ME 450 F15 Final Report

Team 26: Sleeping Environment For A Baby

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Abstract
Kids In Danger is a nonprofit organization founded to protect children with improvements to children's product safety and education. Kids in Danger tasked our team with designing a portable and affordable sleeping environment, improving upon the commonly used Graco Pack 'n' Play. This product is aimed towards hospitals or nonprofits being able to supply for families with no safe place to put their baby until the child is 18 months.

Executive Summary

Our sponsor, Kids In Danger, is a nonprofit organization founded to protect children by making safety improvements to children's products and furthering safety education. Our team has been tasked with designing a portable sleeping environment, improving upon the commonly used Graco *Pack 'n' Play* collapsible crib design. In order to avoid the dangers associated with the central "V"-shape collapsing frame design used by Graco, we purposefully designed our portable sleeping environment to include sides that fold outward and down to avoid contact with a child inside of the crib. Even if the crib were to become unlatched while in use, no portion of the frame would create a pinching point or suffocation point for the infant occupant. Additionally, we designed our frame to fold up to be more ergonomic to carry than the Graco *Pack 'n' Play*, and it is also lighter by at least 3 pounds. The four locking joints on the frame have two possible positions, fully assembled and fully disassembled. The frame prototype is easy to manufacture and set up because we designed one simple joint that works on both the top and the bottom of the rib frame which allows the crib to fold smoothly in an "accordion" style. A fabric insert has been created using the fabric materials extracted from a Graco *Pack 'n' Play* and modified to fit onto our frame, covering any exposed metal from the inside. Instead of being suspended, the thin mattress is placed on top of the fabric insert, and is supported by the ground. All hardware and fasteners have fabric coverings to avoid occupant laceration, tearing of the mesh walls, or potential choking hazards. The most important design features of this frame prototype are the locking system that also allows for easy and intuitive setup, and the collapsing method and direction that ensures no hardware could fall onto the child occupant during an unexpected collapse. An obvious warning label system and setup instructions are also be provided to avoid incorrect setup and improper use associated with user error.

In order to validate our prototype crib design, we tested it to make sure our design meets ASTM collapsible crib strength requirements. We used UMTRI's 18 month old representative dummy to validate our crib's uncollapsed dimensions. We confirmed that a 95th percentile child fits (standing and lying down) within the interior of the crib frame while it is uncollapsed. Using linear force meters we followed ASTM protocol to apply forces to potential weak points in the frame. Our prototype passed all of these strength tests, except for one test that we could not complete because of how our crib folds the upper rail bar. The test was designed for testing the locking joint constraining the upper rail joint of a Graco *Pack 'n' Play*, but our design does not use that component, so that specific test was no longer needed. Also, following ASTM guidelines, we used a linear force meter to test the strength of all fabric attachment points to the frame. We performed this test, and confirmed that the crib walls do not tear or separate from the frame; such a failure mode could provide a strangulation hazard to the infant user.

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Problem Description and Background

Kids In Danger (KID) is a nonprofit organization founded in 1998 that strives to protect children with improvements to children's product safety. KID was founded by the parents of Danny Keysar, a sixteen-month-old who was strangled to death at his daycare when a portable crib collapsed around his neck. The information that the particular crib had been recalled five years prior had not reached Danny's parents, caregiver, or a state inspector who visited the home eight days before Danny's death. To date, 19 children have died in cribs of similar faulty design [1].

Although mandatory standards exist for cribs, it was not until 2011 that efforts were made to strengthen the standards and to require testing of cribs. New federal safety standards put into place on cribs manufactured after June 28th, 2011, as mandated by the Consumer Product Safety Improvement Act of 2008 (CPSIA). The five new federal requirements prohibit the use of traditional drop-side cribs, and require that wood slats must be made of strong material to prevent breakage, hardware must have anti-loosening devices, the mattress supports must be more durable, and rigorous safety tests must be conducted [2]. Recalls on cribs have occurred for many reasons including non-compliance with safety standards, strangulation hazards, risk of entrapment in slats, side rails loosening, risks of suffocation, choking hazards, risks of falling, and risks of trapped fingers in drop gates.

Specifically, these new safety standards stated that a diameter of 2.6 inches shall not fit between any slats of the crib, there shall not be corner post extensions or decorative cut-outs on the crib, and hardware shall not be loose or missing. The crib shall also be free of rivets, metal nuts or bolts, knobs, and wing nuts. The mattress shall be tight fitting and have a maximum of a one-inch gap from the crib's frame. Joints and parts must also fit tightly, and wood must be smooth and free of splinters. There shall be no paint imperfections, and all paint must be lead-free. Lowered crib sides shall be at least 9 inches above the mattress support and raised crib sides shall be at least 26 inches above the mattress support in the lowest position. All cribs must include proper assembly instructions and diagrams as well as proper warning labels as determined by federal law [2, 3].

According to the NEISS CPSC, there were 14,100 estimated emergency room treated injuries due to cribs and mattresses in children under five in 2013. CPSC staff received reports of a total of 336 deaths associated with nursery products from 2009-2011, an annual average of 112 deaths. About 41% of these deaths were associated with cribs or mattresses. CPSC staff considered all incidents involving a non-full-size crib to identify hazard patterns. Similar to full-sized cribs, 72% of the incidents were product-related issues. The most prevalent incidents involved falls from cribs, limbs caught between slats, issues related to drop-sides, and hardware issues [4].

Cribs should be designed to keep a baby safe without requiring supervision. New mandatory standards subject cribs to the more rigorous testing in order to eliminate many of the hazards. Our team has been tasked to design a non-full size, affordable sleeping environment for a baby. Our product should be available for hospitals or nonprofits to supply for families without a safe place for their baby to sleep up until the child is 18 months old. Currently most programs now give Graco *Pack 'n' Plays*. This design is safe, but Kids in Danger is looking for something different.

A non-full-size crib can be smaller or larger than a full-size crib. It may also be shaped differently than the expected rectangular shape. CPSC staff estimates that there are approximately 2.4 million cribs sold to households annually. Of these, approximately 293,000 are non-full-size cribs [3]. The category of non-full-size cribs includes oversized, specialty, undersized, and portable cribs. Although the CPSC standard for non-full-size cribs does not apply to play yards, which are mesh or fabric-sided products we will still be using these standards for the design of our product.

Children's products are required to undergo third party testing and to have a written Children's Product Certificate (CPC) demonstrating compliance. Non-full-size cribs manufactured or sold must meet all requirements of the non-full-size crib standard by June 28, 2011. Childcare centers, family child care homes, and other public accommodations that provide cribs must meet the non-full-size crib requirements by December 28, 2012.

Benchmarking

Our sponsor requested that we design a portable sleeping environment that is different from their current model in use, the Graco *Pack 'n' Play* [Fig. 1]. Because of this, we focused our preliminary benchmarking efforts on this particular portable sleeping environment design.

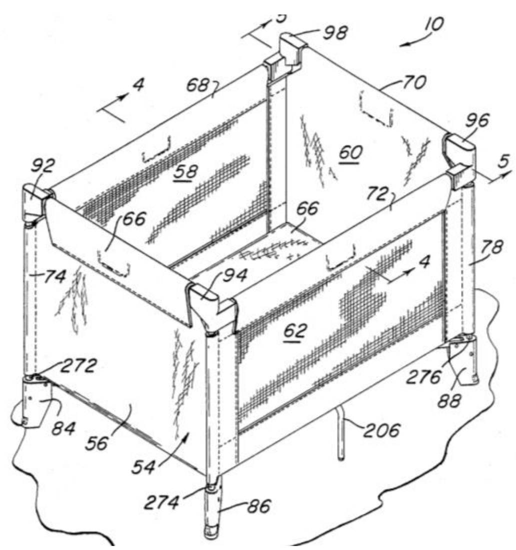


Figure 1: Isometric view of the Graco *Pack 'n' Play* from 1987 patent [6]

Graco filed to patent their foldable crib and play-yard in 1987. This patent was for their first model of a foldable play yard composed of upper and lower frame assemblies and a central hub unit [Fig. 2] for the foldable bars in the lower frame assembly [6]. Since then, the design for Graco's collapsible play-yard, now called the *Pack 'n' Play*, has changed little structurally except for a few new patents filed to add safety features [7]. Graco currently sells accessories compatible with the *Pack 'n' Play* such as the *Simplicity Bassinet* used for cradling infants in suspension while sleeping. In 2009, Graco recalled these bassinets produced between 2001 and 2008 due to a design flaw with the velcro that was capable of causing infant strangulation.

In 1997, Graco filed for another patent, called "Floor Locking Linkage For Collapsible Playpen" [8]. This design change was enacted to prevent the playpen from unintentionally collapsing and causing strangulation while occupied by a child, a safety problem inherent to their collapsible design since it was first released to the market. Design problems similar to these have plagued Graco and other manufacturers over the years as their products have been blamed for numerous infant hospitalizations [9].

Features that our team would like to adopt from the *Pack 'n' Play* include tall sidewalls, and mesh fabric materials that are breathable to prevent suffocation. In order to design a safer portable sleeping environment and help prevent misuse, our sponsor required that we eliminate the bassinet feature from our design. Our team also would like to avoid the safety hazards associated with using a central hub lower frame assembly in our design, so we are planning to design a different way to allow the unit to collapse into a travel size safely.

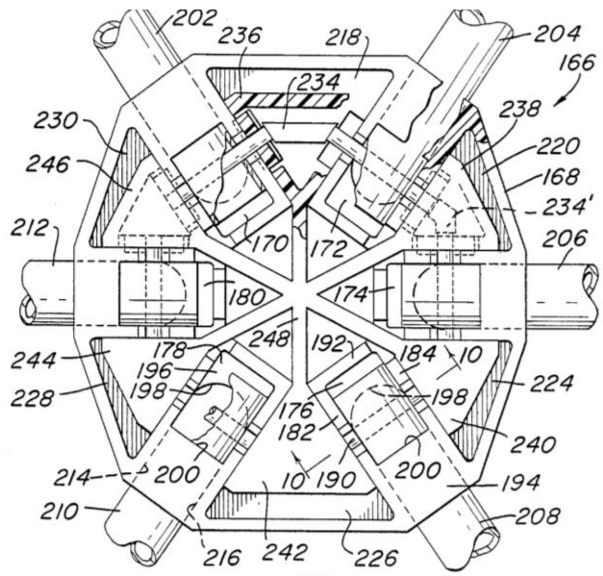


Figure 2**:** Graco *Pack 'n' Play* central hub unit for lower frame assembly as designed in 1987 [6]

During our benchmarking phase we also came across a collapsible sleeping environment product called *Travel Crib Light* [Fig. 3] made by Baby Bjorn [10]. We particularly liked the feature of this product's design that allows the child's mesh play area to hang clear of the hard frame components on the crib. This design feature mitigates potential safety hazards related to head impacts with the hard frame components, and pinching and/or strangulation traditionally associated with gaps and slats in the sidewalls of portable cribs. The worst feature of the *Travel Crib Light* was its price. Costing around $300, this safe collapsible sleeping environment is not affordable for most needy families.

Figure 3**:** A fully assembled Baby Bjorn *Travel Crib Light* [10]

While we will not entirely replicate the safety features from the *Travel Crib Light* and the *Pack 'n' Play*, our goal is to strive to create an entirely new design that is simple, and presents a safe and cheaper alternative to designs currently on the market. Our sponsor mentioned that this prototype would not be patented for mass production in the near future, so we were directed to focus more on designing a safe product instead of focusing too much attention on having a product similar to a company's existing patent.

Principal Requirements

The principal requirement for our design is safety, which encompasses various safety testing processes. Dynamic impact testing of the mattress support system is required to address incidents involving collapse or failure of mattress support systems. Mattress support system testing ensures that the mattress support does not become detached from the frame, potentially resulting in a fall. Cyclic testing addresses incidents involving hardware loosening and poor structural integrity. Requirements for mattress support systems address gaps in the mattress support system to minimize risk of entrapment. Impact testing of side rails and strength testing is required to prevent breakage and/or detachment during use. Latching mechanism tests ensure that latching and locking mechanisms work as intended, preventing unintended folding while in use. Label requirements cover numerous hazards, such as falls from the crib, suffocation on soft bedding, and strangulation on strings and cords. It must be impossible to assemble key elements incorrectly. Those elements must have markings that make it obvious when they have been misassembled.

The principal mattress requirements state that when not compressed, the mattress must allow for a distance of at least 20 inches from the top of the mattress to the top of the crib side and the gap between the perimeter of the mattress and the crib's frame cannot be greater than 1/2 inch at any point [11].

User Requirements and Engineering Specifications

Table 1 summarizes our complete list of user requirements and their respective engineering specifications. Priority was determined on a scale of 1-5, 5 being the highest priority. At a priority of 3 we must determine if this item is a want or need. This determination was made to ensure compliance with all standards.

The user requirements with highest priority are the safety requirements. Our sponsor requires that our product have obvious warnings to prevent user error that may result in an unsafe situation, and that the materials of the bedding must prevent suffocation [3]. The corresponding engineering specifications are a warning label system and use of breathable material for the bedding. Another safety user requirement is that the product must be able to hold and contain a child, sleeping or awake, between newborn and 18 months old. The corresponding engineering specifications, based on 95 percentile for an 18 month old child, are that the product must hold a child as long as 35 inches and as heavy as 31 pounds [12].

From the communication with our sponsor, Kids in Danger, our product must be able to contain a child both while sleeping and while awake for brief periods without direction supervision. The product must be large and stable enough to account for both rolling and standing. Our design must also be easy to collapse and store. Our design should be more portable than the Graco *Pack 'n' Play*, so the size of our product when collapsed should be less than 28''x10''x10'' [3]. Our sponsor also asked that the design be intuitive to use, which means no tools should be required for user assembly. As stated previously, our sponsor does not want our design to include a bassinet feature to avoid user confusion about when a child becomes old enough that the use of the bassinet is no longer safe.

System	User Requirement	Engineering Specification	Priority	Source
Dimensions	Smaller than Graco Pack 'n' Play	Smaller than 41"x29"x29.3", wall height at least 20"	3	Graco Pack n' Play
	Collapsible	Utilize linkages	5	ASTM Standards
	Age Range: 0-18 months	95 percentile for 18 month old: 35"	4	CDC
	No large gaps or holes	No gaps larger than 2.6"	5	ASTM Standards
	Lighter weight than the Graco Pack 'n' Play	Less than 22.9 lbs	4	Graco Pack n' Play
Safety	Obvious warnings	Warning label system	5	ASTM Standards
	Weight bearing	95 percentile for 18 month old with safety factor 2: 62 lbs	5	CDC
	Avoid suffocation	Breathable material; polyester foam	5	ASTM Standards
	Hygienic	Washable material	3	Kids in Danger
Mattress	Thickness	>20" from top of mattress to top of crib side (See Figure 4)	3	CPSC Guidelines
	Gaps	Gaps smaller than 1"	5	ASTM Standards
Function	Sleep and awake	Crib dimensions large enough to account for rolling and standing	5	Kids in Danger
	Easy to collapse and store	Less than 28"x10"x10"	4	Graco Pack n' Play
	Intuitive use	No tools for user assembly	4	Kids in Danger
	Avoid bassinet component	No bassinet feature	5	Kids in Danger
Price	Affordable for low income families	Under $100	3	Kids in Danger

Table 1**:** User requirements and engineering specifications (Highest to lowest priority: 5 to 1)

According to our sponsor, our fully assembled design also needs to be smaller than the Graco *Pack 'n' Play*. That is, the maximum dimensions of our design should be 41''x29''x29.3'', with a wall height of at least 20'' [3, 13]. There also shouldn't be any large gaps or holes in our design. According to ASTM standards, no gaps larger than 2.6'' are allowed, the nominal diameter of a can of soda [3].

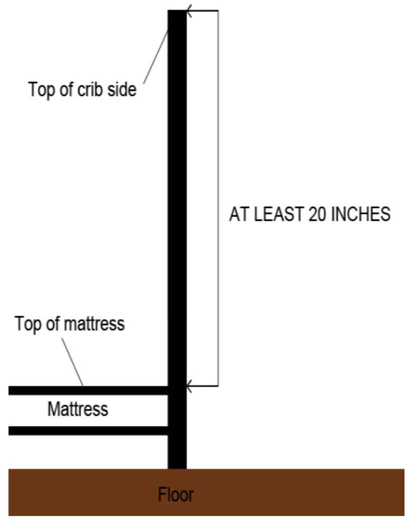


Figure 4: CPSC standard defining minimum mattress height relative to crib side height

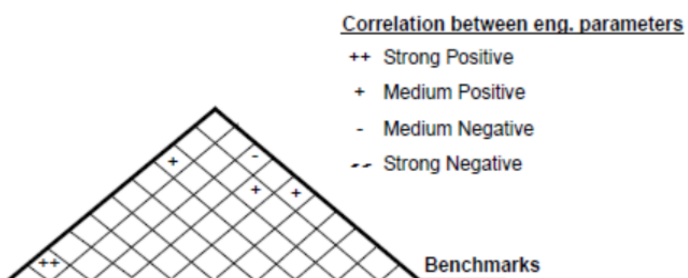
The price of our design has the least priority. According to our sponsor, our design will be mainly used for hospital donations or low-income families. The price should be affordable for low-income families, although safety standards must all be met regardless of cost. The maximum possible cost of our design is US $100.

The quality function deployment (QFD) is shown in Figure 5. The left column shows the user needs, with weights ranging from 1 to 10, where 10 is the highest priority. The upper column shows the engineering parameters. The table in the middle shows how the engineering parameters correspond to the user needs, where 9 means a strong relationship, 3 means a medium relationship, 1 means a small relationship and nothing means no relationship, as shown in the bottom of the figure. The triangle part above the engineering parameters depicts the correlation between them, which is explained in the upper part of the figure. The right column shows the benchmarks comparing with other products. We compared the Graco *Pack 'n' Play* to the Baby Bjorn *Travel Crib Light*. In the benchmarks, 5 means "satisfies perfectly" and 1 means "does not satisfy at all." The bottom row shows the measurement unit, target value of the engineering parameters, total value, normalized value and importance rating, with 1 being most important and 10 being least important.

Concept Generation

Our concept generation stage began with performing a functional decomposition to break down our complex problem into simple functions. During our decomposition we identified the functions of supporting a child, restraining a child, avoiding suffocation, avoiding laceration, and collapsing, all while ensuring comfort and intuitive use for all of the users. After decomposing our problem into simple functions, the team decided that all identified sub-functions were critical and needed generated concepts to ensure the user's safety. As a team we decided that the best way to ensure the support of the child would be to have our crib's base directly on the ground. After gathering background information, researching patents, and benchmarking the Graco *Pack n' Play* and BabyBjorn *Travel Crib*, the four members of our team brainstormed 20 concepts each (See Appendix A). The brainstorming was done individually to ensure no member had an influence over anyone else's ideas to prevent design fixation.

Once all members had 20 concepts compiled, together the team had to keep in mind manufacturability, safety, and cost while we eliminated a majority of the concepts that were deemed not feasible. The team also eliminated any concepts that required an apparent, complicated set-up. While we were still left with a number of concepts, we focused on choosing 4 unique frame designs to compare to each other. Focusing on simplicity, we picked out a frame design with a collapsible top and legs that folded in. However, while benchmarking the Graco *Pack n' Play,* one of the most unsafe features was the collapsible top so we decided to "flip the design over" and have the bottom of the structure be collapsible instead. Another concept that we focused on was to create a rubber frame with telescoping layers (Figure 6, page 11).



	Weight (1-10)	Maximum Dim. Assembl	Overall material weight	Max set up time	Cost	Load bearing capacity	Max frame gap size	Max mattress gap size	Max Dimension Collapse	Warning Label System	Linkages/hinges for colla	Graco Pack 'N Play on T	BabyBjorn Travel Crib L
safe	10					9	9	9		9	1	4	5
cheap	8				9							3	1
intuitive assembly	9			1							3	3	4
portable	8		3						9			4	4
last a long time	6	9				3					9	4	4
child fits inside	8	3				3						3	4
quick assembly	8			9								4	5
can hold some weight	7					9					1	5	4
lightweight	8		9									3	4
easy to manufacture	7										3	2	3
style/appearance/color	5				3							5	4
Measurement Unit		in	lb	s	usd	lb	in	in	in	N/A	N/A		
Target Value		41	23	255	100	31	2.6	1	28	#	#		
Total		78	96	81	87	195	90	90	72	90	119		
Normalized		0.08	0.10	0.08	0.09	0.20	0.09	0.09	0.07	0.09	0.12		
importance rating		9	3	8	7	1	4	4	10	4	2		

Competitive benchmarks
5 = satisfies perfectly
4 = satisfies "mostly"
3 = satisfies "somewhat"
2 = satisfies "slightly"
1 = doesn't satisfy at all

Correlation between user needs and eng. parameters
9 = Strong Relationship
3 = Medium Relationship
1 = Small Relationship
(blank) = Not Related

Figure 5: Quality Function Deployment (QFD)

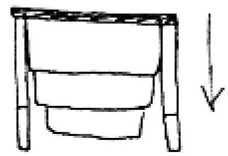


Figure 6: Rubber telescoping frame concept

We also focused on a foldable frame concept as depicted in Figure 7. This design allows for a safe environment where, if the crib collapses while the child is in it, nothing will fall on, or suffocate, the child. Our team continued to develop the folding frame concept by identifying that the collapsed size was still large and decided to add another joint in the middle of Bar 1 shown in Figure 7. To make the setup of this product safe and intuitive, the decision was made that each joint should only have two possible locking positions: the folded position and the fully set-up position. After focusing on these four mentioned frame concepts, we transitioned into the concept selection phase.

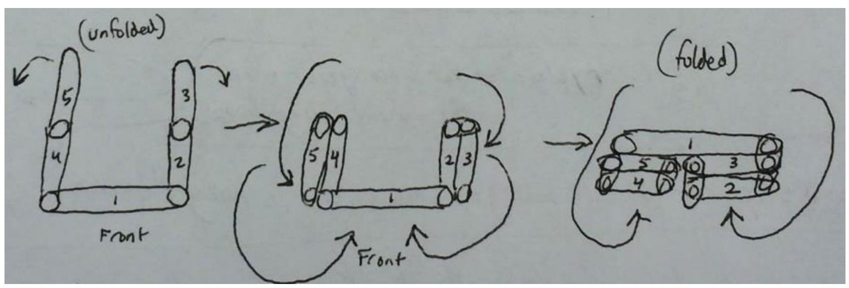
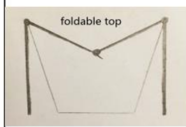
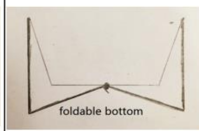
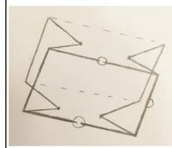
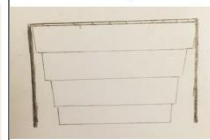


Figure 7: Original folding frame concept

Concept Selection

We used the Pugh chart to select the best concept for the frame of the crib, shown in Figure 8. The criteria we used are shown in the left column of the figure (*Portable (Lightweight), Portable (Small Volume After Folding), Avoid Falling, Intuitive Assembly, Weight Bearing, Easy to manufacture, Avoid Suffocation, Stability, and Cost*). We did not use exactly the same user requirements as we did in our QFD analysis. This is because, for the QFD, we took into account the size and material of the crib and the dimensional properties of the crib mattress. At this stage in our design process, the potential size and material of the crib and the properties of mattress will not vary much, and will not influence the frame of the crib, therefore we did not analyze them in the Pugh chart. For now, we are assuming that all four concepts have the same size and use the same materials. The second column from the left in the Pugh chart is the weight of each criterion, ranging from 1 to 3, where 3 signifies the highest importance and 1 signifies least importance. The first row in the chart shows the different concepts we chose to compare. The first concept was determined to be the "datum." This is the design similar to the *Graco Pack 'n' Play* with the foldable top. In the center of the chart, we compared each selected concept with the datum, where "++" means meeting criterion much better than datum, "+" means meeting criterion better than datum, "0" means meeting criterion as well as datum, "-" means meeting criterion not as well as datum and "--" means meeting criterion much worse than datum.

		Concept 1 (Datum / Baseline)	Concept 2	Concept 3	Concept 4
Sketch					
Criteria	Weight				
Portable (Light weight)	2	0	0	0	0
Portable (Small volume after folding)	2	0	0	++	0
Avoid Falling	3	0	0	0	0
Intuitive Assembly	2	0	-	-	+
Weight Bearing	1	0	+	0	0
Easy to Manufacture	1	0	0	-	-
Avoid Suffocation	3	0	-	++	++
Stable	2	0	+	+	0
Cost	1	0	0	-	0
	+	0	3	12	8
	0	17	9	6	11
	-	0	5	4	1
	Total	0	-2	8	7

Weight 3 - 1: Most Important to Least Important

++: Meets criterion much better than datum
+: Meets criterion bettern than datum
0: Meets criterion as well as datum
-: Meets criterion not as well as datum
--: Meets criterion much worse than datum

Figure 8: Pugh Chart comparison for best concept selection

The first criteria is *Portable (Lightweight);* because we assumed all four concepts had similar dimensions and used the same material, the weight of them are all comparable enough to ignore their differences (all of them get "0"). The second criterion is *Portable (Small Volume After Folding)*. We can see in Figure 8 that Concepts 1, 2 and 4 all need more space to store after folding, because one of their sides cannot be folded. Since all of the sides of Concept 3 can be folded, it is more portable than the others, so it earns a "++" in the second criterion. Next we considered the criterion of *Avoid Falling*, but since all concepts show the mattress being placed near or on the ground, and we assumed that they all have the same wall height, all concepts get a "0" weight in this row. The next criterion is *Intuitive Assembly*. Concept 1 and 2 have to fold or lock up the same number of linkages, but the joint in concept two is in the bottom of the crib where it is harder to reach. Concept 3 needs to fold or lock up more linkages than the datum, and Concept 4 needs to fold or lock up less linkages than datum. So Concepts 2 and 3 get a "-" and Concept 4 gets a "+". For the criterion of *Weight Bearing*, both Concepts 1 and 4 do not have linkages lying on the ground, and a very heavy weight might cause the side linkages in Concept 3 to bend under loading, so Concepts 3 and 4 both get "0". Concept 2 can bear a heavier weight than the others because it has linkages resting on the ground and unfolded side linkages, so it gets a "+". Since babies do not weigh hundreds of pounds, the criteria of weight bearing is not extremely difficult to handle for the types of materials we have selected, so we only gave it a weight of 1. The next criterion is *Easy to Manufacture*. We can easily tell that the frames in Concepts 3 and 4 are more complex, so they did not meet this criterion as well as the datum. The next criterion is *Avoid Suffocation*, which is very important. When the crib collapses, both Concept 1 and Concept 2 could squeeze the baby inside the crib, which could also cause suffocation. Furthermore, the bottom part where the baby is lying in the design in Concept 2 would provide pinching points first, so it could potentially be more dangerous if the structure unfolds unexpectedly. If the designs for Concepts 3 and 4 were to collapse unexpectedly, then the baby inside would be much less likely to become squeezed in the frame, therefore these concepts are much better at satisfying the *Avoid Suffocation* criterion. The next criterion is *Stable*. Since both Concepts 2 and 3 have linkages supported by the ground, we determined that they are more stable when the baby is rolling in the crib. The last criterion is the *Cost*. Because the design in Concept 3 would require the usage of more joints and linkages, it is more expensive than the others. Furthermore, we assume that the material used for all four concepts would be the same, so Concepts 2 and 4 get “0” and Concept 3 gets a “-”.

The bottom of the chart shows the sum of all of the signs and the total of the sums. We can see that Concept 1 has a total of 0 (because it is the datum), Concept 2 has a total of -2, Concept 3 has a total of +8 and Concept 4 has a total of +7. Since Concept 3 scored highest using our Pugh Chart comparison method, it appeared to be our most likely concept to be selected.

We believed that all four design concepts were feasible to design and build within the time constraints of ME450. The main advantage of Concept 1 was that it was very easy to assemble, but it was not portable and could possibly allow infant suffocation. Concept 2 was able to bear a lot of weight and was quite stable, but the potential suffocation safety problem made us avoid choosing it for our final design. The design in Concept 4 was quite novel. It was capable of being very safe and could be designed to be assembled easily, but it was inherently not as portable as Concept 3. Concept 3 came out on top in the Pugh chart comparison, because it was able to be designed to be safe, stable, and portable. Concept 3 was not without disadvantages in this analysis; it was not the easiest to assemble and manufacture, and its material costs will present a challenge being potentially more than the other concepts, but those criteria were not weighted as important as safety and portability. After concluding this extensive comparison analysis of our four most-feasible design concepts, we have chosen to move forward with designing and prototyping Concept 3.

Concept 3 includes sides that fold outward and down to avoid contact with a child inside of the crib. The base linkage is also foldable to allow for a more compact carrying size. Ideally, the joints will only have two locking positions, fully assembled and fully disassembled to eliminate any confusion in user setup. The frame will also be equipped with a handle and latching mechanism for easy carrying. A fabric insert will be created, utilizing mesh that will be placed onto the frame covering any exposed metal from the inside. All hardware will have anti-loosening devices and coverings to avoid laceration. We hope to also double the fabric insert and mattress components as a carrying case for the frame. The most important features of this frame are the locking system to allow for intuitive setup and the collapsing method to ensure that no hardware will fall onto the child during a potentially accidental collapse.

Primary Design Drivers and Challenges

To determine our primary design drivers, we considered the requirements outlined by our sponsor, the engineering specifications, and our functional decomposition for the design. From this information, we determined that the most important design driver is safety, given that the main goal of the design is to provide a safe sleeping environment for a baby. We then split the concept of safety into three main areas based on what our sponsor stressed as important. Collapsibility was chosen as our other final primary design driver.

Safety was divided into three subsections: structure and stability, materials, and intuitiveness. One of the main dangers of many *Pack ’n’ Play* style cribs is a partial or full collapse of the crib structure, which can crush, suffocate, or strangle a sleeping baby. Therefore, we decided that the structure and stability of our design is critical to prevent a potential collapse and ensure the safety of the user. The design must be able to hold a baby up to 18 months old, which presents a potential challenge to our design, as the structure must accommodate the size, weight, and movement of a child this age while remaining lightweight and portable. To analyze our design, we will create an analytical model to determine the forces acting on the structure and set strict tolerances to prioritize safety. We will apply various loads and movements to our proof-of-concept to demonstrate its stability.

Another element of safety is the material chosen, particularly for the sides and mattress of the crib. One of the most common causes of infant deaths is suffocation on the bedding or mattresses materials. Our sponsor stressed that the sides and mattress of our design should be made from a breathable material to prevent suffocation, even if the baby is erroneously placed on its stomach. We also determined that the sides should be made of a breathable material, likely mesh, so that if the baby rolls or moves into a position where they are trapped against the side of the crib, they will not suffocate. The material must also be strong enough, or at least attached strongly enough, to prevent it from collapsing and trapping the baby. Overall, the design and chosen material must not have any holes larger than about the size of the diameter of a can of soda, as holes this size could cause a child to become trapped or strangle, per ASTM standards. Using another analytical model, we will determine the strength of material needed and ensure that the chosen material allows a child to breathe through it. For validation, we will apply various loads to demonstrate material strength, conduct tests to show breathability of the fabric, and measure any holes to demonstrate compliance with standards.

The final primary element of safety is intuitiveness, in terms of both assembly and general use. While we must ensure that all safety standards and requirements are met, these measures will not work unless the product is used as intended. Assembling our design should be easy, with clear instructions, to make it difficult or even impossible for the user to assemble it incorrectly or in a way that compromises its safety. The design should also include labels and warnings about improper use that are simple and obvious to prevent misuse as much as possible. For example, there should be a clear warning label depicting that a baby should never be placed on its stomach. An example of this requirement in our current chosen design concept is the joints of the frame linkage, which will only lock in the folded position and in the fully assembled position, and when unlocked the frame will fall to make it clear to the user that it is not properly assembled. To unlock the joints, there will be a button on the outside of each joint, however, we anticipate this design detail will be difficult to design and implement. Our biggest challenge with this design driver will be validation; "intuitiveness" is subjective, and difficult to actually prove. To analyze intuitiveness, we plan to conduct further research and possibly speak with industry experts about how to design for intuitive assembly and use. We will demonstrate intuitive assembly and safe use by conducting focus groups.

The last primary driver for our design is collapsibility. The structure of the crib must collapse to a smaller size for storage to meet our sponsor's requirements, while maintaining stability when assembled and in use. In our current chosen design concept, the joints of the frame linkage will only lock in the folded position and in the fully assembled position, and when unlocked the frame will fall to make it clear to the user that it is not properly assembled. To unlock the joints, there will be a button on the outside of each joint, however, we anticipate this design detail will be difficult to design and implement. We plan to create an analytical model of our concept to determine position of joints and the collapsed size of the structure. We will then conduct testing of our proof-of-concept to determine its collapsed size and compare it with our engineering specification for collapsed size.

Concept Description

Our chosen concept includes sides that fold outward and down to avoid contact with a child inside of the crib. The base and top linkage are also foldable to allow for a more compact carrying size. Ideally, the joints will only have two locking positions, fully assembled and fully disassembled, to eliminate any confusion in user setup and to ensure safety. The frame will be symmetrical and can be thought of as an “accordion” style of folding. The frame will also be equipped with a handle and latching mechanism for easy carrying. A fabric insert will be created, utilizing mesh that will be placed onto the frame, covering any exposed metal from the inside. A thin mattress will then be placed onto the fabric insert, resting on the ground. All hardware will have anti loosening devices and coverings to avoid laceration or tearing of the fabric. We hope to also double the fabric insert and mattress components as a carrying case for the frame. The most important features of this frame will be the locking system that also allows for an intuitive setup and the collapsing method to ensure that no hardware will fall onto the child during a potential accidental collapse. An obvious warning label system and setup instructions will also be provided to avoid incorrect setup.

Engineering Analysis

In order to conduct a relevant engineering analysis, we will perform all testing while keeping in accordance with our primary design drivers. These design drivers were determined based on requests from our sponsor, federal regulations for crib design with their respective engineering specifications, and our own functional decomposition analysis for what we needed to be included in our design. From this information, we determined that the most important design driver was safety, given that the main goal of the design was to provide a safe sleeping environment for a baby. We then split the concept of safety into three more specific design drivers based on what our sponsor stressed was important: structure/stability, materials, and intuitiveness. Finally we chose collapsibility to be our fourth primary design driver as it was deemed important by our sponsor.

In order to create a collapsible crib that is safer structurally than the Graco Pack ‘n’ Play, we designed our version of the collapsible crib to support the mattress using the ground. This removed excess forces on the base of the frame, which could cause the frame to collapse should those components fail statically, and it made the design simpler to manufacture. Collapse of the Graco Pack ‘n’ Play frame base could be dangerous to the infant occupant because it could lead to the occupant being crushed, suffocated, or strangled by the sidewalls and fabric materials falling on top of it. By reducing the number of components that could fail in our design, and by reinforcing the corner joints which will support the rest of our crib’s frame (Figure 9), we made steps towards having a safer design structurally. We conducted a thorough static analysis of the forces that would act on each part of the crib that we expected to be the weakest (See the Theoretical Modeling portion of this report on page 16). After creating a free body diagram depicting all of the forces acting on each component, our team decided to use CAD software to perform a finite element analysis, which allowed us to most-easily determine how each component would behave ahead of the manufacturing phase.

Figure 9: Updated CAD for DR3, including reinforced corners

Additionally, we deemed it necessary to validate our prototype design empirically through lab testing on our physical prototype, in addition to our theoretical static force finite element analysis. Federal regulations on crib designs point to the ASTM standard number F406 which outlines all of the industry-accepted testing protocol for non-full sized collapsible cribs and playards. Our team reserved a segment of lab time at the UMTRI lab on north campus to validate our design using accurate dummy models for an 18 month old baby while also performing various tests from this ASTM guide. Specifically, to test the structural safety of our crib's base we will follow ASTM F406 Section 8.7 which is the mattress support system vertical impact test for rigid sided products. Similarly, to test the structural integrity of the sidewalls, and bending mechanisms in our design we will draw upon F406 tests, which we will outline in the Empirical Testing portion of this report (Page 18).

We selected material safety as another one of our four primary design drivers. Our material safety focus for this design is primarily on the soft materials that we will use for the crib sides and the mattress. One of the most common causes of infant deaths is suffocation on the bedding or mattresses materials. Our sponsor stressed that the sides and mattress of our design should be made from a breathable material to prevent suffocation, even if the baby is erroneously placed on its stomach. We also determined that the sides should be made of a breathable material, likely mesh, so that if the baby rolls or moves into a position where they are trapped against the side of the crib, they will not suffocate. The material must also be strong enough, or at least attached strongly enough, to prevent it from collapsing and trapping the baby. Since we have been benchmarking the Graco Pack 'n' Play, our first prototype will use the mesh material from a representative Pack 'n' Play, and we will modify its dimensions to fit our crib. It is important with this portion of our design that we pay special attention to how the material is attached to our frame to prevent any large holes from opening up. Within the ASTM F406 standards there are numerous guidelines we will follow to ensure that our fabric materials are safe empirically after our product has been fabricated. These tests cover dimensional checks regarding gap sizes and gap shapes, and also depict how much force a soft material should withstand before deforming too much in a single direction. These tests and checks mainly fall within Section 5.1 of ASTM F406, and our lab tests related to these regulations are also outlined in the Empirical Testing portion of this report (Page 18).

Our third primary design driver is safety through intuitiveness, in terms of both assembly and general use. While we must ensure that all safety standards and requirements are met, these measures will not work unless the product is used as intended. Assembling our design should be easy, with clear instructions, to make it difficult or even impossible for the user to assemble it incorrectly or in a way that compromises its safety. The design should also include labels and warnings about improper use that are simple and obvious to prevent misuse as much as possible.

For example, there should be a clear warning label depicting that a baby should never be placed on its stomach. An example of this requirement in our current chosen design concept are the joints of the frame linkage, which will only lock in the folded position and in the fully assembled position, and when unlocked, the frame will fall to the ground to make it clear to the user that it is not properly assembled. To unlock the joints, we included in our design a button on the outside of each joint, however, we anticipate this design detail will be difficult to manufacture and implement on our first prototype. To work around this, we have designed in hard stops in each of the joints on the frame. By potentially using clamping hinges at those joints, and requiring the user to unfold the frame until it strikes the hard stop, we can demonstrate how the crib will look when it is fully set up, compared to how misshapen it will appear when it is improperly or not completely set up. In order to test the intuitiveness of our design prototype empirically, we will follow ASTM F406 Section 5.8, which describes all safety requirements for latching and locking mechanisms on a crib. We also will follow ASTM F406 Section 8.18, which describes all regulations involving warning labels, their clarity, and how to fix them permanently on the crib. To further analyze our prototype's intuitiveness, we plan to conduct small-scale research and possibly speak with industry experts about how to modify our design for intuitive assembly and use. We will conduct small focus groups, and gain the opinions of other people who will be using our product for the first time.

Our team's last primary design driver is collapsibility. The structure of the crib must collapse to a smaller size for storage than a collapsed Graco Pack 'n' Play collapses to meet our sponsor's requirements, while maintaining its stability when assembled and in use. In our design, the joints of the frame linkage will only lock in the folded position and in the fully assembled position, and when unlocked, the frame will fall to the ground to make it clear to the user that it is not properly assembled. We modeled our design using CAD to demonstrate where the joints will be in the frame to allow it to collapse and fold into a compact shape. Once we have manufactured our prototype, we will verify all dimensions to make sure that the design fits within the dimensional boundaries initially given to us by our sponsor. Furthermore, within ASTM F406 there are various regulations regarding crib wall height and mattress thickness within Section 5.1. Our current design already meets these requirements, but after manufacturing the prototype we will measure the finished product to ensure that it still meets the ASTM regulation dimensions.

Theoretical Modeling

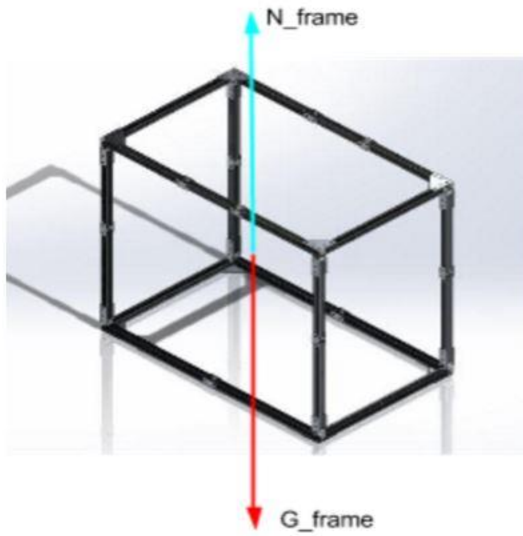


Figure 10: Free body diagram of the whole crib frame

The free body diagram of the whole frame is shown in Figure 10. First, we assume the baby is placed in the middle of the mattress, which means that he/she does not have any contact with the frame of the crib. Furthermore, the mattress in our design is resting on the ground, so the baby does not apply any force on the crib frame. Thus, the free body diagram of the whole frame only includes the gravity of the frame itself, G_frame, and the upward normal force of the floor, N_frame. The equation of this balance is $G\_frame = N\_frame$, which are both 16.5 lbf.

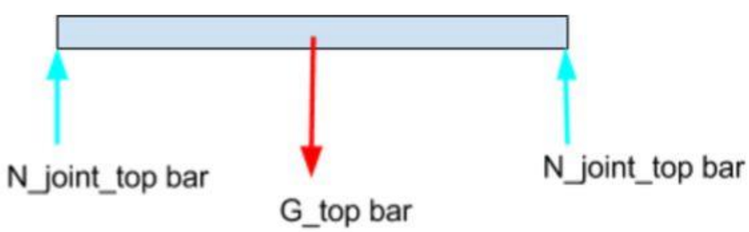


Figure 11: Free body diagram of the entire crib upper rail

The free body diagram of the entire top bar assembly is shown in Figure 11. We analyzed only the top bar in detail because we determined that it is the bar that is most likely to fail. We supposed that the baby is in the middle of the mattress and does not have any contact with the frame of the crib. Furthermore, because the connecting joint is very light compared to the bar, we neglected the weight of the joints. We can conclude that the free body diagram of the top bar in the system only contains the gravity of the bar itself, G_top bar, and the upward support from the joint, N_joint_top bar, as shown in Figure 11. The force balance equation for this is $2 * N\_joint\_top\ bar = G\_top\ bar$, where G_top bar is 0.58 lbf, and N_joint_top bar is 0.29 lbf.

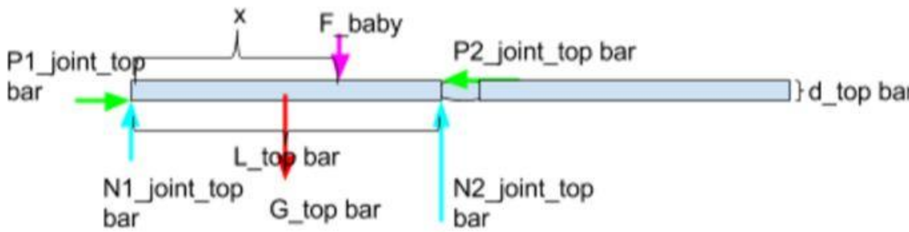


Figure 12: Free Body Diagram of the Top Bar with a Force Applied by Baby

When the baby applies force on the crib, the situation becomes more complex. We considered a force applied directly downward by the baby on the top bar (the situation when the entire baby weight is hanging on the top bar). The free body diagram for this scenario is shown in Figure 12. Besides the gravity of the top bar itself and the upward support force from the joint, there are also horizontal pressure forces from the joints. The equations for the left top bar are:

$$F\_baby + G\_top\ bar = N1\_joint\_top\ bar + N2\_joint\_top\ bar$$
$$P1\_joint\_top\ bar = P2\_joint\_topbar$$

$$F\_baby * x + P2\_joint\_top\ bar * d\_top\ bar / 2 + N2\_joint\_top\ bar * L\_top\ bar = G\_tap\ bar * L\_\ top\ bar / 2$$

(moment equation with respect to the bottom left corner in the graph), where F_baby is force applied by the baby, P1_joint_top bar and P2_joint_top bar are the pressure forces from the joint to the top bar, N1_joint_top bar and N2_joint_top bar are the supportive forces from the joint to the top bar, G_top bar is the gravity of the top bar, d_top bar is the width of top bar, L_top bar is the length of the top bar, and x is the distance between F_baby and the left end of the bar.

Because there are four unknowns and only three equations, we cannot solve for the forces applied by the joints to the bar. Thus we introduced the method of finite element analysis, and did so using the worst case scenario load. In the finite element analysis, we fixed one end of the crib's top bar, and applied a shear force of 62 lb to the other end, because the weight of the baby is 31 lb, and we used a safety factor of 2. The result shows that the yield strength of the material should be larger than 55.15 MPa to pass the test. The t-slot aluminum we are using has a yield strength of 241 MPa. Thus the top rail of the frame won't fail under the weight of the baby with at least a safety factor of 2.0. Because our testing passed with such a high safety factor, and the design should only be experiencing static loads, we are very confident that this structural analysis validated that our design materials would not fail, and that we should move forward with building our prototype.

Empirical Testing Overview

Since our team has not finished manufacturing our prototype model, the data collection for the empirical testing phase of our design analysis has not yet occurred. The following section describes the details of the tests that our team will perform on our manufactured prototype to validate our design, and determine if it meets federal requirements for a collapsible crib. In addition to conducting the tests outlined in this section, further analysis will still be required to make sure our design meets the expectations of our sponsor in terms of function and expected safety.

Each test and regulation is geared to analyze a feature that most commonly fails on cribs of similar design. Since, our design is in its early stages of development, our trials will focus on the static testing of our prototype. This includes strategic weight placement testing, and loads applied to features of the prototype for a duration of time. Because our prototype is a proof-of-concept for our sponsor to solve an issue regarding collapsibility and subsequent user safety, and this product is not entering the market in the near future, we will not conduct the F406 cyclical loading testing on this prototype that is typically required for all collapsible crib designs. If a design based off of our prototype were to enter mass production, it would be composed of different materials, and would need to be re-evaluated by a third party corporation to meet federal regulations. Our team adopted the force values, and force application locations from the ASTM F406 regulatory tests to make sure our frame design could handle the worst case loads that would be experienced during third-party testing. We will not follow every exhaustive detail of the F406 testing guidelines however (Nor are we capable within the bounds of our project budget), because our prototype will not be sent to the market. It should be concluded that only the protocol outlined in this design report (DR3), and future design reports authored by our team members encompass all empirical structural testing performed on this prototype. Since these tests have not yet been performed, any empirical results drawn from this DR3 protocol are speculative, and were authored with the intention of aiding the design process.

Empirical Testing Protocol

In order to test the structural stability of our prototype we will conduct the following tests using basic tools such as: a 100 lb calibrated weight, a 45 lb calibrated weight, a pair of locking pliers, and a Chatillon tension/compression force gauge. We will conduct 5 different tests, each with a different number of trial locations on the crib structure. We will use the ASTM F406 definition for failure preceding each test to determine if our prototype will pass or fail structurally.

“3.1.28 structural failure, n—damage to a component(s) or assembly resulting in partial separation (greater than 0.04 in. (1 mm) over original configuration), or complete separation of the component(s) or assembly.” [3]

Test 1: The purpose of our first test is to validate the structural stability of the prototype with a heavy vertical load placed onto its upper rail in its center. The applied weight must be 45 lbs, and must be applied within a time span of 5 seconds. The prototype base must be fixed to the ground to prevent sliding or movement during testing. The structure must hold the weight for a total of 10 seconds without showing any signs of failure. Figure 13 illustrates where on our prototype the 45 lb weight will be placed using side view and top view diagrams.

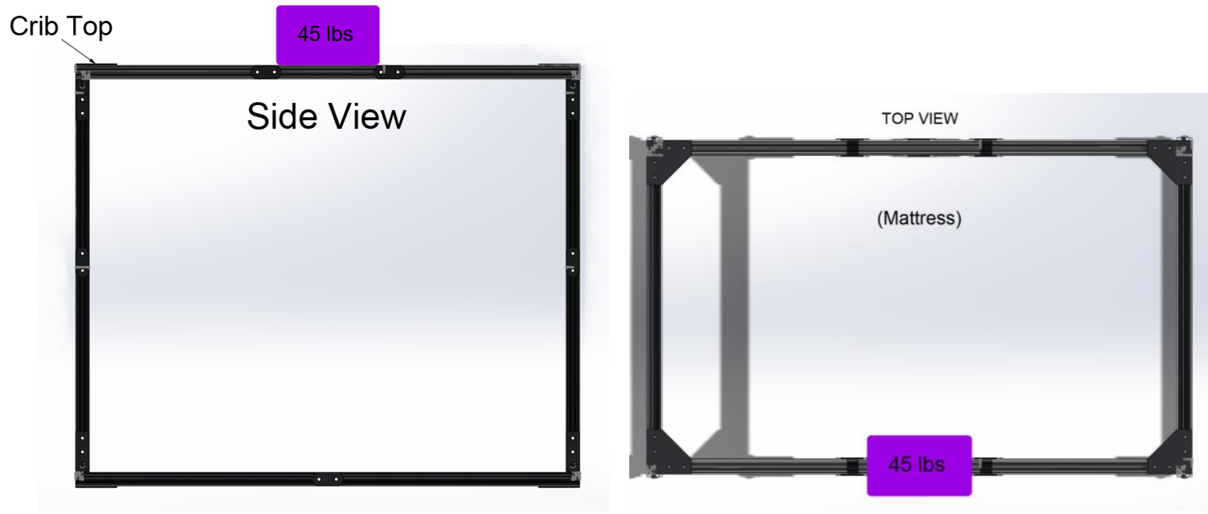


Figure 13: Protocol schematic for Test 1. Representative 45 lb weight shown in purple.

Test 2: The purpose of our second test is to validate the structural stability of the prototype with a force applied at a 45 degree angle onto the upper rail in its center. The force must be 100 lbf, and must be applied within a time span of 5 seconds. The prototype base must be fixed to the ground to prevent sliding or movement during testing. Using a force meter, one of our team members will apply the force to the structure at approximately a 45 degree angle. This test must be conducted twice, acting on the prototype wall from both sides. The structure must withstand the force for a total of 10 seconds without showing any signs of failure. Figure 14 illustrates where on our prototype the force will be applied using a side view diagram.

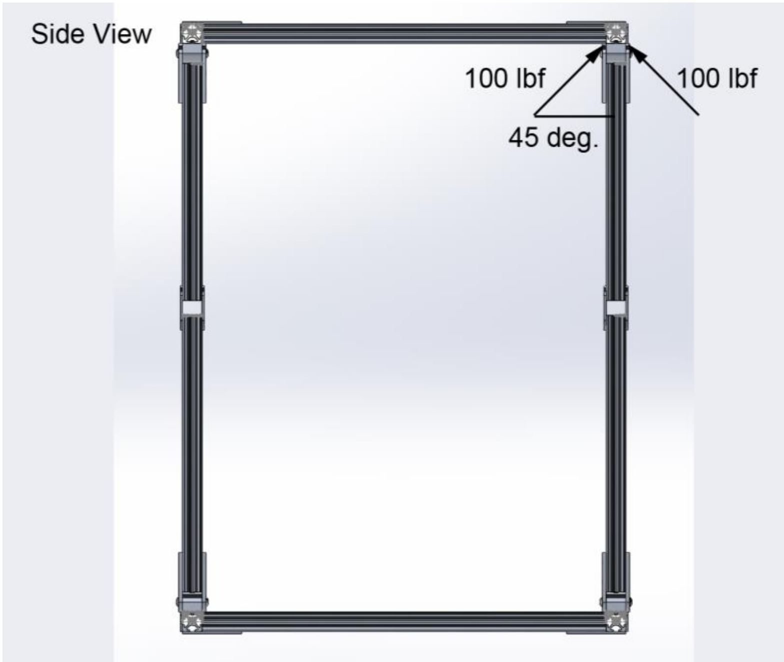


Figure 14: Protocol schematic for Test 2. Force gauge loads are indicated with black arrows.

Test 3: The purpose of our third test is to validate the structural stability of the prototype's upper rail joint with a force applied normally onto the upper rail's underside in its center. The force must be applied in a direction that is parallel to the plane of rotation of the neighboring joint. The force must be 30 lbf, and must be applied within a time span of 5 seconds. The prototype base must be fixed to the ground to prevent sliding or movement during testing. Using a force meter, one of our team members will apply the force to the structure by pushing the meter vertically upward against the prototype upper rail. The structure must withstand the force for a total of 30 seconds without showing any signs of failure. Figure 15 illustrates where on our prototype the force will be applied using a side view diagram.

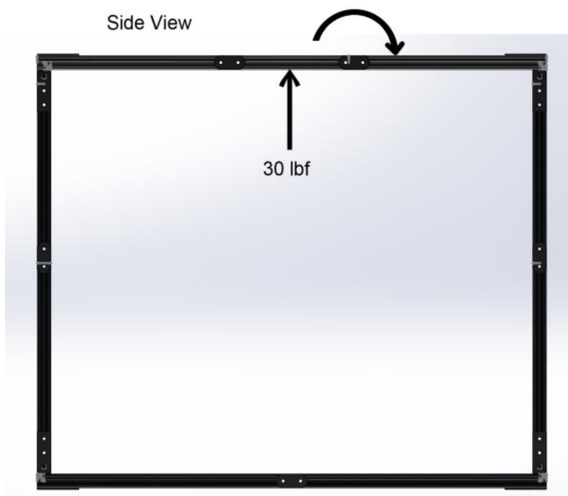


Figure 15: Protocol schematic for Test 3. Force gauge load indicated with a straight black arrow, plane of joint rotation indicated with a bent arrow.

Test 4: The purpose of our fourth test is to validate the structural stability of the prototype's lower rail with a heavy vertical load placed onto its lower rail in its center. The applied weight must be 100 lbs, and must be applied within a time span of 5 seconds. The prototype base must be fixed to the ground to prevent sliding or movement during testing. The structure must hold the weight for a total of 30 seconds without showing any signs of failure. Figure 16 illustrates where on our prototype the 100 lb weight will be placed using a side view diagram.

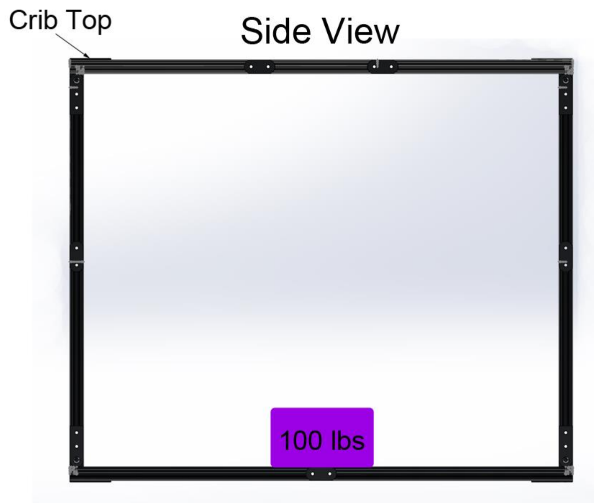


Figure 16: Protocol schematic for Test 4. Representative 100 lb weight shown in purple.

Test 5: The purpose of our fifth test is to validate how securely the soft materials of the crib are fastened to the crib frame. First, the crib mesh walls and mattress must be attached to the crib frame in their designed positions. Then, the prototype base must be fixed to the ground to prevent sliding or movement during testing. Finally one of our team members will use the pair of locking pliers to grab the soft material near an attachment point to the frame. Once the material has been clasped by the pliers, the force meter will be used to pull on the material in the direction it would normally be in tension with 30 lbf for a duration of 10 seconds. The soft material must withstand the force without showing any signs of failure, which in this case is defined as tearing or permanent stretching. This test will be conducted on each soft material attachment point to the frame.

Empirical results from each of the five tests will be compiled, and the crib prototype will be given either a passing or failing score for federal regulation testing. If we grant the prototype a passing score, then it will be ready to present to our sponsor. If the prototype were to fail any of the tests, our team would redesign and manufacture the necessary components to better handle the loads.

Failure Mode and Effects Analysis

Table 2: Failure Mode and Effects Analysis (FEMA)

Item	Function	Potential Failure Mode	Potential Effects of Failure	Severity	Potential Causes of Failure	Occurance	Concept Design Controls	Detection	RPN	Recommended Action
Side Wall Linkage	Holds weight	Linkage bends too much	The linkage will break and could fall on the baby	9	Material is not strong enough	2	Test and perform strength calculation	1	18	Choose material that is strong enough and calculate the best cross section area
Joint	Folds the linkages	Joint looses or falls apart	Linkages fall down and could hit the baby	9	Design failure	3	Test and ensure the joints won't fail	2	54	Research more on the different types of joints
Automatic lock of the joints	Locks the joints and linkages to a certian position	The pivot pin or the tab of the lock falls apart	Linkages fall down and hit the baby	10	Fatigue failure	2	Test and perform strength calculation	2	40	Choose material that is strong enough and learn more about automatic locks
		The lock is compressed beyond capability	The joints can no longer be locked	8	Failure of the spring	1	Test and validate method	3	24	Choose a spring that is strong enough
		The user fails to lock the joints with enough force	The side linkages will fall down and hit the bottom linkages	7	Design failure / Assembly failure	3	Test and validate method	3	63	Learn more about automatic locks
Mesh wall	Constraints the baby and the location of the mattress	Mesh wall falls down	Baby will climb out the cribs without constraint and could cause accident	9	Mesh wall is not assembled correctly	1	Test and validate method	4	36	Research more about the method to assemble the mesh wall with the frame
		Baby digs a hole on the mesh wall	Baby's hands or head could be stuck in the hold	9	Material is not strong enough	2	Test and ensure the mesh wall has enough strength	2	36	Choose material that is strong enough
Mattress	Supports the baby	Too soft	Could suffocate the baby	9	Design failure	2	Test and find the thickness of the mattress	2	36	Research more on the thickness of the mattress
		Not breathable material	Could suffocate the baby	9	Material chosen is wrong	2	Test and find the breathable material	1	18	Choose a breathable material for the mattress
Frame Bars/Components	Supports crib walls	Fracture under load of child	Crib collapses, choking hazards created, baby could suffocate.	10	Material is not strong enough	3	FEA analysis and functional testing, cyclical load testing, shock load testing.	2	60	Perform thorogh FEA analysis and functional testing to satisfy a factor of safety of 2 or higher.

Table 2 shows the failure mode and effects analysis (FMEA). In the table, the severity is scaled from 1 - no noticeable effects, to 10 - potential failure mode affects safe operation or regulatory requirements, without warning; the occurrence is scaled from 1 - highly improbable, to 10 - very high: failure all but guaranteed; the detection is scaled from 1 - almost certain, to 10 - almost no chance of detection prior to release to customers. The risk priority number (RPN) is calculated by multiplying the severity with the occurrence and the detection. It will be in a range of 1 to 1000.

From the FMEA we can know that the item with highest risk priority number (RPN) is the automatic locking of the joint which will be used to lock the joints and linkages to a certain position. The potential failure mode is that the user fails to lock the joints with enough force. The severity of this failure is not so high because it will happens before parents put baby inside the crib, so it will not cause serious safety problem. But the occurrence of this failure is relatively high, and it is hard to detect before selling it to customers, so it has a highest RPN of 63. So we are going to learn more about automatic locking joints and ensure its safety.

Another high risk of our design is the frame bars which are used to support the crib walls. It has a RPN of 60. The potential failure mode of the frame bars is fracture under load of child, which might cause crib collapse, choking hazards, or even suffocation of the baby. The consequence of this failure is severe, because it might cause injury or death of the baby. The occurrence of this failure is low, and it is easier to detect before selling to customers by running tests.

To reduce the risk of causing baby suffocation because of the failure of frame bars, we decided to change the bending direction of the crib. The frame bars which are used to support the crib will only be able to bend down. So the baby will not be able to bend up the frame bars and get injured or suffocated, the risk in this aspect is reduced to an accepted level.

The risk analysis is shown in Table 3 (Page 26). The hazard that is most likely to happen is falling caused by baby moving and the entire structure falling over. It has a high likelihood and a critical impact. The consequence of this risk is severe because baby might injured in fall, trapped in frame or material after falling, which might result in suffocation. To reduce the risk of falling, we need to make sure the structure is stable (sleeping area is directly on ground, etc.) and can withstand motion.

Another hazard that most likely to happen is laceration caused by sharp corners and edges. It has a high likelihood and a high impact. To reduce the risk of laceration, we will file down manufactured prototype to get rid of unnecessarily sharp edges, and cover entire frame in cloth tube to avoid contacting with it.

Most of the risk and failure are caused by the unstable structure of the crib and the material of the mattress. So we will make sure that we test and ensure the strength of the frame (linkages, joints and automatic lock) of the crib, and we will use breathable material to make the mattress. Thus the overall risk associated with our design is now at acceptable levels.

Table 3: Risk Analysis

Hazard	Cause	Consequence	Likelihood	Impact	Safeguards	Recommendations
Suffocation	Baby is face down on mattress (placed or rolled)	Suffocation on mattress	Medium	Critical	Mattress made of breathable material, if baby is face down can still breath through it without suffocating	Look into designing intuitive warnings about placing baby face down, concave mattress to prvent baby from rolling
	Baby rolls or is placed close to cloth sides, in position where suffocation on sides possible	Suffocation on soft siding	Low	Critical	Siding made of breathable material, if baby is facing siding can still breath through it without suffocating	Concave mattress to prevent baby from rolling to sides
Entrapment /Strangulation	Frame material is too weak to handle a shock load; it fractures and crib frame collapses	Frame collpses on child and/or child is pinched in collapsing pieces. Child may also choke on broken parts.	Medium	High	Conduct thorough analysis while designing components to make sure each part will suppport its load. Use factor of safety of 2.0	FEA analysis of SolidWorks CAD files of critical components to iteratively design components that are not expected to fail under load.
	Frame falls and baby is pinched in sides or any pinch points	Baby trapped, injured, or strangled, depending on how the frame falls and how the baby is positioned	Low	Critical	Strong joints that lock to avoid coming apart, cloth or structure keeping sleeping area separate from pinch points	Design joints to lock in place when fully assembled to ensure correct assembly and protect against falling, design so that sleeping environment is contained within crib, frame falls away from sleeping area
	Material falls or frame falls and material folds	Baby is stuck in material and suffocates or is strangled	Low	Critical	Strong joints that lock to avoid coming apart, make cloth siding from breathable material	Breathable material so that even if this happens the baby doesn't suffocate, design so that cloth won't bunch if the walls fall
	Holes in sides, holes are too large	Baby trapped in holes, possible strangulation depending on position	Low	High	Ensure design does not necessitate large holes, measure holes on prototype	Don't use material with large holes in design
Lacerations	Any sharp corners or edges	Baby or caregiver is cut by corners or edges	High	High	Avoid sharp corners in design, over sharp parts of frame with cloth	File down manufactured prototype to get rid of unnecessarily sharpe edges, cover entire frame in cloth tube to avoid contact with it
Falling	Walls are too short or fall/droop	Baby climbs over walls or falls out	Medium	High	Ensure wall height meets standards, build strong joints that lock in place so the walls don't fall	Design so that crib is slightly shorter than 95th percentile 18 month old, conduct testing

Final Design

Our final design, detailed in Figures 17 through 21 below, includes four sides which bend inwards to fold into a portable configuration. The bottom bar is divided into two sections, with one joint in the middle, and a plastic handle on one side to allow the user to carry it the crib when folded. The top bar is divided into three sections, with two joints that allow it to bend and wrap around the outside of the folded design. For stability, there are 8 corner plates connected to secure the four bars on both the top and bottom, each secured with five fasteners.

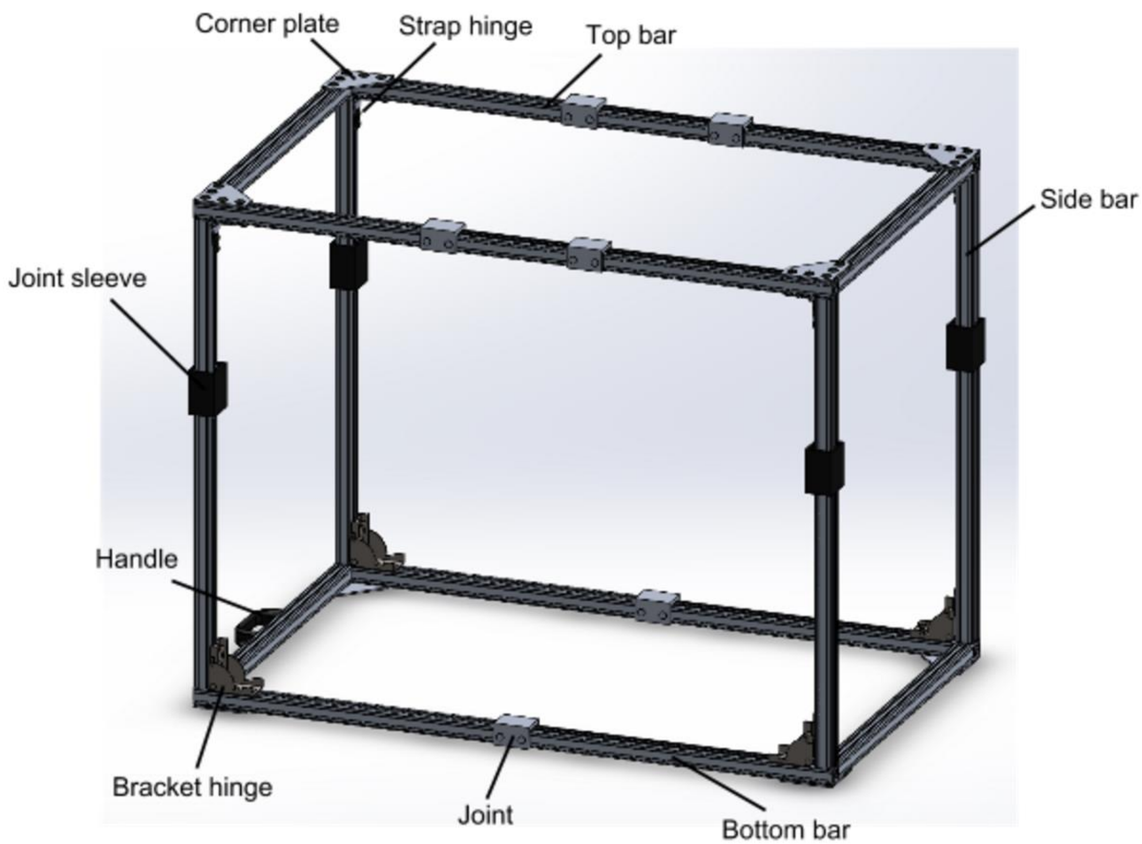


Figure 17: Isometric view of assembled design

The details of this design include four table leg bracket hinges at each bottom corner, connecting the bottom frame to each side bar, secured with four fasteners each. These hinges have a button, which when pressed allow the side-bar to be raised to a 90 degree angle with the bottom, or lowered to be parallel with the bottom for folding. These hinges only lock in place in the 90 degree position, and make a clear clicking sound when fully locked, which ensures that the user will properly assemble the frame. When the bracket hinge is not locked, the frame will not stand up properly, making it clear that it is not correctly assembled. The bracket hinges used for our prototype are different from what would be used on a final consumer version of our product, as they are large and difficult to maneuver. On each of the top corners, a small strap hinge is used to connect the top frame to each of the side bars. The hinges are each secured with four fasteners, and include a plate between each side and the attached bar to increase the strength and stability of the hinge and allow better alignment when folded. The hinge plates were produced using the water-jet.

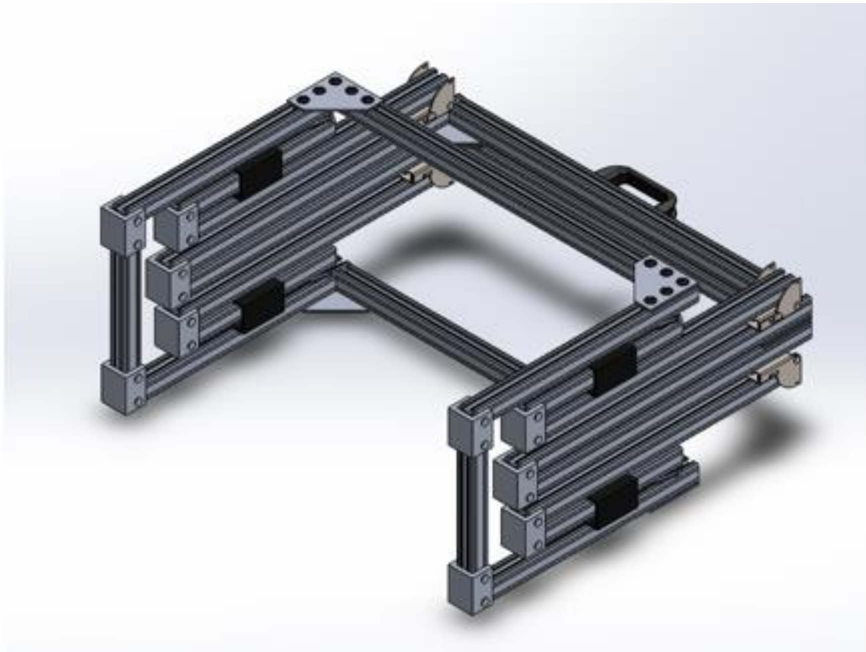


Figure 18: Isometric view of folded design

For the joints that do not utilize a hinge, a mill was used to machine three-sided rectangular joints. Each joint includes two through-holes, press-fit with bushings, to connect them to each bar. Holes were drilled into each bar, which were also press-fit with bushings. The joints and bars were connected with low-profile binding posts. The joints are designed with a flat side on the side opposite the direction of bending. This flat side allows for stability, and acts as a hard stop to ensure that the joints can only bend in one direction, preventing the frame from collapsing on a child inside when it is assembled. For further increased stability, and to ensure that the joints are fully locked when the frame is assembled, the design includes plastic sleeves that slide down over each joint on the side bars. The design of these sleeves have changed slightly since our initial concept. We planned to machine the parts on a mill from aluminum stock, but found it would be much easier to manufacture out of plastic using a 3D printer. The sleeves have two notches on the inside face, which align the sleeves with the t-slotted bars, ensuring they can easily fall into position over the joints without catching.

The finished prototype will include a fabric lining similar to the Graco Pack'n'Play. The sides will be made of mesh to ensure that the child could still breathe, even if rolled into a position against the fabric. The mesh will be tight when the frame is assembled to prevent the child from suffocating in the side fabric, and to keep the child away from pinch points in the frame. Additionally, the frame will be covered in fabric, to protect both the user and the child from laceration and pinch points during assembly and disassembly.

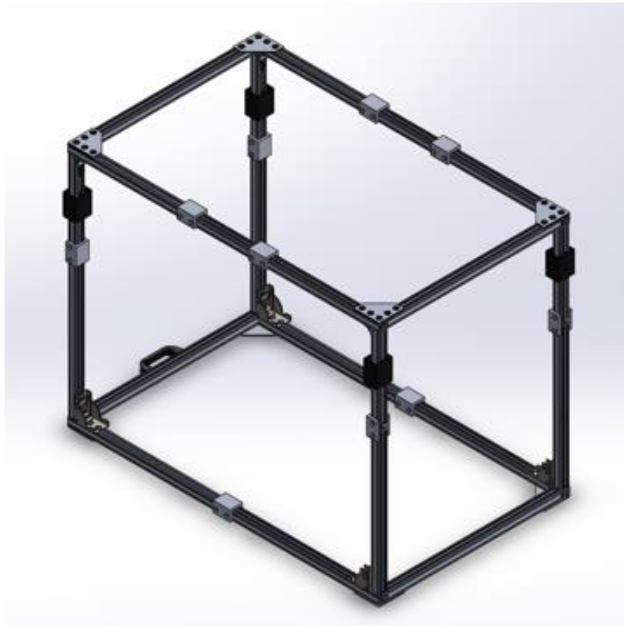


Figure 19: Isometric view of assembled design showing joints on side bars

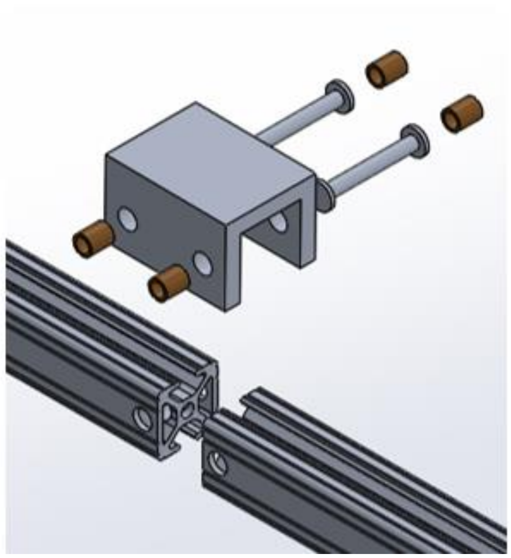


Figure 20: Exploded view of joint

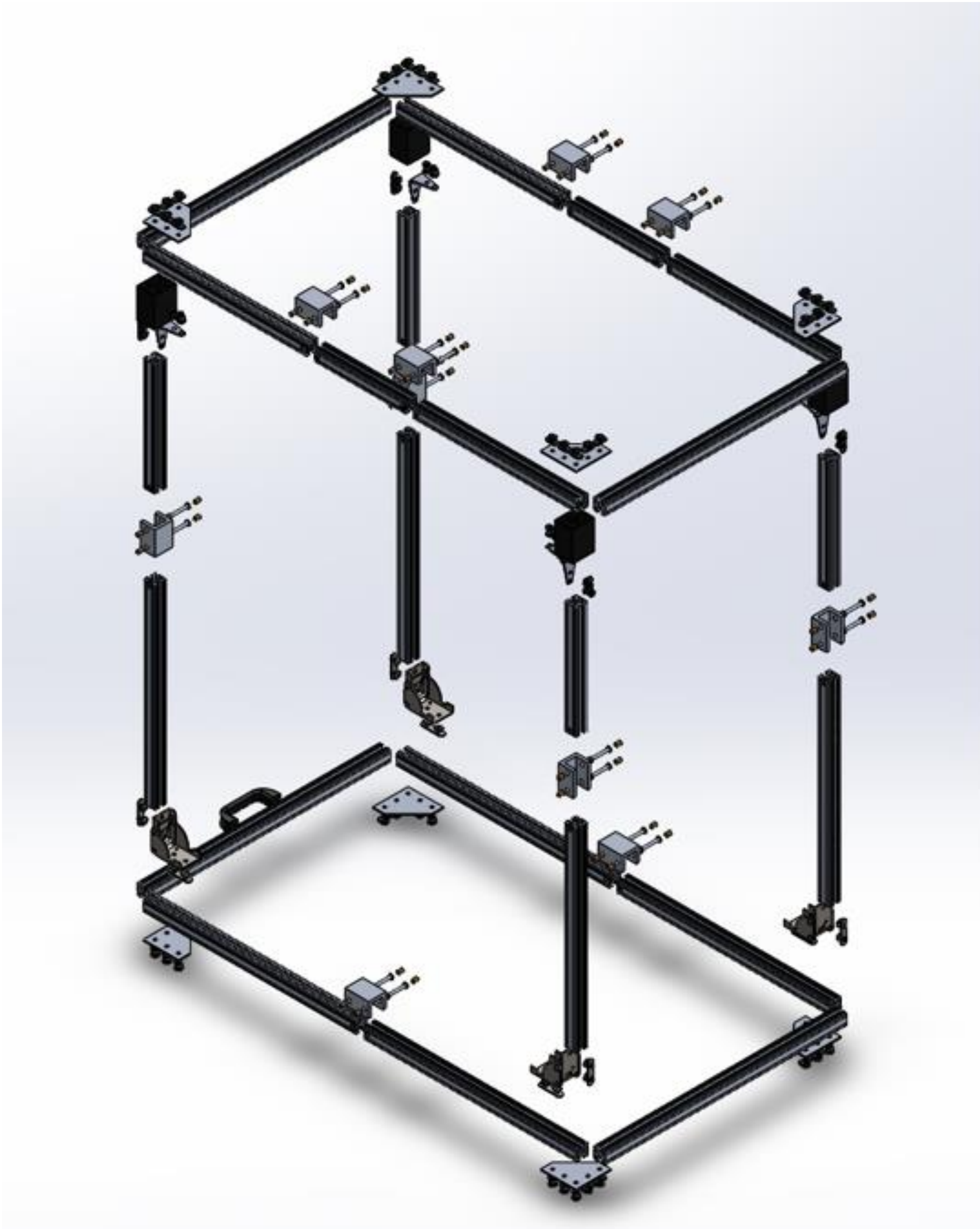


Figure 21: Exploded view of assembled design

Design Critique

All specifications were met and exceeded. The sponsor and team were both very pleased with the final prototype results. If the team were looking to redesign this prototype looking into preventing pinch points would be a first step.

In the final design the crib would need anti loosening devices, rounded corners, rubber stoppers to eliminate pinch points, and correct warning labels. The final product should also be made of a different material. The team would need to research the material more but assumes the Graco *Pack'n Play* material (hollow aluminum tubing) would be a good benchmark. T-slot aluminum presented more manufacturing challenges than it was worth. The team had to make more modifications to parts than necessary and parts slid out of the t-slot easily so it may have been more beneficial to use a material more representative of the final product.

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Appendix A
Bill of Materials

Description	Quantity	Unit	Part Number	Manufacturer	Associated manufacturing process or assembly process	Unit price ($)	Total Price ($)
1'' T-Slotted Guide Rails	6	per 6 ft	47065T209	McMaster	Cutting (Bandsaw), Drilling	19.79	118.74
90 deg Plates	8	ea	47065T267	McMaster	Fasteners	8.47	67.76
Low-Profile Binding Post, Aluminum	1	pack	93121A355	McMaster	N/A	8.23	8.23
6063 Aluminum Architectural Tube	1	per 3 ft	88935K11	McMaster	Cutting (Bandsaw), Milling, Drilling	38.20	38.20
Folding Leg Bracket	4	ea	18095A51	McMaster	Fasteners	5.72	22.88
Dual End-Feed Fastener	2	pack	47065T147	McMaster	N/A	4.29	8.58
Handle	1	ea	47065T164	McMaster	Fasteners	6.40	6.40
Zinc-Plated Steel	4	ea	1526A43	McMaster	Drilling	1.63	6.52
Steel End-Fastener	4	pack	47065T142	McMaster	N/A	2.30	9.20
.09 Aluminum Sheet	1	ea	N/A	Remnant	Cutting (Bandsaw)	13.08	13.08
3D Printing	4	ea	N/A	UM 3D Printing Lab	N/A	74.00	74.00

Appendix B
Manufacturing Plan

Most of the parts included in our prototype design will require only minor alterations, using manufacturing processes such as cutting and drilling. The inline pivots and 90 degree plates will be ordered ready to assemble with fasteners included, and will not need any additional machining. The bars will be made of t-slotted framing aluminum, and will be cut to the correct length from 6 ft. stock using the band saw set to the correct speed for aluminum (275-325 fpm). In each bar, holes will be drilled to fit the fasteners connecting the bars to the joints, inline pivots, and 90 degree corner plates. The hole locations should be measured and marked on each bar using a ruler and caliper, then drilled using a drill press at 1000 or less rpm. The holes will first be center drilled using a #4 center drill, then drilled with a size F drill bit.

The only parts that will require more advanced manufacturing are the end-to-end joints connecting the bars on the top and bottom, which will have to be cut and milled from stock material. The manufacturing plan for the joints is shown below.

Part Number: 001 Revision Date:10/22/2015
Part Name: Inline Joint
Team Name: ME 450 - Team 26

Raw Material Stock: Aluminum square stock, 2in x 2in x 3ft

Step #	Process Description	Machine	Fixtures	Tool(s)	Speed (RPM)
1	Mark aluminum stock with dimensions 0.2 inches greater than desired part length			Ruler, scale, caliper, marker	
2	Make sure that speed is set for aluminum, place material so it isn't touching the blade when machine is turned on	Vertical Band Saw			275-325 fpm
3	Turn on machine, make cut making sure to use extra 2x4	Vertical Band Saw	Wood block		
4	Place part in vise to machine ends of part. Mill the part to correct dimensions, taking several passes at 0.05 inches per pass. Turn off the spindle	Mill	Vise	¾ inch 2-flute end mill, collet	500

	and measure part with calipers				
5	Remove part from vise. Break all edges by hand			File	
6	Remove collet. Install drill chuck.	Mill	Vise	Drill chuck	
7	Find datum lines for X and Y. Move to hole locations.	Mill	Vise	Edge finder, drill chuck	900
8	Center-drill and drill the holes.	Mill	Vise	#4 center drill, F drill bit, drill chuck	1000
9	Remove drill chuck. Install collet.	Mill	Vise	Collet	
10	Place part in vise to machine centered slot in part to correct dimensions, taking several passes at 0.05 inches per pass. Turn off the spindle and measure with calipers.	Mill	Vise	¾ inch 2-flute end mill, collet	500
9	Remove part from machine, clean area and return tools to crib.	Mill			

Appendix C
Changes in Design since Design Review 4

Since the design freeze at DR4, we have not had to make any design changes to our prototype collapsible crib. Instead of achieving a perfect design “in the first shot”, our team was proactive, and built our prototype early in the design process, and we were able to complete all of our design changes before DR4. Because of this, we had adequate time to finish fabricating, and tweak our prototype frame design to function perfectly before DR5.

The only fabrication work required since DR4, was the addition of the frame leg joint sleeves. Once they finished being 3D printed, we added them to the prototype, and confirmed that the finished crib frame functioned as we intended. Additionally, we finished sewing velcro fasteners to the fabric materials of the crib so that those components could stay attached to the crib frame. We also added a velcro fastener hold the crib in its collapsed state during transportation or storage. These velcro fasteners were already included in our design strategy, and they required no machine operations to attach them to the crib frame.

Appendix D
Validation Protocol and Expectations

To meet the size requirement engineering specification, the crib needed to be smaller than 41''x29''x29.3'', with a wall height of at least 20". We measured these dimensions of the prototype with a measuring tape. First, we made sure the prototype was in its set up position, and then we measured the overall length, width and height of the prototype. Finally, we compared the measured dimension with the engineering specification. Our measured dimensions of the completed prototype are summarized in Table 4. Since we designed our prototype to accommodate a smaller age range of child, the outer dimensions for our crib prototype uncollapsed are smaller than the outer dimensions of the uncollapsed Graco Pack 'n' Play with the exception of the crib height, which we kept roughly the same to protect infant from getting their chin above the upper rail. Our collapsed design also takes up about half as much volume than the collapsed Graco Pack 'n' Play (about 3000 cubic inches), because the volume of our design (about 1600 cubic inches) is distributed into more of a "U-shape briefcase" instead of a long rectangular prism.

Table 4: Approximate uncollapsed crib dimension comparison

Uncollapsed Crib	**Length (Inches)**	**Width (Inches)**	**Height (Inches)**
Our Prototype	37.0	23.4	29.1
Graco Pack 'n' Play	40.0	28.5	29.0

To meet the engineering specification of holding babies up to 18 months of age, we checked our crib dimensions against that of a 95th percentile 18 month old. The equipment we used was a measuring tape, and a 95 percentile 18 month old dummy from the lab at UMTRI. We measured the dimensions of the dummy when it was sitting, standing, and lying with its arms stretched out. Finally we compared the measured dummy dimension with the measured dimension of the prototype. We confirmed that the measured dummy dimensions were smaller than the measured dimension of the prototype, so we conclude that we met the engineering specification of holding babies up to 18 months of age. We also placed the 95 percentile dummy inside of the uncollapsed prototype as a physical test to make sure that it fit (Figure 22).

To meet the structural and safety requirements of ASTM standard F406 for collapsible cribs, we performed the five empirical tests described in *Empirical Testing Protocol* (Page 19) and evaluated the results of this testing.

For Test 1, we first fixed the prototype to the ground with weights, and then we used a Wagner Instruments Model FDV digital force gauge with a flat threaded attachment to securely apply a force of 45 pounds downward on the prototype for a duration of 10 seconds as depicted in Figure 13 on page 21. After the test, we inspected the prototype for signs of failure, and found none. During the test, we observed that the frame handled the load well, and no components appeared to be in danger of being damaged. This test confirmed that our prototype passed this ASTM requirement.

Figure 22: 95th percentile 18 month old anthropomorphic test dummy inside of our prototype

For Test 2, we first fixed the prototype to the ground with weights, and then we used a Wagner Instruments Model FDV digital force gauge with a flat threaded attachment to securely apply a force on the crib's upper rail at a 45 degree angle as depicted in Figure 14 on page 21. During the test, it became quickly apparent that the ASTM standard was developed for a crib that folds in a different direction with a different type of hard stop. We allowed the prototype to undergo 43.5 pounds of force before stopping the test. The hinges attaching the longer rails to the shorter upper rails were not designed to handle torsion in that direction of motion, so we called off the test to prevent the prototype from failing. No part of the crib's upper rail itself deformed due to the force, and we speculate that the crib would have survived the load being ramped up to 100 pounds without failure, but we did not risk damaging our only prototype due to the limitations of our budget within this class setting. Although this test could not confirm that our prototype had passed this ASTM requirement, it did handle a load of 43.5 pounds which is greater than one factor of safety multiplied by the amount of force that a single 18 month old infant can generate on the crib in that direction.

For Test 3, we first fixed the prototype to the ground with weights, and then we used a Wagner Instruments Model FDV digital force gauge with a flat threaded attachment to securely apply a force of 30 pounds upward on the prototype for a duration of 30 seconds as depicted in Figure 15 on page 22. After the test, we inspected the prototype for signs of failure, and found none. During the test, we observed that the frame handled the load well, and no components appeared to be in danger of being damaged. This test confirmed that our prototype passed this ASTM requirement.

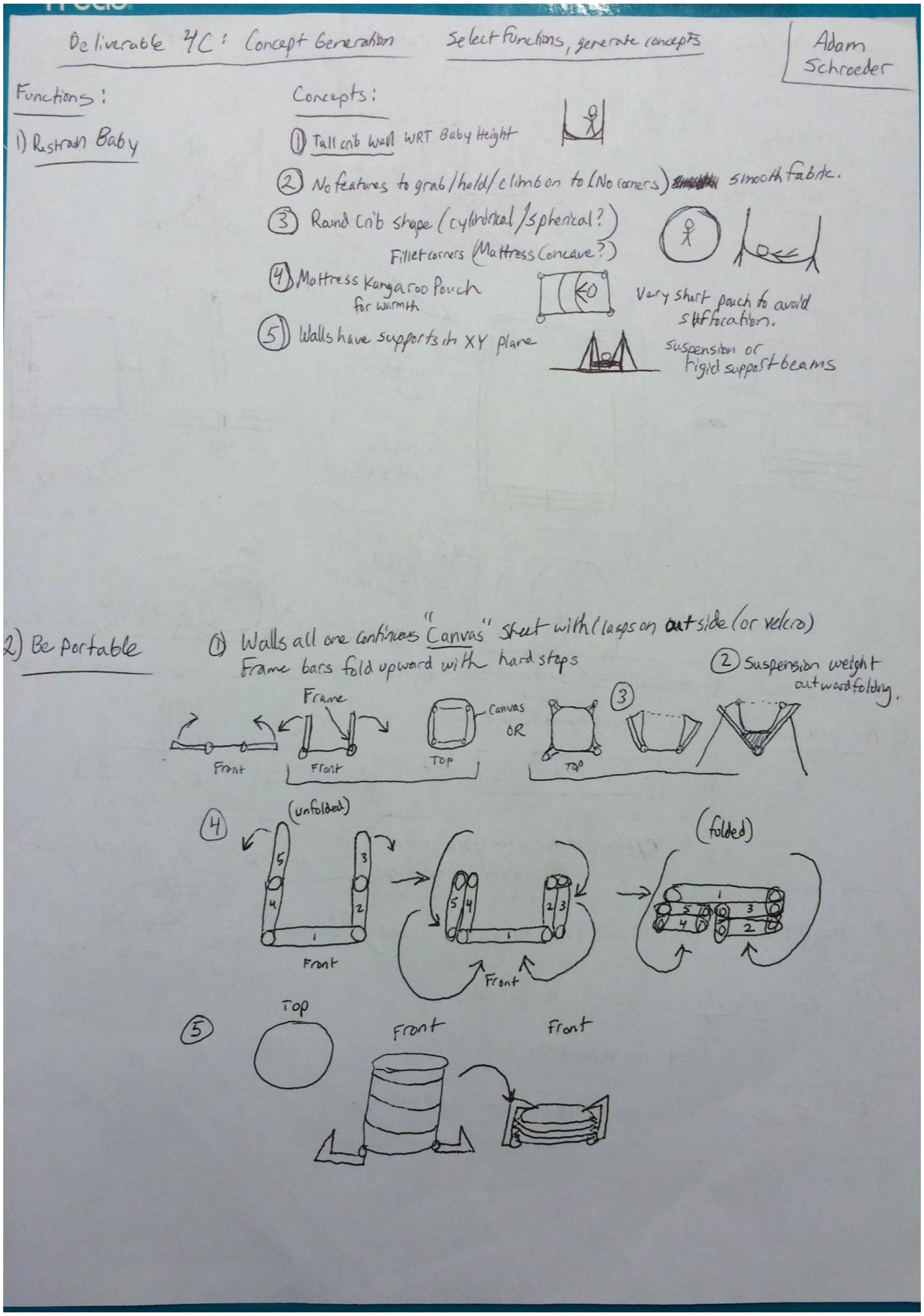
For Test 4, we first fixed the prototype to the ground with weights, and then we used two Wagner Instruments Model FDV digital force gauges with flat threaded attachments to securely apply a total force of 100 pounds downward on the prototype for a duration of 30 seconds as depicted in Figure 16 on page 23. After the test, we inspected the prototype for signs of failure, and found none. During the test, we observed that the frame handled the load well, and no components appeared to be in danger of being damaged. This test confirmed that our prototype passed this ASTM requirement.

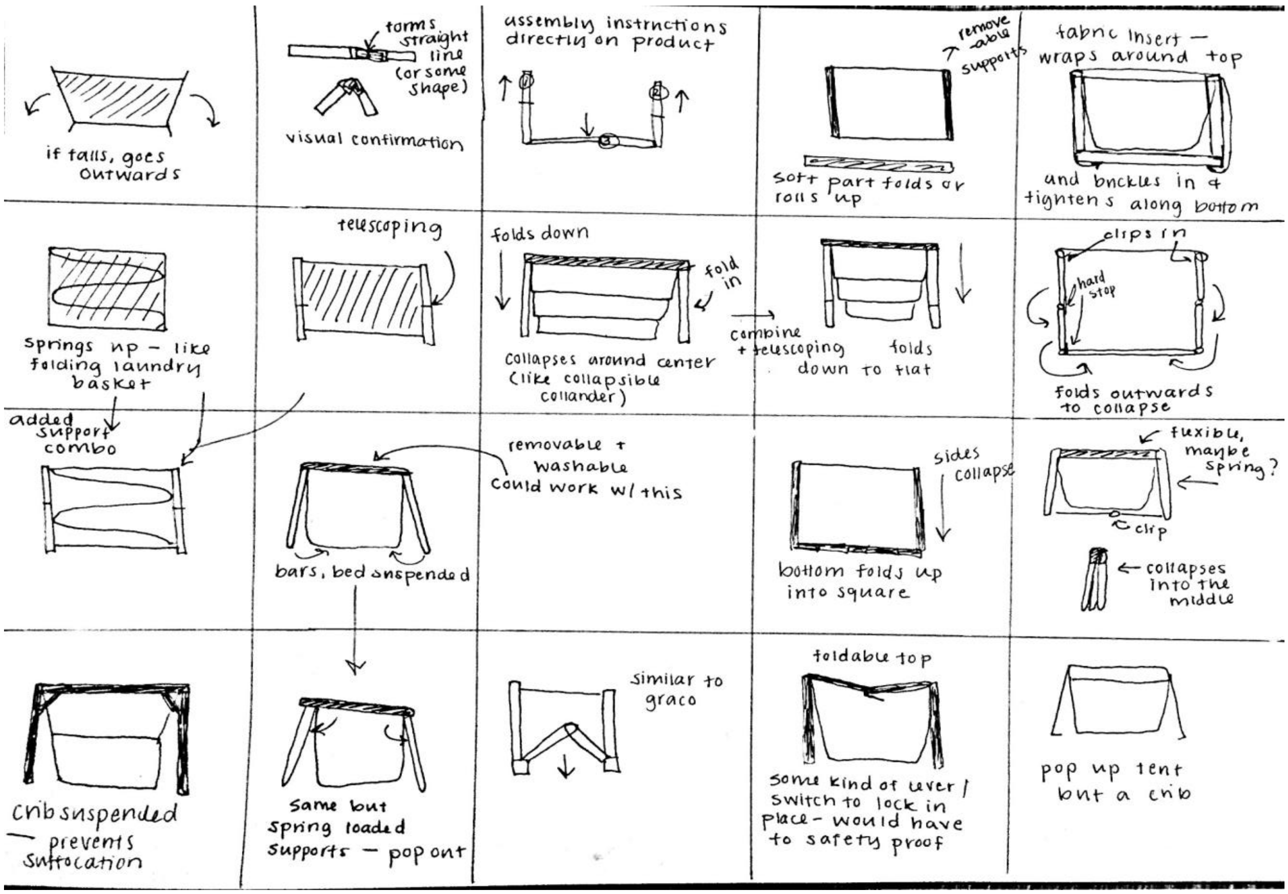
For Test 5, we first fixed the prototype to the ground with weights and secured the crib mesh walls and soft materials to the frame using velcro fasteners and ribbon loops reinforced with kevlar string. Then we used a Wagner Instruments Model FDV digital force gauge with a hook attachment to provide a pulling force of 30 pounds to all of the fabric material attachment points for a duration of 10 seconds. After the test, we inspected the prototype for signs of failure, and found none. During the test, we observed that the mesh handled the load well, and no components appeared to have separated or ripped. This test confirmed that our prototype passed this ASTM requirement.

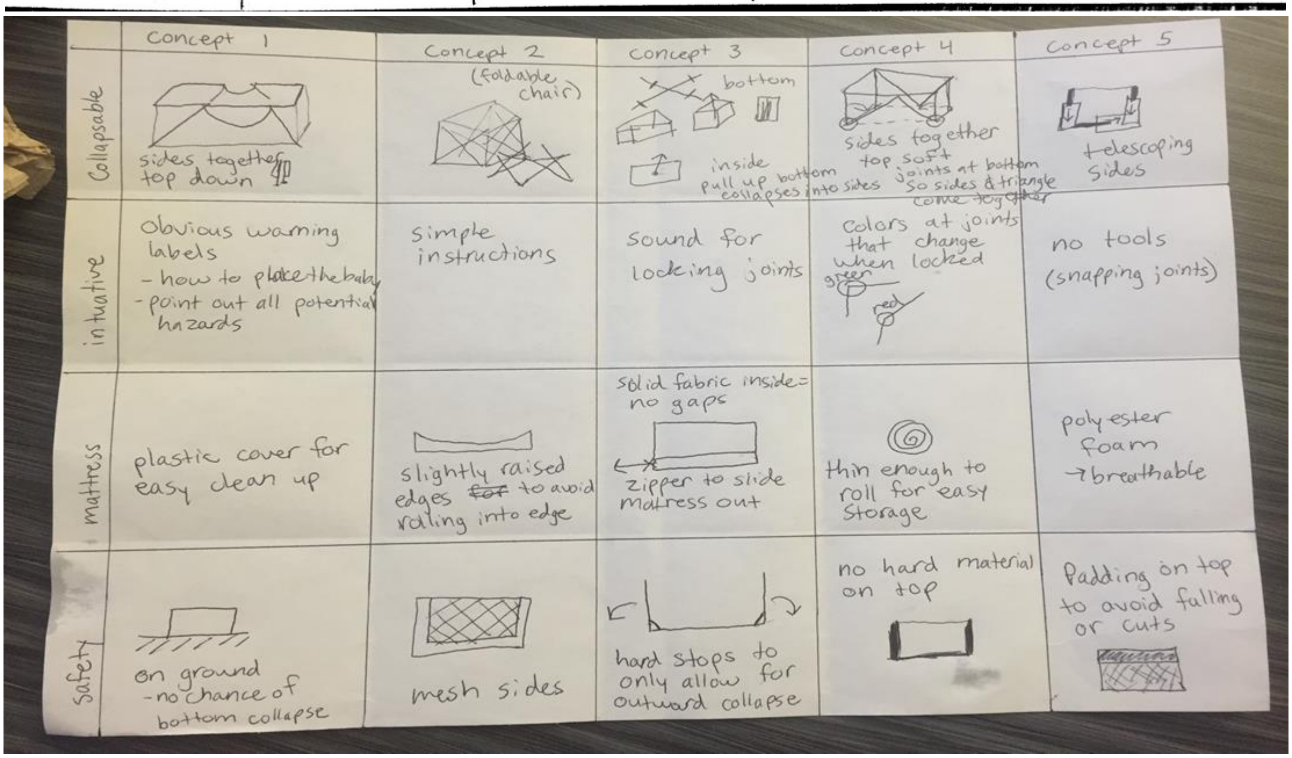
Because our task was to create a functioning prototype, and our prototype passed all of the ASTM F406 tests that were applicable to it during this stage in its design process, we conclude that this design meets our sponsor's user requirement that it be stable and safe. However, the prototype is not safe enough, or ready to enter the market for consumer use. Our task was to design a safe mechanism that improves upon the folding mechanism used on a Graco *Pack 'n' Play*. By designing and manufacturing a working prototype that also meets ASTM standards, we have far surpassed our sponsor's expectations, and have given this project the start that it needs to eventually become a safe consumer product in the future.

Appendix E

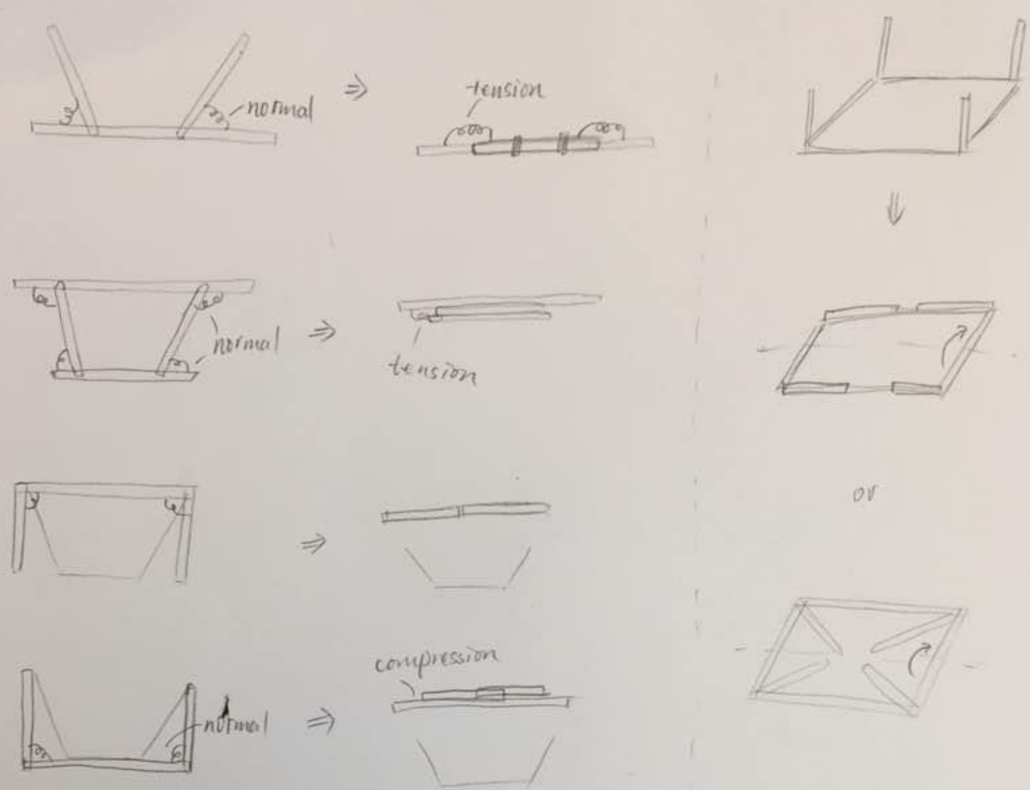
Concepts Generated




if falls, goes outwards
forms straight line (or some shape)
visual confirmation
assembly instructions direction on product
remove -able supports
soft part folds or rolls up
fabric insert — wraps around top
and buckles in & tightens along bottom
springs up — like folding laundry basket
telescoping
folds down
fold in
collapses around center (like collapsible collander)
combine + telescoping
folds down to flat
clips in
hard stop
folds outwards to collapse
added support combo
removable + washable
could work w/ this
bars, bed suspended
sides collapse
bottom folds up into square
flexible, maybe spring?
clip
collapses into the middle
crib suspended — prevents suffocation
same but spring loaded supports — pop out
similar to graco
foldable top
some kind of lever / switch to lock in place - would have to safety proof
pop up tent but a crib


Concept 1
Concept 2
Concept 3
Concept 4
Concept 5
Collapsable
sides together top down
(foldable chair)
bottom
inside
pull up bottom collapses into sides
sides together top soft joints at bottom so sides & triangle come together
telescoping sides
intuative
Obvious warning labels
- how to place the baby
- point out all potential hazards
simple instructions
sound for locking joints
colors at joints that change when locked
green
red
no tools (snapping joints)
mattress
plastic cover for easy clean up
slightly raised edges to avoid rolling into edge
solid fabric inside = no gaps
zipper to slide matress out
thin enough to roll for easy storage
poly-ester foam → breathable
safety
on ground - no chance of bottom collapse
mesh sides
hard stops to only allow for outward collapse
no hard material on top
Padding on top to avoid falling or cuts

fold linkages



comfort: use satin (smooth surface) on top of mattress

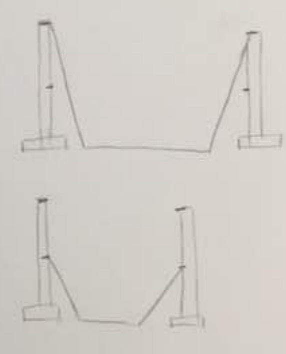
add soft hook on top to hang toys

light weight: Aluminum alloy, (hollow)

bamboo

wood.

plastic ?

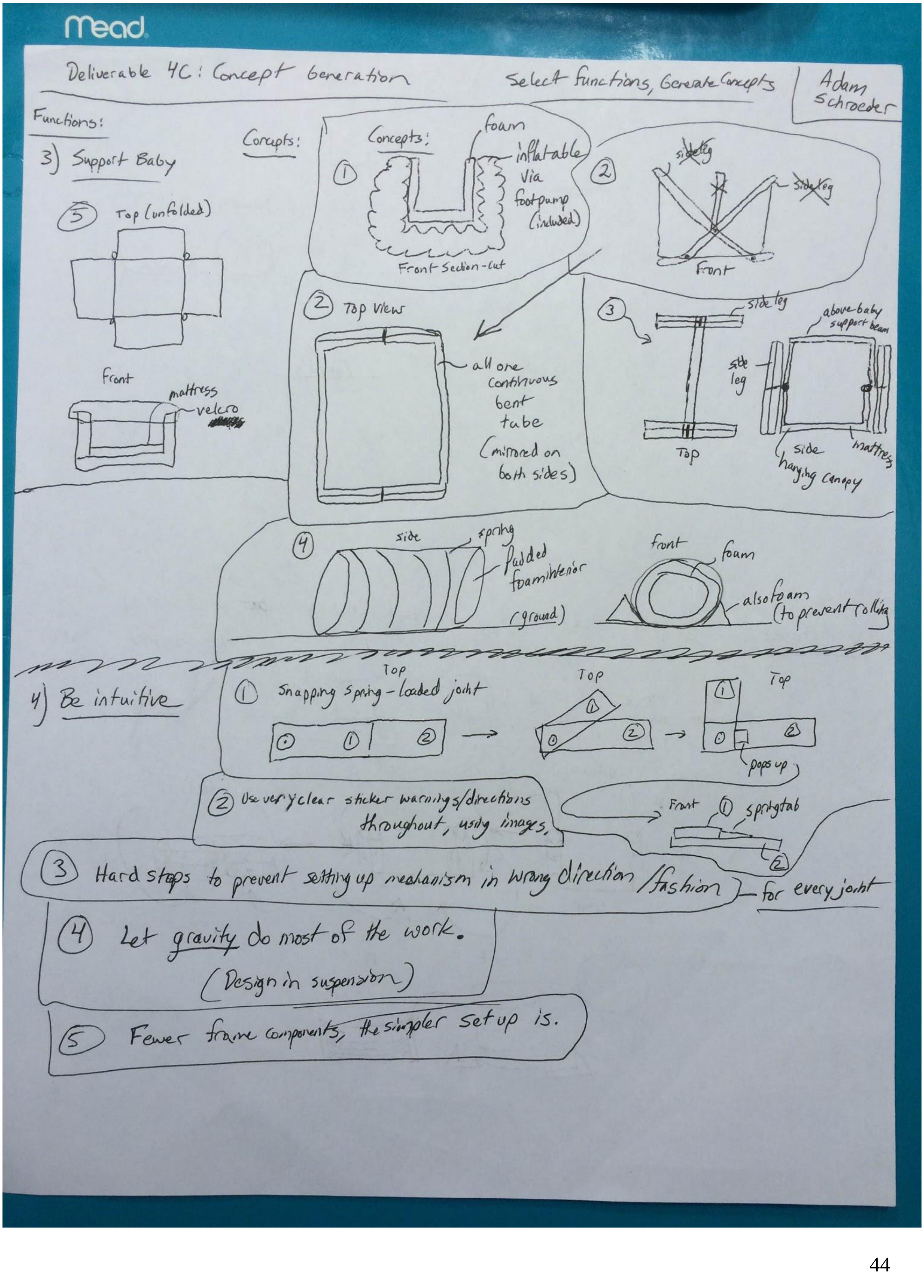


avoid suffocation: use mesh as wall

avoid laceration:

avoid falling: mattress near the ground, zipper at the wall side (outside)

a mesh at the top,


Deliverable 4C: Concept Generation
Select functions, Generate Concepts
Adam Schroeder
Functions:
Concepts:
3) Support Baby
5 Top (unfolded)
Front
mattress
velcro
Concepts:
1
foam
inflatable via footpump (included)
Front Section-cut
2
side leg
side leg
Front
2 Top view
all one continuous bent tube (mirrored on both sides)
3
side leg
above baby support beam
side leg
Top
side
mattress
hanging canopy
4
side
spring
padded foam interior
(ground)
front
foam
also foam (to prevent rolling)
4) Be intuitive
1 Snapping spring-loaded joint
Top
Top
Top
pops up
2 Use very clear sticker warnings/directions throughout, using images.
Front
spring tab
3 Hard stops to prevent setting up mechanism in wrong direction/fashion – for every joint
4 Let gravity do most of the work. (Design in suspension)
5 Fewer frame components, the simpler set up is.

Appendix F
Personal Statement (Ethical Design)

Chloe Randich:
The main focus of my group's project, to design a sleeping environment for a baby, is safety. The purpose of our design was to improve on the current pack'n'play models on the market, which can in some cases allow a baby inside to strangle or suffocate. Therefore, we considered safety as the primary design driver during concept generation and selection.

During concept generation, one of our primary goals was to eliminate the V-shaped upper rails in the Graco Pack'n'Play design, which are a leading cause of death in portable crib-related incidents, as the child can strangle if their neck is caught in the V. To prevent this type of injury, we focused on designing our frame to collapse in the opposite direction. We also designed our frame to prevent collapse into the center of the crib, and instead collapse around the edges, away from where the child would be inside. Another common incident is the frame falling onto the baby, resulting in entrapment or strangulation. One element that we did not really consider was the design of the soft material part of the crib. For our prototype we modified the liner of a Graco Pack'n'Play to fit our frame and show a complete concept, but we spent the majority of our time this semester working on the frame. For a more finalized design, we would require a breathable material for the liner, and a liner and mattress design that would comply with all regulations. We would also need to consider how the material would fall in the event of the frame collapsing. Ideally, the fabric would fall and fold away from the center of the crib to prevent the baby from moving and suffocating on the folded fabric as much as possible.

Courtney Riley:
Overall, our team kept the Engineering Code of Ethics in mind throughout the design process, and particularly focused our energy on safety given the nature of the project.

As engineers we take on the responsibility for the quality of our work as well as the safety of our products users and the public. Safety was a main design driver of our product. Some may say that the Graco Pack and Play is unethical due to the amount of risk and deaths associated with it. Our task was to make a safer portable crib and therefore a more ethical one.

We had to take into consideration the health safety and wellbeing of the public when designing our product. We created our design with back up mechanisms of safety in case of failure such as locking joints, hard stops, and a folding mechanism that does not collapse onto a child.

If our product were to be put into production we would also need to include other ethical safety items such as anti-loosening devices and eliminating any sharp edge so that a child outside of the crib could not injury themselves.

We must also disclose any potential hazard. These will be clearly laid out in the instruction manual and warning labels. We must also perform all tests by standard. We completed static testing and will only be reporting results obtained. No data can be forged or altered.

The code of ethics also states "engineers shall perform services only in the areas of their competence. " Because of this we have made it clear that we are not experts in material selection, anti-loosening devices, or fabric creation. Anti-loosening devices are a set standard that our team is not directly familiar with, we can choose material to the best of our ability but were limited for resources and manufacturability for prototype creation, we are also not sewing expert so we used a pack and plays fabric insert and have disclosed this for our prototype.

Lastly, we have made it very clear that our product is simply a prototype that demonstrates functionality and an actual child should not use it.

Adam Schroeder:
The Code of Ethics for Mechanical Engineers as determined by the American Society of Mechanical Engineers has been applied extensively throughout our team's design process for our collapsible crib product. Since the focus of our project this semester was to improve on a design to make it safer and prevent user deaths, it was imperative that our engineering analysis be ethical and thorough.

Specific aspects of the Code of Ethics that pertained to our design decisions included the following canons: "(1) Engineers shall hold paramount the safety, health and welfare of the public in the performance of their professional duties; (2) Engineers shall perform services only in the areas of their competence; they shall build their professional reputation on the merit of their services and shall not compete unfairly with others; and (8) Engineers shall consider environmental impact and sustainable development in the performance of their professional duties. [1]" While my team and I upheld all canons and fundamental principles of the Mechanical Engineering Code of Ethics, these three before-mentioned canons have examples related to them that I can easily recall.

While generating our final proposed design, my team consistently set user safety as the top priority in all discussion; we made every design change with the safety of the infant user and his/her caretaker in mind. This appeared in the design in how we chose to have the crib frame collapse outward from the center of the crib instead of toward the infant user, and the various warning labels we chose to include to meet ASTM F406 requirements, and to guide the caretaker to use the collapsible crib in a safe manner. By taking safety of the general public into consideration we upheld the first canon of the Code of Ethics.

Throughout our entire design process, my team evaluated which skills we had internally, and we utilized those skills to the best of our abilities to make a responsible design. Any time we encountered an aspect of the design that we were not trained to work with (Ex. Materials strength, child psychology), we responsibly consulted sources that knew more than us to make an educated decision. Not once did we make those decisions ourselves, claiming that we knew more than someone who had studied their field for many years. By not making critical decisions on topics we had not been educated on, my team upheld the second canon of the Code of Ethics.

The eighth canon was an important part of our design for our prototype in terms of how it was manufactured, and what will become of the crib once the user is done with it. We chose aluminum as our primary material to provide a structurally safe frame, but also because aluminum is recyclable and non-toxic to the environment. We used universal fasteners such as shoulder bolts purchased from McMaster Carr which could be re-purposed to other projects when our prototype is no longer needed. We used mostly manual manufacturing techniques to reduce cost, and to reduce the carbon footprint of how our prototype was constructed. By considering the environmental impact of our prototype, we upheld an ethical design process as we pursued a product that met our sponsor's needs.

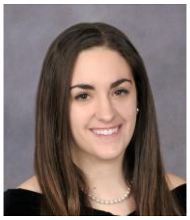
Citation:
[1] National Society of Professional Engineers, 2007, "NSPE Code of Ethics for Engineers".

Qianyu Sun:
The Code of Ethics for Mechanical Engineers has been applied seriously to the design process.

Our project is a safety sleeping environment for baby, so we considered safety as our first priority in the selection of the final proposed design. We learned many accidents of the cribs from our sponsor, Kids in Danger's website. Some accidents were caused by the V shape bar at the top of the cribs, which could suffocate the baby when it is not set up correctly; some were because of the large holes in the side wall of the cribs, which could stuck the baby inside and cause injury; some were caused by mattress, babies could get suffocated when they were facing down to the mattress. So when we were brainstorming about different ideas of the structure of the crib, we tried to avoid using a V shape bar at the top of the crib to avoid possible suffocation caused by it. We also avoid fences at the side wall, to make sure that the baby won't be stuck in the space between the fences. So we agreed on using a mesh side wall in our proposed design. We also chose to use breathable material, such as polyester foam, to make the mattress, so that the baby won't be suffocated when facing down the mattress.

We also tried our best to enhance the welfare of the user, which would be the low income families according to our sponsor. We didn't include any fancy functions that the Pack n' Play has to minimize the cost of the crib. We also designed our crib to be strong and stable enough so the user could keep it for their future babies.

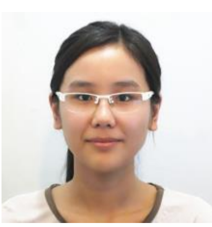
Report Authors



Chloe Randich, randich@umich.edu, Safety Officer & Facilitator
Chloe is a senior pursuing a BSE degree in Mechanical Engineering with the International Minor for Engineers and a manufacturing concentration, projected to graduate in May 2016. Outside of academics she is the Vice President of Standards for Phi Sigma Rho Engineering Sorority and participates in Dance Marathon. She completed an internship during the 2015 summer at General Motors in the Manufacturing Engineering department working with a

Courtney Riley, ceriley@umich.edu, Sponsor Contact
Courtney is a Mechanical Engineering student projected to graduate in May 2016. Aside from academics, Courtney serves on the Women in Science and Engineering Advisory Board and is the Vice President of Collegiate Affairs for Phi Sigma Rho Engineering Sorority. Courtney was a rehabilitation engineer intern at Human Engineering Research Laboratories during the 2014 summer. She most recently completed an internship at Nissan North America in the Total Customer Satisfaction and Quality Product Management department. With her strong communication skills and experience working with federal standards she was chosen to be our team's sponsor contact.

Adam Schroeder, feqma@umich.edu, Portfolio Manager
Adam is a senior pursuing a BSE in Mechanical Engineering and a Multidisciplinary Design Minor. He has previously served as the head of the brakes division on the Michigan Formula Hybrid SAE Race Team, and is currently an elected senator on the Michigan Engineering Student Government on the Student Life Committee. Adam has completed a total of 5 different internships and co-ops during his college career, and has experience working in manufacturing settings, automotive design/evaluation, and investigative engineering consulting. With his organizational skills, and experience with timeline-based project management, Adam was chosen to be our team's Portfolio Manager.



Qianyu Sun, qianyus@umich.edu, Treasurer
Qianyu is a senior student majoring in Mechanical Engineering, projected to graduate in May 2016. She is an international student also pursuing a BSE in Electrical and Computer Engineering at Shanghai Jiaotong University. She was involved in automotive catalyst research for Ford and titanium nanotube research for biomedical applications. She was previously a member of the Dare to Dream project for AIESEC (International Association of Students in Economic and Commercial Sciences). She also had an exchange experience studying at the Technical University of Berlin. She has been assigned the Treasurer role on our team.