Engineering Project

Safe Crib
ME 450 Fall 2008
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Section Instructor

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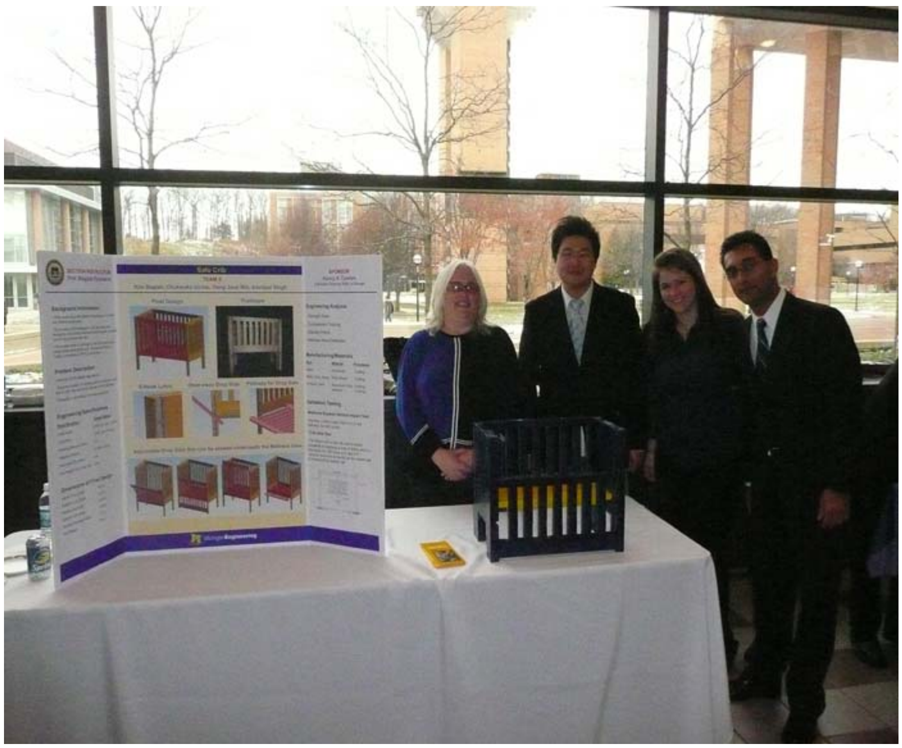

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1.0 Executive Summary

Cribs cause injury and death to thousands of infants and children every year. By focusing on the dangers a crib can have and designing a layout that address those hazards, a child's risk of injury can be reduced. This project aims to redesign a crib and improve its safety while meeting the U.S. Consumer Product Safety Commission (CPSC) guidelines. Our team is working with Nancy A. Cowles, Executive Director of Kids in Danger, a non-profit organization whose goal is to protect children by getting manufacturers to make their products safer.

After analyzing various recalls from CPSC, our team reached the argument that various manufacturers failed to address the safety regulations from CPSC to ensure child safety. This failure to meet the guidelines lead to a less safer crib causing child injury due a fall hazard in some cases while in others entrapment hazard was the prominent cause of accident. In addition, poor and complex assembly instructions lead to improper installation of the crib causing injuries to the child due to hardware disengagement. Due to these over looked hazards, our main specifications related to the crib design are in terms of meeting the federal CPSC guidelines for the crib dimensions [4]. This will ensure a safer crib, less prone to crib related hazardous incidents. In addition, we present an alpha design in this report with a focus on minimum mobile parts and installation, reducing the risk of hardware failure and creating an easy assembly method that can be shipped in compact packages by manufactures.

We succeeded in these focus points for the alpha design, mentioned above, through our manufacturing plan. Our manufacturing plan for the prototype and final design both focus on simplicity by only creating five key pieces for assembly. The first step of the manufacturing is the general manufacturing where the four sides with slats get their slats either created by removal of material from the side or lathed and then installed into the side's frame. Then each side is specifically detailed with the correct amount of male or female portions of the T-slot specific to the piece's placement. Most of the manufacturing for the prototype is done by a table saw, jigsaw, and drill, while most of the manufacturing for the final design will be done by mill or lathe, with a few pieces initially cut by a table saw and drilled.

Through data analysis and research on benefits of current materials used for cribs, we were able to use different programs, such as SimaPro, CES, and Hypermesh, to better understand what materials would be best to used for our prototype and for our final design. Due to material strength, the material's environmental impact, material cost, and material accessibility, the data we received from these programs lead our team to choose Oregon Pine wood as our material for the whole crib, with small amounts of aluminum and stainless steel used in detailing.

2.0 Abstract

From 2004-2006 an average of 63,700 children each year under the age of 5 were injured by nursery products; and in 2006, an estimated 11,300 of those injuries were caused by cribs and mattresses alone. With the concept of a crib being a place where children can sleep safely, there has been a serious lapse of judgment as to what can be considered safe. This project is a continuation of a 2007 ME450 crib design project. Our Project of building a Safe Crib is a severe issue that is commonly overlooked. This year we started off by brainstorming new ideas about how society thinks about what a crib should look like and what functions a crib really needs to have. We also addressed problems that the previous team found and problems we found with our new prototype, to the best of our ability. Throughout the semester we truly engulfed ourselves with the everyday hazards that babies and children run into when they are in their crib that are often overlooked. By researching recalled cribs and reports of injuries due to cribs, we examined and fixed almost all the issues of current crib hazards that we found with new and inventive solutions. We ended up with a product that we feel is safe, consumer friendly, and affordable. For more information on the topic of children's product safety including cribs, visit www.KidsInDanger.org and www.cpsc.gov.

3.0 Customer Requirements and Engineering Specifications

After a series of communication with our sponsor, we came up with a list of costumer requirements (CR) that best represented what our sponsor wanted. These customer requirements all revolved around the safety of the child in his or her crib. Our team related each of these CR to engineering specicfications, seen in our Quality Funtional Development (QFD) chart in Appendix-A on p-53. The CR on the QFD were rated, from 1 to 14, based on their importance to the design for our new crib, with a ranking of 1 being the most important requirement to be considered. The most significant of our CR was making sure our product meets the U.S. Consumer Product Safety Commission (CPSC) guidelines. From the CPSC guidelines, our team was able to come up with benchmarks for the engineering specifications listed in Table-1. These benchmarks will help us with designing a safer crib and ensure that our crib meets the CPSC requirements.

Table-1. Engineering Specifications related to Benchmarks from CPSC

Engineering Specifications	Benchmark Specifications
Crib Length	CPSC standard (52 3/8 ± 5/8 in)
Crib Width	CPSC standard (28 ± 5/8 in)
Spacing Between Rails	2.5 in
Fatigue Lifetime	250,000 cycles
Rail Height for infant	9 in
Rail Height For 2 year old	26 in

With our QFD, we found the relationship between the CR and our engineering specifications by considering each CR and seeing which specification had an effect on which requirements. The team correlated an engineering specification with the customer requirement with a number. Each relation was assigned either 1, 3, or 9, with 1 being weakly related, 3 being somewhat related, and 9 having the strongest relationship. If there was no relation at all then the space was left blank. The requirements that ended up holding most significance were meeting the CPSC guidelines, and being able to easily manouver the crib, which had the weakest relationship with the engineering specifications.

3.1 *Reason for choosing the Engineering Specifications*

Once our customer requirements were decided on, we needed to create engineering specifications that would help us quantify what our sponsor wanted. In order to do this, our team had to take each requirement into consideration and think about the scientific way we could ensure the sponsors needs were met. For example, in order to meet the CPSC guidelines, our design will have to uphold all of the dimsional specifications in Table 2. Another CR that was more difficult to create specifications for was crib stability. The way we quantified how to make the crib stable was by analyzing what stability entails. Through this analyzation we realized that this meant our team would have to take crib weight, the cribs center of gravity, and the material density of the crib into consideration during the designing process. All of our engineering specifications and their weighted relationship to the CR can be seen in our QFD listed in Appendix A on p-53.

3.2 *Description of key Engineering Specifications*

Crib Length: Crib length would meet the CPSC standard of (52 3/8 ± 5/8 in)
Crib Width: Crib width would meet the CPSC standard of (28 ± 5/8 in)
Crib Height of the ground: Approximately 29 inches off the ground
Spacing Between Rails: 2.5 inches
Material Density: Wood, typical along grain (37.5-49.9ft/lb^3) [7]
Material Surface: Surface finish would be smooth and splinter free
Material Yield Strength: 4.35 -10.2 ksi
Young's Modulus of the Material: 0.87 – 2.9 (10^6) psi
Manufacturing Cost: Below $300
Number of Movable Parts: Minimize number of mobile parts to one or none
Force Railing will endure: Must withstand a 20 lb force (CPSC standard)
Force Mattress Support will endure: Approximately 30 lb
Fatigue Lifetime: 250,000 cycles (CPSC standard)
Rail Height 1: 9 inches above the mattress for an infant (CPSC standard)
Rail Height 2: 26 inches above mattress for a 2 year old (CPSC standard)

4.0 Concept Generation

In this section we will be documenting the functional decomposition of our concepts, concept sketches with motivation behind these concepts, and finally the problem associated with each one of them.

4.1 Functional Decomposition

After analyzing our preliminary ideas documented in Appendix D, our team picked up key design features from these preliminary sketches to produce our Alpha Design. The key features can be decomposed by function as follows:

- Mobility of parts
  - All four side rails
    - Hank Crank Motion (Idea-3)
    - Rod inside a rod (Idea-8)
  - Single mobile drop side
    - Pressure Gate (Idea-2)
  - Fixed rails but adjustable height mattress
    - Stacking Mattress (Idea-1)
    - Corner Posts with holes (Idea-4)
    - Foot Gear Lifter (Idea-5)
    - Slide-in tray mattress frame (Idea-9)
    - Slide-in slot mattress frame (Idea-10)

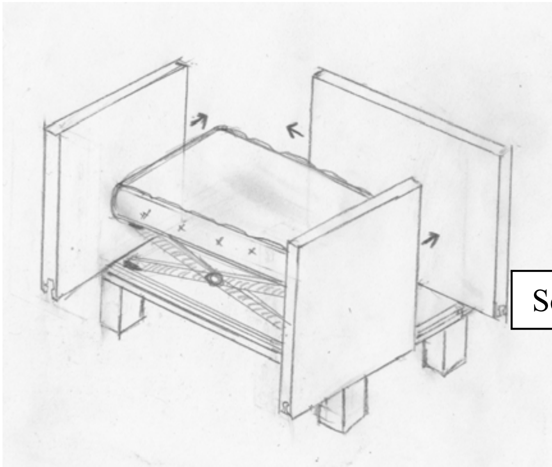
4.2 Generating Concepts

In order to ensure the crib design is safe, concepts were generated with a focus on hardware, various mechanisms to add mobility to moving parts in the design, and overall structural stability. We also analyzed the report of the previous team that worked on this project sponsored by, Nancy A. Cowles. From that report, we took the design challenges that their team faced during their concept generation process, and our team brain stormed new ideas to meet those challenges. In this section we present the four design sketches, the motivation behind the concepts, and the challenges we might potentially face while taking these concepts into the manufacturing stage of our project cycle.

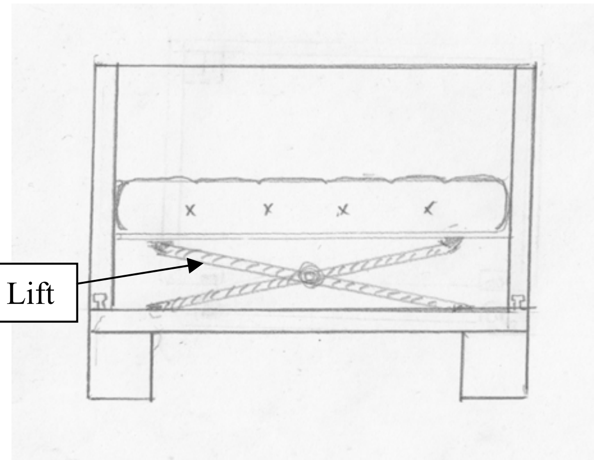
4.2.1 Concept 1: Scissors Mattress Lift

Motivation for the Concept: The main objective that pushed forward this concept was to find a way to vary the height of the mattress frame, and make all the side stable. Most of the recalls researched were due to hardware failure that connected the mattress to the crib rails. The scissors mattress lift would eliminate that possible hazard. The mechanism has two hollow shape bars made of steel attached together with a pin joint. Sketches-1A, and 1B shows the isometric and the front view of the scissor lift mechanism that would be used to adjust the height of the mattress.

Sketch-1A: Isometric View of the mechanism



Sketch-1B: Front View



In addition, the mattress frame would have multiple slots where the scissor bars would be fitted into and locked in place. Also the four sides would be assembled using slots. These slots would vary in size to ensure proper assembly. The detailed sketches of slot design are in Appendix-D. Each side would slide in and lock in place. This way there is only one way for the customer to assemble these parts. This idea reduces hardware failure due to the use of fewer screws and also makes installation easy and less complex.

Problem associated with the Concept: The main problem with this concept would be the stress on the slots that would be holding the mattress in place. The slot can potentially fracture leading to side rails to fall off the crib. There is a possibility of mattress dropping to its lowest position if the mobile mechanism fails causing an entrapment hazard for the child.

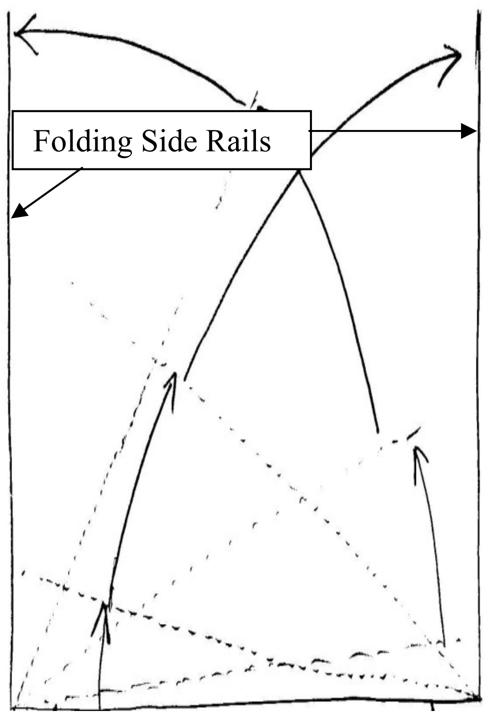
4.2.2 Concept 2: Crib-In-A-Box

Motivation for the Concept: During our CPSC recall analysis, we studied a design that was recalled due to improper assembly instructions that caused customers to improperly install the drop side. If improperly installed, the drop side could disengage and cause injury to child due to falling, and an entrapment hazard [5]. With this in mind, we set up an objective to create a design that is very easy to assemble with minimal to no potential human error during assembly of the crib by making the sides of a crib foldable.

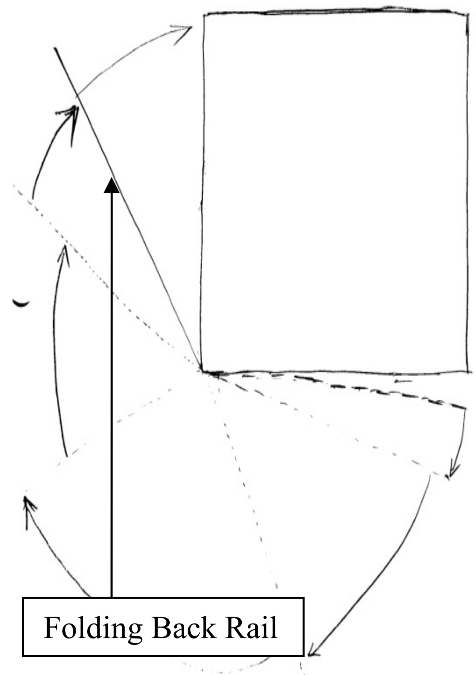
In addition to poor assembly instructions leading to a CPSC recall, we studied the challenges addressed by the past team who worked on this project during their concept generation phase. The team had a concept of a hardware free crib, in which a single-body crib basket would be pre-assembled with all four sides for the customer, and shipped in one piece. Their goal was to eliminate all the hardware with this concept. They found that "The main problem with the hardware free crib basket is it would be hard to store or transport as trucks would not be able to transport as many cribs per trip as with today's cribs that are transported in flat boxes" [6]. Hence, a folding crib can overcome this transportation challenge the past team expressed by

folding sides on top of each other ending up with a flat rectangular shape that can be shipped in a flat box.
The front view of the folding crib design is seen in Sketch-2A. The sketch shows how the two collapsible side rails fold onto the base, which acts as a fixed mattress support when the crib is in use with the side rails in the upright position. The folding side rails are connected to the base with a simple hinges. Sketch-2B shows the side view of the crib with arcs and dotted lines depicting the motion of the folding back rail for the crib. The back rail folds underneath the crib base and connected to the base by hinge(s) as well.

Sketch-2A: Front View of the Crib

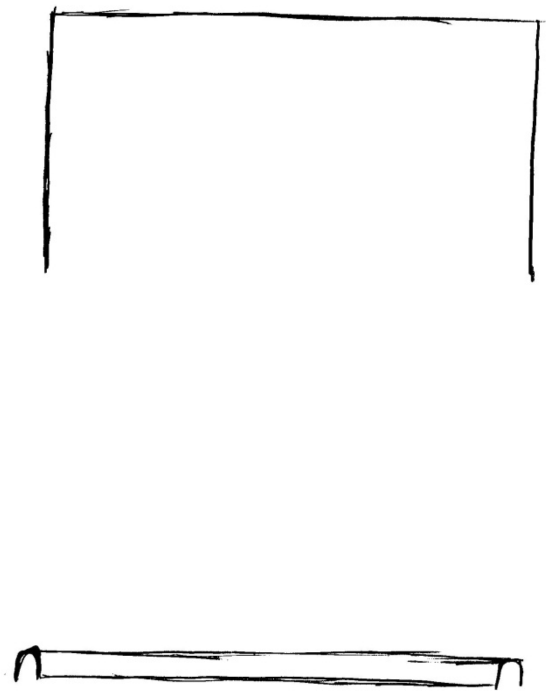


Sketch-2B: Side View of the Crib

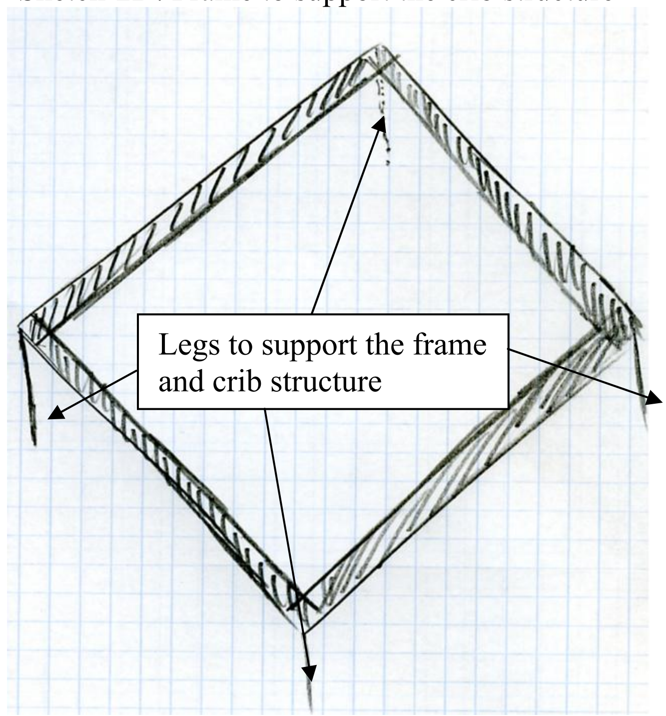


When assembling the crib, once these three sides (two side rails and the back rail) are in their upright position, they will be secured in place by tubing, Sketch-2C. This tubing fits on the top of the three rails to lock them in place. With the three sides secured, the structure will be secured on the top of the frame as shown in Sketch-2D with the help of screws in order to provide legs of appropriate dimension such that the mattress frame is off the ground just enough for parents to access their child with ease.

Sketch-2C: Tubing to lock three side rails

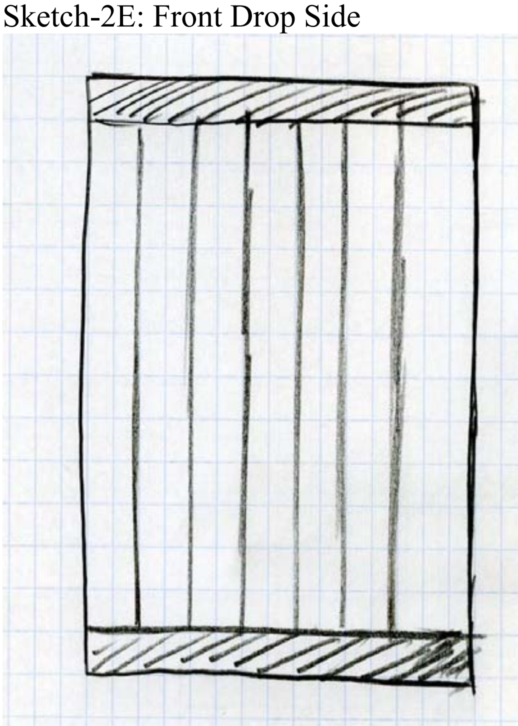


Sketch-2D: Frame to support the crib structure

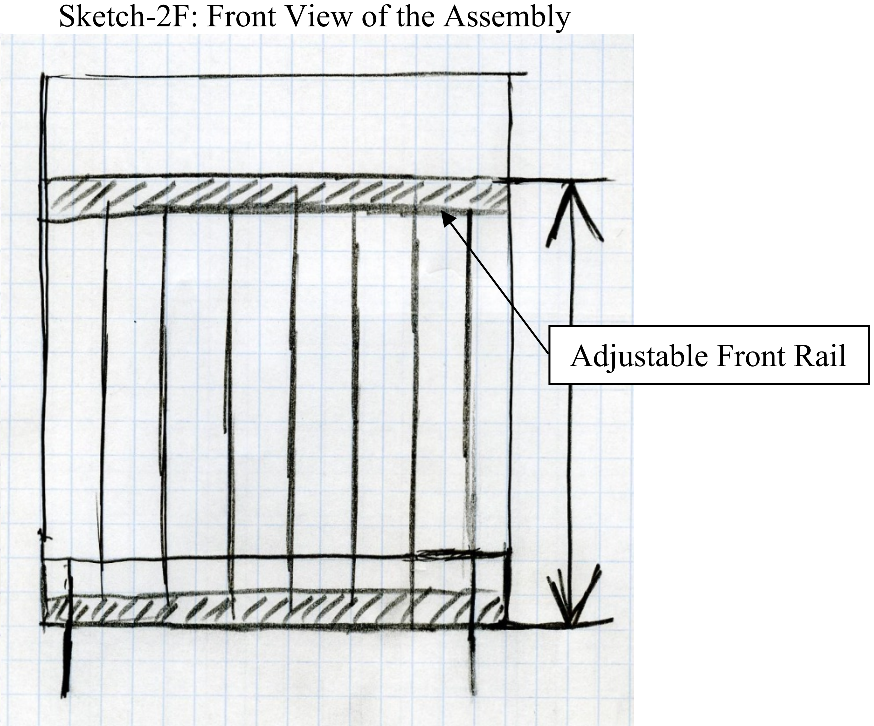


On securing the two side rails and the back rail on the base, Sketch-2E shows the front drop side along with the complete assembly in Sketch-2F.

Sketch-2E: Front Drop Side



Sketch-2F: Front View of the Assembly

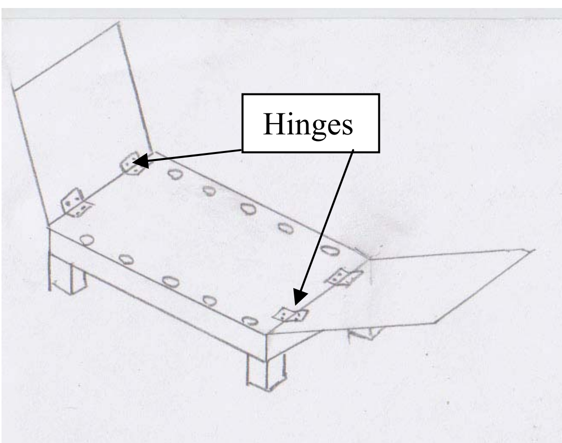


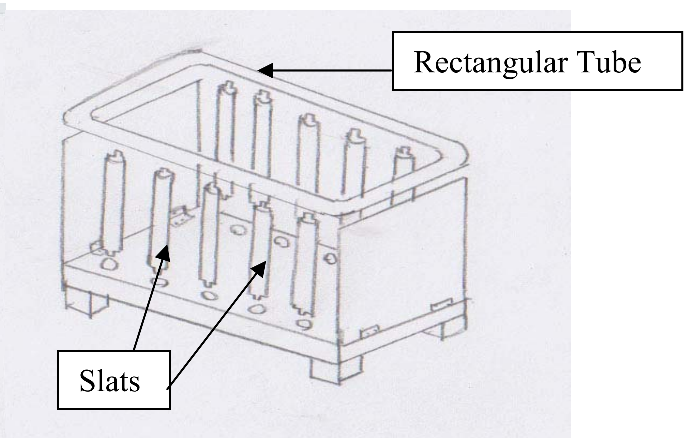
Problem associated with the Concept: The folding cribs implements hinges to provide easy assembly of the rails so that they can be folded onto and off the base. Since, hinges are mechanical parts, this creates potential for a hardware failure for the assembled rails.

4.2.3 Concept 3: Foldable side walls with a Dome

Motivation for the Concept: This concept's main objective for having foldable side walls is to provide easy installation of the crib for care giver. Sketch-3A shows two side rails that can be selectively positioned vertically or horizontally with the help of hinges. When positioned horizontally, they yield a compact assembly for ease of transportation. After sticking slats in the holes of the base as shown in Sketch-3B, the rectangular tube will be covered to hold both side walls and slats.

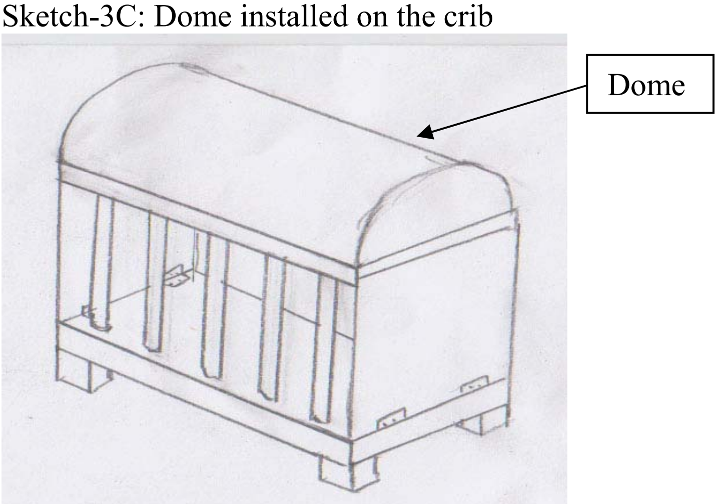
Sketch-3A: Isometric View of the Design   Sketch-3B: Securing Mechanisms for slats and rails





Once the side rails and the slats are secured, the dome as seen in Sketch-3C can be installed in order to prevent external objects from falling inside the crib.

Sketch-3C: Dome installed on the crib

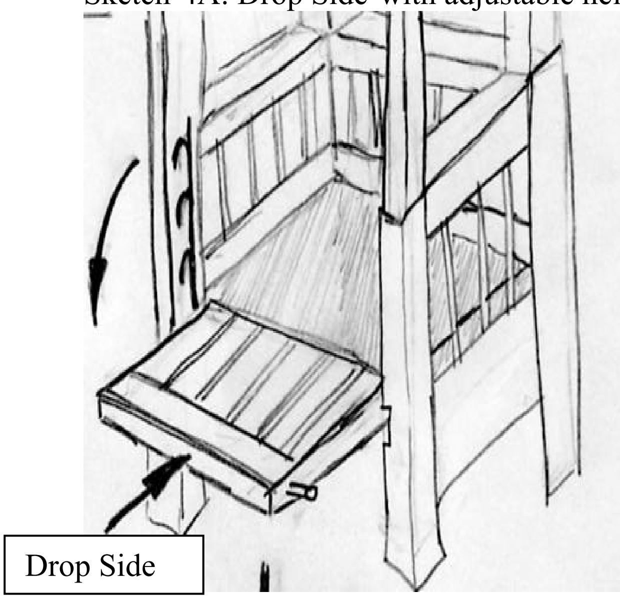


Problem associated with the Concept: There are two main problems associated with this concept; the stress on the side walls can cause the failure of hinges, and this concept has relatively complex installation. This design also creates an issue with proper ventilation for the child when the dome top is on.

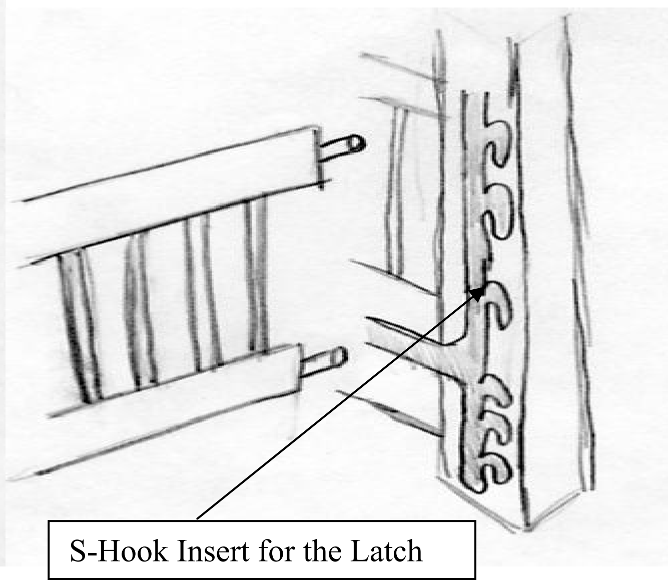
4.2.4 Concept 4: Single Drop Side

Motivation for the Concept: This design reduces the number of mobile parts to one, the drop side depicted in Sketch-4A. By having only one side is mobile, the child is less at risk to immediate injury if the moving part fails.Sketch-4B shows the S-hook latch with which the drop the side is secured to the crib, and it also provides the possibility for height variation.

Sketch-4A: Drop Side with adjustable height

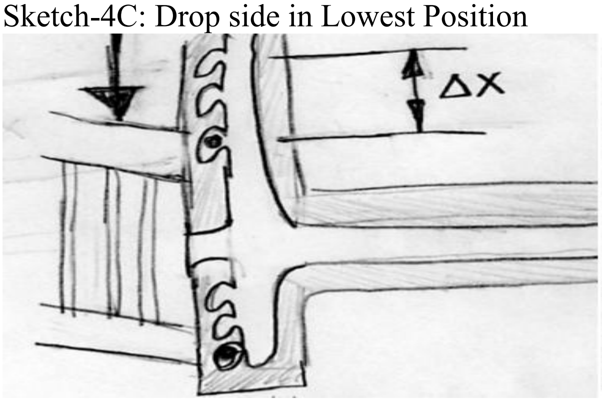


Sketch-4B: S-hook Latch

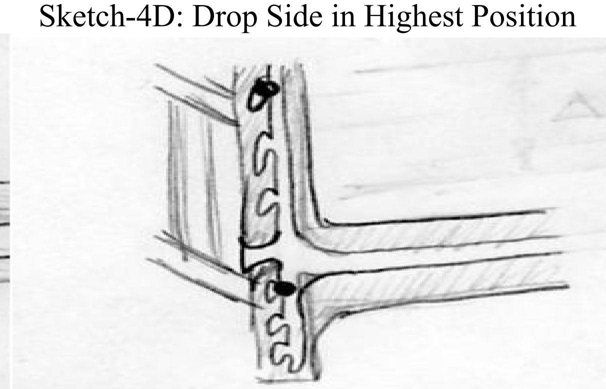


By having an adjustable height drop-side, the care taker can keep the rail height low when the child is younger as seen in Sketch-4C, but also allows for the height of the rail to be raised when the child is older, taller, and of climbing age, as shown in Sketch-4D thereby lowering the risk of child falling. This design satisfies the age requirement of 0-2 years old through the adjustable height.

Sketch-4C: Drop side in Lowest Position

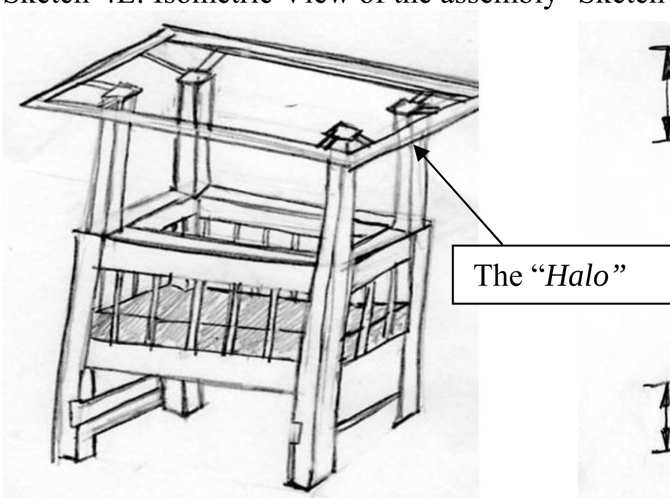


Sketch-4D: Drop Side in Highest Position

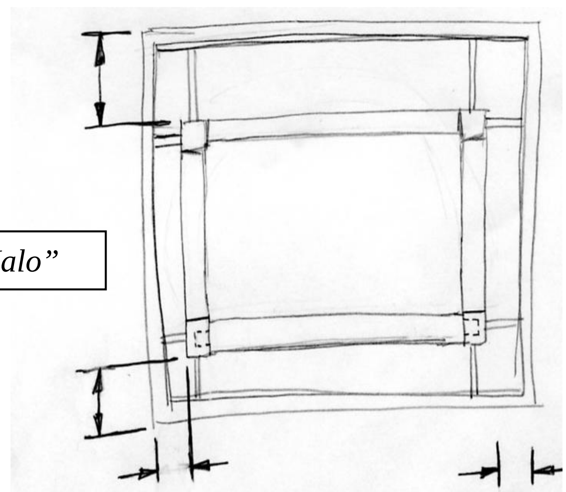


Besides satisfying this customer requirement, there are a few extra features to this design that make it a safer crib. One of these features is the "halo"." The "halo" is the above rail that is attached to the crib by raised corner posts, as shown in isometric view of assembly in Sketch-4E. This above rail has a wider diameter that the inside rail of the crib. The difference in radius between the inside crib rail and the above "halo" is greater than the average length of a 2 year olds arm so that no child from 0-2 years old will be able to reach anything that may be hanging outside of their crib, such as an ornate tapestry or cord from a window shade. By having this buffer push everything away from the cribs edge, the risk of a child suffocating and strangulating him or her, decreases. Sketch-4F, 4G, and 4H depict the top, front and the side view of the assembly respectively.

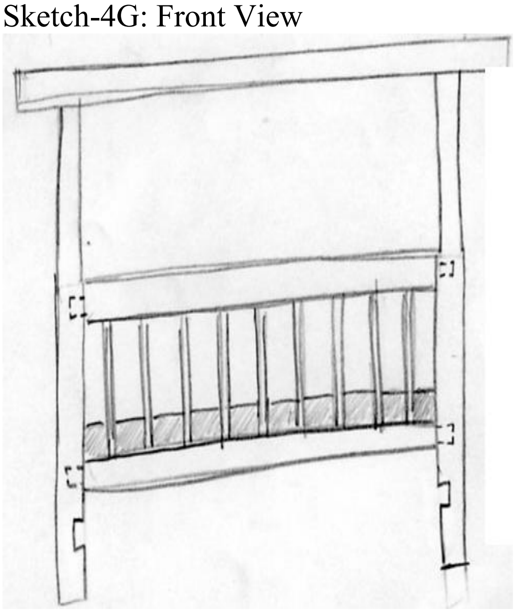
Sketch-4E: Isometric View of the assembly



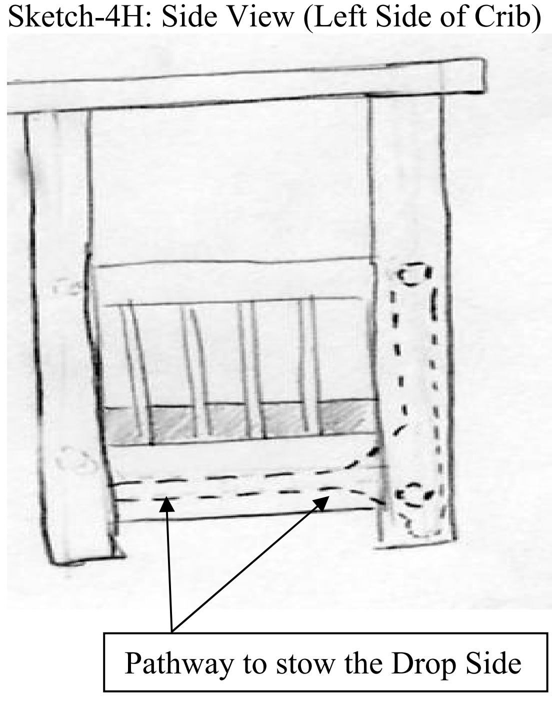
Sketch-4F: Top View



Sketch-4G: Front View

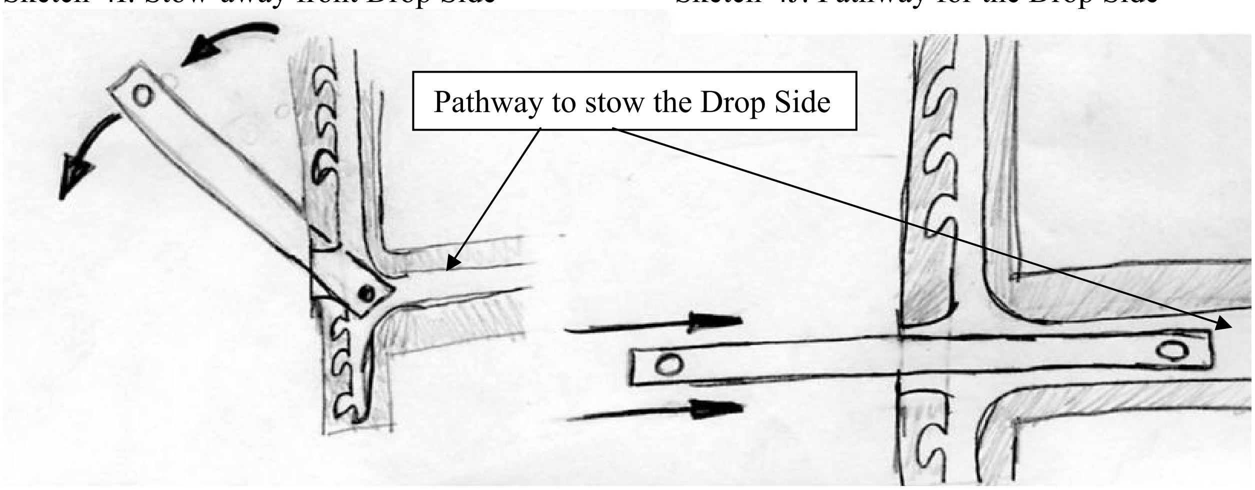


Sketch-4H: Side View (Left Side of Crib)



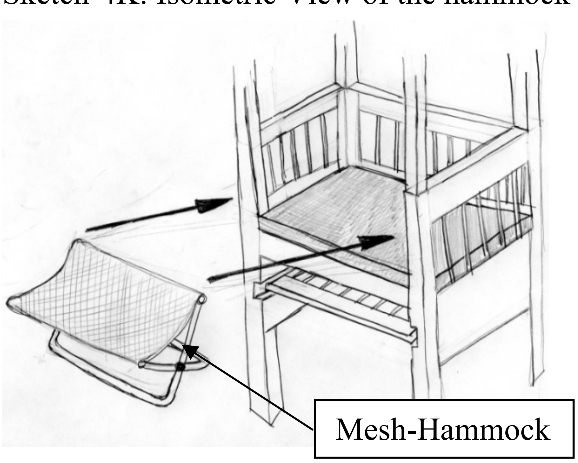
The second feature this design has is the advantage of the drop side to go completely under the crib frame, Sketch-4I, and 4j. This ability to slide completely away will allow for the care taker to use the crib not only for a place where the child sleeps, but also as a place to change a child's diaper at. By incorporating this features into the design, the care taker is getting two necessities in one, saving them money and space in their home. This stow-away side also allows for the last feature to be installed.

Sketch-4I: Stow-away front Drop Side Sketch-4J: Pathway for the Drop Side

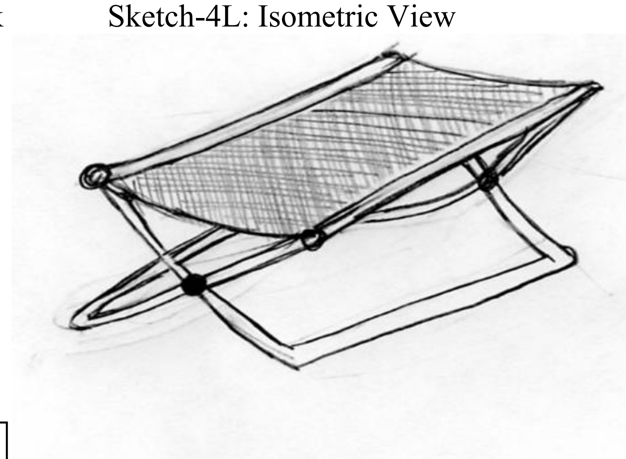


The last feature is the baby mesh hammock, Sketch-4K. In addition Sketches-4L, 4M, 4N, and 4O show the isometric, top, front and the side views of the mesh hammock respectively. This mini hammock for infants is designed to slide into the crib for a snug fit for when the infants are going to sleep. Once this hammock is put into place inside the crib as seen in Sketch-K with a raised drop side, the hammock will cover all the possible gaps between the mattress and the crib side, reducing the risk of child entrapment. Also, with the shape of the hammock, the infant will be sleeping on its back in a slight valley making it more of a challenge for the child to roll over on his or her face, lowering the risk of the child's mouth to be covered which would lead to suffocation. However, with this design and use of mesh material, even if the infant did manage to roll on their stomach, their mouths would be against mesh which would still allow them to breath and not suffocate.

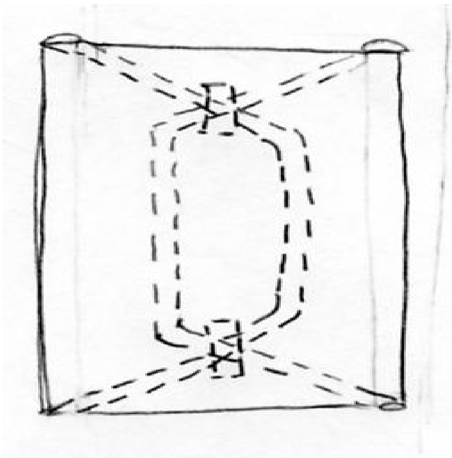
Sketch-4K: Isometric View of the hammock

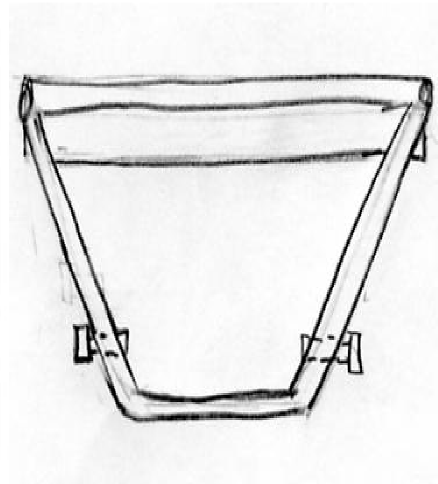


Sketch-4L: Isometric View



Sketch-4M: Top View Sketch-4N: Front view Sketch-4O: Side View





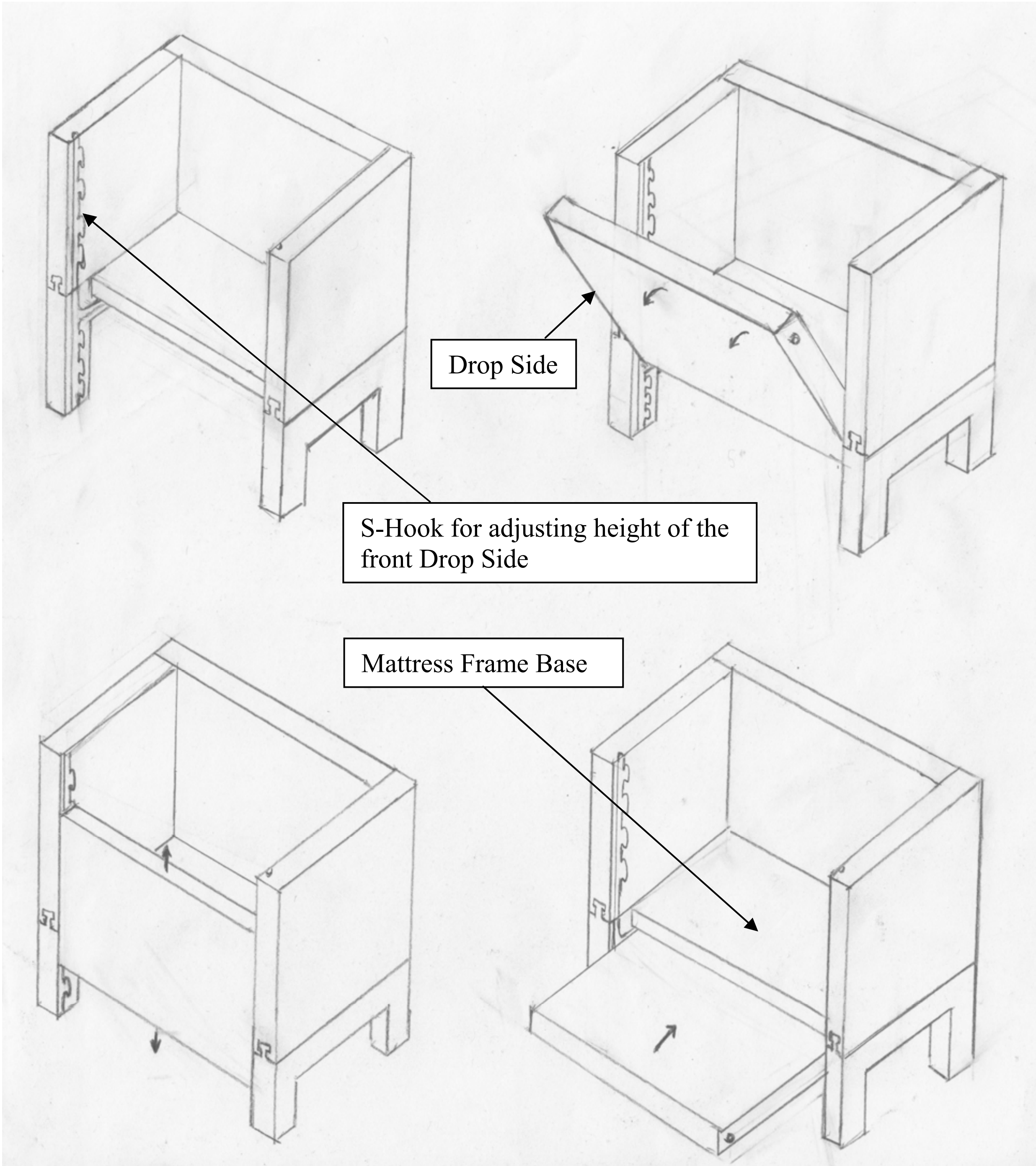
Problem associated with the Concept: One of the problems that stems from this concept is that if the drop railing is not locked into place, failure could occur and the railing could lower when it is not supposed to. If this occurred, the child could fall out of the crib and severely be injured. Another issue that this design could cause is if the mesh fabric fails, the child could get entangled in the material and strangulation could occur as well as the possibility of total material failure which would cause the child to fall to the crib mattress below.

5.0 Concept Selection Process for the Alpha Design

We studied the various concepts presented in the previous section, and merged the positive design features from each concept design yielding us with an Alpha Design. The key customer requirement was to ensure a safe crib for children 0-2 years of age. With this in mind, we will be making sure that we meet the CPSC safety standards [4] because failure in meeting these guidelines has lead to various safety recalls in the past due to hazardous crib design. In this section, we will be documenting the Alpha design and the process that lead to the design selection.

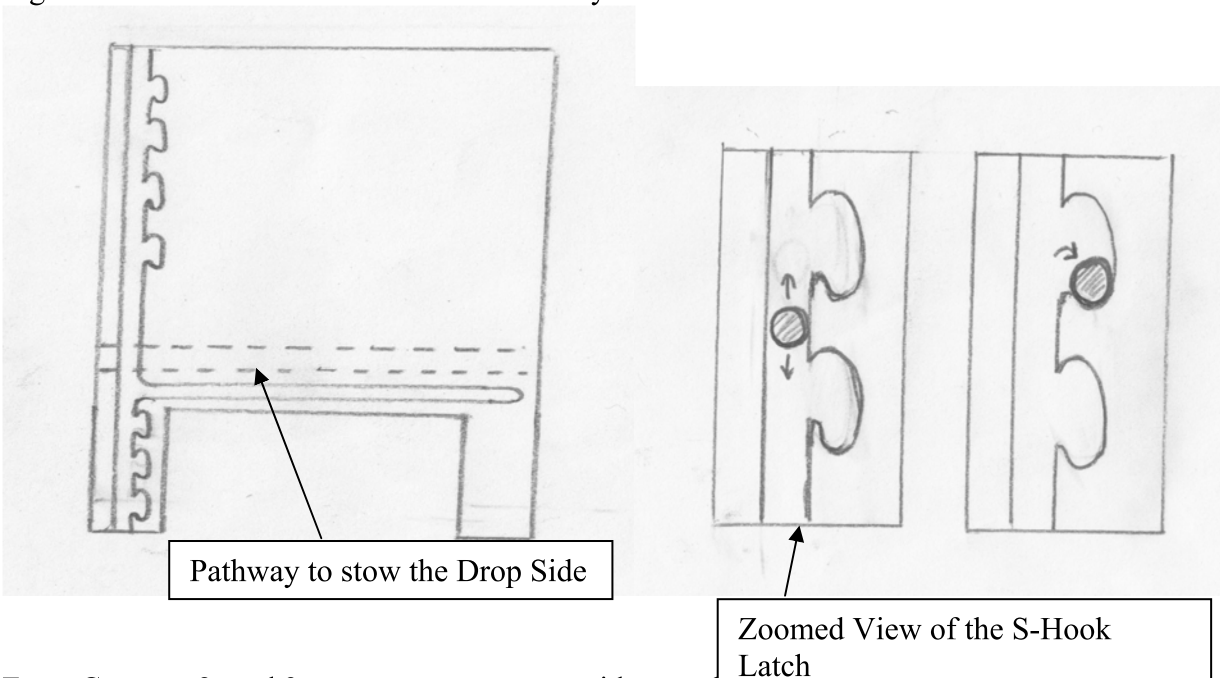
After analyzing our preliminary ideas in Appendix D we reached the argument that having a single drop side as the only mobile part provides safety to the crib design as the care giver doesn't have to keep track of all four sides to ensure safety of its child. Hence this feature stemmed from one of the four elite concepts; Concept-4. In addition, the S-hook mechanism to adjust the height and the Stow-away idea were extended to the Alpha Design from Concept-4. Figure-A depicts these key sorted concepts of the Alpha design.

Figure-A: Sorted Concepts for the Alpha Design from the four Concepts



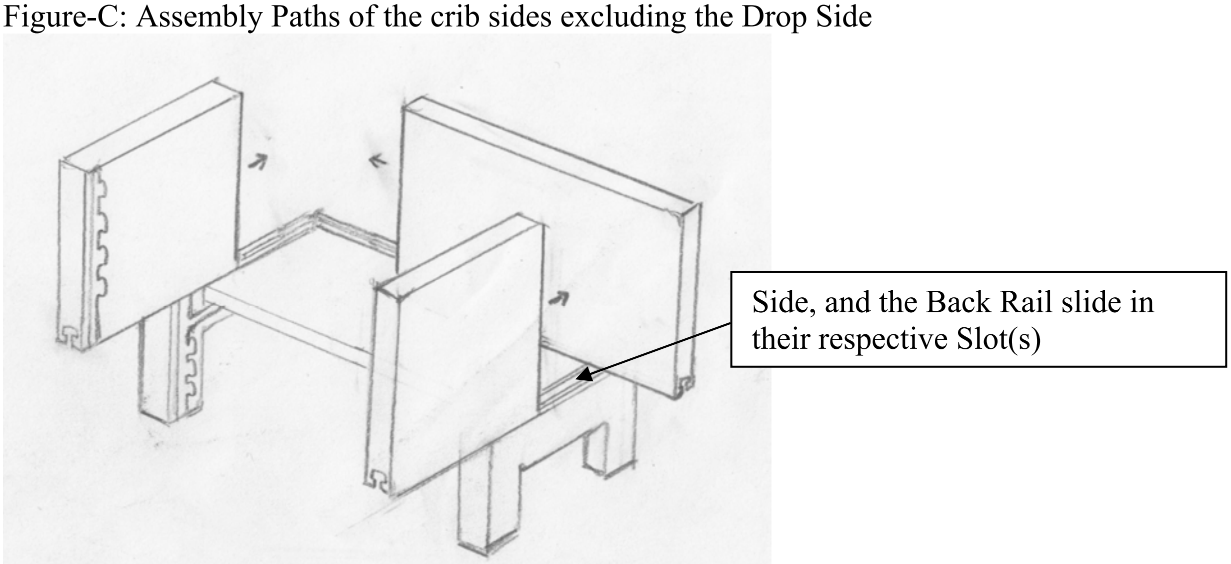
In the following figure, Figure-B, we present the side view of the crib which shows the S-hook mechanism in detail to adjust the height. Also, the stow-away path for the drop side is shown in the picture as well.

Figure-B: S-Hook Mechanism and Stow-Away Path



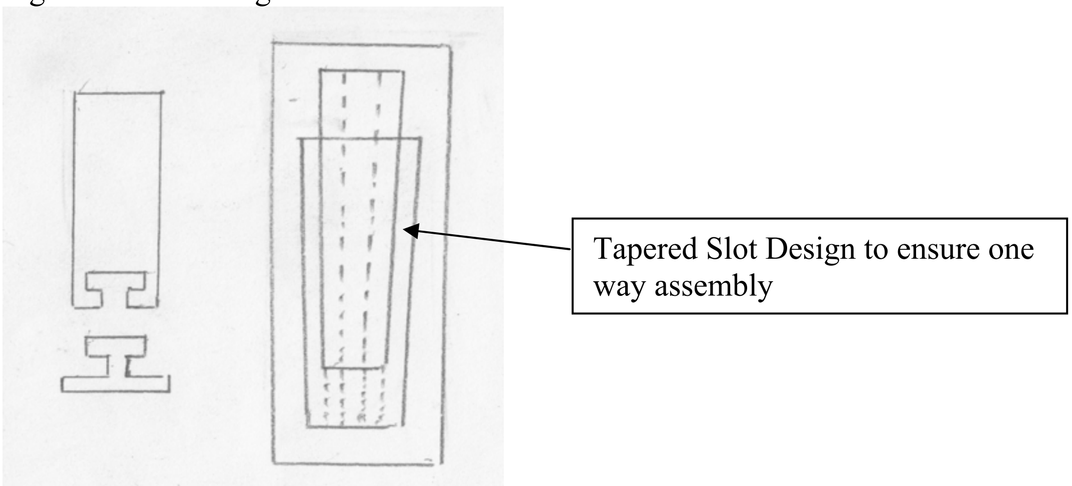
From Concept-2, and 3, we set a target to provide a packaging box for the crib parts for the ease of transportation, and also that the crib be easy to assemble without complex assembly requirements. To achieve the target, we decided to keep the crib sides detachable from the base (the support for the mattress, and the end user would simple slide them into their respective slots upon assembly. The idea of having slots for assembly of the crib sides was developed from Concept-1. Figure-2 shows the assembly paths of the three sides.

Figure-C: Assembly Paths of the crib sides excluding the Drop Side



In addition, Figure-D shows the slot design which is tapered to ensure that the end-user can install the crib side in only one direction. This will prevent assembly error, thereby eliminating the potential for any hardware failure due to poor assembly.

Figure-D: Slot Design



6.0 Engineering Design Parameter Analysis

Several tools and resources were used to determine specific parameters for the final design. Our sponsor, Nancy Cowles provided us with documentation that helped in the material selection process. We also referred to Matweb site for material properties. In this section we present the review of the analyses that helped us finalize the design parameters. The detailed version of the analyses showing the use of engineering equations along with free body diagrams is documented in the Appendix-E on p-65.

We analyzed the crib structure's components namely slats, stainless steel screws (referred to as pegs during analyses) that hold the drop side, and the mattress base supports using the static analysis with the help of free body diagrams. In addition we checked for material strength by analyzing the maximum stresses that it would have to endure under usage. Stability analysis was also conducted to check if the crib could be tipped over during use by a child aged 0-2 years. Since our team is designing a full sized crib in accordance to the US CPSC guidelines, the core of the analyses is based on the full sized dimensions of the finalized design. This was done to ensure that all the crib parts with full scale dimensions will comply with the federal safety guidelines and the design will not face the possibility of a safety recall. We also referred to the past team's report to make sure that the new analyses that our team conducted holds for the data they researched during their project term. The team also performed the Finite Element Analysis to model the US CPSC Loading scenario [4] for components that are critical to the crib design.

6.1 Material Selection

Through using CES EduPack 2008, our team was able to find possible materials that we could use when making for the production of the finalized concept and the prototype. By entering engineering specifics that we had computed and researched, such as listed in Table-2 below, the CES program was able to recommend materials that fell under those specific material properties.

Table-2: Input Material Properties for CES Edupack

	Minimum		Maximum	
Young's Modulus	1	* 10^6 psi	2	* 10^6 psi
Poisson's Ratio	0.2		0.5	
Tensile Strength	0	ksi	16	ksi
Compressive Strength	5.2	ksi	6.7	ksi
Flexural Strength	6	ksi	13	ksi
Fracture Toughness	0.2	ksi*(in^1/2)	3.9	ksi*(in^1/2)

To narrow the search even further, our team then focused on the fact that we are working for a non-profit organization and have a minimal budget. In order to input the need for inexpensive material, we calculated approximately how much volume our crib design would be and then figured out that we were willing to pay around $1.50 per pound for material. CES then gave us its top six suggestions, all of which were woods: Ash, Douglas Fir, Fir, Pine, Redwood, and Spruce (Appendix-H on p-82). We researched these top six and found through calculating the environmental impact, that not only was the Pine wood more easily accessible and inexpensive, but it also was the most environmentally friendly. Specifically the Oregon Pine wood was the material of choice that our group ended up deciding on.

The material properties namely specific gravity, Modulus of Elasticity, and strength(s) of the Oregon Pine used during analyses are shown in Table-3.

Table-3: Material properties for Oregon Wood

Material Property	Corresponding Value
Specific Gravity	0.0137 lb/in^3
Tensile Strength	15,900 psi
Compressive Strength	6000 psi
Transverse Strength	13,630 psi
Flexural Strength	9700 psi
Shearing with the grain	600 psi
Modulus of Elasticity	1,272,000 psi

6.2 Dimensions for the Final Design

Our team designed a full sized crib with the key dimensions laid out by the US Consumer Product Safety Commission's Office of Compliance [4]. These benchmarks are documented in Table-1 on pg.5. The dimensions were followed from the US CPSC to ensure safety of the child in the crib in a full sized crib.

6.3 Analysis of the Crib Structure, and parts

The feasibility of the finalized design due to the chosen dimensions for the full sized crib is documented in this section. In this section the key results from the analyses and its implications on the final design are included and as previously mentioned the detailed analyses showing the calculations is presented in Appendix-D.

6.3.1 Crib Mattress Base Support Analysis

The crib mattress base supports endure a bending moment due to the weight of the child, the mattress and the weight of the mattress board itself. This bending moment causes a stress of 38.86 psi at the contact area between the mattress support and the crib side rail. This stress value is well within the flexural strength of 9700 psi for the material [9].

In addition to check if failure due to transverse shear could occur we compared the stresses due to shear with the shear strength for the material. The maximum value of shear stress for was computed to be 6.9 psi which is well below the shear strength of 13,630 psi for the material [12]. Therefore the mattress support system is safe.

6.3.2 Peg(s) that support the drop side

To ensure the safety of the drop side, stainless steel screws of radius $1/8^{th}$ of an inch will be used to provide mobility to the drop side in its tract. Each peg, referred to the individual screw, endure a shear stress of 205 psi. This shear stress arises due to the drop side weight of 26.8 lb adjusted for a safety factor of 2. This stress is acceptable as it is contained by the average shear strength of 32,770 psi for stainless steel [12].

Along with the shear stress, these pegs endure stresses due to bending moment as well. The maximum stress due to bending moment was computed to be 4,374 psi which is below the average yield strength of 89,610 psi for the stainless steel [12]. Hence, failure of peg(s) is not a concern.

6.3.3 Deflection of the Mattress Base

We analyzed the maximum deflection that the mattress base can undergo during usage. This was done to ensure that the mattress would not undergo deformation due to the deflection of the mattress base thereby creating a suffocation hazard. This maximum deflection was computed to be 0.006 in. which is an extremely small value and our team reached the argument that there will be no suffocation hazard.

6.3.4 Compression Yielding in Crib Legs

To determine if the legs of the crib structure would fail due to compressive yielding, the team analyzed the forces exerted on the structure during the usage. These forces result due to the combined weight of the child, and the crib components supported by the legs. This combined weight of 204.31 lb with built in safety factor of 2 creates a compressive stress of 12.8 psi within each leg. This value is contained by the compressive strength of 6000 psi for the material thereby making the material safe from failure due to compressive yielding [9,12].

6.3.5 Strength of Slats

In order to ensure the safety of slats during usage, we conducted the stress analysis for the material during which a 20 lb force was exerted on the slat. The 20 lb force was derived from the loading wedge test put forward by the US CPSC [4]. This force creates a stress of maximum stress of 69.4 psi due to the bending moment experienced by the material. In addition to the bending moment, the shear stress experienced by the material causes a shear stress of 8.3 psi. The team agreed that the slats are safe as both of the stresses are well within the flexural and shear strength for the material documented in Table-3 on p-19.

6.3.6 Stability of the Crib

We performed bending moment analysis to check if the crib structure would be stable during use. The maximum bending moment that would be required to tip the crib was computed. Furthermore, a force from within the crib would have to be exerted to counteract this bending moment. We calculated this force to be 50.76 lb which is almost twice the actual weight of the child and is very difficult to be generated by the child [17].

6.3.7 Finite Element Analysis

In order to check the static analyses discussed in the previous parts of this section, we used Hypermesh 9.0 software suite to conduct the Finite Element Analysis (FEA). The stresses, displacements, and forces acting on critical components on the cribs were analyzed and ensured that they were within the accepted levels. The FEA thus backs up the statics analyses we conducted in the previous sections. The detailed documentation of these analyses is a part of Appendix-E on p-65 as well.

7.0 Potential Hazards

In this section we present a review report from the DesignSafe Software in which we performed risk assessment and found out what the major risks are and who is at risk. The detailed assessment report documenting the risk reduction methods and the residual risk levels are included in Appendix –F on p-74. After assessing the severity, exposure and probability of hazard occurrence, the risk reduction methods were studied and the residual risk level upon implementation of these methods was derived by the software and is documented in the detailed report in the Appendix-F. In all the potential hazards, the team reached the argument that the residual risk level is at acceptable levels. On the following page, Table-4 thus shows the review report.

Table-4: Designsafe Review Report

Safety of the Crib 11/10/2008

Review Report

Application:	Safety of the Crib
Description:	Assessment of potential hazards, risk levels and methods in place to reduce these risk levels.
Analyst Name(s):	Kim Bagian, Chukwuka Isichei, Dong Joon Min, Amritpal Singh
Company:	Safe Crib Team
Facility Location:	University of Michigan College of Engineering 1221 Beal Avenue Ann Arbor,MI 48109
Product Identifier:	
Assessment Type:	Detailed
Limits:	
Sources:	

Guide sentence: When doing [task], the [user] could be injured by the [hazard] due to the [failure mode].

User	Task	Hazard	Failure Mode
set-up person	periodic maintenance	Periodic Checkup : Dust Entrapment in the Slots/S-hook	Lack of frequent cleaning checkup of crib structure
set-up person	installation	mechanical : Pinch Point	Improper attention on the part of care taker while adjusting the drop side with baby's body part(s) in the slot pathway of the adjustable drop side
set-up person	installation	mechanical : Accidental Impact	An accidental shock to any part of the crib's structure
set-up person	installation	slips / trips / falls : Fall Hazard	Failure to engage the drop side by the caretaker from it's stowed away position can lead to a fall hazard for the child
set-up person	installation	ergonomics / human factors : Duration	Usage of the crib for infants beyond 2 years of age may lead to failure of parts due to fatigue
set-up person	installation	ventilation : Exhaustion	Inadequate fabrics covering the slats on the sides of the crib
set-up person	installation	chemical : Reaction to/with chemicals and wooden parts	Reaction between wooden surface and the chemicals considered inappropriate for cleaning wooden surfaces
set-up person	installation	chemical : Skin exposure to toxic chemical residue	Inappropriate usage of chemicals while cleaning the wooden surafces of the crib
set-up person	installation	chemical : Failure at key points and trouble spots	Frequent usafge of inappropriate chemical causing rusting in the slot(s) of the S-hook
set-up person	check alignment	Improper Assembly : Drop side disengaging	Improper installation of the drop side in it's s-hook

Page 1

8.0 Final Design Description

The final design of the crib is based on the alpha design that's shown on Figure-A on p-16. The key components of the final design along with their dimensions are documented with the help of Computer Aided Design software namely UG NX 4.0. The following CAD image shows the isometric view of the crib assembly.

CAD-1: Isometric view of the Crib Assembly

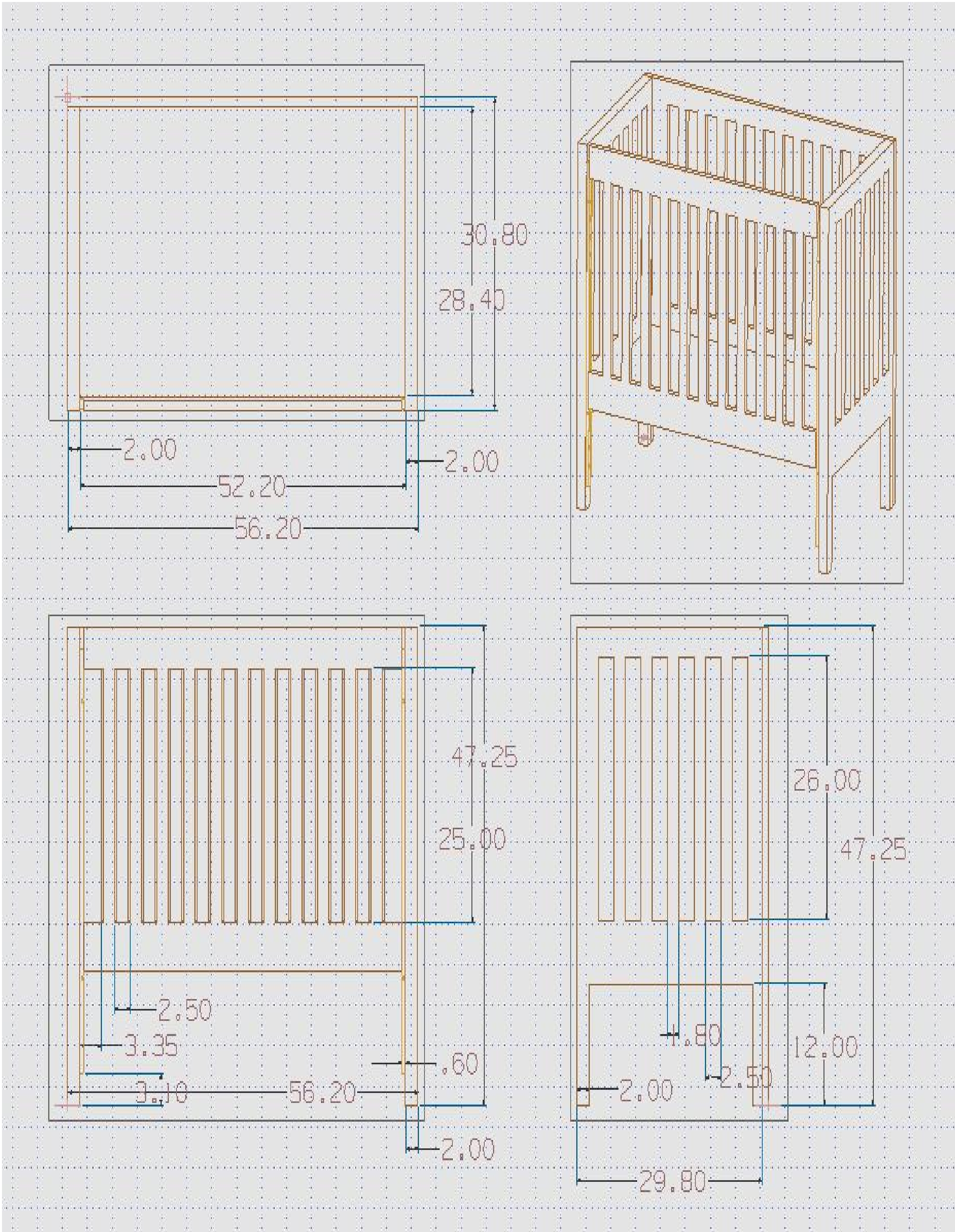
8.1 Overall Crib Shape

The overall shape of the crib is similar to the Alpha design. It has only one movable part and that is the front drop side. The only change between the final design and the Alpha design is that the final design has a separate mattress base from the body and the legs are connected to each side walls and the back wall. The specific dimensions for the crib are shown below in Table-5 and depicted on CAD-2 on the following page. These dimensions meet the US Consumer Product Safety Commission (CPSC) guidelines.

Table-5: Dimensions of the Final Design

	CPSC (in.)	Final Design Dimensions (in.)
Interior Crib Width	28 ± 5/8	28.6
Exterior Crib Width	N/A	30.8
Interior Crib Length	52 3/8 ± 5/8	52.2
Exterior Crib Length	N/A	56.2
Rail Height	≥ 26	26
Spacing Between Rails	2.5	2.5

CAD-2: Crib Dimensions



8.2 Single Drop Side with adjustable height

The final design reduces the number of mobile parts to a single drop side that can provide safety for the child by reducing the chances to hardware failure. The single drop side provides the adaptability to the adjustable height and is secured to the crib with S-hook latch discussed in the subsequent section. The drop side can be stowed underneath the mattress frame thereby allowing the care taker to use the crib as a changing station. CAD-3 depicts the drop side's motion.

CAD-3: Adjustable Drop Side that can be stowed underneath the Mattress base

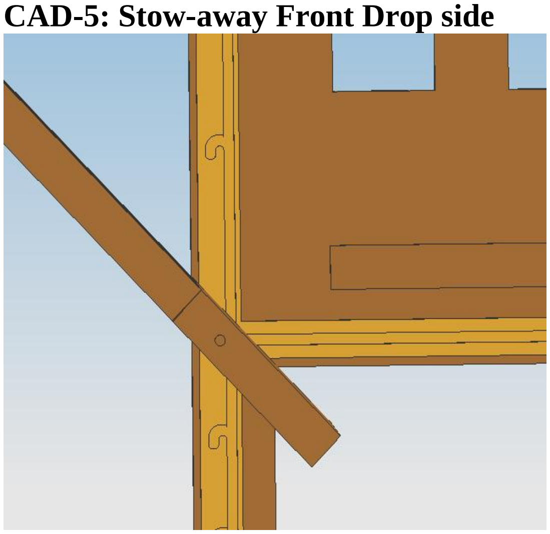
8.3 S-Hook Mechanism for the single Drop Side

In the following images; CAD-4 shows a zoomed in view of the S-Hook latch that provides pathway for motion of the pegs that secure the drop side to the crib.

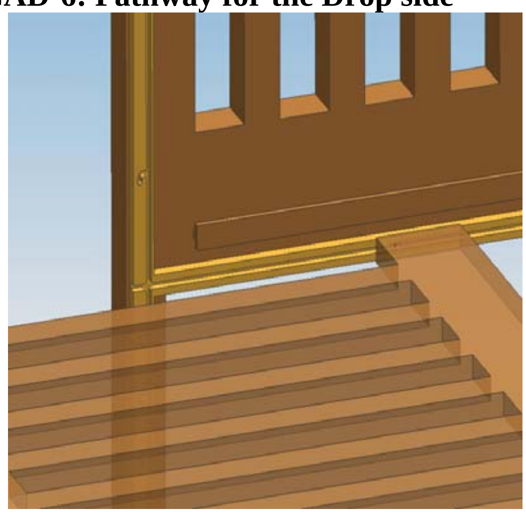
CAD-4: Zoomed View of the S-Hook Latch

The following images attribute the stow away feature of the drop side along with the slot path that the pegs traverse; as seen in CAD-6.

CAD-5: Stow-away Front Drop side

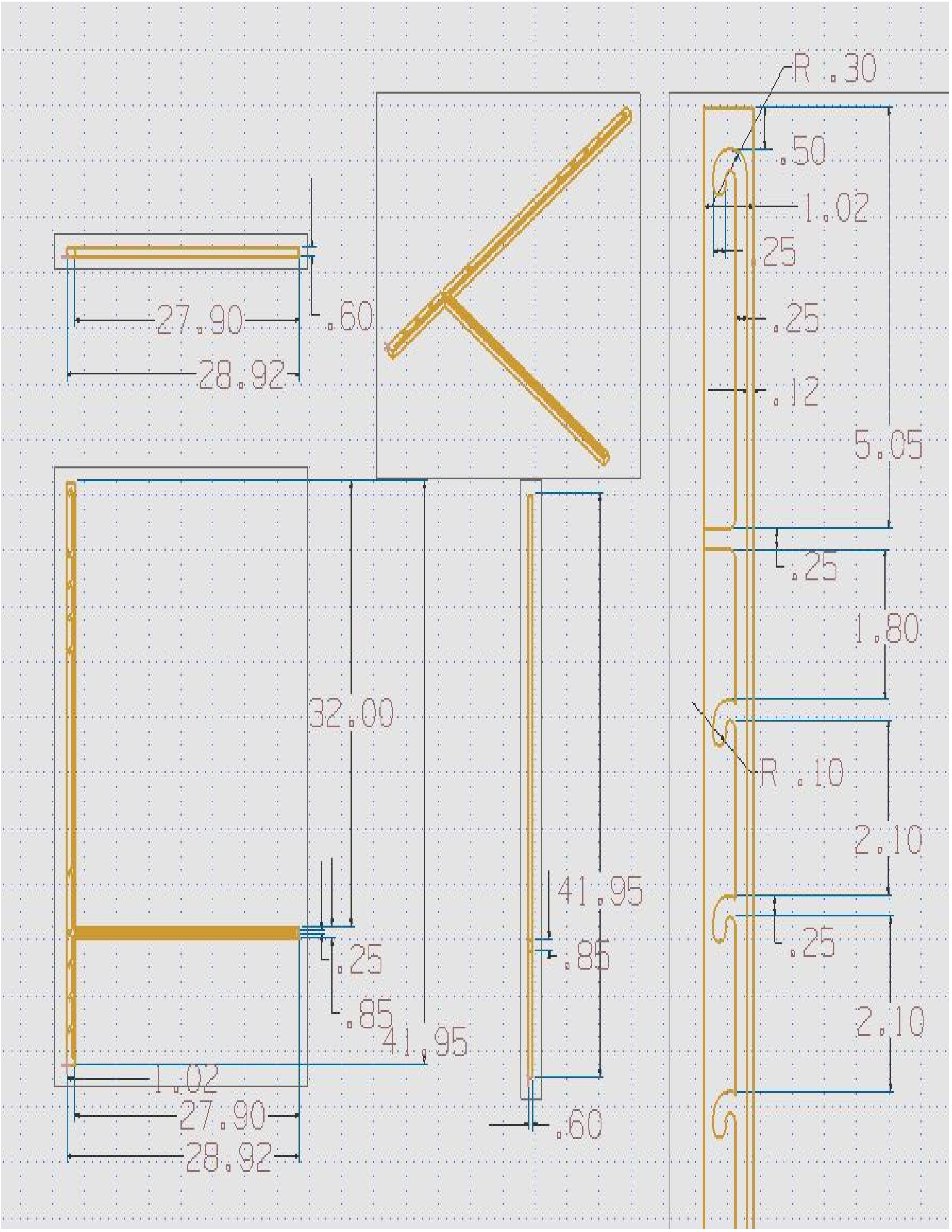


CAD-6: Pathway for the Drop side



The following drawing depicts the dimensions related to the S-Hook pathway. This S-hook pathway will be milled out of aluminum sheet.

CAD-7: Dimensions of the S-Hook



8.4 Assembly of the Crib

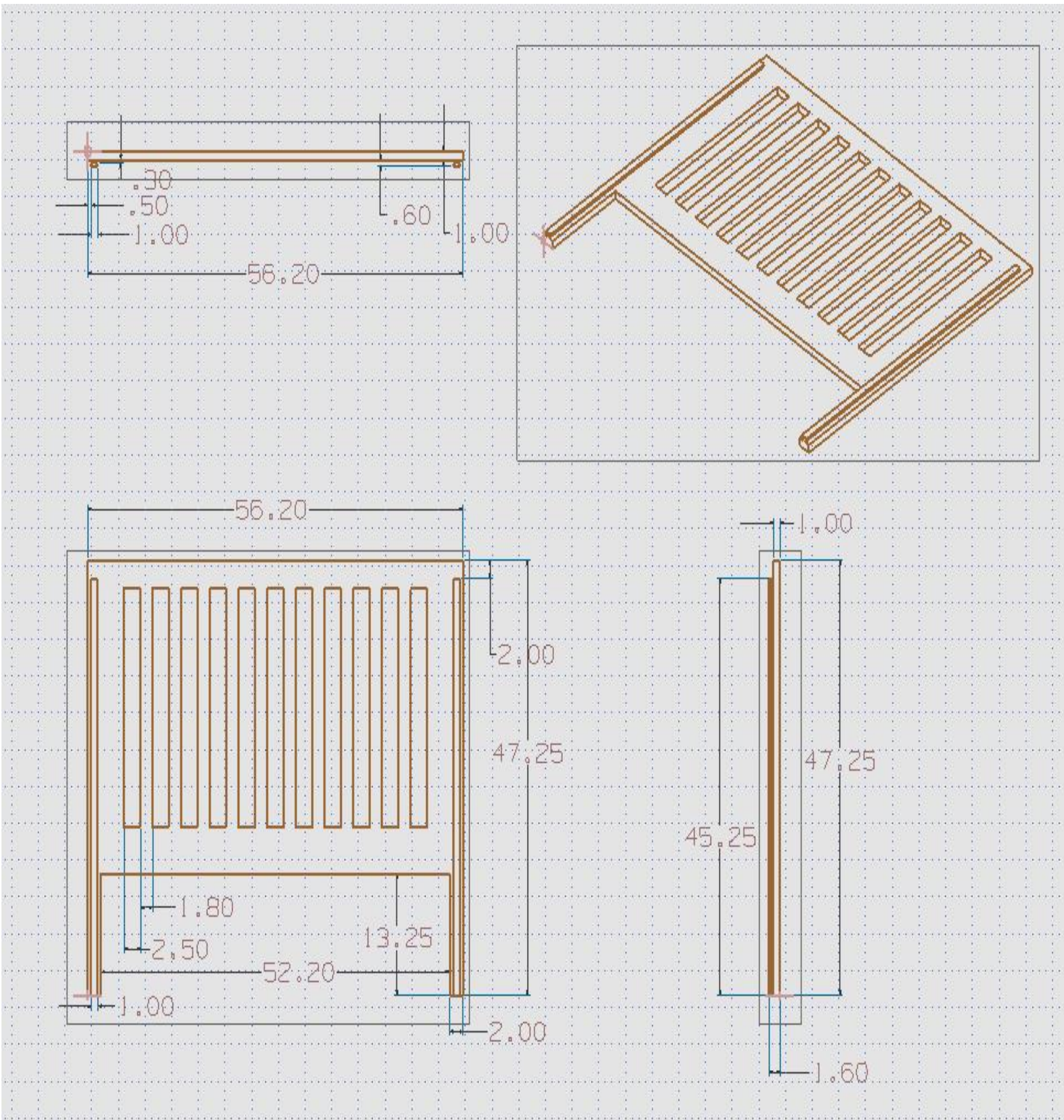
The CAD drawings in this section document the assembly process that will be used. To assemble the crib, the back rail will be laid horizontally on the floor and then the side rails will be installed by sliding them in their respective slots. Once the three sides are secured, the three rail assembly will be tilted about the legs and put in the vertical position so that the care-taker can install the mattress base and the front drop side.

CAD-8: Assembly of the Side Rails, Mattress Base

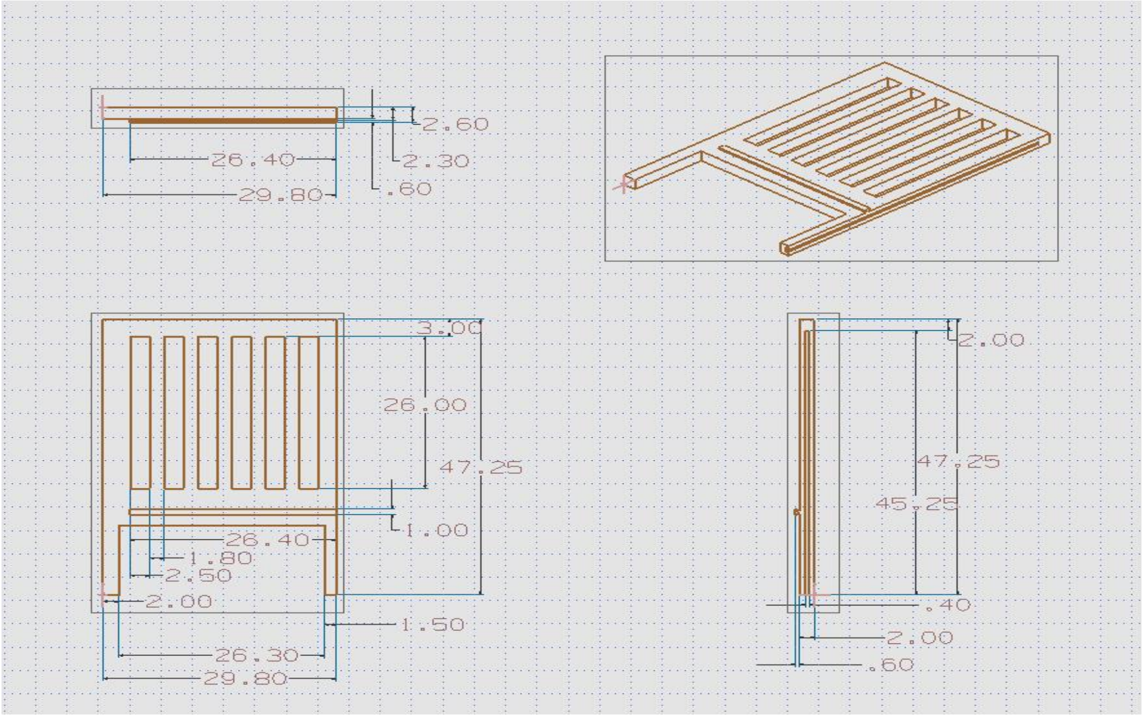
8.5 Detailed Drawings of the Crib Rails

In this section, we are including the detailed CAD drawings of the crib rails; two side and the back rail.

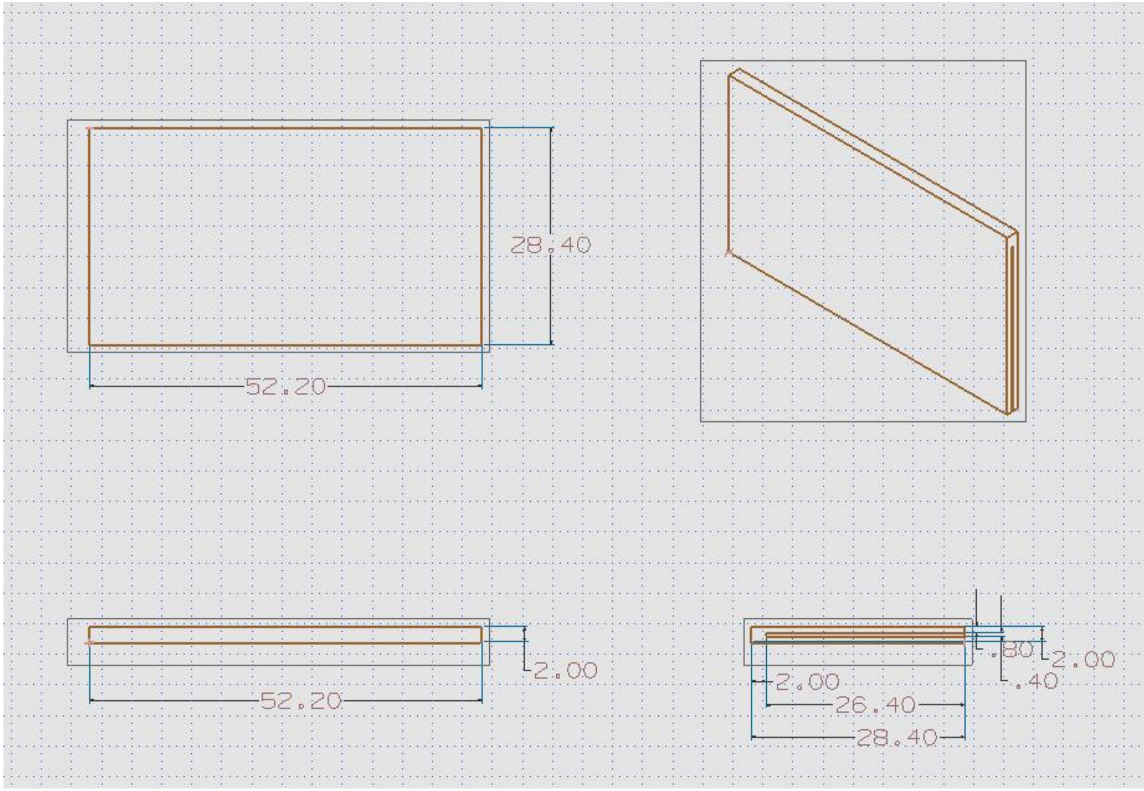
CAD-9: Dimensions of the Back Rail



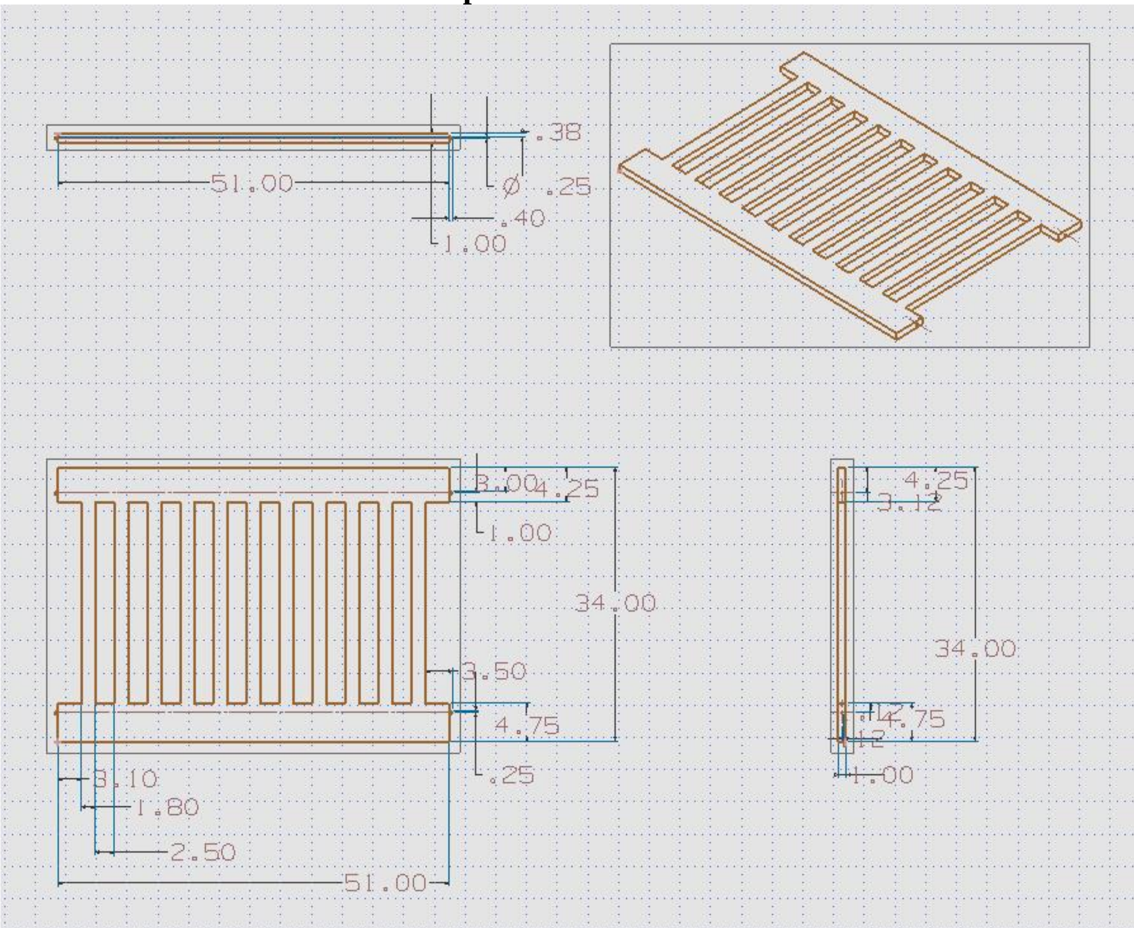
CAD-10: Dimensions of the identical Side Rails



CAD-11: Dimensions of the Base



CAD-12: Dimensions of front Drop Side Rail



9.0 Prototype Description

The prototype is not an exact representation of the final design. The prototype is a scaled-down model of our actual design for the ease of manufacturing, and also due to budget constraints. In this section we document the key factors that will describe the prototype, manufacturing plans and the prototype assembly.

9.1 Main Components of Prototype

The prototype will show five main components of the final design: the back rail, two side rails, the mattress base, the front drop side and the S-hook. The only adjustment between the final design and the prototype is that the prototype has each separate slat for easy manufacturing.

9.2 Scaled Down Prototype

The prototype is a scaled down version of the final design. It is exactly 50% of the final design dimensions as shown in Table-5 on p-23. However, the width of slots and side walls will be same as the final design dimensions in order to allow easy T-slot manufacturing.

9.3 Materials of Prototype

The prototype is made of Oregon Pine wood except the S-hook and the pegs. The S-hook is not made of wood, but rather of Aluminum because it requires durability to sustain the weight of the front drop side, and the stainless steel pegs will be the only other metallic part.

9.4 Prototype Manufacturing Plan

In this section we document the detailed manufacturing plan we followed for creation of the prototype. The prototype had five components namely the side rails (2), front rail (drop side), back rail, and mattress base.

9.4.1 Side Rail(s)

The two side rails were mirror images of one another. Figure-P1 shows one of the side rails with slats. The side rail began as a solid plank of wood from which pieces of material were removed to create the impression of the slats.

Figure-P1: Side Rail

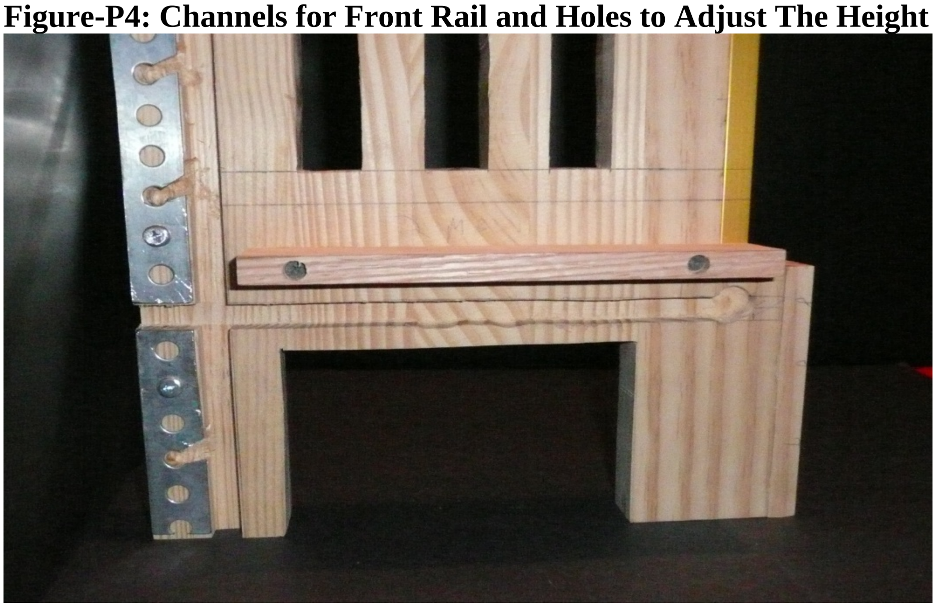
The mattress base support and the female track on the side rail (for installation of the back rail) can be seen in Figure-P2 and P3 on the following page. Screws were used to hold the female track and the mattress base as seen in Figures-P2 and P3 respectively.

Figure-P2: Featuring Female Track

Figure-P3: Depicting Mattress Base

The side rail also has the detail that allows for the adjustable height of the front rail. To provide motion to the front rail, the vertical and horizontal channels were carved out of the side rails as can be seen in Figure-P4. In addition, the figure shows an aluminum strip with holes that was attached to the side rail along the vertical carved out channel to hold the front rail and allow for height adjustment.

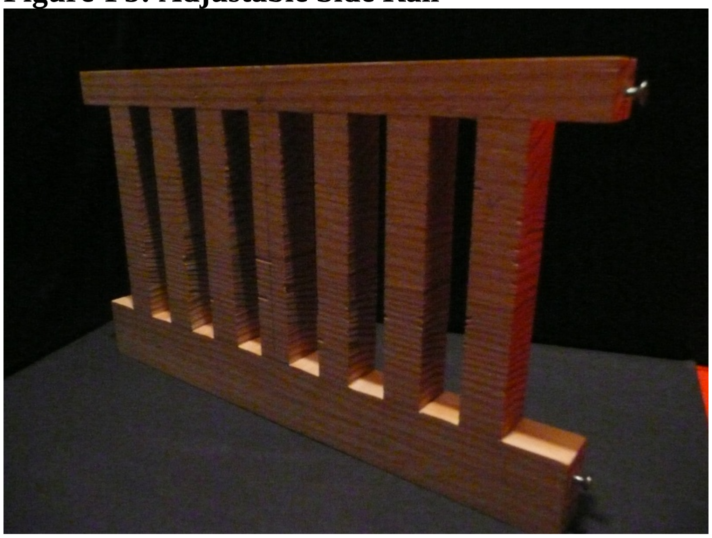
Figure-P4: Channels for Front Rail and Holes to Adjust The Height of the Front Rail



9.4.2 Front Rail

The front rail's slat feature was achieved in a similar fashion as we did for the side rails; by simply removing sections of material from a solid wood plank. In addition to the slats, Figure-P5 shows the screws attached to the four corners that acted as the peg protrusions which would be guided by the carved out channels of the side rail so that the front rail can achieve the appropriate height for safety.

Figure-P5: Adjustable Side Rail

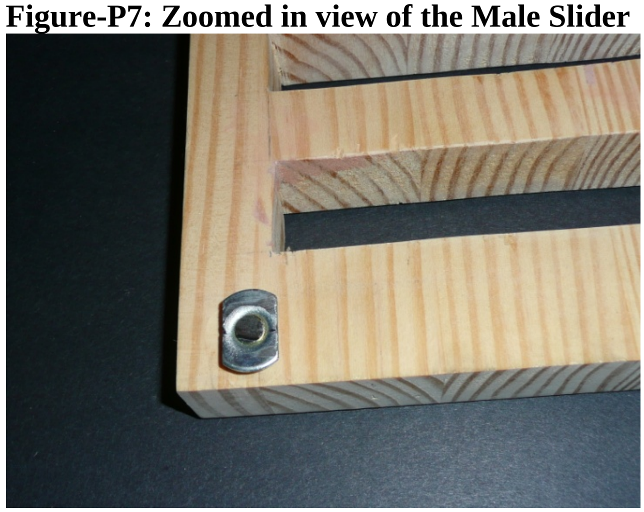


9.4.3 Back Rail

The back rail as seen in Figure-P6 features the slats, manufactured in the same way as the previous pieces' slats, along with the male sliding counterparts used as a substitute for the male part of the T-slot featured in the final design. The purpose of the sliders was to act as a way to engage the back rail in the respective female track on the side rails. A zoomed in view of the male sliding counterparts can be seen in Figure-P7.

Figure-P6: Back Rail

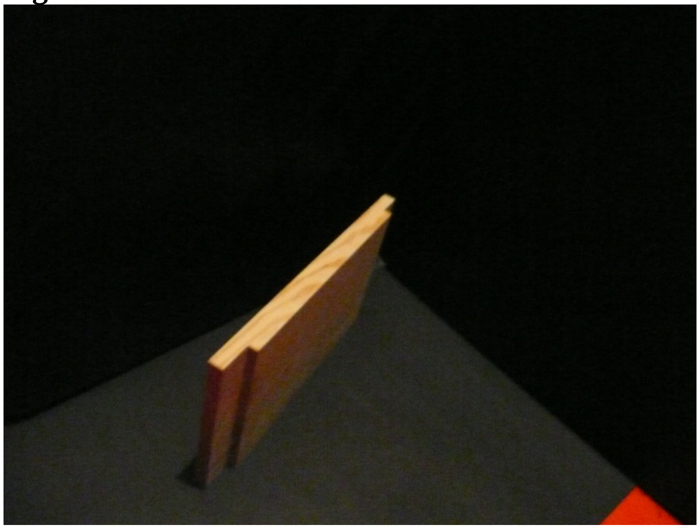
Figure-P7: Zoomed in view of the Male Slider



9.4.4 Mattress Base

The mattress base as seen in Figure-P8 was simply cut out of a wooden plank to the appropriate dimensions.

Figure-P8: Mattress Base



9.5 Prototype Assembly

The assembly of the prototype starts with laying the back rail on the floor followed by engaging the side rails with female tracks. Figure-PAS1 shows one of installation of one of the side rail.

Figure-PAS1: Side Rail(s) being engaged onto the Back Rail

Once this three part assembly (two side rails and the back rail) is complete as seen in Figure-PAS2, the crib would be set in the vertical position as seen in Figure-PAS3.

Figure-PAS2: Complete Three Part Assembly

Figure-PAS3: Vertical Setup

To the three part assembly as seen above in Figure-PAS3, the mattress base is installed by sliding onto the supports as can be seen in Figure-PAS4.

Figure-PAS4: Installation of the Mattress Base

To complete the crib assembly the front adjustable rail is installed in two steps as can be seen in Figure-PAS5 and PAS-6 on the following page.

Figure-PAS5: Step-1 of Front Rail Installation

Figure-PAS6: Front Rail Fully Engaged

In addition, Figure-PAS6 shows the highest position of the front rail. The lowest position of the front rail along with the stowed position can be seen in Figure-PAS7, and PAS8 respectively.

Figure-PAS7: Lowest Position of Front Rail

Figure-PAS8: Stowed Postion

10.0 General Manufacturing Plan

Our final design has five major pieces that need to be assembled together by the set-up person: the two side rails, the back rail, the mattress base, and the front drop side. Four out of the five key pieces, the two sides, the back, and the drop side, have a general assembly of slats that is done during manufacturing before the detailing of how to fit the pieces together is completed. The fifth key piece of our crib is the mattress base, this piece is a simple solid structure strong enough the most impact from the child's weight. Each of the five key pieces in our crib design is detailed with a difference in the number of slots cut out of each piece and the geometry of each slot cut so that no two pieces have amount of specific slots. Our team has designed the crib this way for easy identification of each piece by the customer, therefore reducing the possibility of confusion during assembly. In the section below, the plan of how our team will manufacture the pieces of our crib so they fit seamlessly together is explained.

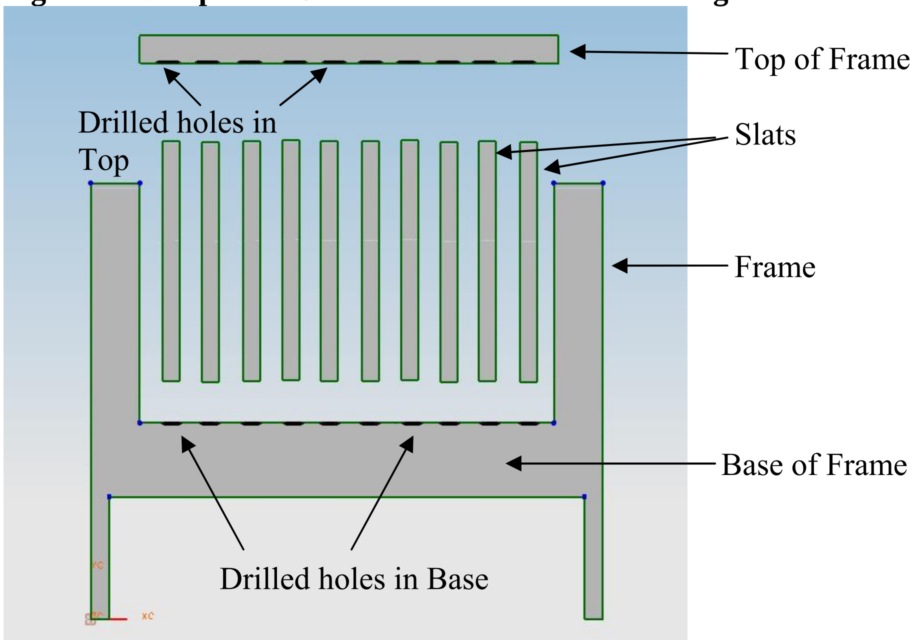
NOTE: Although not specifically stated, every piece mentioned below will be sanded down after manufacturing to reduce the risk of injury to the child or the child's care giver so that all surfaces are splinter free. With our sponsor, Nancy A. Cowles's go-ahead for the prototyping stage, our team will be following the plan as discussed in the subsequent sections.

10.1 General Manufacturing of Four Side Rails

Each of the four pieces is initially manufactured in the same way but to different proportions depending on where the piece is located in the crib. These different proportions can be seen in the CAD drawing (CAD-3 on p-25). The first step for each individual side is to cut out three fourths of the general frame of with a table saw, making sure to include an empty space for the slats and to leave off the top of the frame so that the spinals can be put in with ease (Figure-M1 on the following page).

The second step is to manufacture all the slats using a lathe and bore holes in both the inside top and the base of the four frames for the slats to sit. The holes will be drilled so that when slats are put into place there will be a 2.5 inch space between the slats. Then we use an adhesive to secure the slats into the frame's base and place that same adhesive to the frame's top holes and place the top piece onto the slats (Figure-M1 on the following page).

Figure-M1: Exploded View for General Manufacturing of Slatted Sides



After the four sides have been generally manufactured and their slats are in place, each side is individually detailed to insure a proper fit upon customer assembly.

10.2 Detailing Pieces for Assembly

Our Alpha design is a crib made with the consumer in mind. One of the many consumer friendly features our design has is the easy slot assembly. This portion of our manufacturing plans discusses how we create this easy nearly full proof method of assembly by going through how we manufacture each of the five key pieces of the crib.

10.2.1 Two Sides

The two sides of the crib are the longest pieces of the crib and are designed almost identical to one another, but in mirror image. On each of the sides there are metal tracks located towards the front face of the crib for the drop side to be guided in. The metal track perpendicular to the ground has 'S-hooks' manufactured into it, while the parallel track does not. The perpendicular track's purpose is to provide the drop side with vertical movement and the 'S-hook' detail will be milled out of an aluminum U-channel. The parallel track's purpose is to provide the drop side with horizontal movement and allow the crib to be converted into a changing table. This track for horizontal movement will be an un-milled U-channel which is used to guide the drop side under the mattress and not allow the drop side to come apart from the crib when in motion (Below Figure-M2,M3 and M4).

Figure-M2: Side Piece Profile View Detail

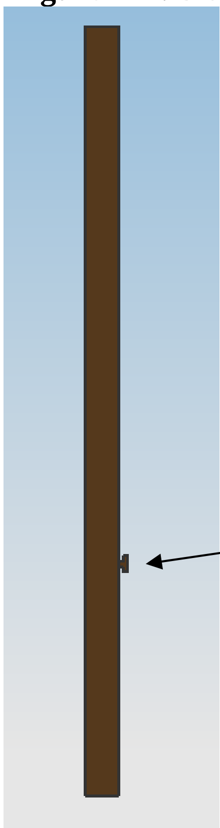


Figure-M3: Left Side Piece Detail

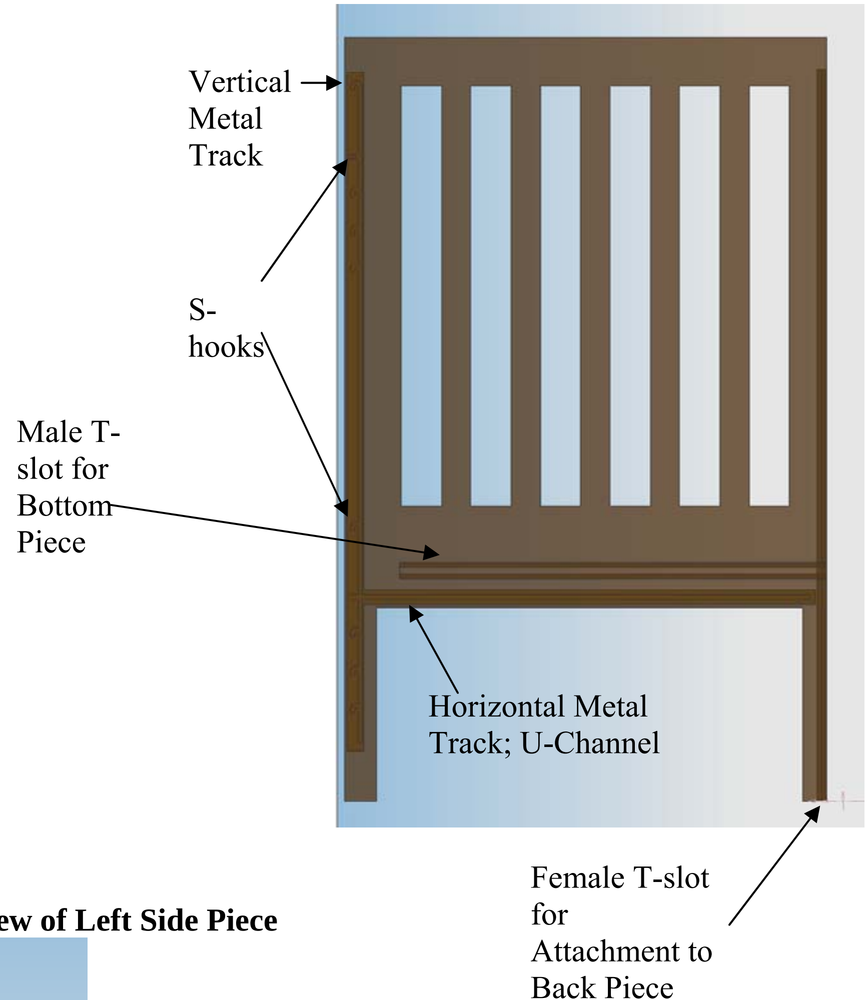
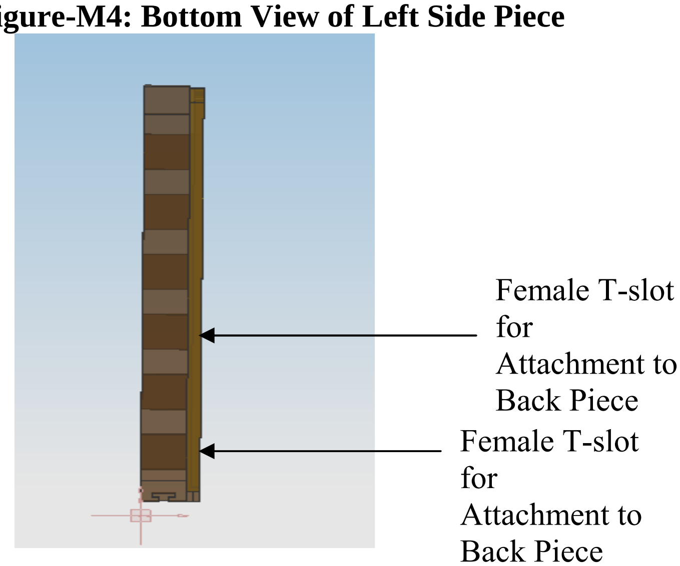


Figure-M4: Bottom View of Left Side Piece



In addition to the metal tracks for the drop side, there is one male and one female part of a T-slot cut into both side pieces. Located directly above the horizontal metal slot and below the frame for the slats, this male part of a T-slot is cut with a mill and runs parallel to the metal track (Figure-M3 on p-34). This slot is where the bottom piece of the crib will be placed. The female geometry of the T-slot is the located on the back edge of the side pieces and will be manufactured with a mill. These back edges are manufactured in this way so that the side pieces can be slid onto the corresponding male part of the T-slot that is located in the back piece of the crib, this will be discussed further in the coming sections. By having each piece cut having different numbers of male and female geometries of the T-slot, the customer is forced to place the two sides pieces, bottom piece, and back piece into the correct slots, therefore reducing assembly error.

10.2.2 Back Rail

Once the back rail of the crib goes through the general manufacturing and has slats, the next step is to complete it by creating two T-slots.

Figure-M5: Front View of Back Piece

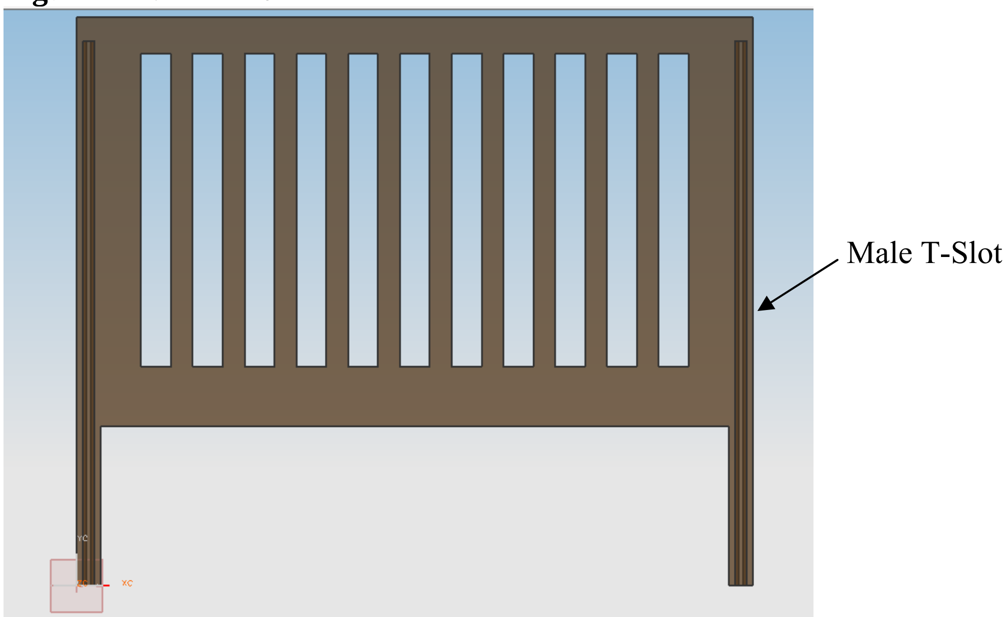
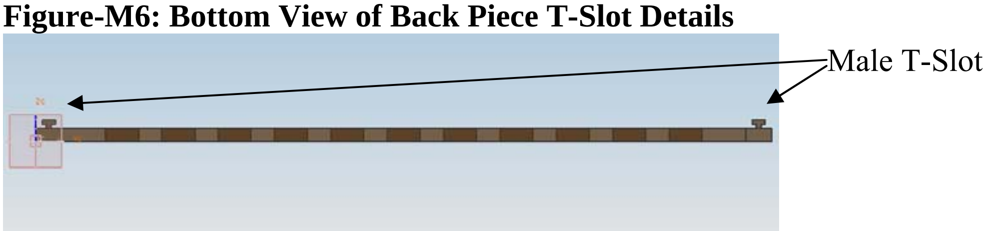


Figure-M6: Bottom View of Back Piece T-Slot Details

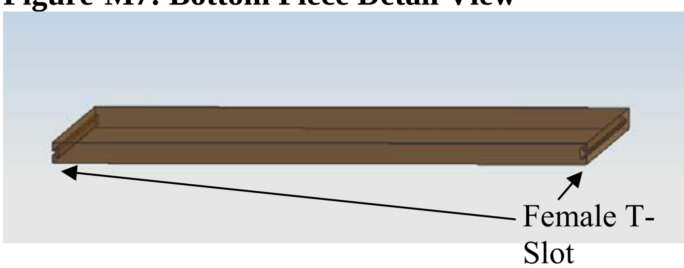


As Figure-M5, and M6 shows, the two male parts of the T-slot are placed near the left and right edges of the back piece. These two T-slots near the edges are milled out to fit the corresponding dimensions of the female portion of the T-slot mentioned in the previous *Two Sides* section. Through this placement the T-slots on the back piece, the two side pieces of the crib can be assembled so that the edges are flush at the corners. These slots and milled edges are designed to prevent against consumers misassembling our product, therefore reducing the risk of failure from improper assembly.

10.2.3 Mattress base

The mattress base is the simplest of the five pieces with no general manufacturing needed to add slats and only a few details added to be complete. These details of male portions of the T-slot were mention briefly in the above sections. For this bottom piece, two female parts of the T-slot (Figure-M7) will be milled out from the side edges of the piece. This will allow the bottom piece to slide into place by using the two male portions of the T-slots previously manufactured in the two side pieces of the crib. Through this the bottom piece will be secured in the correct position in the crib so as not to allow the space between the top of the mattress and the top of the rail to exceed CPSC guidelines. The back edge of the bottom piece will not be shaped but will be guided towards and abut the back piece’s once it’s in position.

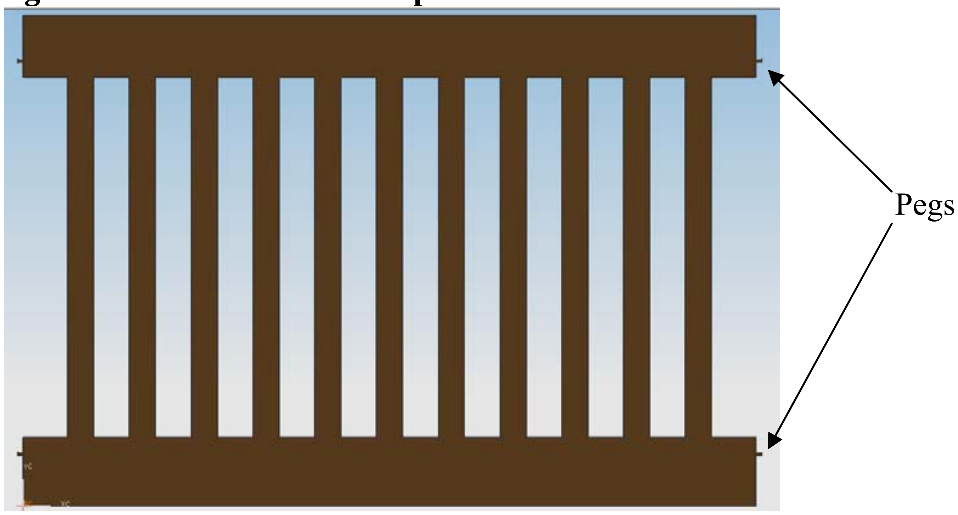
Figure-M7: Bottom Piece Detail View



10.2.4 Drop Side

The drop side is the only mobile part of the whole crib. This drop side is located as the front face of the crib and through the manufacturing of the other four key pieces, is given both vertical and horizontal motion. The drop side does not possess any of the slots that the previous pieces do, such as the T-slot or linear slot; it instead has four pegs which protrude from its two sides. As seen in the Figure-M8 on the following page, the four pegs are each positioned near one of the corners and are meant to travel in the metal tracks that were milled out of the U-channel mentioned above in the subsection *Two Sides*. This drop side is placed into the crib’s assembly last by lining up the pegs with the four openings in the metal track of the two side pieces (Figure-M8). Once in the metal track of the side pieces, the drop side has vertical mobility and can be adjusted to different heights by placing the pegs in the different “s-hook” heights. This vertical motion can switch to horizontal motion by disengaging the top pegs and rotating the top of the drop side’s frame away from the crib and pushing inwards towards the crib so that the two bottom pegs will be guided into the two horizontal metal tracks (mentioned previously in the *Two Side* subsection) and commence its horizontal motion. These pegs will be pieces of stainless steel, about a half of an inch long, with screw-in attachments at their ends so that they will be able to be easily secured to the drop side.

Figure-M8: Front View of Drop Side



The list of the materials is as follows:

Table-6: List of Materials

Material	Location on Crib	Manufacturing Process
Oregon Pine Wood	Slats	Lathe
Oregon Pine Wood	Side frames	Table saw and drill
Oregon Pine Wood	Slots in frames	Milled out
Aluminum	Used for tracks in two side frames	Milled out

11.0 Validation Plan

In other to make sure that our crib is safe and comfortable, we have series of test that would be carried out to ensure all our engineering specifications have being met. Since we are building a scaled model of our crib not all testing would be relevant. However a for a full size crib all test would be done to validate our design. Our crib would carry out test by the American Society of Testing and Materials (ASTM) [8].

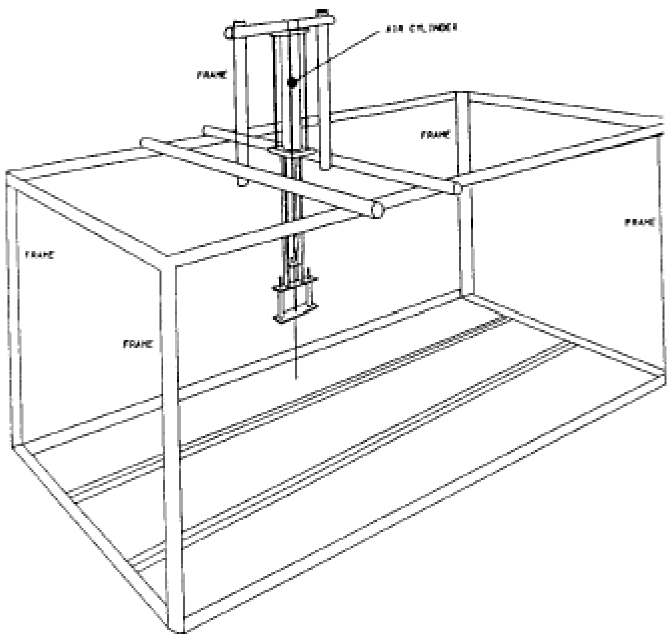
11.1 American Society of Testing and Materials (ASTM)[8] Test

These tests include the mattress support vertical impact test, the crib side test, and the mattress support system test.

11.2 Mattress Support System Vertical Impact Test

This test helps examine the structural integrity of the crib, it consist of applying a load of 45lbs repeatedly on the foam pad held by the crib mattress support system as shown in Figure-V1 on the following page. All our joints would be subjected to abusive loads and stresses. The weight would be allowed to free fall 6 in on the top surface of the foam pad at a rate of 4 ± 1 s/cycle. 500 cycles would be done within the .25 in of the geometrical center of the crib and 100 cycles at two diagonally opposite corners 9 in from the crib corners. After this test it is required that all the components of our crib assemblies should not be more than .04in.

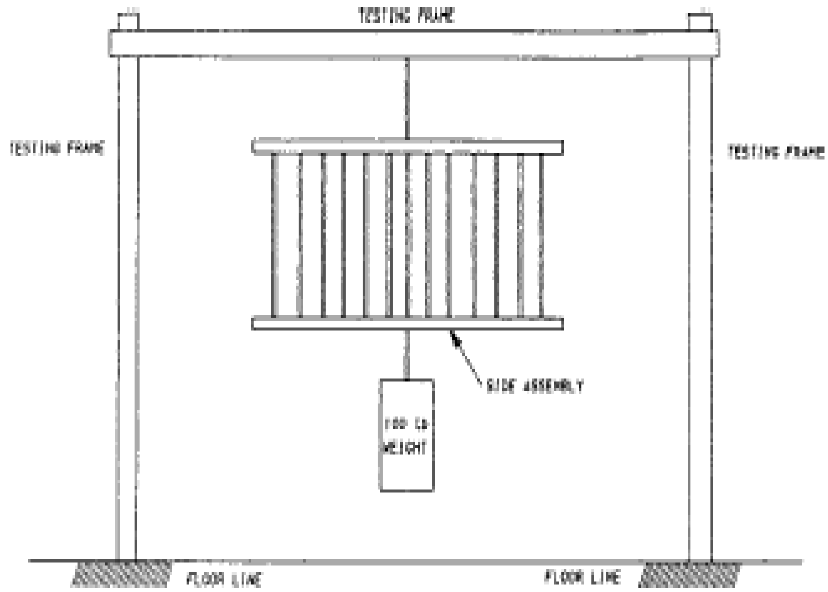
Figure-V1: Mattress Support Vertical System Impact Test Frame



11.3 Crib Side Test

The crib side test consists of three series of experiments. In the first test, the side rails would be removed and it will be placed in a text fixture with the same assembly feature with the crib. The bottom rail on the crib side is tested repeatedly by applying a load of 30lbs which is free-felled 3in. 250 times at a rate of 4 ± 1s/cycle, this force is directly on the rubber pad on topside of the bottom rail. It is required that none of the spindles or slat be separated from the top and bottom rail. The second test begins by applying a load of 100lb at the center of the bottom rail as shown in Figure-V2 on the following page this load is slowly applied for a period of 5 seconds and maintained for an additional 10 seconds. Finally the third test consists of applying a torque of 30lbf-in at the middle of each slat. It is required that when the torque is applied all spindles comply with the crib component spacing

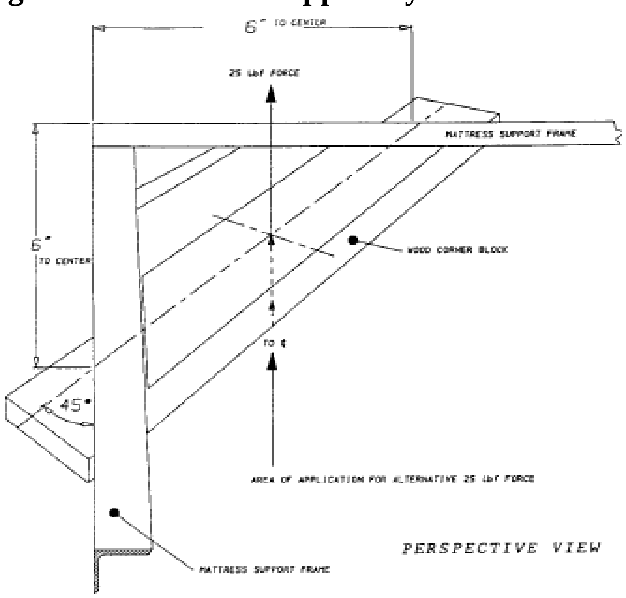
Figure-V2: Crib Side Static Test Frame



11.4 Mattress Support System Test

This test examines how the mattress support is assembled to the crib. No mattress is used in this test, and it requires only one corner of the crib as shown in Figure-V3. A 25lbs force is applied to the mattress support slowly for 5 seconds and kept constant for about 10 seconds. It is required that there should be no detachment in any of the mattress support attachments when this test is carried out.

Figure-V3: Mattress Support System Test Frame



Additional test would be carried out to ensure all our engineering specifications are met.

Crib Dimensions - We would used a measuring device to ensure our crib meets all the CPSC dimension standards for the crib length, crib width, and crib height, and the spacing between the crib rails.
Material Density - This will be checked using the standard mass divided by volume formula. The mass would be measured using a weighing scale device, and the volume would be computed using a ruler.
Surface finish – All wood surfaces will be checked to ensure and smooth surface free from splinters.

12.0 ENVIROMENTAL IMPACT

We had to make a decision between two categories of wood (Aspen Wood and Oregon Pine Wood), and we choose the Oregon pine because it has less environmental issues than aspen wood. To make this decision the software SimaPro was used to compute the environmental profile of the two materials. The software gives the life cycle of different products and services, and it is a very useful tool to use when computing the environmental issues of a product.
With the use of SimaPro we computed four results on the Impact assessment. Results are in charts that can be seen in Appendix-G no p-78

12.1 Characterization

In the characterization all the products emissions are explored due to their environmental impact (radiation, toxicity etc). SimaPro produced results comparing both aspen and Oregon pine wood as shown in Figure-G1 in Appendix-G on p-78. Results shown in Table-7 show that Oregon Pine has less environmental Impact than Aspen wood.

Table-7: Summary of results produced by SimaPro in terms of environmental impact

Categories	Higher Impact	%Difference
Carcinogens	Aspen	70
Resp. Organics	Aspen	20
Resp. Inorganices	Oregon Pine	15
Climate Change	Aspen	18
Radiation	Neglible	Neglible
Ozone Layer	Aspen	72
Ecotoxicity	Aspen	53
Acidification/Eutrophication	Oregon Pine	12
Land Use	Aspen	42
Minerals	Aspen	65

12.2 Normalization

The characterisation results does not specify whether our results in each chategory are high or low. With the normailzation steps all our resuts are compare with a set benchmark. This results helps us undertand whether an aspect of our chategories is significant or not. From the results shown in Figure-G2 in Appendix-G on p-79 , we can indicate that land use would be the most important aspect of our resutls. And Aspen has a higher enviromental impact on land use with a percentage difference of about 40.6%.

12.3 Single Score

The single score results uses the eco-indicator methos which allows us to sum up the weighted resuts into a single score. This gives us the overall enviromental load. From our results in we can indicate that Aspen wood has a higher enviromental load than oregon pine. With a difference of about 140mPt.

12.4 Mass Results

We also used SimaPro to analyse the emmisions due to mass, in raw materials, air, water and waste. In raw materials Aspen has a higher emmission with a difference of about 4500g, in aire aspen has a greater impact with a difference of about 200g, while in water and waste they both have very little impact.

13.0 Information Sources

Preliminary information was obtained from the sponsor's website (www. KidsInDanger.org), the U.S. Consumer Product Safety Commission (CPSC), and a conference call with the Kids in Danger's Executive Director, Nancy A. Cowles, on September 11, 2008 during which the primary cause of concern for crib safety was discussed. The sponsor's website provided the team with information related to product hazards, news publications, and programs to help keep children safe in cribs. In addition to KidsInDanger.org, the CPSC website provided us with the federal guidelines for the design of cribs. Furthermore, CPSC provided our team with past recalls and safety hazards that caused injuries and deaths of babies and infants as a result of the design of cribs in Appendix C. In order to gain further understanding of the cribs that are currently on the market, the team made a visit to the retailer *Babies "R" Us.* We analyzed various crib designs, styles, and material used to build the cribs that are currently available in the market.

The team will refer to the American Society of Testing and Materials International (ASTM) standards for material selection. Furthermore, we plan to refer to The US Patent and Trademark Office Website at www. Uspto.gov for information regarding patents filed for various mechanisms that we think could be implemented for our crib design.

13.1 *Research on Existing Patents and Their Descriptions*

Several patents of possible interest to our design are quoted below with representative quotes from their abstracts or descriptions [3].

This patent provides us with information as to how to implement the "*halo*" concept for our crib design.
US Patent # **6,859,957**
A baby crib includes a bed frame structure, a fabric member mounted on the bed frame structure to define a surrounding wall around the bed frame structure, and a plurality of positioning posts

mounted on the fabric member. The bed frame structure includes a plurality of upright tubes, each of which has a tube wall defining a receiving hole and having a slit that extends along the length of the tube wall and that is in spatial communication with the receiving hole. The positioning posts are inserted respectively into the receiving holes in the upright tubes. The fabric member is clamped between each upright tube and a corresponding positioning post, and extends outward through the slit in each upright tube.

The following patent has information to implement the changing table feature into our crib design.
US Patent # **D535,489**
Crib with changing table.

This patent helps us to incorporate an adjustable height mechanism with the help of this following patent.
US Patent # **7,020,916**
A crib and toddler elevation device having selectively adjustable height and tilt angle is described. The elevator includes a base for placing on the floor and for receiving the legs of the crib or toddler bed. The elevator also includes a variety of mechanisms for adjusting the height of the crib or toddler bed, including elevating blocks. The elevator may also include an optional centerpiece to facilitate installation of the crib or toddler legs into the elevator.

13.2 Benchmarked Designs:

The following quotes are the various benchmarks for our design excerpted from the U.S. Consumer Product Safety Commission's Office of Compliance in the document 16 C.F.R Part 1508, Requirements for Full Sized Baby Cribs [4].

- Dimensions of the full sized crib: The interior of a full size crib has to be 52 inches long and 28 inches wide.
- Adjustable Constraints: The top of an adjustable rail at its highest position must be at least 26 inches above the top of the mattress support at its lowest position. The top of the adjustable rail at its lowest position must be at least 9 inches above the top of the mattress support at its highest position
- Hardware: Hardware accessible to a child must be designed and constructed so that it does not pinch, bruise, crush, lacerate, break, or amputate any part of a child's body during normal use.
- Construction and Finishing: All wooden parts shall be free from splits, cracks or other defects that might cause a crib or any of its parts to fall or come apart.

14.0 Project Plan

This section gives a brief overview of the major milestones that we plan to achieve. These range from the period of time where we were assigned to this project leading up to the Design Expo. Furthermore, in Table-3, we document the milestones that play a critical role in ensuring the completion of the project in a timely fashion.

Table-8: Project Milestones

Date	Milestone
September 11	Initial Sponsor Meeting
September 16	Research Cribs on the Market
September 24	Finalization of QFD
October 5	Concept Generation
October 6	Alpha Design Selection
October 8	Material Selection
October 21	CAD Drawing for Final Design
November 21	Manufacturing Prototype
November 27	Final Assembly of Prototype
December 3	Final Testing of Prototype
December 12	Finalization of the Report

Table-8 is a summary of our project plan that must be completed prior to the Design Reviews and Design Expo. The complete plan can be seen in our Gantt chart listed in Appendix B. We found the following contents of this table to be the most important of the deadlines to complete our project. First of all, we had a conference call with our sponsor, Nancy A. Cowles, Kids in Danger on Thursday, September 11th to get a better understanding of what our sponsor was looking for in our design. We planned a visit to a retail outlet where cribs were sold to research various cribs that are already on the market to visualize some of the hazards that can occur by Tuesday, September 16th. The next date of September 24th was chosen to finalize a QFD because we knew that the information from the cribs would allow our team to define engineering specifications and customer requirements, therefore allowing us to weigh and compare the two to one another and come up with our QFD. Each team member generated the concept design and we selected the alpha design by October 6th. We completed our material selection and CAD drawing for the final Design by October 8th and 21st respectively. Then, we are going to start manufacturing the prototype before the third Design Review and complete the final assembly and testing of the prototype.

15.0 Problem Analysis

Most manufacturers failed to meet the CPSC safety regulations thereby building cribs that were hazardous to children and hence were recalled. These cribs posed fall and entrapment hazard causing immediate injuries in some cases. To address this problem, our crib design will be designed in accordance to the dimensions laid out by the CPSC guidelines which call for a minimum of 26 inch height between the secondary mattress support (at its lowest position) and the top of the side rail (at its highest position). To incorporate this guideline into our design, we designed a single drop side that can be adjusted to accommodate different heights for children ages 0 to 2 years as seen in Sketch-4C, and 4D on p-11.

In addition, we focused on mobility of the crib parts which was another prominent cause of crib recall; the less the number of mobile parts lesser the crib structure prone to failure. For instance, the mechanical parts that provided mobility to drop side or the adjustable mattress failed causing immediate injury to the child due to falling. To address this issue, we kept the number of mobile parts to minimum, and that is with only one drop side and fixed mattress as depicted by Sketch-4A of Concept-4 on p-11. To address the entrapment hazard causing injury in children while crib usage, our team designed a mesh-hammock, Sketch-4K on p-13, which can be installed on the top of the mattress covering all the gaps between the mattress and the crib frame.

To overcome poor and complex assembly instructions that led to CPSC recall, our team generated a slot design documented in Concept-1, Sketch-1A on p-7, and pre-assembly concepts with the help on hinges (Sketch-3A on p-10) in which the side rails are pre-assembled onto the mattress support base. Also documented in Concept-2 on p-9, in which all the three sides (two side rails and the back rails) are assembled to the base with the help of hinges thereby providing a compact package for transportation purposes and an easy installation. During recalls, poor assembly instructions lead to improper installation of the drop side, which disengaged during crib usage and was the cause of injury due to child entrapment. The slot design addresses this issue by forcing the care giver, in a way, to install the crib sides in only one easy possible way; by sliding the side rails into their respective slots.

16.0 Conclusion

Our team, in association with the Kids In Danger organization, plan to create a safe and an affordable crib for children from 0-2 years of age. We were introduced to the current crib hazards by researching KidsInDanger.org and also from the U.S. Consumer Product Safety Commission. The hazards we found were mainly due to the manufacturer not following CPSC guidelines, failure of mobile parts, and improper assembly. To address these issues, our team created and analyzed four different concept designs and combined the best features from each of the designs to create our alpha design. The alpha design was refined and CAD drawings were generated to help the manufacturing process. The prototype thus manufactured was presented at the Design Expo on Dec. 4, 2008.

17.0 Team Roles

The team roles are given below. All team members share responsibility for the design generation and engineering work.

Kim Bagian	Team Leader
Chukwuka Isichei	Task Manager
Dong Joon Min	Researcher
Amritpal Singh	Treasurer

We as a team share the enthusiasm and motivation to build a safe and an inexpensive crib. We are excited to work with Prof. Bogdan Epureanu and our sponsor from Kids In Danger, Nancy A. Cowles.

18.0 Biographies

Amritpal Singh is a senior in Mechanical Engineering (CoE) and Economics (LSA). He was born and raised in India. After finishing high school, his family immigrated to the US. He has lived in Michigan for four years, and upon graduation plan to relocate to California where his family resides. Eventually, he would like to go into the design and development field for new products used in defense industry. A particular interest of his is Unmanned Aerial Vehicles (UAV). He has a great passion for the game of golf and loves to both play and teach it in his free time. He is preparing for the 2010 U.S Amateur golf tournament that will be played at Southern Hills Country Club in Tulsa, Oklahoma.

Kim Bagian, a senior in Mechanical Engineering, plans to attend graduate school next year at a University either down south or along the west coast. She is from Northville, Michigan and has two younger brothers, one in high school and the other a freshman at Indiana University, and an older sister, a graduate student at Georgia Tech. Studying and working abroad last summer in China has really ignited her interest in travel and all the new experiences it brings. She hopes to be able to work abroad in future years and maybe even return to China for a period of time. Next summer she is looking at possibly working in Zambia or Denmark before school starts up again. In her spare time, she enjoys playing soccer and softball or just tossing around a frisbee.

Dong Joon Min was born in Seoul, South Korea. He is a senior in Mechanical Engineering. Actually, he has never been to any other country before he entered the University of Michigan. Therefore, the University of Michigan was his starting point to fulfill the dream of being an engineer. Especially, he is interested in the vibration and dynamics. He is doing a research about structural interrogation through nonlinear feedback excitation as the independent study. After graduation, he is going to attend graduate school. In his free time, he enjoys listening to the classical music, playing the piano and playing squash. His parents live in South Korea and he has a sister who works as the jewelry designer in London.

Chukwuka Isichei is a senior in Mechanical Engineering. He would like to work in a top oil and gas Company. Growing up in Nigeria, which is one of the largest oil producing nations, was his motivation to pursue his degree in mechanical engineering. His hobbies are travelling, soccer, basketball, video games keeping up to date with current events.

19.0 References

[1] "Nursery Product Related Injuries and Deaths Among Childern Under Age 5", http://www.cpsc.gov/library/nursery06.pdf

[2] Mission Statement from Kids in Danger, http://kidsindanger.org/aboutus/mission.asp

[3] The US Patent and Trademark Office Website, http://www.Uspto.gov

[4] "Regulatory Summary for Full Size Baby cribs", http://www.cpsc.gov/BUSINFO/regsumcrib.pdf

[5] The CPSC recall due to poor assembly instructions, http://www.cpsc.gov/cpscpub/prerel/prhtml07/07205.html

[6] Concept Generation challenges/problems documented by the previous Safe Crib Team for Me-450 during Fall 2006.

[7] CSE Edu Pack for Material Properties

[8] ASTM International. "Standard Specification for Full-Size Baby Crib." Designation F 1169 - 03.

[9] Physical Properties of Oregon Pine at Matweb's Website Link, http://www.matweb.com/search/DataSheet.aspx?MatGUID=3e4523f2117f4d1f8cc751a1fca882bc&ckck=1

[10] Statics and Mechanics of Material by R.C. Hibbeler, Chapter 12 on Bending

[11] Statics and Mechanics of Materials by R.C. Hibbeler, Chapter 6 on Geometric Properties and Distributed Loadings

[12] Physical Properties of Oregon Pine Not covered by [9],
Page-182 of the Second Biennial Report of the Oregon State Board of Horticulture to the Legislative Assembly, Seventeenth Regular Session posted the following Link:
http://books.google.com/books?id=geQ1AAAAMAAJ&pg=PA182&lpg=PA182&dq=Yield+Strength+of+Oregon+Pine&source=web&ots=Sc9lTxN818&sig=5lWOOGIs1GEVTL-1tavnM-rAf7M&hl=en&sa=X&oi=book_result&resnum=1&ct=result#PPA182,M1

[13] Statics and Mechanics of Materials by R.C. Hibbeler, Chapter 13 on Transverse Shear

[14] Physical Properties of Stainless Steel at Matweb's site with the link: http://www.matweb.com/search/DataSheet.aspx?MatGUID=71396e57ff5940b791ece120e4d563e0&ckck=1

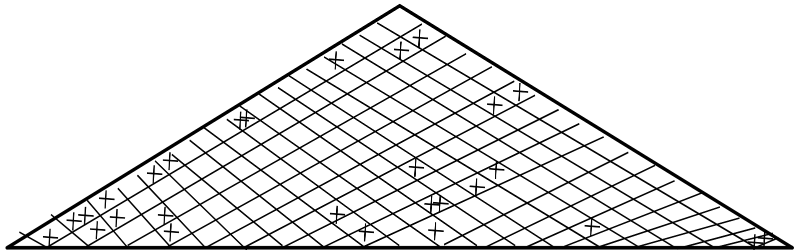
[15] Statics and Mechanics of Material by R.C. Hibbeler, Chapter 8 on Stress and Strain

[16] Statics and Mechanics of Material by R.C. Hibbeler, Cover Page Summary of Simplified Beam Slopes and Deflections

[17] Stability Analysis from the past safe crib team (Fall '06)

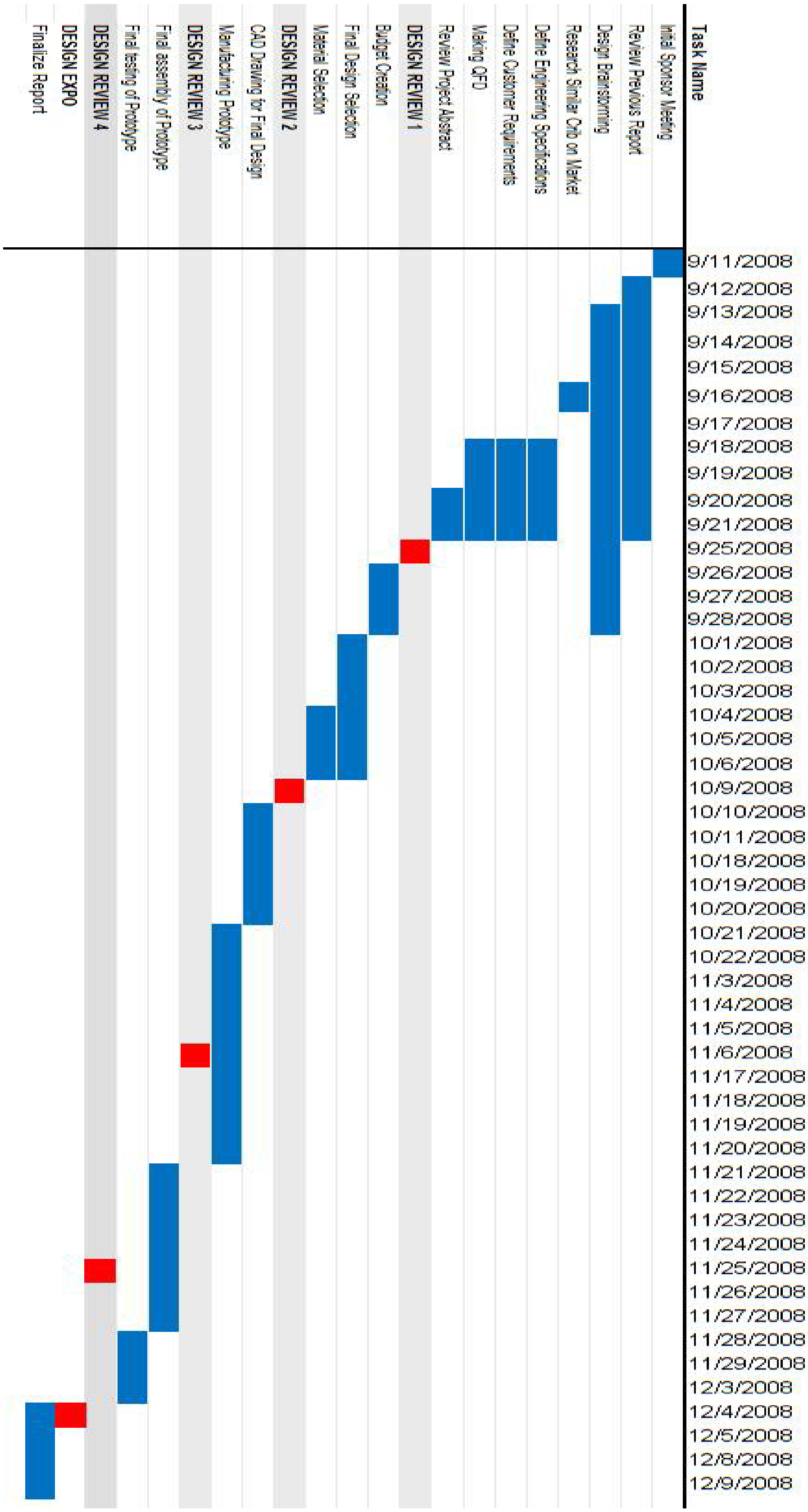
[18] Data gathered from Past team's report (Fall'06)

Appendix A: QFD



COSTUMER REQUIREMENTS / Engineering Specifications	IMPORTARNCE	Crib Weight	Crib Height off of ground	Crib length	Crib Width	Spacing between rails	Rail dimensions	Material density	Material surface finish	Material Yield Strength	Manufacturing Cost	Number of parts	Number of Movible Parts	Maximum Deflection	Force Mattress supports endure	Force Railing will Endure	Young's Modulus	Moment of Inertia	Fatigue Lifetime	Rail Height (setting 1: infant)	Rail Height (setting 2: 2 yr old)	Total Costumer Requirements	RANK
Practical	3	3	3	1	1	1		3	3		1	9	9	1				1	1	9	9	165	10
Easy to assemble	2	9	3	3	3	1	1		1			9	9									78	12
Standard size	6	1	3	9	9	9	9				3	3	1							9	9	390	6
Stable	7	9	9	1	1		1	3		3	1	3	3	9	3	9	9	9	3	1	1	546	3
Inexpensive	5	9		3	3	1	3	1	9		9	3	3						3	1	1	245	8
For children 0-2 yrs	4		3	3	3	9	1						1	1	9		9		9	9	9	264	7
Protects baby from suffocation	9					9	3															108	11
Meets CPSC Guidelines	13			9	9	9			9	9					9	9	9		9	9	9	1287	1
No hardware failure	12	3		3	3	3	3	3		9		3	3	9	9	9	9	3	9	1	1	996	2
Easy to manouver	1	9	1	3	3			3	3			9	9					9		1	1	51	13
Ventilation	8		1			9	1		3			9	3							1	1	224	9
Protects baby from strangulation	11					9	1		3			3	3							9	9	407	5
Protects baby from falling	10		9	1	1	9	1					1	3							9	9	430	4
Units		lbs	in	in	in	in	in	slug/in^3	lb/in	lb/in^2	$	#	#	lb/in^2	lb	lb	lb/in^2	slug/in^2	cycles	in	in		
Current Crib Design				52	28										25					20			
Target				52	28										25					20			
Total		186	129	69	210	214	157	15	27	81	3	48	312	64	117	189	243	108	55	186	491		
Ratings		6%	4%	2%	7%	7%	5%	1%	1%	3%	0%	2%	11%	2%	4%	7%	8%	4%	2%	6%	17%		
Ranked Imporrtance		6	9.00	13	3	3	8	17	27	12	19	13	1	13	9	3	2	9	13	6	2		

Appendix B: Gantt Chart



Appendix C: Information researched about recalls from CPSC

We studied the following links to obtain information about safety hazards that led to the recall of various crib designs.

- Baby Appleseed Recalls Cribs Due to Fall Hazard (August 5, 2008)

  http://www.cpsc.gov/cpscpub/prerel/prhtml08/08351.html

- Mother Hubbard's Cupboards Recalls Cribs Due to Fall Hazard (August 5, 2008)

  http://www.cpsc.gov/cpscpub/prerel/prhtml08/08350.html

- Stanley Furniture Recalls Cribs Due to Entrapment Hazard (June 26, 2008)

  http://www.cpsc.gov/cpscpub/prerel/prhtml08/08314.html

- Jardine Cribs Sold by Babies"R"Us Recalled Due to Entrapment and Strangulation Hazard (June 24, 2008)

  http://www.cpsc.gov/cpscpub/prerel/prhtml08/08312.html

- Bassettbaby Cribs Recalled Due to Entrapment Hazard; Sold Exclusively at Babies "R" Us (June 5, 2008)

  http://www.cpsc.gov/cpscpub/prerel/prhtml08/08581.html

- Munire Furniture Recalls Cribs Due to Fall Hazard (February 28, 2008)

  http://www.cpsc.gov/cpscpub/prerel/prhtml08/08202.html

- Bassettbaby Drop-Side Cribs Recalled Due to Entrapment and Strangulation Hazard (February 14, 2008)

  http://www.cpsc.gov/cpscpub/prerel/prhtml08/08544.html

- Cribs Sold By Bassettbaby Recalled Due to Entrapment and Strangulation Hazard: Sold Exclusively at Babies R Us (November 8, 2007)

  http://www.cpsc.gov/cpscpub/prerel/prhtml08/08075.html

- About 1 Million Simplicity Cribs Recalled Due To Failures Resulting in Infant Deaths (September 21, 2007) http://www.cpsc.gov/cpscpub/prerel/prhtml07/07307.html

- NettoCollection Recalls Cribs Due to Entrapment and Strangulation Hazard (September 4, 2007)

  http://www.cpsc.gov/cpscpub/prerel/prhtml07/07300.html

- CPSC, Stokke Announce Recall of Sleepi Crib Foam Mattresses Due to Entrapment Hazard (August 23, 2007)

  http://www.cpsc.gov/cpscpub/prerel/prhtml07/07286.html

- Simplicity Recalls Cribs Due to Fall, Entrapment and Choking Hazards (June 6, 2007)

  http://www.cpsc.gov/cpscpub/prerel/prhtml07/07205.html

- Song Lin Industrial Inc. Recalls Cribs Due to Fall Hazard (May 31, 2007)

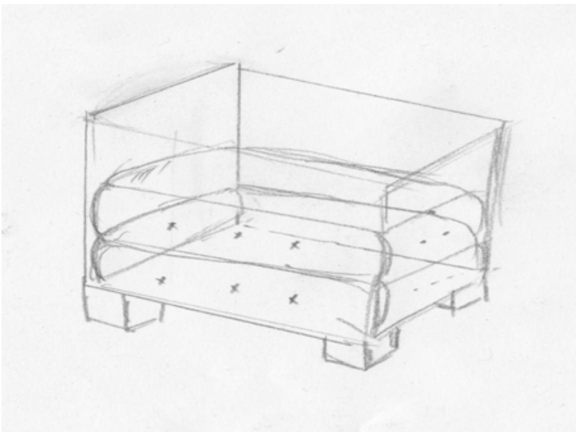
  http://www.cpsc.gov/cpscpub/prerel/prhtml07/07199.html

Appendix D: Preliminary Ideas

***Idea-1*: Stacking Mattress for the adjustable height**

Motivation for the Idea: The main objective of stacking mattress is to provide the adjustable mattress height. By taking flat lying mattresses from one level and delivering them to a different level, we can make several different heights for ease of access to their children for the parents.

Sketch-A shows the stackable mattress idea.

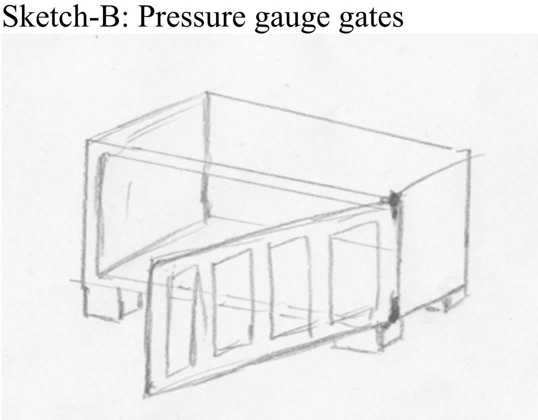


Problems Associated with the Idea: Stacking mattresses can make the whole system unstable because it causes the mattress to tilt and the baby to fall into the gap between the mattress and crib side walls.

***Idea-2*: Pressure gauge gates**

Motivation for the Idea: Pressure gauge gates are mounted using pressure and can create a strong force on the surfaces. These gates can make parents reach their babies easily. Sketch-B shows this idea.

Sketch-B: Pressure gauge gates

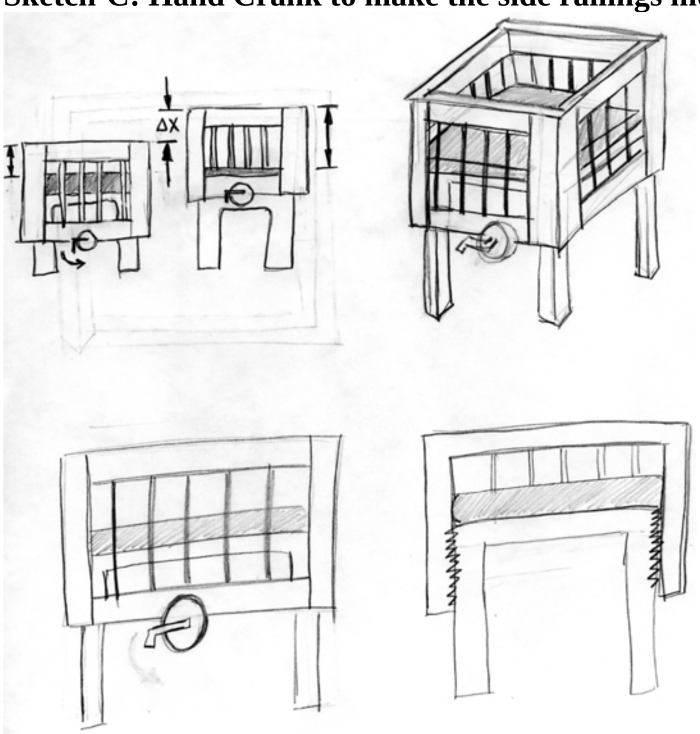


Problems Associated with the Idea: Although pressure gauge gates create a very strong force on the surfaces that they are mounted between, the pressure can push out on the two surfaces enough to eventually slip out of place with force. Therefore, these gates must be checked frequently to ensure that they are remaining tight in the space.

***Idea-3*: Hand Crank Motion**

Motivation for the Idea: In this design, only one part is mobile, the railings. This design focuses on a different way to give motion in order to vary the height of the railings in relation to the mattress. In this design, all four side railings are fixed together to form a frame around a central fixed mattress. By fixing the mattress to a secured non-mobile center part, the immediate impact to the child if the mobile piece were to fail would be minimal because the platform that the child is on, the matteress, would still stand intact in the case of failure. The mechanism chosen for this design is the hand crank. In order to have any care taker be able to adjust the four railed sides heights at once, the mechanism that would give motion needed to be easy for the feablist of physiques to use. Through the hand crank, the care taker would be able to adjust the height between the top of the mattress and the top of the railing by simply turning the crank, allowing for the rails to be raised by turning one way and lowered by turning it in the opposite direction. A combined Sketch-C depicts the handcrack, the mobile railings, and two positions that the crib sturcture can be adjusted to.

Sketch-C: Hand Crank to make the side railings mobile

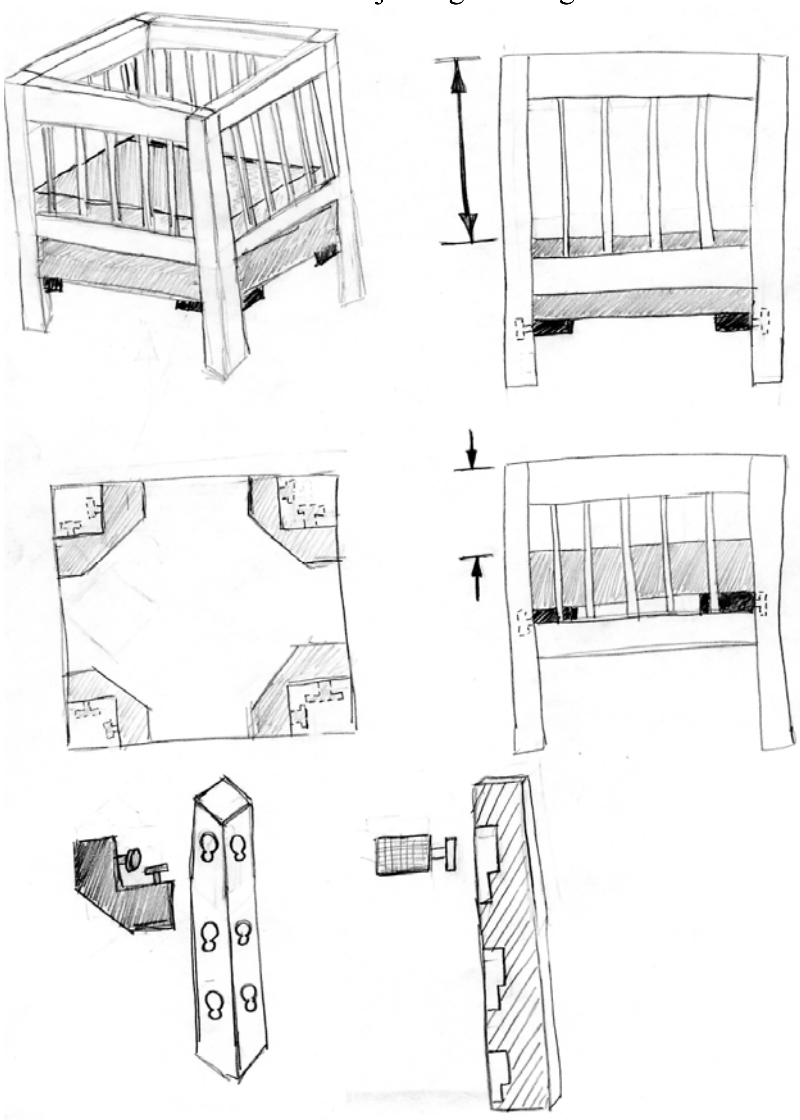


Problems Associated with the Idea: One of the main problems we found with this design was that the hand crank would be too awkward to use and too difficult for assembly.

Idea-4: **Adjustable Mattress through Corner Supports**

Motivation of the Idea: This design allowed for the height of the top of the railing to the top of the mattress to be varied by adjusting the mattress height off the ground. The mobility of the mattressed was created by the four corner supports that attached to the corner posts of the crib frame. These four supports locked into place by two knobs coming out of the supports that would be slid into a larger mouth hole in the post and pushed down to a more snug hole where the knobs would the be secure. Sketch-D documents the corner post and the various heights that the cirb mattress can be adjusted to.

Sketch-D: Corner Post for adjusting the height of the mattress

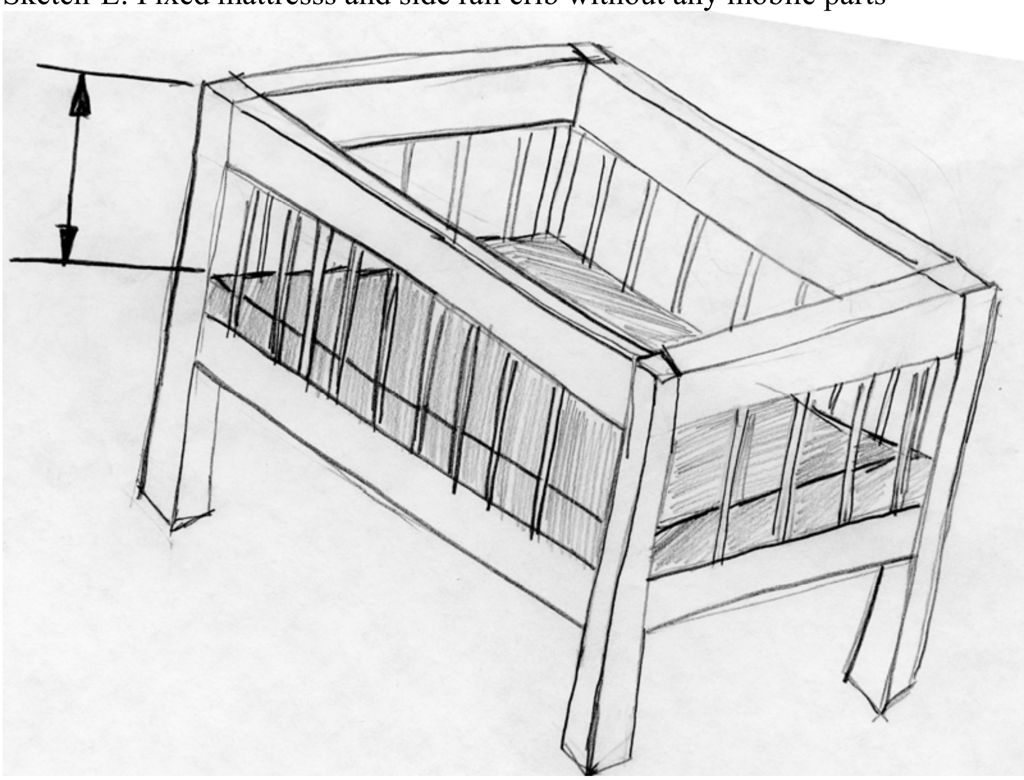


Problem associated with the Idea: One of the issues with this design is the fact that there aren't supports that go under the full bottom of the mattress. With the mattress only being supported at it's corners, there is a higher risk for the mattress to fall and the gap that would be created from the fall could lead to possible entrapment or suffocation.

***Idea-5*: No Mobile Parts**

Motivation for the Idea: This design, Sketch-E, has no moving parts. It's mattress is low to the ground and both mattress and rail heights are fixed at the standard height for 2 year olds. By having no mobile parts, the difficulty level of crib assembly and the risk factor of failure due to mobile parts is decreased.

Sketch-E: Fixed mattresss and side rail crib without any mobile parts

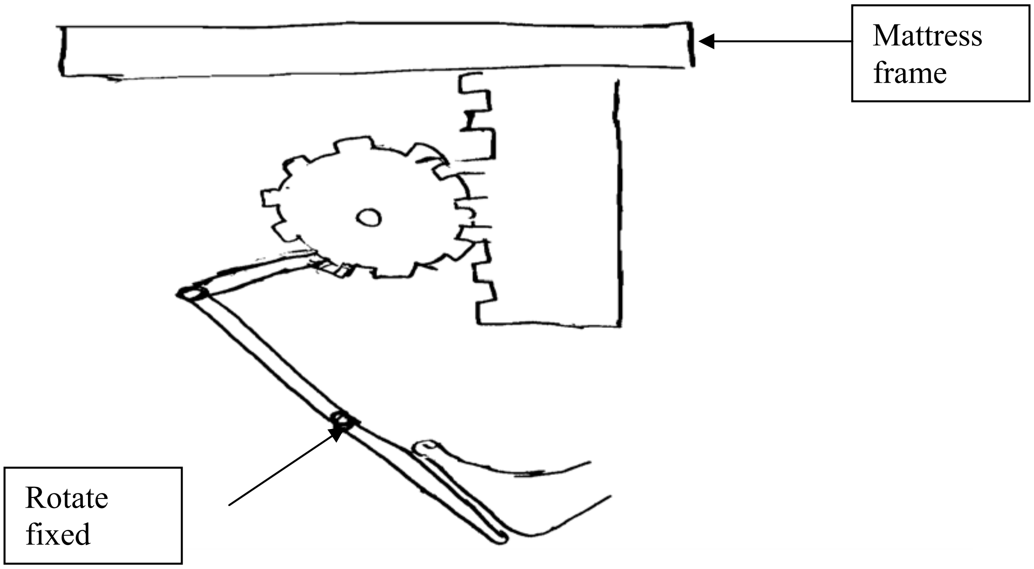


Problem Associated with the Idea: An issue with this crib is that there is more stress placed on the care giver when placing or removing a child from the crib due to all of the bending over and lifting that would occur. By having an adjust table height of one of the parts in a crib, the distance that a care giver must lift a child can be minimized.

***Idea-6*: Foot gear Lifter**

Motivation for the Idea: The gear lifter, Sketch-F, is used to vary the height of the mattress while four side rails remain stable. It involves the care giver applying a force with his or her foot on a shaft that rotates about a fixed point. This shaft is also connected to another shaft that applies a force on the gear. The gear itself is connected to a lifter with its teeth, and this varies the height of the matress frame.

Sketch-F: Gear Lifter to provide adjustable height to the mattress

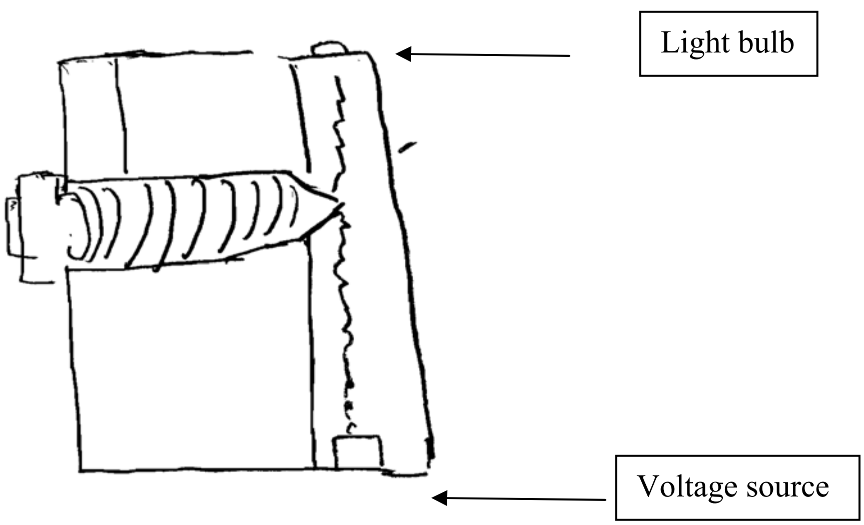


Problem Associated with the Idea: The main Problem with this idea is its complexity to install. Also the ratchet would have to be made of a hig strength material and this would add to cost.

***Idea-7*: Screw light bulb**

Motivation for the Idea: The screw light bulb reduces the chance of hardware failures of tight screws. The idea is for a wire as seen in Sketch-G, to run through a drilled hole. Below the drilled hole is a low voltage source and above is a light bulb. In between are wires that are loose. When the screw is tight enough it completes this circuit and the light bulb comes on as an indication that the screw is tight enough.

Sketch-G: Light Bulb Signal System

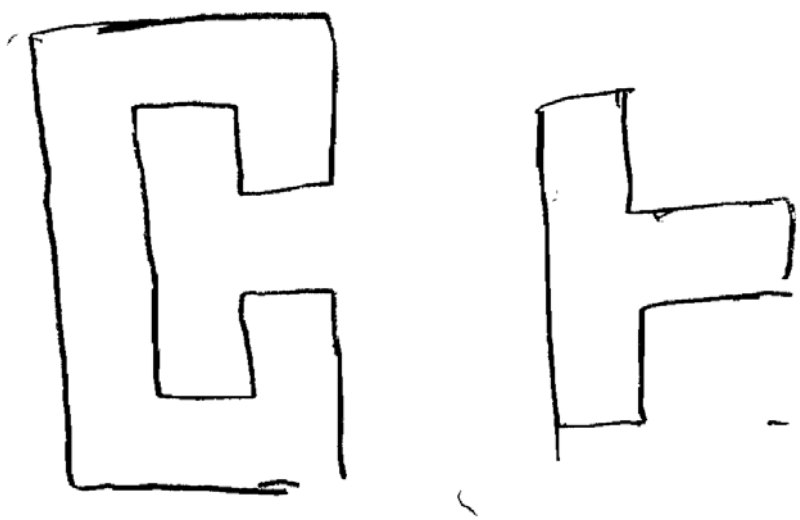


Problem associated with the Idea: Any failure in the wiring will render the signal system ineffective.

***Idea-8*: Hole /Slots**

Motivation for the Idea: This idea reduces hardware failure due to the use of less screws and direct installations. The goal is to use slots, Sketch-H that vary with different sizes to assemble multiple parts. This way the customer can only assemble these parts in one way only. This guarantees proper installation

Sketch-H: Slot Design



Problem Associated with the Idea: Failure of the slot due to stresses that it cannot withstand.

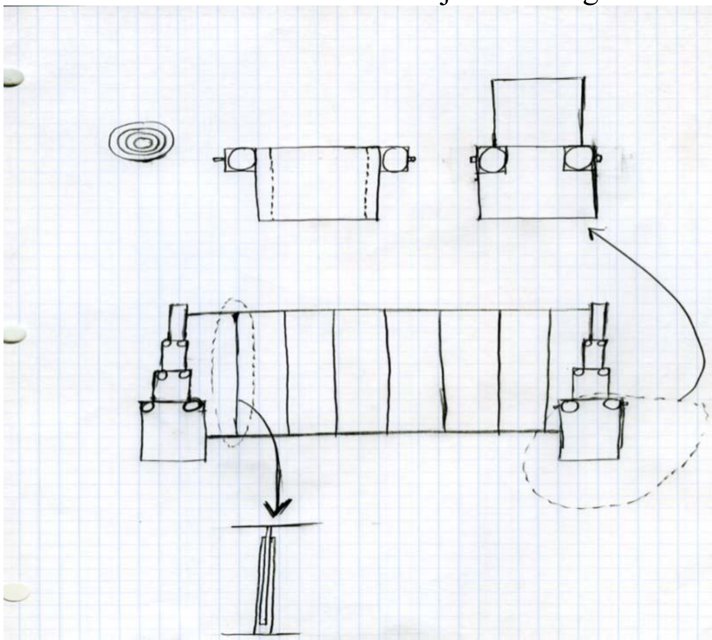
***Idea-9*: Rod inside a Rod**

Motivation for the Idea: This idea was built in order to give the crib an adjustable height with rod inside a rod, Sketch-I so that as the child grows, the mattress can be lowered to overcome the falling hazard. To ensure that the idea would be practical, the crib with this idea would be made out of suitable material besides wood to ensure the structural integrity.

The ball bearing as seen in Sketch-I, can be pushed in to lock the height.

The rail are built as another rod-in-a-rod structure to ensure that the entire structure; the legs along with the side rails are mobile at the same time.

Sketch-I: Rod inside a rod that adjust the height of the crib



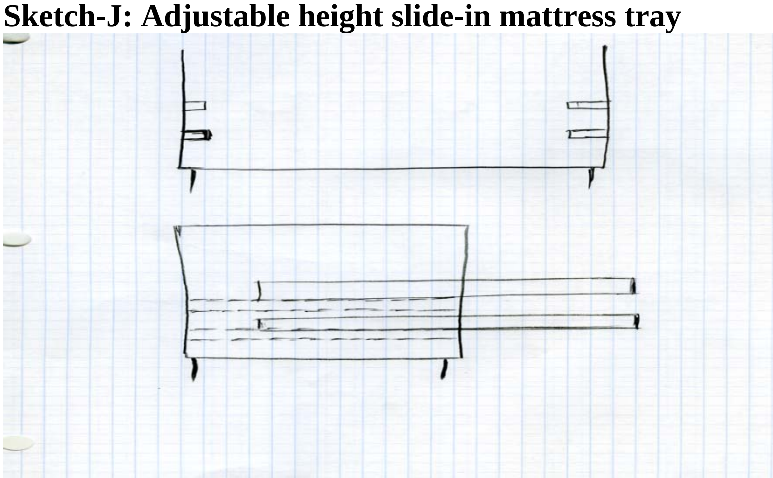
Material Selection for such a design would be crucial. So, for practicality of this design, it would have to be made out of Aluminum to ensure the structural strength required to ensure a safe and secure environment for the baby.

Problem associated with the Idea: The crib can be bulky due to the weight of the rods. There are a lot of moving parts, which can add up to a potential for failure of either ball bearings, for the rods can simply lock up due to rust.

***Idea-10*: Slide in Mattress Support to Vary Height-1**

Motivation for the Idea: This idea was developed to provide the customer with an adjustable height mattress frame such that the frame can simply be installed like a refrigerator tray at various heights. Sketch-J shows the mattress frame and the support at various heights.

Sketch-J: Adjustable height slide-in mattress tray

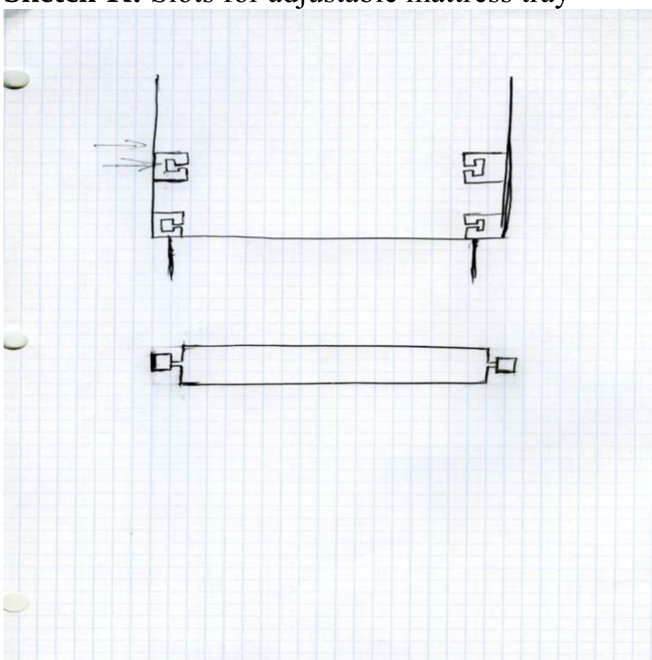


Problem associated with the Idea: The end posts that support the mattress can fail because of the stress distribution on the mattress which is help by only the end posts.

***Idea-11*:** Slide in Mattress to Vary Height-2

Motivation for the Idea: This idea is another variation of the Idea-10. The difference is; in this design instead of having the end supports for the mattress, there will be slots on the side rails that the mattress support frame can be inserted into, Sketch-K. The motivation behind the idea was the same; to provide the customer with an adjustable mattress frame.

Sketch-K: Slots for adjustable mattress tray



Problem associated with the Idea: Failure of the slots due to excessive uneven stresses during usage.

Appendix-E: Details of the Engineering Analyses

In this appendix, the detailed calculations including all the engineering equations and the free body diagrams are shown.

E.1 Crib Mattress Base Support Analysis

The mattress base support is shown in the following figures along with its contact area's cross section. This area was used to determine the moment of inertia for calculating the stresses due to the bending moment that the mattress support endures.

Figure-E1: Mattress Base Support

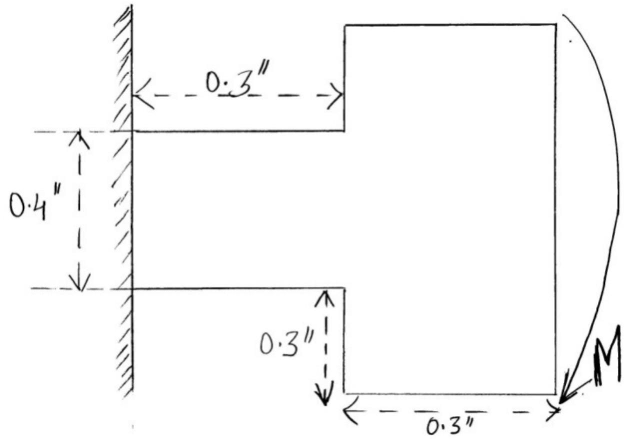
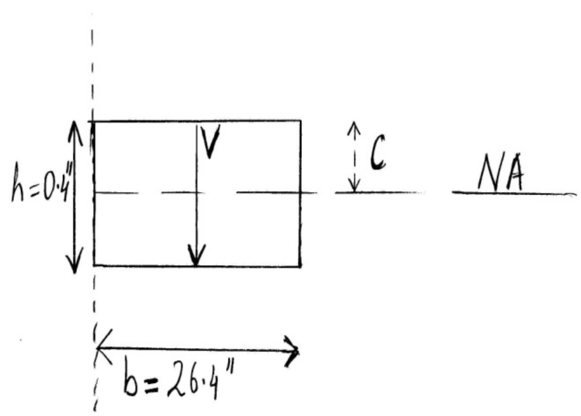


Figure-E2: Cross Section of the Contact Area



The following calculation shows the bending moment that the mattress support endures:

The maximum average weight of the child using the crib is 27.2 lb [18]. To account for a safety factor of 1.5, we used a weight of 40.5 lb for the child.

The team analyzed various full sized mattresses that are already available on the market and found 16 lb to be the typical mattress weight.

The mattress board itself weighs 40.61 lb. This number was computed using the density of Oregon Pine as 0.0137 lb/in^3 [9] and a volume of 2964.96 in^3.

Combining these three above stated components add up to a force of 97.11 lb that creates a maximum bending moment of 2728.79 lb-in. This bending moment was computed using the following relation [10]:

$$Bending\ Moment = Force \times Moment\ Arm \qquad Eqn.1$$

A moment arm of 28.1 in; is half the distance between the two mattress base supports. This moment arm was used to account for the maximum bending moment that the supports would endure.

The maximum stress of 38.86 psi due to bending at the point of contact between the mattresses support and the crib due to bending was computed as follows [10]:

$$\sigma_{max-bending} = \frac{MC}{I} \qquad \textit{Eqn.2}$$

Where *M* is the maximum moment of 2728.79 lb-in, *I* and *C* are the moment of the inertial for the cross sectional area, and the distance from the neutral axis (*NA)* respectively as shown in Figure-E1 on p-65. *I,* the moment of inertial was computed using the following relation; the dimensions *b and h* are shown in the Figure-E1 on p-65 [11]:

$$I = \frac{bh^3}{12} \qquad \textit{Eqn.3}$$

Since the maximum stress of 38.86 psi due to bending is well within the flexural strength of 970 psi for the material [9], the mattress supports are strong to carry the load of child, mattress board and the mattress itself.

In addition, to check if there is a potential for failure due to transverse shear, we calculated the maximum traverse shear stress to be 6.9 psi with the help of the following relation [13].This value of transverse shear is well within the transverse shear strength of 13,630 psi [14]. Therefore the mattress supports are strong enough to endure the normal usage by child 0-2 years of age.

$$\tau_{max} = \frac{1.5V}{A} \qquad \textit{Eqn.4}$$

Where *V, and A* are the force due to shear (48.5 lb that is half of the loading on the supports), and the contact area respectively as seen in Figure-E1 on p-65.

E.2: Peg(s) that hold the drop side

To ensure the safety of the drop side, stainless steel screws are used to hold the front drop side in its respective positions. These screws will be referred to as pegs during this analysis. The following figures depict the key dimensions that are required to compute stresses in these pegs.

Figure-E3: Peg(s) that hold the front drop side

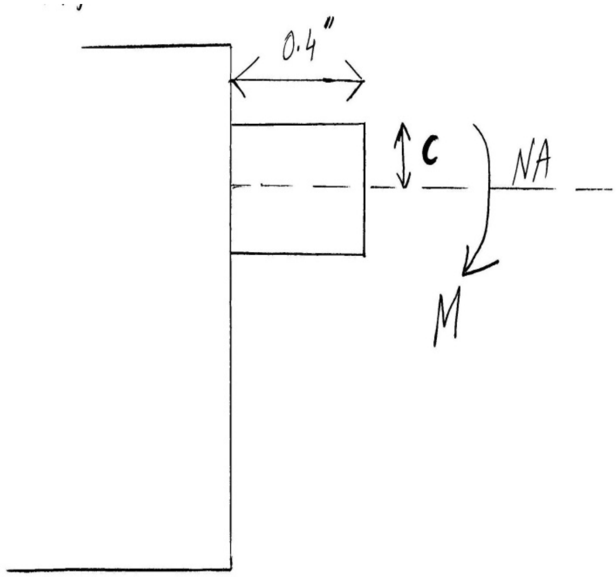
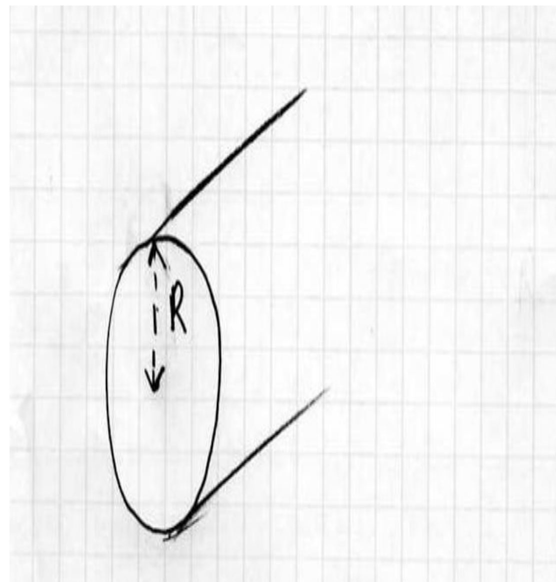


Figure-E4: Cross section used for Inertia Calculation



There are four pegs that hold the weight of the drop side. The weight of the drop side is 13.4 lb. To include a safety factor of 2, we use a force of 26.8 lb that these four pegs have to endure. Each peg therefore endures a force of 6.7 lb. The bending moment *M,* acts about the neutral axis (*NA)* as seen in Figure-E2. In the case of the peg, the moment of inertia for its circular cross section was computed using the following relation [15];

$$I = \frac{\pi r^4}{4} \qquad \textit{Eqn.5}$$

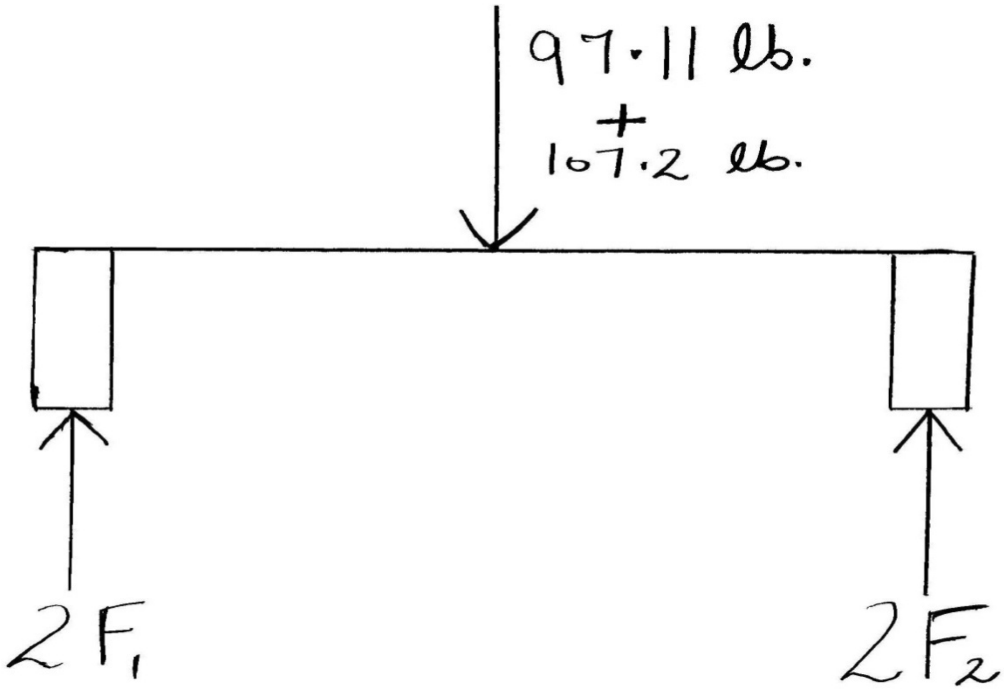
In Eq.5, *r* is the radius of the cross section of the peg with a value of 0.125 in. The maximum stress due to bending that each peg endures is 4,374 psi which is within the yield strength of stainless steel; 89,610 psi [16]. Therefore the pegs face no potential of failure due to bending.

The maximum shear stress that each peg endures is 205 psi which is much smaller than the shear strength of the stainless steel (the peg material) of 32,770 [16]. Therefore the pegs are safe and can withhold the stresses during normal usage.

E.3: Compression Yielding in Crib Legs

To determine if the legs of the crib would fail by compressive yielding, we analyzed the forces exerted on each leg during use. The following free body diagram was used to compute the maximum compressive force that each leg would have to endure. In the diagram the 97.11 lb force is the combined weight of child, mattress and the mattress board, and the 107.2 lb force is due to the remaining cribs part (namely side rails). This combined force that acts on the legs has an inherent safety factor of 2 that was used in the calculation. $2F_1$, *and* $2F_2$ represent the combined force endured by two legs on each side of the crib.

Figure –E5: Free Body Diagram showing the forces exerted on the legs of the crib



A compressive stress of 6.1 psi was calculated using the following expression [17].

$$\sigma_{compressive} = F/A \qquad \textit{Eqn.6}$$

F is the compressive force of 51.1 lb in each leg with a cross section area, *A* of 4 in^2. The compressive strength of the material is 6000 psi [12] thereby making the compressive stress value of 8.3 psi well within the acceptable levels. Therefore compressive yielding is not a concern.

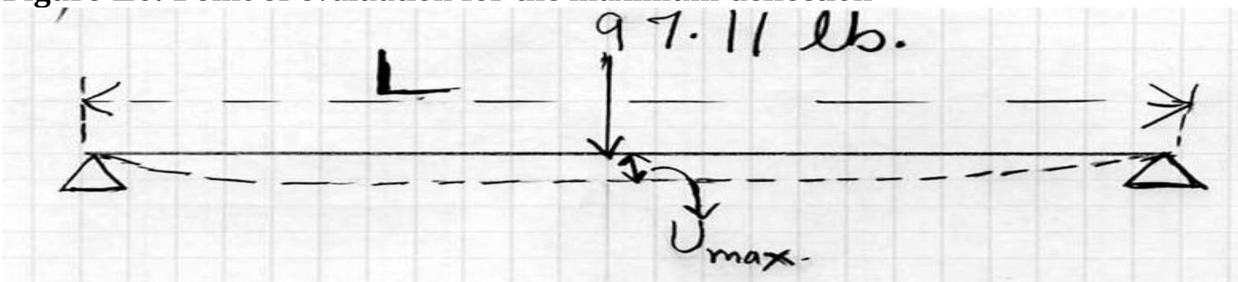
E.4: Deflection of the mattress base

The maximum deflection acts at the center of the mattress base when seen from the front in Figure-E6 on the following page. The mattress base's deflection of 0.006 in, which is very acceptable was computed using the following relation [18]:

$$U_{max} = \frac{PL^3}{48EI} \qquad \textit{Eqn.7}$$

Where *P* is the load of 97.11 lb that the mattress board endures, *L* is the length of the mattress board, *E* is the Young's modulus of 1,272,000 psi for the material, and *I* is the moment of inertial that was calculated using Eqn.3 on p-66 for cross sectional area of the mattress board with the dimensions that can be seen in the following figure.

Figure-E6: Point of evaluation for the maximum deflection

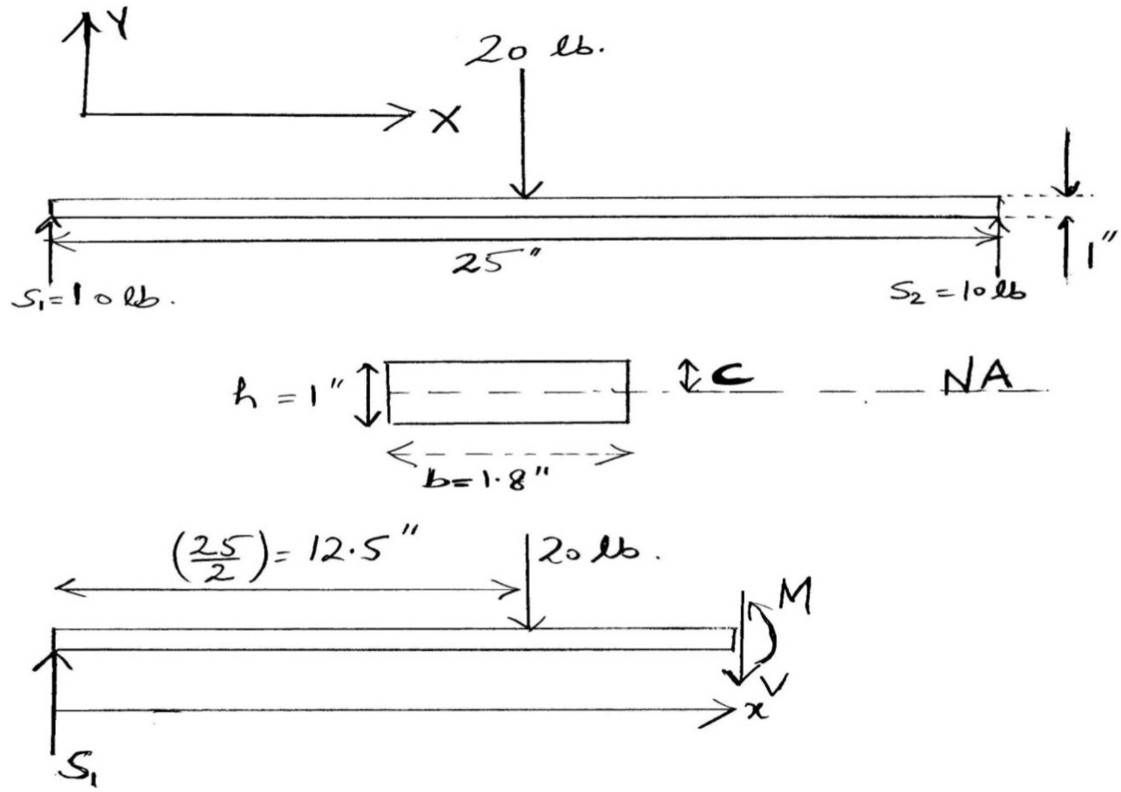


E.5: Strength of the Slats

To ensure that the slats are strong enough to endure forces during usage, we conducted the stress analysis during which a 20 lb force was exerted on the slat. The 20 lb force was derived from the loading wedge test put forward in the regulatory summary document by the US CPSC [4].

The following free body diagram shows the internal bending moment *M* that the slat material will endure along with the shear stress *V*.

Figure-E7: Free Body diagram for the Slat and the respective area that was used for Inertia Calculation



The maximum bending moment of 125 lb-in was computed using the following relation [10]:

$$M_{max} = \frac{PL}{4} \qquad \textit{Eq.8}$$

P is the vertical load of 20 lb, and *L* is length of 25 in.

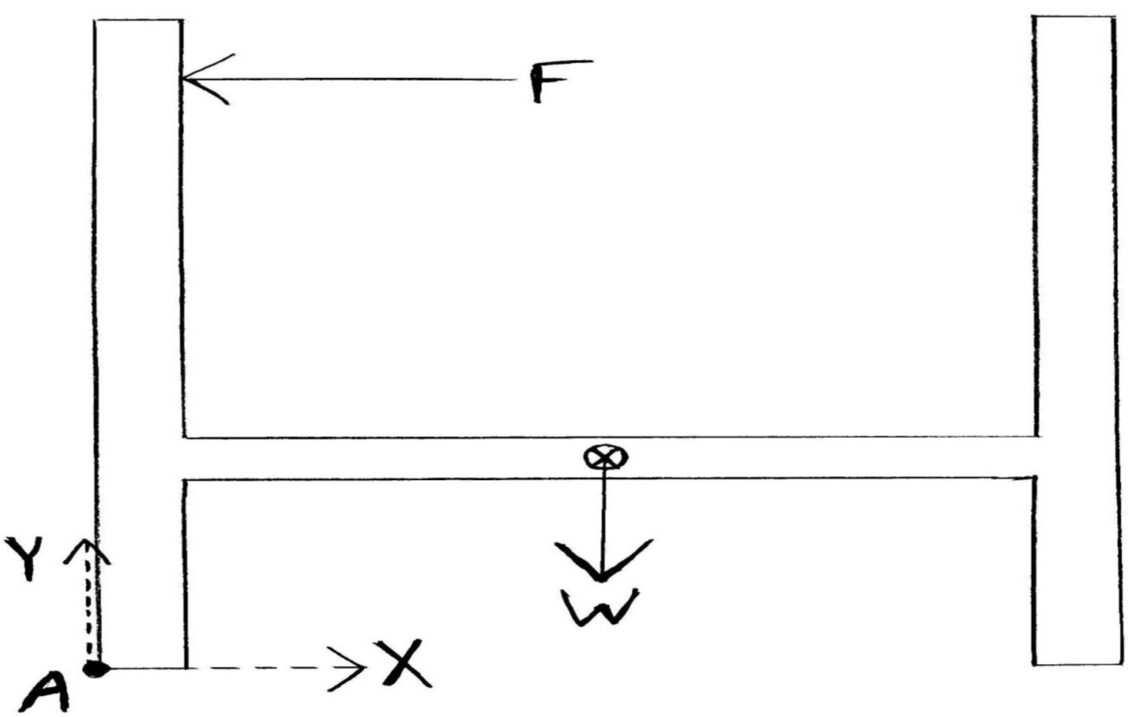
A support force S_1 of 10 lb was computed by balancing forces in the Y-direction using Newton's second law. Using the same law, we computed the shear force of 10 lb which is equal and opposite of the support force.

Therefore the maximum stress due to bending was computed using the Eqn-2 on p-66 was calculated to be 69.4 psi. The moment of inertia that was used for calculating this maximum bending stress was calculated using Eqn-2 on p-66 with dimensions as can be seen in Figure-E5. The maximum shear stress of 12.8 psi due to the shear force *V* was calculated using Eqn.4 on p-66. Both the stresses due to bending and shear are well within the acceptable values of flexural strength and shear strength for the material documented in Table-3 on p-19. Therefore the crib's slats pass the US CPSC strength test.

E.6: Stability of the Crib

The following free diagram shows point-A about which a bending moment acts in the clockwise direction due to the combined weight of child, mattress board and the mattress itself; *W*.

Figure-E8: Side View of the Crib



The maximum bending moment that would act at this point was computed to be 2728.8 lb-in using the Eqn.2 on p-66. This would happen when the child is precisely in the center of the crib; at the center of gravity of the mattress and its base support.

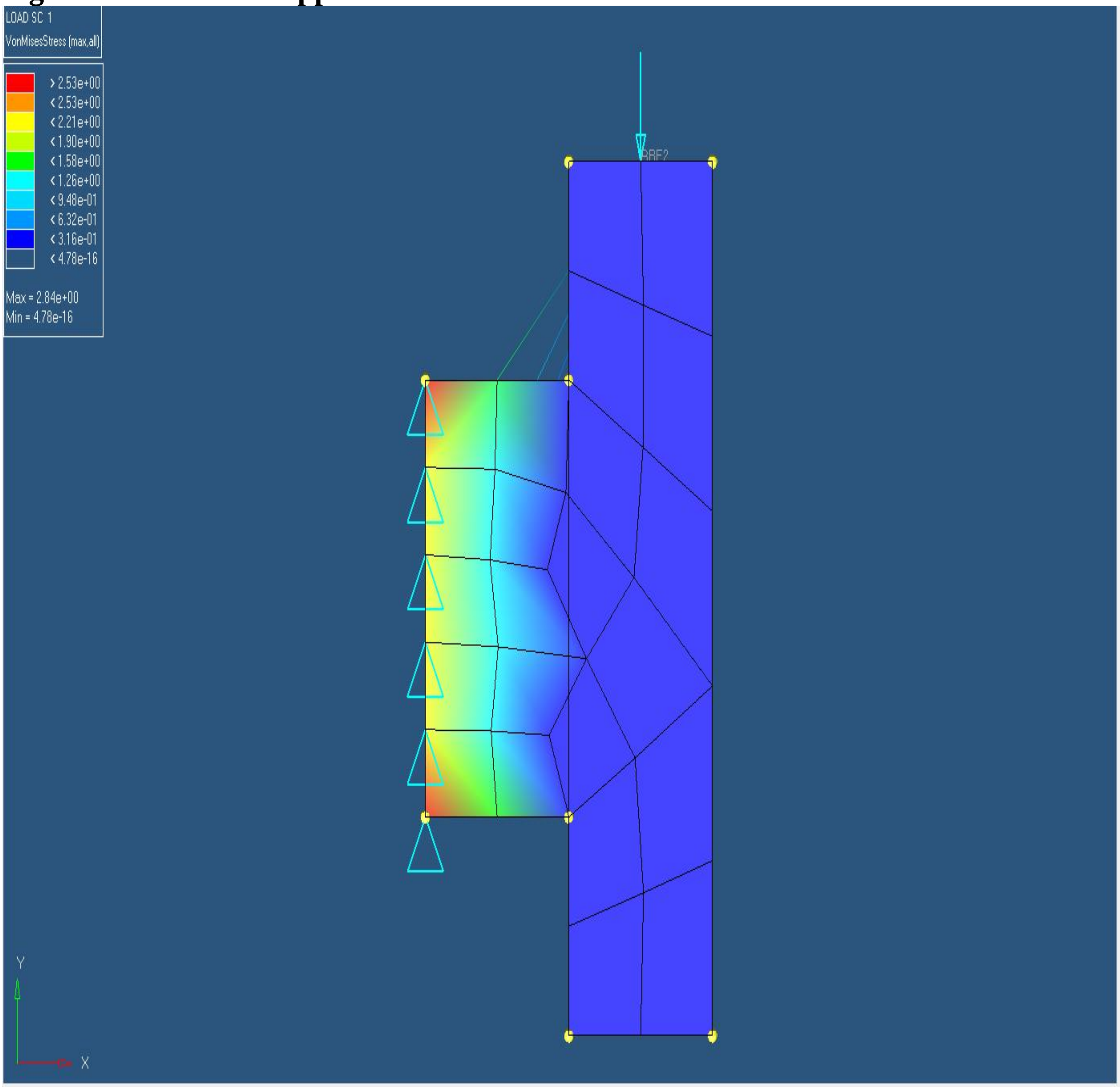
In order to tip the crib, this bending moment has to be overcome by applying a force *F* as seen in the free body diagram in the above figure. The moment arm for the force would be 53.75 in. which was obtained by combining the maximum height of the child of 33.75 in [19], 8 in. for the mattress board and the mattress, and 12 in. which is the height of the mattress base off the ground. The force thus computed using the Eqn.1 on p-65 was 50.76 lb which is almost twice the actual weight of the child and is very difficult to be generated by a child [19]. The crib is hence stable enough to handle a force exerted by the child in the crib.

E.6: Finite Element Analysis

To check the crucial components of the crib, we performed the Finite Element Analysis on these components using Hypermesh 9.0. The crucial components namely, T-Beam that supports the mattress base, the mattress base itself, and the slat(s) were exposed to the US CPSC loading scenario as documented in the Regulatory Summary from US CPSC document [4]. The loading scenario calls for applying a 20 lb force to various parts of the crib to check for structural integrity.

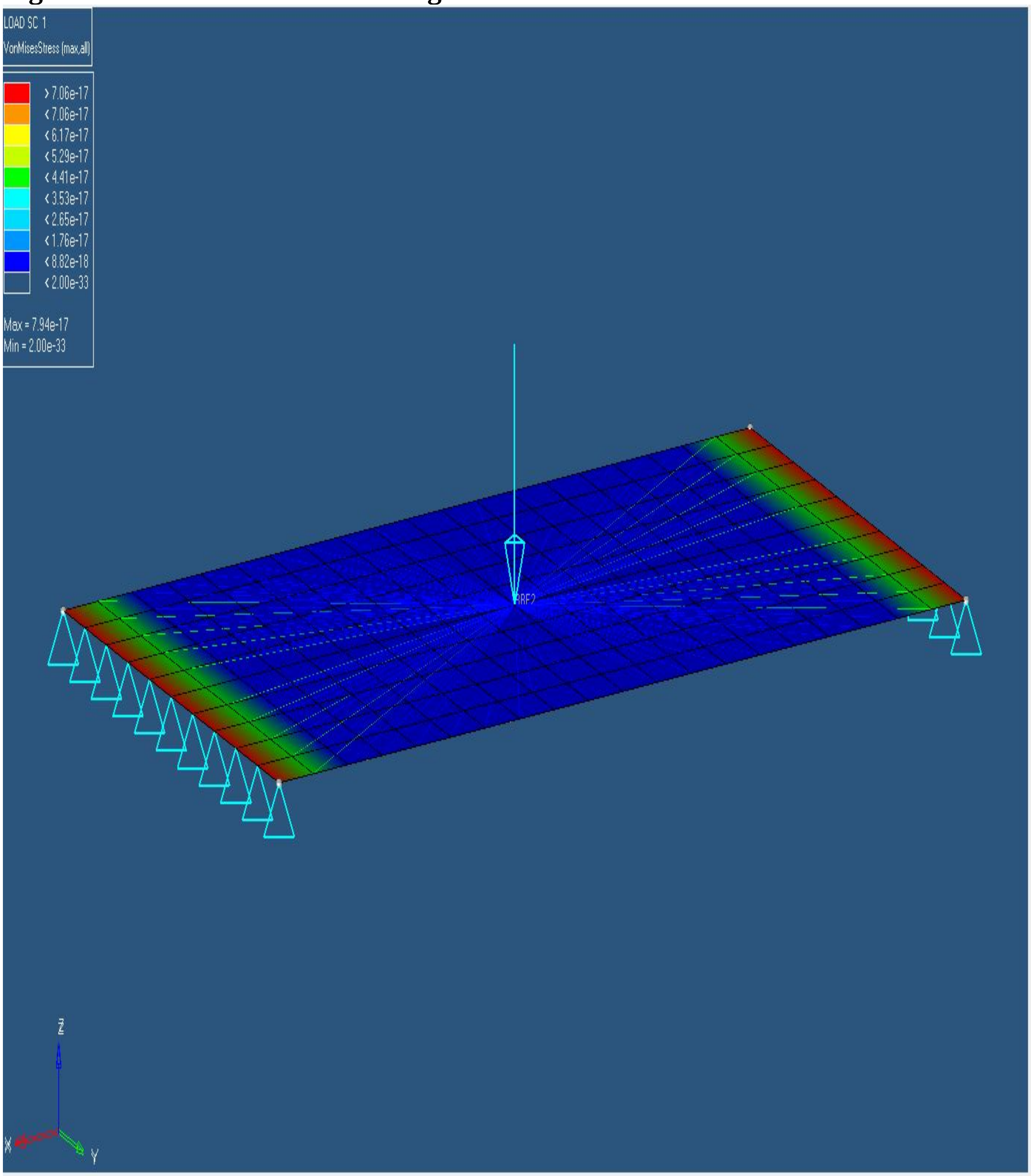
The screenshot as seen in Figure-E9 on the following page shows the loading scenario for the T-Beam onto which the mattress base slides. The maximum stress value of 2.84 psi is depicted in the screenshot and was determined by the solver integrated within Hypermesh 9.0. This value is well within the flexural strength of the material, giving a safety factor of 3880.

Figure-E9: T-Beam Support for the mattress base



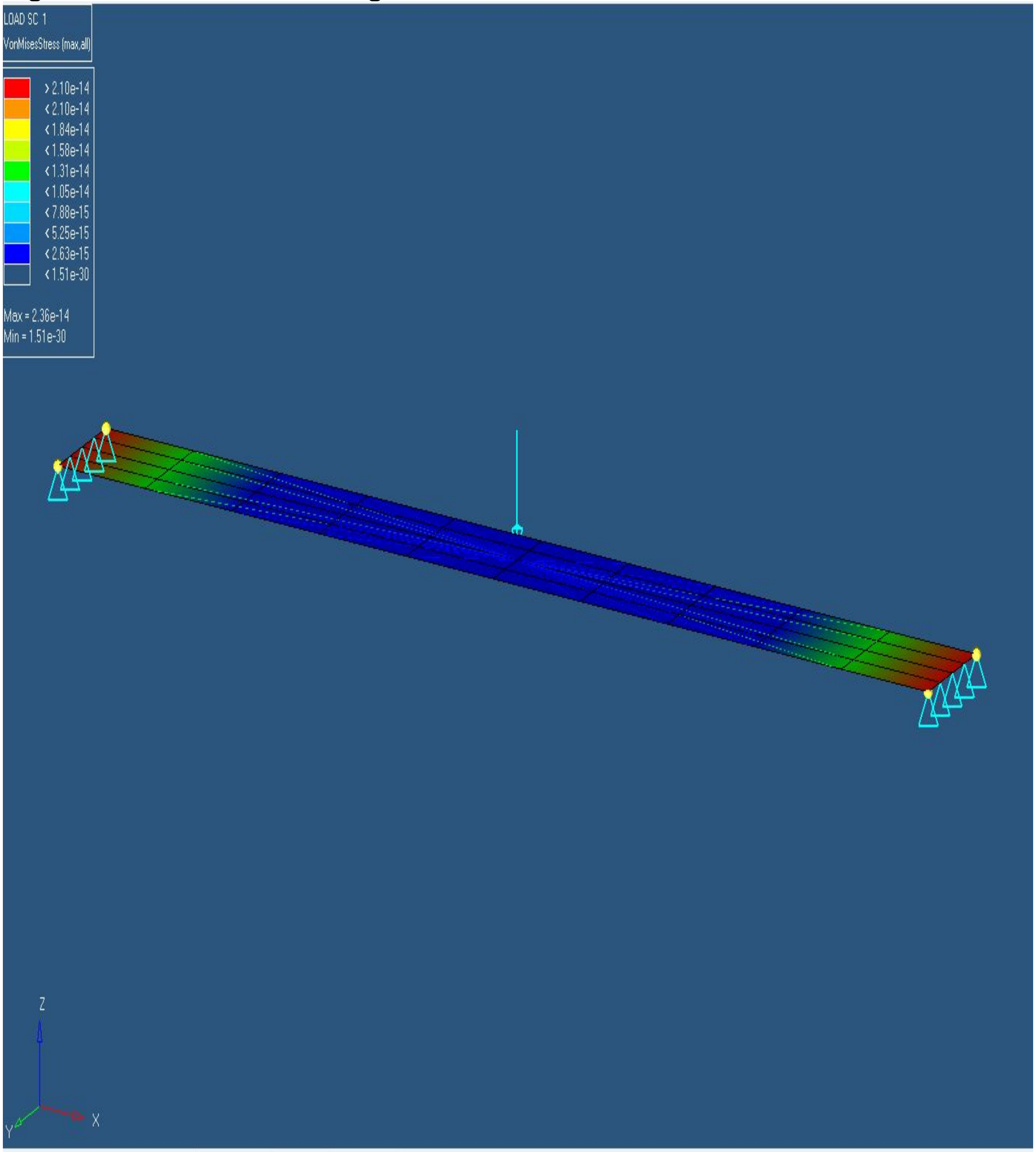
The mattress base was exposed to a load of 20 lb as seen in the Figure-E10 on the following page. The maximum value of stress reported is negligible, and hence is not a concern.

Figure-E10: Mattress Base Loading



To check for the strength of slat according to the US CPSC guidelines, the slat was exposed to a 20 lb force as can be seen in the following loading scenario in Figure-E11 on the following page. The maximum stress value returned by the solver, as reported on the screenshot is negligible and hence not a concern.

Figure-E11: US CPSC Loading for a Slat



Appendix:F Detailed Risk Analysis Report using Designsafe

This appendix included the detailed reports from the Designsafe software suite. The report in Table-F1 in the subsequent pages shows the risk levels before and after the risk reduction methods are implemented. It also includes the potential hardware failure mode that the set-up person is potentially exposed to along with the severity, exposure and the probability of the mishap happening due to the failure.

Table-F1:- Detailed Design Safe Hazard Report

designsafe Report

Application:	Safety of the Crib
Description:	Assessment of potential hazards, risk levels and methods in place to reduce these risk levels.
Analyst Name(s):	Kim Bagian, Chukwuka Isichei, Dong Joon Min, Amritpal Singh
Company:	Safe Crib Team
Facility Location:	University of Michigan College of Engineering 1221 Beal Avenue Ann Arbor,MI 48109
Product Identifier:	
Assessment Type:	Detailed
Limits:	
Sources:	

Guide sentence: When doing [task], the [user] could be injured by the [hazard] due to the [failure mode].

User / Task	Hazard / Failure Mode	Initial Assessment Severity Exposure Probability	Risk Leve	Risk Reduction Methods /Comments	Final Assessment Severity Exposure Probability	Risk Leve	Status / Responsible / /Reference
set-up person periodic maintenance	Periodic Checkup : Dust Entrapment in the Slots/S-hook Lack of frequent cleaning checkup of crib structure	Slight Remote Unlikely	Low	Adequate cleaning practises on the part of the caretaker	Minimal Remote Unlikely	Low	On-going [Daily] Caretaker/set up person
set-up person installation	mechanical : Pinch Point Improper attention on the part of care taker while adjusting the drop side with baby's body part(s) in the slot pathway of the adjustable drop side	Serious Remote Possible	Moderate	Narrow pathway for the S-Hook so that baby's body part(s) cannot get into the pathway while adjusting the drop side	Slight Remote Unlikely	Low	Complete [11/3/2008] Design Engineers
set-up person installation	mechanical : Accidental Impact An accidental shock to any part of the crib's structure	Serious Occasional Unlikely	Moderate	Proper handling instructions/labelling on the crib packaging	Slight Remote Negligible	Low	On-going [Daily] Caretaker/Set up person
set-up person installation	slips / trips / falls : Fall Hazard Failure to engage the drop side by the caretaker from it's stowed away position can lead to a fall hazard for the child	Serious Occasional Probable	High	Adequate label warning acting as visual reminder at all times	Slight Remote Negligible	Low	On-going [Daily] Caretaker
set-up person installation	ergonomics / human factors : Duration Usage of the crib for infants beyond 2 years of age may lead to failure of parts due to fatigue	Slight None Possible	Low	Include a factor of safety into our design to ensure structural integrity beyond two years	Minimal None Unlikely	Low	Complete [11/3/2008] Design Engineers
set-up person installation	ventilation : Exhaustion Inadequate fabrics covering the slats on the sides of the crib	Serious Occasional Possible	High	Designing the crib's sides with round surfaces so that fabrics fall off if the caretaker tries to peg them onto these sides	Slight Remote Unlikely	Low	Complete [11/3/2008] Design Engineers/Caretak er

User / Task	Hazard / Failure Mode	Initial Assessment Severity Exposure Probability	Risk Leve	Risk Reduction Methods /Comments	Final Assessment Severity Exposure Probability	Risk Leve	Status / Responsible / /Reference
set-up person installation	chemical : Reaction to/with chemicals and wooden parts Reaction between wooden surface and the chemicals considered inappropriate for cleaning wooden surfaces	Slight Remote Possible	Moderate	Warning labels as part of instruction and on the crib structure	Minimal Remote Possible	Low	On-going [Daily] Caretaker
set-up person installation	chemical : Skin exposure to toxic chemical residue Inappropriate usage of chemicals while cleaning the wooden surafces of the crib	Serious Remote Unlikely	Moderate	Warning labels as part of instruction and on the crib structure	Slight Remote Unlikely	Low	On-going [Daily] Caretaker
set-up person installation	chemical : Failure at key points and trouble spots Frequent usafge of inappropriate chemical causing rusting in the slot(s) of the S-hook	Serious Remote Unlikely	Moderate	Warning labels as part of instruction and on the crib structure	Slight Remote Unlikely	Low	On-going [Daily] Caretaker
set-up person check alignment	Improper Assembly : Drop side disengaging Improper installation of the drop side in it's s-hook	Slight Occasional Unlikely	Moderate	Adequate pictorial representation in the assembly instructions	Minimal Remote Unlikely	Low	Complete [11/8/2008] Set up person

Appendix:G Environmental Impact Analysis using SimaPro

In this section we document the detailed results for the environmental impact analysis that was done using SimaPro.

Figure-G1: SimaPro characterisation Results Comparing Oregon Pine and Aspen Wood

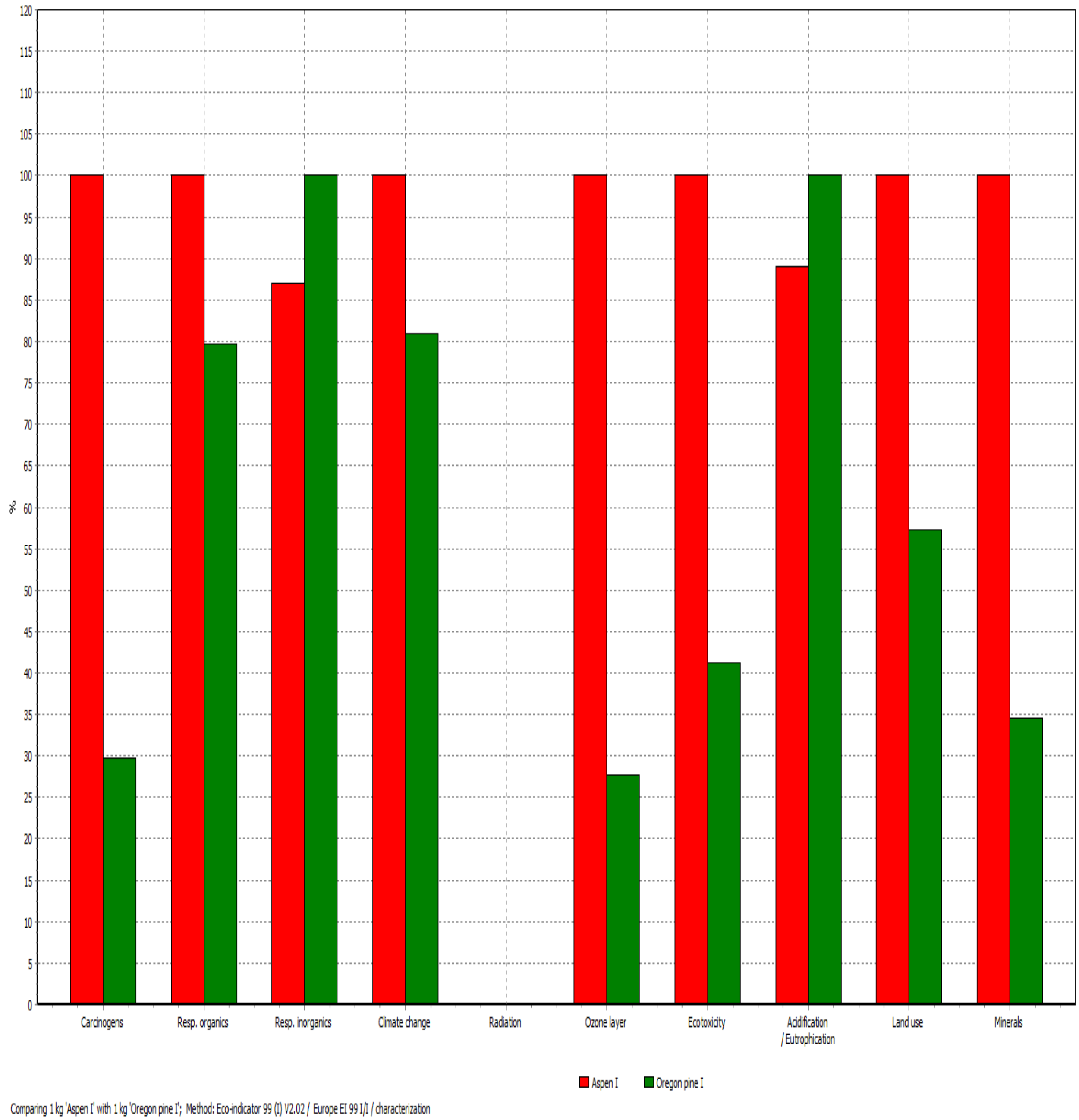


Figure-G2: SimaPro Normaliztion Results Comparing Oregon Pine and Aspen Wood

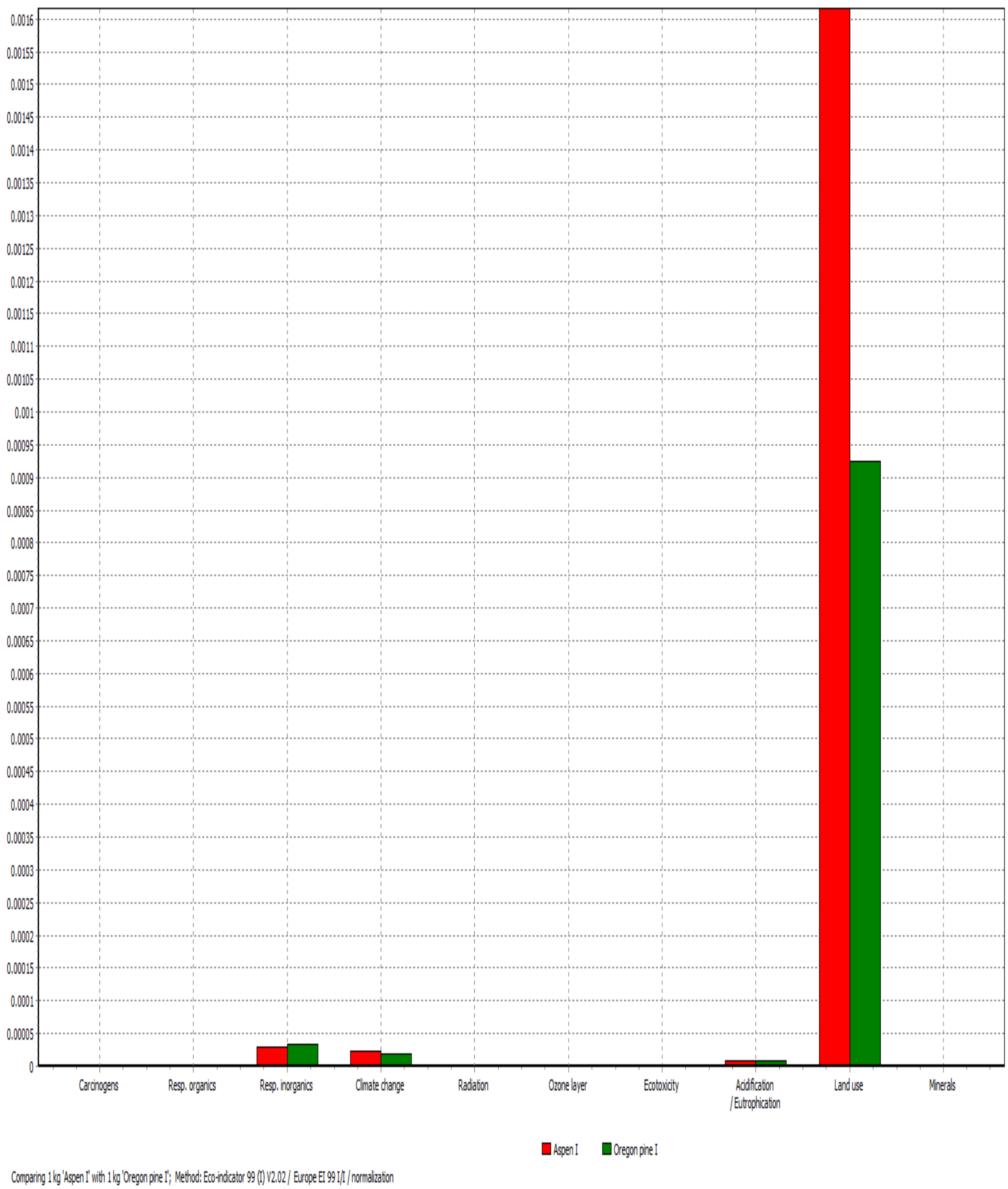


Figure-G3: SimaPro Single Results Comparing Oregon Pine and Aspen Wood

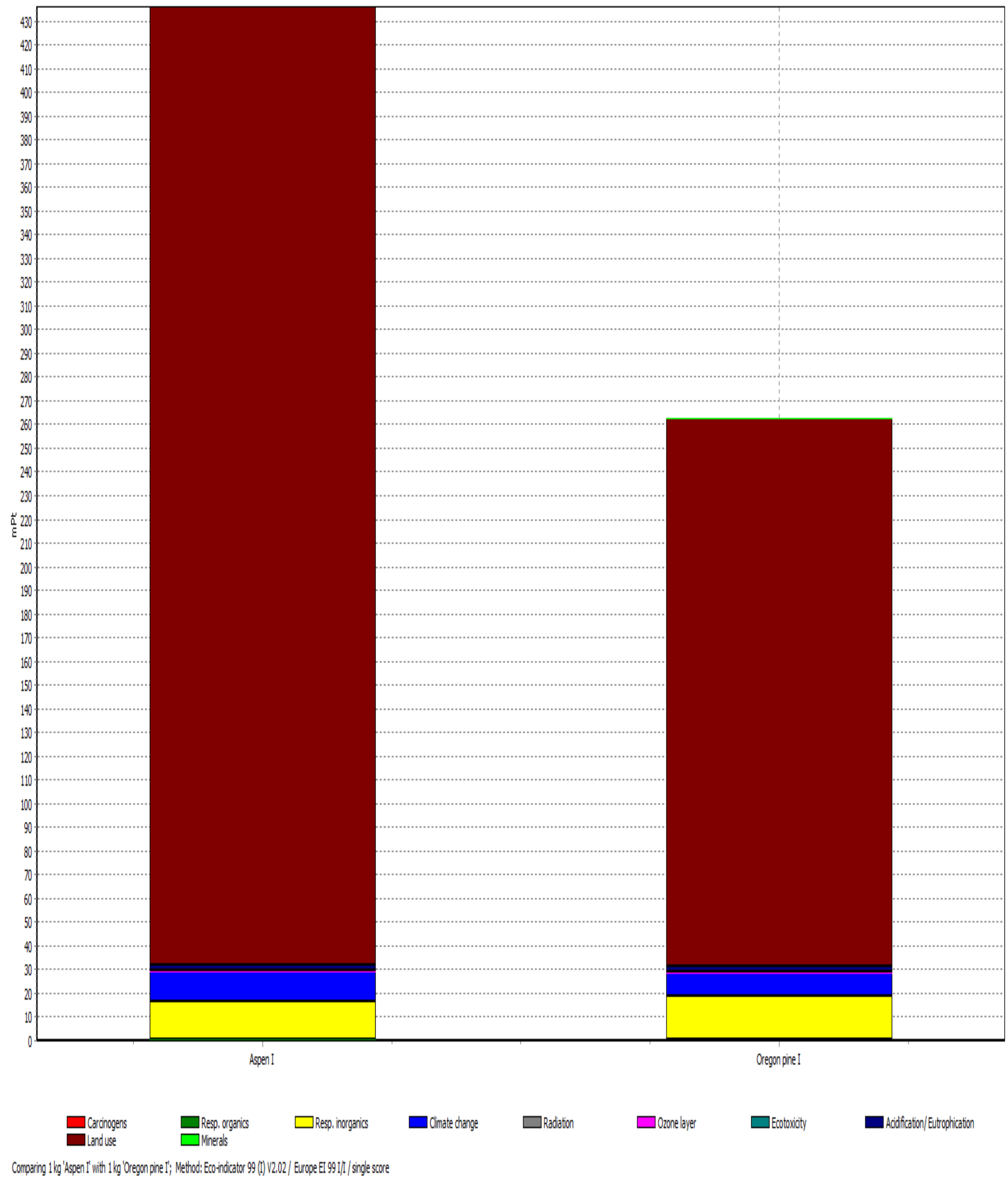
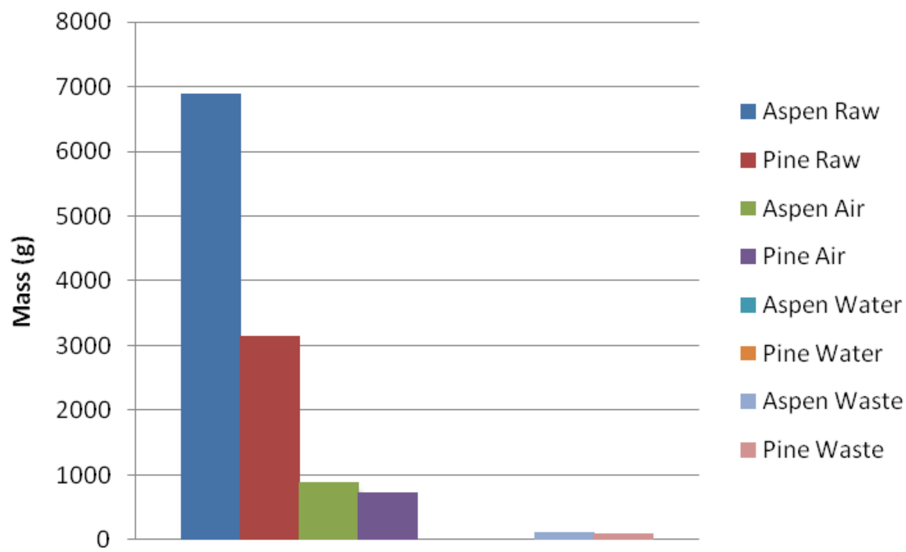


Figure-G4: SimaPro Mass Results Comparing Oregon Pine and Aspen Wood



Appendix-H: CES EduPack 2008 Program

The CES Program aided our team in figuring out what material would be the best to use when making our project. After imputing analyzed data and researched values, CES outputted what materials would follow these material properties.

Figure-H1: Plot of Material Density and Young's modulus for a range of materials

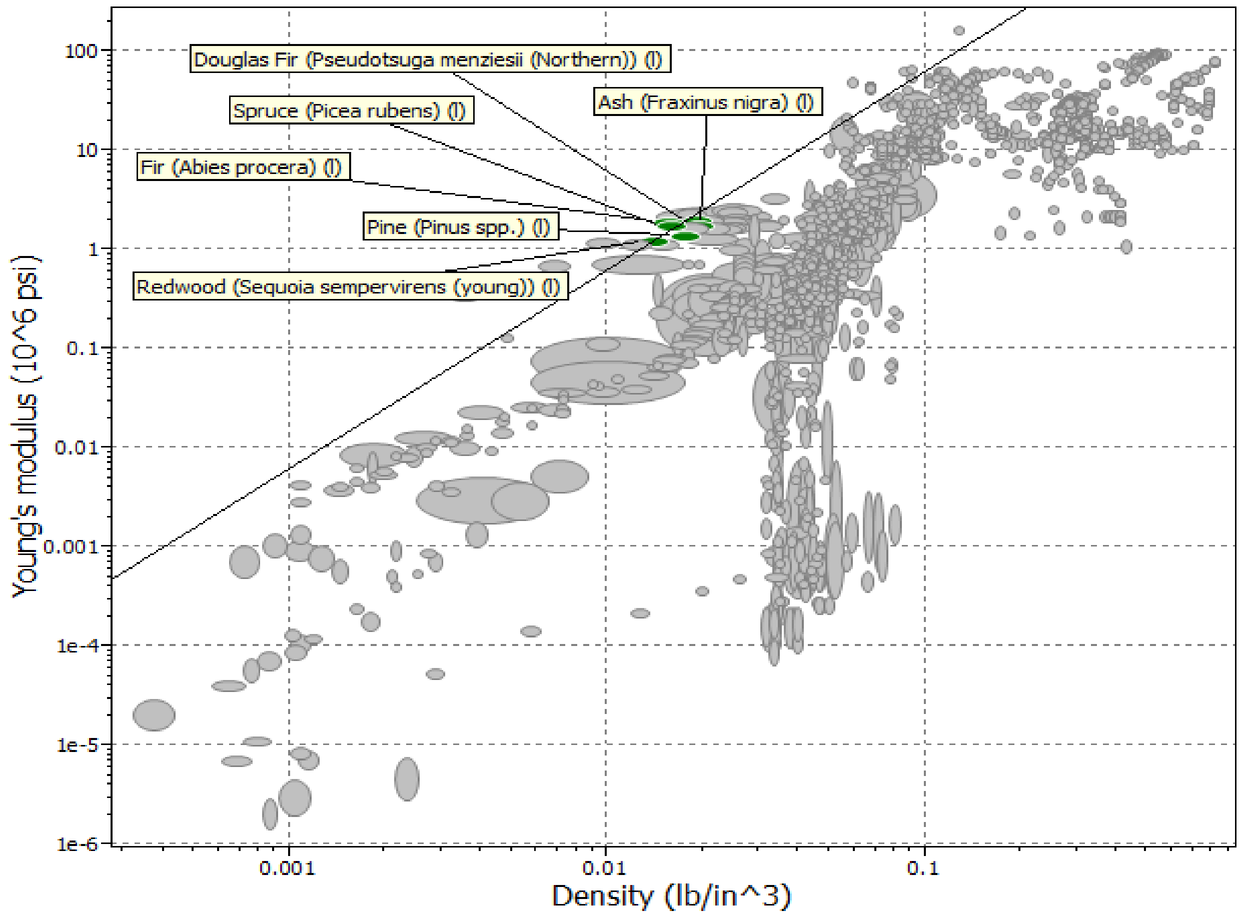


Figure-H2: Zoomed-in Plot from Figure-H1 after we eliminated the materials that failed to meet the criteria

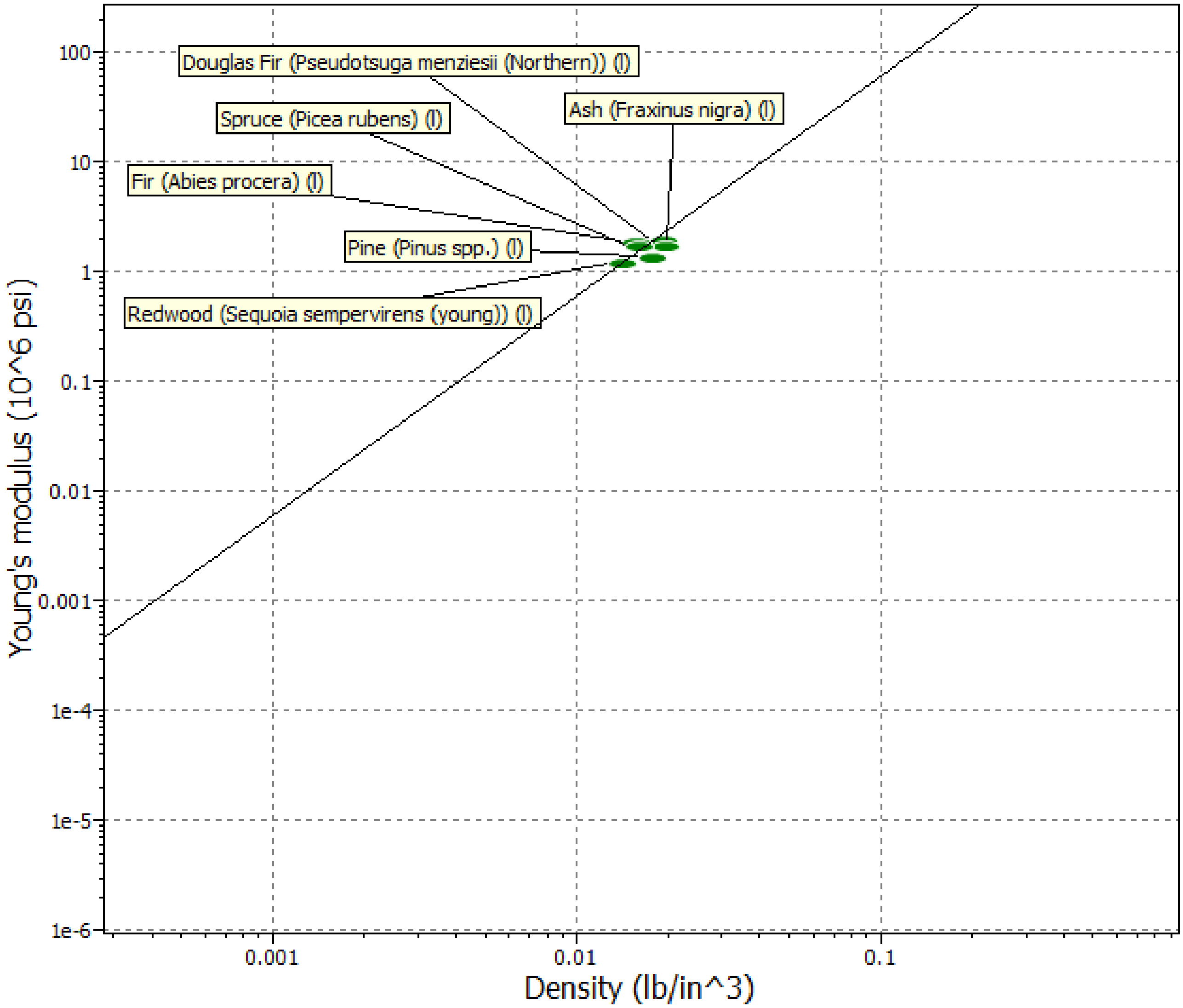


Figure-H3: Plot of Material Toughness