

Safe Sleep for Baby Final Report

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Overview, Design Problem

Each year, approximately 3,400 infants in the U.S. tragically die unexpectedly during sleep, a statistic worsened by the unregulated use of unsafe sleep products by consumers. These products, particularly those with improper sleep surface inclinations, pose serious risks like falls, pinching, and asphyxiation due to bedding obstruction. Despite recalls, educational initiatives, and regulatory efforts such as the Infant Sleep Product Rule, unsafe sleep products persist in homes, second hand markets, homeless facilities, and ongoing production. Our project sponsor, Kids in Danger (KiD), is dedicated to establishing and enforcing safety standards for infant sleep products. We've identified a critical need in the design of bassinets, as the homeless and displaced populations of caregivers and their infants are subject to harsh, dynamic conditions, inadequate shelter and limited access to essential resources. Low-income households lack access to affordably portable products with essential safety features to mitigate risks associated with unsafe sleep. Infants sleeping on welfare office floors and enduring unsanitary hotel stays underscore this vulnerability, highlighting the urgent need for a portable, affordable solution like our *Backpack Bassinet*.

Requirements, and Specifications, and Verification of Selected Concept

KiD aims to utilize our efforts to communicate standard efficacy and enhancement. Given the problem context, product **SAFETY** is the highest priority. The Backpack Bassinet must adhere to ASTM's Bassinet Standard, meeting detailed testing protocols for safety, stability, durability, component sizing, and sanitation. We've verified our product's safety specifications through strategic material and geometry selection and static analysis of structural components like folding legs and covers, tested under various everyday use scenarios. Stakeholder engagement and sponsorship insights have shaped the requirements for an enhanced user experience. The solution must prioritize **USABILITY** and **PORTABILITY**, ensuring easy transfer of the baby in/out of the product and facilitating travel and relocation. The Backpack Bassinet provides a maximum sleeping space of 30"L x 18"W x 28"H for a 0-5 month old infant, and folds into a portable configuration of 24"L x 18"W x 9"H (similar to carry-on bag sizes compatible with public transportation storage spaces), verifiable by CAD inspection. This is achieved by a low-cognitive, single point of actuation to engage 4 spring pins in the product frame. The final physical prototype meets these dimensions and weighs 8.5 lbs, significantly lighter than the targeted 15 lbs total product weight. Although the estimated total cost is \$107.49, slightly exceeding the \$100 **AFFORDABILITY** requirement, this is based on prototype development and could likely be reduced below \$100 after implementing mass manufacturing processes.

Critiques and Conclusions

Given the high ethical and ergonomic demands in designing an infant sleep product, high amounts of interest lie in assessing product usability using the weighted CAMI dummy prescribed in ASTM tests. We recognized that caregivers are experts in reenacting common loading cases, and providing adequate feedback concerning ergonomic comfort, apparent safety features/failures, and how our presentation of these factors impact their decisions as a consumer. Given more time in this course, stakeholder engagement and usability testing would induce the most development towards our product's ability to reduce the occurrence of *preventable* death among infants.

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Introduction

The primary objective of this project is to design and build a functioning prototype of a safe, portable and affordable baby sleep product for children between zero and five months old that meets safety guidelines outlined in the CPSC's Bassinet Standard, which will be discussed later in this section. While safe and portable products already exist in the market, the distinguishing feature of this product lies in its affordability. Existing products that meet all safety and standards and are portable are costly, restricting their accessibility to caregivers who possess lower budgets. The intended users of the product include not only caregivers, but also baby daycares and homeless shelters. These groups likely have limited living space. As such, one of our goals is to develop a product that can be packed up and stored away quickly and multiple times per day to free up space when needed.

Background







The sponsor for this project is a non-profit organization called Kids in Danger based in Chicago, Illinois. The company was originally founded by a couple that lost their child due to unsafe sleeping conditions (Kids in Danger, 1998). The goal of this organization is to advocate for safer products and more childcare education. They provide a list of safe sleep guidelines and have worked with previous ME450 groups in the past to understand the areas in these guidelines where safety hazards in infant sleep products are not sufficiently captured. Giving this project to an ME 450 group allows young engineers to undergo the design process for a safe sleep product and potentially find new guidelines that should be included in the standard. However, these new guidelines are not the primary goal of this project. Instead of approaching the project from a testing view to evaluate the current standard, the project will be completed from the standpoint of a product designer and will have to conform to the ASTM bassinet standard. This standard provides the criteria used to create the requirements and specifications and ultimately forms our design decision.

Benchmarking

Safe sleep products are immensely important due to the number of infants that die due to Sudden Infant Death (SID) each year. A large number of these deaths are caused by unsafe products that do not meet the current sleep standards (Pike, 2009). For example, before April of 2019, Fisher Price sold a product called the Rock 'n Play Sleeper that placed the infant user at a 30° angle. This incline caused babies to roll forward onto their stomachs and suffocate. It also did not follow the American Academy of Pediatrics Guidelines by having loose fabric that increased the risk of suffocation. This product resulted in at least 8 infant deaths and possibly many more (US Consumer Product Safety Commission, 2019).

To aid in the design of a product that is as safe as possible, further benchmarking was performed on additional previously recalled products as well as products that are currently on the market. Table 1 outlines this benchmarking, discussing both failed and recalled products.

Table 1. Various current and recalled products with descriptions of the product and notes about how it informs our problem understanding. Additionally, a previous ME450 project for the same sponsor is listed, though they developed a play yard similar to the Graco Pack ‘n’ Play instead of a bassinet.

Current		
 (Guava)	 (Soobaby)	 (Baby Delight)
<p>Very portable, converts to a play yard, waterproof mattress, side-to-side rocking</p> <p>Combo device increases cost and increases the number of standards and regulations that need to follow</p> <p>Upper end of extra features, can ask people what they would remove to decrease the cost (Lotus, 2023)</p>	<p>Not super portable, adjustable height, detachable side, optional rocking</p> <p>Closer to our price point, shows us what features we might want to aim for (Amazon, 2023)</p>	<p>Very portable, no legs, no carrying case, no side-to-side rocking</p> <p>Nothing spring loaded in the set up (reduces cost and prevents injuries)</p> <p>Very much the lower end of what is usable, can use this as a starting point for adding extra features (Amazon, 2023)</p>
Recalled		Previous ME450 Design
 (2019)	 (2001)	 (Randich et al., 2015)
<p>30 degree incline causes huge increase in infant deaths (low blood O2 saturation and babies can roll over)</p> <p>Loose cloth creates suffocation risks (U.S. Consumer Product Safety Commission, 2019)</p>	<p>Children and adults reported pinching their fingers (cut fingertips, infections, and broken fingers)</p> <p>Users are both the caregivers setting it up and the babies sleeping in it</p> <p>Consider visual or auditory cues to indicate product configuration (U.S. CPSC, 2001)</p>	<p>They designed a play yard, not a bassinet</p> <p>Very portable, especially for the size</p> <p>Might be able to give us some mechanism ideas later, especially with its collapsible but rigid joints</p>

Sources

The following section consists of a list of the most influential sources of information for this project and how they have influenced the design process.

Standard Consumer Safety Specification for Bassinets and Cradles: This standard serves as the primary source of information on how to create a safe sleep product. In order for a product to be put on the market, it must fulfill all the requirements and pass all the tests stated in this standard. Examples of these requirements include a maximum incline, a minimum side height of the bassinet walls, a maximum rocking angle, and range of allowable mattress thickness. The testing procedures within the standard cover statics, stability, torque, tension, folding, mattress flatness, sidewall strength, rocking angle and more. The standard contains in-depth descriptions of how each of these tests should be performed and what materials are necessary to perform it correctly. The standard also contains sections about best practices for warning and labeling the product (ASTM International, 2022)

KiD Safe Sleep Guidelines: This is a resource page found on the Kids in Danger website. They have worked with doctors and various other experts to build a list of safe sleep habits for caregivers to reference. This includes an instructional video and an explanation of the ABCs of safe sleep. (Alone, Back and safe Crib). This page also provides a list of recalled products and current products they recommend caregivers buy (Kids in Danger, 2023).

Dr. Jonathan Midgett: This man works at the Consumer Product Safety Commission and has provided a wealth of knowledge for this project. He has worked with KiD before and was provided as a resource by the sponsor. Dr. Midgett provided more information on many of the requirements stated in the standard and provided the team with techniques on how to use the standard to inform design decisions.

AAP-Updated 2022 Recommendations for Reducing Infant Deaths in the Sleep

Environment: The American Academy of Pediatrics provides a list of recommendations for safe sleep. This list applies to children under one year old and contains extensive explanations for each recommendation. In the context of this project, this list can be used to determine how the product will be used and what environment it should be used in. For example, the AAP recommends the babies should sleep in the same room as the caregiver but in a separate sleeping area. This implies that the bassinet should fit into a room that already has a full sized bed in it (Moon et al. , 2022).

Caregiver Interviews: While our primary stakeholder target consists of housing insecure caregivers, we interviewed a broad range of caregivers to establish a range of common user preferences in order to make the product appealing to as many people as possible. New mothers who have recently used a bassinet or are about to start using one have provided first-hand information about the benefits of the current products and what features they wished these products offered. They have commented on pricing and the safety of current products and mentioned attitudes towards specific features. For example, we have gotten mixed reviews on if rocking is a necessary feature to incorporate into our design and have decided that the cost of implementing rocking outweighs the potential benefits of adding this feature.

Recalled/Current Products: As seen in the *Benchmarking* section, other products are a large source of information for this project. They provide insight on what features are good and what features should be avoided. They can also impart design ideas.

Design Process

While developing the scope for this solution, we established the process used to design the solution. Stage-based design process models like the one shown below were advantageous in the context of our class because they provide nice checkpoints that can line up with the prescribed design reports. The main drawback of stage-based models is that it can be hard to reevaluate requirements or specifications late in the process if new information becomes available and changes our problem analysis. This difficulty emerges from the fact that iteration is not encouraged in this design process as it is in others. This process does not give the option to move back to the exploration process and change our problem statement. Throughout our design process, we found it necessary to regularly circle back to the “exploration” section when talking to new caregivers and potential users. Due to the step-by-step nature of the stage-based design, our process might not have been able to change with those new discoveries from new stakeholders.

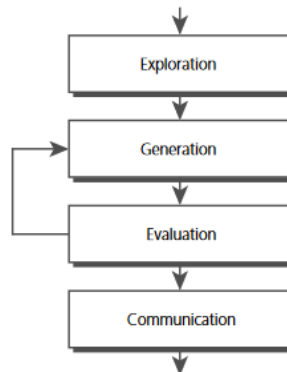


Figure 1: Typical stage-based design process, from Cross’ model of the design process (Cross, 1994)

For this project, we used the below design process model. It was still largely stage-based, but provided more cyclical elements that allowed for redevelopment and maturation of our problem analysis, especially early on in the process while working on conceptual design.

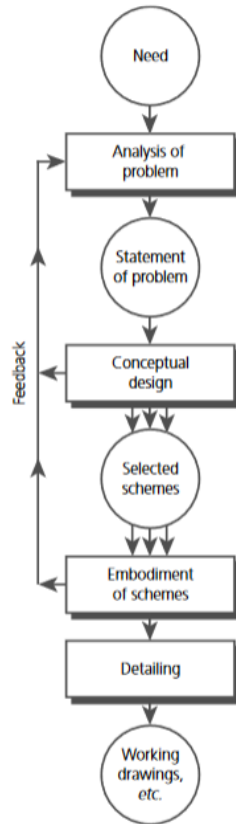


Figure 2: Our selected design process. The feedback after generating concepts and developing them allows us to mature our problem understanding while developing the solution after engaging stakeholders. (French, 1999)

This process is very similar to the one introduced in class, mostly by being stage based while having cyclical elements. The one introduced in class had cyclical elements linking almost every stage in the process, leaving a possibility to go back to the start and reevaluate the need based on the realization of the original solution. Due to the limited timeframe of this course, we were not able to completely reevaluate once our final project was fabricated. There was not enough time to cycle through multiple prototypes as we would have liked. However, mock prototypes and testing still provided similar reevaluation opportunities.

Throughout the design process, we employed several stages shown in Figure 2. After identifying a market need for a cheap, portable, and affordable bassinet, we wrote a problem statement and formed a list of requirements in the Analysis of Problem block. Throughout the conceptual design phase, we generated many design concepts and often returned to the Analysis of Problem block through the feedback loop shown in Figure 2 to update our requirements such that they would more accurately represent our solution. These requirement updates were made due to new information learned through our exploration of the design space and feedback gained from interactions with stakeholders in which we'd demonstrate possible design concepts to them.

Stakeholder Analysis

Cultural, social, and environment contexts significantly impacted the design of our portable bassinet. Before we could analyze those factors, we sought to gain a deeper understanding of the stakeholders involved in this project, especially those that would feel the greatest impact from the design decisions that are made in the development of our product. The figure below summarizes the stakeholders of this project and separates them into primary, secondary, and tertiary stakeholders.

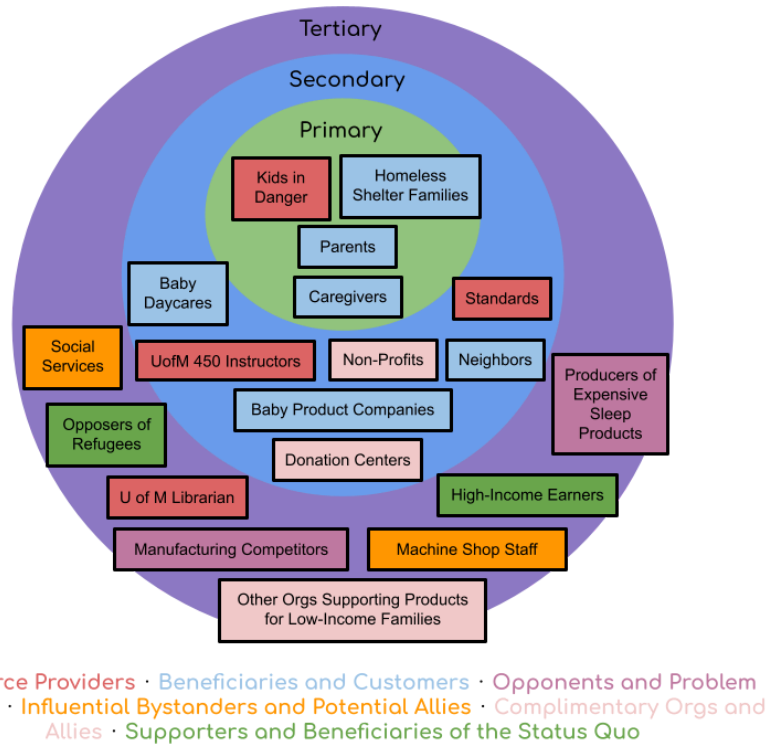


Figure 3: Stakeholder map for this project. Many of the primary and secondary stakeholders for this project are various customers of the product. The notable exception is our sponsor, Kids in Danger.

The following subsections explore in more detail some of the stakeholders that are boxed in the figure above. These stakeholders had the biggest impact on the development of requirements and specifications for this project. These requirements and specifications will be discussed in more detail in the following section.

Kids in Danger: The project’s sponsor was a source of technical expertise and gave our group several connections that provided additional insight into standards and design considerations. They also provided us with several design criteria that we translated directly into requirements and specifications, including the maximum cost of our prototype.

Homeless Shelter Families: The primary audience for our product is low-income families, specifically those who stay in homeless shelters. Research revealed that many shelters lack sufficient space to house all of the families that need them, forcing them to sleep in locations that are in violation of city policies (Little 2022). Within homeless shelters, these products may be owned either by the shelter or by the families. For scenarios where the shelter owns these products, it can provide some flexibility in configuration of their spaces and provide easy storage when they aren't needed. If the families own them, they may want to only have this set up when they need it due to a lack of space in the sleeping area.

Caregivers: In the absence of direct interaction with families in homeless shelters, these stakeholders provided input about needs and desires in a child sleep product through interviews. For example, they provided insight on the level of importance of designing a product with rocking capabilities. Their feedback was also converted into several requirements and specifications, including the maximum portable dimensions of the product that would be desirable.

Baby Daycares: In contrast to caregivers, who are more individualistic stakeholders, daycares are examples of users who operate in a more communal environment where many different infants may be using the same child sleep product. As such, our product needed to be sanitizable and durable so that it can be used safely with many different infants.

Standards: Standards have been established by the CPSC to minimize the risk of deaths and injuries associated with child sleep products. To ensure that our product is as safe as possible, we adhered to all guidelines listed in the CPSC Bassinet Standard, several of which we directly translated into requirements and specifications, including requirements surrounding stability and durability.

To establish the broader context that would influence the design of our product, we needed to first analyze how various stakeholders would be impacted, either positively or negatively, by our product. All target end users, including caregivers, baby daycares, and homeless shelters, would be affected positively by the development of a low-cost-portable, and safe bassinet as a result of them having an alternative to the more costly portable bassinet options on the market. On the other hand, the development of such a product may impact other groups negatively. One group that may experience negative impacts associated with our product is producers of more expensive infant sleep products. These groups often take advantage of caregivers who have trouble sleeping with a young infant in the household (Frankel, 2021). If we provide a product that has a lot of value through its safety and portability features for its cost, these sleep-deficient caregivers may be less likely to purchase the expensive infant sleep option, which could lower business for these producers.

Negative impacts aren't limited to specific companies or users; they can also be felt on a broader scale. The affordable nature of the product may incline some users to trash the product after they have finished using it rather than attempt to donate or reuse it. That, combined with the fact that for many individualistic users, the product will only be used for about five months, the time it will take for an infant to outgrow the product, will likely result in a lot of waste associated with the product. An excessive amount of waste, especially poorly managed waste, can contribute to pollution, affecting whole communities negatively. These impacts underscored the need for a design that could be easily and cost-effectively repaired as the ease of repairability overpowers the benefits of disposing of the product.

Social Impact

Given the previous descriptions of the key stakeholders and the potential positive and negative impacts of our project on those stakeholders, the social impacts of the project could be analyzed further. The problem itself contains a few social aspects worthy of consideration. Within local communities, the lack of safe, portable, and affordable baby sleep products on the market can create unsafe and unsecure living conditions, as caregivers may be unaware of the potential dangers associated with their baby sleep product. Part of the reason for designing this product is to promote features in our design that address unsafe aspects of products on the market, like pinch points and suffocation hazards. Additionally, there aren't rigorous mandatory standards in place that require manufacturers to test their nursery products for safety before they are sold (Kids in Danger, 2023). This lack of transparency about the potential dangers of their products is another social aspect contributing to the problem. While our product adhered to all standards, we attempted to guard against misuse and other unsafe practices that are not covered by the standards, allowing us to investigate how these additional factors change the design space compared to a strict following of the standard.

Our sponsor ranks both social impact and education highly. According to the Kids in Danger website, their mission is to “save lives by enhancing transparency and accountability through safer product development, better education, and stronger advocacy for children.” Their emphasis on education is evidenced by their creation of the KID Design Safety Toolkit, an online course that provides children's products companies information on designing, developing, and marketing products more safely. This toolkit, along with their outreach efforts that include Safe from the Start, an initiative to reach families and caregivers with important product safety information, also demonstrates their commitment to creating social impact in the form of safer communities for infants. Through their status as a non-profit organization and their desire for us to create an accessible product for a wide range of people, including low-income caregivers, it's clear that profit is a low priority for our sponsor.

Our sponsor's high ranking of social impact relative to profit affected our design decision-making. The executive director of our sponsor, Nancy Cowles, stated that consumers don't always use a product the way a designer intends it to be used. This meant that when designing the product, our team needed to regularly view our design from the perspective of a

potential end user to discern how certain aspects of the product may be misused. We had to ensure that all aspects of our product were as intuitive to use as possible. Decreasing the amount of uncertainty in how an end user will interpret the correct use of our product will lead to positive social impact by decreasing the prevalence of potentially hazardous uses of the product in communities.

Sustainability is at the forefront of many design processes and plays a central role in the design decisions we make. To increase the sustainability associated with disposal of our product, we designed it to be easily disassemblable so that individual components can be recycled or reused. Similarly, designing a product that can be assembled by a user easily allows for more users to obtain replacement parts in the event that a part of their product breaks. In these situations, having the ability to replace specific parts rather than having to replace the whole unit decreases the amount of parts that manufacturers must produce, thus decreasing the amount of pollution associated with this product that manufacturing facilities generate.

Requirements and Engineering Specifications

The process of determining the requirements and specifications for this project was heavily research involved. The initial meeting with the sponsor provided a great starting point. Following that meeting, the team dove into the bassinet standard. This provided a specific set of requirements that are necessary for the product to be safe for children. The sponsor provided the other major requirements outside of safety, namely portability and affordability. Through further interviews with Jonathan Midgett and current caregivers, these major requirements were validated and specified. We learned where the gaps are in the current market for baby sleep products and used that information to create specifications. Other products are not targeted towards low-income families and their producers aren't worried about making the product simple. Many of the competitors have added features that increase the cost of the product. For this project, the goal was to keep the design features simple and focus on what was most important to the sponsor and future users.

The most important requirements are the requirements related to safety. These included stability, durability, and regulation size. There are requirements spelled out in the standard and further described in the testing portion. This group was the most important because without these requirements, the product would not be able to enter the market. Additionally, failure to satisfy these requirements would violate the morals of Kids in Danger, who advocate for safe sleep products. The portability and affordability of the product are the next most important requirements. Both of these requirements steer this product towards the target audience of low-income families within homeless shelters, since these products may be owned either by the shelter or by the families. For scenarios where the shelter owns these products, it can provide some flexibility in configuration of their spaces and provide easy storage when they aren't

needed. If the families own them, they may want to only have this set up when they need it due to a lack of space in the sleeping area. The product could get to the market without these requirements so it is not as important as the safety requirements, but they are still important per the sponsor's instructions and without the affordability requirement the project would not stand out and fill a gap in the market. (ASTM International, 2022)

Expanding from these important targets, the safety requirements (stability, durability, washable and regulation size), portability, and affordability of the product were necessities in this design. The project would not have been successful unless all of these requirements were fulfilled and tested. The remaining requirements like intuitive use, and ease of assembly were less essential in the design. They were not necessary for the success of this project. Ideally, if one of these requirements was not satisfied, it would not result in any deaths, unlike failure to satisfy one of the safety requirements. The ease of assembly requirement was intended to separate this product from others on the market so caregivers were more likely to buy it.

Due to the fact that a bassinet is the main product size, the Standard Consumer Safety Specification for Bassinets and Cradles must be followed. This was where the safety requirements for the bassinet came from. This standard also incorporates Chapter 16 of the Code of Federal Regulations on infant sleep products. Both of these pieces of literature have been important in the development of this project statement and the requirements and specifications. This is the bare minimum of what the product needs in order to keep children safe, which was the number one priority of our sponsor and this team.

The following table contains the requirements and specifications for this project, as well as the justification and verification for each. The justification section provides the reasoning for each requirement and the sources that each came from. The verification section explains how the specifications were tested using measurements and computer analytics.

Table 2. Safe sleep product requirements and specifications			
Requirement	Engineering Specifications	Justification	Verification
Portable	Fold for convenient storage on buses/other public transport Folded: 24"L x 18"W x 9"H Weighs < 15lbs	The sponsor desires a portable sleeping product that can fold up for easy relocation (Cowles, 2024) (Guava Bassinet, 2023) (Sperry, 2024)	Use the folded dimensions in sketch or CAD to ensure it fits within the space stated in the requirement
Affordable	Price is < \$100	The sponsor wants the product to be available to low income families and possible homeless shelters. (Cowles, 2024) (Baibourine, 2024)	Calculate production costs, add profit margin, and determine if that was within the spec
Usable by newborns and young infants	Must hold babies 0-5 months old Sleep space is 30"L x 18"W x 28"H	The product is designed to provide a safe sleeping space for infants across a broad age range.	Use a weighted dummy that is the same size as a 0-5 month old and put them in the product

		(Cowles, 2024) (Chicco LullaGo, 2024)	Measure the sleep space sketch in CAD, use modeled babies to ensure they would fit.
Stable when used during sleep	Sustain 23lb angled topping load for 10s	Crucial safety feature, ensuring caregiver confidence in product stability (US Consumer Product Safety Commission, 2019) (Kids in Danger, 1998)	Use the description in the bassinet standard, created a force mode Conduct free body diagram analysis
Durable when in use and over time	Sustain a weight of 54 lbs for 60s Sustain 156 washes	Product should endure child growth and be reusable for subsequent children. Approximately 2 years. It should be washed at least twice a week for that time. (US Consumer Product Safety Commission, 2019) (Adoptation, 2023)	Conduct free body diagram analysis Determine the fabrics and other materials used can sustain this amount of washes
Regulation size	Mattress thickness < 1.5” Space between mattress and wall < 0.5” Side height 7.5” above mattress < 10° incline of mattress	The standard for Bassinets and Cradles specifies these requirements and specifications. If our product does not meet these measurements then we will fail the testing. (US Consumer Product Safety Commission, 2019) (Midgett, 2024)	Measurement tools within CAD or sketches can be used to verify each of these dimensions
Easy to assembly	< 5 steps (step is defined as one movement with up to 2 pieces of hardware being added/subtracted to the product)	If the product is too difficult to reconfigure then the “portable” aspect can’t be used to describe our product (Cowles, 2024) (Guava Bassinet, 2023)	Document the steps necessary to reconfigure the bassinet
Intuitive to use	There is only one way to build the product that has high effectiveness, low cognitive effort and strong feeling of fluency. A <i>click</i> or auditory cue to show each step was done correctly	If the product is used incorrectly then there can be dire consequences for the child. We need the product to be used correctly without extra instruction. (Cowles, 2024) (Reinhardt, 2023)	Have 10 people who know nothing about the device put it together. We can use students in our section.
Washable	Wipe clean food grade material for sleeping surface Machine washable Passes the wipe test and tape test	If the product is to be used at a homeless shelter then the product should be sanitized to keep diseases from spreading to different children using the same product. (Cowles, 2024) (Adoptation, 2023)	Use a material that has been graded for food and already evaluated that way. Compare to the federal surface finish regulation Test with machine washing 20 times to make sure it doesn’t fall apart.

Portable: There is a strong need for sleep products to be portable. Caregivers constantly need to travel with their child and have a place where they can sleep. For example, one of the caregivers we interviewed stated that she could never bring her bassinet with her on the plane to visit family. Instead, she needed to build a “nest” for her baby. This “nest” was thrown together and did not meet any safety regulations. However, the mother had no choice because there was not a portable bassinet option. The frequency of portability will change depending on the family. For

the target audience of low-income families, it is assumed that the need for portability will be frequent, specifically about three to five times a week. This assumption was because low-income families typically have smaller living spaces and they may want to store the bassinet away during the day. Low-income families also often take public transportation and need the bassinet to fit within that environment (Criden, 2008). The specifications were made based on these assumptions. The dimensions given are the typical dimensions of a carry-on suitcase that may fit in the spaces mentioned. The weight listed in the specifications is based on the weight of similar items on the market (Guava Bassinet, 2023).

Affordable: This requirement was what set this product apart from those already in circulation. The sponsor made it clear that this requirement was important for our target audience. What is considered “affordable” varies based on the target demographic. Based on the experience of the sponsor and interviewees, the specification was set to less than \$100.

Usable by newborns and young infants: The product was based on the design of a bassinet. Bassinets are typically used for infants of zero to five months old. Once babies exceed this age range they are able to push themselves up and roll over and bassinets are not equipped to handle this type of movement. The purpose of the bassinet is to be a place for the child to sleep in the first few months of life where they can be near their caregivers for easy care but do not move around frequently. Therefore, this product must have a large enough sleep space to fit children up to five months old. The dimensions for this sleep space is not regulated by the bassinet standard. However, there are common dimensions used by bassinets on the market. These dimensions are also supported by the CDC’s infant size chart. (Amazon, 2023)

Stable: When the bassinet is in the unfolded position, it should be strong and sturdy. The caregivers do not want to be worried about the bassinet toppling over with their child inside of it. This could be caused by the top edge of the bassinet being knocked or the baby moving around or even something falling onto the sleep product. The bassinet standard has a test described within it to ensure the stability of the product. The specification listed is a summarization of that test. The “angled load” is achieved by applying a vertical and horizontal load to the top edge of the bassinet while it is braced in a specific way outlined in the standard. This load is used to simulate the bassinet being pushed unexpectedly. (ASTM International, 2022) (Kids in Danger, 2023)

Durable: Durability has a similar explanation to the stability requirement. The product must be durable to withstand everyday use and frequent travel. The testing process of adding a force was also taken from the standard. It is assumed that the test is used to simulate a situation where the caregiver accidentally leans into the bassinet when placing the child. This tested the structural integrity of the product while the number of washes tested the fabric longevity. The number of washes in this specification was calculated assuming the product is washed two times a week (as is recommended) and used for 2 years. This can be verified without washing the prototype 156

times by choosing materials that are already rated for that number of washes. (ASTM International, 2022) (Adoption, 2023)

Regulation size: There are multiple dimensions of the bassinet that are called out within the standard. This product must meet all of the guidelines in the standard in order to be considered “safe” and put on the market. Therefore, the specific dimensions called out in the standard that relate to this product are given specifications that can be verified using measurement tools. (ASTM International, 2022)

Ease of assembly: In order for this product to be appealing, the assembly of the product must be simple for all users. “Assembly” simply means changing the bassinet from its portable state to its sleep state and vice versa. The products that were benchmarked had simple instructions for their assembly, some also provided a video to follow along with. The number of steps for these benchmarked products ranged in quantity depending on their definition of a “step”. For this specification, the number of steps no matter what they are defined as will be less than five. That way, the instructions will not seem overwhelming to the user. (Lotus, 2023)

Intuitive to Use: It is extremely important for this product to be used correctly by the audience. If the product is used incorrectly, the child or caregiver could be injured or killed. If the product isn’t completely unfolded into its sleep position when the baby is placed inside, the bassinet may collapse around the child. Therefore, the intuitive use requirement was added. Using individuals who know nothing about this product will simulate the future users. Ideally, there is a higher success rate than 90%. However, for the prototype, this is the specification that will prove whether or not the design is heading in the right direction with respect to intuitive use. (Reinhardt, 2023)

Washable: This requirement is particularly important when it comes to use of the product in homeless shelters or daycares. In these facilities, the product will be used by many different infants in short time periods. Therefore, the product needs to be easily washed to keep disease from spreading across all the users. It’s also relevant for other groups of users as the transportation of this portable bassinet may cause it to become dirty easily, necessitating the need for a washable requirement. The specifications for this requirement are associated with the material selection. The materials should be machine washable and waterproof. For example, polycarbonates are known for being able to withstand many machine washes (Adoption, 2023).

When taking a final look at the requirement and specifications table, it is important to note that all of the requirements and specifications listed are what is needed at this level of the design process. Each recommendation was paired with an appropriate specification that can be reasonably tested. Each specification has not necessarily been quantified. For example, within the washable requirement the specification “machine washable” is not quantifiable, but it is a characteristic that will be looked for when choosing specific materials for the design. All the

specifications are either quantifiable or a specific characteristic can be identified and clearly labeled as either “satisfied” or “not satisfied.”

Concept Generation

The concept generation process we used to reach concept selection is displayed in Figure 4 below. Individually, each member of the team generated 20 concepts and used ideation tools like Design Heuristics (*Home*, www.designheuristics.com) and SCAMPER (Dam & Siang, 2024) to generate 20 more concepts based on those original ideas. Then, as a team, we discussed these concepts with people from other teams to get a fresh perspective and grouped all of the generated ideas into various categories based on the features and functionality of each design, such as ideas involving rocking and ideas involving a bag or storage element. Many of the concepts generated revolved around one specific element of the bassinet, such as the leg design or the mattress style, rather than a comprehensive design. As such, each team member combined concepts for various sub functions to produce three “final” full ideas with each of the bassinet sub functions represented for a total of 12 “final” ideas.

These ideas were then narrowed down to three ideas that could then be evaluated in the Concept Selection process. This process will be discussed in more detail in the Concept Selection section. The following subsections will expand more on each step of the Concept Generation process.

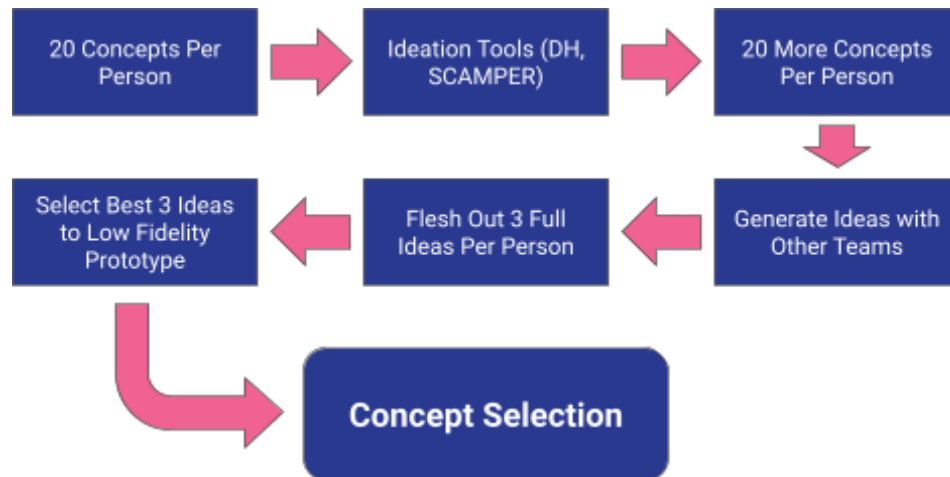


Figure 4. Flowchart of the concept generation process. Each team member generated 20 concepts and used ideation tools to generate 20 more. Together, we generated more ideas with other teams, grouped all of the ideas together. Each team member produced three “final” designs for a total of 12, which were then down selected into three designs that would be prototyped and brought into concept selection. **The concept selection process involved narrowing these three design concepts into a singular concept to pursue.**

Initial Concept Generation

As part of one of the learning blocks in ME 450, each team member generated 20 concepts. Some of these concepts were subsystem-level (i.e. legs, rocking base, etc), and some of these

concepts were more system-architecture focused (i.e. folding, interaction between subsystems, etc). After these initial concepts were generated, ideation tools were used to generate 20 more ideas. The main ideation tools that were used in this project were Design Heuristics and SCAMPER.

Both of these ideation tools follow the same principle: get your brain to think about the concept in a different way. Design Heuristics does this using a set of 77 cards that each have a different design change on them. An example of this can be seen in Figure 5, where the original idea for a bassinet with mesh sides and a rocking base combined with card 35 (flatten) produced an idea for folding joints at the top and bottom to make the original design fold flat when not in use.

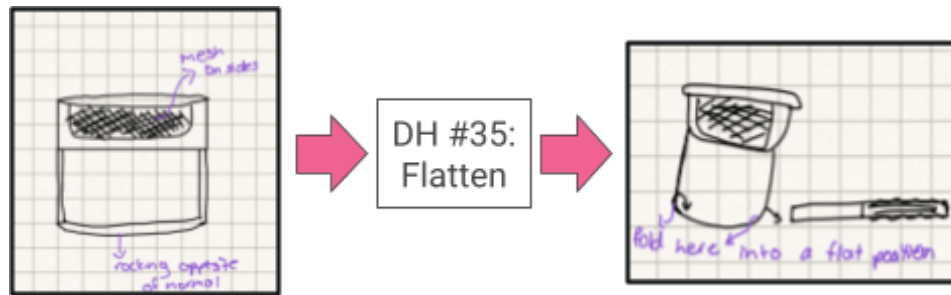


Figure 5. Design heuristic card 35 being used to transform the original idea for a bassinet with mesh sides and a rocking base into one that can fold flat with the use of folding joints at the top and bottom of the legs.

SCAMPER, the other main ideation tool that we used doesn't suggest changes to the design but rather poses questions to make you reconsider the concept. In the example shown in Figure 6, the original concept for a side opening with a zipper is combined with the SCAMPER category of Substitute, transforming the idea to one involving snap buttons instead of a zipper.

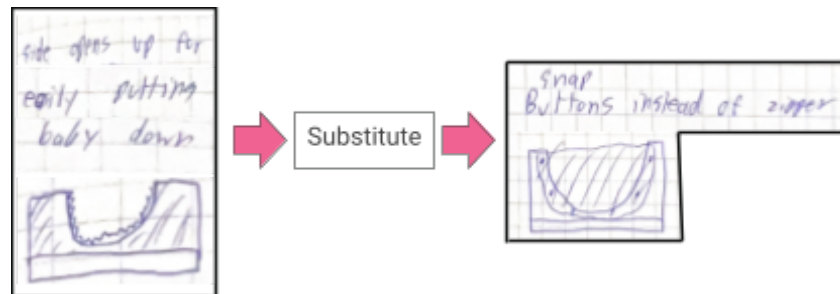


Figure 6. SCAMPER's Substitute category used to transform the idea for a zipper opening on the side of the bassinet into one that uses snap buttons.

These tools allowed our group to generate about 120 concepts that we grouped into the following categories: Mounting and Stand ideas, Rocking Ideas, Mattress Mechanics, Bag/Storage, Folding, Container Ideas, and a catch all Special Features category. A sample of the generated ideas can be seen in Figure 7, below, while the full list of ideas can be found in Appendix A. The list below provides a brief description of the different categories:

- Mounting and Stand: Ideas that contribute to the way the bassinet touches the floor and how the main sleeping area interacts with potential legs
- Rocking: Ideas for rocking the bassinet
- Mattress Mechanics: Ideas for how the mattress can convert between the portable and deployed states
- Bag/Storage: Ideas that involve the bassinet turning into a bag or other storage device in the portable configuration
- Folding: Ideas for how the whole system can fold up
- Container: Ideas for how the bassinet can be transported
- Special Features: Catch all for additional features that could be added to make it more appealing to the user

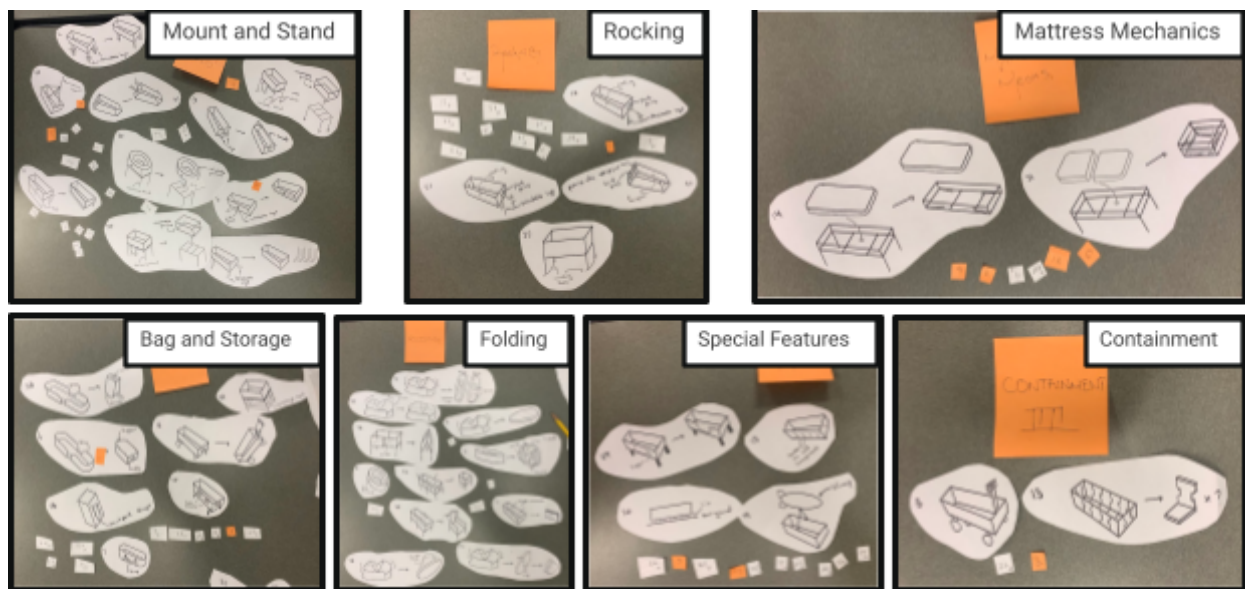


Figure 7. Sample of the ideas sorted into seven categories: Mounting and Stand ideas, Rocking Ideas, Mattress Mechanics, Bag/Storage, Folding, Container Ideas, and a catch all Special Features category.

Final Concept Generation

Many of the initial design concepts only captured certain subsystem features of a bassinet, such as a design for the legs or a design for the mattress. Using the initial concept generation results as a jumping off point, each member of the team created three “full” designs by combining the best ideas for various subsystem designs concept created in the initial concept generation. Decisions about which subsystem design ideas to incorporate into each “full” design idea were based largely on the feasibility of various subsystem concepts. “Full” ideas were ones that could be translated to a final product with a small amount of work to define the fine details. These 12 ideas all had fully defined system architecture and subsystems. These ideas are shown in Appendix B and were sorted into two main categories: bassinets that have another use while in the portable state, and ones that don’t. This sorting was done in an effort to compare the level of

appeal bassinets with extra features possessed compared to those that didn't. Stakeholder interviews with target users allowed us to gauge that interest.

Concept Selection Process

The goal of the concept selection process was to narrow down the 12 full concepts chosen from the Concept Generation process to a single concept to pursue. From these 12 ideas, we narrowed them down to three through an elimination process. We first merged similar concepts and eliminated the concepts that had major design challenges that would be extremely difficult to solve within the scope of this class. This step brought the total of possible design ideas down to about six. Of those remaining, we were able to narrow them down to three by identifying ones that lacked certain features that had been voiced as preferences in our previous stakeholder interactions. For example, one such concept didn't include legs, which our users had expressed appeal in, so we eliminated this concept. Eventually, we landed on the three designs shown below in Figure 8. The concept in Figure 8(a) is similar to a folding chair that you might take camping or to a sporting event, and was chosen because it was not something that we had seen on the market but was a mechanism that users may be familiar with in other contexts. The concept in Figure 8(b) contains detachable legs and would turn into a backpack that the user could put other items in when in its portable state. Carrying a portable bassinet using backpack straps is something that we've seen on other products, but it is usually in the form of a bag that the bassinet goes into, not the bassinet itself turning into a backpack. Thus, we wanted to further explore this concept in the concept selection process. Finally, the concept in Figure 8(c) would turn into a basket that a user could also carry items in while the bassinet was in its portable state, again something not seen on the market and something that we could gauge user interest in as part of the concept selection process.

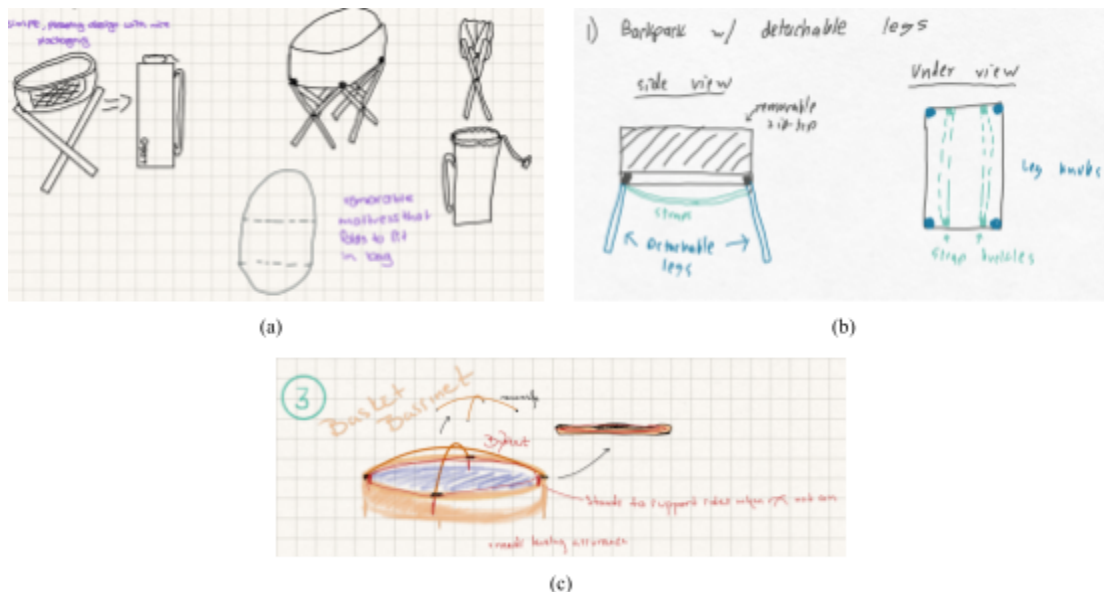


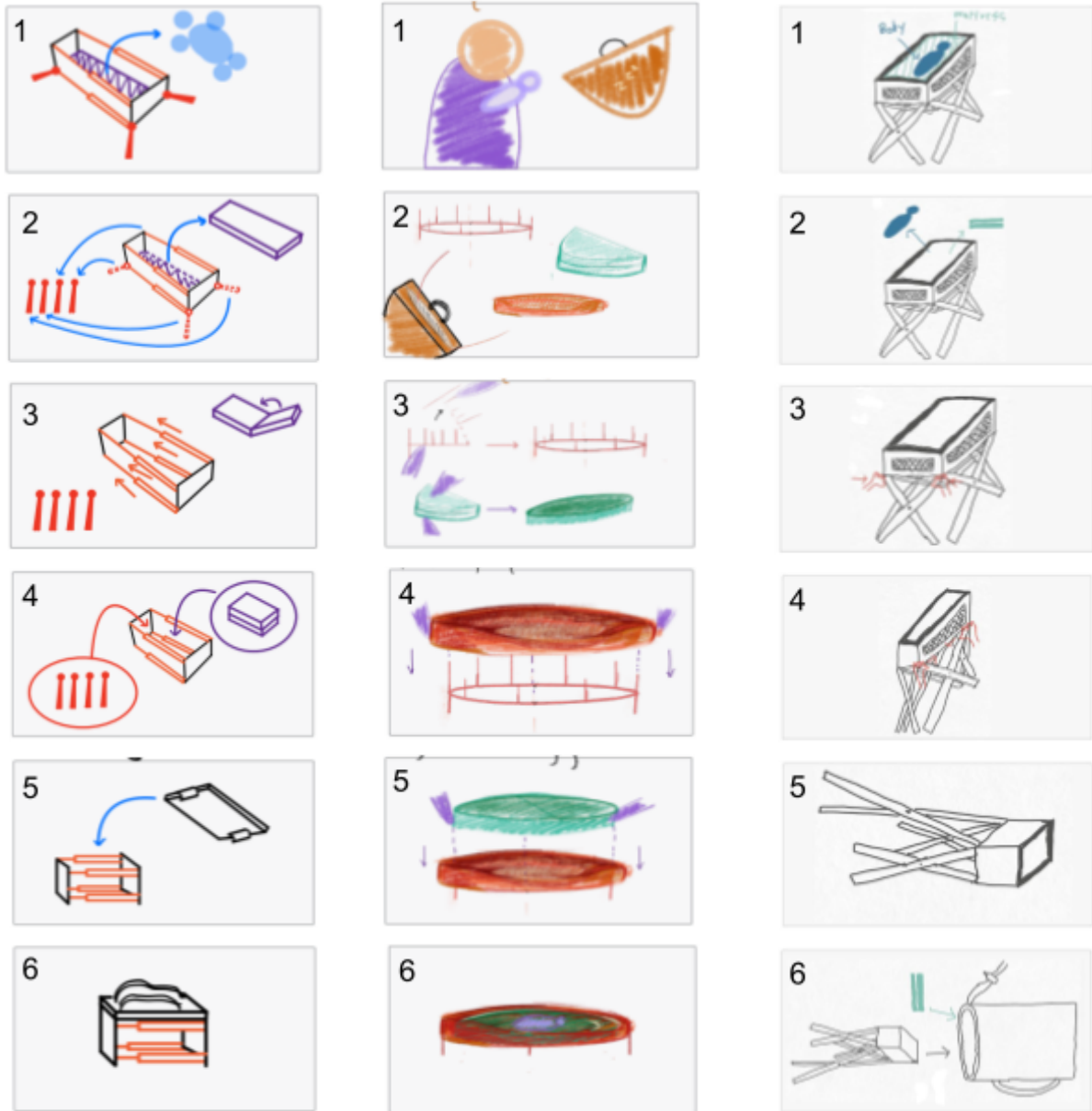
Figure 8: Three chosen concepts to move forward into concept selection. (a) “Folding chair” bassinet, a common mechanism not commonly used in the bassinet space. (b) Backpack bassinet, with a familiar carrying mechanism employed with the structure of the bassinet itself. (c) Basket bassinet, a novel form factor with the common feature of being close to the ground.

A combination of low fidelity prototyping and stakeholder engagement was used to iterate on each of these three concepts in order to increase the merit of each of them. We could then proceed with analytically comparing them through the use of a Pugh chart. This whole Concept Selection process will be outlined in more detail in the following subsections.

Low Fidelity Prototyping

To gain an early visualization of each of our design concepts, we constructed a couple low fidelity prototypes for each of the three concepts selected in the Concept Generation process. These prototypes provided a fast, easy, and inexpensive means to identify any glaring challenges we’d face with each concept and make changes to the concepts accordingly. We focused on two low fidelity prototyping methods, namely storyboarding and mockups, each of which served a different purpose.

Storyboarding: We constructed a storyboard for each of the three full concepts. This tool allowed us to understand and predict how a user would interact with each product. Storyboarding was a logical prototyping choice for our particular product, specifically a portable bassinet, because the nature of this product will require users to complete a series of steps in order to reconfigure the bassinet from its portable to functional states and vice versa. Storyboards are beneficial in this case because they can capture each step in a single cell, allowing us to break down the complex process of reconfiguring our portable bassinet into simple step by step subsections. This enabled us to explore in detail the potential challenges users would face in each step of reconfiguring our product and identify potential safety concerns surrounding infants being placed in or near the product. Figure 9 below illustrates the three storyboards created for each concept.



(a) Backpack Bassinet

(b) Basket Bassinet

(c) Folding Chair Bassinet

Figure 9: Bassinet Storyboards

These storyboards gave us several useful insights into each concept. The folding chair bassinet storyboard, for example, made it apparent how numerous potential pinch points in the product

were. These constituted a safety concern for this particular design. It also made us realize that the folding chair concept may be quite tall when in its portable state as a result of the legs compressing inwards, which posed a potential challenge related to meeting our portability requirement. The backpack bassinet storyboard gave us a sense of how bulky this concept could be. This bulkiness was a characteristic we wanted to gain feedback from stakeholders on. Additionally, the basket bassinet storyboard illuminated several potential challenges with this concept, namely the issue of how the folding mechanism would work with the basket mounting poles impeding the folding function. These were the types of insights we gained from storyboarding each product. Even the issues we identified with each concept were useful because they revealed several points of discussion we could engage with on specific stakeholders, including Don Wirkner, to make them more feasible.

Mockups: After creating the storyboards, we sought to construct a physical model for each concept. We used cheap household supplies to create these 3D representations of each concept. These models are shown in Figure 10.

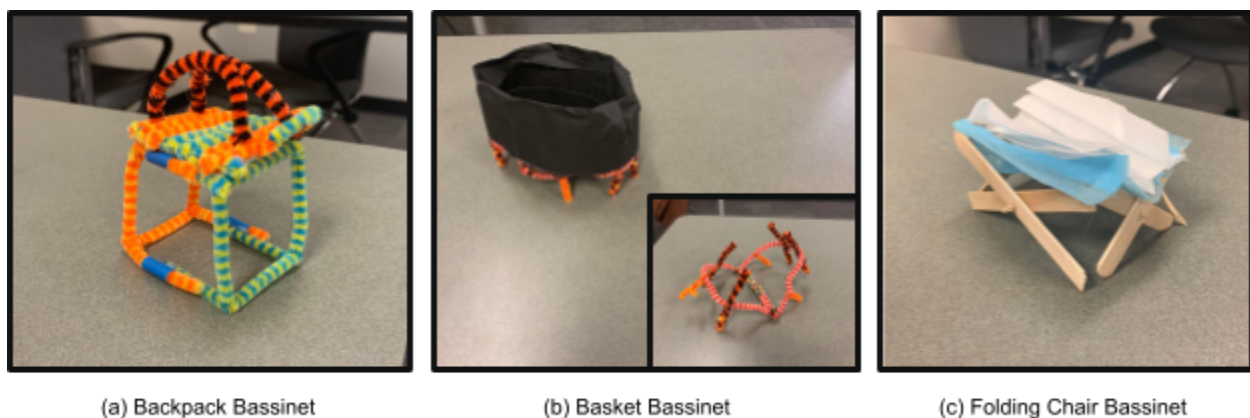


Figure 10: Bassinet Mockups

The main function of each of these simple mockups was to present something tangible to stakeholders, specifically product end users, when requesting feedback on our concepts. This allowed them to visualize our concepts more easily than if we were only describing them with words. The mockups incorporated several of the key features of each concept. For example, the backpack bassinet mockup contained telescoping elements and the basket bassinet mockup included a foldable frame. With these features captured, we could then more easily gather feedback on each concept from stakeholders, which will be discussed in the next section.

Stakeholder Engagement

To address some of the concerns and questions that arose during the process of constructing low-fidelity prototypes for each of the three full concepts, we engaged with various stakeholder groups to gain feedback and finetune our concepts before ultimately selecting a final concept. We first met with our project sponsor, Nancy Cowles, using our storyboards and mockups to provide

her with a visual representation of each concept. This meeting was used as a screening process to potentially eliminate concepts that would fail to meet certain sponsor expectations other than our requirements. Nancy, however, approved of each concept, which left us to engage with stakeholders who possess more design experience and stakeholders consisting of end users. Throughout this process, we met with Don Wirkner, the ME 450 Lab Services Manager, Katie Lim, a product designer with experience in designing infant products, and various end users, including caregivers and mothers. Table 3 below summarizes the most useful points of feedback obtained through these stakeholder conversations. After discussing the folding chair bassinet with Don Wirkner and Katie Lim, it was mostly eliminated from contention due to concerns surrounding safety in addition to challenges associated with it meeting the portability requirement. In conversations with end users, who were made up of caregivers that were interviewed about the various concepts, the low-fidelity prototypes for all three concepts were displayed. More emphasis was placed on feedback for the backpack and basket bassinet concepts, so feedback from folding chair bassinet was not collected from end users.

Table 3. Feedback Obtained from Project Stakeholders for Each Full Design			
Stakeholder	Backpack	Basket	Folding Chair
Don Wirkner	<p>Detachable legs can be lost.</p> <p>Removable cover with straps can be lost.</p> <p>Telescoping beams can lock if retraction force isn't distributed evenly.</p>	<p>Proximity of basket to ground will increase safety and stability.</p> <p>Legs can snag on something when frame being carried.</p> <p>Infants may be able to grasp cover, leading to risk of suffocation.</p>	<p>Incorporate vertical rail in each corner for stability.</p> <p>Everything being in one piece will increase ease of assembly.</p> <p>May need to incorporate telescoping legs to meet portability requirement.</p>
Katie Lim	<p>Human factors should be considered. Straps should fit on people with various body types.</p> <p>Having straps permanently attached to bassinet instead of on removable cover might be safety concern for infants.</p> <p>May be bulkier than desirable for users.</p>	<p>Folding frame seems tedious to reconfigure.</p> <p>Caregivers may find it uncomfortable to bend down when removing or placing infant in bassinet.</p> <p>Short legs may lead to misuse in form of caregivers placing bassinet on unstable surfaces, such as couch or bed.</p>	<p>Feet could be wobbly.</p> <p>Concept contains many possible pinch points, posing safety concerns.</p>
Caregivers	<p>Seems most versatile in terms of which environments can be used in.</p> <p>Backpack aspect makes it most functional.</p>	<p>Washing the whole basket cover would be challenging.</p> <p>It would be tedious mounting the cover sheet to each of the mounting poles on the frame.</p>	<p>Eliminated from contention before concept brought to end users for feedback due to the amount of safety concerns identified.</p>

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Further Iteration

After discussions with stakeholders, we iterated on our concepts to incorporate as much stakeholder feedback as possible. For the backpack bassinet, this iteration entailed making the legs permanently attached to the bassinet on a pivot point rather than fully detachable to prevent the chance of one of the legs being lost by the user. To address concerns surrounding ease of assembly and the telescoping beams locking in the event of an uneven force distribution, we devised a rough concept involving bowden cables and spring pin clips that would allow the user to pull a handle and actuate all four telescoping beams simultaneously with one hand. In response to concerns regarding human factors, specifically how the backpack design will fit on people with various body shapes, we will incorporate some adjustability in the backpack straps.

We also sought to incorporate feedback obtained from the basket design. We iterated on the leg design concept by making the legs longer and incorporating rotation to them such that they can fold away when the bassinet is in its portable configuration to meet the portability requirement. This would also address the concern brought up of the legs snagging on something when the frame is being carried around. To address another concern about the tediousness of reconfiguring the folding frame, we simplified the frame shape to be more rectangular instead of ovular, which reduced the number of basket cover mounting poles that would be required to keep the ovular shape of the basket.

While at this point, we had mostly eliminated the folding chair bassinet from contention, we still wanted to iterate on this concept in case these iterations made it more palatable. We addressed stability concerns raised by stakeholders by connecting the feet in each corner to a vertical rail. Addressing the safety concerns regarding the number of pinch points in this bassinet proved difficult, however, and we were unable to successfully resolve this concern.

Concept Comparison and Final Concept Selection

With our three concepts improved and iterated on through stakeholder engagement, we proceeded with determining the optimal design by constructing a Pugh chart, shown in Table 4 below. Before scoring each concept, we first listed all of the criteria that each concept would be evaluated on. Most of these criteria were directly taken from our requirements, but a few criteria were added as additional goals for our design. For example, Aesthetics is one such criterion that isn't a requirement due to its low priority, but it was still a quality that possessed some value in a final design, so it was included as a criterion evaluated for each concept. Once all criteria were listed, we assigned each criterion a weight from one to five, with the most critical criteria receiving weights of 5 and the least critical criteria receiving weights of one. The specific weight values were determined through deliberation on the most emphasized requirements from our sponsor and the most mentioned priorities from end user interviews. For each criterion, if either

the basket or folding chair bassinets were deemed superior in that criterion than the backpack bassinet, they were assigned a “+1.” If they were deemed inferior, they were given a “-1.” Otherwise, a “0” was assigned.

Table 4. Pugh Chart Comparison to Select Final Design Concept

Criteria	Weight	Backpack	Basket	Folding Chair
Weight	4	0	0	-1
Stability	4	0	+1	-1
Compactibility	5	0	0	-1
Regulation Conformity	5	0	0	0
Ease of Reconfiguration	4	0	-1	-1
Sleep Space Safety	5	0	-1	-1
Sanitation	3	0	+1	0
Affordability	4	0	0	-1
Feasibility	4	0	0	-1
Aesthetics	1	0	0	-1
	Weighted Score	0	-2	-31
	Rank	1	2	3

The backpack bassinet received the highest score of the three full concepts from the Pugh Chart analysis. However, since the backpack and basket designs were so close, we decided to meet with Don Wirkner again to discuss how the mechanisms needed for both designs might work in practicality. From this conversation, it became clear that the mechanisms necessary to design for the basket design would be less practical, so the backpack design was selected as our Design Alpha.

Concept Description

The Backpack Bassinet offers easy product relocation and reassembly for caregivers with limited storage and sleeping space. In the section below, we have outlined how specific product features accomplish this.

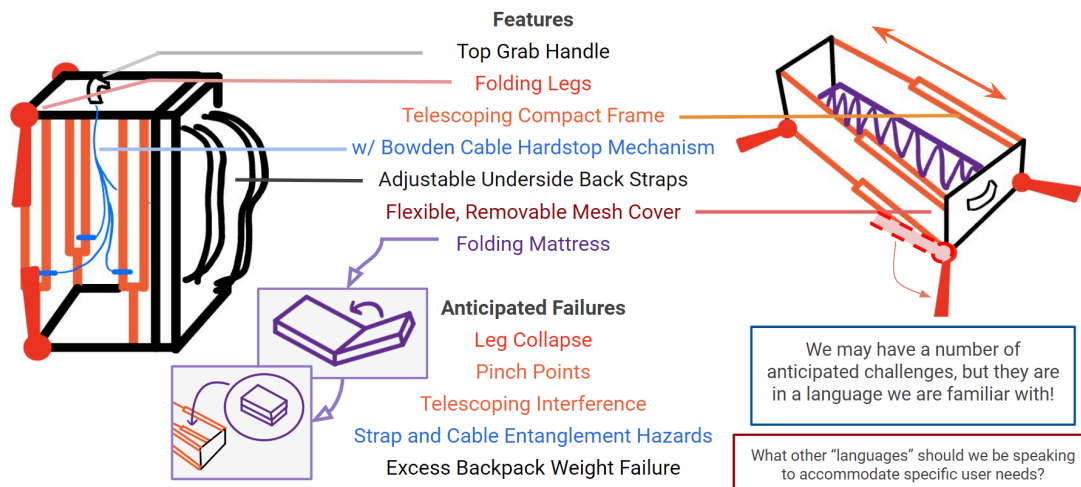


Figure 11: Features and Anticipated Failures of Design Alpha, the Backpack Bassinet

Features

The following subsections outline the key features of the backpack bassinet.

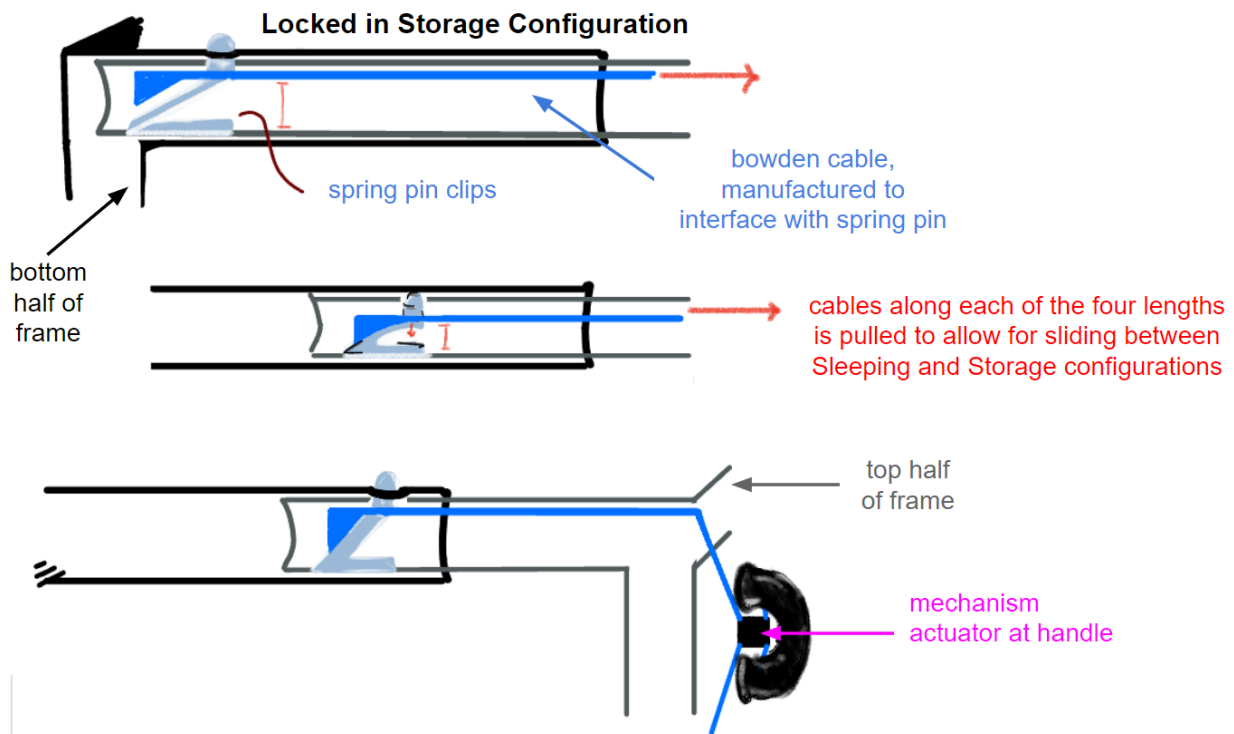


Figure 12: Telescoping Frame, actuated by a bowden cable system

Bowden Cable-Actuated Telescoping Compact Frame. Portability and infant usability requirements are satisfied by a telescoping frame, capable of compressing the footprint of the product from a sleep space of 30"L x 18"W x 9"H, to the folded 24"L x 18"W x 9"H, a volume

compatible with modes of urban transportation. We have implemented a Bowden Cable-Actuated subsystem for each telescoping tube to actuate spring pin clips used to lock the tubes in both the intended sleeping and storage configurations. This system, shown in Figure 12 on the previous page, provides a single point of user actuation at the grab handle (low cognitive effort) and each of the four telescoping tubes is connected to the same handle, allowing a user to actuate all four telescoping tubes with one hand. The click of the spring pin clips when they lock into place, serves as an auditory cue to inform the user of correct assembly.

Top Grab Handle. This handle is linked via the Bowden cable system to each of the four telescoping tubes. This handle must be capable of holding the weight of the product, as well as any additional items the user may choose to pack in the storage configuration.

Folding Legs. The thin tubed legs of the product can fold along the length of the product, again bridging the gap between usability and portability. Ensuring the integrity of these components is crucial for stability and durability while managing weight and production costs. With consideration of ASTM loading cases, we have designed simple, yet reinforceable wheel joints to act as leg pivots. This system, sketched in Figure 13 on page 30, contains a wheel joint with two notches, one for the leg-folded-out configuration, and one for the leg-folded-in configuration. A spring-loaded ball plunger is connected to each leg. These ball plungers lock the legs in either their folded in or folded out configurations. When a leg needs to be folded in, the force applied by the user to rotate the leg should be sufficient to release the ball plunger from its notch due to the spring in the ball plunger. Once the leg is rotated such that the ball plunger reaches the other notch, it should snap into that notch, clicking the leg in place (again providing assembly auditory cues for our users).

Adjustable Underside Back Straps. Alternatively, the backpack can be carried via backpack straps that would extend in the same direction as the legs. We wished to give users multiple options in carrying the product, as infant care often requires transportation of many supplies and carriers. These straps will be adjustable, and they too must hold the weight of the product, as well as any additional items the user may choose to pack in the storage configuration.

Flexible Mesh Cover. The walls of the product will be formed from a removable mesh cover. This cover drapes into and secures to the frame of the product and can be removed for washing. The cover will be as large as the sleeping configuration, and can easily compress when the product is converted into its portable configuration. Stakeholders who are caregivers have expressed value in being able to see the baby through the walls, and have suggested that infants intuitively feel separation from their caregiver, and so we selected a utility mesh that is lightweight and translucent as possible, while still suiting functional and sanitation needs. If our selection had been more objective in nature, we would miss opportunities to accommodate common caregiver needs even as they are facing larger contextual safety concerns.

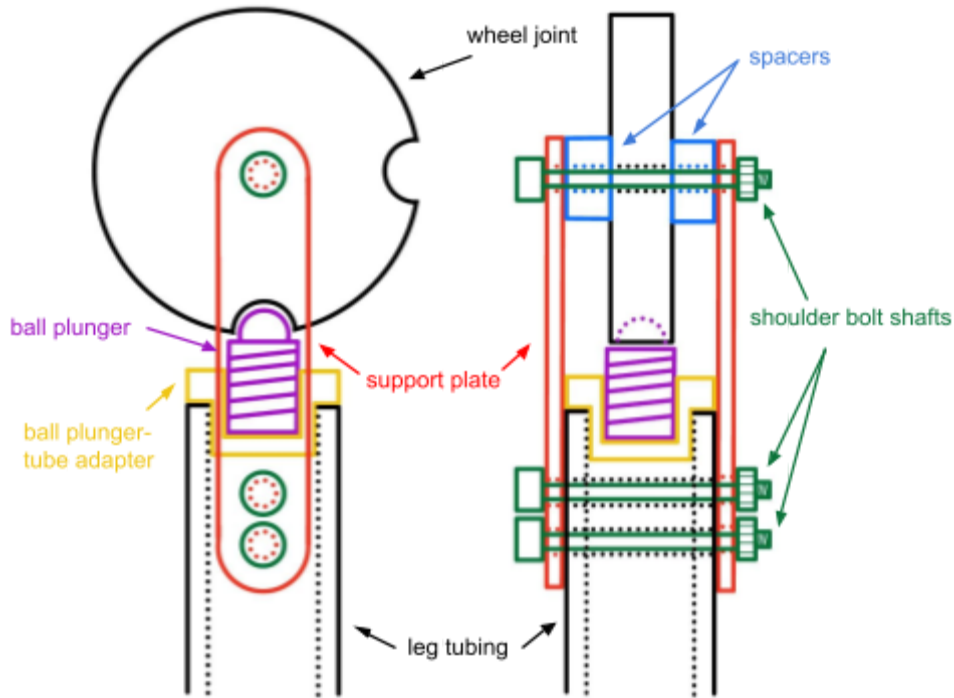


Figure 13. Leg Folding via Wheel Joint design

Folding Mattress. The material properties of the mattress will be heavily guided by the ASTM standards and benchmarking, as this is the point of contact between the infant and product. Additionally, our design allows for the mattress to be folded in half for easy packing into the portable configuration.

At this point in our project development, the selected concept is well defined in a way that allows us to assess the feasibility of individual mechanisms rather than rigorous analysis of a fully defined system. In approaching our problem this way, it has been easier for us to anticipate failure modes that are within the constraints of ME 450. Additionally, we are working to organize the use of our resources and analysis methods in a way that is most time efficient and informative for the next design phase. Our proposed methods of doing so can be found in the following section.

Engineering Analysis

We used multiple analysis methods to develop, evaluate, refine, and optimize our design choices. The bulk of the analysis that was done was “proof of concept tests”. These tests were combined with active prototyping of the device to determine if our design ideas were feasible. To prove these ideas this, we designed separate prototypes of subassemblies that needed to be tested and

then fully fabricated and assembled in the design space. The following section describes the tests conducted and our results.

Leg Joint Subassembly

As depicted in Figure 13, our team designed a folding joint for the legs of the bassinet that allowed the legs to extend out when the bassinet is in use and then fold back in when the product is collapsed. We chose to use a ball plunger paired with a wheel joint containing indentations for this design. A prototype of this sub assembly was built to test the feasibility of this design concept. The build design for this subassembly is similar to that shown in Figure 13 except for the wheel joint itself. We weren't sure what indentation geometry would work for our application in terms of indentation depth and width, so we waterjetted a single disc with multiple indentations of varying depths and shapes. The first version of this wheel joint is shown in Figure 14. Here, there are eight different indentation depths, each formed to the shape of the tip of the ball plunger. This wheel joint was added to the subassembly shown in Figure 15.

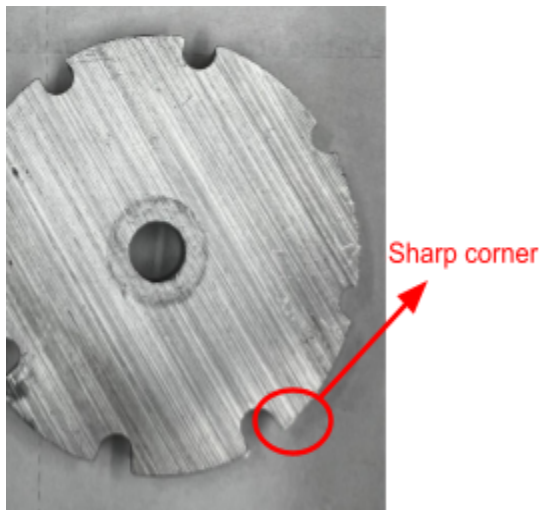


Figure 14. Wheel Joint V1

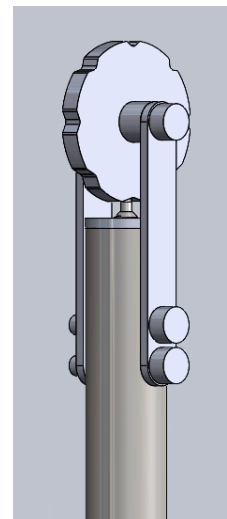


Figure 15. Current Wheel Joint Design

Unfortunately, when the leg joint sub assembly was tested, it failed. We tested the assembly by seeing how much force was necessary to rotate the wheel into different positions by grabbing the wheel with our hands and trying to turn it. The test was ruled a failure because even when the ball plunger was in the shallowest indentation, the wheel could not be easily rotated. In fact, the joint was stuck and the only way to remove the wheel from the spring force of the plunger was to take out the bolts and disconnect the entire assembly.

The next step after this test failure was to see how we could redesign the joint to perform as intended. Through examination of the ball plunger's interaction with V1 of the wheel joint we found that the corner between the indentation and the outer diameter of the wheel was too sharp.

For ease of understanding, this corner has been pointed out in Figure 14. In the next version of the wheel joint, we still tested different depths of indentation, but this time, the corners were rounded so the ball plunger could slide more gradually towards the outer diameter of the wheel. Version 2 of the wheel joint can be seen in Figure 16.



Figure 16. Completed Leg Joint subassembly with Wheel Joint V2

This version of the wheel joint tested much better than the first version. The shallowest indentations provided a smooth rotational feeling and proved this concept could work for our design. This subassembly design also allowed our team to pick the correct indentation depth based on feeling during testing. We found the groove with a depth and width that provides a comfortable amount of force to keep the plunger in place, but also allows for the leg to be folded without too much effort from the user. The smallest width that was still easy to rotate the leg was chosen because the smaller the width, the more secure the ball plunger is locked into the groove.

The final result of this analysis was the indentation depth and shape used in the wheel joint of the leg subassembly. Due to the fact we built the subassembly in real life, we could see how the concept we made up in our minds would work with real life forces and how the typical user would interact with it.

Bowden Cable-Actuated Telescoping Compact Frame Subassembly

This subassembly was the most complex in the entire device, and thus contained the most potential complications. Therefore, our team decided to test the feasibility of the wedge-pin-cable interaction. Specifically, using this interface would have successfully moved the pin out of its slot so the telescoping could occur, and then spring back into place once the device

had expanded/contracted. The cable mechanism is explained in Figure 12, but the first thing we noticed when assembling our prototype of the assembly was that the spring pin clip was modeled incorrectly. In Figure 12, the bottom section of the spring clip is flush against the bottom of the tube, but in real life, the top of the spring clip was found to be flush with the top of the tube. This caused our first version of the cable wedge to be a failure. As shown in Figure 17, this piece would not fit between the top section of the clip and the tube.

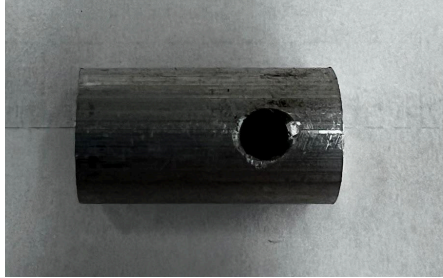


Figure 17. Cable Wedge V1



Figure 18. Cable Wedge V2

Once our team had this realization, we improvised so we could obtain results using the other parts made for this subassembly as soon as possible. That is when we came up with Cable Wedge V2 that is depicted in Figure 18. We used this design for the sole purpose of proving the spring clip can be actuated using a wedge and a perpendicular force. Through some trial and error, we got the mechanism to work, but it was not to the caliber our team wanted. Instead we learned a lot about what needs to be changed based on this test. For example, we needed a wedge that easily aligned with the pin and fit along the inside of the tube.

The first element we learned from this test was that we needed to find a way to secure the bottom section of the spring clip to the bottom of the tube so the wedge doesn't push the entire clip instead of pushing the pin down. In the prototype we used a piece of tape to secure the clip, but in our build design, we used a 3D printed hard stop that the bottom piece of the clip slides into. This hardstop was secured to the tube using a rivet.

The second element we learned from this test was that it was very hard to align the wedge with the top of the spring pin with no guidance. Therefore, we decided to design the wedge so that it was a cylindrical shape that fits into the tube and aligns the wedge with the top. This was the wedge design that is shown in our build design section. This wedge was also designed to be pulled instead of pushed as V2 was. Ideally, we would perform another test where we use the subassembly with the new 3D printed wedge. Unfortunately, due to project time constraints, we were not able to perform this test.

This test did not allow us to experiment with the cable routing of our device and work out any issues with the path. Before finishing our build design, it would have been beneficial to make sure that all of the 90 degree turns the cable must go through did not cause fatigue to the user or

the cable material itself. It would have also been beneficial to test how the movement in the handle transfers to the cable wedge as some of the motion may be lost throughout the path. Unfortunately, we were not able to test these things until close to the expo deadline and did not apply the findings to our final build.

Final Design Description

Figure 19 shows an overview of the CAD of the build design for our portable bassinet. There is a frame made of hollow tubing that provides the structure for the sleeping space and can telescope inward to make it more portable. It is held up off of the floor with legs that can fold up for portability. The mattress has a stiff back with foam on top and a wipeable cover and can fold in half. The fabric cover holds up the mattress and encloses the sleeping space.

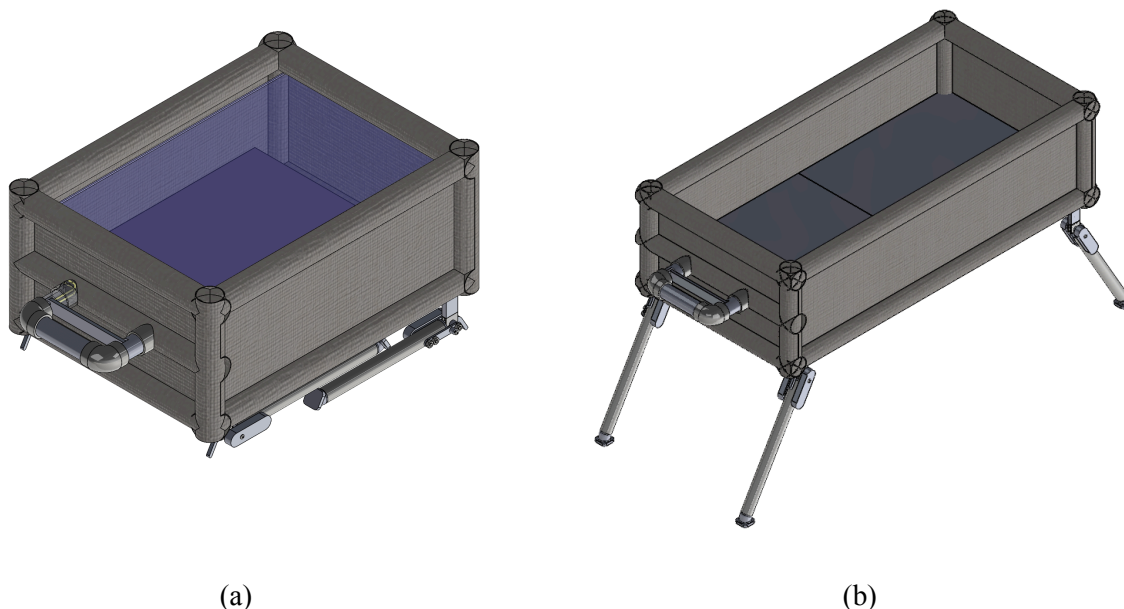
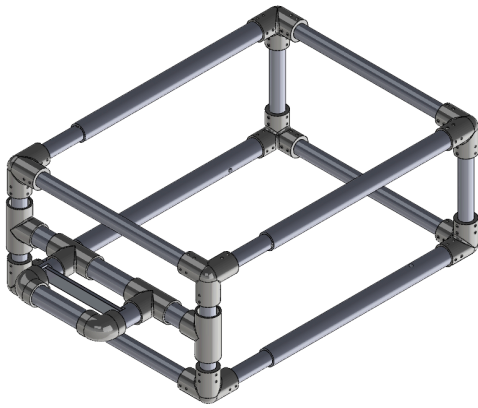


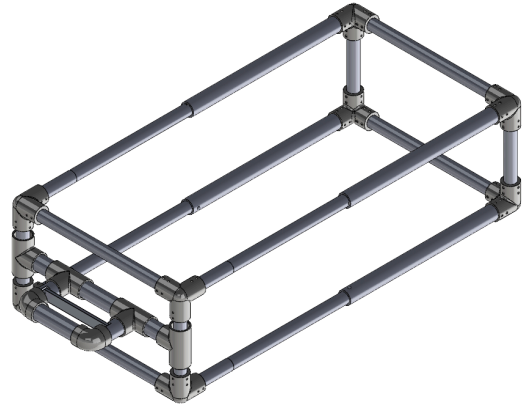
Figure 19. (a) CAD assembly of the build model in the portable state. The legs fold up and the frame telescopes in to compress the space and be used as a backpack. (b) CAD assembly of the build model in the deployed state. The mattress unfolds to provide a sleeping surface and the top cover unzips.

Frame Subsystem

The frame subsystem can be seen below in Figure 20 in both the portable and deployed state. The tubing is made of polycarbonate and telescopes along the longest dimension to change into the portable state. It is held together with 3D printed joints that are made to fit the various diameters of tubing on the frame. The handle at the top of the bassinet actuates the spring pins that retain the frame in the configuration.



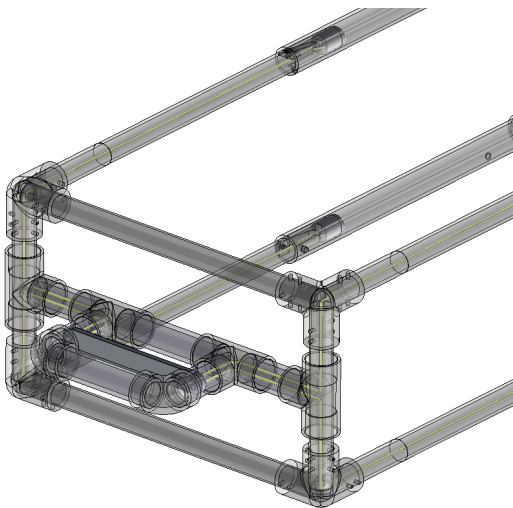
(a)



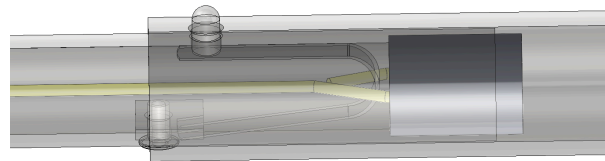
(b)

Figure 20. (a) CAD assembly of the frame in the portable state. (b) CAD assembly of the frame in the deployed state.

Handle and Spring Clip Puller. The spring pins that set the position of the frame are actuated remotely from a single point to make the reconfiguration process more convenient to the user. On the handle side, a 3D printed piece has four cables tied to it. Figure 21(a) shows the path that these four cables take through the frame. On the other end of the cable is the spring clip puller which will push down the spring clip and allow the outer tubing to move. The spring clip is also held in place by a 3D printed piece that is riveted to the inside of the tube. Figure 21(b) has the CAD model of the spring clip puller apparatus.



(a)



(b)

Figure 21. (a) Cable path through the frame, shown in yellow. These four cables are all tied to the handle and run through the tubing. (b) Wedge assembly shown in CAD.

Corner Joints. The corner joints are SLA 3D printed due to the stronger material properties of the resin used for this. Another advantage of 3D printing these is that the openings can be custom made to the various diameters of tubing that meet at this joint. There are holes on all sides of this joint to simplify the CADing process; the final build will not have this many holes.

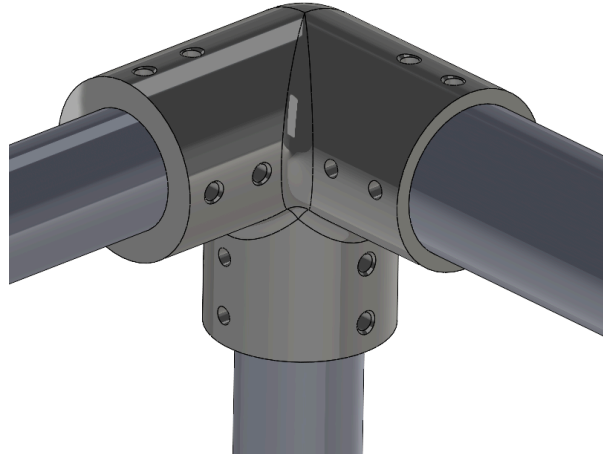


Figure 22. The corner joints will be SLA 3D printed due to the customizability of this manufacturing method.

Leg Subsystem

The legs rotate into two positions with the use of a spring-loaded ball plunger and a waterjetted plate. The legs on one side of the bassinet have a spacer between them and the frame to prevent leg interference when folded, as shown in Figure 23 below. The two legs with spacers are slightly shorter than the other two legs to ensure that the legs sit the bassinet flat when in its functional state.

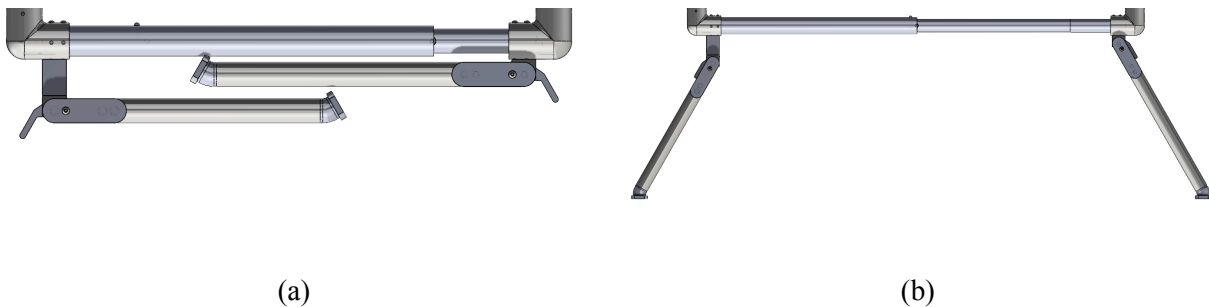


Figure 23. (a) CAD assembly of the legs in the portable state. (b) CAD assembly of the legs in the deployed state.

Mounting to Frame. The legs are mounted to the frame using two 6-32 screws per leg. This is the largest bolt size that has a nut that can fit in the bracket that secures the waterjetted plate in place. The bracket is made from U-channel stock that is cut down and has holes drilled into it.

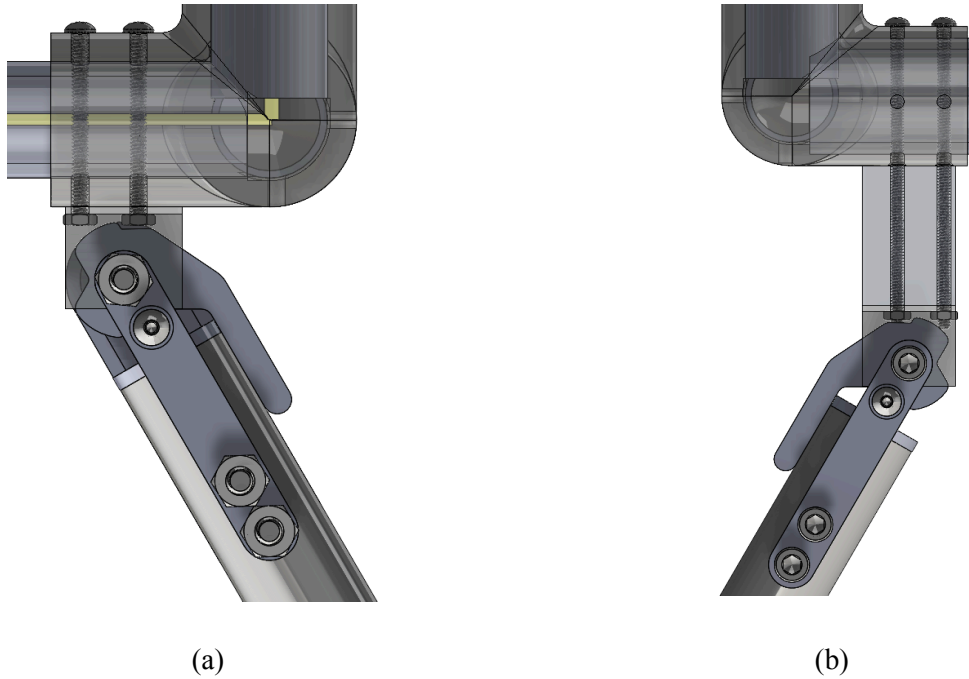


Figure 24. (a) Leg mounting without the spacer. (b) Leg mounting with the spacer

Wheel and Ball Plunger Interface. The ball plunger is threaded into the leg using a 3D printed adapter that has the same threading as the ball plunger. The ball side sits in grooves on the water jetted plate, visible in Figure 25 below. It's designed to move out of these grooves only when a user rotates the legs by hand. This water jetted plate also has a hard stop to prevent the leg from rotating past the deployed position.

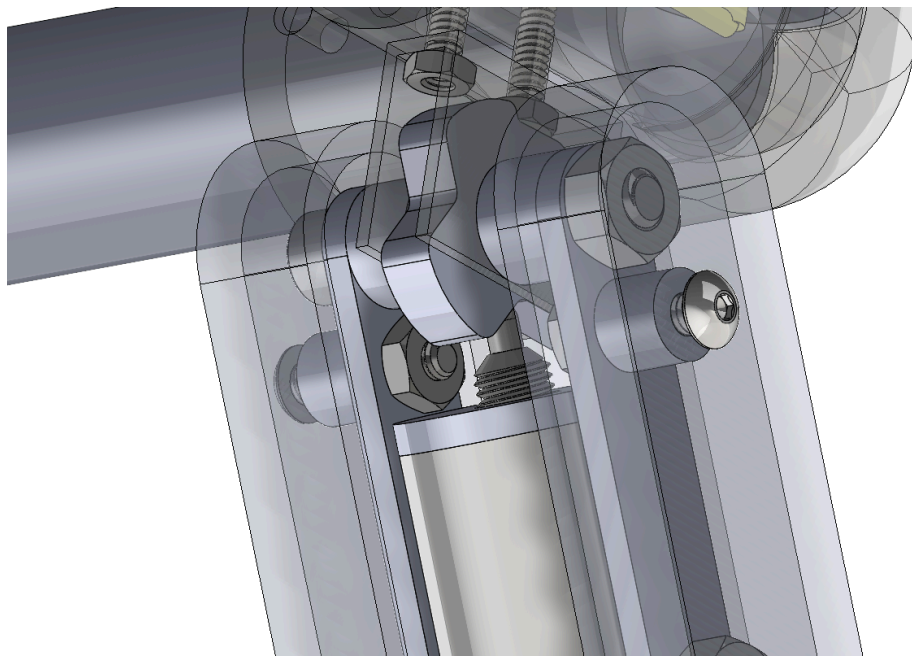


Figure 25. CAD of the interface between the water jetted wheel and the ball plunger.

Mattress Subsystem

The mattress was made of a stiff back sheet to keep the mattress flat with foam on top. It was also encased in a wipeable cover to make it easy to clean in the event of a spill. The mattress was made out of two segments so that it could fold in half when the bassinet is in its portable state. In its deployed state, the mattress was 16 in x 33 in, similar to the size of many other bassinets on the market, which allowed many off the shelf fitted sheets to fit onto the mattress.

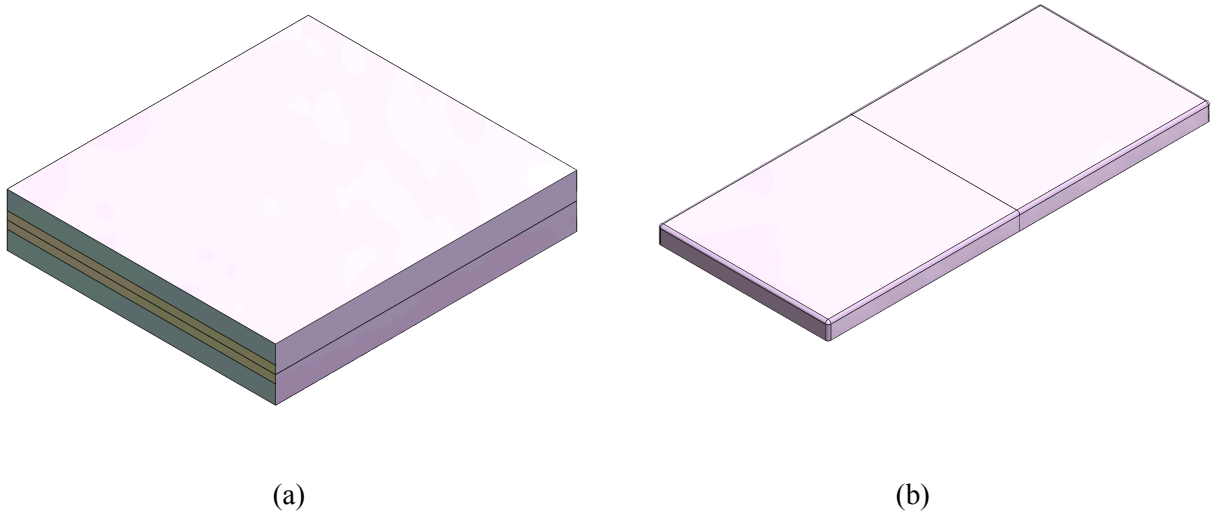
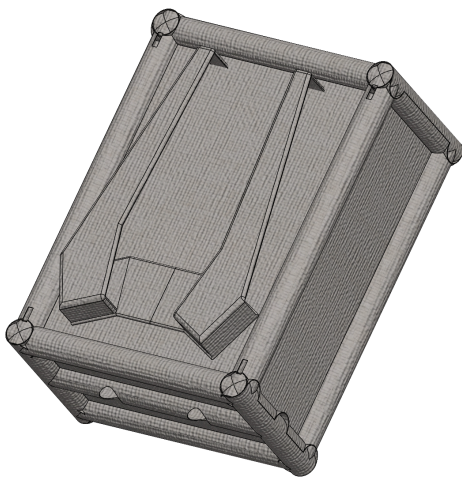


Figure 26. (a) CAD assembly of the mattress in the portable state. Stiff material is in yellow, foam is in green, and a wipeable cover is shown in pink. (b) CAD assembly of the mattress in the deployed state.

Fabric Cover Subsystem

The fabric cover, illustrated in Figure 27, was made of many panels of fabric that will be stitched together. There were backpack straps on the back of the bassinet to make it usable in the portable state. Additionally, there were cutouts where product components that must go through the cover to the frame, like the handle and the leg mounts. Not currently the CAD model are the zippers that will make the fabric cover removable from the frame and the top cover that will fully enclose the frame in the portable state.



(a)



(b)

Figure 27: (a) CAD assembly of the fabric cover in the portable state. (b) CAD assembly of the fabric cover in the deployed state.

Build Description

The physical embodiment for this project was a physical build of the final design. Pictures of the physical build can be found below, in figure X. Most parts of the build were the same as the final design, with two notable exceptions: the fabric cover and the handle part of the frame.



(a)

(b)

Figure 28: (a) Physical build in the deployed state as seen at the ME450 Design Expo on April 18th, 2024. (b) Physical build in the compact state as seen at the ME450 Design Expo on April 18th, 2024.

Sourcing and Manufacturing

To simplify the build process, all of the off-the-shelf parts and stock needed to reproduce this build can be found on Amazon, McMaster, or Grainger. These parts and stock are common and it is likely that other suppliers would have identical or substantially similar parts available. The aforementioned suppliers were familiar to us and had decent prices on the parts we needed, which allowed us to stay under the \$400 project budget that we had. A full bill of materials needed to make this design can be found in appendix C.

The manufacturing of all of these parts was done using the resources available to us in both the U-M Mechanical Engineering Machine Shop and the Ford Motor Company Robotics Building Makerspace. The Machine Shop tools that were used included 3-axis mills, lathes, drill presses, horizontal and vertical bandsaws, and a CNC waterjet cutter. Any reasonably-outfitted machine shop would be able to replicate this design, with the only specialty piece of equipment being a CNC waterjet cutter, though the waterjetted parts could likely be milled, albeit with more complicated machining setups than the ones available to us. The only Makerspace tools that we used were two 3D printers: a Fused Filament Fabrication printer and a Stereolithography resin printer. FFF 3D printers are so ubiquitous that we would consider this a standard tool in most manufacturing environments, while SLA 3D printers are a bit more specialized. The SLA parts in this build could likely be done by an FFF printer with sufficient testing and modifications prior to deployment, but would likely best be served by a print-to-order service like Protolabs or

Xometry if in-house SLA printing is unavailable. Manufacturing and assembly plans for all parts of the build can be found in appendix D.

Similarities between Build and Final Design

As mentioned before, the build design mostly follows the final design, including the frame construction, the mechanism to remotely actuate the spring pins, and the entirety of the leg mechanism, and the mattress.

Spring Pin Mechanism. The wedge described in the final design was used in the build to depress the spring pin, which were also identical to those in the final design. This wedge mechanism was important to replicate in the build, as it is the key to the design being easy to reconfigure between the deployed and compacted states. The big problem with this mechanism is that the wedge takes a lot of force to depress the spring pin, which would make the handle really hard to use. There are a lot of variables to change here, including the spring pin mounting method, the type and size of the spring pin, and most importantly, the design of the wedge itself.

Leg Mechanism. The leg mechanism was built exactly as designed and was found to have minimal issues. The biggest issue with the leg mechanism was that there was too much play in the mounting of it, which is something that could easily be fixed by a redesign of the leg mounts to have a third screw that is not in line with the others. The other issue with the leg is that it does not sit tightly in the groove that we designed when in the carrying position, indicating that the geometry of the groove likely needs to be changed.

Mattress. The mattress was built almost exactly as designed. Ideally, some sort of wood or other stiff material would've been used on the underside of the mattress to make it stiff, however the only material that we had the time to manufacture into the necessary shape was cardboard. This proved to not be stiff enough when a roughly 10 lb stuffed animal was put into the bassinet in the deployed state, as the mattress had a noticeable bow when this weight was applied.

Differences between Build and Final Design

The build design mostly follows the final design. However, the fabric cover and the handle are different, which will be explained below.

Fabric Cover. Due to the limited timeframe of the project, the fabric cover construction was simplified in the build. Instead of zippers along each tube that the cover went around, the build had a fabric cover that fit inside of the frame like a garbage bag fits in a garbage can. This still allowed us to test the ability of the fabric to hold the mattress up, but doesn't exactly mimic the construction in the final design.

Handle. In the process of preparing the build, we did initially assemble the handle in the same way that the final design had it. However, when we did this, the string that actuates the spring pin was unable to smoothly run over the edge of the tubes on its way from the handle to the spring pin. Thus, the 90 degree angles that were causing the issues were modified so that the string was

running through some PTFE tubing around these corners instead of rubbing on the tubing edges. This allowed the tubing to go around these corners much more smoothly.

Even with this change to the corners, three 90 degree angles proved to require too much force to actuate the spring clips with the wedge mechanism we designed. Thus, on the build, the handle was removed and the strings came out of the frame on the same plane as the telescoping tubes. This meant that the string only had to go around two 90 degree angles to the actuation point and that the spring pins could still be remotely actuated.

Description of Verification and Validation Approach

After reaching a point in our analysis where we were ready to move forward with specific subassembly geometries and materials, we applied appropriate techniques to verify that our designs met specific design requirements and specifications. This allowed us to identify and, if time permitted, correct any issues in design and functionality. The following sections describe our verification plans for each of our product requirements, and Table 5 below provides our progress in meeting product requirements and verification testing expectations.

Requirement	Testing Description	Status	Plans for failure
Portable	CAD Visual Inspection Measure Prototype Weight	<i>PASS</i>	Design iteration in CAD until we fit into our bounding box.
Affordable	Cost estimation on mass manufacturing parts (Boothroyd et al., 2010)	<i>FAIL*</i>	Within 10% over the price target can be worked out with further development
Usable by newborns and young infants	CAD Visual Inspection of Product Volume	<i>PASS</i>	Design iteration in CAD until we fit into our bounding box.
Stable when used during sleep	Statics Analysis modeling ASTM Stability Test	<i>PASS</i>	Structural redesign to reinforce failure points
Durable when in use and over time	Statics Analysis modeling ASTM Stability Test	<i>PASS</i>	Structural redesign to reinforce failure points
Regulation size	CAD Visual Inspection	<i>PASS</i>	Design iteration until components sizes are compatible within multiple configurations
Easy to Assemble	Quantify user assembly steps with final design	<i>PENDING</i>	Rethink or simplify component interfaces to reduce assembly complexity
Intuitive to use	Usability tests in assembly	<i>PENDING</i>	Simplify user interfaces to increase success cases among participants

Washable	Wipe or wash relevant component	<i>PENDING</i>	Consider appropriate materials
<p>* Total cost estimated as \$107.49, which is over \$100 price target. However, this is a cost estimation on a prototype product that would need substantial development to move forward into mass manufacturing, and thus it is likely that the cost of production could be lowered below \$100.</p>			

Portable Verification

Our goal is for the product, when stored, to be able to fit into standard storage spaces and transportation compartments. Our target folding dimensions, 24”L x 18”W x 9”H, are influenced by product benchmarking, sponsor input, and carry-on luggage sizes. We used a CAD bounding box of the folding dimension size (see Figure 29) to verify if our latest full-scale CAD model meets portability standards, and is proportional in size to a variety of users using visual inspection.

Additionally we are able to use this model to inspect delicate interfaces that play an essential role enabling product portability. We are able to visualize the telescoping interfaces (see Figure 29) and interactions between the wedge and spring pin clip, which is nearly impossible to do in real life without altering component dimensions, as we physically can’t see down the tube. If complications arise for these mechanisms, we can use our model to identify locations of stress imbalances and component dimensions to change to address identified issues.

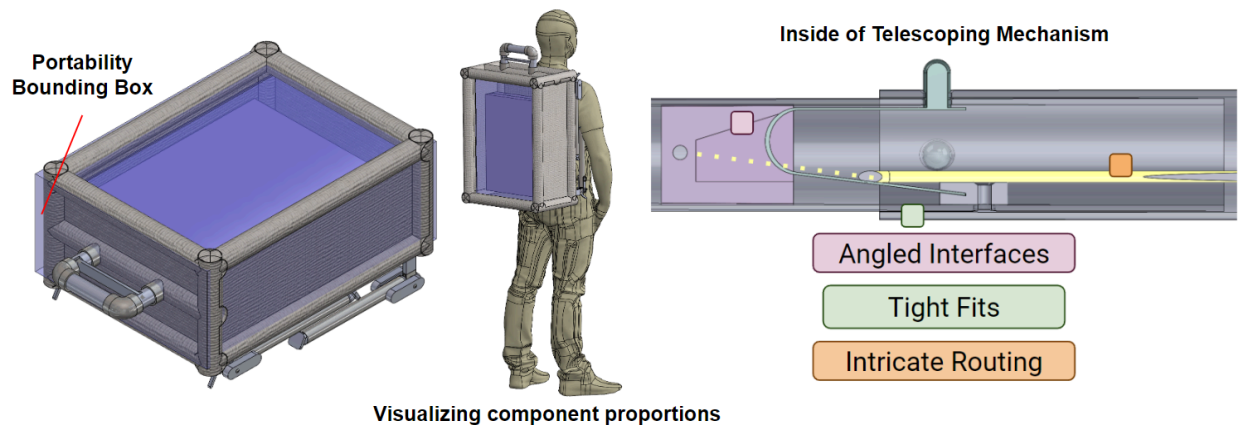


Figure 29. Visual Inspection Methods using CAD Model. The figure in the center is a 6ft male wearing the bassinet in its portable position

Our final prototype weighed to be 8.5 lbs, leaving plenty of weight allocated for structural reinforcement and additional items the user may want to carry in the portable configuration.

Affordability Verification

The price to the consumer must be < \$100, which we have accommodated in earlier design phases by carefully selecting geometries and materials to induce low weight and low cost manufacturing. To estimate what the bassinet would cost when manufactured at a large scale, the manufacturing cost of each part was estimated. For standard parts, like fasteners, and textile parts, like the mattress and fabric cover, comparable products were found on wholesale sites and the prices of those were used. For custom-manufactured parts, which were estimated as extruded and (sometimes) machined for metal parts and injection molded for plastic parts, methods from *Product Design for Manufacturing and Assembly* (Boothroyd et al., 2010) were employed. Appendix E contains a table showing the results of this analysis for each part.

Once the manufacturing cost per part was calculated, it was multiplied by the quantity of each part and summed to get the manufacturing cost per assembly of \$63.98 per assembly. To make the analysis easier assembly cost was estimated as 20% of the manufacturing cost, totalling \$12.80. Per the recommendation of Professor Randy Schwemmin, the overhead cost of a hypothetical company that manufactures this bassinet was estimated at 40% of the manufacturing and assembly cost, totalling \$30.71. Summing these together, the total cost of the product to produce is \$107.49.

This is a preliminary cost analysis of a prototype product that needs substantial development in many areas to even start moving towards mass manufacturing. Thus, even though our cost estimate shows that the cost of the product is even more than what a hypothetical company would want to price it at, it shows that this prototype is not too far off from meeting that <\$100 price specification. With more development on designing for manufacturing and further prototyping of the system as a whole, it is likely that the real cost of manufacturing this product would be below \$100 and allowing a hypothetical company to be profitable while pricing this product at or below \$100.

Usable Verification

Users expressed a need for a product large enough to accommodate infants across a broad size range, and comfortable for daily interaction. Hence, our product provides a sleeping space (total product volume) that is no greater than 30"L x 18"W x 28"H, which was verified using visual inspection of our CAD model.

Stable Verification

The ASTM Bassinet Standard specifies that a product in all manufacturer's recommended use positions shall not tip over and shall retain the CAMI dummy when tested in accordance with physical world stability test. The test outlined in section 7.4 of the standard involves placing a 23-lb vertical load and 5-lb horizontal load on the most onerous point of the bassinet for 10 seconds to simulate the mean strength of a male 2 year old.

Before proceeding with the purchase of materials for our full-scale prototype, we performed a simple statics analysis on the bassinet as a quick way to verify that our product would meet our stability specifications. This calculation was to ensure that we wouldn't waste funds on materials in the event of a necessary redesign should the stability analysis fail. In the bassinet standard, the stability test described involves the application of a vertical load of 23 lbs and a horizontal load of 5 lbs. Within this test, there is an angle stop on the ground that prevents the bassinet from being able to slide on the ground, forcing the tipping condition. That horizontal load is pointed towards the angle stop. **Figure XX** shows the forces acting on our bassinet. F_{as} represents the force applied by the angle stop on the feet of the bassinet that are pushed against the angle stop. F_f and F_N represent the friction force and normal force, respectively, on the two feet that are pushed against the angle stop. Because the bassinet is forced into its tipping condition, in which the two feet not contacting the angle stop would be just barely separated from the ground, these two forces can be neglected from the two feet not contacting the angle stop. The weight, W , applied at the object's center of mass includes the weight of the bassinet and the weight of a CAMI dummy, which is part of the standard's test. This weight force is shown in the free body diagram of **Figure XX** in addition to the applied vertical and horizontal forces described in the standard. These vertical and horizontal forces are represented as P_y and P_x , respectively.

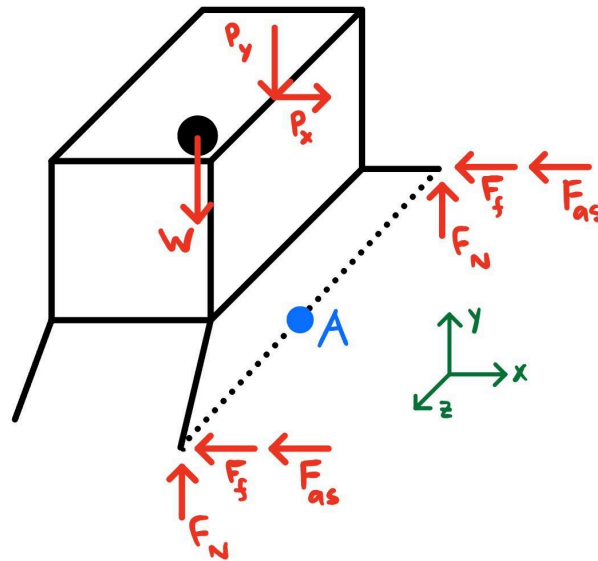


Figure 30. Free Body of Diagram with Forces Acting on Body

In this analysis, the resultant of the applied forces, P_x and P_y , was assumed to act in the same direction as the resultant of the corresponding applied forces in the standard's test. Thus, the resultant applied force, P , can be written in terms of the two components of the applied force, P_x

and P_y , using the same angle that exists between those two force components in the standard's test. Therefore, P_x and P_y can be written as Equations 1 and 2 below:

$$P_x = P \times \sin(13^\circ) \quad [1]$$

$$P_y = P \times \cos(13^\circ) \quad [2]$$

In the following analysis, the applied force P required to maintain equilibrium was solved for and compared to the resultant applied force in the standard's test. To do this, moments were taken around Point A in the z-direction shown in the above figure, resulting the following equation:

$$(W \times r_w) - (P_x \times r_p) = 0 \quad [3]$$

In this equation, r_w represents the moment arm distance between Point A and the weight force W while r_p represents the moment arm distance between the horizontal applied load P_x and Point A. All other forces in the figure above did not contribute a moment around Point A in the z direction, so were neglected from the above equation. r_w was determined through inspection of our CAD model to be 9 in. while r_p was determined to be 23 in. through inspection of our CAD model. While the exact weight of our bassinet is currently unknown, for the purposes of this analysis, we assumed it would be the maximum weight allowed by our portability requirement, which is 15 lbs. After substituting Equation 1 into Equation 3 and solving for P , the following equation was obtained.

$$P = \frac{W \times r_w}{r_p \times \sin(13^\circ)} \quad [4]$$

After plugging in numbers for each variable, P was determined to be 41.5 lbs. This is the maximum force that can be applied to our bassinet while maintaining equilibrium under the conditions described in the standards test. The corresponding force in the standards is the resultant force of the 23 lb vertical load and the 5 lb horizontal load, which is 23.5 lbs. Because the force applied in the standards test is below the maximum force that our bassinet will be able to sustain without tipping, this analytical verification shows that our stability specification will be met.

Durable Verification

Verifying this specification involves applying a 54 lb static load for 60 seconds onto the center of the bassinet mattress, as described in section 7.3 of the standard. Similar to the stability verification, we performed some simple analytical calculations to provide assurance that our design will be adequate to withstand the test load. A statics analysis informed us if there are any major issues with our material selection or design choices with respect to durability.

Figure 31(a) below shows a top view of the mattress with the blue rectangles representing members of the PVC pipe frame. As shown in the figure, the 54 lb load is distributed over a 6 in. by 6 in. area on the mattress, which is represented as the large black rectangle. The purpose of this analysis is to determine whether or not any of the PVC pipe beams onto which the applied force is transmitted will yield. In this analysis, a couple simplifying assumptions will be made. Each pair of telescoping tubes will be viewed as a single beam with a length equivalent to the expanded length of the bassinet. This assumption works if the fit between each tube in a pair of telescoping tubes is tight. Additionally, the 54-lb force will be represented as two point loads, each with a 27-lb magnitude, applied at the center of each of the long beams. This assumption is fine to make because it represents the most extreme way to distribute the 54-lb load to the beams. In other words, if this load case doesn't cause the beams to fail, then no other possible loading case will.

Figure 31(b) shows a free body diagram of one of the telescoping beams with the point load P acting at the midpoint of the beam. The magnitude of this force is 27 lbs, half of the magnitude of the total force being applied in this test case. The other half is applied to the beam on the opposite side of the bassinet. For the sake of this analysis, the end points of the beam were represented as built-in supports. The magnitude of the moment at a built-in support is equal to $PL/8$, as shown in Figure 31(b).

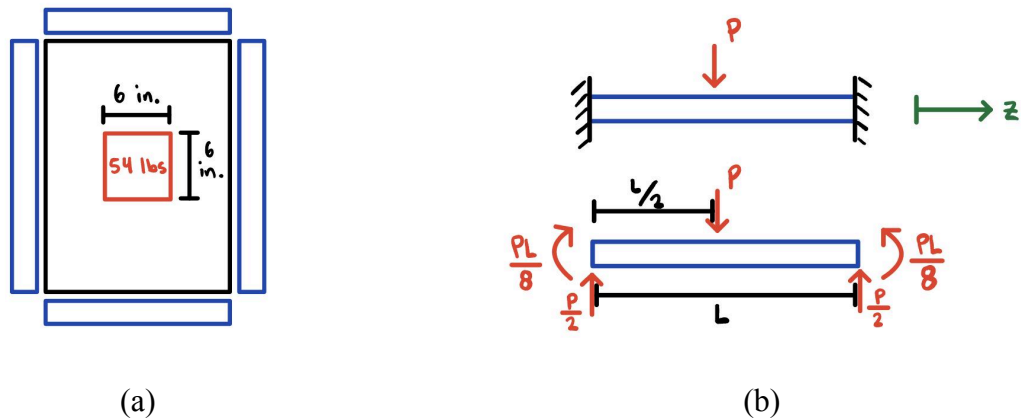


Figure 31. (a) Top view of the bassinet with the load represented as a red box placed at the center of the mattress. (b) Free body diagram of one of the PVC pipe side beams. This particular beam was analyzed because it will experience the largest load and will therefore be the most likely to fail.

To determine whether or not this beam will yield, the maximum stress experienced by the beam needs to be determined. We first found the maximum bending moment in the beam by constructing shear force and bending moment diagrams, shown below in Figure 32.

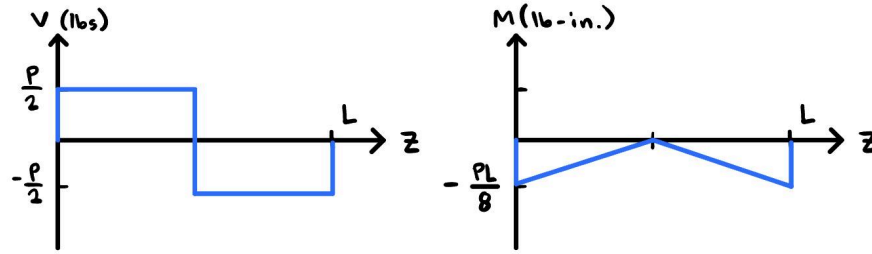


Figure 32. Shear force diagram along the beam under examination on the left and corresponding bending moment diagram on the right.

As can be seen in the bending moment diagram of the figure above, the maximum bending moment occurs at the end points of the beam and has a magnitude of $PL/8$. With a force P of 27 lbs and a beam length L of 35 in., this maximum bending moment, M_{max} , has a magnitude of 118 lb-in. The maximum stress, σ_{max} , can be calculated using Equation 5 below.

$$\sigma_{max} = \frac{M_{max} r}{I_{xx}} \quad [5]$$

In the above equation, r is the outer radius of the telescoping tube and I_{xx} is the second moment of area of the tube, which is 0.0329 in.^4 for a tube of our cross-section dimensions. Plugging in values to the above Equation yields a maximum stress of roughly 1800 psi. These beams will be made out of polycarbonate, which has a yield strength of about 9000 psi. As discussed earlier, the simplifying assumptions made to construct the analytical model resulted in the 1800 psi being an overestimate of the actual maximum strength experienced by the bassinet. Thus, the yield strength of polycarbonate is well above the maximum stress experienced by the bassinet, so the product should have no problem withstanding the 54-lb load and passing the durability specification.

Regulation Size Verification

Certain bassinet-specific components must adhere to dimensional restraints described by the ASTM standard, such as minimal gap between mattress and inner perimeter and mattress sizes. As we modeled our product, we outlined any specific restraints presented in the standard that we wish to hold true as we make iterations in our design. Visual inspection of the CAD model will allow us to verify this specification.

Ease of Assembly Verification

Our product is considered easy to assemble if it takes less than 5 steps to do so. A step is defined as one movement with up to 2 pieces of hardware being added/subtracted to the product. Below, we have identified the steps users must take to convert the product between sleeping and portable configurations in **Figure XX**. Both conceptually, and using our prototype, a user may do so in 5 steps.

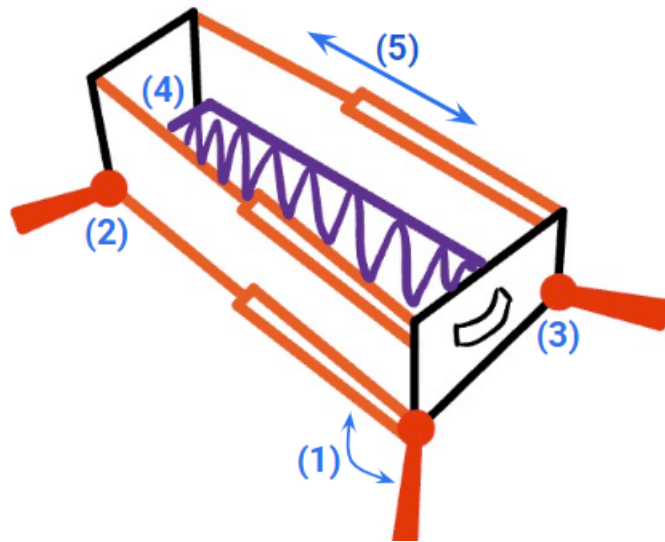


Figure 33. Assembly steps 1-4 configure the legs, while step 5 engages the telescoping frame.

Intuitive Use Verification

We wished to gauge the amount of intuitive vs. cognitive effort that accompanies use of our product, considering the highly dynamic nature of the problem context. If the user is unsure of correct assembly or product use, they will lose their faith in the product being valuable to them. To mitigate design biases in testing, we wished to have 10 people who knew nothing about the device put it together. By the time our allotted fabrication and assembly time was spent, nuanced component failures such as wobbly leg interfaces, loose fastening materials, and a highly sensitive bowden cable mechanism made our prototype extremely delicate to handle, and so this test could not be conducted.

Washable Verification

Our product should use wipe-clean grade material that is machine washable. In designing, we chose from materials that have been graded for food. We considered mesh materials for parts of the bassinet that would allow the user to see the baby easier, while other parts will be thicker and stronger fabrics to support the weight of use cases. There will be delicate stitching between these parts, so we wished to test with machine washing 20 times to make sure it doesn't fall apart. While there was inadequate time to perform this test, we sourced and altered a vinyl cushion cover to serve as a wipeable mattress sleeping surface, compatible with the commonly sold ~32" x 18" bassinet mattress sheet. Additionally, we sourced utility mesh that is used for functional purposes and is known to be machine washable. While we haven't manually completed this verification test, we have much optimism in their results.

Product Validation Suggestions

In verification testing, we asked ourselves “Did we make the product correctly?” Now we seek to know, “Did we make the correct product that solves the needs of our primary stakeholder group?” Although there is not adequate time for us to produce a detailed product subject to usability validation testing, we have explored factors for validating the success of our design that may still be useful to our sponsor and further standard development.

Product Usability Validation

Our verification testing does not offer much insight into the amount of comfort or discomfort that the caregiver may experience when transferring an infant in and out of the product. Stakeholders have described their interactions in putting their infants to sleep, and in some cases, the caregiver may have to leave their arm in the product until the infant falls asleep. These accounts have painted a picture of a wide array of use cases that the ergonomic design of our product may or may not be compatible with. If there are general amenities to comfort that a user can identify while using our product, this information would be helpful for future developers to know.

Even more unfamiliar to us is how the product in its collapsed, portable configuration, will meet user desires of comfort, intuitive use and aesthetic quality. Usability testing will be especially informative for this as well. Given more time, we would have liked to observe our stakeholders interacting with and storing the portable device in common storage locations offered by public modes of transportation, or by temporary housing situations such as hotels and shelters. We have tried our best to engage stakeholders throughout our design process in ways that have made the product more ergonomically sound, such as folding the legs along the length of the frame, providing the user with more space for their back to comfortably support the backpack configuration.

Usability tests would tell us the order in which steps are most comfortably taken in order to write a simple, intuitive instruction manual, and we must figure which steps are particularly difficult/time consuming. Caregivers of the University of Michigan community easily understood mechanisms and component manipulation, as expressed when we featured our product at the Winter 2024 Design Expo, however, we wish to document insight from our primary stakeholders on the intuitive nature of the Backpack Bassinet.

Additionally, we intend for the washable parts of the product to withstand multiple washes in a week, so full scale testing would require us to wash the fabric components 156 times to gauge everyday maintenance durability. This will help us determine which fabrics and materials used in the product can sustain this amount of washes, while still providing desired qualities for vision and support of the infant. Our prototype used Utility Mesh, a material project experts recommend

for making *and washing* structural components as common as Bassinet covers, however, we admit that simulating lifetime wash durability is an informative mode of testing that entities with greater resources and time would be able to conduct.

Many of our observation modes would be most useful and ethically sound if conducted using the ASTM Bassinet standard protocol prescribed CAMI infant dummy, which we were not able to source given its high expense and low accessibility to alternatives. For low fidelity testing of our prototype, one of our team members suggested the use of their Hugimals Weighted stuffed animal, to loosely capture at the least, the weight distribution of a 0-5 month old infant, aiding in visualization of our validation suggestions.

Manufacturing Process Qualification

Given a final product design, the process design (i.e. manufacturing processes) must be evaluated to determine if they are capable of reproducible commercial manufacturing. In selecting these processes for a final design, we must gain a high degree of assurance in the performance of those processes. We must understand sources of manufacturing variation and gauge their impact on our specific components. We are interested to see how such decisions will affect the costs at which we are able to produce the product, and it takes much more time and development than allotted to us to make conclusive decisions about this.

Given we have explored these decisions, we would then be able to visualize product decomposition, how that affects our packaging options (and which are convenient for our stakeholders), and shipping costs.

Discussion

The ME450 Design and Manufacturing III course offers senior design students 14 weeks to engage in an in-depth, iterative design process of their choice to define and approach a unique design problem. In this section, we offer a complete critique and discussion of our design and design processes to highlight weaknesses and suggest improvements we would potentially make given more time and resources.

Problem Definition Critique

Our initial engagement opportunities with our primary stakeholder group, with our sponsor and with caregivers familiar to members of our team were highly accessible and responsive. Our meetings with KiD were especially informative and drove many of our problem definition decisions, such as highlighting high rates of unsafe sleep practices among housing insecure populations and supplying us with a product price within the purchasing power of this population. If we had more time, expertise in surveying, and most importantly, access to communication with individuals who have been subject to conditions we describe, we would then be able to identify unique needs that our product could satisfy. Throughout the semester, we

tried to reach out to doctors at shelters who care for these populations, in addition to local emergency housing providers (Alpha House Ann Arbor), but these larger entities were hard to contact and did not respond. If they did, we would ask different questions concerning situation sleeping arrangements, consumer and caregiving practices, or any other need identifying questions based on their realm of expertise.

For Experts in Caregiving, especially those familiar with housing insecurity conditions :

- Can you describe your current sleeping arrangements for your infant?
- What challenges have you faced in providing a safe sleeping environment for your infant?
- How do you typically access or acquire baby products, considering your current living situation?
- What qualities or features are most important to you when selecting a sleep product for your infant?
- Have you ever encountered any safety concerns with previous sleep product's you have used?
- How often do you need to relocate/travel with your infant's sleep setup?
- How do you typically transport/carry your infant sleep setup when traveling?
- Are there specific design features or functionalities you would be willing to invest in for a portable infant sleep product?
- How much would you be willing to invest in such a product?

For Experts in providing housing and spaces for the housing insecure/displaced populations:

- What are common challenges faced by individuals experiencing housing insecurity, in providing safe sleep environments for their infants?
- What factors contribute to the safety and comfort of infants in temporary/transitional housing situations?
- What are common misconceptions or product misuses related to infant sleep safety in housing or shelter settings? How do you address them?
- How do providers such as yourself assess efficacy and suitability of sleep products arrangements for their spaces and facilities?
- How do you address mobility and portability needs of caregivers undergoing frequent relocation with their infants?
- What safety standards/protocols do you follow in selecting sleep products for infants in your facilities?

To increase accessibility to these groups, we would need time to collaborate with local shelters, community centers, or outreach programs that serve the housing insecure population. Such entities have already established relationships and trust within the community, making it easier to reach and connect with individuals with unique needs. We would wish to conduct one-on-one interviews to allow for more in depth conversations and opportunity to build rapport on a personal level, while we recognise the use of less intrusive options like online surveys and forum participation for those who may not be comfortable with in-person engagement. Either way, with ample resources, we would offer incentives such as gift cards, vouchers, meals, etc. to encourage participation and acknowledge the value of our stakeholder's time and input.

Design Critique

The Backpack Bassinet offers several strengths in addressing the needs of caregivers, particularly those facing housing insecurity; however, there are weaknesses that we would wish to address given more time and resources.

Design Strengths:

- **Unique Portability Features:** The Bassinet's ability to fold into its smaller portable configuration has been well received for a wide array of reasons. Our stakeholders appreciate our product's intended compatibility with transportation storage spaces and limited storage provided by temporary housing situations. We have received positive feedback on our design's single point-actuation, as users have expressed that interacting with multiple spring-clips, a component commonly used in manual telescoping mechanisms, is rather uncomfortable and preferably avoided.
- **Safety Compliance:** After deciphering the ASTM Bassinet standard's impact on component design, it became apparent to us that the simplicity of our structural design was easily compatible with conducting first principles statics analysis to verify the stability and durability of our product. Given more time, proper design refinement, and much help from our instructors, these tests could be modeled within FEA software to simulate real-world loading cases, however our analysis was efficient within the scope of our course.
- **Highly Intuitive Design to promote Safety:** Unfamiliar mechanisms become quickly intuitive in end use with the use of auditory cues. Both the spring clips and leg wheel joints provide clicking, auditory cues that signal the user of completion of an assembly step for either configuration. If we had more time and had conducted more research on useful safety features that can prevent, warn against, or obstruct possible safety hazards.

Design Weaknesses:

- **Product and Component Bulkiness:** Our users have expressed that while the Bassinet is being used in its portable, backpack configuration, the parts in physical contact with their back are bulky and uncomfortable to physically interface with. In order to provide more comfort for our users, we would have to consider design and cost for padding on our original design to attach to parts of the frame resting on the users back. More extreme iteration on the frame would involve replacing the rectangular shaped frame with a shape that is more suitable to the ergonomic functionality and compliance of backpacks. We must note, however, that benchmarked bassinet products that model backpack features lack structural components that normally mitigate misuse cases. Our Backpack Bassinet is limited in which surface and inclination types users can place it on, while products that lack structural integrity are more likely to be placed in unsafe, undesirable configurations and environments. This is a tradeoff that takes much time and effort to evaluate and make decisions on.
- **Complicated Machining and Combining Techniques:** As we were fabricating our prototype, we noticed small nuances in our design that make fabrication and product assembly difficult. Our telescoping tube stock had to be machined to tight tolerances at specific locations to support structural integrity and maintain defined dimensions. We imagine this is more easily accomplishable via mass manufacturing techniques, however we do realize an opportunity for strategic design. The feasibility of addressing strategic

design issues would improve if we instead addressed hardware and component assembly. Particularly, machined components and purchased hardware were modeled with clearance in our CAD assembly, but as they were assembled piece by piece for our prototype, it became harder for our team members to manipulate small components and bulky hand tools at the same time. Mass manufacturing may involve assembly by robotic arms, and so in designing a product such as this, we must consider the physical space allotted to the assembler.

Now that we are finished with the design process, we recognize general practices, if implemented more often and more efficiently, that would mitigate the design of risky components and mechanisms. We should have done more benchmarking, not only to identify what didn't work in recalled products, but also to model simple and child safe hardware design and component selection. Modern day children's products employ less extrusive hardware with softer looks that may be cheaper than industrial grade hardware selections. We could have done additional research into the childcare environment to suggest and test our own loading cases similar to those provided by the ASTM standard, and if we had the time to visualize the product used as a backpack, loading cases related to carrying product and any additional weight would be informative of any iterations needed to be made. Because of the constrained duration of this course, we couldn't conduct a comprehensive reevaluation once our final project was constructed. Time constraints prevented us from iterating through multiple prototypes as desired. Nevertheless, mock prototypes and testing still afforded comparable opportunities for reassessment.

Risks Posed by Final Design

In conceptualizing our design, we made the decision to pursue one of two comparably feasible designs, the Backpack and Basket Bassinet. We took an early risk by going with the Backpack Design, deciding that design issues associated with a telescoping mechanism would be more easily addressable considering the design experience that the University of Michigan has offered our collective team. Otherwise we would need to address geometric unknowns posed by the Basket design despite it having less hardware and easier assembly methods. Unfortunately, complexities in design are then translated to unfamiliarities to users when interacting with our product. Our Backpack design could have easily taken on a design with multiple obstructive components, however, this was avoided by placing limitations on assembly cognitive effort and by adhering to ASTM standard recommendations for component design and finishing.

Reflection

Contextual Factors

Several factors played large contributing roles throughout our project. Public health, safety and welfare was extremely relevant to our project. One of our primary goals was to increase the safety of infant sleep environments in dynamic environments, reducing infant casualties among housing insecure and displaced populations.

The social impacts associated with the use of our portable bassinet were also relevant to our project. Several examples of social impact are reflected in our project. People of different cultures may interact with the product differently from each other, underlying the importance of making the product as intuitive to use as possible. The affordable and portable nature of the product makes it more accessible to a wider range of people, increasing the accessibility of travel for families with infants. Additionally, on a more serious note, the safety of the product also relates to social impact. If this product was put on the market and its safety specs weren't met, it could be faced with recalls, damaging the reputation of our sponsor and lowering their standing for advocating for safer products in the future. Stakeholder mapping allowed us to identify some of these potential societal impacts.

Economic impacts associated with the use of our portable bassinet were less prevalent than the social impacts and public welfare factors. Some people may replace their existing bassinet with our cheaper alternative product, which could lower business for the producers of those products. The increased supply of bassinet in the market due to the introduction of our product may cause a slight decrease in the price of other bassinet products, but these shifts likely wouldn't be significant. It is also our hope that our product discourages the purchase of recalled products that are still circulating in secondhand marketplaces, producing a positive impact on the reliability and purchase of safe and inexpensive infant sleep products.

Intercultural Dynamics Between Team Members and Sponsor

The members of our group possessed several cultural and stylistic similarities and differences that influenced our approach to various design decisions. Each of us shared the cultural identity of being students, which is perhaps what caused us each to gravitate towards the backpack concept as our design alpha. Throughout the concept generation process, despite the fact that each of us generated 40 concepts independently, one of the few common design concepts we each sketched included some version of the backpack concept. Stylistic differences between members of our group were evidenced through our approaches to the construction of different subsystems. For example, some of us preferred to construct their subsystems, like the fabric cover, by physically laying out the material and parts for these subsystems next to the overall assembly, and seeing how they can integrate into our system. On the other hand, others preferred to model everything for their subsystems in CAD before continuing with any fabrication and

assembly work. However, neither of these approaches was more correct than the other as they were each beneficial in different circumstances, working with different material types.

There were also differences in identity between our group and our sponsor that contributed to our thought processes throughout the project. Our sponsor's vast amount of experience in infant products made them much more capable than us of identifying potential misuse opportunities with our product. Being aware of this difference in identity made us more cautious in designing the subsystems with potential for misuse cases to make the product as safe as possible.

Throughout each step of the design process, we regularly paused to reflect on if there were ways in which the designs of these subsystems could be misinterpreted by users. Additionally, locational differences between our group and our sponsor likely influenced our perception of the target user base compared to that of our sponsor. Our sponsor, Nancy, was located in Chicago, a much more well-populated city than our location in Ann Arbor. This difference may have given us a different view of housing insecure populations compared to the view of our sponsor. That's why we sought feedback from our sponsor before pursuing homeless shelter populations as our primary target end user.

Inclusion and Equity

Throughout our interactions between our sponsor, along with the end users of our product, there were certain power dynamics at play. Our sponsor wielded a level of power over us through their status as an expert in the field of infant sleep products. As such, we needed to get their approval before proceeding with any major design decisions or overall directional changes to the product, including changes to our target base of end users. On the other hand, our team had power over the end users because we had some freedom to decide who the primary end users were, and which of their many expressed needs we chose to prioritize, which could have influenced our design decisions in terms of what features we prioritized.

To identify and avoid other inclusivity issues, our team attempted to perform highly diverse stakeholder engagement. While we were able to engage with a broad range of stakeholders, including lower-income mothers and more well-off caregivers, it was a challenge to connect with people who work with or around homeless or otherwise housing-insecure people. Our sponsor, Nancy Cowles, attempted to connect us with some of her contacts who work with homeless populations, but each of those contacts were unavailable. Because one of our primary stakeholder targets is such people, we also contacted a local Ann Arbor homeless shelter, Alpha House, in our efforts to connect with this group of stakeholders. Unfortunately, by the time they responded to our initial request, it was too late to incorporate any potential feedback from them in our prototype. However, garnering feedback for our prototype from these people allows us to determine whether our product possesses all of the features that would appeal to a large base of target users. Thus, if we possessed more time to work on this project, we would seek to use this connection with Alpha House to validate that our prototype meets these users' needs.

Ethics

Ethical considerations played a role in our approach to resolving design decisions. The project had the potential to produce several ethical dilemmas that our team needed to face. These included decisions about whether or not to use cheaper and weaker material to lower cost. Deciding to use certain materials may have created a more unstable product, thereby decreasing the level of safety it possessed. To manage this dilemma, our team conducted verification testing for stability and durability on the prototype before fabricating it to ensure that all requirements and specifications would be met and that we haven't dangerously sacrificed durability for the benefit of affordability. On a similar note, we were faced with the decision to sacrifice sustainable design for affordability. Since each team member on this project has an interest in sustainable design, this dilemma didn't pose major challenges, but to help manage it, we regularly reflected on our analysis of the negative social impacts that accompany a product that hasn't been designed sustainably from the learning blocks. Our fairly constrained timeline also raised additional ethical dilemmas such as rushing product development due to time constraints, causing decisions to be made that could potentially decrease the safety of the product. This dilemma was alleviated by maintaining a strict project schedule to ensure that needlessly hasty decisions were not made and by communicating with our sponsor on a weekly basis to share our progress with them. These weekly sponsor meetings also placed pressure on ourselves to maintain steady progress so that we had updates to share during these sponsor meetings.

Within the scope of ethics, we also needed to manage clashes between our personal ethics and the professional ethics we are expected to uphold as University of Michigan students. This clash between personal and professional ethics also applies to the work we perform for our future employers. Such a clash may take the form of our personal priorities differing from the priorities established by these employers. For example, a team member may strongly value sustainable design while their future employer may pressure them to think about profit instead of sustainability when designing a product. This dynamic can also apply to our current project, with Kids in Danger representing the employer. There are also similarities between our personal ethics and professional ethics. Personal morals, such as honesty, respect for others, and accountability, are often included in one's personal ethics while also being things that employers and the university expect them to uphold. As such, these personal morals constantly guided our approach to communicating with our sponsor and maintaining integrity and transparency in all phases of our project.

Recommendations

As the main deliverable for this project is a physical build, it is essentially a first generation prototype of this concept. As expected, there are several issues, both system-wide and detail-specific, that must be remedied with this design before it would be ready to move forward into validation and mass manufacturing design.

Detailed Design Recommendations

There are not that many detail-oriented problems with the design as we built it. The ones we found are briefly summarized below.

Leg Mechanism. One of the main detail-level changes we recommend would be a better mounting method for the legs that has three points of contact, as the current leg design allows for significant side-to-side play in the leg mounting. This would likely be as simple as a wider mount with room for a third bolt. Additionally, the grooves that the ball plungers sit in likely need a small redesign to make the leg sit tighter in the groove.

Different Fabric for Cover. Another detail would be a different fabric on the cover, as the mesh fabric that we used was too stretchy, allowing for the mattress to bow more than it should've, and was incredibly susceptible to tears that both look bad and pose potential entrapment risks for the fingers of children that use the bassinet.

Different Backing for Mattress. The final detail would be a different backing on the mattress, as the cardboard we used was too flimsy. Something like ¼" thick plywood would likely be sufficient, though care would need to be taken to ensure that it doesn't rip through the fabric of the cover on the mattress.

System-Level Design Recommendations

The biggest problems with this design are at the system level, stemming from the limited time we had to prototype the mechanism, and are summarized below.

Spring Pin Mechanism. The spring pin mechanism is easily the weakest part of this design and potential fixes could go in a variety of directions. The crux of the problem is that the wedge that we designed requires too much force to depress the spring pin. There are a few potential solutions that we can recommend, but all of them require more prototyping on a subsystem level before being integrated into the full design.

One potential solution of this problem is a redesign of the wedge that has much less contact with the spring pin. The current design of the wedge has the opening close to the width of the spring pin in order to keep the spring pin parallel to the length of the tube. However, this is likely adding unnecessary friction and it is likely that a wedge could be designed that doesn't need the spring pin to be parallel to the length of the tube.

The other potential solution is a complete overhaul of the mechanism. By ditching this method of actuating the spring pin, other options could be explored, including something similar to the way a suitcase handle works, which uses a push rod instead of a string in tension. This would also make the system easier to assemble, especially at a mass scale.

It is also a reasonable thought to wonder if remote actuation of these spring pins is even necessary to appeal to our target stakeholders. Since this idea was added late in the design process after we met with caregivers to gain feedback on our concepts, it might be worth exploring a design that doesn't remotely actuate the spring pins. However, in order to get viable feedback from caregivers, especially those in low-income and housing insecure families, it may be necessary to develop both ideas and have them compare the physical prototypes side-by-side and ask if they would pay the additional price for remote actuation of the spring pins.

Handle and Cable Path. If the tensioned string is still a viable method of actuating the spring pin, then it would be a necessity to redesign the cable path to minimize the amount of added friction on the string. We were able to combat this with PTFE tubing around the corners, but this didn't fully solve the problem, nor would it be feasible to mass-produce in a way that keeps the price low. Ideally the cable wouldn't have to make these 90 degree turns through the tubing, so a more complicated handle design may have to be developed to achieve this.

Conclusions

In the infant sleep product market, there is a lack of safe, portable, and affordable bassinets. Our sponsor has tasked us to fill this gap by designing and building a fully functional prototype that meets these criteria. We first pursued a rigorous benchmarking process that included conducting interviews with caregivers, researching recalled bassinet products, and exploring the CPSC Bassinet standards. The caregiver interviews allowed us to identify the most critical needs and wants of potential end users in our product while the research on recalled products allowed us to discern where potential safety concerns may arise within our design and how to alleviate those concerns. The standards also provided necessary safety guidelines that we will follow throughout our design process. Each of these benchmarking techniques were used not only to acquire information, but also to craft requirements and specifications intended for our own product. The most important requirements that we established are portability, stability, durability, and affordability. For each requirement, we also created quantifiable and verifiable specifications.

With our requirements and specifications defined, we proceeded with concept generation. This process involved the team coming up with a plethora of initial ideas that were iterated into new ideas using tools including design heuristics and SCAMPER. These tools allowed us to generate a total of about 120 unique concepts, which were then whittled down to three “full” concepts. In the Concept Selection process, we created low-fidelity prototypes, namely storyboards and cheap mockups, of each of these three concepts which allowed us to identify any immediate issues with any of these designs. These prototypes also provided us something tangible that we could present to our stakeholders when obtaining feedback and preferences on the design concepts. Stakeholder engagement provided a crucial means by which we could obtain user preferences and ideas for prototyping the mechanisms incorporated into the concepts. After obtaining that user feedback, we systematically selected a design alpha through the use of a Pugh chart in which we evaluated and compared each design based on a variety of criteria. This ultimately led us to select a bassinet that also functions as a backpack as our design alpha.

This backpack bassinet design consists of telescoping tubes that can be actuated to compress or expand the bassinet to its portable or functional state. It also contains legs that fold out of the way when in its portable state. Engineering analysis was conducted through the construction of viability prototypes for each of these mechanisms and they successfully demonstrated the feasibility of each of them. We also employed several verification techniques, including statics analyses and CAD inspection, to evaluate whether or not our design meets each of our specifications. Upon successful completion of these initial verification methods, we proceeded to fabricate our prototype. The tight project timeline forced us to rush through this phase a bit and we encountered several challenges that we needed to resolve on the fly, such as finding methods to mount our spring pin clips and to rout the telescoping rope

After assembling our prototype, we identified several of its strengths, including its unique portability features and its safety compliance, and weaknesses, including the overall bulkiness of the design and the friction associated with the cable path from the handle to each telescoping joint. If there was more time in the course, we would further explore some of these strengths and weaknesses through validation testing. These validation tests would consist of usability testing to ensure that all requirements are met for users in typical use cases and trialing the product with a representative group of users for a period of a week to gauge consumer satisfaction with the product. Given more time we would also complete additional verification testing for the requirements related to stability and durability by physically conducting the tests outlined in the standards on our built prototype. These tests had been modeled in free body diagram analyses before the prototype was constructed as an initial verification, but these analytical verification methods can contain uncertainty, so completing the physical tests would serve as a final verification for those requirements.

Acknowledgements

We have had a lot of support from various people not on our project team over the course of the semester. Without the time, expertise, and resources that these people have, this project would've been substantially less successful. We would like to acknowledge those people below.

Dr. Shanna Daly, Section Instructor, ME450: Professor Daly has guided us through this course and this project, and her knowledge of front-end design made the analysis of our design problem much more impactful than it would've been without her guidance. Additionally, her passion for engineering education is evident in the patience and dedication she shows to her students.

Nancy Cowles, Executive Director, Kids in Danger: Kids in Danger was the sponsor of this project, and we commend the work they have done and continue to do in ensuring the safety of children's products. We thank Nancy for sharing her wisdom and passion for child product safety with us and for guiding this project at every step of the way.

Don Wirkner, ME Instructional Lab Services Manager, Kemal Duran, Design Instruction Engineer, and the rest of the ME Machine Shop Staff: Every member of the ME Machine Shop provided support on this project, either through drawing reviews, direct help with machine operation, or conversations about the manufacturing processes. Don and Kemal provided us with additional support in the early phases of this project by helping us brainstorm mechanisms and prototypes to jumpstart the solution development process. We would like to thank all of the people involved with the ME machine shop for sharing their intuition and wisdom with us.

Dr. Jonathan Midgett, Consumer Ombudsman, Consumer Product Safety Commission: Dr. Midgett met with us at the beginning of the project to break down the ASTM bassinet standard and discuss other aspects of product safety that were informed by his years of experience at the Consumer Product Safety Commission. Without his expertise in this area, we would not have been able to digest the standard as easily as we did, nor would we have considered as many areas outside of the standard when thinking about safety in our design.

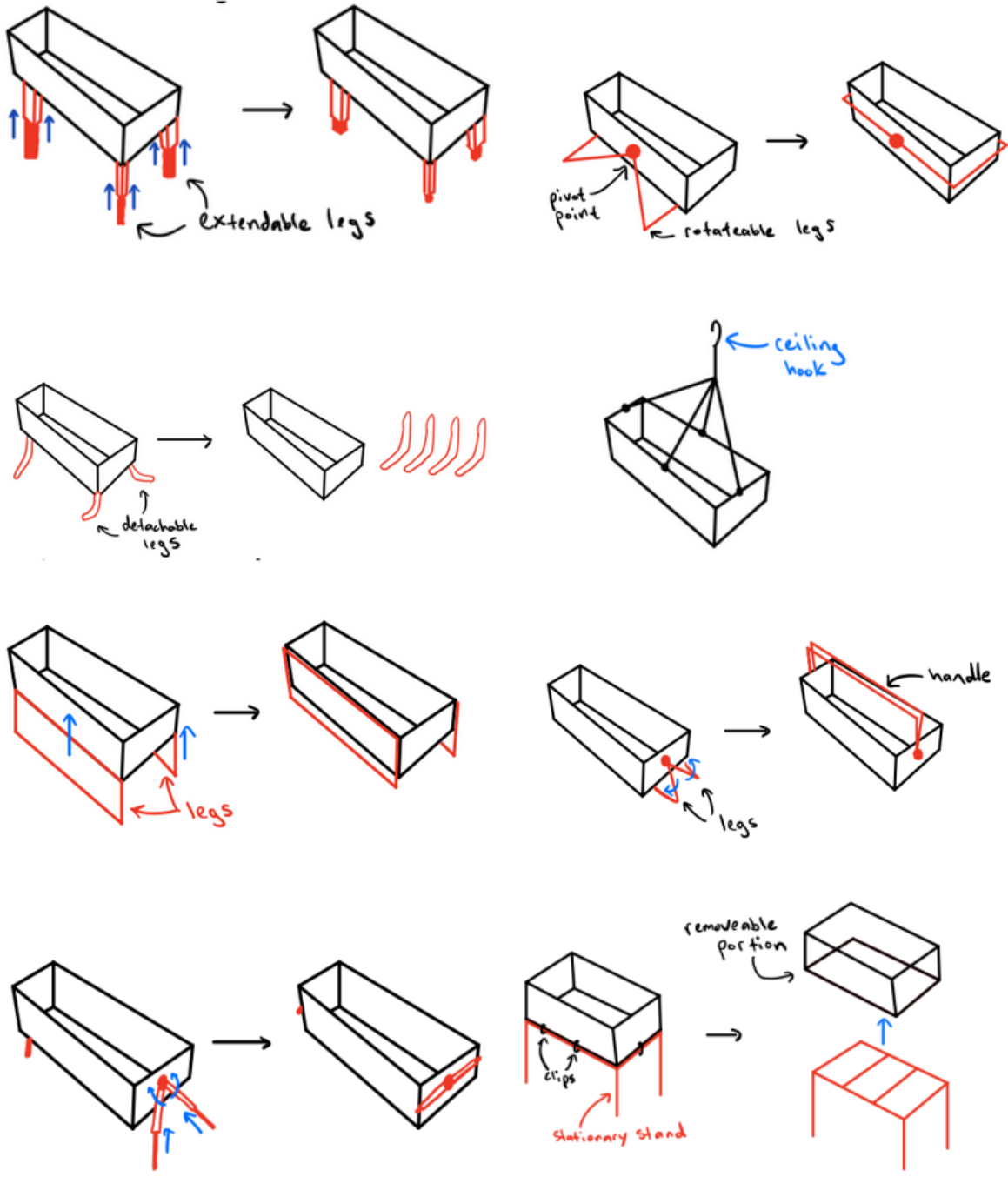
Sarah Barbrow, Assistant Director, U-M Libraries: Sarah provided her expertise in finding resources on other relevant standards to investigate test methods, especially those relating to the testing of fabrics. She is clearly very passionate about helping students find the resources they need, and we appreciate her help with our project.

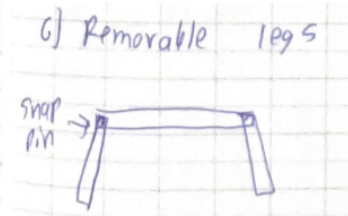
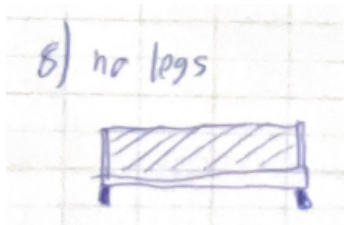
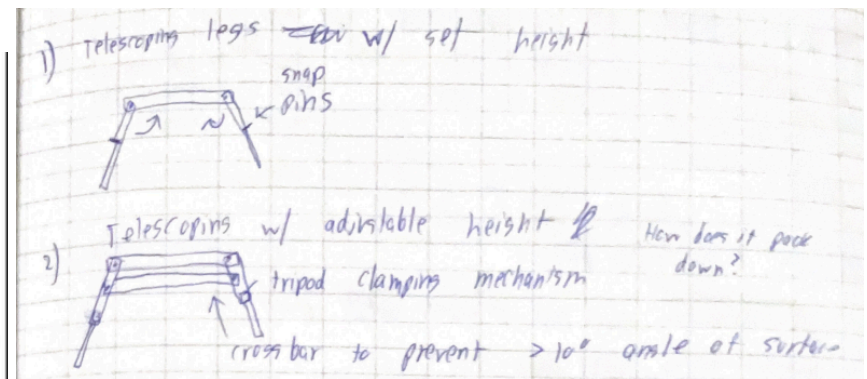
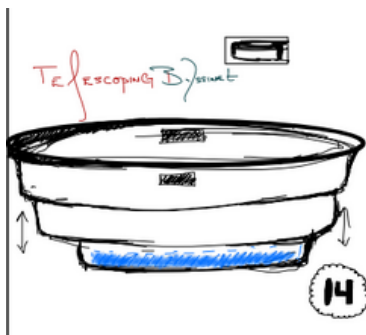
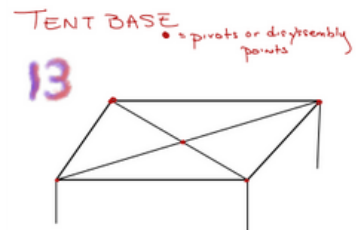
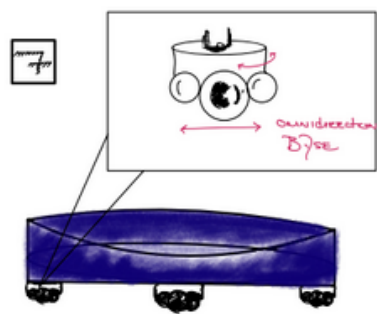
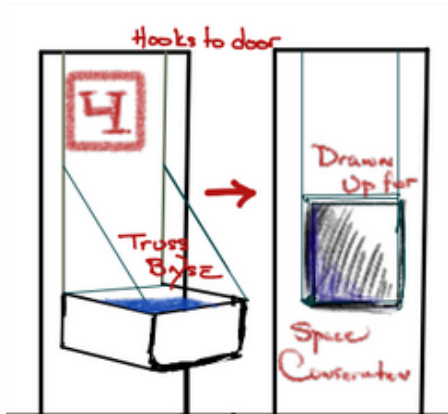
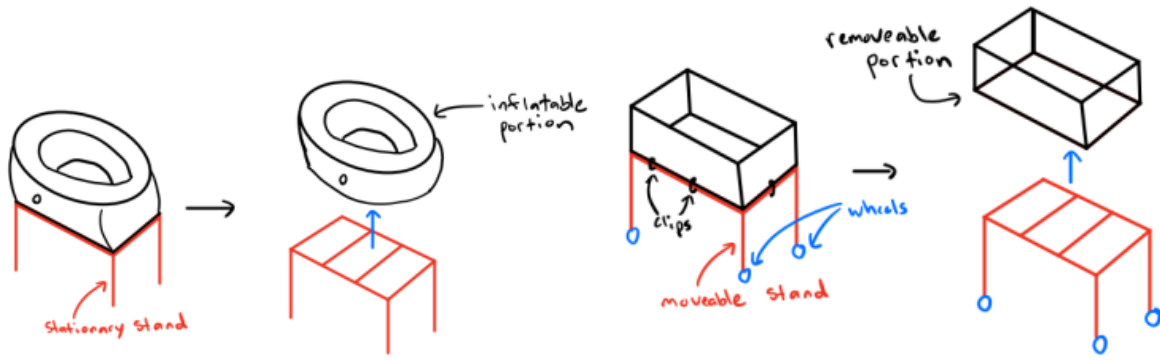
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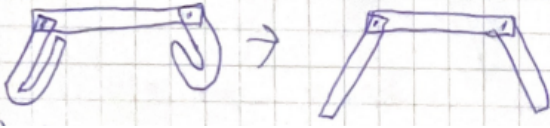
Appendix A: Concept Generation Groups

Mount/Stand Ideas

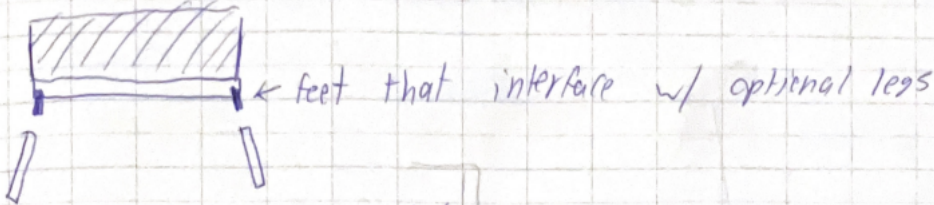




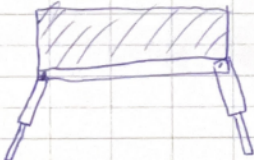
14) 13) Folded legs "tape measure idea" would need a way to make this strong enough



7) Design 6 → DH # 49 → Removable legs are optional



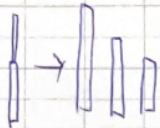
10) Design 2 → Scamper "Eliminate" → Get rid of stabilizing bar, add a level that indicates when it's past 10°

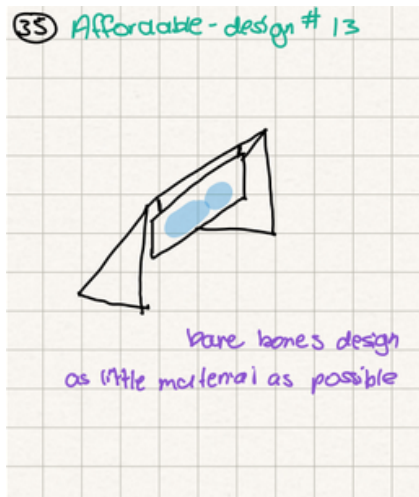
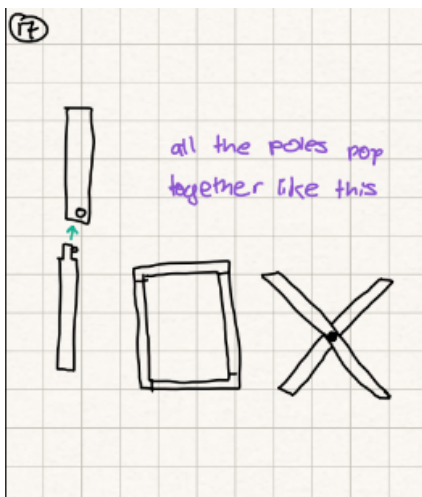
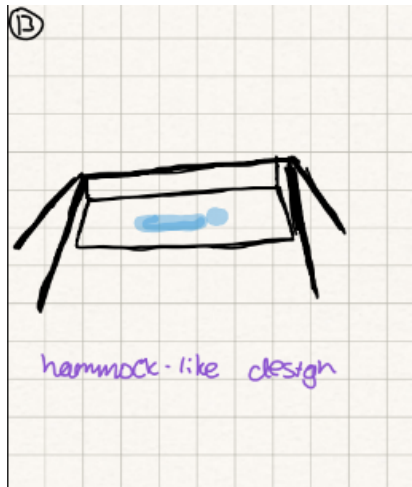
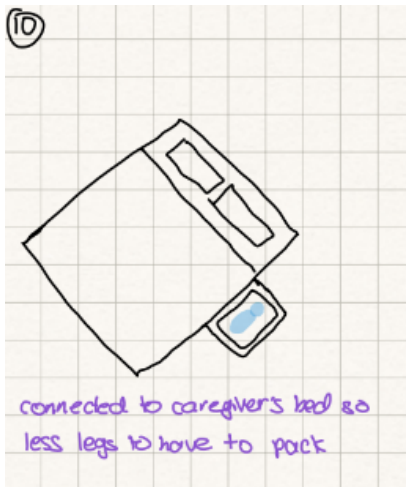
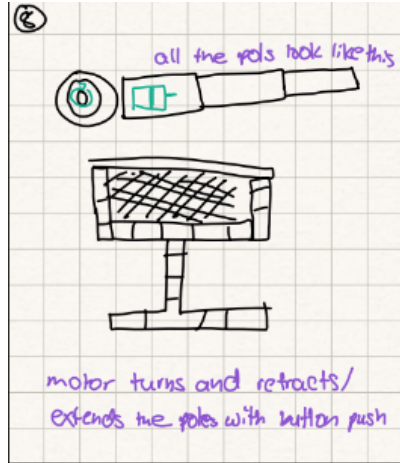
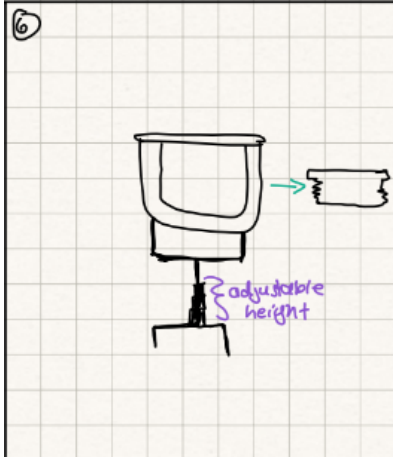
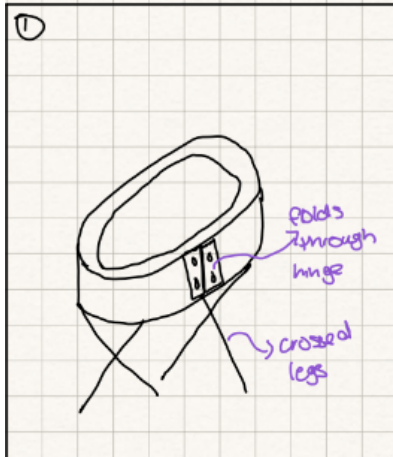


14) Design 14 → DH # 46 → Use a ^{tegrin} real springs instead of material

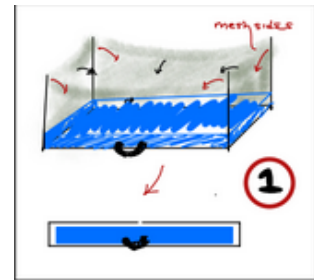
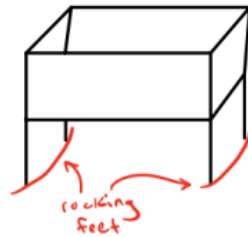
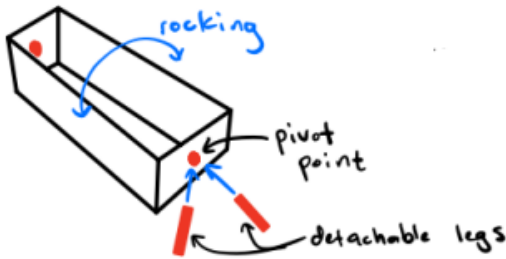
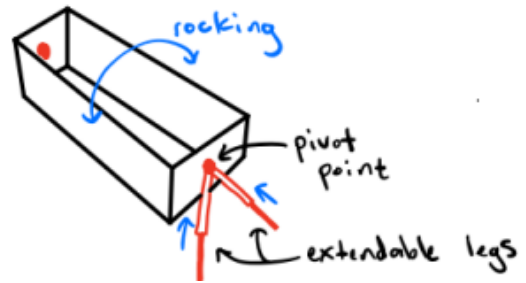
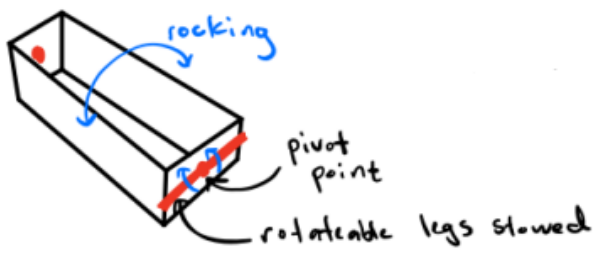


Design 5
13) ~~Adjustable side height~~ → DH # 60 → Include separate heights instead of continuous adjustment

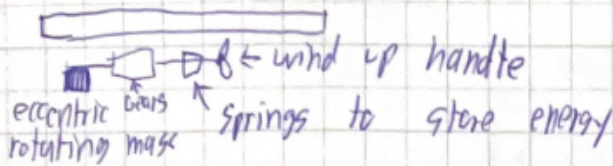




Rocking Ideas

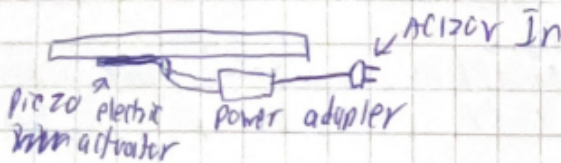


1) No-electronics vibration



stored energy in springs
rotates mass
for vibration

12) piezo-electric vibration



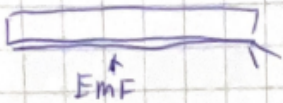
20) Rocking side-to-side Front view



1) Design 12 → TP12 Effects → Electroactive polymer

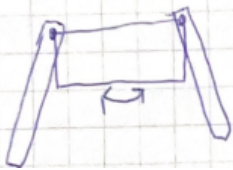


2) Design ¹² → TP12 Effects → Electromechanical film (basically a big speaker)



13) Design 20 → Scamper "Adapt" → more rocking to upper level

Front view



- legs stationary
- mattress + sliding ^{swing} move relative to legs

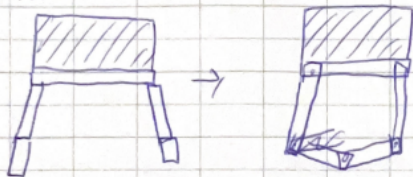
trach

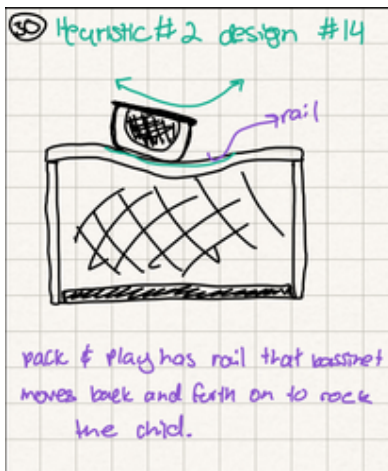
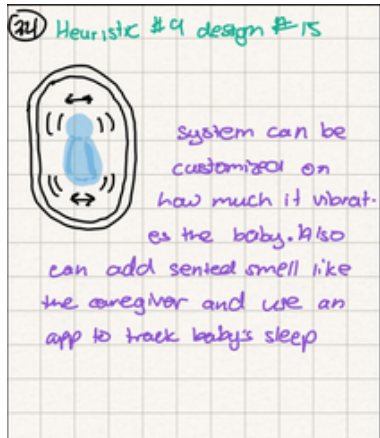
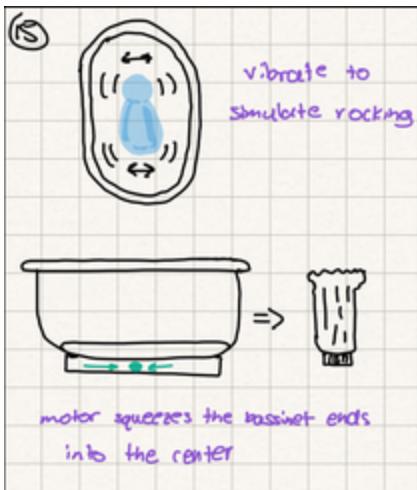
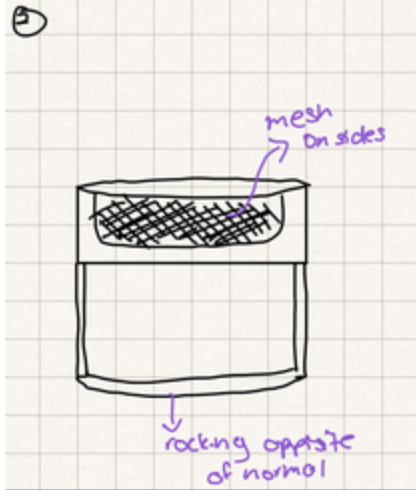
16) Design 11 → DH #49 → Powered vibration sold separately



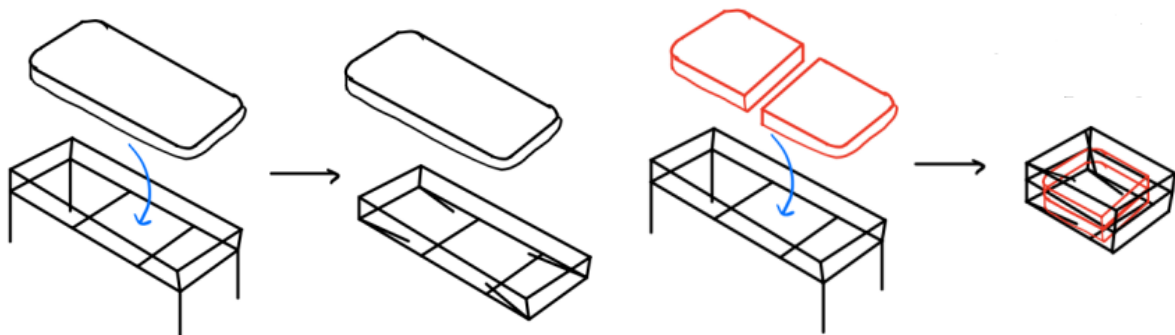
19) Design 13 → DH #26 → Legs rotate into a rocking position

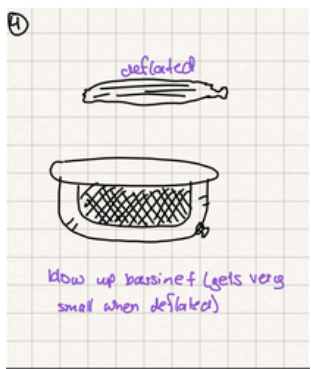
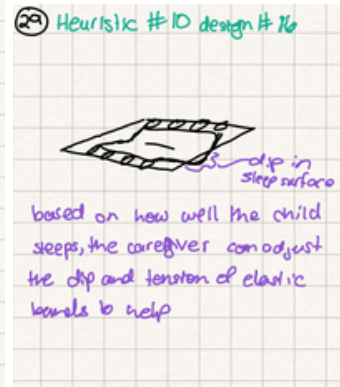
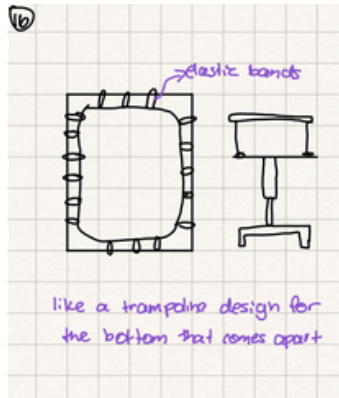
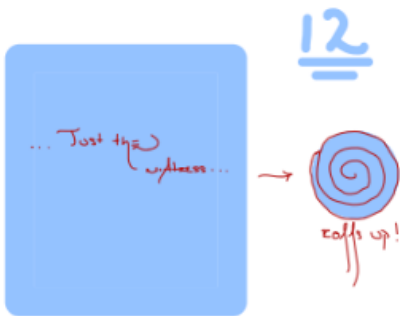
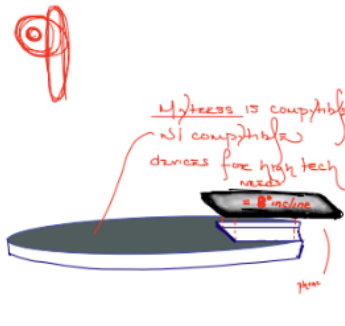
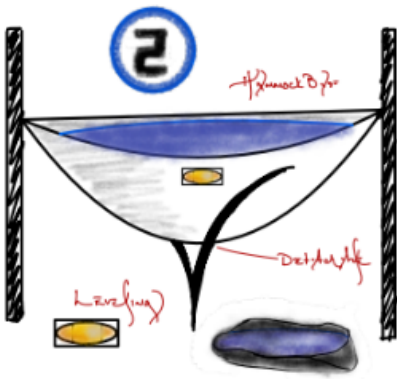
Front view



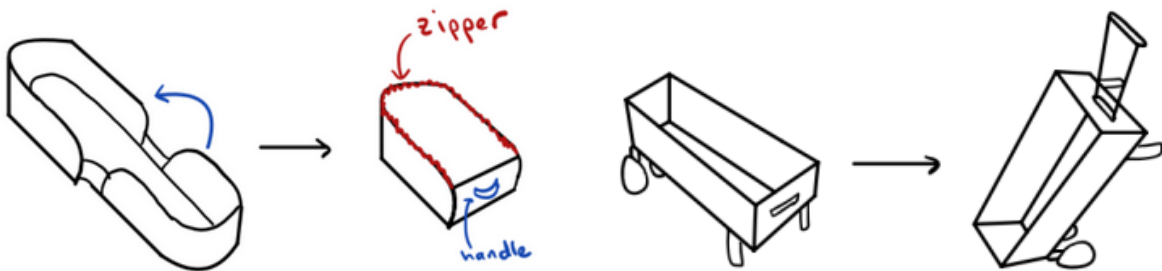


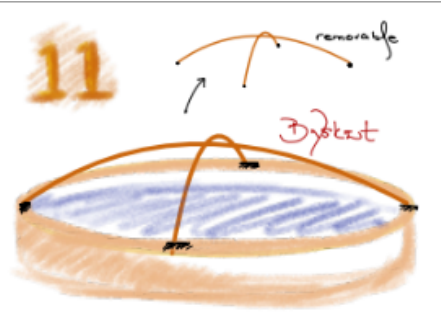
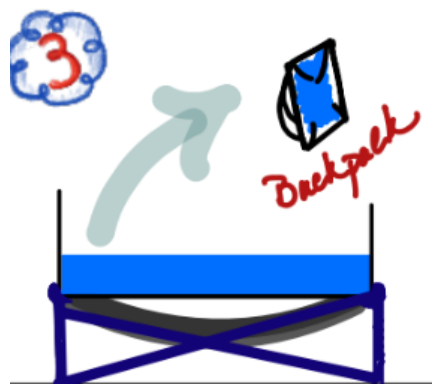
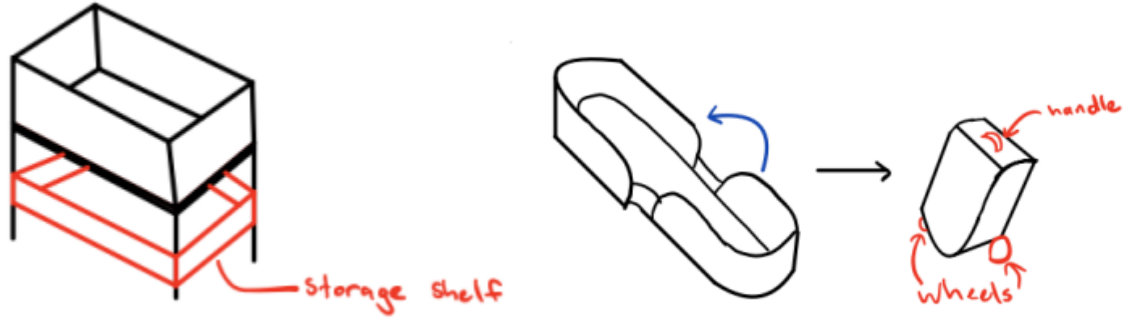
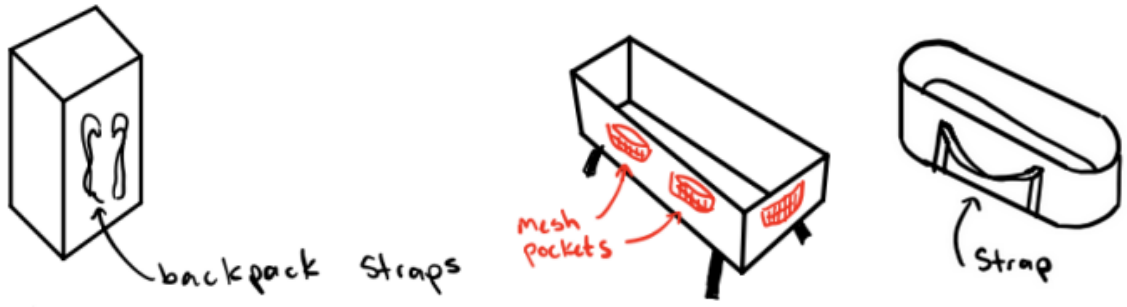
Mattress Mechanics Ideas





Bag/Storage Ideas





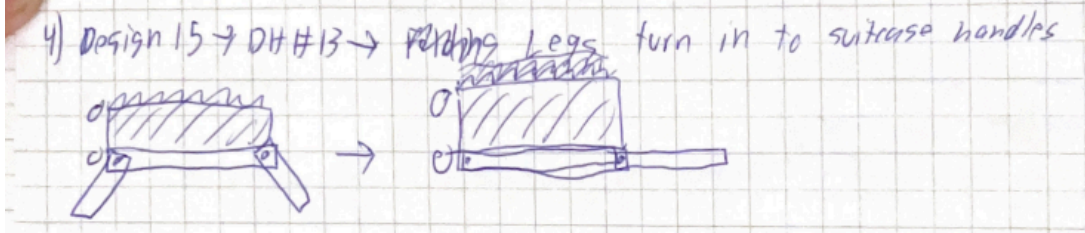
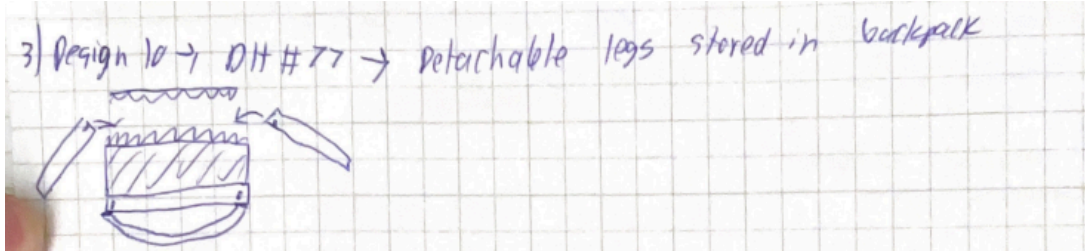
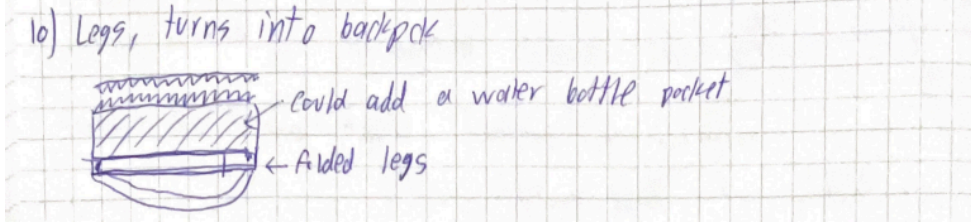
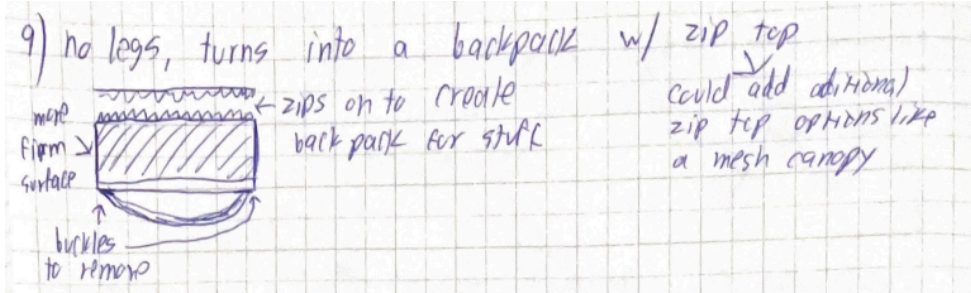
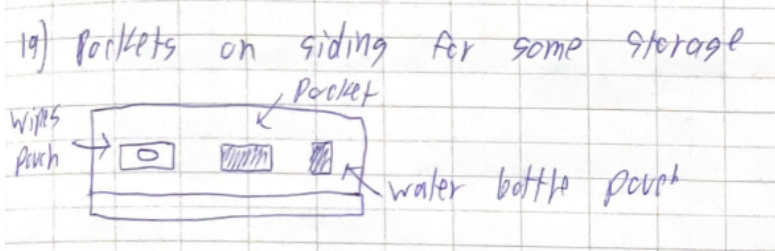
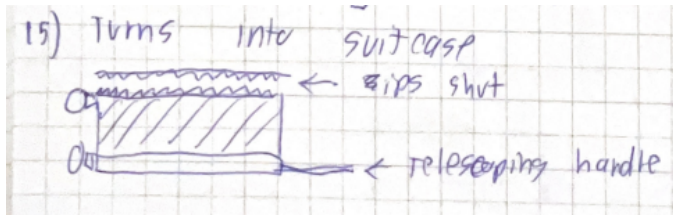
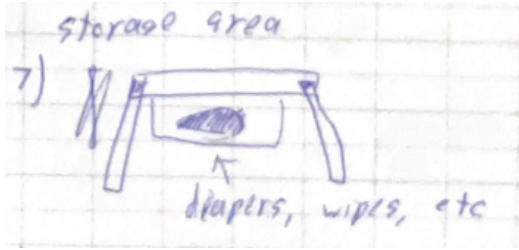
4) Use siding as carrying bag

side view

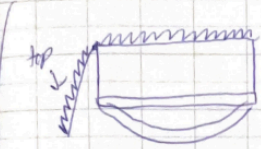
zipper

zipper

mattress comes out and sides can be zipped together, mattress and other stuff can be put in bag



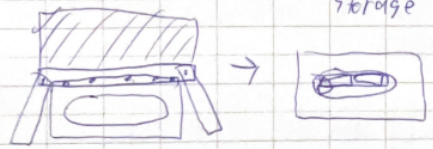
8) Design 9 → ~~scamper~~ ^{fabric} substitute → ~~hinge~~ hinge w/ ~~spars~~ spars



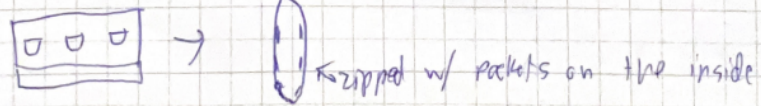
9) Previous design → DH #76 → Add zipper pockets to the "top"
Back view



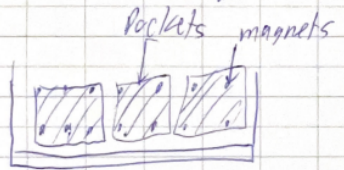
11) Design 7 → DH #26 → storage area detaches and becomes storage bag



17) Design 4 → DH #76 → make bag flip inside-out and preserve pockets to be used during regular use



20) Design 19 → ~~scamper~~ ^{"adapt"} → Magnetic array for customizable Pockets

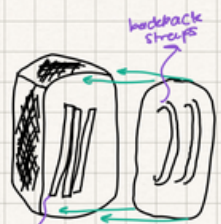


37) Durable - design #18



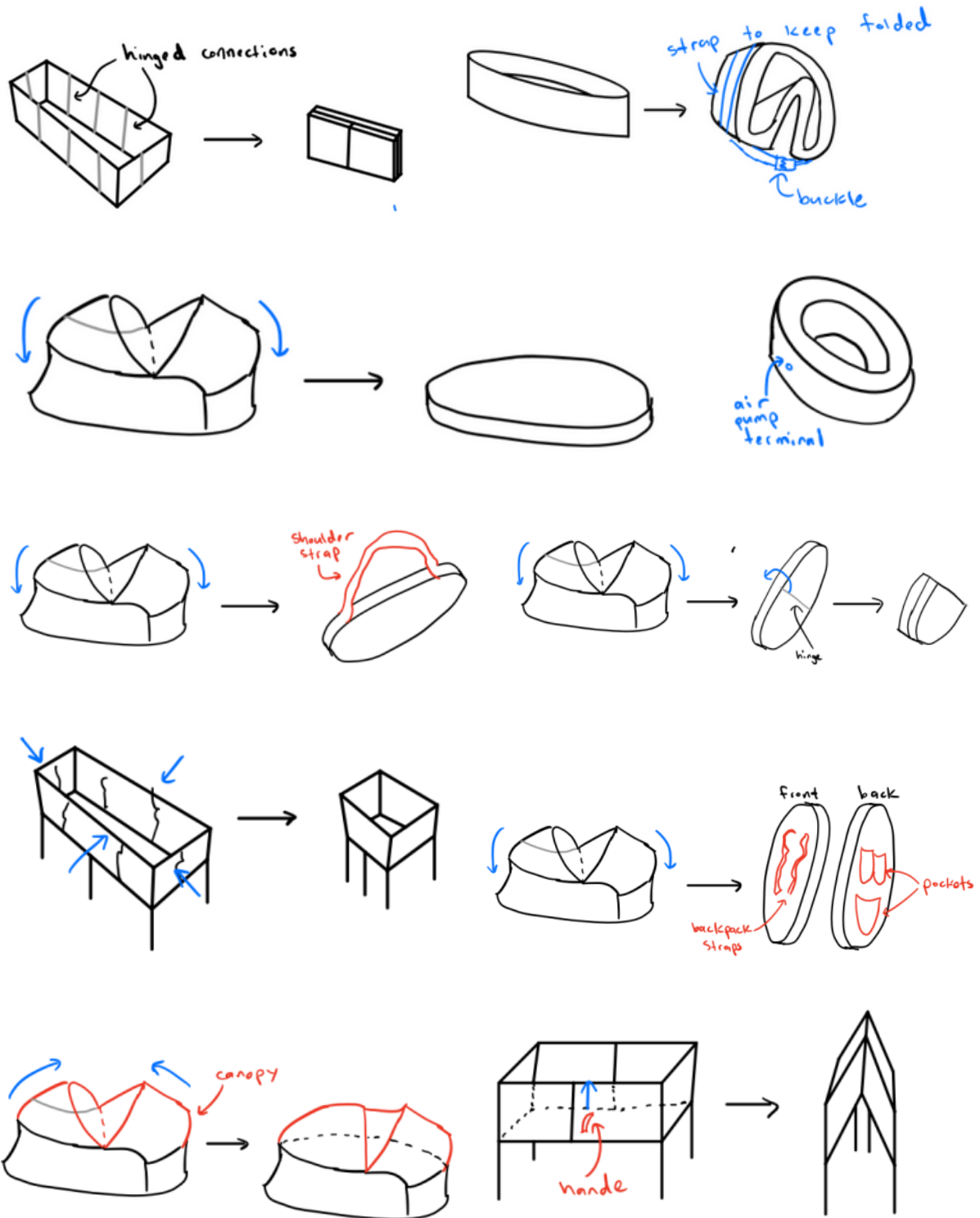
back-pack base is made out of metal to protect child within if even necessary

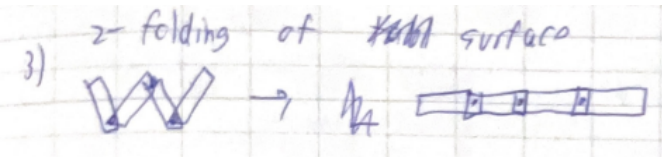
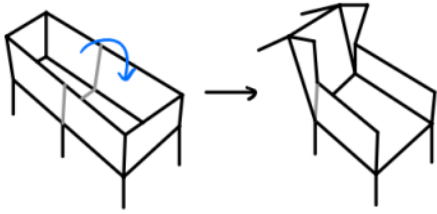
18



poles packed into center for travel

Folding Ideas



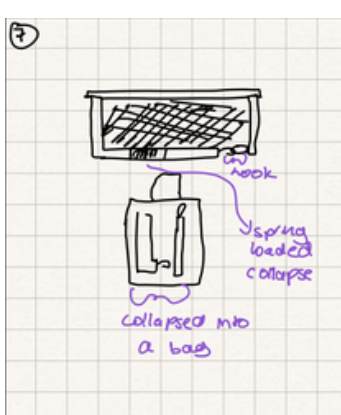
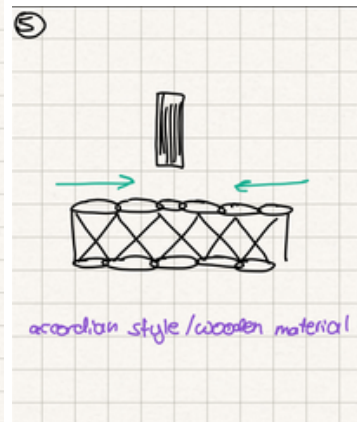
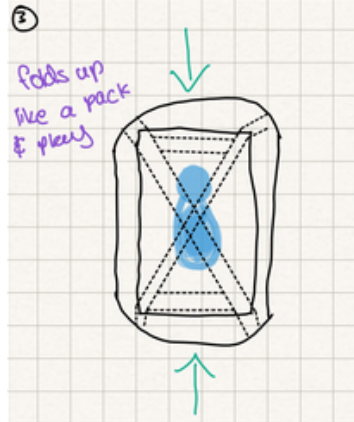
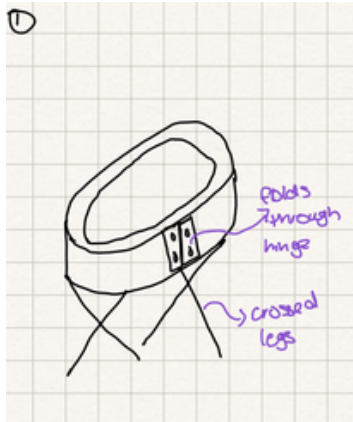


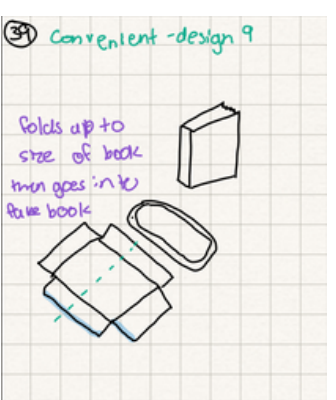
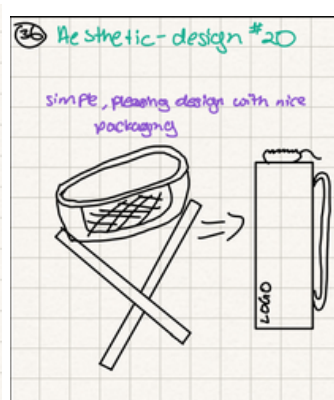
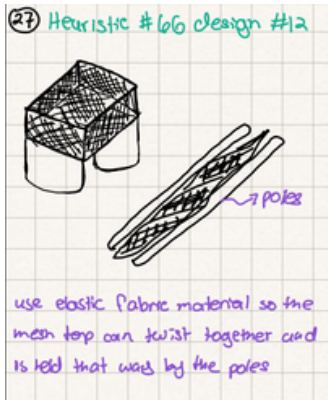
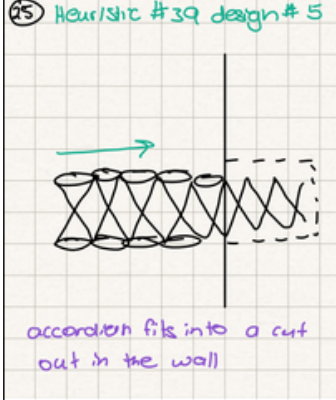
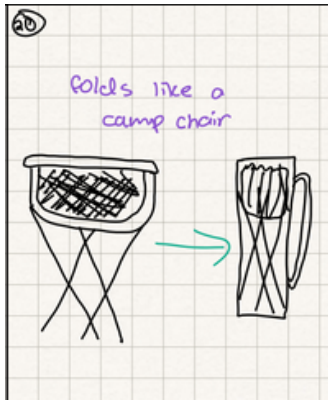
17) Telescoping base

- packs up small
- mattress can fold in half

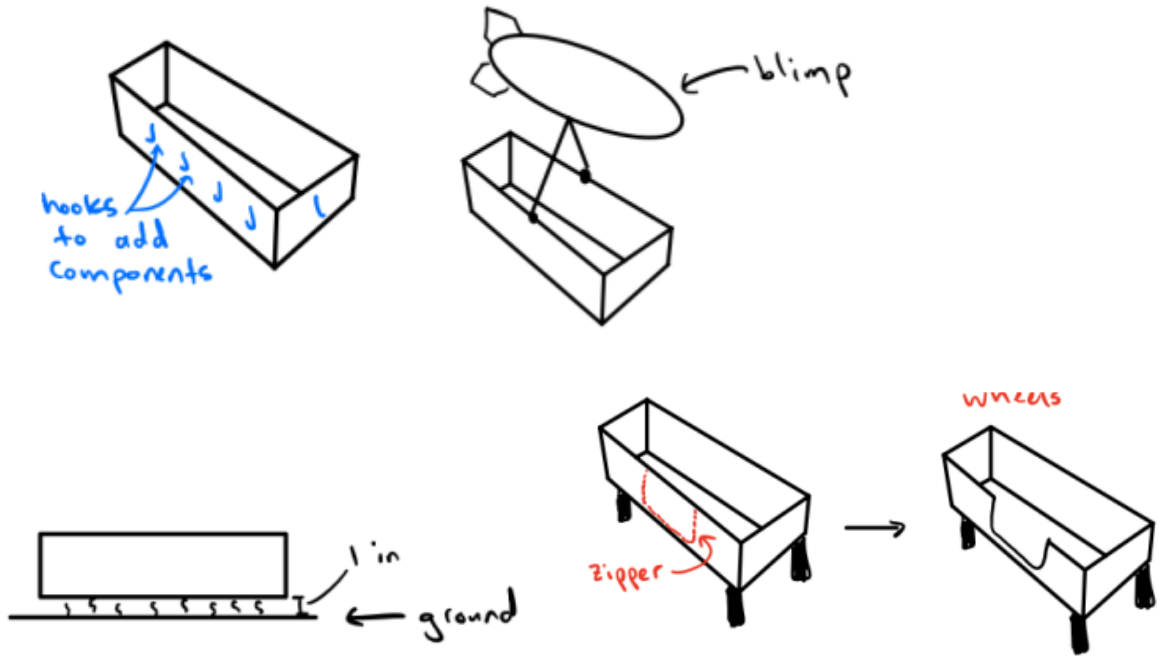


15) Design 17 → DH #51 → Folding base instead of telescoping

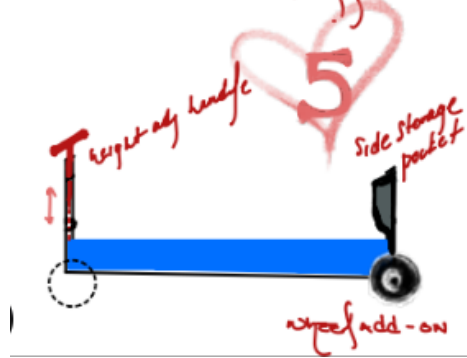




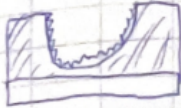
Special Feature Ideas



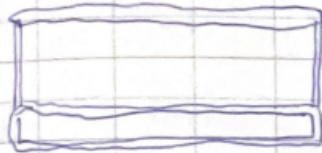
B. B. SINET → W. SYGON



16) side opens up for easy putting baby down



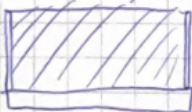
18) siding + mattress cover lean are continuous

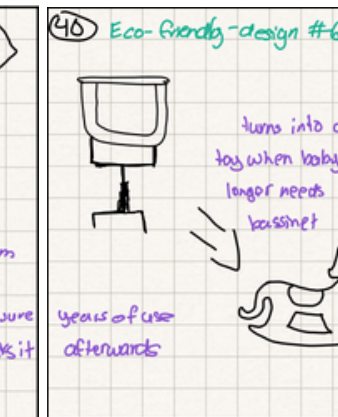
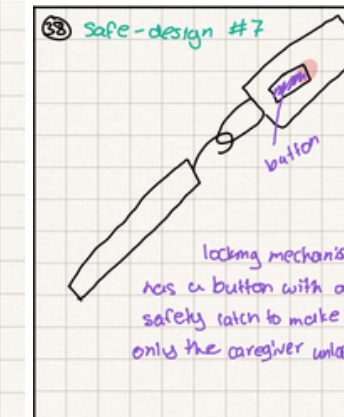
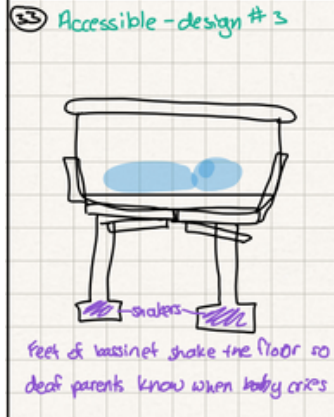
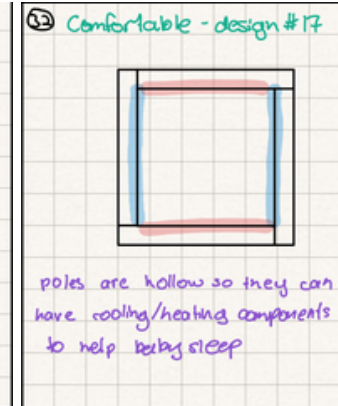
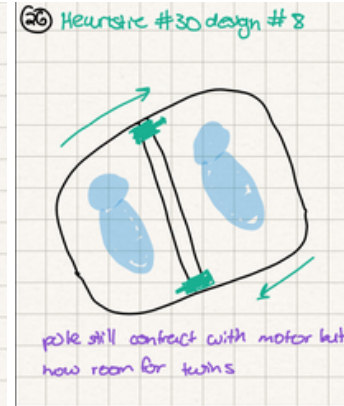
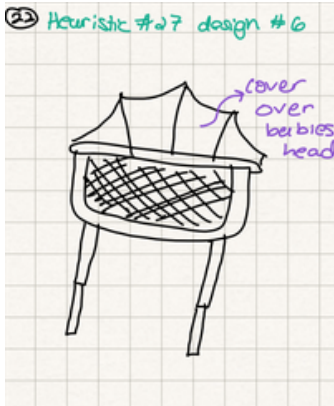
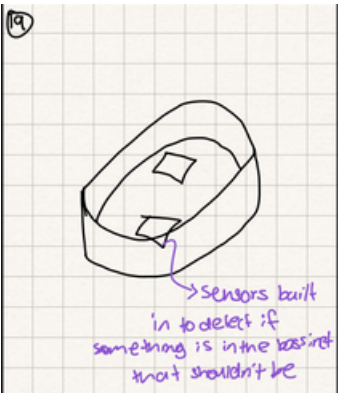
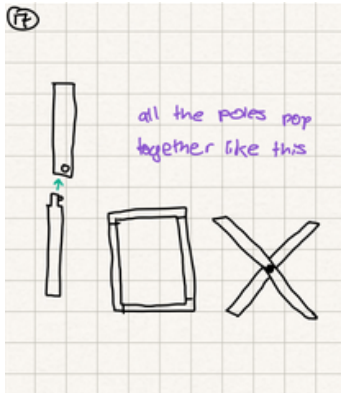
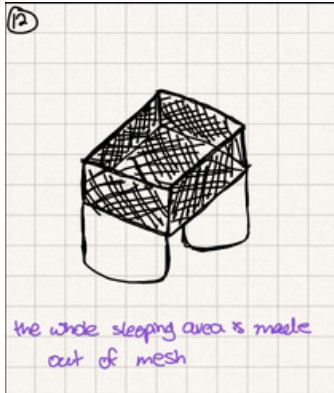


5) Design 16 → Scamper "substitute" → Buttons instead of zipper



6) Design 18 → DH # 67 → mattress + cover + siding are all one

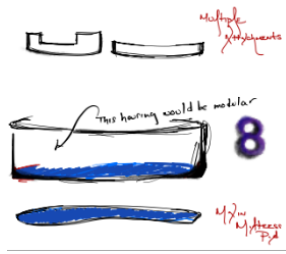
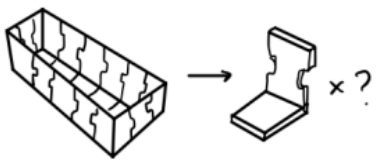




Container Ideas



Jigsaw bassinet that can be disassembled like puzzle to move around



Appendix B: "Full" Design Ideas

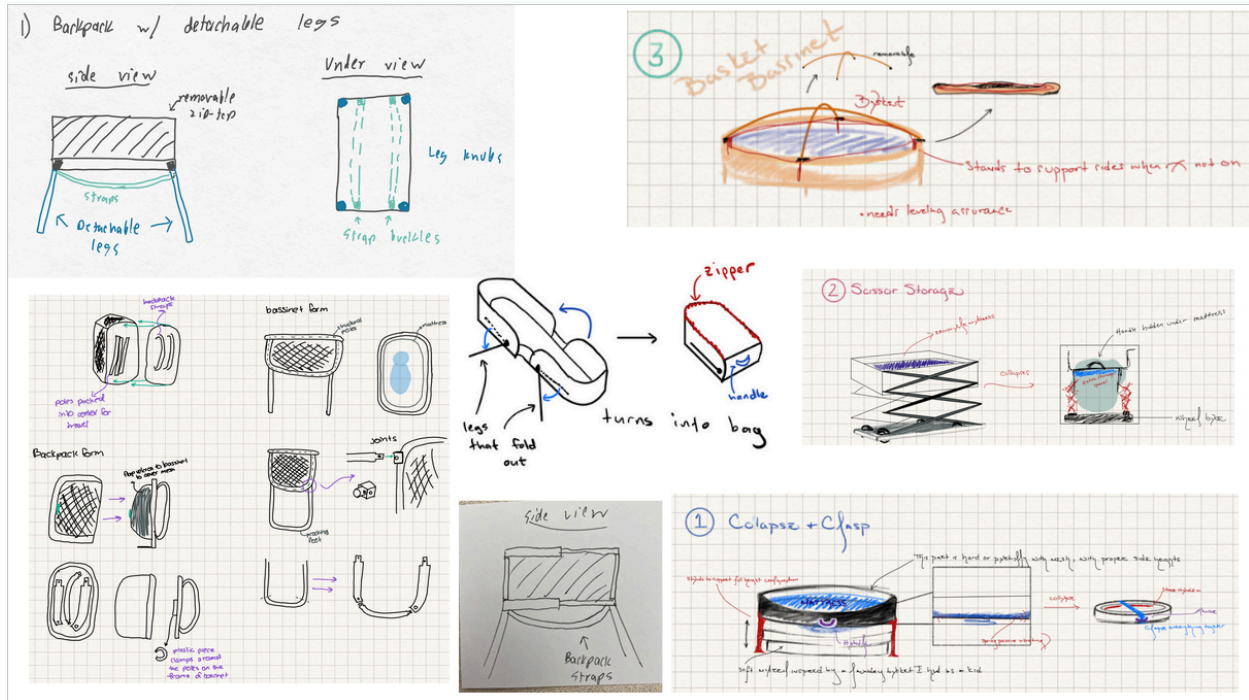


Figure B.1: Ideas that allow the bassinet to have another function when in the portable state.

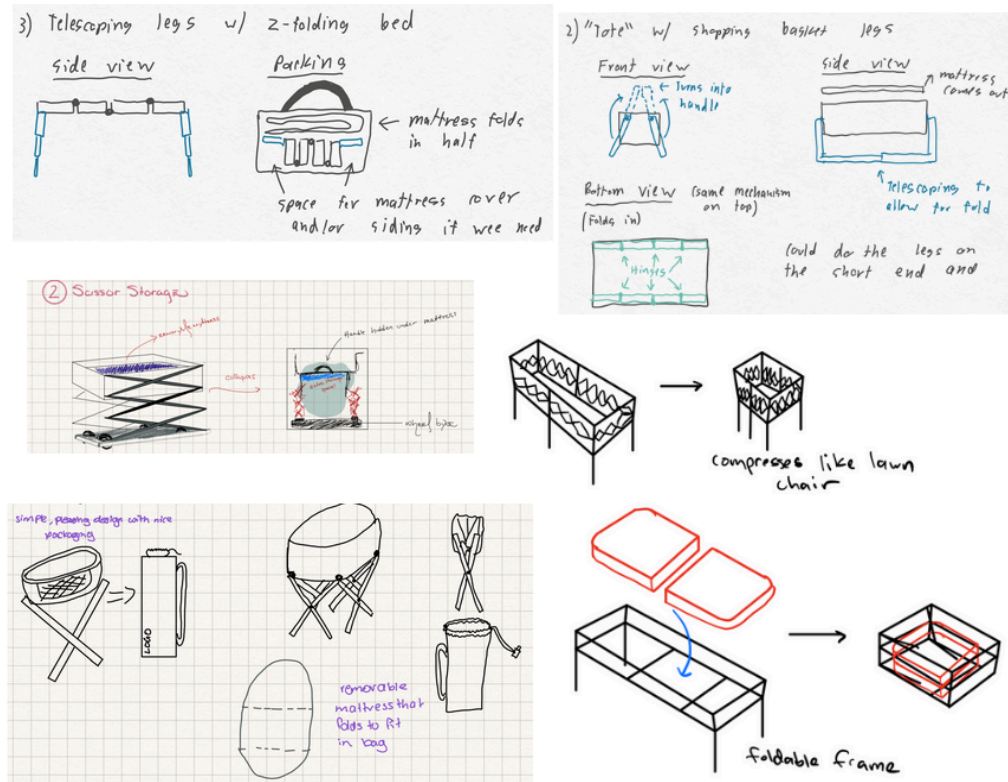


Figure B.2: Ideas that did not allow the bassinet to have another function when in the portable state.

Appendix C: Full Build BOM

Hardware						
Item	Qty	Source	Catalog #	Cost	Contact	Notes
Spring Pin with Button Head	4	Amazon	Link to Amazon Page	\$4.40 pack of 8	amazon.com	37mm leg length, 6mm button diameter
6-32 x 1-5/8" Lg Bolt	4	McMaster-Carr	90272A339	\$7.64 pack of 50	mcmaster.com	Philips Drive Button Head
6-32 x 3-1/4" Lg Bolt	4	McMaster-Carr	92224A148	\$11.97 pack of 25	mcmaster.com	Philips Drive Button Head
6-32 Nut	8	McMaster-Carr	90760A007	\$3.13 pack of 100	mcmaster.com	1/4" Drive, <0.1" thick
Spring Loaded Ball Plunger	4	McMaster-Carr	8495A25	\$5.78 ea	mcmaster.com	1.5-4.5 lb Nose Force, 5/16"-18 External Threads
1/4"-20 x 1-1/2" Lg Bolt	12	McMaster-Carr	90128A251	\$8.75 pack of 25	mcmaster.com	
1/4"-20 Nut	12	McMaster-Carr	95505A601	\$7.08 pack of 100	mcmaster.com	
8-32 x 3/4" Lg Countersunk Bolt	8	McMaster-Carr	90273A197	\$5.50 pack of 100	mcmaster.com	82 degree countersink
8-32 Nut	8	McMaster-Carr	91841A009	\$4.56 pack of 100	mcmaster.com	
Stock						
Item	Qty	Source	Catalog #	Cost	Contact	Notes
1" OD x 0.065" Wall Thickness 6061 Al Tubing	1	McMaster-Carr	89965K681	\$25.89 ea	mcmaster.com	3 ft long

1" OD x 0.065" Wall Thickness 6061 Al Tubing	1	McMaster-Carr	9056K75	\$12.74 ea	mcmaster.com	1 ft long
3/8" x 1" 6061 Al Bar	1	McMaster-Carr	8975K54	\$5.21 ea	mcmaster.com	1 ft long
1/4" x 5" 6061 Al Bar	1	McMaster-Carr	8975K432	\$9.74 ea	mcmaster.com	1/2 ft long
6" x 6" 6061 Al Sheet	1	McMaster-Carr	89015K235	\$11.93 ea	mcmaster.com	1/8" Thick
1" OD x 1/8" Wall Thickness Polycarbonate Tubing	3	Grainger	55PF54	\$35.30 ea	grainger.com	6 ft long
1-1/4" OD x 1/8" Wall Thickness Polycarbonate Tubing	1	Grainger	55PF58	\$37.35 ea	grainger.com	6 ft long
12" x 12" 3003 Al Sheet	1	Grainger	786AN0	\$11.77 ea	grainger.com	0.063" Thick
3D Printed Components (No cost to us)						
Item	Qty	Printing Method	Material	Notes		
Inner Tube Corner Joint	4	SLA	Formlabs Tough 2000 Resin	When printing and curing, orient so that resin can't pool up in any cavities and leave a sticky residue once complete.		
Outer Tube Corner Joint	4	SLA	Formlabs Tough 2000 Resin			
Wedge	4	SLA	Formlabs Tough 2000 Resin			
Leg Adaptor	4	SLA	Formlabs Tough 2000 Resin			
T-Connects	4	SLA	Formlabs Tough 2000 Resin			
90 degree connects	2	SLA	Formlabs Tough 2000 Resin			

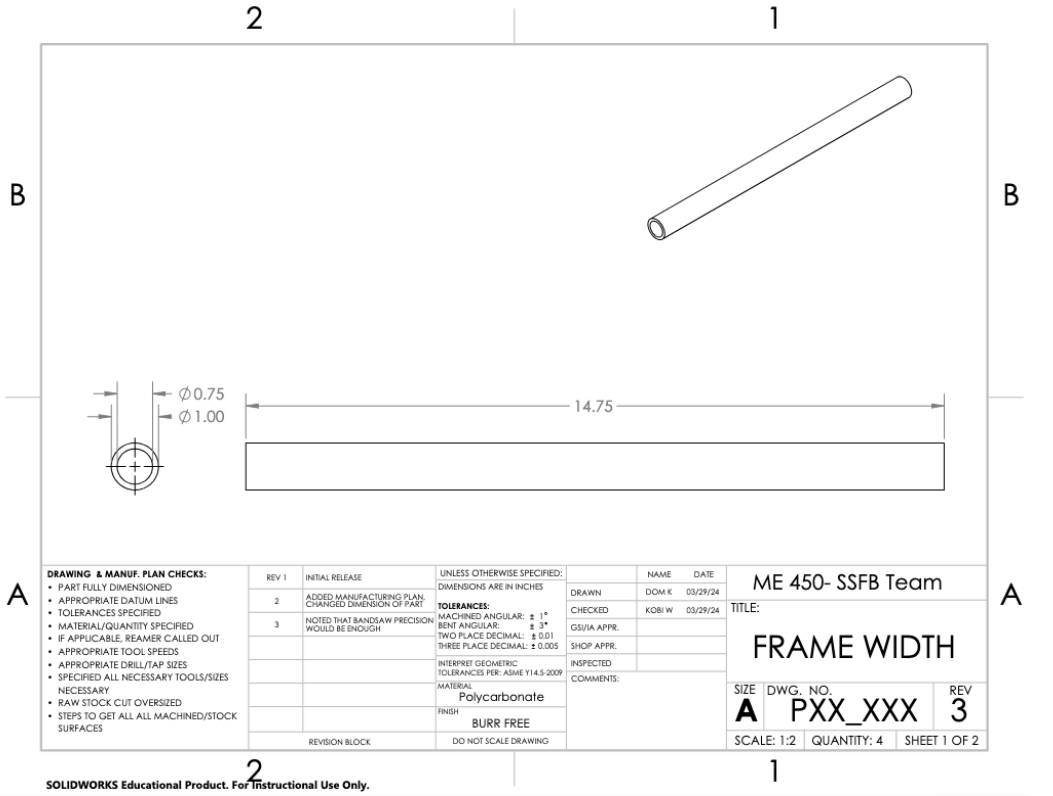
Spring Pin Hardstop	4	FDM	Polylactic Acid (PLA)	
Handle Crossbar	1	FDM	Polylactic Acid (PLA)	
Spacers for Leg Mounting	8	FDM	Polylactic Acid (PLA)	
Foot	4	FDM	Polylactic Acid (PLA)	
Leg Bolt Cover	8	FDM	Polylactic Acid (PLA)	

Appendix D: Manufacturing and Assembly Instructions

Manufacturing Instructions

1. Use an SLA 3D printer to print the following parts
 - a. Inner Tube Corner Joint
 - b. Outer Tube Corner Joint
 - c. Wedge
 - d. Leg Adaptor
 - e. Handle T-Connects
 - f. Handle 90 degree Connects
2. Use an FDM 3D printer to print the following parts
 - a. Spring Pin Hardstop
 - b. Handle Crossbar
 - c. Spacers for Leg Mounting
 - d. Foot
 - e. Leg Bolt Cover

3. Follow the manufacturing plan in Figure D.1 to make the Frame Width tubing



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MANUFACTURING PLAN
 RAW MATERIAL STOCK: 1" OD x 0.75" ID Polycarbonate Tubing

STEP	PROCESS DESCRIPTION	MACHINE	FIXTURE	TOOL(S)	SPEED (RPM)
1	Cut tube to length, bandsaw precision will be enough	Horizontal Bandsaw	Bandsaw Clamp		300 ft/min
2	Deburr all faces			File, deburring tool	

SHEET 2 OF 2

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Figure D.1

4. Follow the manufacturing plan in Figure D.2 to make the Frame Height tubing

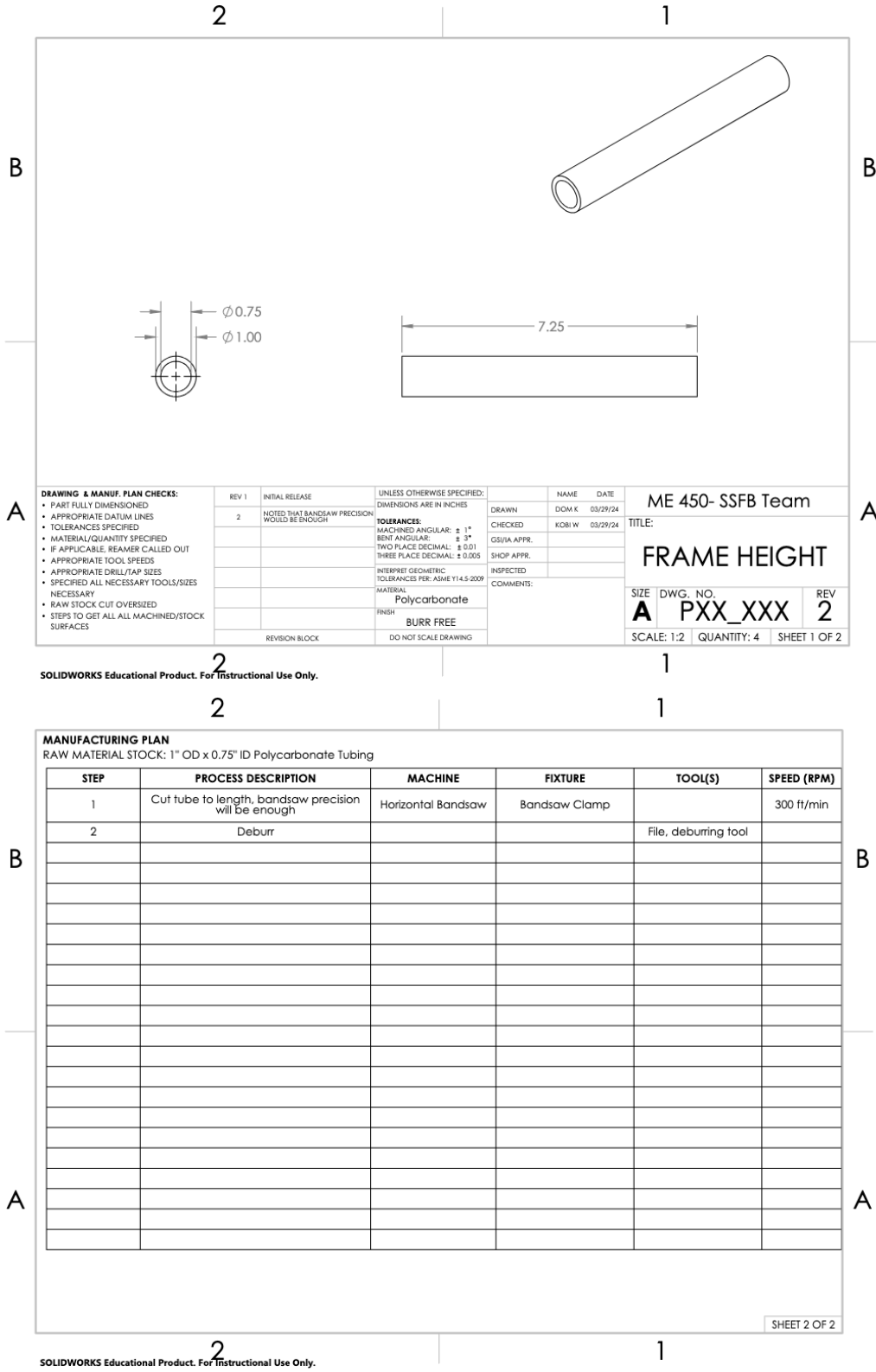


Figure D.2

5. Follow the manufacturing plan in Figure D.3 to make the Handle Width tubing

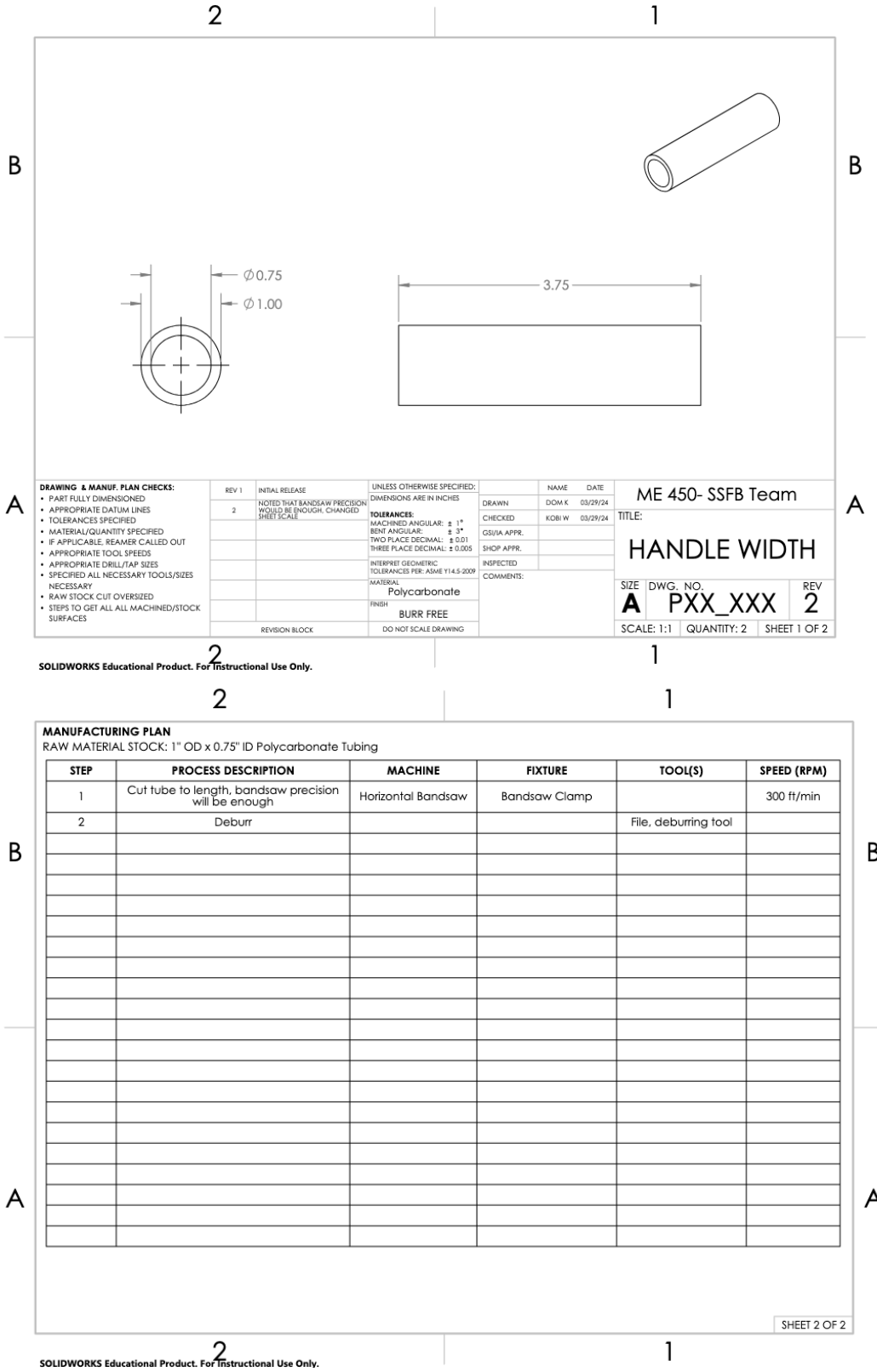


Figure D.3

6. Follow the manufacturing plan in Figure D.4 to make the Handle Height tubing

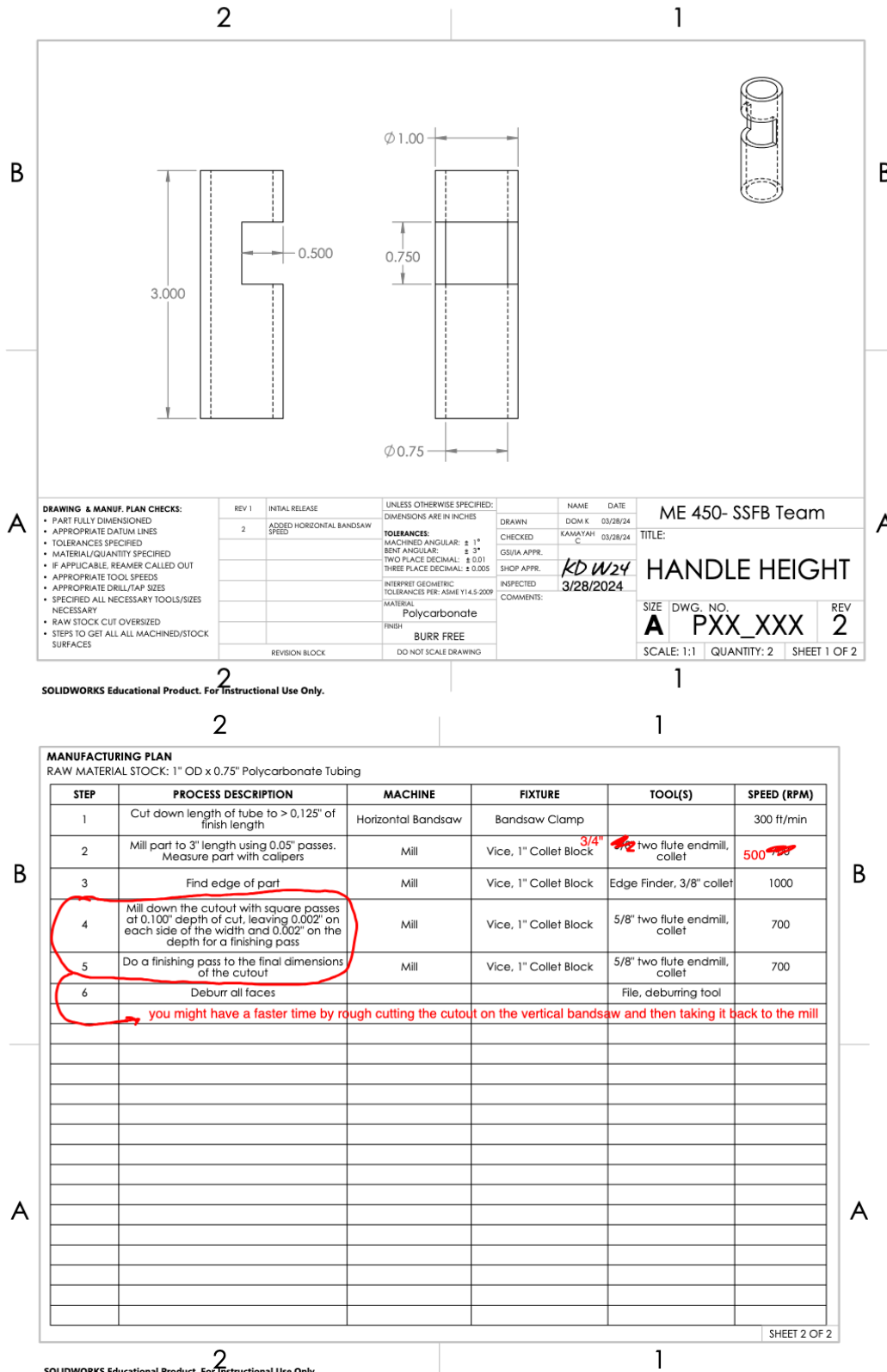
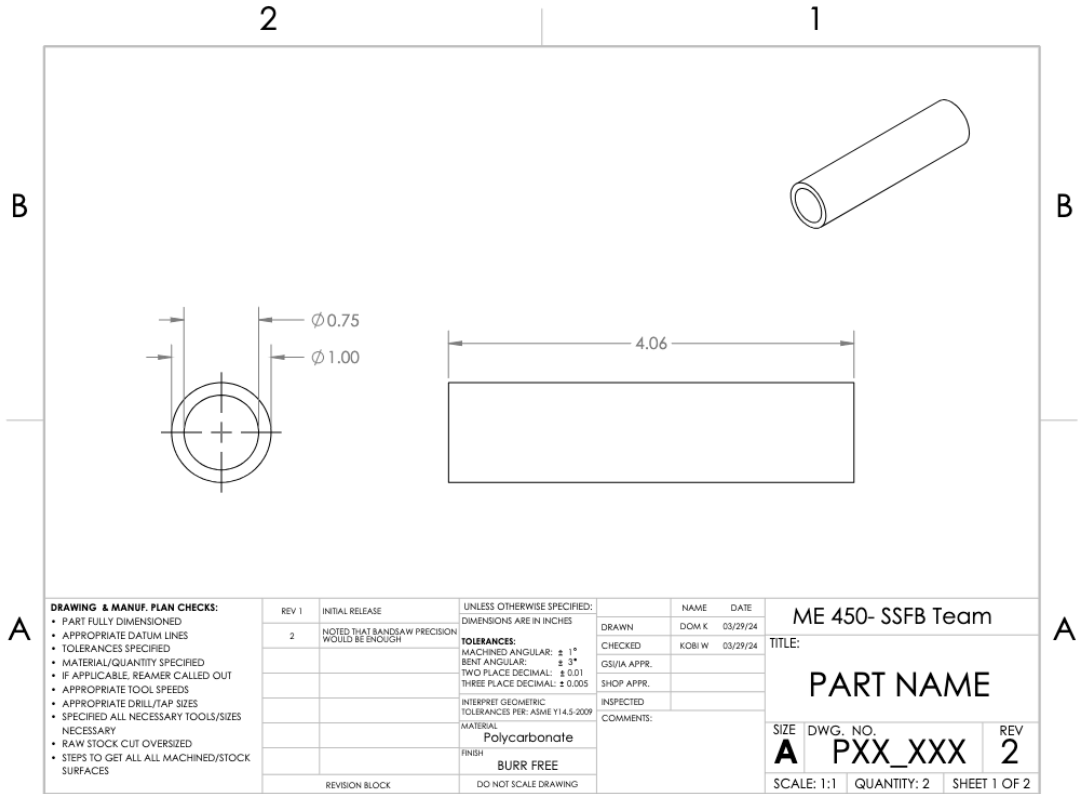
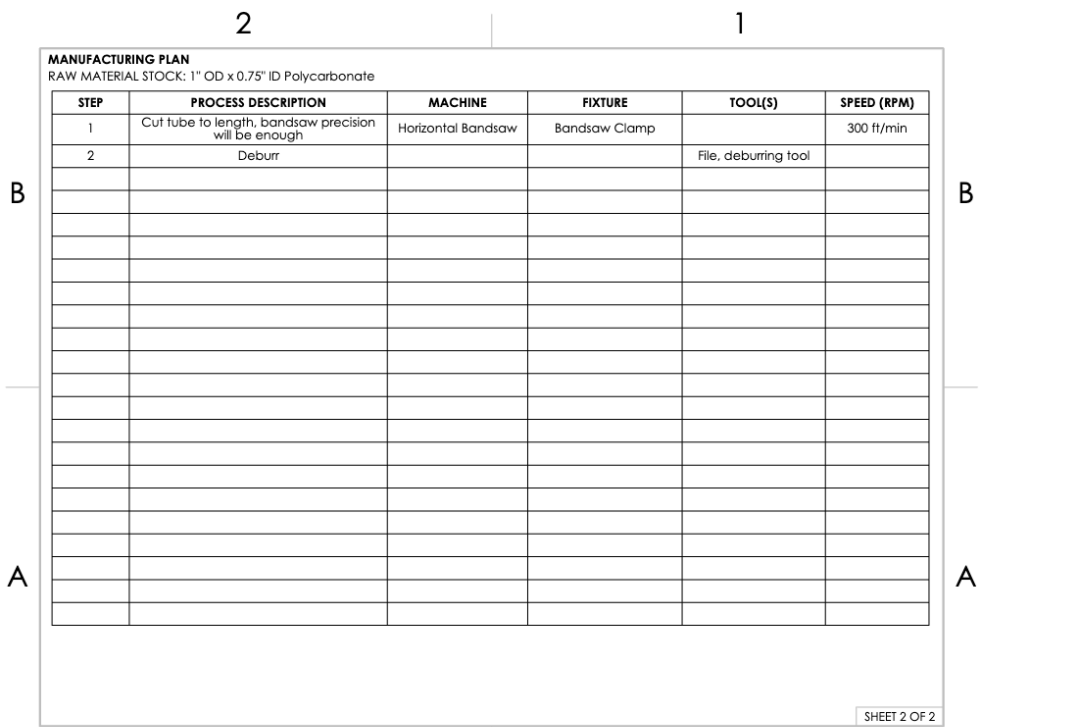


Figure D.4

7. Follow the manufacturing plan in Figure D.5 to make the Handle to Frame tubing



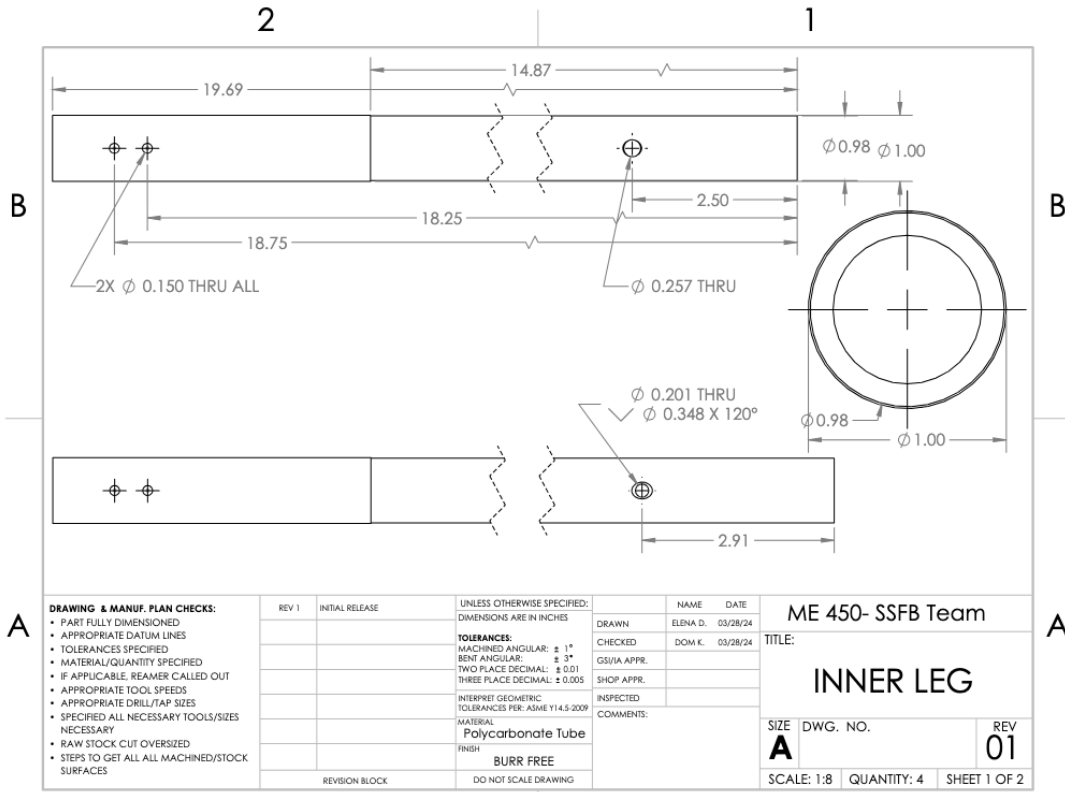
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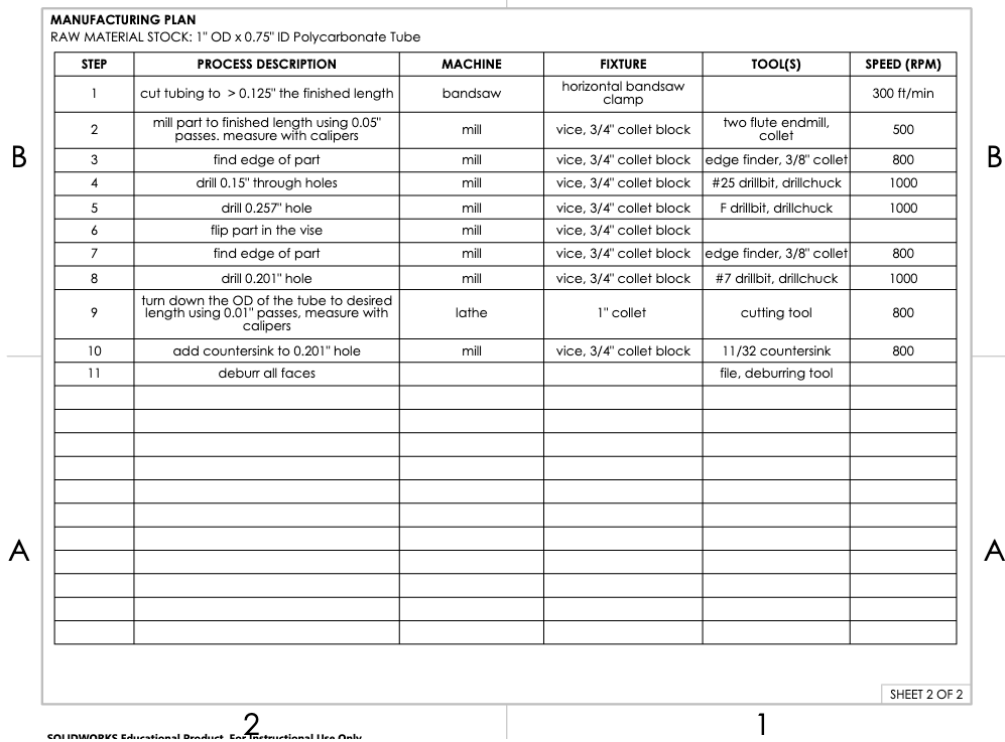
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Figure D.5

8. Follow the manufacturing plan in Figure D.6 to make the Inner Telescoping tubing



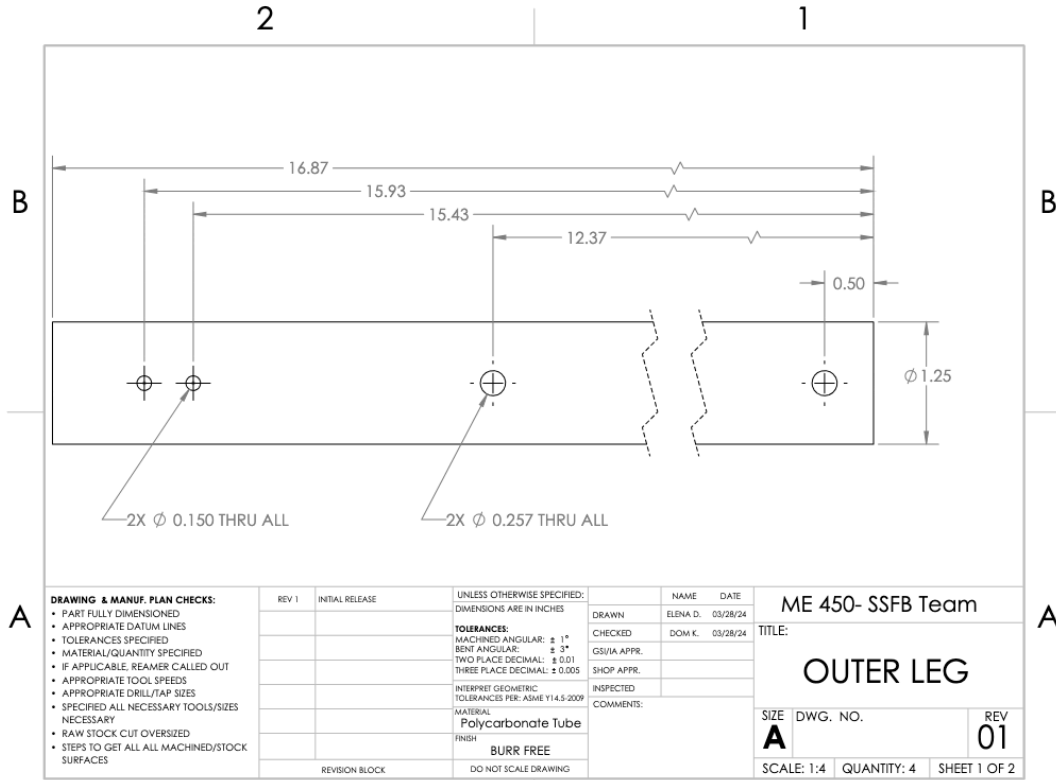
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Figure D.6

9. Follow the manufacturing plan in Figure XX to make the Outer Telescoping tubing



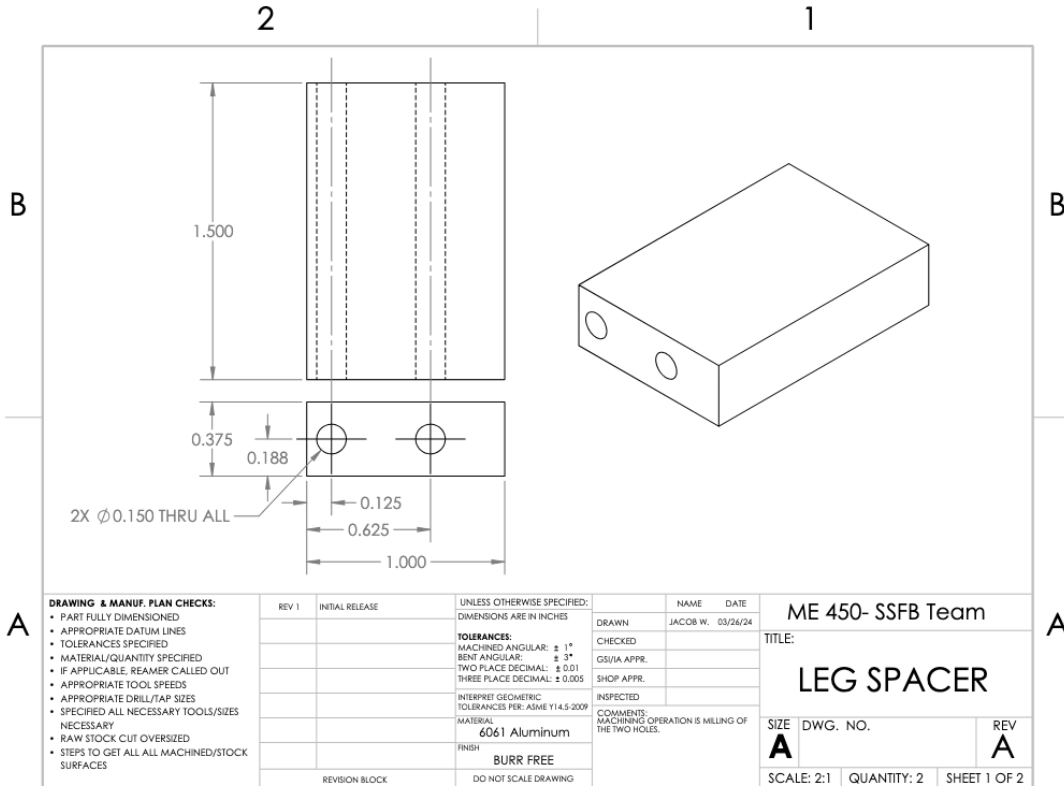
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STEP	PROCESS DESCRIPTION	MACHINE	FIXTURE	TOOL(S)	SPEED (RPM)
1	cut down length of tube to > 0.125" of finish length	horizontal bandaw	bandsaw clamp		300ft/min
2	mill part to finish length using 0.05" passes, measure with calipers	mill	vice, 3/4" collet block	two flute endmill collet	500
3	find edge of part	mill	vice, 3/4" collet block	edge finder, 3/8" collet	800
4	drill 0.15" through holes	mill	vice, 3/4" collet block	#25 drillbit, drillchuck	1000
5	drill 0.257" holes	mill	vice, 3/4" collet block	F drillbit, drillchuck	1000
6	deburr all faces			file, deburring tool	

SHEET 2 OF 2

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10. Follow the manufacturing plan in Figure D.7 to make the Leg-Frame Spacer



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MANUFACTURING PLAN					
RAW MATERIAL STOCK: 0.375" x 1" x 12"					
STEP	PROCESS DESCRIPTION	MACHINE	FIXTURE	TOOL(S)	SPEED (RPM)
1	Cut approximately 1.625" of aluminum from stock piece.	Horizontal Bandsaw	Vice	n/a	300 ft/min
2	Place in vice such that the 1.5" by 1" face is facing upwards and one end of the part is hanging off of the end of the vice, using a short set of parallels to ensure that part is clamped evenly. Take 0.010" passes using end mill on the end that is hanging off of the vice.	Mill	Vice	0.5" Diameter 2-Flute End Mill	650
3	Unclamp part from vice, rotate part 180 degrees such that the same face is facing upwards, and reclamp into vice with the opposite end from the one that was just smoothed hanging off of the end of the vice. Zero on the smooth end (the end towards the middle of the vice) using edge finder.	Mill	Vice	0.5" Diameter Edge Finder	900
4	Reduce the length of part to 1.5" using 0.04" passes of an end mill on the end of the part hanging off of the vice, leaving 0.010" for finishing pass.	Mill	Vice	0.5" Diameter 2-Flute End Mill	650
5	Unclamp part from vice and rotate such that one of the 0.375" by 1" faces is facing upwards and reclamp in vice with parallels still in place. Edge find on two faces to place the zero on the back left corner of part, adding appropriate 0.25" offset due to the radius of the edge finder.	Mill	Vice	0.5" Diameter Edge Finder	900
6	Center drill at both hole locations.	Mill	Vice	Small diameter center drill that's at least smaller than diameter of final hole.	1100
7	Drill both holes using same datum established in Step 5.	Mill	Vice	0.150" diameter drill bit or similar size for #6 screw clearance hole	1550

Figure D.7

12. Follow the manufacturing plan in Figure D.9 to make the Short Legs

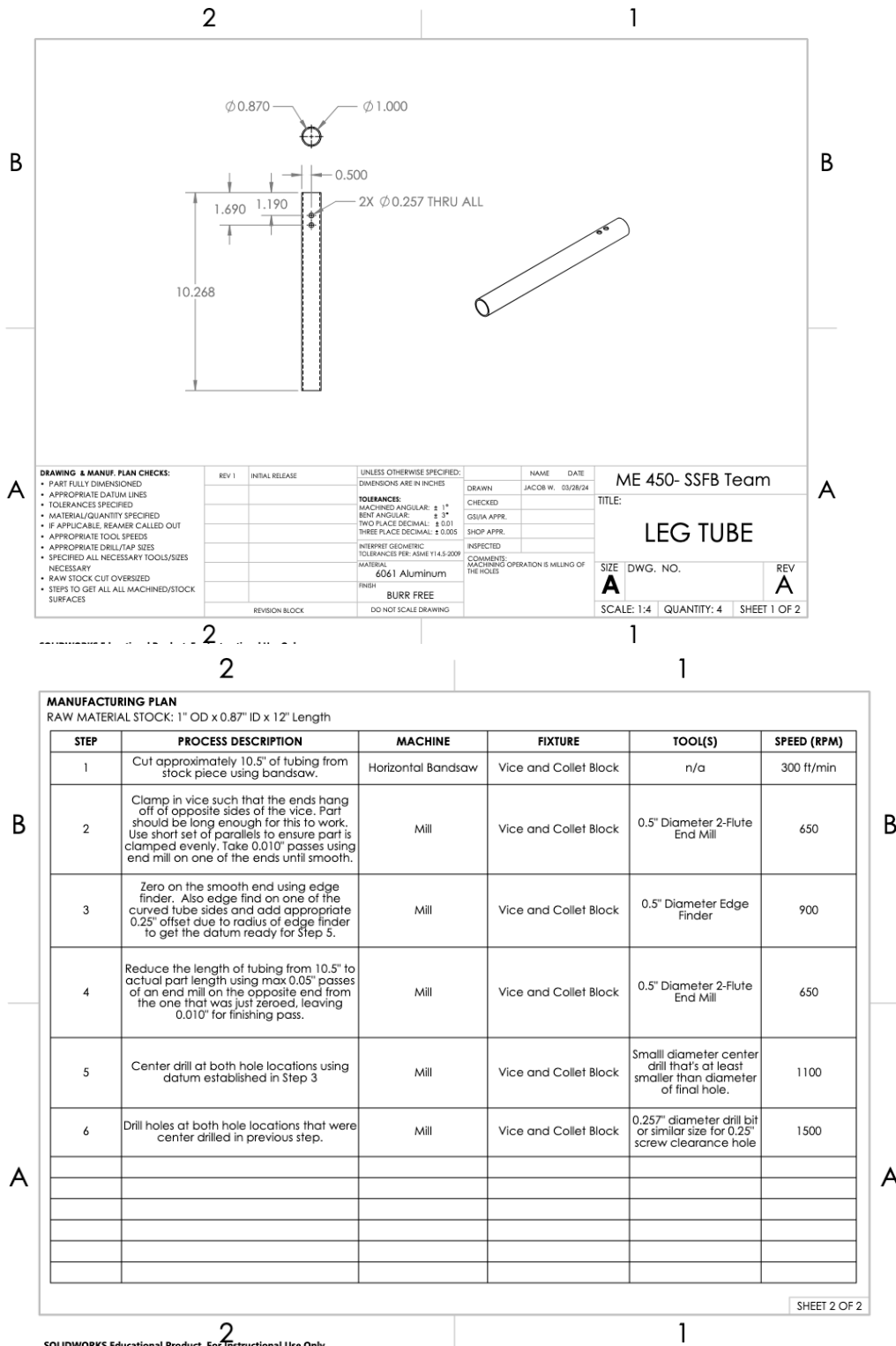
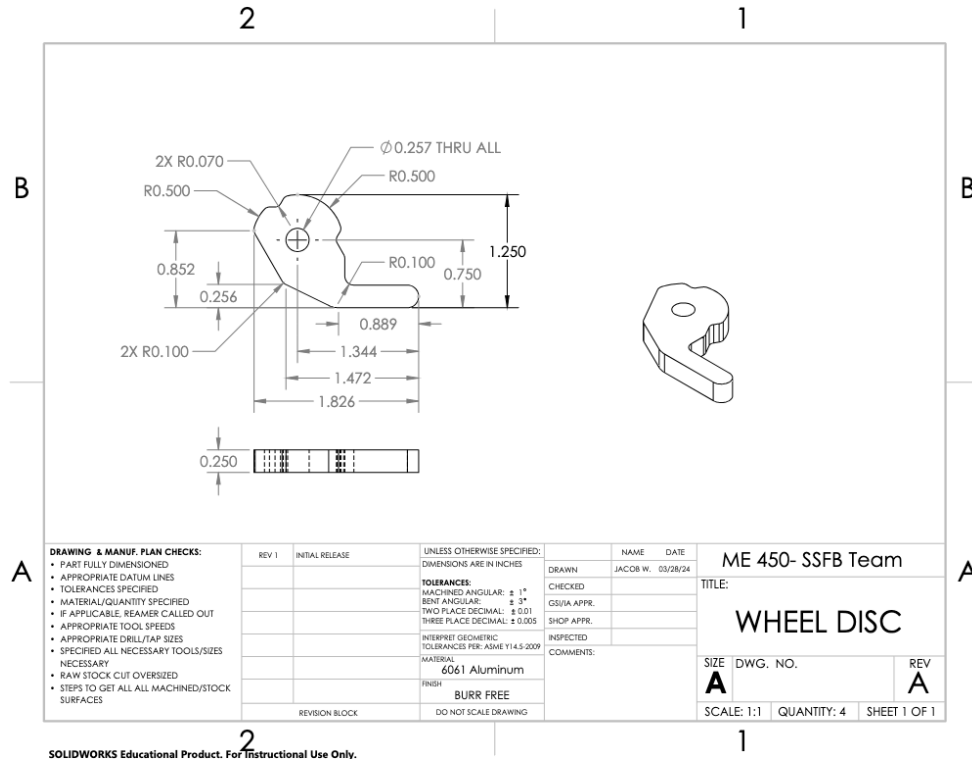
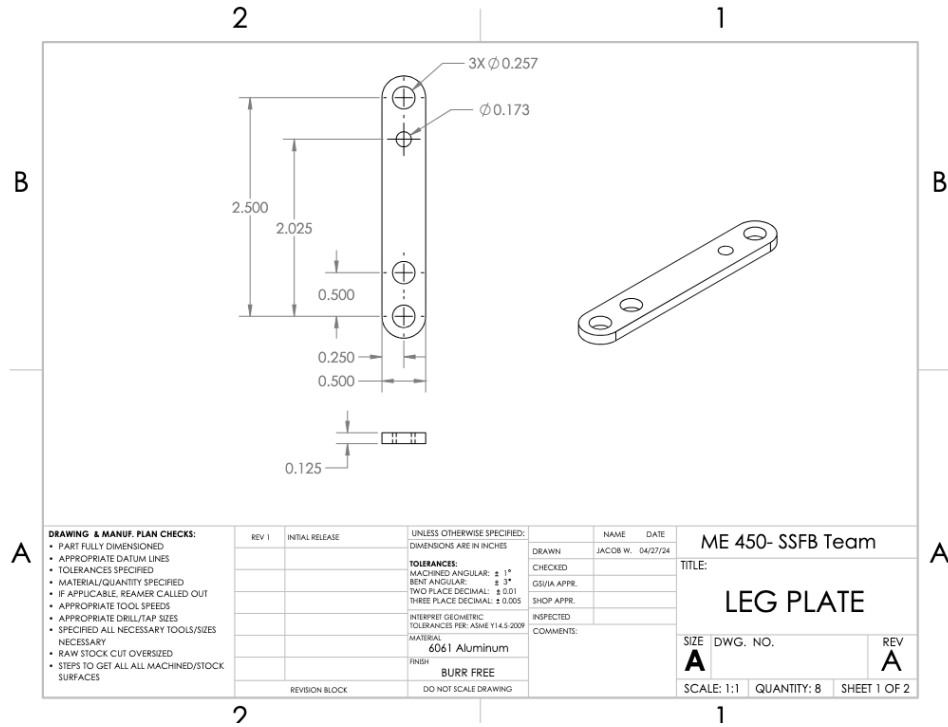


Figure D.9

13. Repeat the same process you did for the short legs but for the long legs cut to a length of 12"
14. Use the waterjet to cut out the following parts from aluminum plate stock
 - a. Leg Wheels



b. Leg Support Plates



DRAWING & MANUF. PLAN CHECKS: • PART FULLY DIMENSIONED • APPROPRIATE DATUM LINES • TOLERANCES SPECIFIED • MATERIAL/QUANTITY SPECIFIED • IF APPLICABLE, REAMER CALLED OUT • APPROPRIATE TOOL SPEEDS • APPROPRIATE DRILL/TAP SIZES • SPECIFIED ALL NECESSARY TOOLS/SIZES NECESSARY • RAW STOCK CUT OVERSIZED • STEPS TO GET ALL ALL MACHINED/STOCK SURFACES	REV 1	INITIAL RELEASE	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES	DRAWN	NAME	DATE	ME 450- SSFB Team TITLE: LEG PLATE SIZE DWG. NO. REV A A SCALE: 1:1 QUANTITY: 8 SHEET 1 OF 2	
			TOLERANCES: MACHINED ANGULAR: ± 1° BENT ANGULAR: ± 3° TWO PLACE DECIMAL: ± 0.01 THREE PLACE DECIMAL: ± 0.005	CHECKED	JACOB W.	04/27/24		
			INTERPRET GEOMETRIC TOLERANCES PER ASME Y14.5-2009	GS/DA APPR.				
			MATERIAL: 6061 Aluminum FINISH: BURR FREE	SHOP APPR.				
	REVISION BLOCK		DO NOT SCALE DRAWING	INSPECTED	COMMENTS:			

15. Cut out pieces of the mesh cloth according to the drawing in Figure D.10.

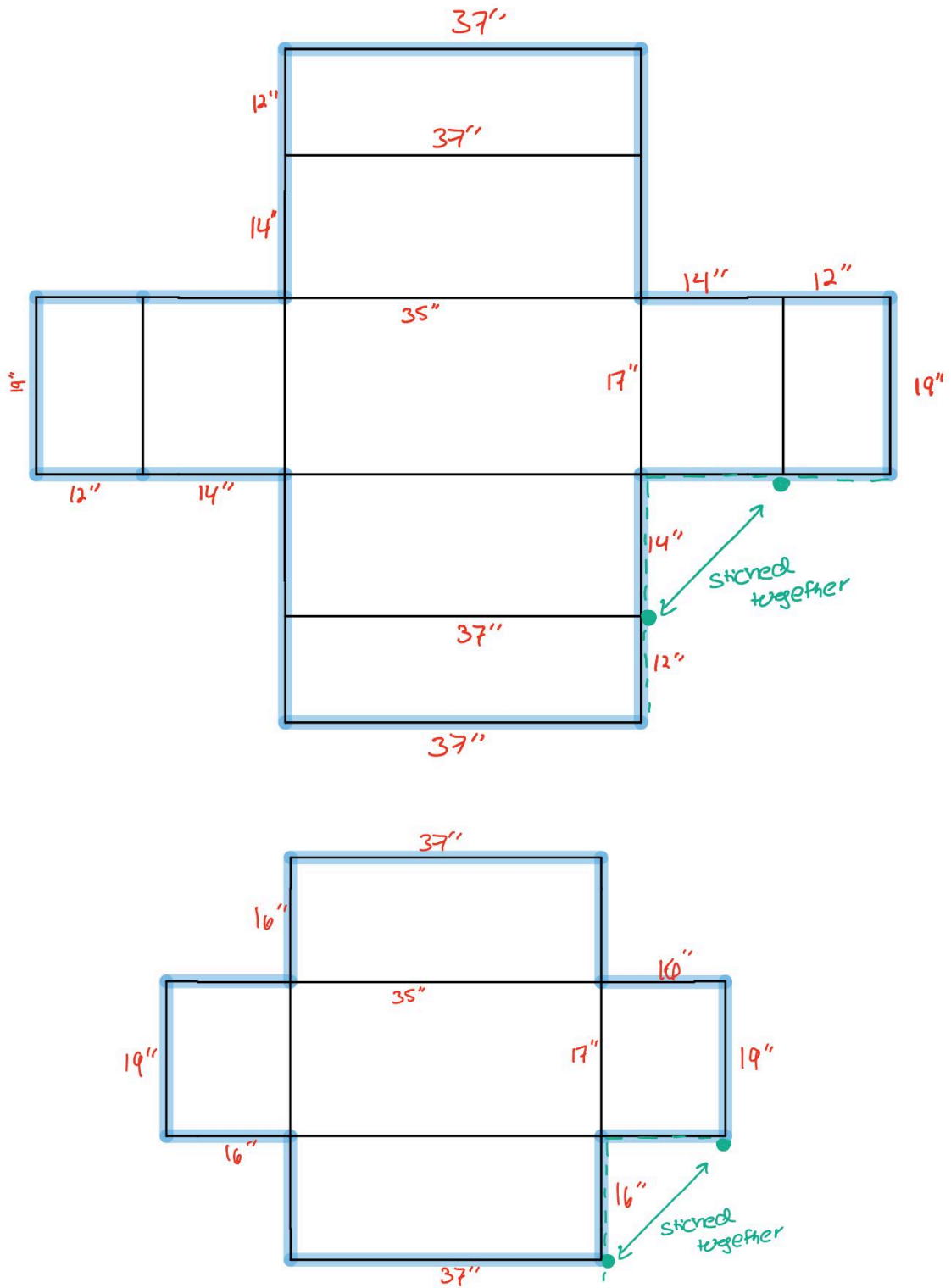


Figure D.10

- a. Use a sewing machine to connect the pieces into a bag shape

16. Use foam to fill a mattress cover of the size shown in Figure D.11.

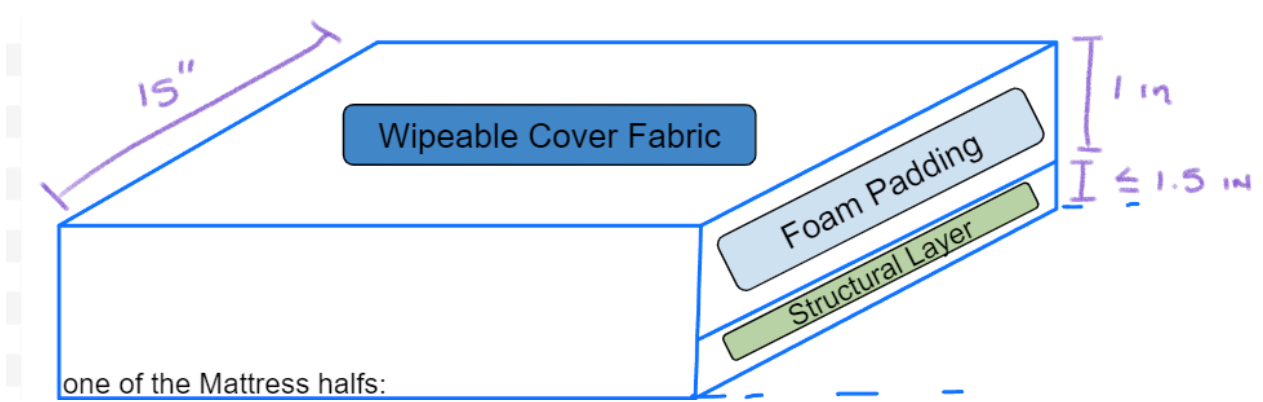


Figure D.11

Assembly Instructions

1. Follow the blow out diagram in Figure D.12 to assemble the cable pin mechanism

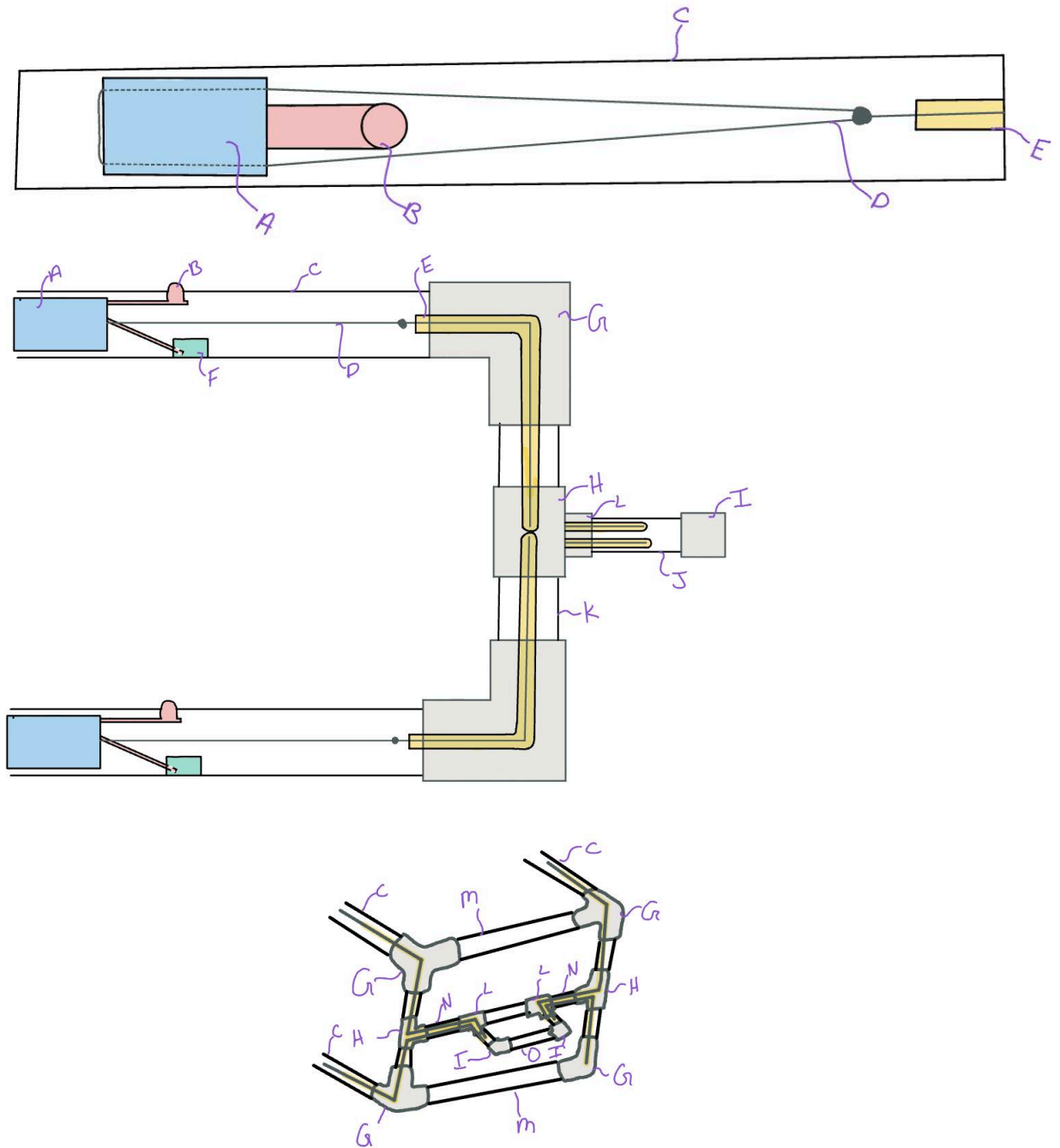


Figure D.12

2. Follow the blow out diagram in Figure D.13 to assemble the rest of the frame and handle

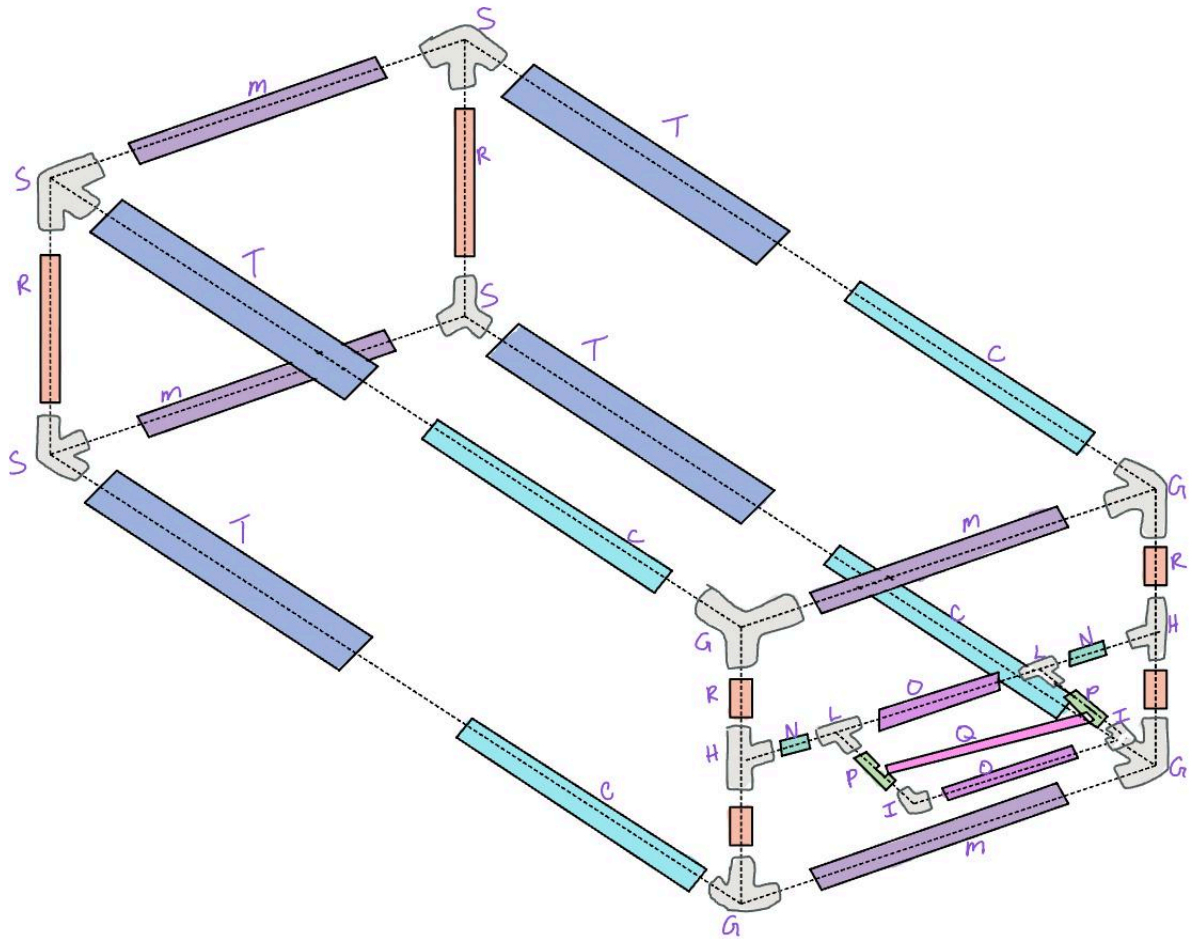


Figure D.13

3. Follow the blow out diagram in Figure D.14 to assemble and attach each leg
 - a. Two legs will be attached using the bracket shown and the other two will be attached using the longer bracket.

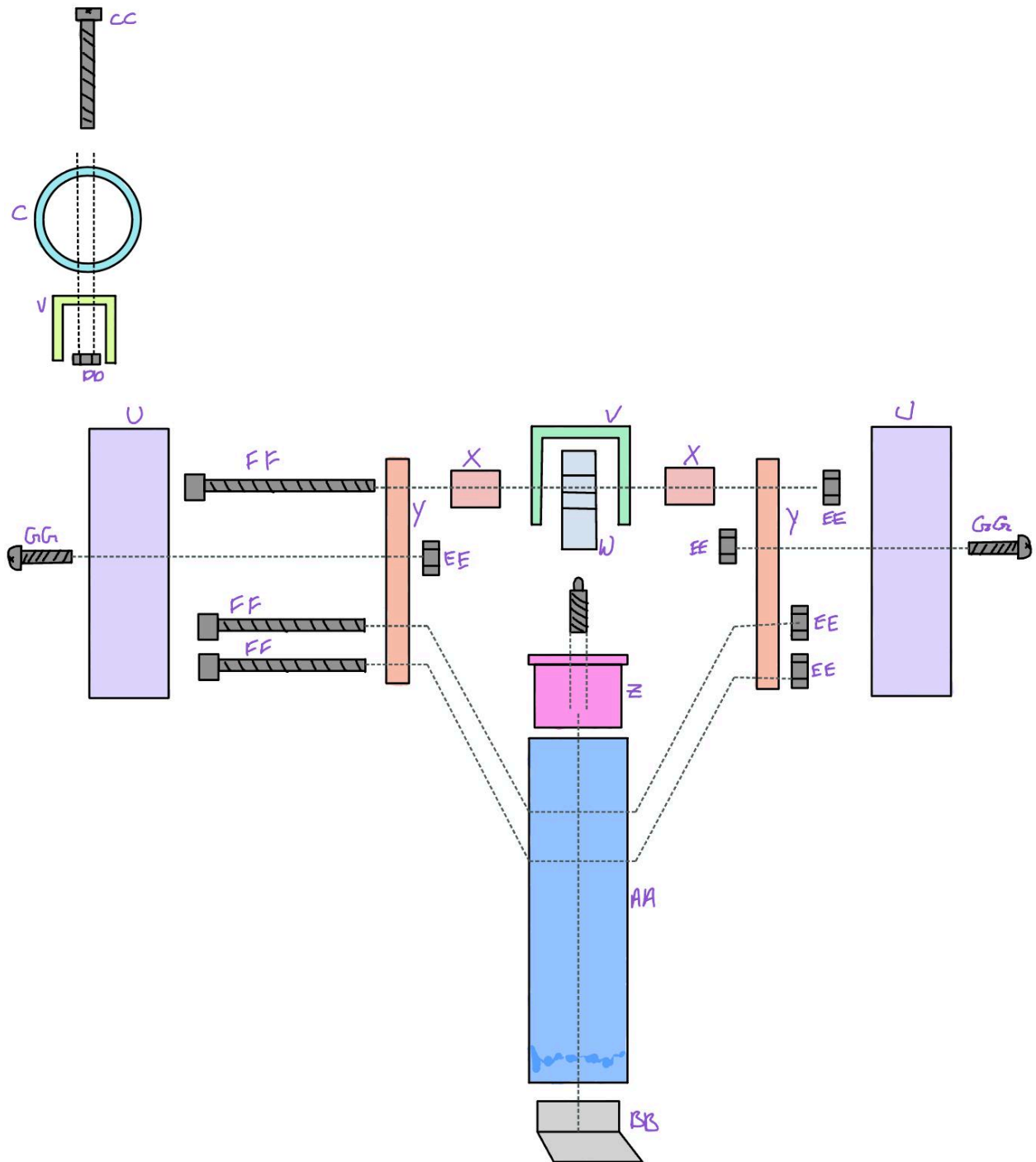


Figure D.14

4. Place the center of the cover in the sleeping space of the bassinet and fold the edges over the outer walls of the frame. Then connect the walls to the underside of the sleeping area
5. Place the mattress in the sleeping area

See the following list for the labels of each component for Figures D.12-D.14

- A - Wedge
- B - Spring Pin Clip
- C - Inner Telescoping Tube
- D - Cable
- E - PTFE Tubing
- F - Spring Pin Hardstop
- G - Inner Tube Corner Joint
- H - Handle T Connect
- I - Handle 90 degree Connect
- J - Handle Height Tube
- K - Frame Height Tube
- L - Handle T Connect
- M - Frame Width Tube
- N - Handle to Frame Connect Tube
- P - Handle Height Tube
- Q - Handle Crossbar
- R - Frame Height Tube
- S - Outer Tube Corner Joint
- T - Outer Telescoping Tube
- U - Leg Bolt Cover
- V - Leg Bracket
- W - Leg Wheel
- X - Spacers for Leg Mounting
- Y - Let Support Plates
- Z - Leg Adaptor
- AA - Short/Long Leg
- BB - Foot
- CC - 6-32 x 1.25" Long Phillips Head Screw
- DD - 6-32 Stainless Steel Hex Nut
- EE - ¼-20 Stainless Steel Hex Nut
- FF - ¼-20 x 1.5" Long Socket Head Screw
- GG - 6-32 x 0.375" Long Button Head Screw

Appendix E: Cost Estimation Results

Subsystem	Part Description	Qty	Material	Mass Mfg Method	Manufacturing Cost Per Part (\$/part)	Mfg Cost Per Assembly (\$)
Frame	Spring Pin with Button Head	4	Alibaba Link	Bought	\$0.02	\$0.08
Frame-Leg Interface	Nuts for interface	8	FastenerSuperstore Link	Bought	\$0.02	\$0.12
Frame-Leg Interface	Long bolts for interface	4	FastenerSuperstore Link	Bought	\$0.16	\$0.64
Frame-Leg Interface	Short bolts for interface	4	FastenerSuperstore Link	Bought	\$0.05	\$0.18
Leg	Spring loaded ball plunger	4	Alibaba Link	Bought	\$0.10	\$0.40
Leg	Bolts for legs	12	FastenerSuperstore Link	Bought	\$0.09	\$1.13
Leg	Nuts for legs	12	FastenerSuperstore Link	Bought	\$0.04	\$0.43
Leg	Bolt for cover	8	FastenerSuperstore Link	Bought	\$0.03	\$0.24
Leg	Nut for cover	8	FastenerSuperstore Link	Bought	\$0.02	\$0.14
Mattress	Mattress	1	Alibaba Link	Bought	\$2.00	\$2.00
Fabric Cover	Fabric cover	1	Alibaba Link	Made	\$3.00	\$3.00
Frame	Tubing Corner Joint- Inner Tube	4	ABS	Injection Molding	\$0.45	\$1.80
Frame	Tubing Corner Joint- Outer Tube	4	ABS	Injection Molding	\$0.45	\$1.80
Frame	Wedge to press down spring clip	4	ABS	Injection Molding	\$0.15	\$0.62
Frame-Handle	90 deg for handle	2	ABS	Injection Molding	\$0.33	\$0.66
Frame-Handle	T-joints for handle and frame connection	4	ABS	Injection Molding	\$0.38	\$1.50
Frame-Handle	Handle to pull cables that pull wedge	1	ABS	Injection Molding	\$0.55	\$0.55
Leg	Adapts leg ID to threads for ball plunger	4	Thermoplastic	Injection Molding	\$0.24	\$0.96
Leg	Spacers for leg mounting	8	Thermoplastic	Injection Molding	\$0.11	\$0.89

Leg	Foot for end of leg	4	Thermoplastic	Injection Molding	\$0.47	\$1.89
Leg	Cover for leg bolts	8	Thermoplastic	Injection Molding	\$0.23	\$1.85
Leg	Spacer for cover	8	Thermoplastic	Injection Molding	\$0.11	\$0.89
Frame	Outer Telescoping Tube	4	Aluminum, tube	Extrusion + Machining	\$2.06	\$8.25
Frame	Inner Telescoping Tube	4	Aluminum, tube	Extrusion + Machining	\$1.62	\$6.49
Frame	Width tube of the frame	4	Aluminum, tube	Extrusion	\$1.08	\$4.33
Frame	Height tube of the frame	4	Aluminum, tube	Extrusion	\$0.53	\$2.13
Frame-Handle	Height tube of the handle	2	Aluminum, tube	Extrusion + Machining	\$0.84	\$1.68
Frame-Handle	Width tube of the handle	2	Aluminum, tube	Extrusion	\$0.28	\$0.55
Frame-Handle	Tube that connects Handle to Frame	2	Aluminum, tube	Extrusion	\$0.30	\$0.60
Leg	Leg material, long config	2	Aluminum, tube	Extrusion + Machining	\$1.40	\$2.80
Leg	Leg material, short config	2	Aluminum, tube	Extrusion + Machining	\$1.25	\$2.51
Leg	Connects Leg to Leg Bracket	8	Aluminum, bar	Machining	\$0.50	\$4.04
Leg	Indents for the ball plunger	4	Aluminum, bar	Sheet Metal	\$0.92	\$3.67
Leg	Leg bracket	4	Aluminum, bar	Sheet Metal	\$1.03	\$4.12
Leg	Leg spacer	2	Aluminum, bar	Machining	\$0.52	\$1.04