the width direction and prevent tipping. These crossbars are located 1in. from the ground for purposes manufacturability. Four legs will be used to support the seat of the bed. In addition to these legs, a crossbar of 2in. wide by 1in. high by 30in. long will be located 19in. from the front of the frame (with the front of the frame being the leftmost edge of Figure 72c).

The legs are connected together with two L-shaped aluminum bars with widths of 2.5in. and 2in. respectively and a thickness of 0.125in. The legs will be connected to the L-shaped bar as shown below in Figure 73.

Figure 73: Connection of L-Shape Bar to the Leg



For the final design, the back support bar was meant to be stopped for different configurations in ledges that would be drilled out of the side edges of the frame.

However, for the prototype, there are two L-shaped bars that were used as the stops for the back support bar. These bars will have the same dimensions (2.5in by 2.0in with a 0.125in. thickness) as those used to connect the legs. The bars are angled so that the edge of the L-shaped bar is in line with the bottom of the L-shaped edge bars. This was found to be beneficial to the design. The pieces were simple to manufacture and assemble. This design also accounts for size adjustments in the back support bar as well as could possibly be designed to act as cross bars for back support purposes. Only two L-shaped bars were used because one of the configurability angles was removed due to the back support bar design. This will be more greatly explained in the back support bar section.

The frame is a full scale-working prototype of this final design with the same project materials. While there are small deviations, such as the stops for the back support bar, we feel these were actually improvements to our design and its functionality. Some considerations through prototyping that we have found may have further improve the final design and these are outlined in the Design Critique section of this report. Despite minor further improvements we would like to make, we expect a fully functional frame able to be placed in KATH and fully operate and support the required weight. The final design will be validated through testing outlined in the Validation section. The frame prototype is complete and all editions to the final design will be tested and analyzed numerically.

Back Support System

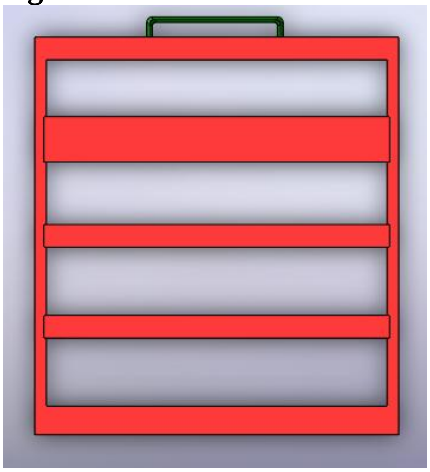


Figure 74a: Front View Back Support

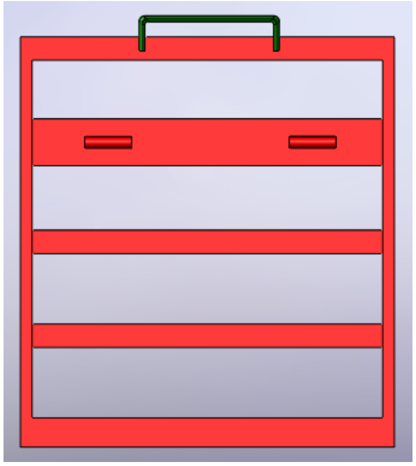


Figure 74b: Back View Back Support

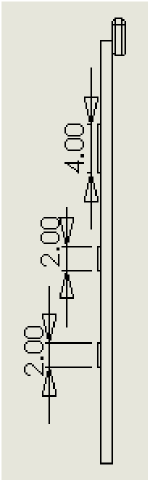


Figure 74c: Side View Back Support Dwg.

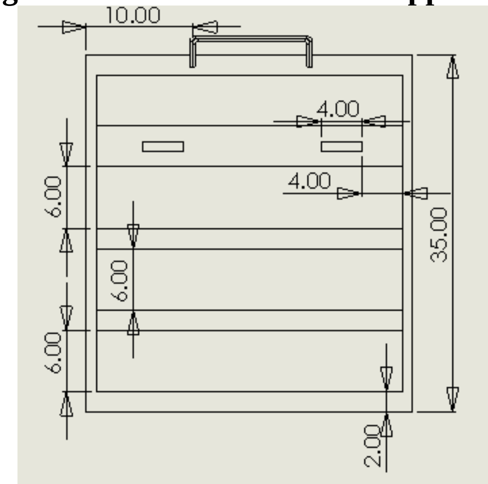


Figure 74d: Back View Back Support Dwg.

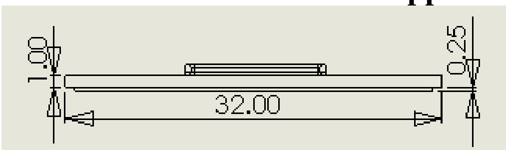
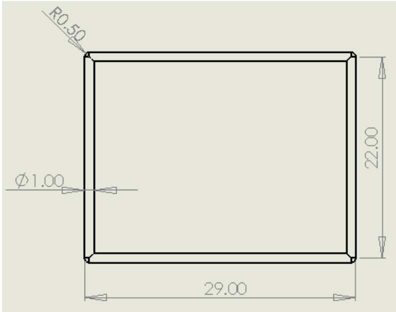


Figure 74e: Bottom View Back Support Dwg.

The purpose of the back support is to support the patient's back, neck, and head when the bed is reconfigured to 180°, 150°, 130°, and 100°. This piece is made of three 1in. by 1in. aluminum bars and one 2in. by 1in. aluminum bar. There are three crossbeams for support. The bottom two crossbeams are 2in. wide by 0.125in thick. The top crossbeam is 4in wide by 0.25in thick. On the back of the top crossbeam, the two collars will be welded for the back support bar. The collars are made of 1in. aluminum round stock with lengths of 4in. Each collar will be 4in. from the outer frame of the back support.

Figure 75: Back Support Bar

Figure 76: Back Support Bar Drawing



The final design for the back support bar is shown above in Figure 75. This bar will allow for rotation of the back support. This bar will run through the two collars that are located on the highest back support crossbeam. This bar will be stopped to adjust for back configurability on the two L-shaped bars welded on the frame. The width of the back support bar is 29in., which allows the bar to lie within the frame. The height of the back support bar (22in.) also allows the bar to fold within the back support frame as in Figure 76 above.

In the final design, the bar would allow for configurability to 3 back support angles of motion. In order for the back support bar to fit within the frame of the back support, the 100° incline was removed from the possible reconfigurable angles from the prototype. The tradeoff was deemed acceptable as the storage consideration was considered more important than that incline level. Another adjustment made to the prototype is show in Figure 77. The final design called for a closed square back support bar. However, in order to bend the bar and assembly the bar into the collars on the back support, the center of the top part of the frame was removed (shown by the red line in Figure 77). This does not affect the functionality of the bar and adds significantly to the manufacturability of the back support assembly.

Figure 77: Prototype Back Support Bar

Seat Support

Figure 78: Seat Support

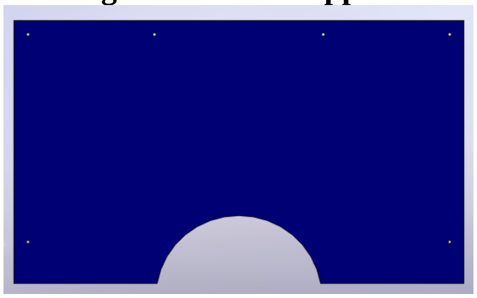


Figure 79a: Seat Support Top Drawing

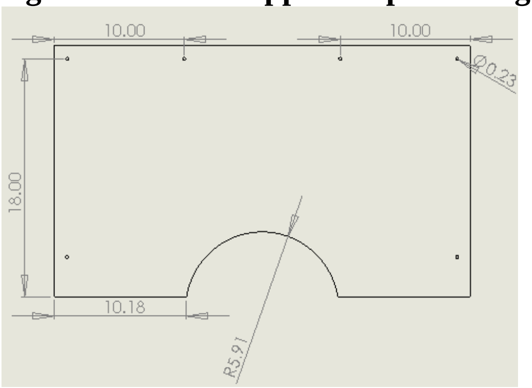


Figure 79b: Seat Support Side Drawing

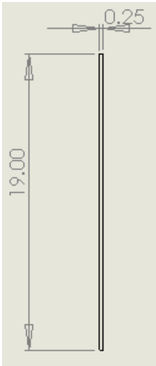


Figure 79c: Seat Support Front View

The seat support functions as part of the supine bed and as the main support of the patient's weight during delivery. This piece does not reconfigure; it is bolted to the frame. This piece is made of 0.25in thick aluminum plate with outer dimensions of 32in. by 20in. The semi-circular opening has a diameter of 12in. that is centered on the piece is meant to facilitate fluid collection during the birthing process.

This component was made as a full scale-working piece for the prototype. With the validation testing on the prototype seat, the design will be validated. There are no differences currently between the final design and the prototype; however, in the Design Critique section, the size of the fluid collection hole will be discussed as a future consideration. We expect the seat to fully support the determined weight specifications without failure. Static loading and visual inspection of bowing will focus the team's future considerations of needed improvements to this component.

Foot Support

Figure 80: Foot Support

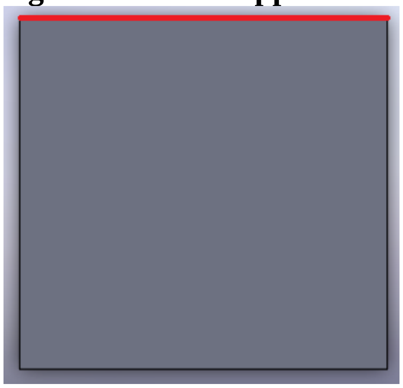


Figure 81a: Foot Support Top View Drawing

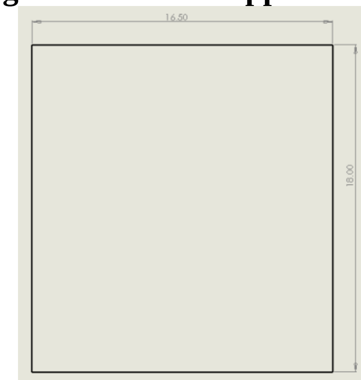
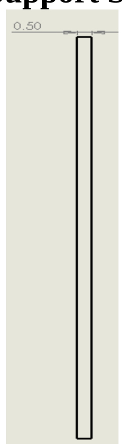


Figure 81b: Foot Support Side View Drawing



The final design for the foot supports are meant to support the patient's legs and feet while the bed is in supine position. The engineering specification for configurability calls on the foot supports to lie flat in the supine position for active labor and to be completely removed from the front of the bed for the delivery process. The foot support system of the bed consists of two foot supports of the design and dimensions shown above. These two foot supports lie next to one another in the supine position with the front edge (represented by the red line in Figure 80) lies flush with the seat support. Each foot support rotates about its own tablet arm hinge that is based on the outer edge of the frame. The tablet arm hinge allows the foot supports to lie horizontally and then rotate to be stored vertically next to the outer edge of the frame. These two positions are shown in Figure 82 and Figure 83 below, which are taken from Ferco Seating, the joint manufacturers. This is not the manufacturer of the joint for the bed. It replicates the desired motion and is meant to serve as a visual aid for understanding the foot support joint mechanism and movement.

Figure 82: Side View of Stored Foot Rests

Figure 83: Side View of Foot Supports in Use

The prototype of the foot supports and rotating joint does differ from this final design. The actual prototype foot support is made of one 2’ x 4’ plywood piece that is hinged on one rotating joint. This joint was provided by Jerry McCartey at the University of Michigan. While a second, identical joint was manufactured, we were unable to match the quality level we desired due to our time constraints. Therefore, the prototype was made using only one rotational joint and one foot support piece. Despite the strength of the joint, the overall length of the foot support (2.8ft) resulted non-horizontal foot support. For purposes of the prototype, foldable legs were added to the foot support to provide support on the side opposite of the joint. The legs were purely for additional support. We do believe that the joint can be manufactured in country, providing that the instructions and CAD are available. For a mass produced bed, there would be two rotational joints and two foot supports.

The prototype is different from the final design for the foot support and rotating joint. The prototype is not a full scale-working prototype for this component. Ideally, the foot supports would be made of two identical piece of aluminum 1.5ft. long by 1.4ft. wide by 0.25in. thick. The use of the plywood was due to budget constraints. This prototype will not validate the final design because wood was used rather than aluminum and only one rotating joint was used. We do not expect that full testing, specifically static loading cannot be validated nor can the full rotation of the joints due to the width of the foot support versus the height of the bed. To validate that the final design is on target, we believe more in-depth engineering analysis with the use of ADAMS or FEA would be necessary to determine the stress and forces on the joint and throughout the foot supports.

Fluid Collection System

Figure 84: Fluid Collection System

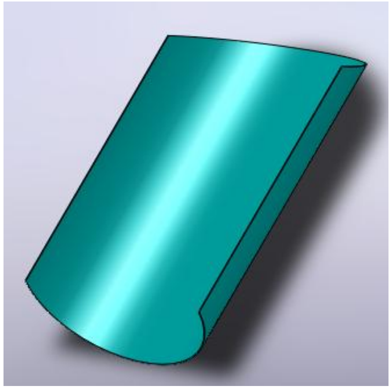


Figure 85a: Front View Fluid Collection System

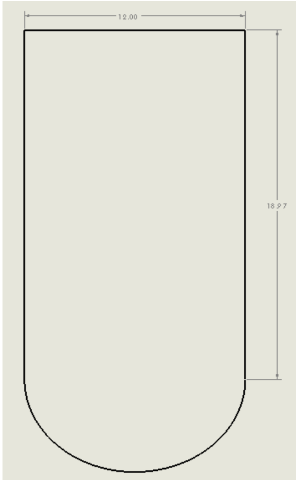


Figure 85b: Side View of System

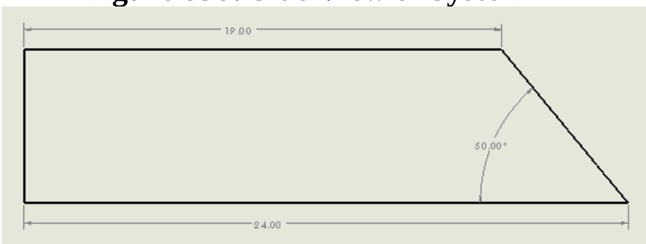


Figure 85c: Bottom View of System

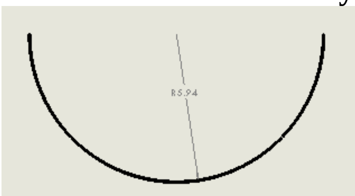


Figure 86: Fluid Collection System Support Bar

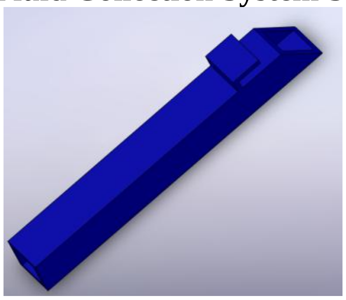


Figure 87a: Fluid Collection Support Bar Side View

Figure 87b: Fluid Collection Support Bar Front View

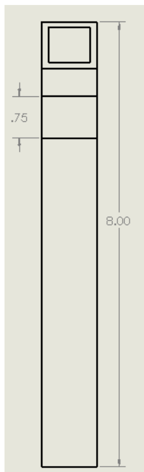
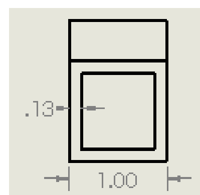


Figure 87c: Fluid Collection Support Bar Top View



The fluid collection system is meant to assist in the collection of birthing fluids. The system is meant to be detachable so it can easily be cleaned along with the bucket that collects fluids. The fluid collection system is shown in Figure 84. The fluid collection support bar is attached to the bottom of the seat and is used to hold the fluid collection system in place at the desired angle. This system angles downwards at approximately a 45° angle to allow gravity to direct fluid. The system has a width of 12in. and is semi-circular in shape, which makes the system fit around the semi-circular opening in the seat. The system decreases in width as it extends from the seat with the final width of the fluid system being comparable in width to a standard bucket. While observing a delivery, it was noted that fluid does drips but also can splash forward. The width is meant to account for as much of this fluid splash as possible. The fluid will be collected by a bucket currently used by the hospital that will be placed at the bottom of the system. The system will be liquid tight to ensure that no fluid collects in the edges of the system. Liquid tight is defined as not allowing any liquid to escape the system through the edge and flat piece connection or any other connections.

The fluid collection system bars that are used to maintain the location and angle of the system are made of aluminum 1in. by 1in. hollow bar. The total length of the longest edge of the bar will be 8in. with a 45° cut made in the bar. These pieces will not move but will be fastened in a stationary position. There will be 4in. of space between the two bars and the bars will be centered within the seat component.

The prototype fluid collection system does not represent a full scale-working prototype of this final design. The prototype system was created with a rounded, plastic trashcan. The trashcan was cut visually to produce the desired system. The prototype also does not create an easily detachable system that remains liquid tight, which means that our prototype does not allow for our final design to be validated. For the prototype, holes were cut into the trashcan in order to attach it to the fluid collection support bars. This resulted in invalidating the fluid tight desire of the system. Re-analyzing the positions of the support bars and system must be done in order to determine whether the current final design will be a feasible solution to the issue. We expect this prototype to be merely a model for the final system and do not expect a usable performance from this system in its current state.

Stirrups

Figure 88: Stirrup Assembly

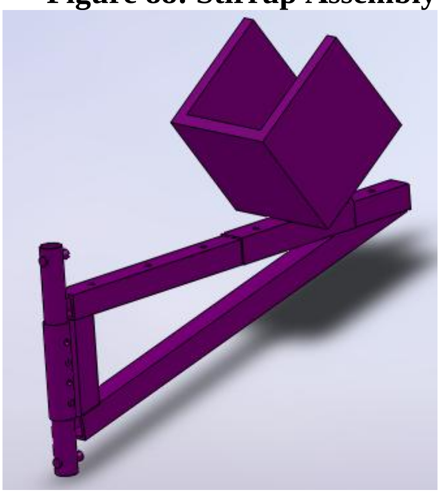


Figure 89a: Stirrup Assembly Side View Dwg.

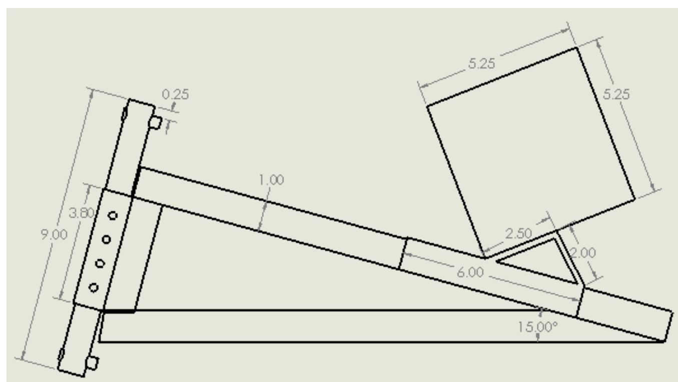


Figure 89b: Stirrup Assembly Back View Drawing

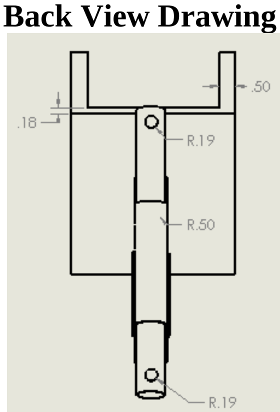
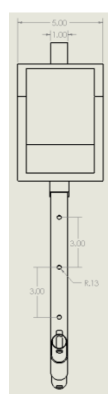


Figure 89c: Stirrup Assembly Front View Dwg.



The stirrups fulfill the normal functionality of stirrups. There were two main design issues that led to this final stirrup design. The first issue was creating stirrups that could adjust for women of different heights. This adjustment would need to be made in stirrup height from the ground and adjustment from the front of the frame. Dr. Jody Lori, a team mentor, recommended that the stirrups raise the patient's legs to approximately 45° from the vertical position. The reason for stirrups at this angle, which is lower than traditional setups, was to allow the stirrups to act more as an anchoring system for the woman during delivery. It also helped facilitate the semi-recumbent delivery position, which research has shown is one of the safest delivery positions for the mother.

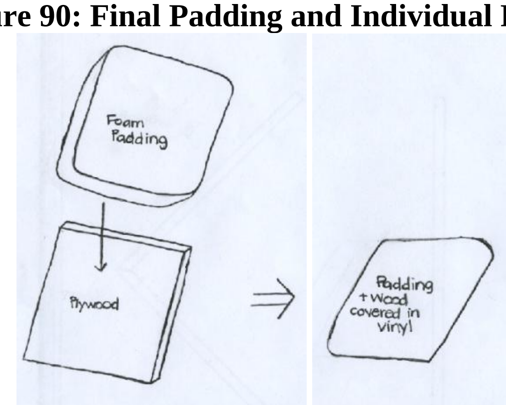
The stirrup arm is made of three 1in. by 1in. bars of aluminum cut to form a triangle. The shortest bar piece will be attached to a circular stock of aluminum, which will allow for vertical adjustment. This hollow tube will move around a smaller circular tube, which will be fastened to the legs of the frame. The adjustments will be made and held with a simple pin mechanism. The stirrup footrest will be attached to the horizontal bar by a collar that can be adjusted using a pin mechanism. Based on the overall width of the bed, it was decided that the ability of the stirrups to rotate and provide different angles was unnecessary. Thus, the stirrup arm has two planes of motion: horizontal towards and away from the frame and vertical.

The stirrup footrest will be made of plywood with a depth of 0.5in. There are four wood pieces 0.5in wide by 0.5in. long that will be screwed together. For comfort, the footrest will be padded with 0.5in. thick foam and wrapped in vinyl.

The prototype for the stirrup system is a full scale-working model of the final design. The materials selected were used in the prototype, and we expect full functionality of our design. This design will be validated through parameter analysis of the weld strengths of the stirrup arm and pin joints. It will also be validated through static load testing. The functionality of the stirrups, specifically with respect to the foot supports, will be analyzed through use of the bed. If the stirrups meets the specifications but does not work within the full design, other options should be considered.

Padding

Figure 90: Final Padding and Individual Pieces



Padding was placed over the foot supports, seat support, back support, and stirrups. The purpose of the padding was to provide the patient with comfort throughout the use of the bed. The padding was made to identically fit each piece it is made of foam from couch cushions provided by Mr. and Mrs. Kaur.

To ensure that the padding maintains its shape and lies flat along the supports, the foam will be glued to the top of a thin piece of plywood. The plywood and foam will then be covered with a non-porous vinyl material, which will be stapled to the wood. The purpose of the plywood is to help the padding maintain its shape and to create a flat surface so that the padding can be perfectly mated to the supports. The entire padding will be attached to the support with Velcro, allowing for easy removal of the padding for cleaning.

The prototype padding is a full scale-working prototype of the final design. The purpose of the prototype padding is to validate the functionality of the padding with respect to the bed cleaning process and patient comfort. The prototype will validate the final design through extensive validation testing. We expect the padding to be fully functioning for comfort. We still need to determine the strength of the vinyl used if continuously washed down with bleach. If the padding can be easily cleaned and removed from the frame without damaging the structural integrity, we believe our design is heading in the correct direction. The availability of foam and vinyl in Ghana must also be further explored before moving forward with this design as the desired final design.

Bill of Materials

A complete list of bill of materials is provided at the end of this report in Appendix B.

FABRICATION PLAN

This section provides a detailed explanation of the fabrication of our prototype of the reconfigurable obstetrics and delivery bed. The fabrication plan is broken down by components with the required manufacturing and assembly steps described in detail. The different components described are as follows: frame, seat, back support, foot support, stirrups, fluid collection system, and padding.

Frame

The components that make up the frame of the prototype are as follows: 6 square hollow tubes (2” by 2”), 4 rectangular tubes (2” by 1”), and 4 L-bars. These components are made of wrought aluminum alloy 6061-T6 and were purchased at the local Alro Metals Plus in Ann Arbor. All of the fabrication took place in the department machine shop and/or the assembly room with supervision and great assistance of Bob Coury and Marv Cressey. All the tools and machines that will be mentioned in this section refer to the ones in the machine shop, unless stated otherwise.

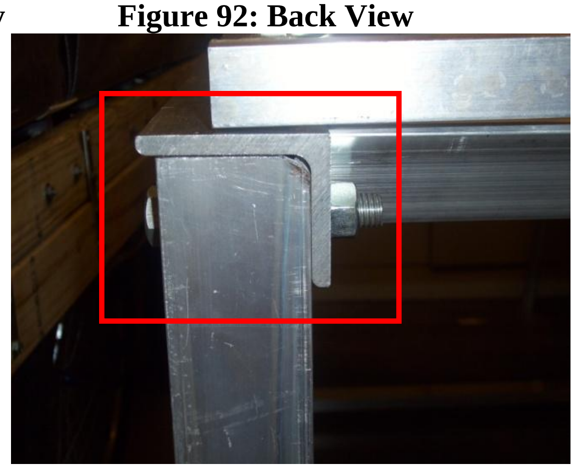
Since these pieces were bought at standard length dimensions off the shelf, most of the parts first needed to be cut to their appropriate dimensions. The ideal range of band saw speed in cutting aluminum metal is 290-325 fpm (feet per minute). All of our aluminum metal that was cut using band saw was at the speed of approximately 300 fpm. This applies to any band saw cutting of any parts that will be referred to in this section, unless specified differently. At any place where there is mention of the process of welding, it should be acknowledged that Bob Coury himself did all of the welding for us after we would accurately align and clamp together our parts in place.

The six square tubes (2” by 2”), legs of the bed, were first cut to their appropriate length of 31” using the band saw. We had an additional pair of legs in order to support the seat of the bed at the location with greatest stress concentration. Once these legs were cut, the next step was to weld crossbars on the bottom of each pair of legs. These cross bars were rectangular aluminum hollow tube, 2” by 1”, and were cut to a length of 30”. Three cross bars were welded to each of the three pairs of the legs an inch off the bottom.

The three pairs of legs with welded crossbars on the bottom were held together in place with two aluminum L-bars which were ¼” thick, 2” long on one side, and 2 ½” long on the other. These L-bars were also cut using the band saw to the length of 54”. The three pairs of legs were placed vertically on the floor and were ready to be held together. The two L-bars were placed on each of the two sides, both covering the top of three legs. The 2 ½” side of the bars was placed on top of the legs will the 2” long side was aligned with the top inside of the legs. The front and back pairs of legs were placed and aligned flush with the angled bar and the middle pair of legs was placed and aligned 20” behind the front pair of legs. The angled bars and legs were fastened together with nuts and bolts which were ½” in diameter. Evidently appropriate holes of the right dimensions and at right locations on all of the six legs and the two L-bars needed to be drilled first. All the holes were drilled on the drill press using a ½” thick twist drill bit at the appropriate speed of 1500 rpm. The holes were first drilled on the 6 legs on top through the side that was parallel to the bottom crossbars. The holes were centered at the top of the legs at 1” from the top and 1” from the sides. Once these holes were drilled the two angled bars were put on top with the three pairs of legs apart at appropriate distances. With the holes that were just drilled on the legs, we were able to go through them with a Sharpie marker and mark the center of the holes that would be made on the angled bars. After double checking our markings with measuring tape, three holes were drilled on each of the two angled bars. At this point, all the holes had been drilled in order to adjoin the three pairs of legs with welded bottom crossbars and the two angled bars. Bolts (½” thick, 3” long) were then fastened from the outside of legs, into and through the side of angled bar and were secured with appropriate sized nuts at all six locations. This assembly can be viewed below in Figures 91 and 92. Figure 91 on the left is of the back left corner of the frame photographed from the side and Figure 92 on the right is of the back right corner of the frame photographed from the back.

Figure 91: Side View of Leg and L-Bar Assembly

Figure 92: Back View



The next step consisted of adding a crossbar on top of the frame adjoining the two L-bars perpendicularly. This cross bar would provide support to the seat attachment that would later be bolted on top of the frame. So this cross bar was positioned at the location where the back edge of the seat would sit on the frame. This cross bar was also an aluminum rectangular hollow tube (2” by 1”) which was cut to a length of 30” using the band saw in order to fit accurately and tightly in between (perpendicularly to) the L-bars. Once this cross bar was tightly fit in its place, 18” inwards from the front of the frame, it was clamped in place and then welded to the frame by Bob.

The final addition to the frame was the attachment of two more L-bars in between and perpendicular to the two L-bars that held the legs together. These two L-bars were attached to the back of the frame at an angle (in a ‘v’ shape) in order to provide a holding support for the back support seat bar. One of these angled bars was placed onto the frame 15” inwards from the back and the other was placed 2 ¼” inwards from the back of the frame. These angled bars were tightly put in place at an appropriate angle and then welded by Bob. Figure 93 below on the left shows the two angled bars welded to the frame in the back and Figure 94 on the right shows one of the corners of the back angled bar welded to the frame in detail.

Figure 93: ‘V’ Shaped Holders for back Support Bar

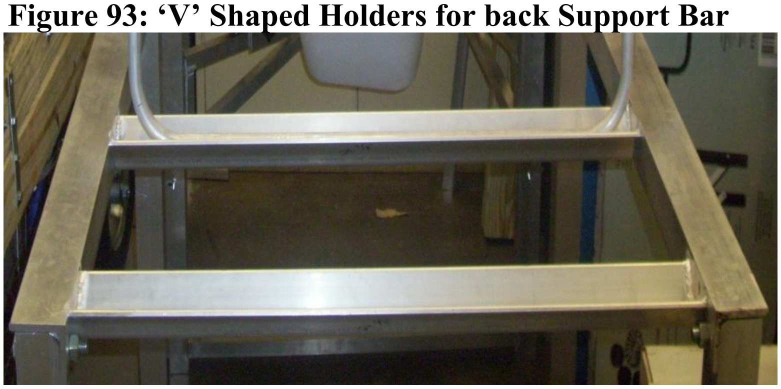


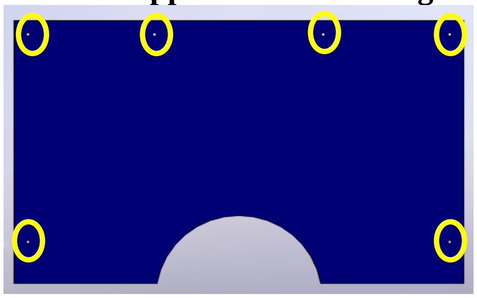
Figure 94: Welding Detail

Figure 95 below is a cad model of the full frame assembly after all the parts were put together.

Figure 95: Full Frame Assembly CAD Model

Seat
The seat piece was essentially an aluminum sheet (¼" thick, 32" by 20") which we bought as a precut piece from Alro to the exact dimensions we needed. The only additional cut that we made to the seat piece was a semi circular cut on the front edge of the seat in its exact middle. This cut was 6" in radius. This cut was made very slowly and carefully with the band saw as well. Figure 96 below shows a cad model of the seat.

Figure 96: Seat Support and its Bolting Locations



The seat was then bolted to the top of the frame on its front edge. The yellow circles in Figure 96 above show the 6 locations on top of the seat where it was bolted onto the frame. These holes (¼" in diameter) were drilled with a hand drill. The seat was clamped in place on top of the front edge of the frame. Once it was accurately placed and clamped, appropriate locations of the six holes shown above were marked and drilled. These holes were drilled through the seat and through the frame underneath the seat at the same time since the seat had previously been clamped. Then the seat was fastened with bolts (¼" thick, 2 ½" long) from the top of the seat, through the bottom and securely tightened with nuts underneath the frame.

Back Support
The back support of the bed was essentially fabricated by welding seven pieces of aluminum tubes and sheet bars together. The outer frame of the back support was constructed with 3 aluminum square hollow tubes (1" by 1") and 1 rectangular hollow tube (2" by 1"). The square inch tubes were obtained from Bob's stock available in the machine shop and the rectangular tube was purchased at Alro. The three square tubes and the rectangular tube were all cut with the band saw to a length of 32". These four pieces were then clamped together as the outer frame and welded by Bob. After the outline of the frame was completed, 3 cross bars (¼" thick) were welded on its front. The top cross bar was 4" wide while the bottom 2 cross bars were 2" wide. All three pieces of these cross bars were cut to a length of 31" with the band saw. The cross bars were then placed and clamped to the back support frame outline, spaced 6" apart, and were welded. The complete assembly of the front of the back support just described is shown below in Figure 97.

Figure 97: Fully Assembled Back Support

The next addition to the back support of the bed consisted of attaching a back support bar to the back of it that would allow the back support to reconfigure at different angles. The back support bar was a circular aluminum rod ¾" in diameter and 102" long. This long circular rod was then bent at four corners with the help of Bob using a metal bender. The rod was bent at four corners to give dimensions of 29" by 22". These dimensions were calculated so the rod would sit perfectly in the back of the back support. In order to attach this support bar to the back of the of the back support, two small circular collars were welded to the back of the top cross bar. These circular collars were pieces cut out of a hollow aluminum tube, 7/8" in diameter, with 1/8" wall thickness. Two collars were cut with the band saw at a length of 2". The collars were then placed and welded to the of the back support on the back of the top cross bar. The collars were placed about 15" apart and appropriately aligned in the middle of the cross bar. A 15" long piece was cut out from the top of the support bar so the bar could be slid into the two welded collars from their outer sides by stretching the bar. After considering the wall thickness of these collars the inner diameter came out to be ¾" (same as the outer diameter of the support bar that was meant to go through these collars). In order to slide the support bar in through the collars, the bar was sanded down until the thickness was just about reduced so it would fit perfectly inside the collars. Figure 98 below shows the full assembly of this back support bar to the back support of the the bed, photographed from the back.

Figure 98: Support Bar on the back of the Back Support

Finally, the last task associated with the back support was identified as its assembly to the frame. Since the back support was to be able to reconfigure at specific angles, we needed to attach it to the frame in a way that would allow it to rotate. To accomplish this, we used shoulder screws provided by Bob. First two rectangular tabs were fabricated out of scrap aluminum sheet which were 2" by 1" and ¼" thick. These two tabs were placed and welded onto the frame on both sides. The distance at which they were welded was determined by placing the whole back support assembly onto the frame so that the tabs would be placed right at the edge of the bottom corners of the black supports. Locations were marked manually while group members held the back support in place. The tabs were then welded at their appropriate locations. The welding and positioning of these tabs can be better viewed below in Figure 99. Next, ¼" holes were drilled using a hand drill through these tabs and also through the bottom sides of the back support. Once again, the location at which these holes would be drilled was determined by holding the back support in between them and ensuring that the back support could rotate to the degree we wanted it to. Finally, the back support bar was adjoined to the frame of the bed using shoulder screws that went through the tabs and into the sides of the back support. These shoulder screws were covered with rubber on the outside. These screws and the assembly process just described can be viewed below in Figures 99 and 100.

Figure 99: Tab and Shoulder Screw Joint

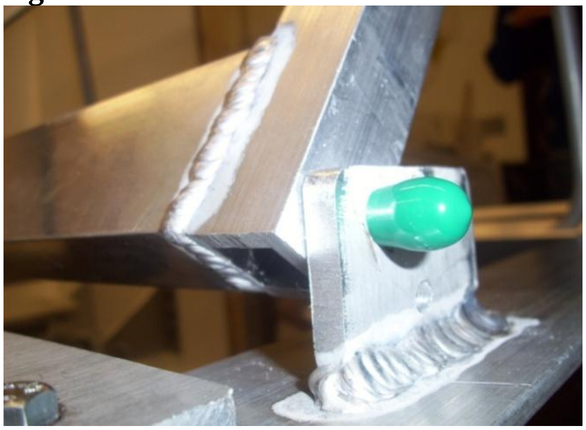
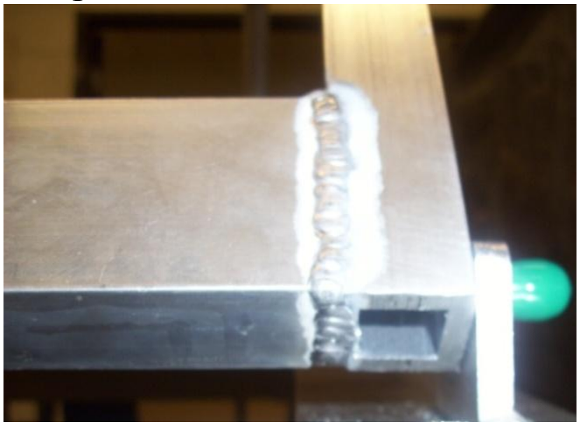


Figure 100: Another View



Stirrups
The stirrups were fabricated with 1” by 1” aluminum bar stock, 1.25” aluminum round stock, and 1” round aluminum stock.

Two pieces of 1” by 1” stock were cut to 17” in length using a band saw. Two pieces were then cut with a 15° angle on one end and straight at the other end to a length of 18”. Two final pieces were cut at one edge at a 75° angle and on the other side to a length of 4”. These pieces are arranged as shown in Figure 101 and welded at the highlighted portions to form two triangle shaped stirrup arms. The pin holes for the stirrup foot rest are drilled into the top bar of the stirrup arm as shown in Figure 101.

Figure 101: Stirrup Arm and Foot Rest

Two 1.25” aluminum round tubes were cut to 4” lengths. Five holes with a diameter of 0.25” were drilled on the square round tube at the distances shown below. This piece was then welded to the triangle stirrup arm so that the pin holes run normal to the length of the stirrup arm.

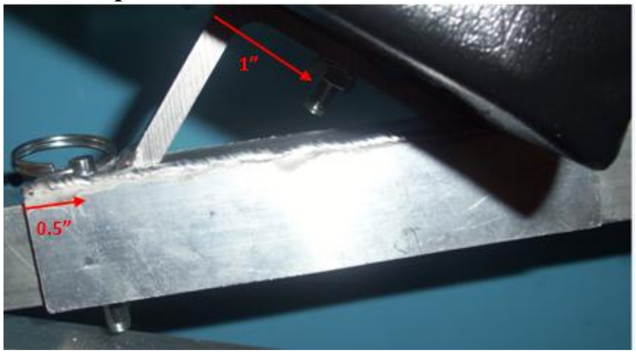
Figure 102: Vertical Adjustment Attachment Piece

Two pieces of 0.75” diameter aluminum round tube were cut to a length of 10”. At 5”, a hole was drilled for a 0.25” pin. In the direction perpendicular to the pin hole, drill two 0.25” bolt holes 1” from the top of the tube and 1” from the bottom of the tube. Measure 18” from the top of the legs and mark as the center of the 10” tube. Four inches above and below this line, centered on the 2” leg, drill 0.25” bolt holes. Slide the 0.75” diameter tube into the 1.25” diameter tube as shown in Figure 103. Once in place, bolt the smaller tube to the front legs of the frame.

Figure 103: Stirrups’ Vertical Movement Mechanism

The collar that the foot rest is attached to that allows for adjustment along the stirrup arm is composed of 0.125” thick aluminum plate. Four pieces of plate should be cut to 1” by 6”, and two pieces should be cut to 1.25” by 6”. These pieces should then be welded to form a collar as shown in Figure 104. One inch from one end of the collar, a 1” length of the L-bar should be welded, with the 2” side facing the closer end. A hole for the 0.25” pin will be drilled 0.5” from the left end of the collar shown in Figure 104.

Figure 104: Stirrups’ Foot Rest Attachment to the Movable Collar



The foot rest of the stirrup is made of plywood, covered in foam, wrapped in vinyl, and bolted to the right angle piece on the collar. To make the foot rests, 4 pieces are cut to 5” by 5” and 4 pieces are cut to 4.5” by 3”. One inch from the bottom of the foot rest (bottom defined as the location of the heel), a 0.25” diameter hole will be drilled. One inch from the edge of the right angle piece on the collar a 0.25” diameter hole will be drilled. The foot rest will be bolted to the collar. Then duplicate pieces of 0.5” thick foam will be cut with the following dimensions: 4” by 4.5”, 4” by 2.5”, 4” by 2.5”, and 4” by 4.5”. These pieces will be glued into the foot support. Then vinyl will be used to wrap the foot rest. The vinyl will be stapled to the wood of the foot rest.

Foot Support

The foot support system was manufactured using a cut stock wooden panel and a tablet arm joint. The oversized wood panel was trimmed to the dimensions of 36” x 20” using the band saw. The tablet arm joint was attached to the wood panel using three steel wood screws and two 0.25” bolts. At this point, two 0.25” holes were drilled through the attachment arm of the tablet arm using the mill in the shop. Clamping the tablet arm to the support frame of the bed, two corresponding 0.25” holes were drilled through the front left leg of the support frame and the foot support system was attached to the bed using two 0.25” bolts. At this point, a foldable leg system was attached to the underside of the foot support on the opposite side from the tablet arm joint. Four 0.25” holes were drilled and the folding leg assembly was attached using 0.25” bolts.
Figures 105 and 106 below show the tablet arm joint and its assembly to the frame in detail.

Figure 105: Foot Support Attachment

Figure 106: Tablet Arm Attachment to Frame

Fluid Collection

The fluid collection system for our bed was simply made out of a plastic trash can purchased at Meijer and 1” by 1” aluminum stock and 7” long to orient the plastic part at the desired angle of 40˚. The trashcan purchased from Meijer was cut in half (first with hand saw and then with band saw for a better finish) and then trimmed to fit under the seat support. Then the edges were smoothed with sand paper. Two rectangular holes were then cut out one inch from the top edge of the plastic portions. The holes are 4 in apart of each other and 2 in away from the center of the plastic portion.

The metal stock were cut at a 45˚ angle to facilitate attachment under the seat support and also to position and maintain the plastic portion at the desired orientation and also to serve as support of the plastic piece. The fluid collection system is displayed in Figures 107 a-b below.

Figure 107a: side view of fluid collection **Figure 107b: front view of fluid collection**

Padding

The padding was manufactured in three separate pieces for the back support, seat support, and foot support. Plywood was cut to three dimensions: 33” by 32” (back support), 20” by 32” (seat support), and 18” by 36” (foot support). Foam from the couch cushions we had was then cut to the identical dimensions. The thickness of the seat and foot support is 4”, while the back support foam has a thickness of 2.5”. The plywood and foam for the seat support have a 12” semi-circular opening cut identical to the seat support (centered on the piece). Once cut, the foam was glued to the plywood. The vinyl was then tightly wrapped around the entire piece and stapled to the wood. These nicely wrapped pieces of padding were then attached to the frame using industrial Velcro. Figures 108 a-b below show the back support padded piece from its front and back.

Figure 108a: Back Support Padding (Front) **Figure 108b: Back Support Padding (Back)**

VALIDATION PLAN AND RESULTS

This section will detail how the delivery bed prototype will be tested to prove that it meets the engineering specifications and the results of each validation test. A validation test description will be provided for each specification that can be tested. A description will also be provided for the specifications that cannot be physically validated.

Robust

The minimum force that the bed must support is 3000N (approximately 674lbs.), which will be distributed amongst the six supporting legs. The prototype will not be tested to failure but static weights will be added to the frame to prove that the bed will be able to support the weight, which are the maximum weights assuming two pregnant patients on the bed and a safety factor of 1.5.

The maximum static force applied to the bed frame was 4137N (approximately 930lbs.) and the frame did not fail or show signs of failure. The load applied was five students sitting on the bed. The load used in this test validates that our bed exceeds the minimum requirement and will not fail if one or two expecting mothers lay on the bed. The bed also withstood the impulsive force of a person quickly jumping onto the bed in a sitting position, the frame did not show any weakness, but the legs lost traction and the entire bed slide back about one inch. This issue can be corrected by making custom fit rubber caps for the ends of the legs.

Longevity

The specification for longevity is a service lifetime of 10 years. This design specification cannot be explicitly tested within the scope of the design project. Longevity will be indirectly validated through robustness validation. If the bed meets design specifications for robustness, then it should maintain the specified lifetime. To ensure the longevity of the padding, team members will constantly get on and off the bed for a period of an hour. At this point, the padding will be removed. Then the padding will be handled and cleaned quite roughly. Once this has been accomplished, we will examine the padding to see if any wear is visible.

The padding test proved successful because the padding maintained its shape. The padding would give when a person sat or laid on it, but would return to its original shape after they got off of the bed. The main failure mode for the padding would be a breach in the vinyl and exposure to the cleaning solutions and other fluids. Manipulation of the leg support proved that the vinyl was susceptible to tearing because of the sharp surfaces on the underside of the movable parts. In a hospital setting, there are many sharp objects that may come in contact with the vinyl and cause tears. Even though our prototype padding is only covered in one layer of vinyl, we would recommend covering the padding in two layers or using a more durable vinyl.

Safety

The safety specification of the prototype will be built into the design material selection and supported by the engineering analysis. The engineering analysis will be based on a safety factor of 1.5 to ensure design success and will be validated by comparing the required maximum load capacity of the materials and joints with the actual maximum load capacities. In addition to engineering analysis validation, the team will account for potential safety hazards through DesignSafe and observe potential safety hazards through human interaction during the fabrication process. One final safety test will be a tipping experiment. The team members will sit on each of the four edges of the bed in both the supine and delivery configurations. This will allow the team to evaluate the potential for tip over in all of the bed's positions.

After having team members sit on each of the four edges of the bed, we concluded that the bed frame will not tip over with unbalance loading. All of the legs of the frame remained firmly planted on the floor. The floor that the bed was tested on was fairly level, we assume that the floor in the delivery ward at KATH will be equally level.

Affordable

Validating that the final prototype is affordable will be accomplished through verification of the budget in the final expense sheet. The cost of every material and component will be recorded and other options noted for future considerations. The final cost of the prototype should be less than $500 and the estimated final cost of the bed manufactured and sold in Ghana should be less than $500.

The total expenditure for the bed prototype is $424.24; this amount meets our specification for the total expenditure of less than $500. We were able to reduce our expenditures on aluminum and wood by using stock material available in the machine shop. We also reduced expenditures by purchasing the vinyl with a discount coupon, by purchasing the Velcro when it was on sale and by receiving the padding as a donation. Without these additional savings, the total cost would probably have been over $500. The bulk of the cost was the aluminum. Aluminum costs less in Ghana than in the States and this price difference would allow for a manufactured final design to still remain under $500 in addition to the reduction in per unit cost that comes with mass production.

Reconfigurable

Prototype configurability will be validated through the physical testing described in the following two sections.

Back support configurability: The back support must be maneuvered from the supine position to the semi-recumbent position with one intermediate position. The angle between the back support and the frame for each of the positions are listed below in Table 6.

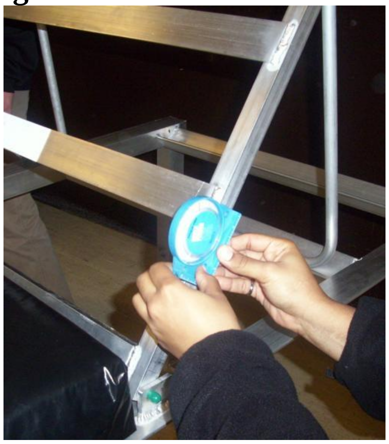
Table 6: Angles of back support positions

Position	Angle
Supine	180°
Intermediate	150°
Semi-recumbent	130°

Once fabrication is complete, the back support will be adjusted to all required positions and the angle between the back support and the frame will be measured at each position from both sides of the frame and with repeated measurements for all conditions. The position angle will be validated if the measured angle is within 5% of the desired angle. All of the angles will be measured with an angle finder.

Measurements with an angle finder, shown below in Figure 109, revealed that the supine position was 179°, which is within 0.56% of 180° and the semi-recumbent position was 126°, which is within 3.08% of 130°. The final angle for the intermediate position did not meet specifications as it was within 9.3% of 150°. This position specification was not meet due to spatial constraints placed on the back support bar and the location of the right angle pieces that support the back support bar. The back support bar had to be short enough to fold underneath the back support and the right angle pieces could not be placed over a bolt location for the frame legs.

Figure 109: Angle Finder Measurement of Back Support



Foot support configurability: The configurability of the foot support section of the bed cannot be physically tested but can be indirectly validated by proving the functionality of the swivel joint that attaches the support to the frame. Proving that the joint is robust and will not fail during the expected lifetime of the bed proves that the foot support section of the bed will always be configurable. Therefore, the strength of the swivel joint and corresponding mechanism will validate the lifetime of the joint. A static load test with a weight of 2000N will be applied to the end of the foot support to prove that it meets specification.

The static test for the foot support was not applicable because the validation test was created for the final design, which has two swivel joints. The prototype only had one swivel joint due to a loss of tolerance control on the manufactured swivel joint after welding. The foot support section of the bed had to be redesigned late in the prototyping process due to the loss of the second joint and thus any testing would not be representative of the actual final design.

Easy to Clean/Sanitize

Validation for cleaning time will be tested by dumping water through the fluid collection system and over all of the padding, allowing for the messiest splashes, and then timing the clean-up of the entire bed. The test will be repeated for variation in the location of the splash zone and for variation in the individual cleaning the surfaces of the bed. It is understood that water does not have the same viscosity and fluid properties as birthing fluids. However, water is the most accessible and the least destructive fluid for most materials, other than the bed, that might get wet in the process of testing.

The specification for easy to clean/sanitize was a clean time of no more than two minutes. Several people were timed while he/she wiped the bed clean with paper towel. The average clean time was 58 seconds, with the longest clean time of 1:08 minutes because the individual had to retrieve more paper towel after the first piece became fully saturated.

Collects Birthing Fluids

The birthing fluids collection specification will be validated with physical testing similar to the cleaning test. The fluid collection system will be tested by dumping water through the fluid collection system. Water will be poured from slightly different start points on the fluid collection system and then the volume collected will be compared with the initial volume passed through the system.

The fluid collection test, shown below in Figure 110, yielded an average collection percentage of 96%. These test results validate our specification of at least 90% fluid collection. Some of the residual water on the plastic chute did fall to the floor after the collection bucket was removed, but in the hospital setting the floor around the delivery chair must be cleaned. There were additional concerns after prototype manufacturing that fluids would leak through the holes where the chute is attached to the bed. This concern was eliminated after testing since the holes are far enough underneath the seat that the fluids land on the chute after the connection point and does not fall through the holes.

Figure 110: Fluid Collection Validation

Fluid collection system location restraints: The second specification for the birthing fluids collection system is that it does not protrude beyond the length of the bed when it is in the supine position. This specification will be validated by taking multiple measurements of the length of the fluid collection system. Those measurements will be compared to the distance of the fluid collection system connection point on the frame to the end of the frame. If the first measurement is less than the second, then the specification is validated.

Visual inspection of the location of the fluid collection system validates that it does not protrude beyond the length of the bed in supine position. The length of the chute that protrudes from the attachment point is completely contained underneath the length of the foot support section of the bed.

Easy to Maneuver/Adjust

The ease of use will be tested subjectively. One of the most important design specifications is that the bed is easy to configure. This attribute will be tested by having different individuals configure the bed into the different positions and rank the relative difficulty on a scale of one to five. The scoring scale and descriptions are in Table 7 below. As outlined in the table, this specification will be separated into two categories, one regarding how difficult the bed is to understand and use and one regarding how much physical strength is needed to operate the bed. The target score for specification validation is a four because the operation of the bed should be fairly intuitive and easy to manipulate, but instructions will be included because the bed is the first of its kind.

Table 7: Ease-of-use rating scale and descriptions

Score	Ease of Use	Description A	Description B
5	Very Easy	Intuitive to operate; no instructions needed	No strength required
4	Easy	Fairly intuitive to operate; no instructions needed	Requires almost no strength
3	Okay	Not intuitive to operate; can operate with minimal instructions	Requires some strength
2	Difficult	Not intuitive; needs written/verbal instructions to operate	Requires a significant amount of strength
1	Very Difficult	Confusing; needs a lot of written/verbal instructions to operate	Requires excessive strength

The target score for both descriptions was a 4. The average score for Description A was a 4.8, based on the results of 30 people operating the bed. The most difficult part of the bed to maneuver was the foot support because of the small clearances for the table leg. The average score for Description B was a 4.3 based on the same survey participants. Once again, the most difficult part of the bed to maneuver was the foot support because of its bulky size and large range of motion. Since the foot support on the prototype is not the same as the final design, we would expect the scores to increase if the final design was critiqued using the same standards.

Comfortable

The validation for comfort will also be tested subjectively. Comfort will be tested by having different individuals lay on the prototype and rate the comfort of the bed on a number scale of one to five. The scoring scale and descriptions are in Table 8 below. The scaling was designed to equate a score of four or five to represent a comfort level that matches with the average labor time. Our target score for measuring achievement of the comfort specification will be a 4 because it is matched with a labor time of 12-24 hours.

Table 8: Bed comfort rating scale and description

Score	Comfort Level	Max. Time On Bed
5	Very Comfortable	≥ 24 hrs
4	Comfortable	12-24 hrs
3	Okay	8-12 hrs
2	Uncomfortable	1-8 hrs
1	Very Uncomfortable	< 1 hr

The same individuals surveyed for ease-of-use were also asked to rate the comfort of the bed. For comfort, the target score was a 4, but we exceeded the target with an average score of 4.9. In addition to the survey participants, we received additional feedback at the Design Expo, where our prototype was on display, that our bed was very comfortable.

DISCUSSION: DESIGN CRITIQUE

In hindsight, there are several aspects of our design that could be changed with more time, a greater budget, and our acquired understanding of the design. These aspects should be focused on in future redesigns. These issues will be addressed component by component in the following sections.

Frame

We believe that the frame is very stable and solid. There are no major changes that we would make to the overall design. However, one smaller issue that could be addressed is the leg height. While the overall height of the bed was determined based on benchmarking of current beds, the height of the padding was not taken into account. Shortening the legs would be necessary before the bed would be beneficial to KATH's patient culture, specifically the pregnant patients having to get themselves onto and off of the bed without assistance. Additionally, shortening the legs may add additional support to the frame by lowering the center of gravity. We anticipate shortening the legs by at least 6" to adjust for the height of the padding the seat support.

Foot Support and Rotating Joint

The final design for the foot supports and rotating joints is logical and fits our design specifications. As the prototype was unable to be produced as a full scale-working prototype of the final design, a critique of the functionality of our design is not fully possible. We believe that as weight was a large issue with using one foot support for the prototype, an FEA analysis would be beneficial in analyzing a two foot support system to ensure that it can support the desired weight load. While the motion of the joint and foot support allows both supine and delivery positions, we do not know whether the foot support will remain horizontal at the point furthest from the joint.

Back Support Assembly

The structure of the back support is very stable. The back support can be easily manufactured in Ghana. However, the hinge for the back support bar should be re-examined. While the hinge serves the function of back configurability, it also creates a space between the back support and the frame. This space resulted in unnecessary force on the joint as well as a needed difference in padding height between the seat and back support so that the bed will be the same height throughout. To rectify this joint issue, there are several possible considerations. First, another joint could be considered. The back support frame could also be increased in width so that the back can be hinged on the outer edge of the frame.

Padding

Although the concept behind the padding was logical and provides a polished appearance, the strength of the Velcro resulted in issues with staple strength. This made it difficult to remove the padding from the frame without loosening the vinyl or needing to carefully separate the industrial strength Velcro. We believe that the padding should be durable enough to be easily pulled off of the frame without damage. One simple adjustment could be to consider continuing to use the plywood, foam, and Velcro, but to have the vinyl sewn and then sealed with liquid sealant. Another option would be to consider using snaps rather than Velcro.

Another issue that arose from the padding was that the padding was not able to adjust to the different configurable locations. If the padding fit perfectly in the supine position, the connection of the padding between the seat and back support when the back support was inclined, resulted in the back support padding being pushed up and pulling at the vinyl. One way to combat this issue would be to angle the edge of the padding at this connection point.

Seat

The seat is a very stable design. However, one issue that arose was the size of the semi-circular opening to facilitate fluid collection. After we began to test the bed, we realized the inherent difficulty that the opening would cause in allowing the patient to sit at the front edge of the seat for delivery.

Stirrups System

Additionally, for a mass produced bed, the stirrup arm joint connection would need to be more carefully determined to provide the maximum support and free space. These two pieces would ideally fit more perfectly. Due to the weld of the outer diameter tube onto the stirrup arm, a more tightly fitting circular tube no longer was able to fit within the outer tube. The strength of the joint and pressure on the pin will be reduced if the tubes fit more closely.

Additionally, the stirrup assembly could be improved by switching from pin joints to pressure joints.

Another consideration that was excluded from the final stirrup design was the ability of the stirrup arm to rotate to provide different angles from the frame. This would be extremely beneficial to address the desired positions of leg extension.

Fluid Collection System

The fluid collection system could greatly be improved. While we feel that the general design makes sense for its function, the execution and material choices can be improved. One relatively easy way to improve the fluid collection system would be to make the fluid collection system of thin aluminum plate that could be molded to the desired shape. This would ensure a large enough initial and final diameter to maximize fluid collection. Another aspect of the design that needs to be addressed is the way in which the system was made detachable. For the prototype, there were simply two holes cut into the trashcan that hooked into the fluid collection support bars. This connection method eliminates the liquid tight system. Therefore, another attachment mechanism must be considered. One former consideration was a track on which a lip of the system could slide into place.

RECOMMENDATIONS

Having progressed through the entire design process, from research to concept generation to final prototype manufacture, we have several recommendations for both improvements on the current prototype and future work.

The final prototype prepared by us is currently not ready for implementation into the strenuous environment presented by the KATH Labor and Delivery ward. Though our final prototype has met or exceeded all of the validation testing we have prepared, further testing is needed. Further testing considerations include possibly approaching the federal government concerning large scale clinical trials and official validation.

Concerning the actual manufacture of the reconfigurable delivery bed, we have several recommendations. On both the back support frame and the actual support frame, too much joining was done with welding. A trained welder can accurately join pieces, but too much deformation with thin walled members can still result in a skewed configuration. Further, the gains made in assembly time by moving away from welding to more bolted joints will decrease manufacturing costs significantly. The size of the bolts used on the prototype were more than adequate, but bolt covers or hiding the bolt tops within a material gap would minimize exposed edges that may present a danger in a hospital setting. Right angle configurations should also be avoided for the very same reason.

Further, the seating platform of the prototype is approximately 6” too high. In an effort to accommodate more patients without the aid of a stepping stool, at least 6” should be removed from the assembled legs.

We believe the greatest strength of the prototype lies in the functionality and overall robustness of the hinged frame and back support system. The frame legs are sturdy and exhibit no buckling stress locations. One possible improvement would be to add rubber plugs to the ends of the hollow legs and/or adding a lockable caster wheel set to the bottom of the frame. The rubber plugs would prevent any sliding of the bed on a wet delivery floor as well as preventing any damage to either the flooring or the ends of the legs. The wheel set is fairly straight forward. The assembled delivery bed is unwieldy to carry so unless final assembly in the ward is a viable option, a rolling bed would greatly ease the burden on the maintenance personnel in KATH. Finally, we recommend maintaining the “lawn chair” inclination system in future versions, as no difficulties have been encountered.

Conversely, we believe the greatest weakness of the prototype lies with the rotating leg support and the attached stirrups. The space constraints within the hospital greatly limit the number of options available to future design teams, but one possibility exists in completely removing the foot support system, lengthening the back support, and somehow stowing the stirrups underneath the bed. We believe that the very first Fall09 ME 450 project approved by Professor Sienko and ideally the Multidisciplinary Design Minor Specialization in Global Health Design is creating a stirrup system that adjusts vertically to accommodate the varying length of women's legs and translates or rotates in the horizontal direction to accommodate different angles for the patient's comfort. The stirrups proved to be the greatest difficulty encountered throughout the design process and at this point, they are unwieldy and difficult to adjust.

One final consideration concerns the padding. The padding created by us was functional but at times vinyl slipped exposing the interior foam. We recommend either double wrapping the padding in the non porous vinyl material or potentially outsourcing the job to a qualified professional. The padding serves several purposes, but one very important function is added aesthetics professional cushions would provide.

Ultimately, we consider the semester a success and are proud of the final prototype. Our final recommendation is for both our professor, Kathleen Sienko, and our sponsor, Multidisciplinary Design Minor Specialization in Global Health Design. We believe that the prototype should be considered a large step in the right direction and the frame with the inclinable back support should be given to a future design team tasked with providing an adjustable, storable stirrup system. The frame and back support would provide this future design team with a working platform to attach whatever they create. At that point, the prototype would ideally be ready for shipment to Kumasi, Ghana and a lifetime spent servicing the patients of KATH.

CONCLUSIONS

The goal of this project was to develop a design and a prototype for a reconfigurable obstetrics delivery bed that combines the functionalities of a supine bed and a delivery chair. The bed was designed for the Labor and Delivery Ward at the Komfo Anokye Teaching Hospital (KATH) in Kumasi, Ghana. KATH is a busy city hospital and the Labor and Delivery Ward is always overcrowded. The bed designed by our team is supposed to increase patient flow efficiency and safety. The bed would be a more efficient solution than the current set-up because it would eliminate the need for the expecting mothers to move themselves from the supine beds to the delivery chair when they are ready to deliver.

The final design specifications were based on benchmarking with current delivery beds, feedback from our mentors and anthropometric data. The most important specifications for the bed concerned safety, configurability, robustness and cost. All of the engineering analysis that was used to determine the material and the assembly process of the frame was based on a safety factor or 1.5. For configurability, we designed a back support that could be adjusted for a semi-recumbent position for childbirth, supine position and an intermediate position. In addition, we designed an adjustable foot support section of the bed that could be moved to the side of the frame to reveal the stirrups and fluid collection system. The total cost of the prototype, as well as the expected cost for mass production of the final bed design, is less than $500.

The prototype was used to validate the specifications of our design. Using a combination of theoretical analysis, physical testing and user surveys, we were able to determine which specifications were satisfied. All of the specifications for the design were met with the prototype except for the following items: the prototype only had one tablet arm joint, the back support does not configure within 5% of 150° and the vinyl is susceptible to tearing. All of the previous issues are included in suggested areas for continued work. In addition to those components mentioned, we also recommend addition work on the stirrups to improve the geometric tolerances and robustness. As the first team to tackle this problem, we believe that we have made sufficient progress towards developing a final solution.

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Dr. Anthony Ofosu: Dr. Ofosu is our team sponsor in Ghana and the Director of the Sene District Hospital in Ghana.

Dr. Timothy Johnson: Dr. Johnson is the Chair of the Department of Obstetrics and Gynecology at the University of Michigan Hospitals. His extensive work in Ghana and knowledge of the design functionality was helpful in determining our design specifications and simplifying our design.

Dr. Jody Lori: Dr. Jody Lori is the CNM Lecturer and Interim Nurse Midwifery Program Coordinator, University of Michigan, School of Nursing. Her knowledge of midwifery and patient care was beneficial in determining the functionality of the bed.

Dr. Grace Adofo: Dr. Grace Adofo, M.D. in Gynecology and Obstetrics in Pennsylvania.

Dan Johnson: Dan Johnson was beneficial is the safety report and CES material selection processes.

Bob Coury: Bob Coury was beneficial in the assembly of our bed. He assisted us with various issues that we encountered throughout manufacturing. He also welded all of our components.

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Jerry McCarty: Jerry McCarty works for the University of Michigan and was kind enough to give us a tablet arm joint for use in our prototype.

Jane Juckno: Jane Juckno is Dr. Johnson’s assistant at the University of Michigan. She assisted us in hospital visiting and observances in the gynecology and birthing department.

Team Ghana, GIEU: Team Ghana members helped us to understand the culture of KATH and the delivery ward. They also gave us their input into design aspects that they felt would most improve the current delivery ward.

Sue Kofflin: Sue Kofflin is the Clinical Nurse Manager in the Women's Hospital Birth Center at the University of Michigan. She helped us with observing the delivery process and donated stirrups for us to use in the design.

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REFERENCES

ACOG. (2007, January). You and Your Baby: Prenatal Care, Labor and Delivery, and Postpartum Care. *The Patient Education Pamphlet* . Washington, D.C.: American College of Obstetricians and Gynecologists.

Ansong-Tornui, J., Armar-Klemesu, M., Arhinful, D., Penfold, S., & Hussein, J. (2007). Hospital Based Maternity Care in Ghana - Findings of a Confidential Enquiry into Maternal Deaths. *Ghana Medical Journal , 41* (3), 125-132.

Ansong-Tornui, J., Armar-Klemesu, M., Arhinful, D., Penfold, S., & Hussein, J. (2007). Hospital Based Maternity Care in Ghana - Findings of a Confidential Enquiry into Maternal Deaths. *Ghana Medical Journal , 41* (3), 125-132.

Bazzano, A. N., Kirkwood, B., Tawiah-Agyemang, C., Owusu-Agyei, S., & Adongo, P. (2008). Social costs of skilled attendance at birth in rural Ghana. *International Journal of Gynecology and Obstetrics* , 91-94.

CIA. (2008). *Ghana People*. Retrieved January 20, 2009, from The 2008 World Factbook: http://www.theodora.com/wfbcurrent/ghana/ghana_people.html

Clark, P. H. (1982). *Patent No. 4,356,578.* United States of America.

D'Ambruoso, L., Abbey, M., & Hussein, J. (2005). Please understand when I cry out in pain: women's accounts of maternity services during labour and delivery in Ghana. *BMC Public Health* , 140.

Feldt, M. (1987). *Patent No. 4,682,376.* United States of America.

Fenwick, L. (1983). *Patent No. 4,411,035*. United States of America.

Hanson, L. (1998). Second-stage positioning in Nurse-Midwifery Practices: Part 1: Position use and Preferences. *Journal of Midwifery & Women's Health , 43* (5), 320-325.

Healthcare Products Comparison System. (2004, November). Beds, Birthing.

Jonge, A. D., Teunissen, T., & Lagro-Janssen, A. (2004). Supine position compared to other positions during the second stage of labor: A meta-analytic review. *Journal of Psychosomatic Obstetrics & Gynecology , 25* (1), 35-45.

Karlson, S. (1942). *Patent No. 2,290,191*. United States of America.

Lauren Dundes, M. (1987). The Evolution of Maternal Birthing Position. *Public Health , 77* (5).

Mayo Clinic. (2007, April 13). *Stages of Labor: Baby, It's Time!* Retrieved January 25, 2009, from MayoClinic.com: http://www.mayoclinic.com/health/stages-of-labor/PR00106

Perineum. Wikipedia. Retrieved January 20,2009, from: http://en.wikipedia.org/wiki/Perineum

Shorten, A., Donsante, J., & Shorten, B. (2002). Birth Position, Accoucheur, and Perinatal Outcomes: Informing Women about Choics for Vaginal Birth. *Birth* , *29* (1), 18-27.

United Surgical Industries. (n.d.). *United Surgical Industries*. Retrieved January 18, 2009, from OB/GYN Delivery: http://www.unisurg.com/delivery-tables-and-bed.html

World Health Organization. (2008). *World Health Statistics.* Geneva: World Health Organization Press.

APPENDIX B: Bill of Materials

Item	Quantity	Unit Cost	Notes	Source	Contact
2" x 2" hollow aluminum 0.125" thick tubes	6	$20.79		Alro Metals Plus	2466 S. Industrial Hwy Ann Arbor, MI 48104 734 213-2727
1/8" x 2" aluminum plate	2	$6.22			
2" x 1" hollow aluminum 0.062" thick tubes	6	$8.72			
20" x 32" aluminum 1/4" plate	*22	$5.67	*unit is pounds		
Right angle aluminum bars	*24	$2.75			
Signature Shiny Black Vinyl	6	$9.99	unit is 1 yd of fabric	Jo-Ann Fabrics	3737 Carpenter Rd Ypsilanti, MI 48197 734 975-0310
4ft Industrial Strength Velcro	1	$13.99	unit is a box		
Plastic Wastebasket	1	$6.89		Meijer	Carpenter Rd. Ypsilanti, MI - #27 734 973-1200
3' x 3' Foam 5 1/2" thick (couch cushions)	3	$0.00	donated	Mr. & Mrs. Kaur	

Appendix C: Description of Engineering Changes since Design Review #3

This section explains the design changes made between DR3 and the prototype. The changes were the result of time constraints, manufacturing errors, and budget restrictions.

The first major change since Design Review 3 (DR3) was the bed frame material. We decided to use 6061-T6 Aluminum instead of A36 Steel. Originally, decided to use steel because it was less expensive than aluminum. Using steel would have required an additional protective coating to protect it from corrosion and we assumed it would be an inexpensive process. Additional research proved that the cost of the protective coating plus the cost of the steel would be more than purchasing aluminum. From this information, the team decided to use 6061-T6 aluminum, which is lighter, corrosion resistant and available in Ghana.

The second change regarded the side bar on the frame of the bed. In DR3, the side bar extended above the seat support plane, as shown in Figure 1 below. On the prototype, the sides of the frame lay flush with the seat support plane, as shown in Figure 2 below. The changed area is highlighted in red on Figure 2. This change was the result of budget limitations; the L-shaped side bars used for the prototype cost less than the T-shaped bars displayed in Figure 1 from DR3.

Figure 1: DR 3 Frame

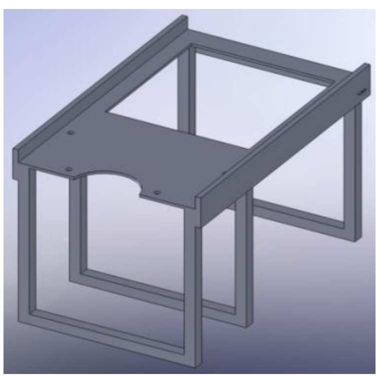


Figure 2: Prototype

The third change involved the back support bar catches. In DR3, the catches were trenches drilled out of the side of the frame; on the prototype, we used two tilted L-shaped bars, as shown in Figure 2 above.

For the fourth change, the handle on the back support was removed from the prototype. The handle was taken from a hospital chair we purchased and was bolted to the top of the back support frame. The handle was removed from the prototype because the end of one of the bolts did not clear the L-shaped bar when the back support frame was placed in the supine position.

The fifth change was with respect to the fluid collection system. After the review of DR3, the team received negative feedback on the design of the fluid collection system. It had sharp corners and thus did not seem to be a safe design. As a result, we redesigned the fluid collection system to be made of plastic instead of metal and to be shaped like a half-pipe rather than the previous rectangular shape. For the prototype, we used a plastic wastebasket cut in half lengthwise. The DR3 design and the prototype fluid collection system are shown in Figures 3a and 3b, respectively.

The DR3 fluid collection system was designed to be bolted directly to the frame. However, for the prototype, the wastebasket was mounted on two aluminum bars which were bolted underneath the seat support. One bar is shown below in Figure 3c. It is important to note that wastebasket was the best approximate representation of the half-pipe fluid collection design but it is missing a key final design specification. The fluid collection system in the final design was supposed to be detachable for easy cleaning, but the wastebasket is not easily detached without removing the bolts from the support bars.

Figure 3a: DR3 Fluid Collection

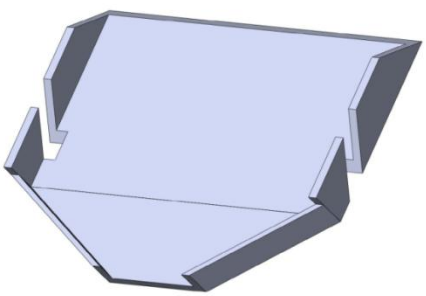


Figure 3c: Support Bar

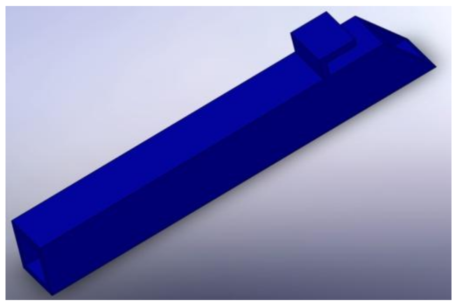
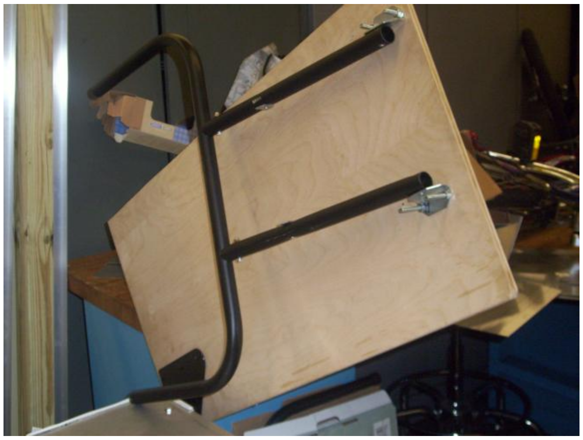


Figure 3b: Prototype Fluid Collection

The sixth change involved the foot supports. The foot supports in DR3 were two separate pieces that were each attached to the sides of the frame with table arm swivel joints. These joints enabled the leg support to rotate from supine position to a position stored on the side of the frame. Only one joint was included on the prototype because of some manufacturing errors and time limitations. Difficulties in clamping the joint components together before welding caused two surfaces to be skewed when they should have been flush. This manufacturing error occurred shortly before the Design Expo, thus forcing us to use one tablet arm joint and a table leg for the opposite side. Since the error was due to securing the joint before welding and not joint design, the joints can be manufactured again for future improvements of the bed. The foot support section of the prototype is shown below in Figure 4.

Figure 4: Prototype Leg Support



The last design change regarded the stirrups. During Design Review 4, Professor Gillespie recommended that the stirrups should be strong enough to hold 100% of a pregnant woman's weight. We valued this feedback and tried to incorporate it into our re-design of the stirrups. From another concept generation session, we came up with the stirrup design that was implemented on the prototype. The new design, shown in Figure 5b below and 5c, is more robust than the old design, shown in Figure 5a below. Even though the new design is more robust than the old one, it is not strong enough to hold a pregnant woman's body weight and therefore this design needs to be reevaluated for strength.

Figure 5a: DR3 Stirrups

Figure 5b: CAD of prototype stirrups

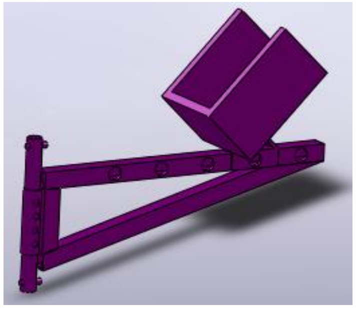


Figure 5c: Prototype Stirrups

APPENDIX D: Design Analysis

Material Selection (Functional Performance)
For the purpose of this appendix, analysis was performed on two major components of the final design: the support frame's legs and the padding cover.

Support Frame Legs
Function: Column under compressive load.
Objective: Minimize the mass of the legs.
Constraints: The leg must not fail under compressive load of the bed i.e. $\frac{F}{A} < \sigma_Y$.

Two material indices were derived to rank the vast material options returned using the CES software. The first index compares the strength of the material to its respective density:

$$M_1 = \frac{\sigma}{\rho}$$

This is a measure of the strength to weight ratio. We were attempting to maximize the strength of the critical supports legs while still maintaining a lightweight maneuverable bed. The target score of this index (i.e. the slope of the CES guidelines) was set at 400. The second material index compared the stiffness of the legs to the material density.

$$M_2 = \frac{E^{1/2}}{\rho}$$

This measure allowed us to analyze the potential for buckling while still minimizing the final weight. Weight was a critical consideration for us as the final prototype is expected to be freighted to KATH upon completion. The target score of this index (i.e. the slope of the CES guidelines) was set at 2.

The attached CES printouts provide supporting documentation and greatly aided us in the final material selection. The CES software returned five possible material choices, listed in descending rank: Wrought Aluminum Alloy 7055 T7751, Wrought Aluminum Alloy 7249 T76511, Wrought Martensitic Stainless Steel AISI 414, Wrought Aluminum Alloy 6061 T6, and finally Zinc Aluminum Alloy Korloy 2573 Wrought Forged. The aluminum alloys provide all of the necessary strengths for the project but average a third of the density of the heavier steel and zinc materials. Advancing with an aluminum alloy was the obvious choice. At this point, we looked to local availability. The local metal supplier offered the necessary columns in only the 6061 T6 alloy. Obviously, one of the 7000 series alloys would have been better, but their use was in infeasible due to the cost of shipping. The final choice for the support frame's legs was the Wrought Aluminum Alloy 6061 T6.

Padding Cover
Function: Material exposed to acidic environment
Objective: Minimize price with acidic resistance prescribed.
Constraint: The material must have a very strong resistance to acidic environments.

No material indices were derived in the analysis of the padding cover, as no quantitative ranking system exists to define the resistance of a material to acidic environments. Rather, the qualifications are given as statements, such as Very Good or Weak. The vast majority of the materials in the CES database were quickly eliminated due to density and composition considerations. Ultimately, the CES software returned five possible material choices, listed in descending rank: PVC (Flexible, Shore 60A), PVC (Flexible, Shore 65A), PVC (Flexible, Shore 85A), PVC-Elastomer (Shore 35A), and finally PP (Copolymer, UV Stabilized). The obvious favorite was the PVC (Flexible, Shore 60A), more commonly known as vinyl. The attached CES printout illustrates that it maximizes the acidic resistance while minimizing the cost. We chose to move forward with this material for the padding covers.

Material Selection (Environmental Performance)

Now that the materials for the two major components have been decided upon, an environmental assessment of the final assembly can be completed using SimaPro software. It is important to note that the materials used in this environmental performance analysis were not the exact materials provided by CES, as the materials list is much more limited in SimaPro.

The assembly used in the SimaPro program was comprised of over 100 pounds of 0% recycled aluminum, 10 pounds of vinyl, and 100 pounds of equivalent aluminum machining. We chose to include the machining process in an attempt to produce more realistic results. Utilizing the EcoIndicator 99 method of analysis, an in depth environmental assessment was completed. Table 1 below illustrates the total mass (in kg) of the resultant air emissions, water emissions, use of raw materials, soil, and solid wastes. It is very evident that the use of raw materials dominated the mass breakdown, as can be seen in the attached bar graphs (See attached bar graphs at the end of this section).

Table 1: Total Mass Consumed

	Aluminum Frame	Vinyl for Padding Cover	Machining Aluminum	Total Mass
Air Emissions	537.33	16.64	6.97	560.94
Water Emissions	8.37	0.11	0.07	8.54
Raw Materials	13393.72	1069.75	160.45	14623.91
Soil	0.05	0.00	0.00	0.05
Solid Wastes	0.00	0.10	54.06	54.16

Within each of the three EcoIndicator 99 damage classifications (i.e. human health, ecosystem quality, and resources, the stock aluminum had the greatest negative impact on the environment. We believe this directly correlates to the fact that the overwhelming majority of the material used in the delivery bed was aluminum. Aluminum also has a large ecological cost in its formation.

Concerning the EI99 point values, it is evident that the vast majority of the points were attributed to the human health and the resources damage meta-categories. Again, the points assessed to the aluminum building materials dominated this particular analysis. However, while the aluminum has a much greater point value, the vinyl will have a much greater impact when the life cycle of the whole product is considered. The vinyl will wear out and be replaced long before the aluminum of the frame. This increasing consumption of vinyl will result in increased permanent wastes, while almost all of the aluminum can be recovered in a recycling process. Further analysis should be completed on the full life cycle of the redesigned delivery bed and its materials in an attempt to minimize unforeseen negative environmental impacts.

Having completed this environmental assessment, we might reconsider using aluminum in the manufacturing process of the delivery bed. In forming aluminum, a negative ecological impact is guaranteed and other nonferrous alloys could provide the required specifications. However, for the scope of this project, we chose aluminum in an attempt to manufacture the final design with materials available in Ghana.

Manufacturing Process Selection

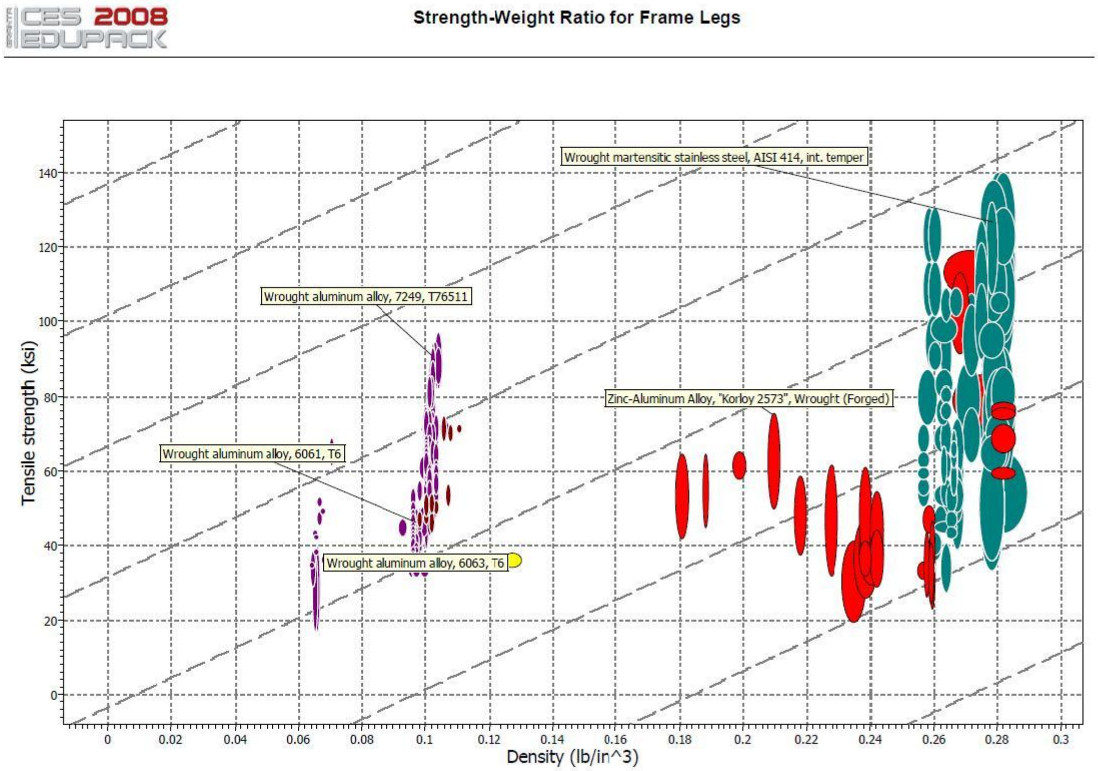
In any Global Health initiative, the ultimate goal is to produce an inexpensive functioning medical device that can be manufactured for distribution to hospitals and clinics worldwide. As such, we believe a real-world production volume of 10,000 to 100,000 reconfigurable beds could be used in global hospitals.

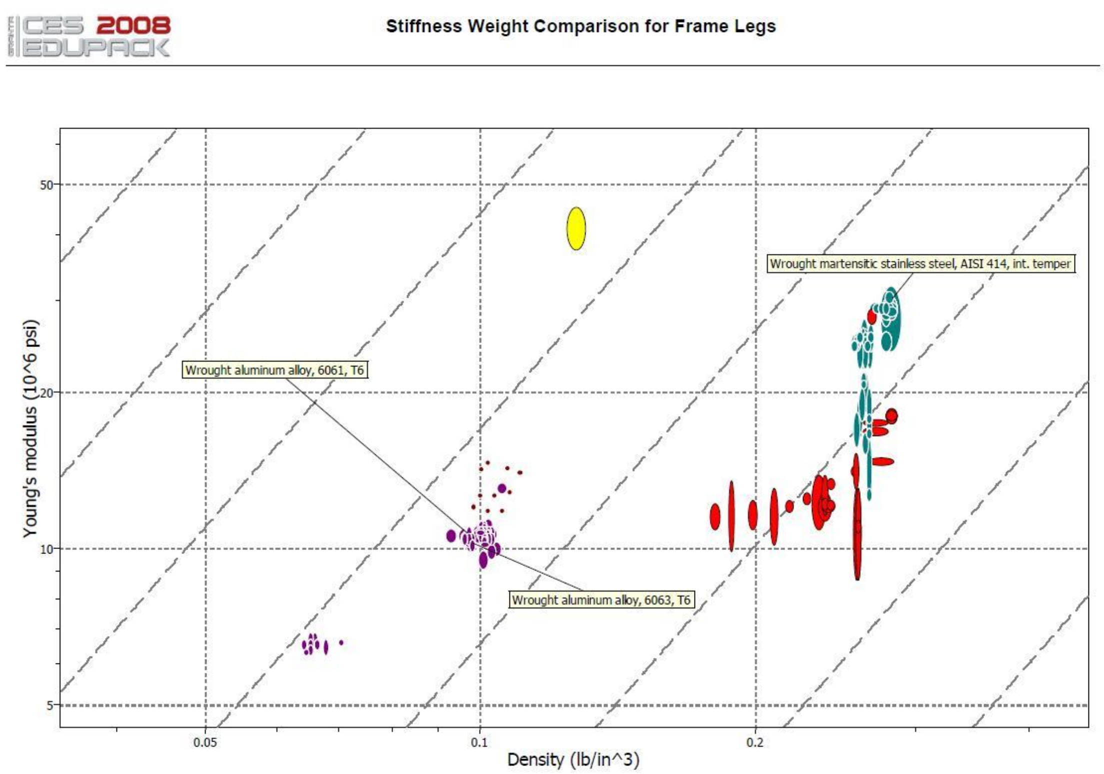
Having established a legitimate production volume, we next considered the possible manufacturing processes for each of the two major components discussed above: the support frame’s legs and the padding covers.

The material for the support frame’s legs was previously chosen to be the Wrought Aluminum Alloy 6061 T6. To further reduce material and thus cost and weight, we believe production should move forward with hollow tubes for the legs. Considering the constant cross section of the legs and the required batch size, several options were quickly eliminated using the CES Manufacturing Process Selection. The attached figures at the end of this section indicate that only hot metal extrusion and tape casting were viable options. Ultimately, we chose to move forward with a hot metal extrusion process. The extrusion manufacturing process handles the tolerances of our design and is a perfect fit for the constant cross sectional area of the aluminum legs.

The material for the padding cover was previously chosen to be PVC (Flexible, Shore 60A). Again, considering the required material compositions and batch sizes, several options were eliminated with the CES selector. Ultimately, we chose to move forward with a calendaring process for the vinyl. This process has excellent material utilization, high production rates, and would produce flat sheets of vinyl that would retain their shape well.

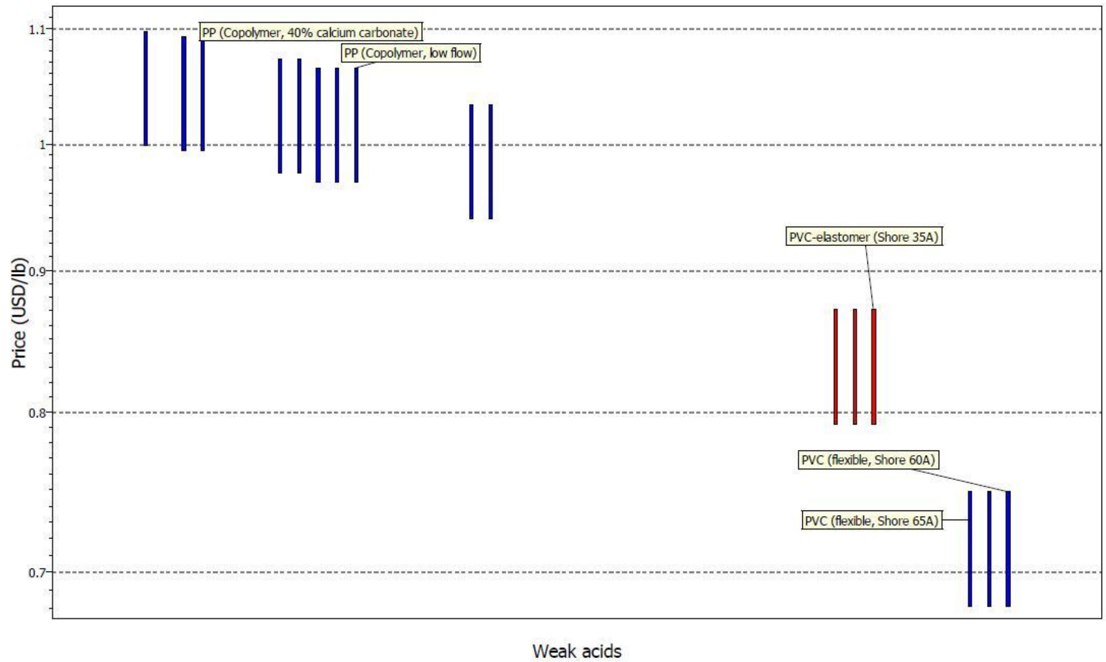
CES Printouts





CES 2008 EDUPACK

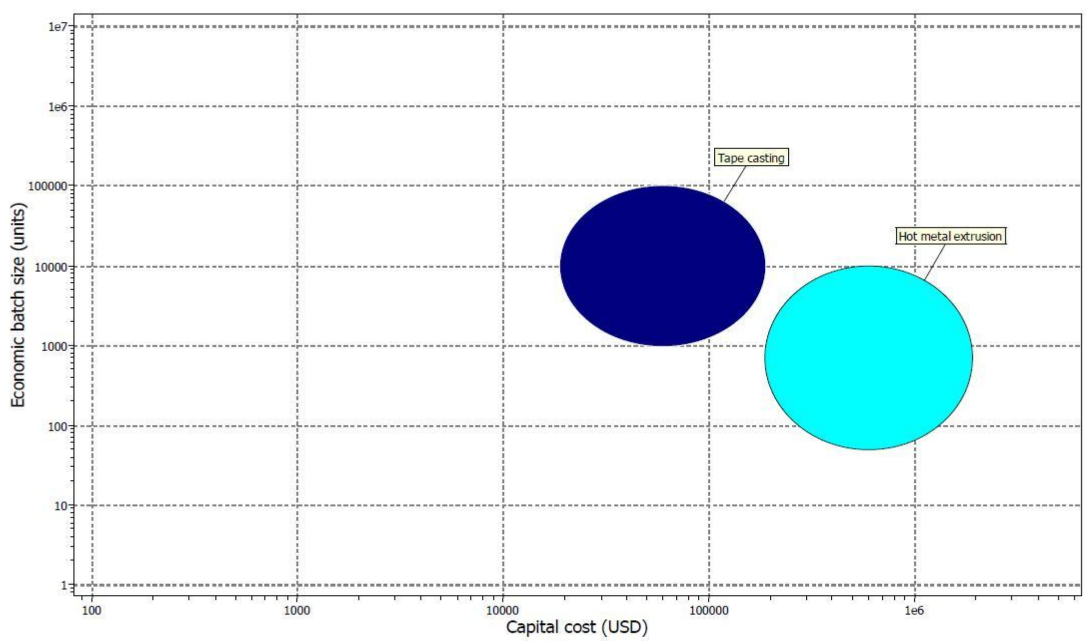
Price as a Function of Acid Resistance for Padding Cover



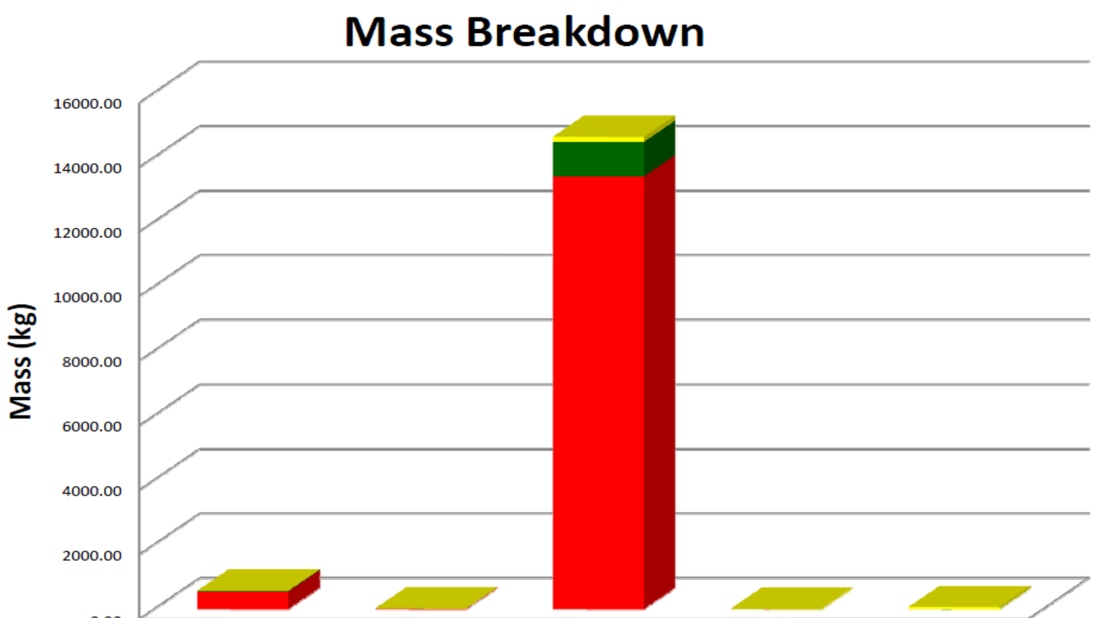
No warranty is given for the accuracy of this data. Values marked * are estimates.

CES 2008 EDUPACK

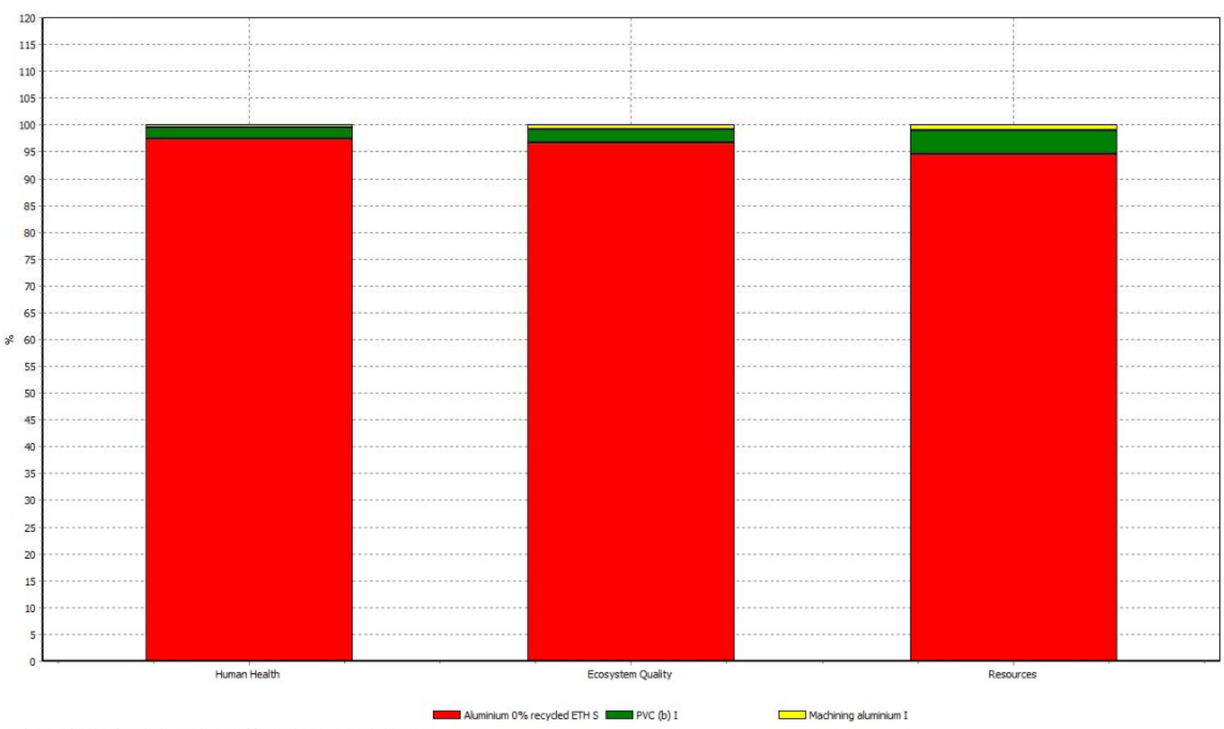
Process Selection for Aluminum

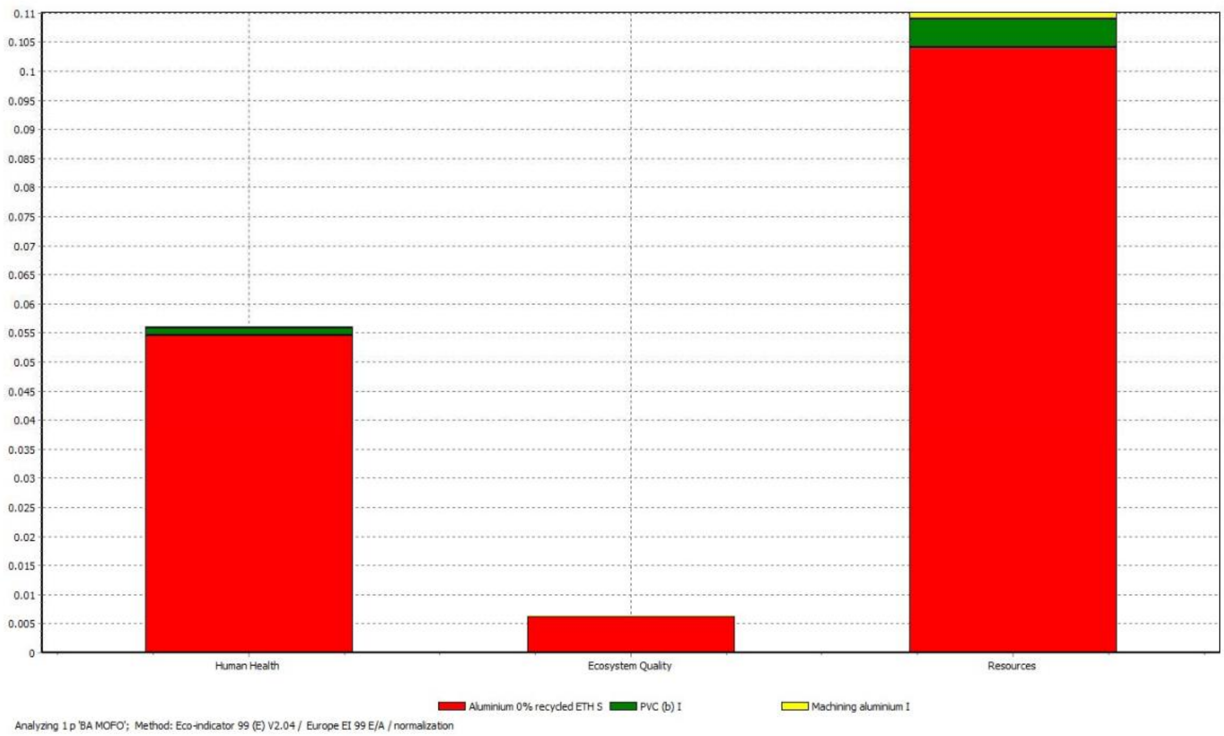


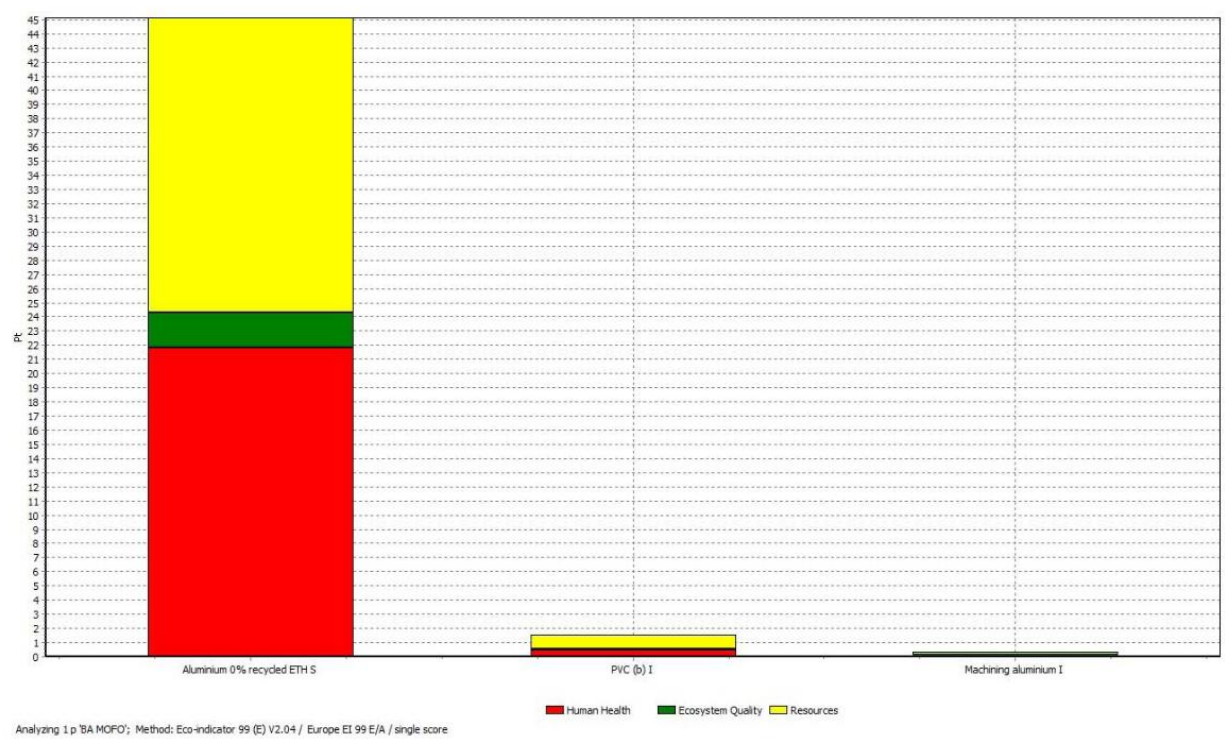
SIMAPro Bargraphs



	Air Emissions	Water Emissions	Raw Materials	Soil	Solid Waste
Machining Aluminum	6.97	0.07	160.45	0.00	54.06
Vinyl for Padding Cover	16.64	0.11	1069.75	0.00	0.10
Aluminum Frame	537.33	8.37	13393.72	0.05	0.00




Human Health
Ecosystem Quality
Resources
Aluminium 0% recycled ETH S
PVC (b) I
Machining aluminium I
Analyzing 1 p 'BA MOFO'; Method: Eco-indicator 99 (E) V2.04 / Europe EI 99 E/A / normalization


Pt
Aluminium 0% recycled ETH S
PVC (b) I
Machining aluminium I
Human Health
Ecosystem Quality
Resources
Analyzing 1 p 'BA MOFO'; Method: Eco-indicator 99 (E) V2.04 / Europe EI 99 E/A / single score

APPENDIX E: Updated QFD

System QFD

Project: **Obstetrics Delivery Bed**
Date: 1/20/09

#	Technical Requirement (correlations)	1	2	3	4	5	6	7	8	9	10	11	12	13
1	Upward Table Support Force													
2	Number of Supporting Legs	9												
3	Service Lifetime		1											
4	Safety Factor	3	1	1										
5	Manufacturing Cost		9	3	1									
6	Back Pad Inclinable					3								
7	Foot Pad Declinable					3								
8	Cleaning Time					1		3						
9	Adjustment Hand Force				3	1	3	3						
10	Coverage of Bed					3				1				
11	Comfortable Usage Time						3	3						
12	Percentage Bodily Fluids Collected					3		9	3					
13	Extra Materials Upward Support Force	1				1								
14														
15														
16														
17														
18														
19														
20														

Technical Requirements

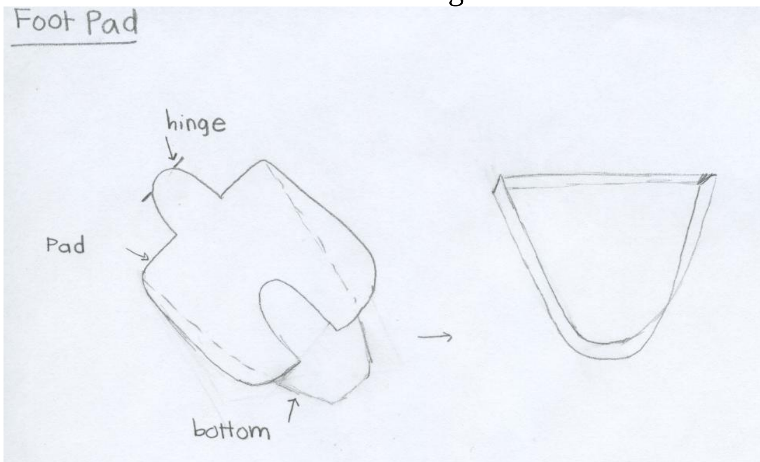
#	Customer Needs	Customer Weights	Upward Table Support Force	Number of Supporting Legs	Service Lifetime	Safety Factor	Manufacturing Cost	Back Pad Inclinable	Foot Pad Declinable	Cleaning Time	Adjustment Hand Force	Coverage of Bed	Comfortable Usage Time	Percentage Bodily Fluids Collected	Extra Materials Upward Support Force
1	Robust Bed	5	9	3	9	1	3								
2	Longevity	4		3	9		3	1	1						
3	Safety	5		1		9				1				1	
4	Affordable	5		3		1	9	1	1			1			
5	Reconfigurable	5					3	9	9		3		3	1	
6	Easy to clean/sanitize	5			1		1		1	9				3	
7	Easy to maneuver/adjust	4						9	9		9		1	3	
8	Privacy	1										9			
9	Comfortable	3						3					9		
10	Collects Bodily Fluids	2							1	3				9	
11	Holds examination/delivery materials	1				1									9
12															
13															
14															
15															
16															
	Raw score		45	47	86	56	92	99	97	56	51	14	46	55	9
	Scaled		0.455	0.475	0.869	0.566	0.929	1	0.98	0.566	0.515	0.141	0.465	0.556	0.091
	Relative Weight		6%	6%	11%	7%	12%	13%	13%	7%	7%	2%	6%	7%	1%
	Rank		11	9	4	5	3	1	2	5	8	12	10	7	13
	Requirement Benchmarking														
	Kano														
	Direction														
	Technical Requirement Units		N	#	Years	#	$	°	°	Min.	N	%	Hrs.	%	N
	Technical Requriement Targets		750	≥4	15	1.5	≤500	180 to 100	0 to -45	2	200-300	50	12	≥90	75

Customer Opinion Survey

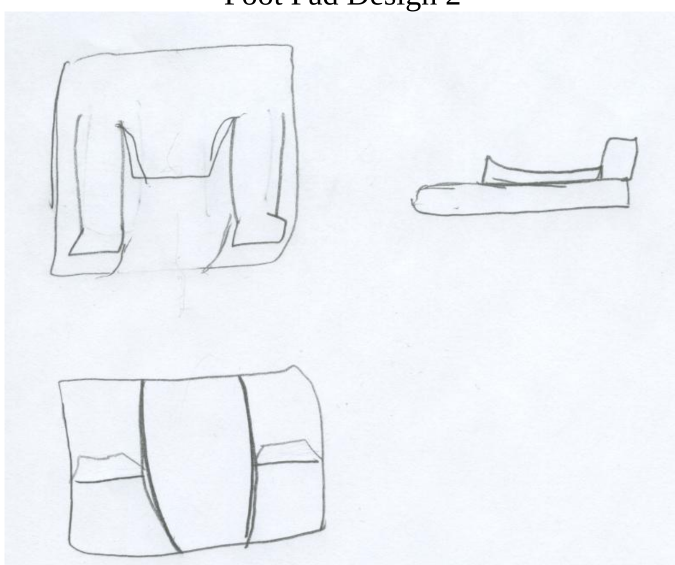
1 Poor	2	3 Acceptable	4	5 Excellent

APPENDIX F: Foot Pad Designs

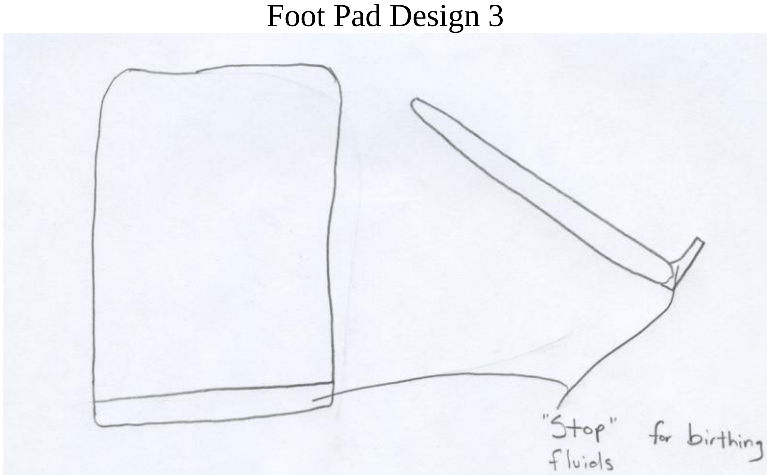
Foot Pad Design 1



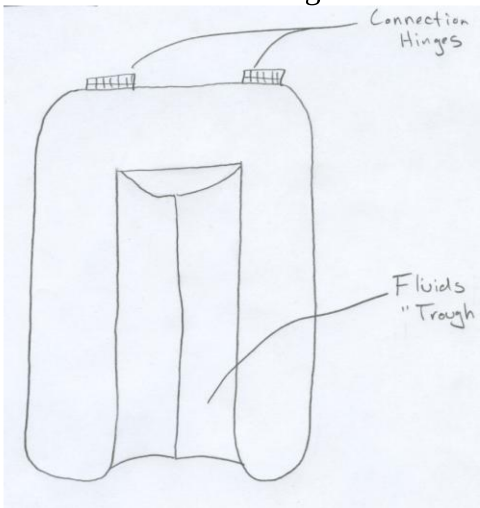
Foot Pad Design 2



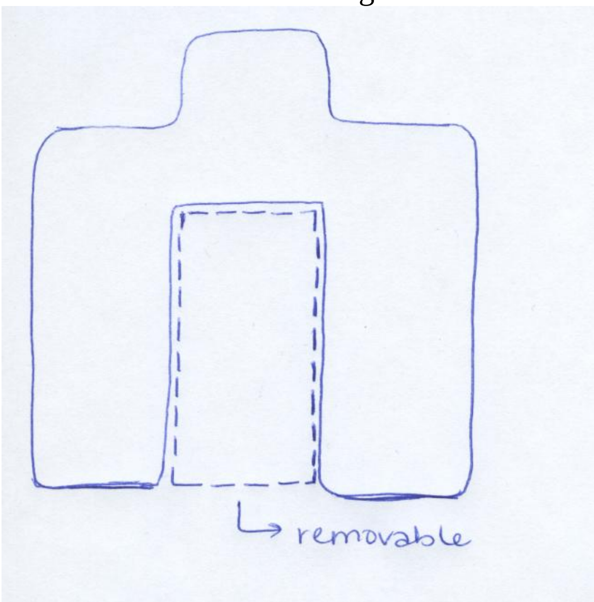
Foot Pad Design 3



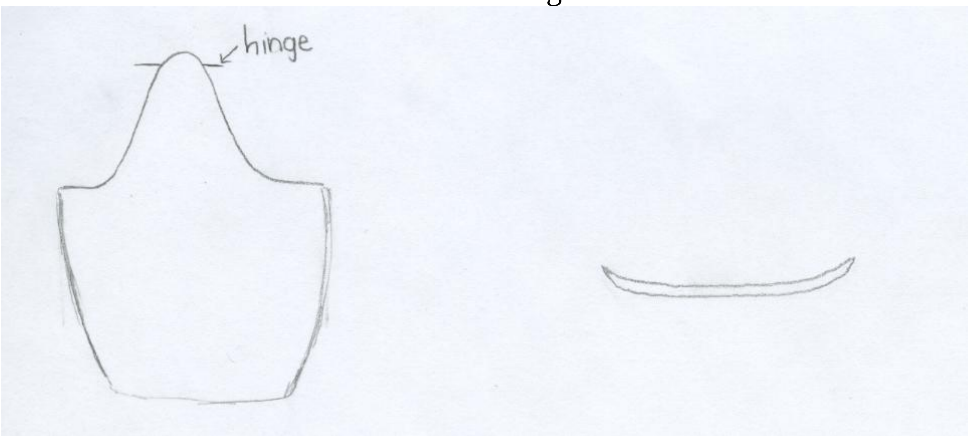
Foot Pad Design 4



Foot Pad Design 5

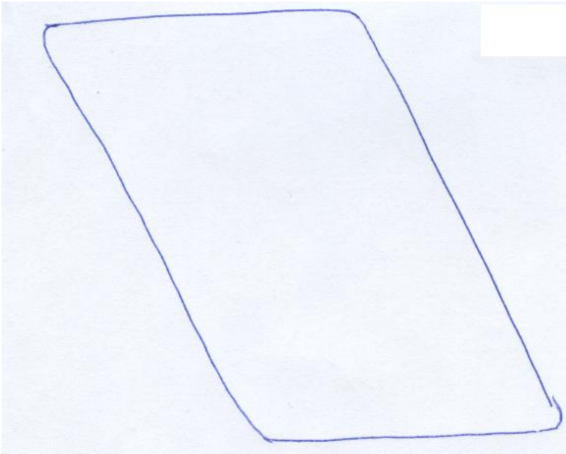


Foot Pad Design 6

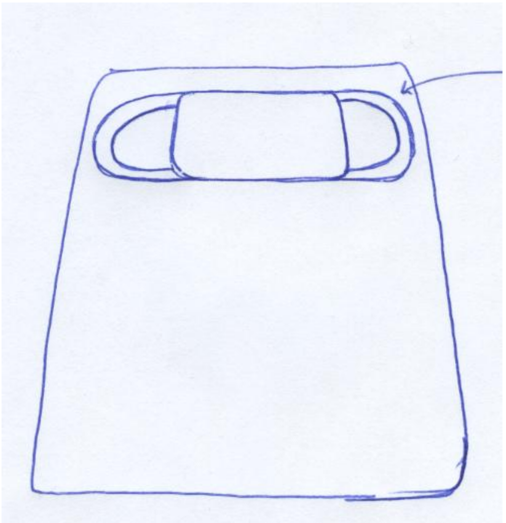


APPENDIX G: Back Pad Designs

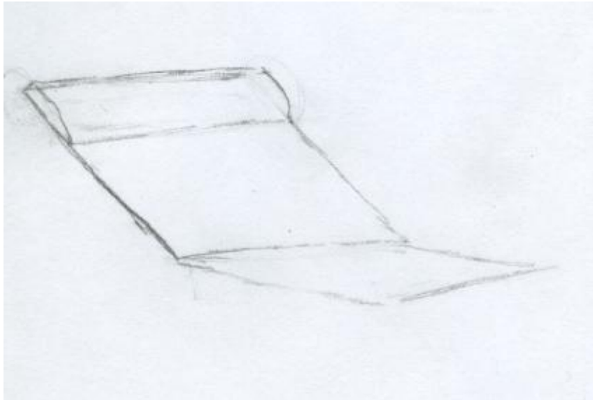
Back Pad 1: Basic Design



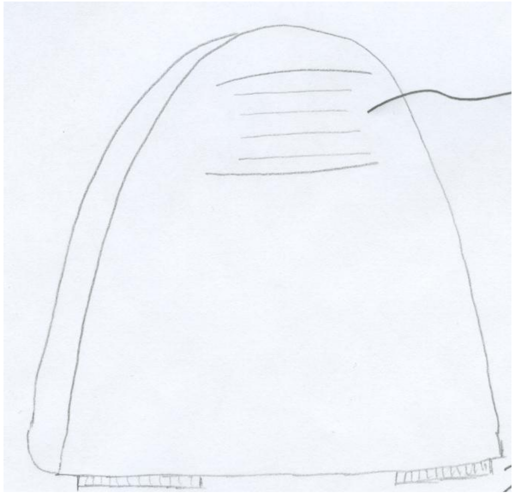
Back Pad 2: Airplane Back Pad



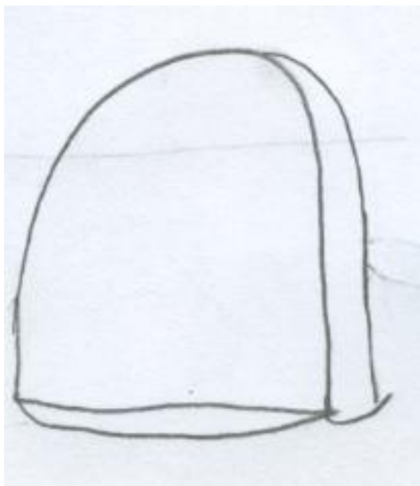
Back Pad 3: Beach Chair



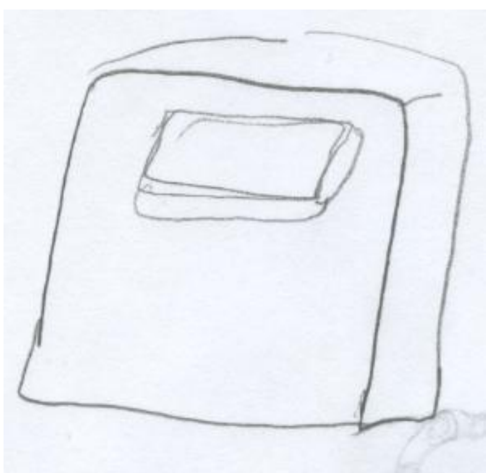
Back Pad 4: Indented Design



Back Pad 5: Rounded Design

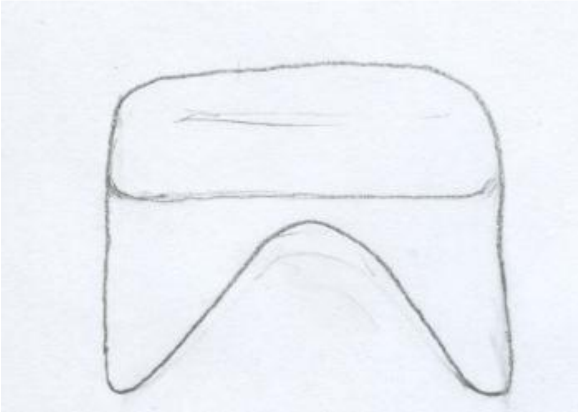


Back Pad 6: Square with Built in Pillow

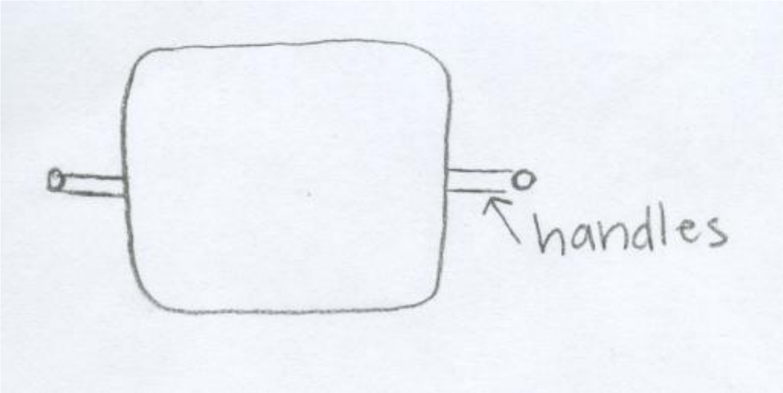


APPENDIX H: Seat Pad Designs

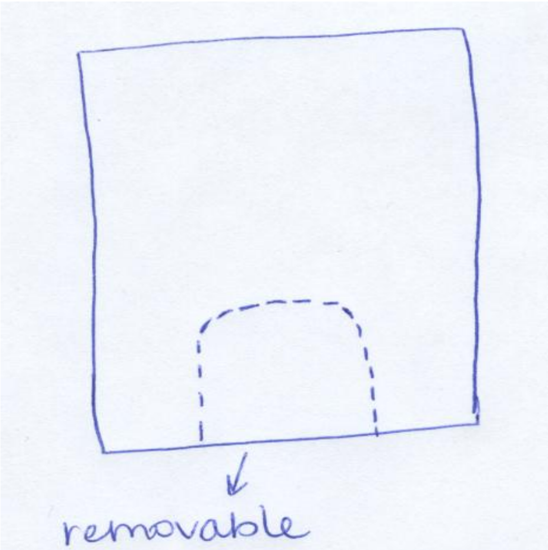
Seat Pad 1: Molar Designs



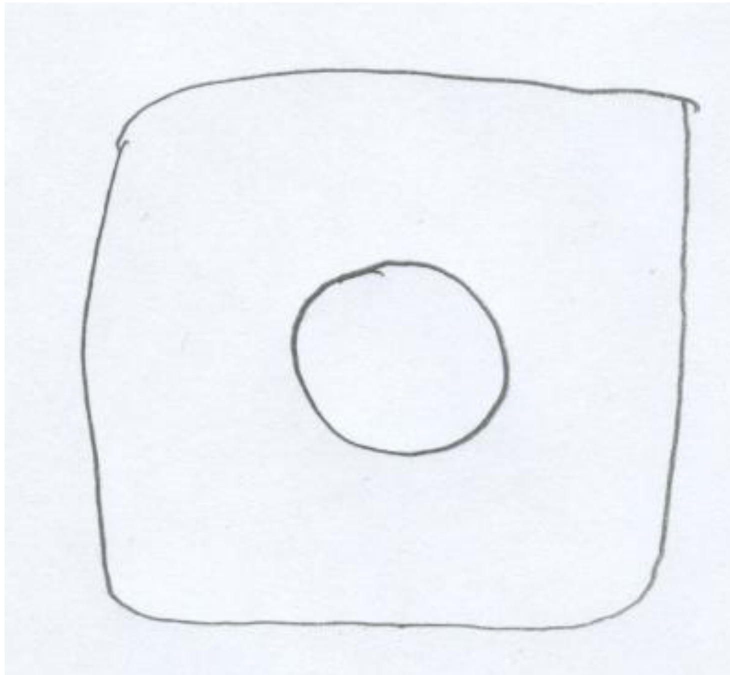
Seat Pad 2: Simple with Handles



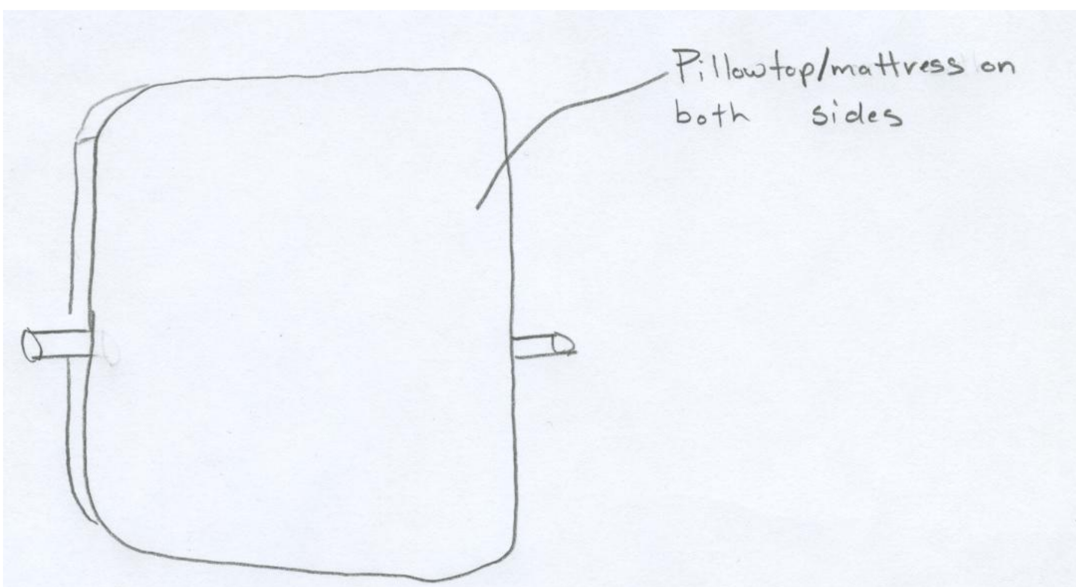
Seat Pad 3: Basic Pad with Removable Semi-Circle



Seat Pad 4: Center Urination/Defecation Hole

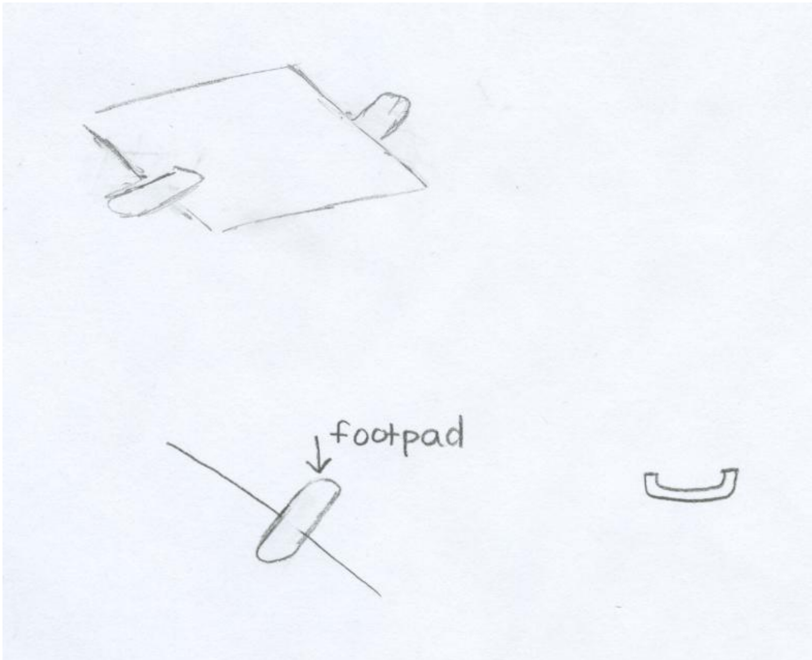


Seat Pad 5: Rotating Seat Pad

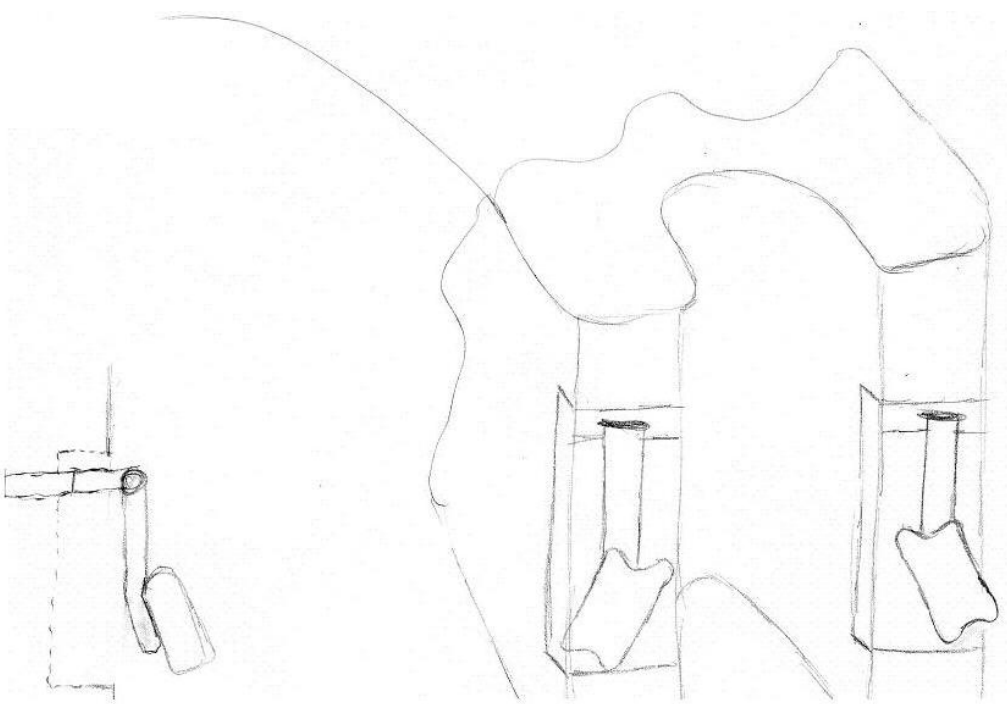


APPENDIX I: Stirrups or Leg Supports

Stirrups 1: Rotating

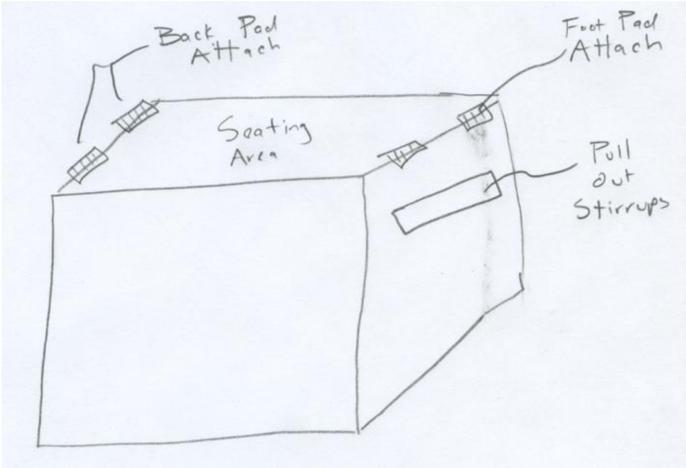


Stirrup 2: Traditional Stirrup

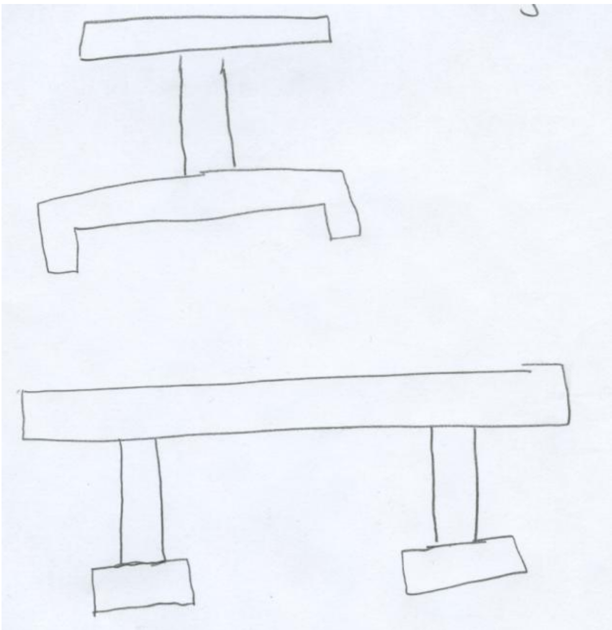


APPENDIX J: Frame Designs

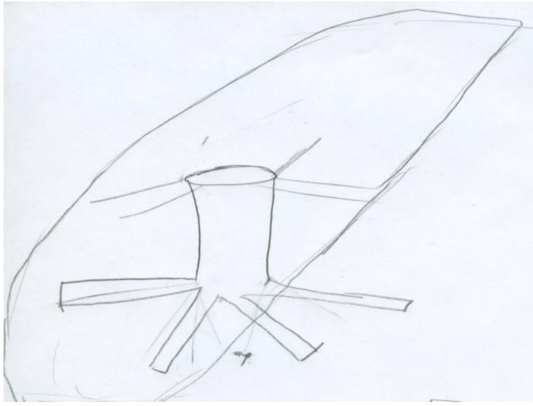
Frame 1: Box



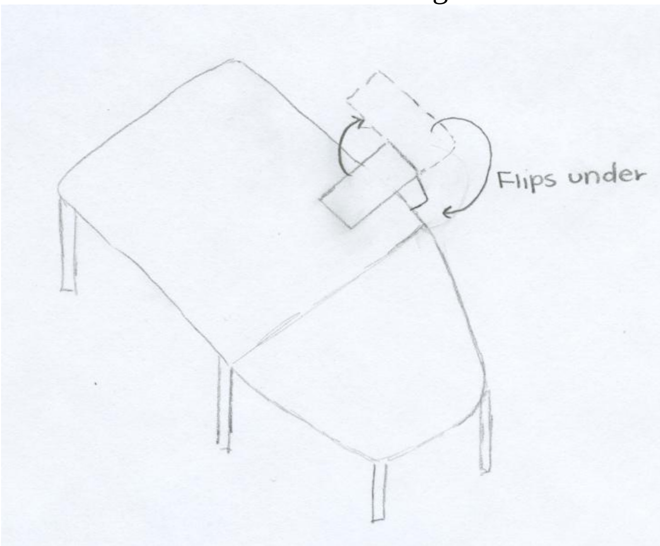
Frame 2: Saw Horse



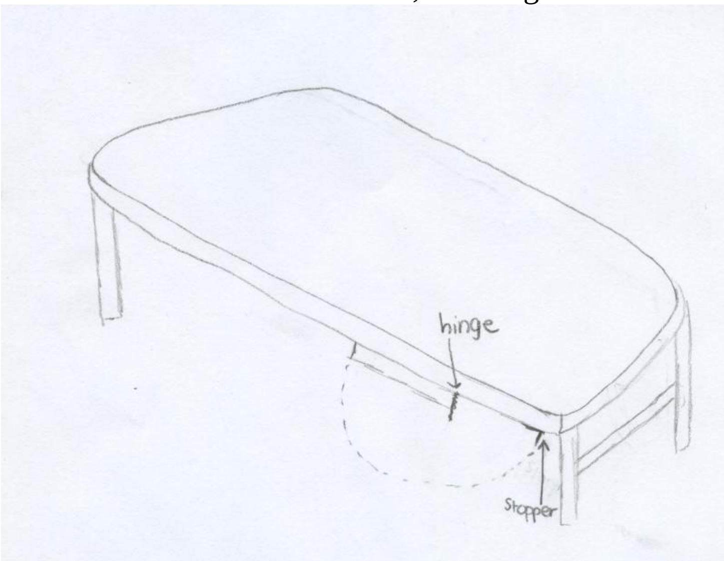
Frame 3: Tree Trunk



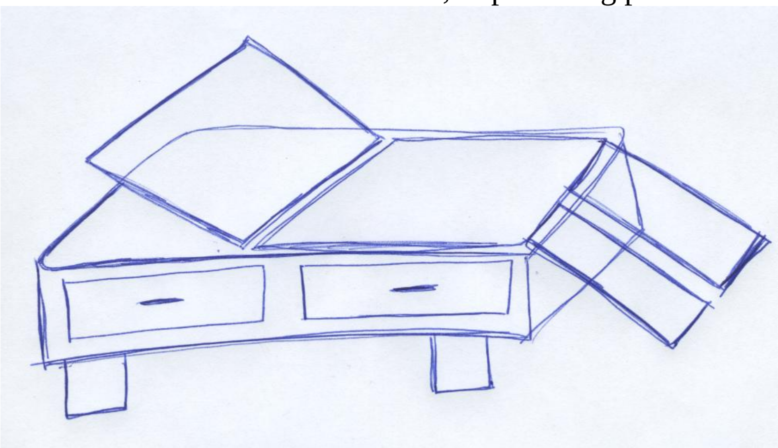
Frame 4: Foot Pad Swings Under



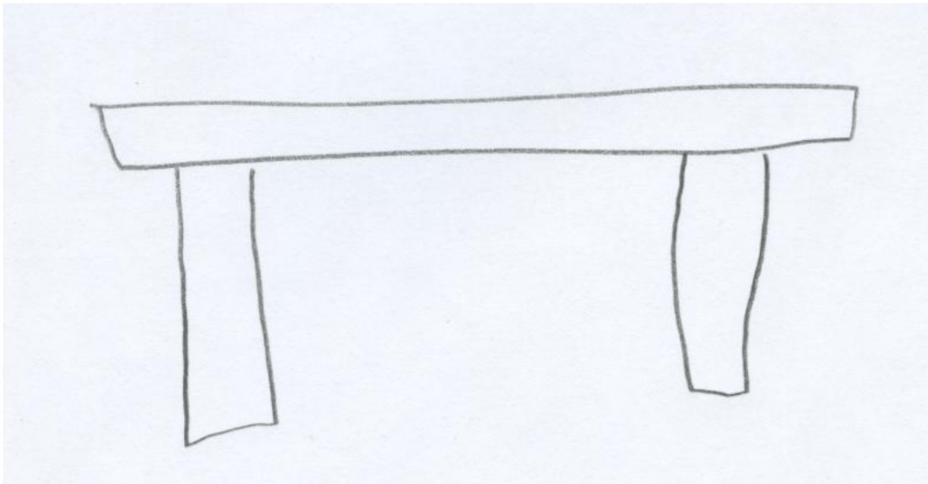
Frame 5: Standard Bed; Rotating Shelf



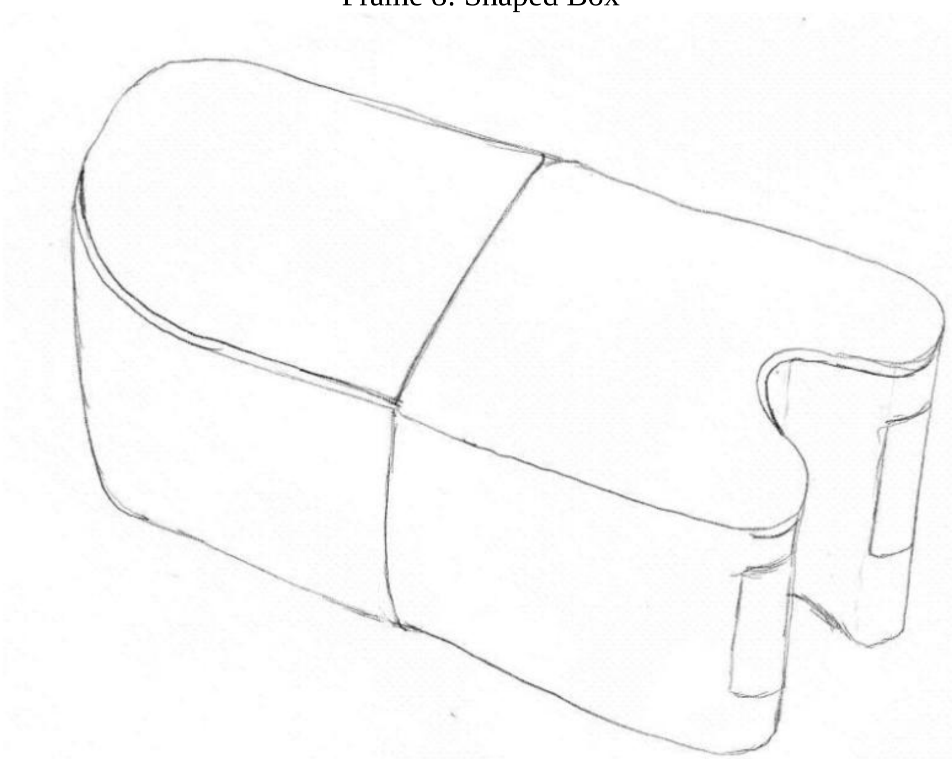
Frame 6: Box with Shelves; Separate leg pads



Frame 7: Table



Frame 8: Shaped Box



APPENDIX K: Pugh Charts

Complete Designs					
Specifications	**Alpha**	**1**	**2**	**3**	**4**
Longevity	+	+	+	+	0
Safety	0	0	0	0	0
Robust	+	+	+	+	0
Affordable	+	-	-	-	+
Reconfigurable	+	0	0	0	0
Easily Sanitized	0	-	0	0	0
Maneuverability	0	-	-	-	0
Privacy	+	0	0	-	-
Comfort	0	0	+	+	0
Fluid Collection	+	+	+	0	+
Holds Materials	-	0	0	+	0
Score:	+5	0	+2	+1	+1

Back Pad

Specs	**Air plane**	**Pillow embedded**	**Removable (flip) pillow**	**No pillow (current)**
Longevity	0	0	0	+
Safety	+	0	0	0
Robust	0	0	0	0
Affordable	-	-	-	+
Reconfigurable	+	-	+	0
sanitation	0	+	0	+
Maneuverability	0	0	0	+
Privacy	0	0	0	0
Comfort	+	0	+	-
Fluid Collection	NA	NA	NA	NA
Score:	+ + (2)	(-1)	+ (1)	+ + + (3)

Seat Pad

Specs	**Rotator**	**With bucket attachment**	**Pillow seat**	**Molar (U shaped FC)**
Longevity	0	0	0	0
Safety	0	0	0	0
Robust	-	-	0	0
Affordable	-	-	-	+
Reconfigurable	+	+	0	0
sanitation	-	+	+	+
Maneuverability	-	0	0	0
Privacy	0	0	0	0
Comfort	0	0	+	0
Fluid Collection	-	+	+	+
Score:	(-4)	+ (1)	+ + (2)	+ + + (3)

Privacy

Specs	**Curtain/Rod Assembly**	**Pull – Up Screen**	**Screen/Curtain on 1 side only**	**No privacy (current)**
Longevity	0	0	0	+
Safety	0	0	0	0
Robust	0	0	0	0
Affordable	-	-	-	+
Reconfigurable	+	+	+	0
sanitation	-	-	-	0
Maneuverability	+	+	+	+
Privacy	+	+	+	-
Comfort	+	+	+	-

Fluid Collection	NA	NA	NA	NA
Score:	++(2)	++(2)	++(2)	+ (1)

Locking Mechanisms

Specs	Beach Chair Locks	Movable Roller	La-Z-Boy Locks	Square rod on the back of the pad – rests on stoppers on the frame	Dial Incliner
Longevity	+	+	-	+	NOT
Safety	+	-	+	+	AN
Robust	+	+	+	+	OPTION
Affordable	+	+	-	+	
Reconfigurable	+	+	+	+	
sanitation	NA	NA	NA	NA	
Maneuverability	NA	NA	NA	NA	
Privacy	NA	NA	NA	NA	
Comfort	+	-	+	+	
Fluid Collection	NA	NA	NA	NA	
Score:	(6)	(2)	(2)	(6)	

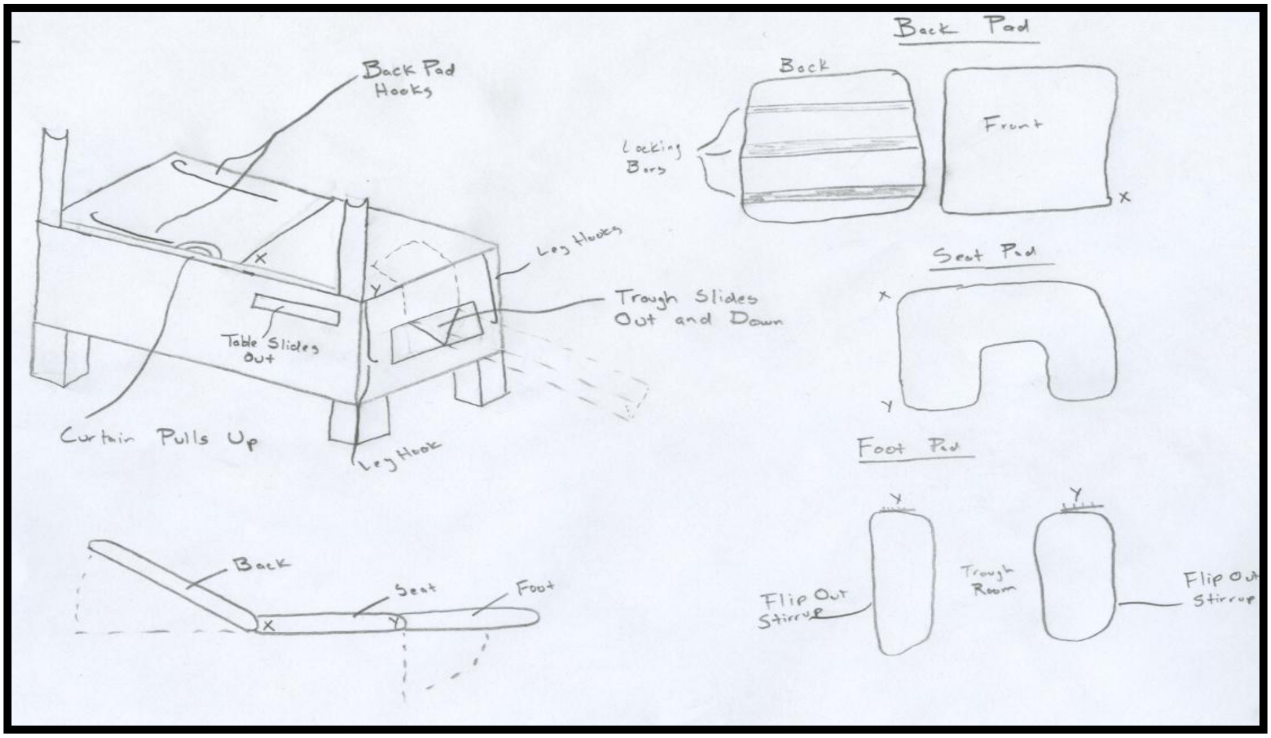
Frames

Specifications	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Longevity	+	0	-	0	0	+	0	+
Safety								
Robust	+	0	-	0	0	0	-	+

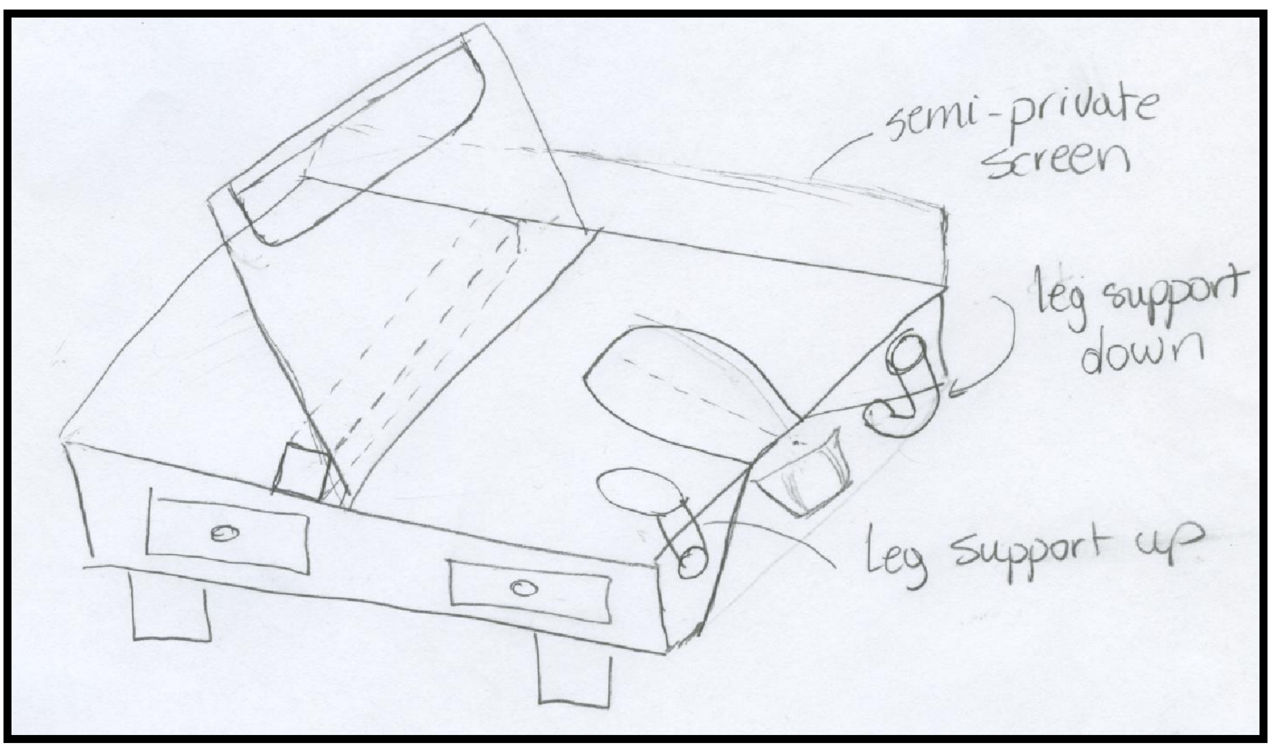
Affordable	-	0	0	0	0	-	0	-
Reconfigurable								
Easily Sanitized	0	0	-	0	0	-	0	0
Maneuverability	-	0	0	+	0	-	0	-
Privacy								
Comfort								
Fluid Collection								
Holds Materials	-	-	-	0	0	0	-	-
Score:	-1	-1	-4	1	0	-2	-1	-1

APPENDIX L: The Four Competing Designs

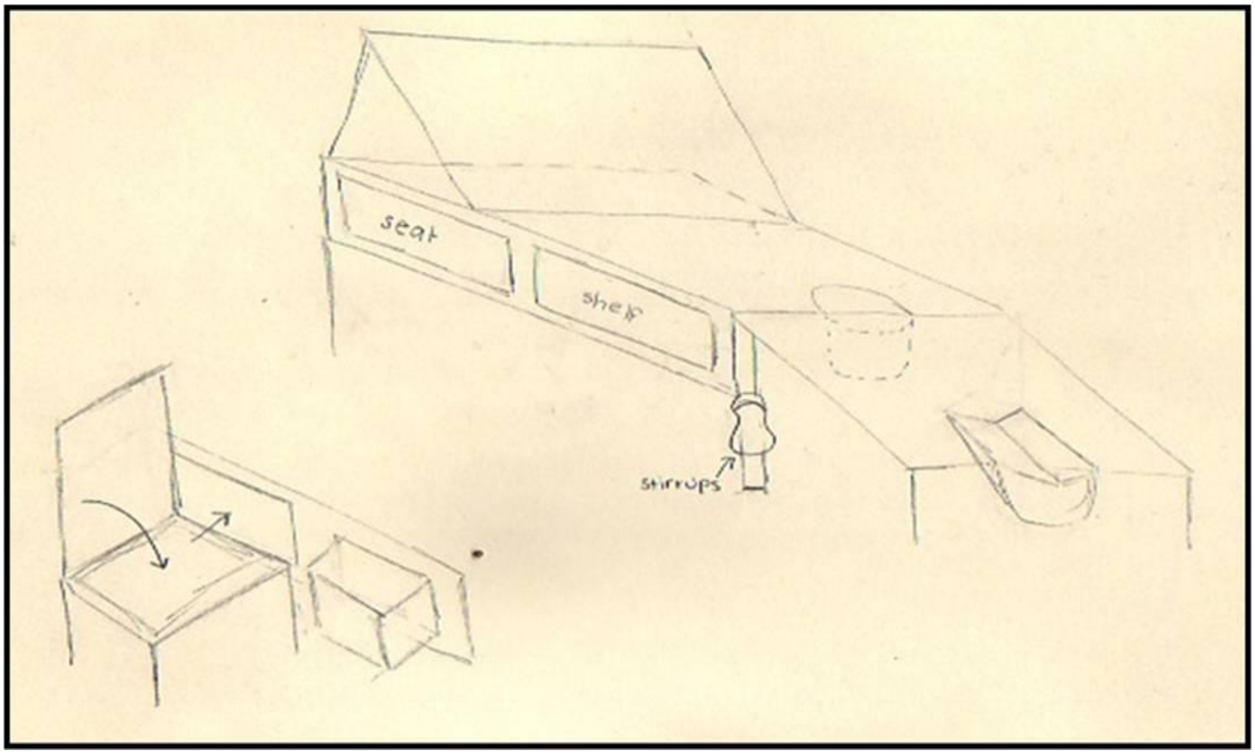
Design 1



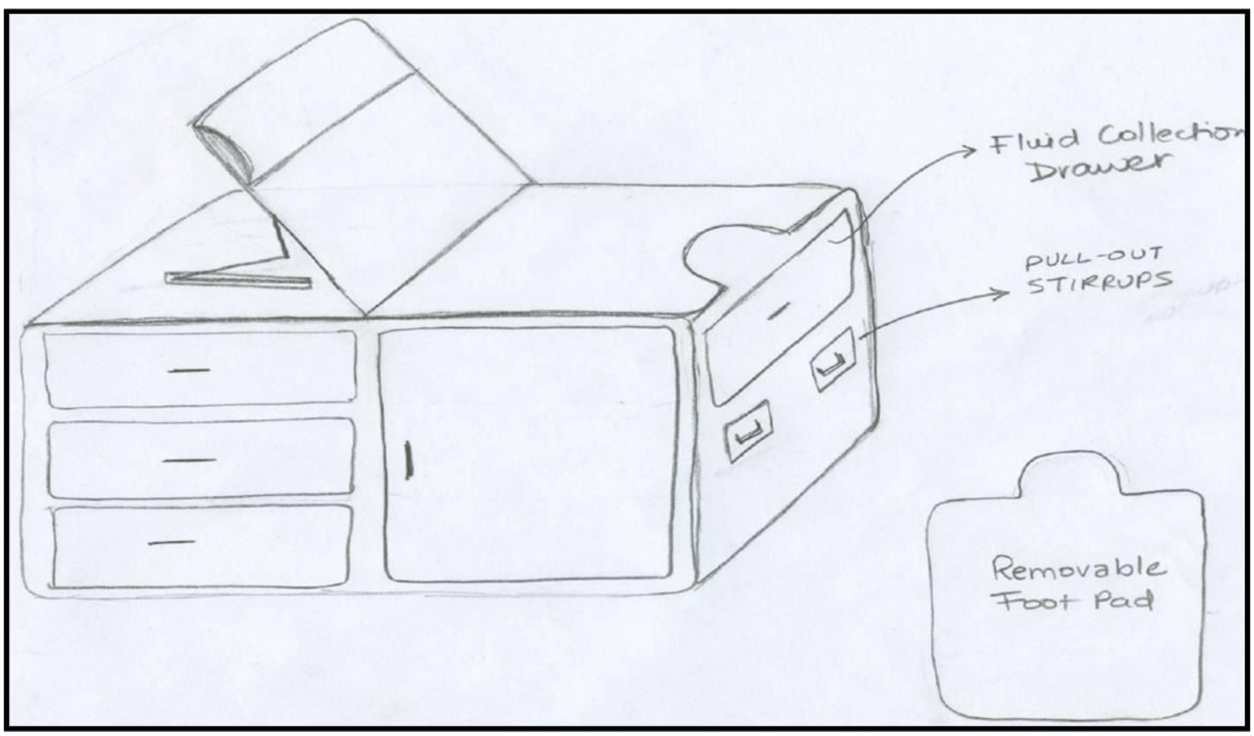
Design 2



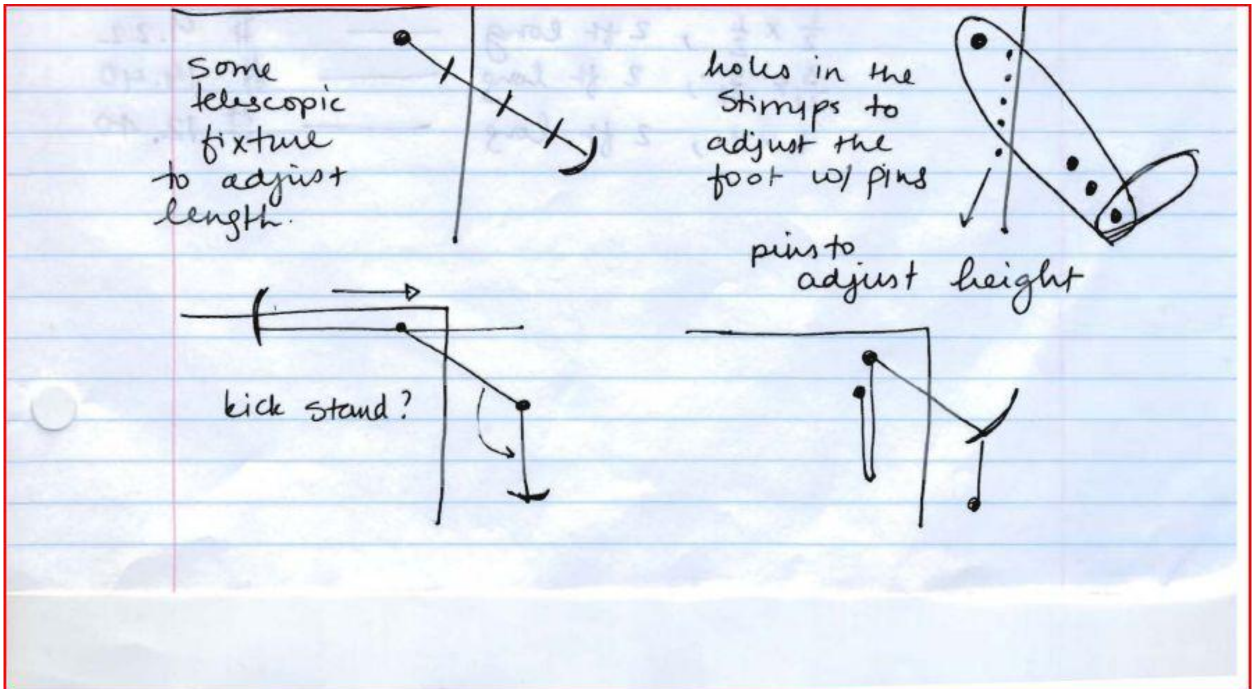
Design 3

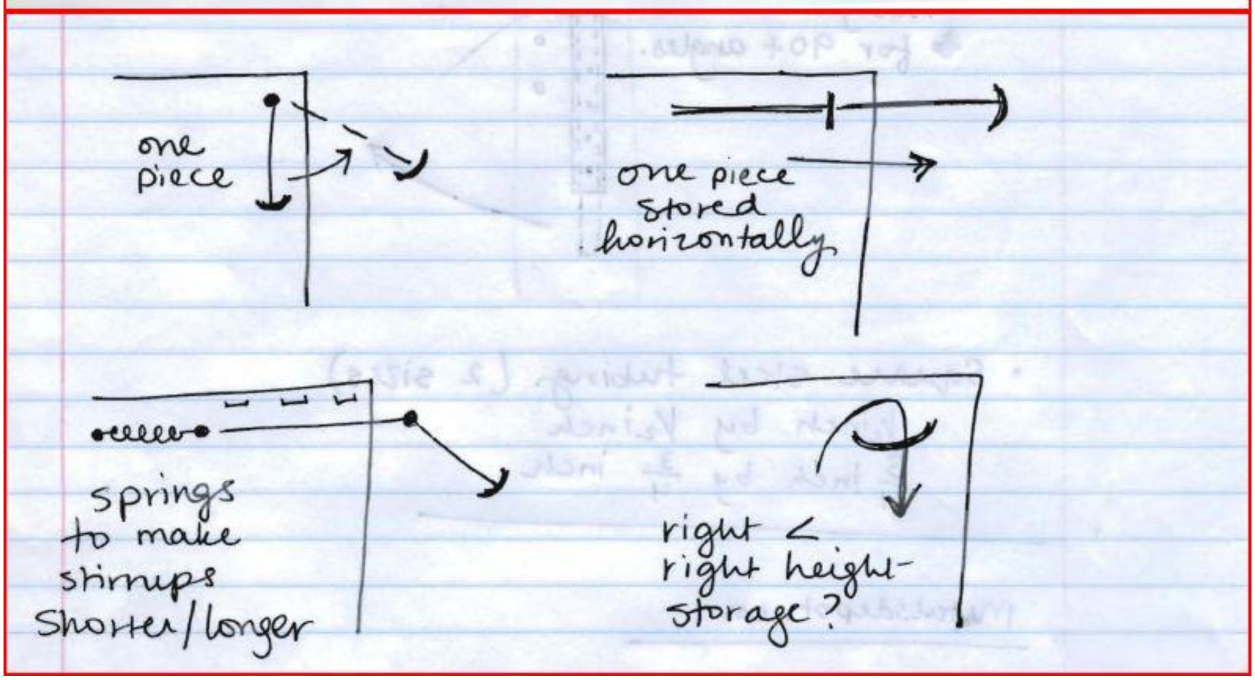


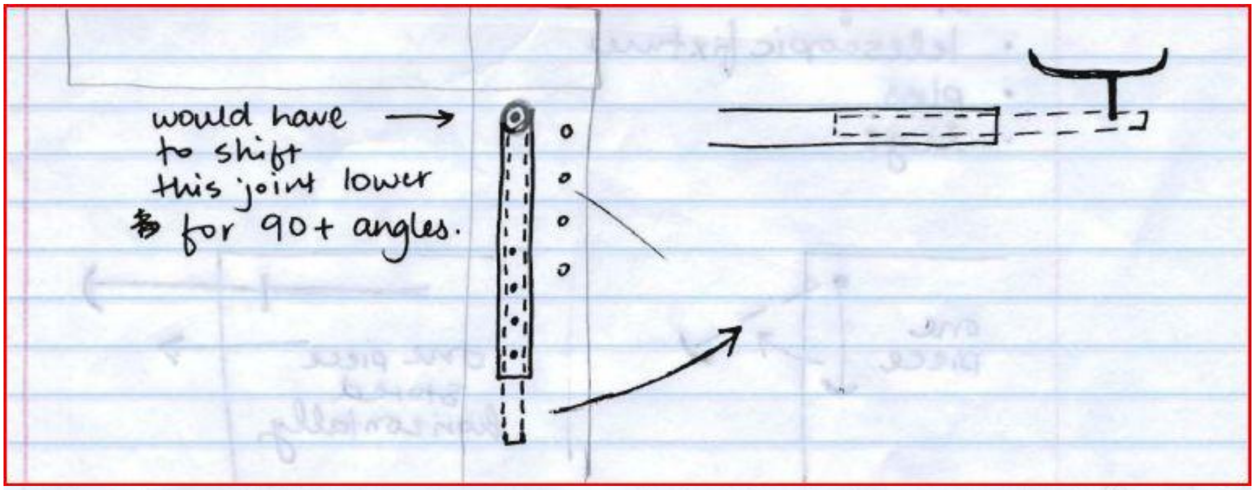
Design 4

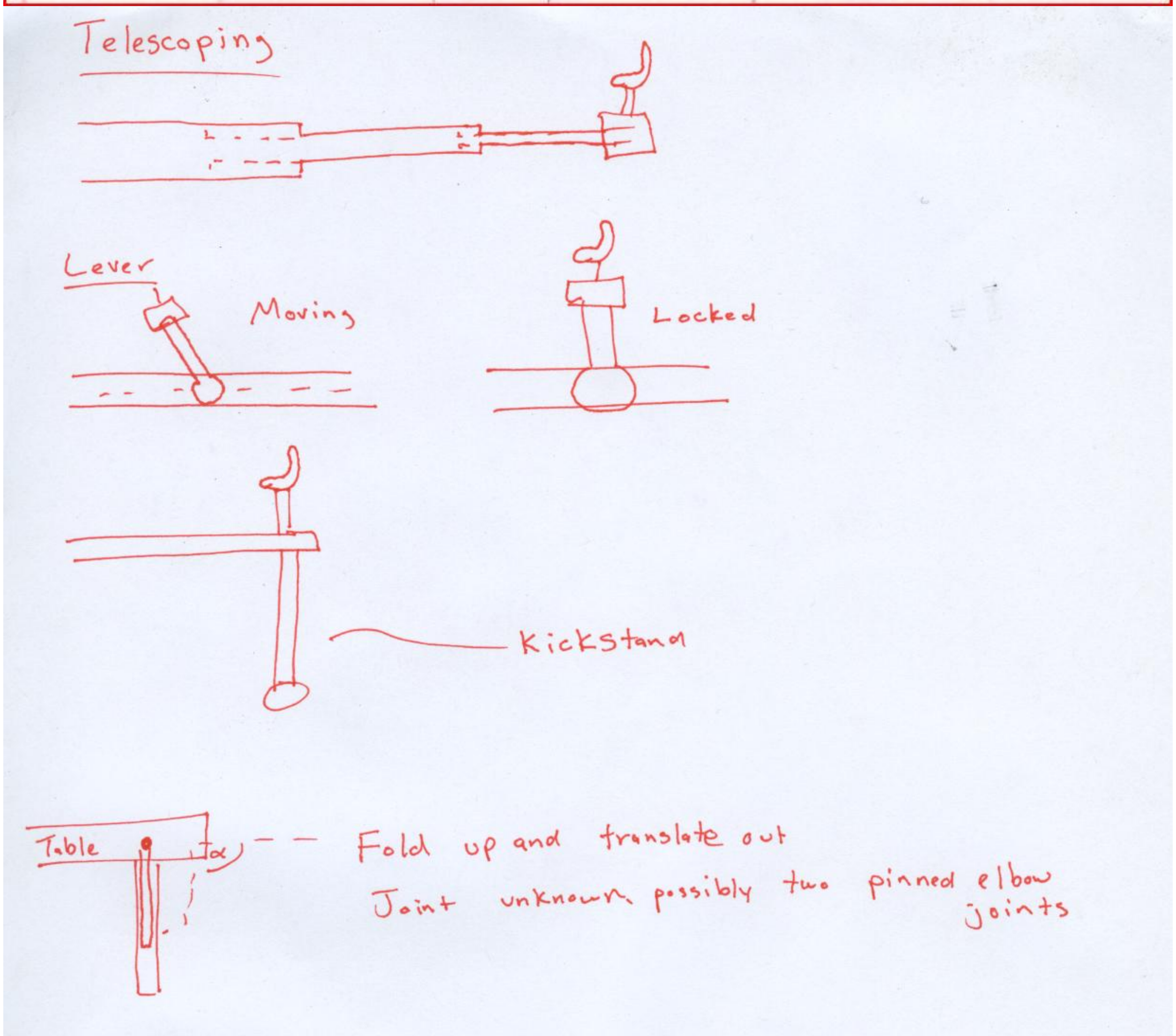


APPENDIX M: Stirrups' Concept Generation






would have to shift this joint lower for 90+ angles.


Telescoping
Lever
Moving
Locked
Kickstand
Table
α
Fold up and translate out
Joint unknown, possibly two pinned elbow joints

APPENDIX N: Engineering Analysis, Equations/Results on Legs and Back Support

Material: Steel

Leg: Bolt Calculations

Members: A36 Carbon Steel $\Rightarrow S_y = 36$ Kpsi, $S_{sy} = 33.466$

Bolts: SAE Grade 5, $S_y = 92$ Kpsi, $S_{sy} = 53.08$ Kpsi

Shear in Bolts:

$$A_s = 2\left[\frac{\pi (3/4)^2}{4}\right] = 0.884 \text{ in}^2$$

$$F_s = \frac{A_s S_{sy}}{n} = \frac{(0.884)(53.08)}{2} = 23.45 \text{ Kips}$$

Bearing on Bolts:

$$A_b = 2(3/4)(1/2) = 0.75 \text{ in}^2$$

$$F_b = \frac{A_b S_y}{n} = \frac{(0.75)(92)}{2} = 34.5 \text{ Kips}$$

Bearing on Member:

$$F_b = \frac{0.75(36)}{2} = 13.5 \text{ Kips}$$

Tension of Members:

$$A_t = (2 - 3/4)(0.5) = 0.625 \text{ in}^2$$

$$F_t = \frac{0.625(36)}{2} = 11.25 \text{ Kips}$$

$$F_{FAIL} = \min(23.45, 34.5, 13.5, 11.25) = 11.25$$

$$11.25 \gg 0.2 \Rightarrow \text{PASS}$$

Leg: Buckling

$$F_{BUCKLE} = \frac{\pi^2 E I}{L}$$

$F_{BUCKLE} = 4.42$ Kips

$4.42 >> 0.2 \Rightarrow$ PASS

Back Support: Bar Buckling

$$F_{BUCKLE} = \frac{\pi^2 E I}{L} \qquad I = mr^2$$

$$F_{BUCKLE} = \frac{\pi^2 \cdot (\cancel{5to3} \cdot (29 \cdot 10^3)(0.25)^2}{22^2}$$

$F_{BUCKLE} = 9.24$ Kips

$9.24 >> 0.2 \Rightarrow$ PASS

APPENDIX O: Engineering Analysis, Equations/Results on Legs and Back Support

Material: Aluminum

Leg Bolt Calculations

Members: 6061-T6

$S_y = 35.05\,ksi$

$S_{UT} = 40.7\,ksi$

$E = 10.28\,ksi$

Shear in Bolts:

$$A_s = 2\left[\frac{\pi(3/4)^2}{4}\right] = 0.884\,in^2$$

$$F_s = \frac{A_s S_{UT}}{n} = \frac{(0.884)(40.7\,ksi)}{2} = 17.9894\,Kips$$

Bearing on Bolts:

$$A_b = 2(3/4)(1/2) = 0.75\,in^2$$

$$F_b = \frac{A_b S_y}{n} = \frac{0.75(92)}{2} = 34.5\,Kips$$

Bearing on Member

$$F_b = 0.75\left(\frac{35.05}{2}\right) = 13.14\,Kips$$

Tension of members.

$$A_t = (2 - 3/4)(.5) = 0.625\,in^2$$

$$F_t = \frac{0.625(35.05)}{2} = 10.95\,kips$$

$$F_{fail} = \min(17.99, 34.5, 13.14, 10.95) = 10.95$$

$$10.95\,Kips \gg 0.2\,Kips \Rightarrow pass$$

Leg Buckling

$$F_{buckle} = \frac{\pi^2 E I}{L}$$

2inx2in square tubes with 1in wall thickness
I (available on supplier website).

$I = 0.486\ in^4$ $L = 31\ in$

$$F_{buckle} = \frac{\pi^2 * 10.28\ ksi\ (.486\ in^4)}{31\ in} = 1.590\ kips$$

$$1.590 >> 0.2 \Rightarrow pass$$

Back support bar buckling

$$F_{buckle} = \frac{\pi^2 E I}{L} \qquad I = mr^2$$

$$F_{buckle} = \frac{\pi^2 (10.28)(.184)}{31} = 6.02\ kips$$

$$6.02\ Kips >> 0.2 \Rightarrow pass$$

[i] Ansong-Tornui, J., Armar-Klemesu, M., Arhinful, D., Penfold, S., & Hussein, J. (2007). Hospital Based Maternity Care in Ghana - Findings of a Confidential Enquiry into Maternal Deaths. *Ghana Medical Journal , 41* (3), 125-132.

[ii] D'Ambruoso, L., Abbey, M., & Hussein, J. (2005). Please understand when I cry out in pain: women's accounts of maternity services during labour and delivery in Ghana. *BMC Public Health* , 140.

[iii] Ansong-Tornui, J., Armar-Klemesu, M., Arhinful, D., Penfold, S., & Hussein, J. (2007). Hospital Based Maternity Care in Ghana - Findings of a Confidential Enquiry into Maternal Deaths. *Ghana Medical Journal , 41* (3), 125-132.

[iv] World Health Organization. (2008). *World Health Statistics.* Geneva: World Health Organization Press.

[v] Bazzano, A. N., Kirkwood, B., Tawiah-Agyemang, C., Owusu-Agyei, S., & Adongo, P. (2008). Social costs of skilled attendance at birth in rural Ghana. *International Journal of Gynecology and Obstetrics* , 91-94.

[vi] Bazzano, A. N., Kirkwood, B., Tawiah-Agyemang, C., Owusu-Agyei, S., & Adongo, P. (2008). Social costs of skilled attendance at birth in rural Ghana. *International Journal of Gynecology and Obstetrics* , 91-94.

[vii] Bazzano, A. N., Kirkwood, B., Tawiah-Agyemang, C., Owusu-Agyei, S., & Adongo, P. (2008). Social costs of skilled attendance at birth in rural Ghana. *International Journal of Gynecology and Obstetrics* , 91-94.

[viii] ACOG. (2007, January). You and Your Baby: Prenatal Care, Labor and Delivery, and Postpartum Care. *The Patient Education Pamphlet* . Washington, D.C.: American College of Obstetricians and Gynecologists.

[ix] Mayo Clinic. (2007, April 13). *Stages of Labor: Baby, It's Time!* Retrieved January 25, 2009, from MayoClinic.com: http://www.mayoclinic.com/health/stages-of-labor/PR00106

[x] Mayo Clinic. (2007, April 13). *Stages of Labor: Baby, It's Time!* Retrieved January 25, 2009, from MayoClinic.com: http://www.mayoclinic.com/health/stages-of-labor/PR00106

[xi] ACOG. (2007, January). You and Your Baby: Prenatal Care, Labor and Delivery, and Postpartum Care. *The Patient Education Pamphlet* . Washington, D.C.: American College of Obstetricians and Gynecologists.

[xii] ACOG. (2007, January). You and Your Baby: Prenatal Care, Labor and Delivery, and Postpartum Care. *The Patient Education Pamphlet* . Washington, D.C.: American College of Obstetricians and Gynecologists.

[xiii] ACOG. (2007, January). You and Your Baby: Prenatal Care, Labor and Delivery, and Postpartum Care. *The Patient Education Pamphlet* . Washington, D.C.: American College of Obstetricians and Gynecologists.

[xiv] Hill-Rom Affinity 4 Birthing Bed. *Hill-Rom Enhancing Outcomes for Patients and Their Caregivers*. http://www.hill-rom.com/USA/Affinity.htm