Designing a Safe, Durable, Affordable Crib

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ME 450 Winter 2010, Team AmeriCrib (#22)
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Final Report
4-20-2010

Abstract

Kids In Danger^{SM}, a nonprofit organization, is concerned with safety and affordability of baby cribs currently available. This is because the crib is the one product where the child is intended to be left alone, and many low-income families with newborns cannot afford safe cribs. Ms. Nancy Cowles, Executive Director of Kids In Danger, contacted us to design and build a safe, affordable crib. Through our research, we have determined the targets needed for the design of such a crib. Using these target engineering specifications and customer requirements, we generated concept ideas in a morphological chart to meet these separate requirements. Using the concept ideas, five total crib concepts were generated and evaluated in a Pugh chart using a weighted scoring system based on the importance of the customer requirements. From this evaluation an "alpha" concept design was selected. Via engineering analysis, the alpha concept design was further refined, and the sides were made to be collapsible. These changes resulted in the final concept design. A working prototype of the final design was made and validation procedures were conducted. The mass production price was found to be $82.58, the overall weight was 45.2 lbs, and the cycles to failure were found to be 55,406. The predicted lifetime based on the cycles to failure analysis was 15.2 years, and computed with equations since there was a time constraint where an actual test could not be completed. We recommend a further refinement which would result in weight reduction as well as more rigorous safety and durability testing before widespread use.

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Executive Summary

Kids In Danger has asked us to solve the problem of the lack of availability of safe cribs at a price point that is attainable for lower income families. The goal of our project is to design and build a crib that satisfies both of these requirements. While also being safe and affordable, we will incorporate design elements that make the crib portable and durable. However, the most important requirement is safety, due to the hazards currently present in many cribs, and the fact that the crib is one of the few places a child is meant to be left unattended. From these basic needs, a detailed list of customer requirements was developed.

After determining all engineering specifications, a morphological chart was made. The chart included various crib functions based on the customer requirements, and different concept ideas that could meet the needs of the functions. Using the various concept ideas, five total crib concepts, titled "A" through "E" were generated from the thirty plus possibilities presented by the morphological chart. The full morphological and crib concept charts can be seen in Appendices F and G. To determine which of the five total crib concepts was superior, a Pugh chart was generated, scoring the five concepts based on the weighted values for the customer requirements we determined for our QFD chart. Of the five, concept A scored the best, and was selected as our "alpha" design. Concept A included a wood frame that uses standard lumber sizes to reduce weight and cost. The sides used a breathable mesh material, similar to the "pack-n-play" cribs currently on the market. Concept A was not foldable but was sized to be easily maneuverable.

The alpha concept was further refined to include collapsible sides. This was done to better meet the customer requirement of crib portability by increasing the foldability of the crib into a more compact size which can easily fit into the trunk of a standard mid-size sedan. For the concept to remain affordable, standard lumber sizes were selected for the alpha concept by performing a finite element analysis on some of the crib assemblies using a safety factor of two on the maximum force a child could exert. These refinements were fully incorporated into our alpha concept, resulting in our final design concept. A full Computer aided drafting (CAD) model of the final design concept was generated, and used to create the engineering drawings for the manufacturing plan to build the final concept design.

A prototype of the final design was completed, and underwent validation testing. The foldability was validated by folding and unfolding the crib several times and verifying that the hinges and fits were still working properly. Portability was validated by verifying the width dimensions and weighing the prototype. The prototype weighed 45.2 lbs, falling within our engineering specifications. Durability was validated by performing a cycles to failure analysis. This was accomplished by theory since there wasn't enough time to actually perform the cycles to failure testing. It was predicted that the design would 15.2 years, exceeding our engineering specifications. Affordability was validated by performing a cost analysis on the final concept design using bulk pricing if the product were to be mass produced. The final cost of the mass produced design was found to be $82.58, within our engineering specifications. Safety was validated by performing a crib side latch test as per ASTM standards; the prototype passed this test. The prototype of the final design concept was shown at the University of Michigan Design Expo on April 15, 2010.

While our design met all our engineering specifications and passed validation testing, there are two major aspects that could be improved. Further weight reductions, specifically in the frame assembly, should be sought to further increase portability. An extensive finite element analysis should be performed on the frame to target low stress areas for material removal. To improve the stability and perceived quality of the design, angled cross members should be added to the endwalls. This would eliminate any flexing of the endwalls, improving rigidity when folding shut, and ensuring the customer that the product is sturdy, and hence, safe. In Conclusion, we recommend that these changes be implemented, a stress analysis be done

on the frame to reduce weight, and more safety testing take place before widespread use.

Introduction

The major goal of Kids In Danger is to improve the safety of children. One of the major areas in child safety is the design and sale of baby cribs. In the past year, 10,000 children were sent to the emergency room with crib related injuries. In the past 20 years, 1,100 children have died from crib related injuries [1]. Over those past 20 years, the safety of cribs has drastically improved with the implementation of many standards from the ASTM (American Society for Testing and Materials) and CPSC (Consumer Product Safety Commission).

Maintaining the requirements for safety, our goal is to design a safe crib that is affordable for low-income families. Many low-income families cannot afford a safe crib for their child. Presently, there isn't a safe crib available for sale which meets the price goal set forth by Kids In Danger. With the development of a low-cost, durable, and safe crib it would be possible for non-profit organizations to supply these families with a safe environment for their newborn child.

Background

A crib is the only location where a child is left unattended during his or her first months after birth. The purpose of a crib is to pose a safe environment for the child so the parents do not have to constantly worry about their child. This means that the crib must be able to safely house the child while they explore the space within the crib.

In 2008, over 3.4 million cribs were recalled due to incidents which resulted in either injuries or death. Twelve different cribs were recalled, making it the largest crib recall in history [2]. Crib safety is the number one goal of our design, as there are many ASTM and CPSC standards that regulate how to effectively design a safe crib. Thus, our crib will exceed the standards set by government agencies by focusing on a number of different areas of safety that will be named later.

One of the problems that we face in designing this crib is that the crib must be affordable for low-income families. Many families cannot afford to buy a new crib when they have a child, and are forced to either buy a used crib or obtain a hand-me-down crib from a friend or family member. Studies have shown that cribs that were manufactured before 1999 do not satisfy the current government stands set by ASTM and CPSC [3]. Therefore, the low-income family takes the risk of putting their child in an unsafe environment. Also, many of these second hand cribs can wear and become unsafe as they are used more and more. For example, the fasteners could loosen, creating gaps at joints within the crib that the child could catch their hand in. With the design of a low cost, safe, and durable crib, low income families will be able to afford a safe environment for their child.

In our proposed solution, we will design a crib that meets all of our customer requirements and engineering specifications. We will need to determine which materials to use for the construction of the crib that will make it lightweight, durable, and child safe. We will also need to determine a way to test our design to predict when the crib design will fail. Lastly, we will have to check our prototype to make sure that the crib follows all government regulations, as well as our own ideas for improving safety.

Customer Requirements & Engineering Specifications

In order to organize our requirements and specifications, we created a QFD to quantify our desired crib qualities and to see how these requirements and specifications were met in other products that we benchmarked. The QFD can be seen in Appendix D.

Customer Requirements

Since our project is directed toward designing a safe crib for lower-income families and non-profit organizations, many of our customer requirements are centered on safety and keeping the cost low. As we've already mentioned, finding a safe crib is not difficult; however, for many families without the disposable income to purchase a safe crib they can often end up using unsafe hand-me-down cribs. Our sponsor, Nancy Cowles, emphasized the importance of safety in these cribs since our sponsor organization, KID, was founded because of a toddler being killed in an unsafe crib. Thus, our primary concern is for the safety of the child using the crib but our challenge is also to make it affordable.

Many of the customer requirements are directly from ASTM standards for cribs such as: having proper spacing between the vertical bars of the crib, and proper spacing between the mattress and the side of the crib. These are in place specifically to reduce the possibility of trapping the child's head, limbs, or extremities in part of the crib. Also, the crib cannot have any sharp corners or edges where the child can injure themselves. As babies grow, they explore the space they are in so we need to ensure that the crib is a safe place for the baby to explore.

Our crib design also should eliminate sheets and soft bedding as they bring a huge possibility of the child suffocating or strangling themselves should be the sheets come off of the mattress. There are some types of sheets that are safe to use in cribs, but for the purpose of safety and reducing cost, we have chosen not to look into those products. A firm mattress should also be used because babies need a firm surface to sleep on as their bones are still developing. Also, the overall porosity of the crib should be high to create good air circulation within the crib.

Durability was the next set of requirements we looked at as it ties directly to keeping cost down. We need to have our crib design stay useable until the child is ready to move to an adult bed with the possibility of it lasting much longer than that since it is very likely that the crib will be used for another child at some point. Obviously, if we want cost to stay down, we don't want the owner of this crib to have to purchase another one when the first breaks a year into its use. Similarly, we need the fasteners for this crib to maintain their functionality for much longer than the crib will actually be used to maintain durability and safety in the design. We also need to consider the fact that newborns will be using this crib for a majority of each day, thus our design needs to account for this.

Since this crib will be used until the child is several years old, we need to design the dimensions of the crib appropriately. We anticipate that this crib will be used in smaller spaces since it will probably be used largely by lower income families who may have smaller households. So, we need to design the crib to comfortable house a toddler while also making sure it is tall enough to prevent tipping and other safety issues.

We also want to make the crib somewhat portable. Our sponsor, Nancy, told us that portability was the least important factor, but we are still going to make our design as portable as possible to make using our design more convenient. Thus, our design needs to be lightweight to ensure a new mother could move it around with relative ease. Also, we need to make sure that the crib can fit through a doorway so it can move from room to room. Similarly, we are hoping to make it compact enough to allow it to be easily transported. In order to incorporate all these features in the crib design, our group will also make this crib both portable and foldable. Portability will be defined by the ability to transport the crib, whether it is around the home or from one household to another. Foldability will be defined by the ability of the crib to disassemble and fold into a more compact volume compared to the already space efficient design that we have generated.

Engineering Specifications

Using the aforementioned customer requirements, we created a list of engineering specifications that our design should adhere to. These values were calculated based on research we did into ASTM crib standards and our benchmarked products. We consulted with our sponsor to make sure that the specifications we came up with were sufficient to meet her customer requirements.

We translated many of our customer requirements into engineering specifications by using the ASTM standards for cribs. Many safety issues were already converted to specifications in the book, such as the distance between vertical bars in the crib which must be less than a can of soda or approximately 2.5”. For other requirements that were not covered in the ASTM standards, we used various resources to get to engineering specifications that we felt best met our requirements. For instance, to calculate the necessary length of the crib, we looked at the average height of a two year old and lengths of standard baby crib mattresses. From those values we found that a range of 30” to 42” was acceptable. Our group aims to achieve portability by designing the crib with a width dimension that is small enough to fit through a standard doorway. Foldability will be achieved through a design that can fold down to nearly 30% of the fully assembled volume for a more space efficient design than can be more easily transported in trunk of a typical midsize sedan.

The rest of our engineering specifications can be found below in Table 2 and our full QFD can be found in Appendix D.

Table 2: Engineering Specifications

Engineering Specifications	*Engineering Targets*
Lifetime of Crib	5 years
Individual Component Lifetime	More than 5 years
Hours used per day	16-20 hours
Cost	$100 max., $60 target
Weight	40-60 lbs.
Length of Crib	30-42 in.
Inside Height of Crib	24-30 in.
Total Height of Crib	34-40 in.
Width of Crib	24-30 in., 36 in. max.
Eliminate Tipping: Proper Width/Height Ratio	3:4
Spacing Between Vertical Bars	2.5 in. max. (~diameter of a soda can)
Spacing Between Mattress & Wall	1/8 in. max.
Porosity of Crib	50% or more
Corner Radii	0.25 in. min.

Benchmarking

Research was conducted in order to develop a standard that our design should meet. Our first goal was to determine how and why cribs failed. Many cribs have been recalled, and we looked at how these cribs were found to be unsafe. Our team then evaluated three benchmarks: an inexpensive crib, a portable crib, and a “standard” crib. We researched these cribs by searching manufacturers’ websites and reading customer and professional reviews. From the information we obtained through research, we assigned values in a quality function deployment chart (QFD) to find how these benchmarked products matched our customer requirements as well as our engineering specifications.

Our group did some field work at Babies R Us to study the kinds of cribs that are currently available on the market. Our first benchmark is the Delta Natural Portable Crib at a cost of $119.99. The crib has assembled dimensions of 39.3” x 25.5” x 40.0” (L x W x H) and a weight of 35.4 lbs. This crib is made of pine wood with a natural finish, includes 1.5” thick mattress that is waterproof, casters, and has two mattress support positions. This is a very simplistic crib that should satisfy the basic needs of the child while also adding a feature that allows for rapid foldability. After removing the mattress, the wooden support that it sits on folds up to one side. Then, two hinges placed in between two bars on the end walls can fold inward, thereby decreasing the width of the crib down to less than 6.0”. This allows for easier maneuverability around the house.

Our second benchmark is the Graco Travel Lite Crib with Stages at a cost of $89.99. This is more of a pack n’ play than an actual crib, therefore, it is made of a metal frame with plastic everywhere else. Actually, this travel crib is about 20% smaller than a traditional pack n’ play with dimensions of 32.0” x 22.8” x 29.3” and a weight of only 19.7 lbs. It also includes a removable bassinet with bumpers for added safety and comfort, a canopy to shield your child, a push-button for simple and fast foldability, wheels to move it around the home, and airy mesh on all sides for maximum ventilation. For safety considerations, use of the bassinet is only recommended for infants who are unable to push up on their hands and knees and weigh less than 20 lbs. Also for safety reasons, the play yard is only recommended for children unable to climb out and under 35” tall due to the travel crib’s dimensions.

Our third benchmark is the Delta Cherry Mini Crib at a cost of $169.99. Although very similar to our first benchmark crib that is made by the same manufacturer, this crib costs a lot more due to the mattress support made of metal springs that is a part of the assembly. This mattress support is included since a critical feature of the crib is that the headboard converts into a twin bed, toddler bed, or day bed. To accommodate this feature and more, the crib has dimensions of 39.5” x 27.0” x 41.3” and a weight of 48.5 lbs. The crib is made of pine wood with a cherry finish, includes a 1.5” thick mattress that is waterproof, casters, and has two mattress support positions.

The specifications for all these benchmarks were taken as a guideline for the design of our crib concept. We looked at all the features the benchmarks included in their designs and discussed how to incorporate some of them into our concepts, and later our final design.

Concept Generation

Based on our customer requirements and engineering specifications, the main functions for our design are as follows: crib frame construction, crib side-wall construction, crib end-wall construction, crib portability, crib shape, crib fasteners, edge protection, and bedding. A morphological chart was then implemented to develop various concept ideas for each function. The full morphological chart can be found in Appendix F. On this chart, the green shaded boxes represent what we determined to be the best concept idea for each function. The yellow shaded boxes represent what we determined to be the second best concept idea. Explanations for each function are located below.

Function 1: Crib Frame Construction

The frame of the crib should be made out of a strong, durable material that will handle the rigors of everyday use for up to five years, as shown in the customer requirements. This material also needs to be inexpensive, as that is also one of the customer requirements for designing this crib. Another factor is the weight of the frame, which corresponds with the customer requirement of making the crib portable.

Taking into account the customer requirements, four concepts were chosen: wood, PVC pipe, aluminum, and steel.

Function 2: Crib Side-wall Construction

The side-walls of the crib should be made out of a durable material that will last the lifetime of the crib, which the customer requirements determine to be five years. Since it has been shown that proper ventilation can help prevent sudden infant death syndrome (SIDS), the sides of the crib must be breathable. This can either be accomplished by putting spacing between a solid material, or making the material itself breathable. As with the frame construction, the side-walls should be made out of a lightweight, inexpensive material to help defray costs and maintain portability. Taking into account these customer requirements, four different material concepts were created: wood bars, PVC pipe bars, mesh, and clear plexiglass.

Function 3: Crib End-wall Construction

The crib end-wall construction requirements mirror those of the side-wall construction. For a detailed analysis of concept generation and material selection, see Function 2: Crib Side-wall Construction.

Function 4: Crib Portability

One of the main customer requirements is that the crib is to be portable. With this in mind, a number of concept ideas were generated which allowed the crib to be maneuvered around a family's home. The generated concept ideas were four locking wheel, two locking wheels, rails, and tennis balls.

Function 5: Crib Shape

Along with the portability of the crib, the amount of space that the crib takes up is also a customer concern. These cribs are to be designed for low-income families, where there may not be a lot of room in the household for a crib. Also, the ease of manufacturing the crib was taken into consideration when choosing a shape. With this idea in mind, several different shapes were generated for the crib design: a square, rectangle, ovoid, circle, and octagon.

Function 6: Crib Fasteners

Maintaining the durability of the crib fasteners is an important part in the safety of the crib. The fasteners must remain in place during the lifetime of the crib. If the fasteners were to come loose and fall out, a child may choke on the loose parts. Also, even if the fasteners didn't fall out, the stability of the crib would lessen and be a cause for concern. The fasteners must be fully embedded in the material, so that they would not provide an edge for a child to get injured on. With the safety and durability customer requirements, we came up with five separate concept ideas for fasteners: screws, bolts, nails, adhesives, and notched fittings.

Function 7: Edge Protection

As a safety precaution, the edges of the crib should be designed so that they cannot cut or injure a child. The safety of the child is a very important customer requirement and it needs to be taken into consideration in the design of the structure and walls of our proposed crib. Keeping this requirement in mind, our team generated three concept ideas for edge protection: rounded edges, foam cylinders, and bubble wrap.

Function 8: Bedding

The bedding selection is an important factor in the safety of a crib. The customer requirements state that no sheets or soft bedding should be used. With this in mind, our team generated three different types of bedding: standard mattress, foam, and a board with a mattress pad.

Concept Evaluation

To evaluate all of the concept ideas for each function, we compared the strengths and weaknesses of each generated concept idea. We evaluated each of the concept ideas separately under each function, and selected the one that we felt would best satisfy the customer requirements. The following section details the evaluation of each design function concept.

Crib Frame Construction Concept Ideas

Our four material selections for the crib frame were wood, PVC pipe, aluminum, and steel. For using wood as a frame, it gave us a durable solution that was lightweight and inexpensive. PVC pipe is lightweight and has a fairly low cost; however, our team has concerns about the durability of PVC pipe, as well as the ability to manufacture a crib out of it that meets the standards of our customer. Aluminum was determined to be heavy and expensive, yet very durable. Lastly, using a steel frame would increase the durability of the crib, but also increase the weight and cost.

Crib Side-wall Construction Concept Ideas

Our team generated four types of materials for the side-wall of a crib: wood bars, PVC pipe bars, mesh side-walls, and plexiglass sides. Using wood bars for the sides of the crib would improve the durability of the crib, and would also be inexpensive. PVC pipe bars are lightweight and are lower in cost; however, PVC pipe bars are not as durable as wooden bars. Using mesh side-walls would allow for proper ventilation of the crib, but some kinds of mesh can tear easily. Lastly, using plexiglass sides would allow designs and slots to be cut into the plexiglass, making the crib aesthetically pleasing. A downside of plexiglass is that it is expensive and heavy.

Crib End-wall Construction Concept Ideas

The crib end-wall construction requirements mirror those of the side-wall construction. For a detailed analysis of concept generation and material selection, see Crib Side-wall Construction Concept Ideas.

Crib Portability Concept Ideas

From our design concepts, we determined that the crib must be able to be moved around a house by one person. Our four design concepts were four locking wheels, two locking wheels with two end posts, rails, and tennis balls. Four locking wheels would make the crib able to be wheeled around a house without having to physically lift the crib off the ground. Using two locking wheels, the owner of the crib would lift the end with foot posts, and be able to move the crib with the two wheels on the other end. Using rails, the crib would be slid around the floor of whatever room it was being kept in. Lastly, using tennis balls would make it easy for the crib to be slid around on hardwood or tiled surface, similar to how they are used in a walker.

Crib Shape Concept Ideas

Our team generated five separate ideas for the shape of our prototype crib: square, rectangular, circular, ovoid, and octagonal. With a square crib, all of the sides would be the same, thus making the crib easier to manufacture. However, the crib would be space inefficient since the crib must be long enough for a child to lay flat within the crib, which would waste space and material. A rectangle is a simple shape to manufacture, and can be used with most materials. An ovoid would use slightly less space than a rectangle, but it would be significantly more difficult to manufacture. The circle design would be aesthetically pleasing, however it would be space inefficient and very difficult to manufacture. The octagon design is similar to the ovoid design in that it saves slightly more space than the rectangle design but it is considerably more difficult to make.

Crib Fasteners Concept Ideas

Our customer requirements state that the crib fasteners must be durable for the lifetime of the crib. Using this, our team generated five concepts for fasteners: screws, bolts, nails, adhesives, and notched fittings. Screws are very easy to drill into wood, and are very durable. They are also able to be taken out of the material, which would allow for the complete disassembly of the crib. Screws would not be able to be used with metals. Nuts and bolts would require drilled and countersunk holes in the material which would increase the manufacturing time. Bolts would be able to be inserted and removed from the crib, making it possible to disassemble the crib. However, the bolts may stick out of the sides of the crib, leaving a raised surface where a child could injure themselves. Nails are very simple to construct a crib with; however, nails would only be able to be used with a wooden structure. With nails, it would be very difficult to disassemble and reassemble the crib. Adhesives are a low cost solution to the problem of fastening different parts of the crib together. However, adhesives tend to wear down over time, which could cause safety hazards if parts begin to come loose. Also, adhesives make it impossible to disassemble the crib. Lastly, our team came up with the concept of notched fittings. These fittings would use press fits to keep the different parts of the crib in place. This would be the cheapest solution; however, over time durability could become an issue with the possibility of parts warping and losing their tolerances.

Edge Protection Concept Ideas

To ensure that our crib didn’t have any sharp edges or corners, we came up with three ways to remove them from our crib: rounded edges, foam cylinders, and bubble wrap. Rounded edges can be included in the manufacturing process if we choose a wood frame, and would require no extra material cost. Foam cylinders can be fitted to each of the posts of the crib, however, they have the possibility of coming loose and causing a safety hazard. As with the foam cylinders, the bubble wrap would wrap around the posts of the crib, but could cause hazards if it were loosened from the posts.

Bedding Concept Ideas

Our team used three different designs for the bedding of our crib prototype: standard mattress, foam, and a board and mattress setup. A standard mattress gives firm support for the child, and is commonly used in cribs. The mattresses come in one or two standard sizes, and are relatively expensive. Foam is an inexpensive alternative to a standard mattress, but is often too soft for a child to sleep on. The board and mattress setup is also a cheaper alternative to the standard mattress. This setup however could be too stiff and be uncomfortable for the child.

Total Crib Concept Generation & Selection

From the morphological chart shown in Appendix F, a new chart was created which took the top choice for each function and combined them together to arrive at our alpha prototype for the crib. This chart can be seen in Appendix G. Other choices were combined together as well and included in a Pugh chart (Appendix I). The Pugh chart was used to select the final concept which best met the customer requirements.

The criteria for the Pugh chart was determined from the customer requirements and the QFD diagram. We selected Concept E as the datum concept, since our team liked the idea of using plexiglass for the side-walls and we wanted to see how it compared to our other four concepts. Within the Pugh chart, a “1” was given when the criterion could be satisfied easily, a “0” was given when the criterion may or may not be satisfied, and a “-1“ is given when the criterion could not be satified.

From the Pugh chart, it was determined that Concept A best met the customer requirements. Concept A uses lightweight materials such as a wood frame and mesh sides, and also has rounded edges and notched fittings. Concept B also did fairly well against the datum concept, but since its frame was constructed from PVC piping, it wasn't as durable as the wooden frame. Concepts C and D fared poorly in this Pugh chart due to the use of heavy, expensive materials. Concept E did not score well due to the high weight and cost of the plexiglass side-walls.

Selected Concept

In this section, we will discuss our selected prototype (Concept A) and the many different components of the said prototype. A sketch of this concept can be seen below in Figure 1.

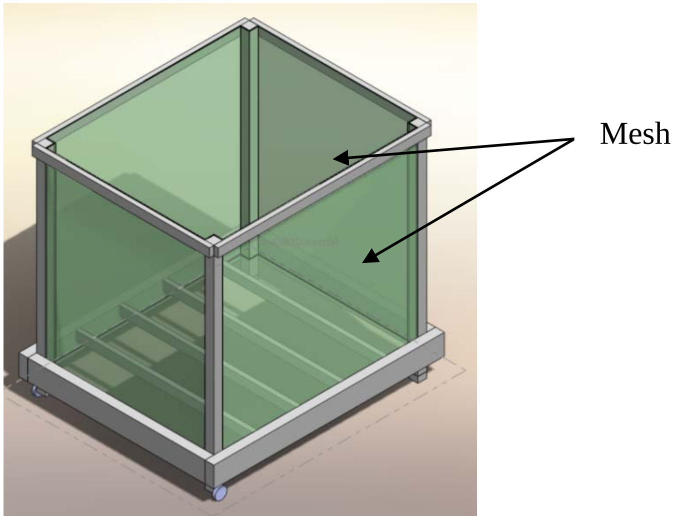

Figure 1: CAD Model of Concept A

Frame Material Selection

Based upon our Pugh Chart, which can be seen in Appendix I, we found that wood is the best material for us to use. This is because wood best meets our requirements for low cost and for low weight. An 8' long 2x4 piece of lumber costs, on average, only $2-$3, which makes it the cheapest material at our disposal [4]. This wood will be sawed and sanded down into the frame design.

Side and End Wall Material Selection

We are planning to use mesh for our four walls at this time. We decided against using solid head and end boards because they restrict some of the air flow within the crib. Mesh was selected because it is relatively cheap at approximately $8/yard [5]. Also, the mesh offers a good view of the child in the crib and it is very breathable. We plan to use a staple-gun to fix the mesh to the exterior of the wood frame where the staples will be out of the reach of the child.

Portability Selection

The selected method of portability is using two, locking wheels located at one end of the crib. This is to reduce cost that would have been spent on purchasing third and fourth wheels. Figure 2 shows that two of the legs are made longer to match the extra height on the crib that is added by the two wheels. Also, close ups of both leg-types can be seen in Figures 3 and 4.

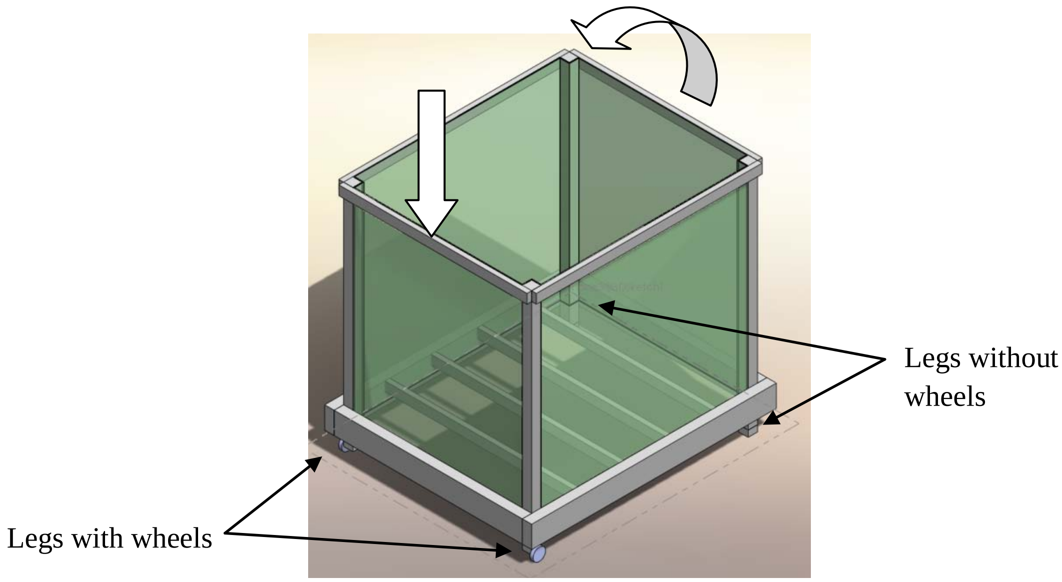

Figure 2: CAD Model of Concept A

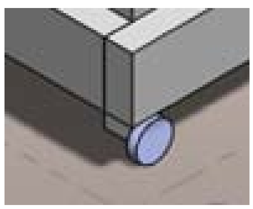

Figure 3: Leg with Locking Wheel

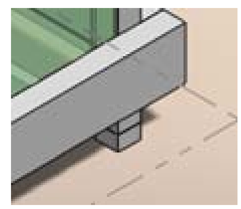

Figure 4: Leg with no Wheel

Using this design, the crib can be moved by tipping it in the direction of the wheels and balancing it on those two wheels, much in the same way that you might tip a shopping cart on its back wheels. This shouldn’t take much force to balance, as we expect the crib to weigh less than 30 pounds.

In order to improve the portability of the alpha design, we are currently working on an altered design which uses hinges to allow the walls of the crib to fold making the crib much more portable. We intend to make the short sides be connected to one of the larger sides by a set of hinges. This will allow the short sides to fold 90 degrees into one of the cribs large sides. After doing that, there will be two condensed walls, which will both fold down onto the base of the crib once the mattress is removed. This will allow the crib to condense enough that it will be able to fit in the user’s car and allow the crib to be significantly more portable.

Crib Shape Selection

Our alpha design will use a standard, rectangular shape. This is because it is easier to find mattresses in this shape, it uses space efficiently, and it is easier to design folding mechanisms out of a rectangular frame than say an ovoid or an octagon. This means the inside dimensions for our crib frame base will be approximately 30” x 36”. Also, inside height of the crib will be 30.75” without a mattress and the total height of the crib will be 36.5”. A dimensioned drawing of the base is seen below in Figure 5.

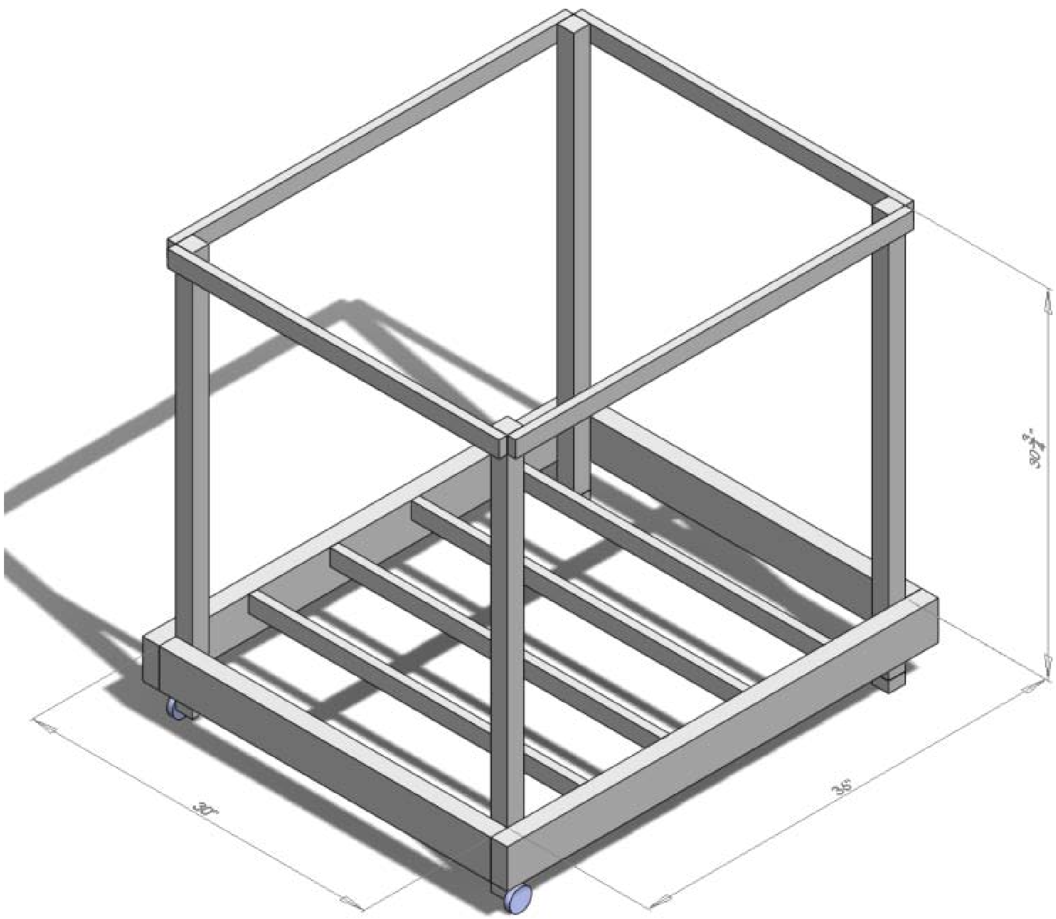

Figure 5: Dimensioned Drawing of Wood Frame

Fastener Selection
Our design will use a combination of screws and nails, notched fittings, adhesives, and staples to fasten our prototype. We plan to use notched fittings, adhesives, and brackets between some wood components such as the base of the crib and the baseboards as seen below in Figure 6.

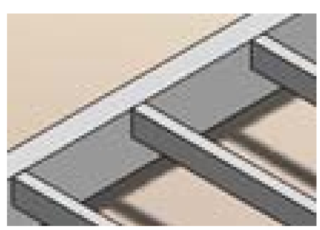

Figure 6: Frame and Bed Support Connection

Screws and nails will be used to fasten most of the wooden components together because they are cheap and very reliable. Also, staples will be used to fix the mesh to the wood frame.

Edge Protection Selection
For our alpha design, we will simply round off the corners of all of the sharp edges. The only sharp edges in the prototype will be made of wood so they will be relatively simple to sand off.

Bedding Selection

Lastly, we selected to use a standard mattress in our prototype because mattresses become more expensive as you start to look at different shapes. We have not selected a brand or model yet, but the size should be as close to the actual size of the base as possible to eliminate the possibility of getting the child's finger(s) stuck in gaps. That means it will have to be just under 30" x 39". Should we find that mattresses are significantly cheaper at another size, we may alter our base size to minimize the cost of the bedding.

Parameter Analysis

Parameter analysis verified that our group was correct in a rectangular shape and using pine wood for the construction of the crib. On the other hand, it allowed us to improve our design by making it more portable by decrease the dimensions for the alpha design of the crib in all directions. This led to an evolution of our alpha design into a final design that includes foldability.

Shape

The shape of our crib design is rectangular not only to follow the industry standard, but since it maximizes space efficiency, which is an important customer requirement. A square crib would require the dimensions of the length and width to be the same. That design would contain an excess amount of space since the human body is a lot longer than it is wide. A round crib is also unfavorable since manufacturing the crib would become much more difficult and costly. The crib would take up nearly the same amount of space as a square crib, as the diameter correlates to a length and width of the same dimension, but there is much less usable space for the child.

One of our customer requirements is portability and our group decided to include this in our design through foldability of the crib. Our design contains a folding mechanism that allows us to decrease the dimensions of the crib down to a size that would fit in the trunk of a typical midsize sedan. In its folded state, the crib has dimensions of 39" x 27" x 12" which results in a volume of 7.31 ft^3. Even the smaller midsize sedans have a trunk volume of at least 13 ft^3, which means our crib can fit comfortably inside with room remaining for other items.

Dimensions

The dimensions of our crib design are 39" x 27" x 30" with an inside height of 24". The height of an average two year old child is 30" and the length of a typical pack n' play is 42" so we set these dimensions as our target range. The crib has to be long enough to hold the child, but we also need to take into account portability. The width of a readily available mattress we could use is 24" and the width of a typical pack n' play is 30" so we set these dimensions as the target range. The inside height of this crib has the same target range as the width of the crib in order to maintain adequate dimensions to prevent the crib from tipping. We want to maximize the amount of force required for the child to be able to cause the crib to tip over by maximizing the ratio of the width to the height.

After researching several sources for a crib mattress, we decided on one with dimensions of 24" x 36" x 1.5" due to its low cost, as that is key parameter of our project. We add 3" to the length and width of the crib for surrounding material which results in dimensions of 36" for the length and 27" for the height. Our group took into account the proper dimensions needed to eliminate tipping and for the folding mechanism in the design to work therefore, we made the inside height dimension 24", since it needs to be the same as the width of the mattress. The height of the wheels plus the frame in our design added to the inside height of 24" results in the total height of 30". All dimensions are within the target ranges that are listed in Table 2 under the Engineering Specifications section.

Finite Element Analysis

We performed finite element analysis on parts of the prototype where we felt had the greatest chance of failure. Using Hypermesh, the top bar of the sidewall was analyzed. A point load was placed at the center of the bar, simulating where a child would grab the bar. This load was taken to be twice the weight of an average two year old, as the crib is designed with a safety factor of two. Upon analysis, it was found that a point load would cause a maximum stress of 6.8 MPa. Using a safety factor of two the resulting stress was less than the along-grain yield strength of pine wood, which is 35.0 MPa. We also performed a finite element analysis on the plywood that makes up the bottom of the crib. We again placed a point load simulating the weight of a child at the center of the crib. Upon using Hypermesh and Nastran, we found that this load produced a maximum Von Mises stress of 2.1 MPa. Von Mises stress was used due to the relatively small thickness of the plywood part, meaning that shear stress could not be ignored. Using a safety factor of two the resulting stress was less than the yield strength of plywood, which is 38.8 MPa. Thus, we concluded that our theoretical model would not fail during everyday usage. For full results see Appendix K.

Materials

Our group decided the crib prototype will be composed of softwood (pine) after using the multi-criteria search algorithm available in the Cambridge Engineering Selector (CES) software package. Appendix C shows the process in which the material for our prototype was chosen. In order to keep costs low, we want to use a material for our crib design that has a high machinablility. Our group decided to consider only materials with a machinability of at least 3 (on a scale of 5), which eliminates all glasses and technical ceramics as shown in Figure 7 below.

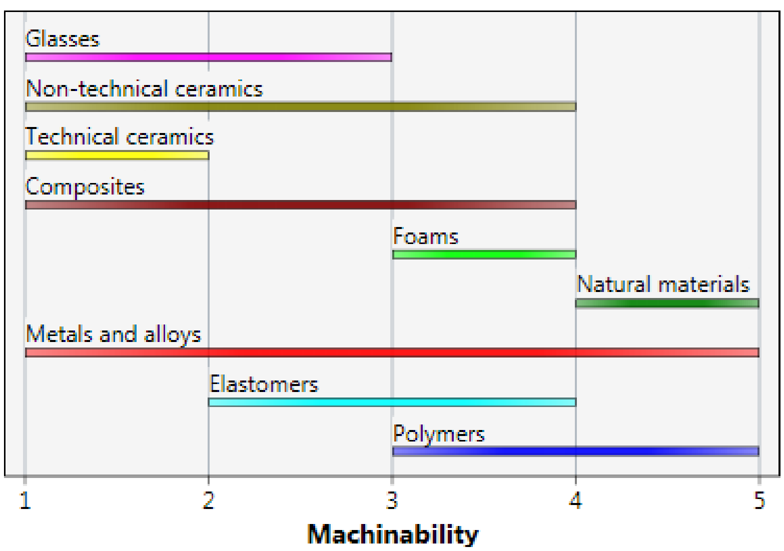

Figure 7: Machinability of Materials

Our group used the evaluate feature in Solidworks to determine that the volume of the amount of material we would need for our design is 1769.4 in^3, which converts to 1.024 ft^3. If we divide the maximum allowable weight of the crib, which is 60 lbs based on our engineering specifications, by the volume of the crib, we can calculate the maximum density of the material we can use to manufacture the crib. We calculated the maximum allowable density to be 58.60 lb/ft^3. This allows us to eliminate non-technical ceramics, composites, metals and alloys from consideration. To achieve a weight closer to the median of our target range for weight, we will also eliminate elastomers and polymers as they barely qualify as satisfactory materials.

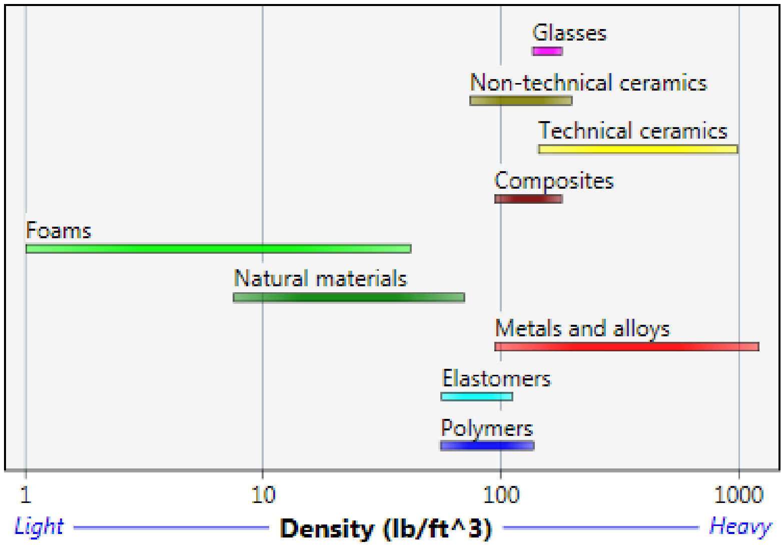

Figure 8: Density of Materials

This leaves us with only foams and natural materials as options for our crib. When comparing these materials, we see that natural materials are generally stronger, while at the same time being cheaper than foams as shown in Figure 9.

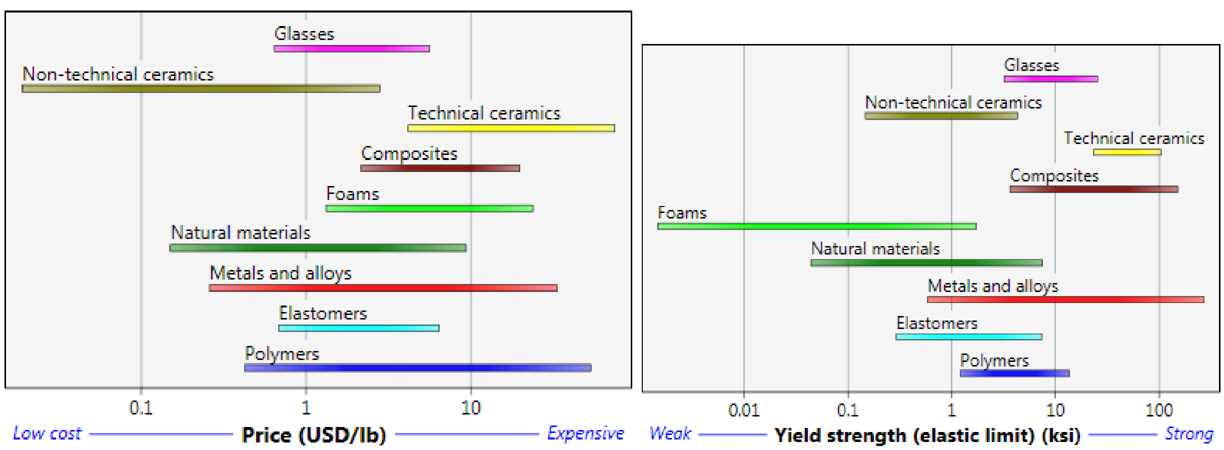

Figure 9: Yield Strength of Materials

Summary of Design Analysis Assessment

Using the CES software, our team selected a material that would be used for the frame of our crib. Taking into account the machinability, the density, and the yield strength of each material, we came to a conclusion that natural materials would work the best for the frame of our crib. We wanted a material that had a high machinability so that the cost would be kept down. Our group wanted a material with a low density, so the customer requirement of lightweight would be met. Lastly, we wanted a material that would have a yield strength that would be suitable for a crib.

Using the SimaPro software, our team learned about the environmental impact of different types of woods that would be used to create the frame of our prototype. Since wood is the main material in our design, two different types of wood, yellow pine and Oregon pine, were selected to be compared for environmental differences. Upon running SimaPro, our team found that the yellow pine had a lesser environmental impact than the Oregon pine. However, it was also shown that since neither material has a large impact on human health, both materials would be suitable in the design of our prototype.

Using FMEA and Designsafe software, our team created a manufacturing plan that would reduce the risk of safety hazards. FMEA helped our team identify different manufacturing processes which could have been hazardous without the proper safety procedures. The Designsafe software generated a report which showed how to reduce the risk level of our manufacturing process. These two tools helped us create a safe manufacturing plan which our team followed to complete our prototype.

Final Design Description

In this section, we will outline our final concept and take a thorough look at each component and function of the crib. A final CAD assembly of the crib can be seen below in Figure 10.

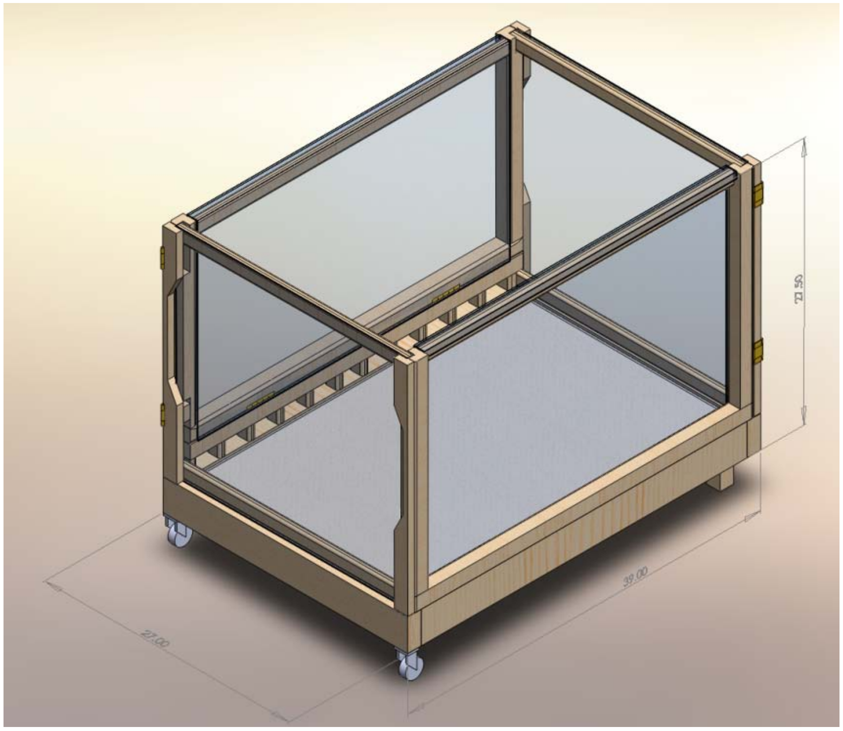

Figure 10: Total Crib Assembly

Crib Base

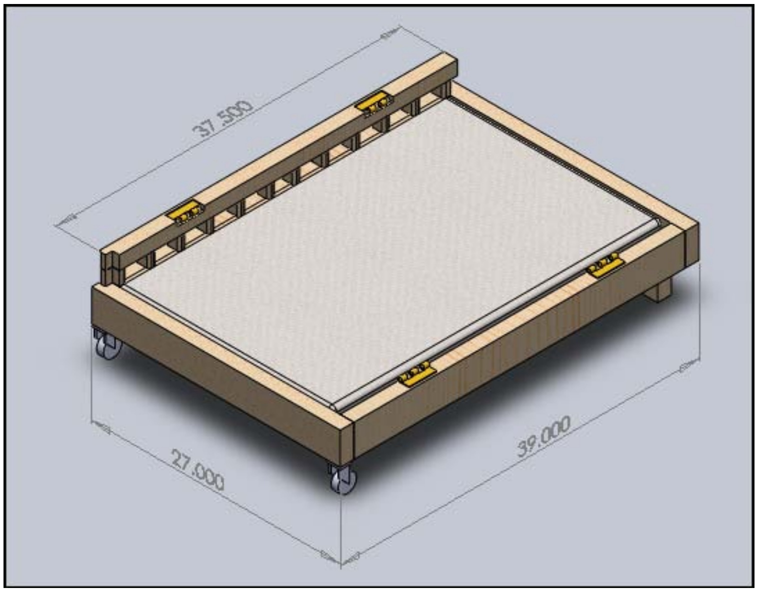

Figure 11: Crib Base Assembly

The base of the crib is shown above in Figure 11. It is constructed using 2”x4” beams for the base and then three 1”x2” beams for the slats that support the child’s sleeping area. On top of the three slats, a plywood board is placed to give a good surface for the child’s mattress to rest on. To further support the piece of plywood, notches will be milled out of the 2”x4” beams to allow the plywood to slide inside. The notches are shown below in Figure 12.

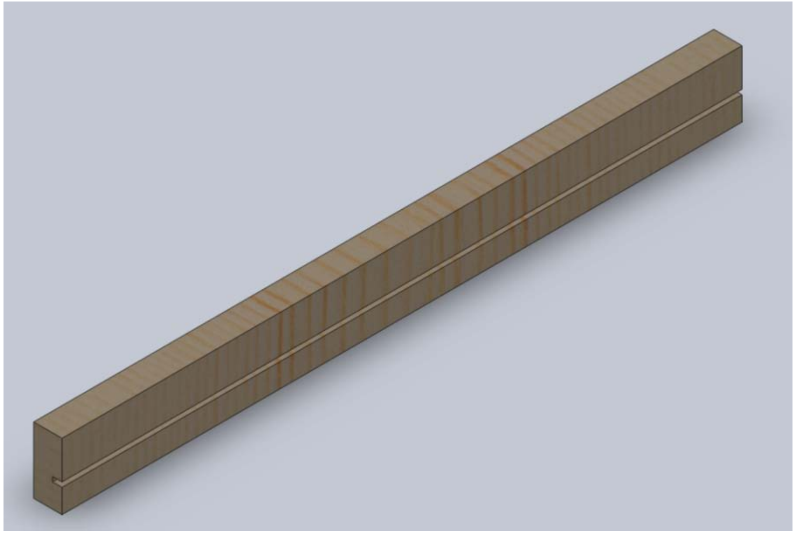

Figure 12: Notched Frame Piece

The crib then rests on two lockable wheels on one end and then two 2”x2” posts at the other end. The wheels are included to allow the crib to be wheeled around whether it is upright or folded. We only included two because it will reduce cost while closely maintaining the ease of moving the crib about.

Lastly, there is a section that is shown in Figure 11 which is raised higher than the rest of the frame. This section is composed of a 2”x2” beam and then that section rests on ten 1”x2”x1.5” blocks. The 1”x2” blocks have radii of ¼” to meet our engineering specifications for corners on the inside of the crib. This entire section is created to accommodate our folding mechanism from the crib which is further discussed below in the section titled “Folding Mechanism” (pg 22). At the each end of the 2”x2” beam, there is a block made of 2”x2” beam that is the same length as the ten blocks previously mentioned. These 2”x2” blocks have a vertical slot milled out of them that is ¾”x¾” as highlighted above in Figure 11. This is to allow the bottom railing of the end-walls to fit snuggly into the rest of the frame to give the user and easy indicator of when the crib is or is not closed.

Sidewalls

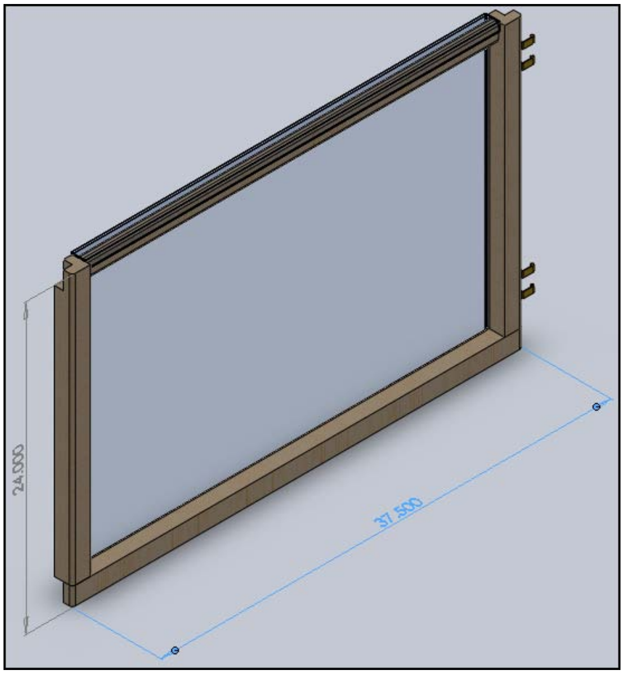

Figure 13: Large Sidewall

The larger of the two sidewalls is seen above in Figure 13. Three of the sides of this wall are made of 2”x2” beams while the top railing is made of a 1”x2” beam. The two, 2”x2” beams that make up the vertical posts have ¾”x¾”x1.5” notches cut out of the corners facing the sidewalls as highlighted in Figure 13. The bottom beam of this wall also has a ¾”x¾” slot cut out of the corner. These cuts are created to let the railings of the end-wall slide into frame.

The height of this sidewall is 24” to meet our engineering specifications for total height and inside height of the crib. Mesh will then be fixed to this wall to keep the child in the crib. The method for fixing the mesh to the sidewall will further discussed in the section titled “Mesh” (pg 22).

The smaller sidewall is seen in Figure 14.

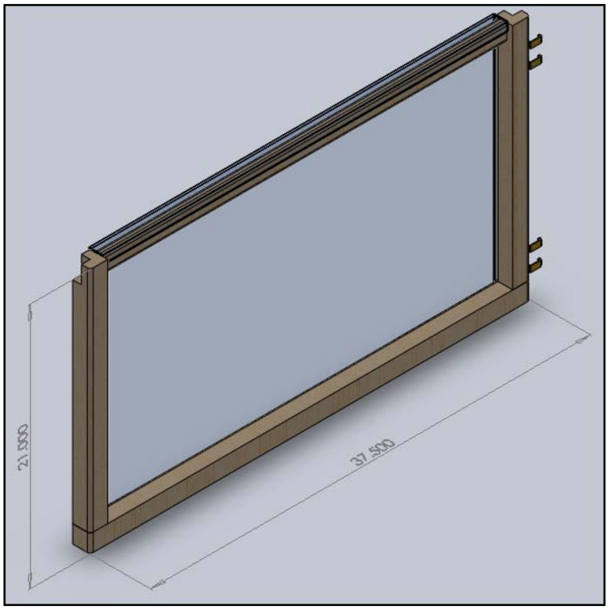

Figure 14: Short Sidewall

This wall is similar to the larger wall in that three of the walls are made of 2”x2” beams and the top railing is made of a 1”x2” except that it is only 21” tall because of the raised section on the base that was discussed above in the section titled “Crib Base” (pg 18). This sidewall also has ¾”x¾”x1.5” notches cut out of the vertical posts’ corners as highlighted in Figure 14. The side was constructed like that because of how we designed the crib to be folded which will be discussed in detail in the section titled “Folding Mechanism” (pg 22). Mesh will also be attached to this side wall in the same way that it will be for the larger wall.

Endwalls

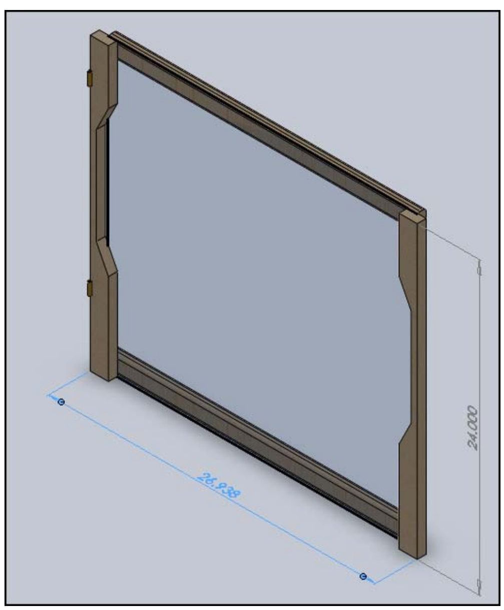

Figure 15: End-wall

The figure above shows one of the endwalls of the crib. Both endwalls are identical to make manufacturing and assembly as easy as possible. The top and bottom beams are both 1”x2” and 25.5” long. Fixed to the outside face of these beams are two more 1”x2” beams. These beams are fixed to the outside face, as shown in Figure 15, to allow the top and bottom bars to fit snuggly to their corresponding notches in the sidewalls and the base of the crib. This allow the user to have a definite way to see that the crib is closed before they end attempt to close the latches that will lock the crib together.

Mesh

Each of the four walls will be covered with mesh to keep the child in the crib. These will be stapled to the frame in such a way that none of the staples can be reached by a child that is in the crib. For each of the four walls, the mesh will be fixed at the top by wrapping the mesh over the top railing and then stapling it to the outside of the top railing. On each side of the walls, the mesh will be pulled around to the side of the wall and stapled there so that when the crib is upright, the staples will be covered by overlapping walls or they will be on the outside of the crib. Lastly, for the bottom of each wall, the mesh will be stapled near the bottom so that when the mattress is in the crib a child will not be able to reach them because of our specification that a child’s finger cannot fit between the wall and the mattress.

Bedding

For our crib bedding, we selected a “LA Baby 2” Compact Crib Mattress. This mattress has dimensions of 24”x36” which fits our crib perfectly.

Folding Mechanism

The most complex function of our crib design is the folding mechanism we designed that will allow the crib easily transported. The crib is shown again below in Figure 16 where it is at its upright position.

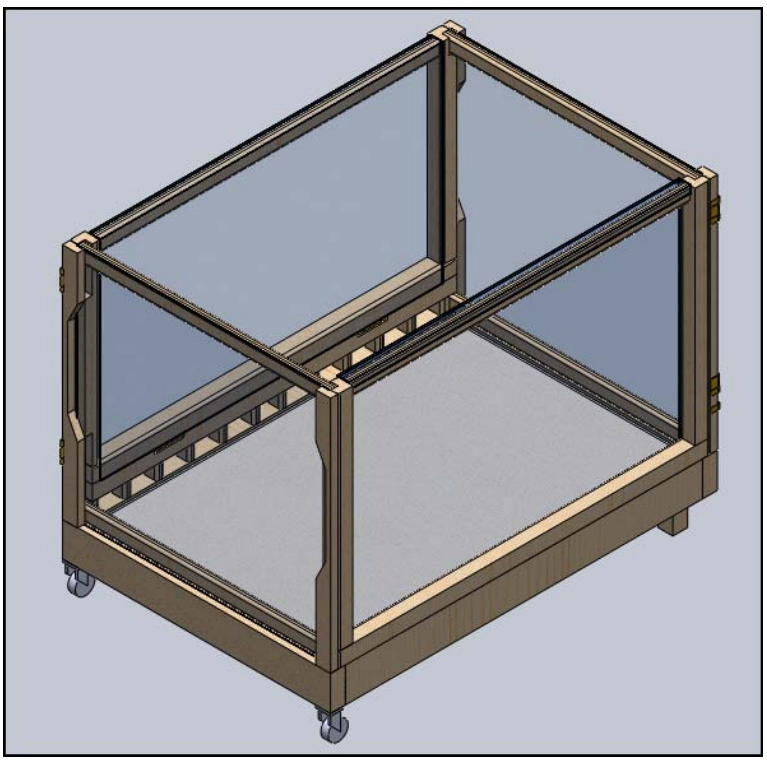

Figure 16: Assembled Crib

From this position, the user will unlatch two (2) latches on the posts to release the end-walls and allow them to swing outward. These latches are not shown in figure 16 because we have not yet decided which company will be our supplier. The crib is shown in its first immediate unfolding step below in Figure 17

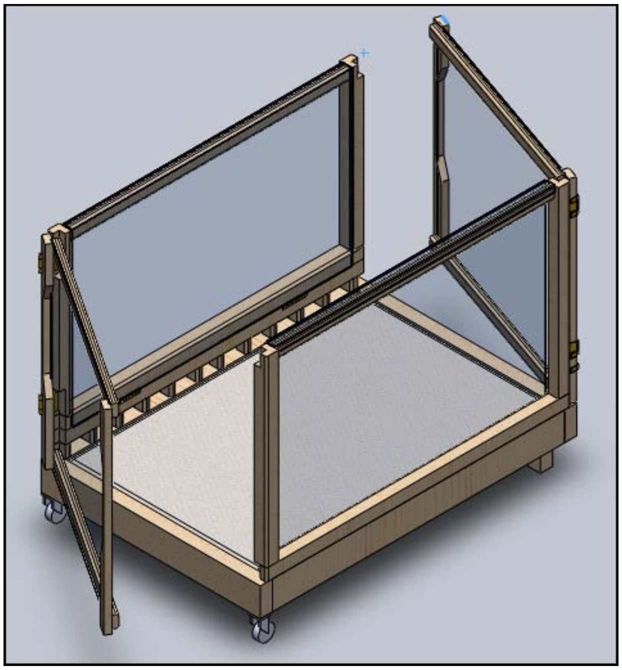

Figure 17: After end-walls are unhinged

The end-walls will then continue to rotate a full 270 degrees until they fold into the outside of the sidewalls as shown below in Figure 18.

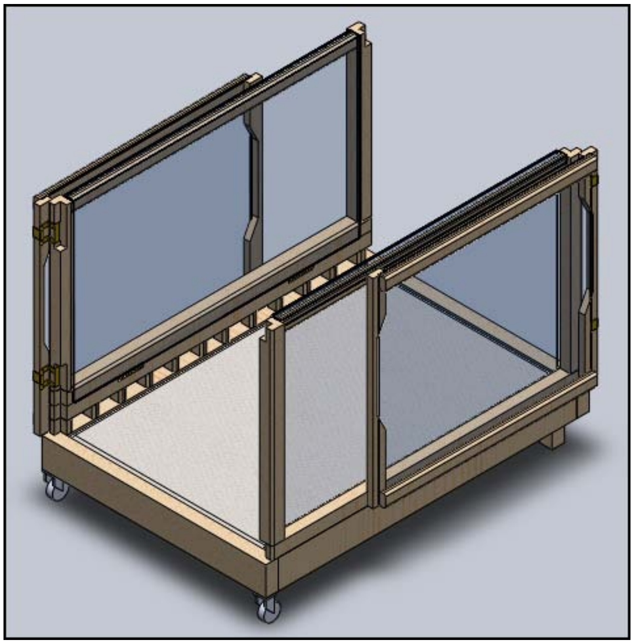

Figure 18: After end-walls have fully folded

Then, the safety latches that are attached to the frame and sidewall (also not shown) are released and the sidewall is allowed to fold down. These latches provide an added measure of safety to the design, holding the sidewalls up if by chance the end-wall latches become undone. Theses latches prevent the crib from folding down and, possibly, collapsing on a child in the crib. The large sidewall must be folded first because it rests lower as shown in Figure 19.

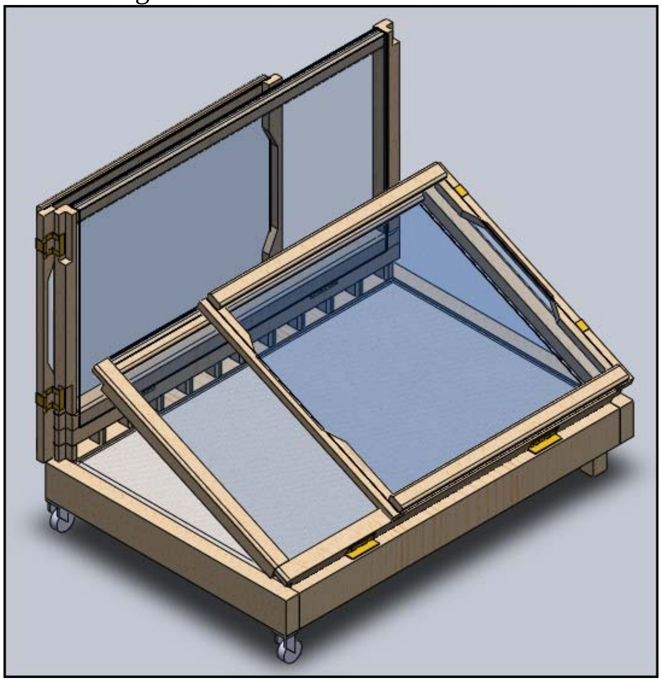

Figure 19: Large sidewall folding down

Then the smaller sidewall will fold down on top of the larger one. This is why there is a smaller wall and why there is the extra section attached to the base. It is to allow that wall to have a higher hinge point which allows it to fold on top of the smaller wall. The smaller sidewall folding can be seen below in Figure 20.

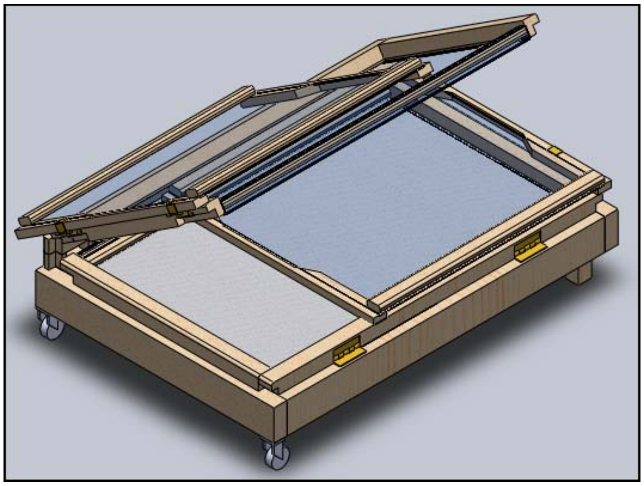

Figure 20: Small sidewall folding down

The full folded assembly is shown below in Figure 21.

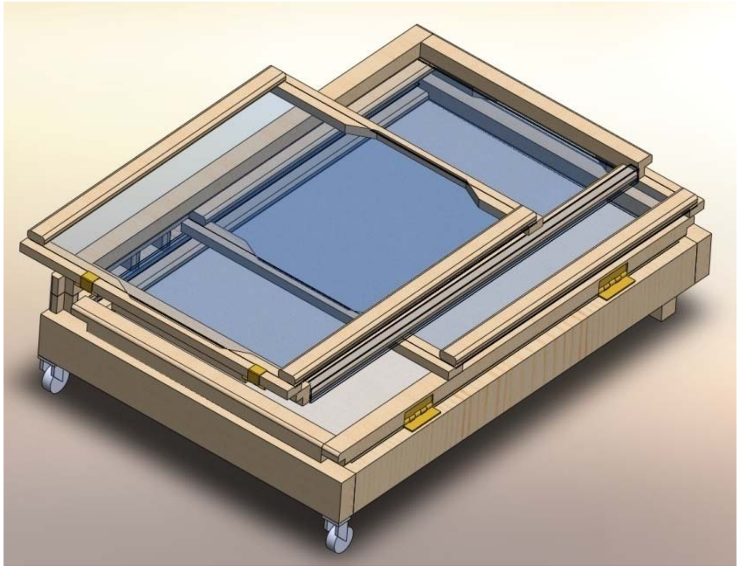
Figure 21: Fully folded assembly

The folded assembly lowers the height of the crib structure from 29 ¾” to 11 ¾” which makes it significantly easier to transport. The width and length do not change significantly when it is folded.

Safety

Our crib design will keep the child using it safe for many reasons, including the ones that have been previously mentioned in this report such as covering staples or rounding sharp edges.

We followed the ASTM standards when designing our crib. We made sure that any vertical bars we had, such as the ones shown in Figure 11 (page 18), were spaced at least 2.5” apart. We maintained proper spacing between the mattress and side of the crib such that no child can get their finger through in the gap. Also, we made sure there were no sharp corners or edges on the inside of the crib. To do this, we rounded the corners of the vertical bars that are seen in Figure 11, and created notches in the frame so that we could hide hinges within the frame as seen in Figure 22.

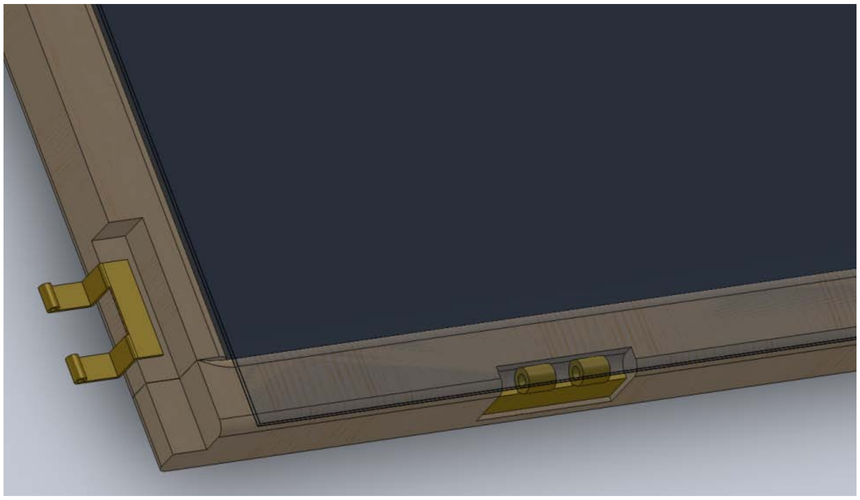
Figure 22: Countersunk hinge

To prevent tipping, we designed the width to length ratio to be close to 3:4 to make it exceptionally difficult to tip over. Also, we made the crib low to the ground which lowers the center of mass and decreases the possibility of tipping.

For bedding, we selected a safe mattress that does not need a sheet. This is because most baby sheets pose a risk of suffocation. While some are safe, we elected not to use sheets in order to keep our overall cost down. A picture of the mattress we are using can be seen in below in Figure 23.

Figure 23: LA Baby 2” Compact Crib Mattress

Cost

The final design is expect cost up to $110 which would be outside of our cost range of $60 to $100. However, it can be expected that when the final design is mass produced that costs will come down. A cost analysis using bulk pricing estimates will be done as a validation exercise on the final design’s affordability.

Prototype Description

The prototype we plan to construct will vary only slightly from the final design. The wooden components of the final design, if mass produced, would most likely be coated with a layer of polyurethane to prevent any possibility of splinters. Polyurethane will not be applied to the prototype because it is a feature that does not affect any validation testing procedures, and thus, for practical purposes, was omitted. Also, the prototype will not use the mattress specified in the final design, but an appropriate mattress of equal dimensions. This was done for the same reason the polyurethane was omitted from the prototype. Lastly, if mass produced, the wooden components could be made of particleboard, which is an industry standard for furniture pieces such as this. We will make our prototype our of pine wood, as specified above, because we would like to explore the possibility of using pine wood as an alternative to particleboard as a weight saving measure.

Manufacturing Plan

The following section details the manufacturing plan for the prototype crib. Included is a list of raw materials needed, a plan of action for the manufacturing of each component in the four-sub assemblies, and a final assembly plan.

Raw Materials

The main material that is used in the construction of the crib is pine wood. Wood is the only material that is being manufactured in the crib design. All other materials are bought and used as-is in the assembly of the crib. The following is a list of all the materials that are needed for the manufacturing and assembly of the crib.

- One (1) pine wood 2” x 4” x 12’
- Two (2) pine wood 2” x 2” x 8’
- One (1) sanded pine plywood ¼” x 4’ x 8’
- Four (4) pine wood 1” x 2” x 8’
- Ten (10) 90 degree brackets
- Two (2) 360 degree rotating wheels
- Twenty-two (22) square feet of mesh
- One (1) baby mattress 2” x 24” x 36”
- Four (4) 90 degree hinges
- Four (4) 270 degree hinges
- Six (6) locking latches
- One (1) box of ½” screws
- One (1) box of ½” nails
- One (1) 12 ounce bottle of wood glue

Manufacturing and Assembly of Frame

The manufacturing of the frame will begin with the cutting the pine wood 2” x 4” into lengths of two 27” pieces and two 36” pieces. These four pieces will be cut with a miter saw. The two 36” pieces will then have a notch cut into them along the entire length using a table saw with a blade speed of approximately 4,000 RPM. The notch will be 5/16” wide, ½” deep. The plywood piece will be cut next. This will be cut in a rectangle with dimensions of 24-1/2” x 36”. Three 1” x 2” pieces of pine wood will be cut next for the use of support underneath the bottom piece of plywood. Each piece will be cut with a miter saw at a length of 25”.

The plywood piece will be inserted with glue into the notches described above. The four 2”x4” pieces will be assembled into the shape a rectangle 39” long 27” wide. Two wood screws 2-1/2” long will be screwed into the 27” pieces at each corner. The 25” 1”x2” pieces will be screwed to the 36” 2” x 4” frame pieces in the above section at 7.2” intervals from the end of the crib using 1-1/2” screws. Also, 90 degree brackets will be used to help support these bars. They will be screwed into each bar and the frame.

Ten 1” x 2” x 1-1/2” pieces of pine wood will be cut for an adjustment of the height of one sidewall of the crib. These pieces will be screwed into the frame on the side which the short sidewall will be assembled. These bars will have fillets of radius ¼” on every edge. A wood router will be used to make these fillets. At each end, there will be a 2” x 2” x 1-1/2” piece with a through notch of ¾” x ¾”. The wood will be cut using a table saw with a speed of 4,000 RPM. Next, a 2” x 2” piece will be cut to a length of 37-1/2” using a table saw. A though notch with dimensions of ¾” x ¾” will be cut out using a jigsaw. This 37-1/2” piece will be screwed into each of the ten 1” x 2” pieces as well as the two 2” x 2” pieces. Two hinges will be located on this bar at a length of 7” from each end of the bar. The 37-1/2”will have a fillet of ¼” on the top side so the sidewall that is attached to it so the bar can rotate on the hinge without interference.

The legs of the crib will be then constructed out of 2” by 2” pine wood. Using a miter saw, the wood will be cut into two 4-1/2” pieces. The legs will be screwed to the frame at one end. The wheels are then attached on the other end of the crib. They will be secured with screws in the same fashion as the legs.

Manufacturing and Assembly of Tall Sidewall

Each sidewall is manufactured differently because of the ability of the crib to fold in on itself. This takes into account the customer requirement of portability. For clarity, this sidewall will be named “Tall Sidewall” due to the fact that this sidewall extends from the frame to the top of the crib.

One 2” x 2” piece of pine wood will be cut into a length of 37-1/2”. This process will be completed by using a miter saw. The wood part would then have a ¾” by ¾” notch cut out on each end by a jigsaw. The purpose of these notches is so the folding sidewalls can properly fit in the prototype. Also, there will be two locations along this part that are milled out for the placement of the hinges which will make the sidewalls have the capability of folding into the crib. There will be two sections milled out starting at 7” from each end of the 2” x 2”. This space is 4” long, with a depth of ½” for ¼” of the width, and a depth of .21” for 1” of the width. This process will be accomplished using the router. This piece will be connected to the frame with the hinges previously described. The top of the bar will have a fillet of ¼” radius. A wood router will be used to obtain this fillet.

One 2” x 2” piece of pine wood will be cut into a length of 22-1/2” for use as one of the posts. This process will be done with a table saw, with the blade speed of 4,000 RPM. There will be one notch with dimensions 1-1/2” x ¾” x ¾” located at the top of the post. This will be manufactured by cutting the notch along the entire length of the piece with a table saw, and then cutting the leftover piece to the proper length and gluing back onto the notched piece. This post will be screwed to the 2” x 2” x 37-1/2” piece described above using two 2-1/2” wood screws.

One 2” x 2” piece of pine wood will also be cut into a length of 22-1/2” in the same process as the above paragraph for use as the other post of the tall sidewall. There will be a vertical notch with dimensions of 4-1/2” x ¾” x ¾” located at the top end of the piece. There will also be a vertical notch with dimensions of 6” x ¾” x ¾” located at the bottom end of the piece. Two 270^{o} hinges will then be screwed into place at a length of 4” from the top and 6” from the bottom. This bar will be screwed to the 2” x 2” x 37-1/2” piece described above using two 2-1/2” wood screws.

One 1” x 2” piece of pine wood will be cut into a length of 34-1/2” This will be done using a miter saw. This piece will be screwed to the two side posts manufactured in the preceding two paragraphs. The top and bottom of the bar will have fillets of ¼” radii. A wood router will be used to obtain these fillets.

Manufacturing and Assembly of Short Sidewall

One 2” x 2” piece of pine wood will be cut into a length of 37-1/2”. This process will be completed by using a miter saw. The wood part would then have a ¾” by ¾” notch cut out using a jigsaw. The purpose of these notches is so the folding end-walls can properly fit in. Also, there will be two locations along this part that are milled out for the placement of the hinges which will make the sidewalls have the capability of folding into the crib. There will be two sections milled out starting at 7” from each end of the 2” x 2”. This space is 4” long, with a depth of ½” for ¼” of the width, and a depth of .21” for 1” of the width. This process will be accomplished using the wood router. The top of the bar will have a fillet of ¼” radius. A wood router will be used to obtain this fillet.

One 2” x 2” piece of pine wood will be cut into a length of 18-3/4” for use as one of the posts. This process will be done with a miter saw. There will be one notch with dimensions 1-1/2” x ¾” x ¾” located at the top of the post. This notch will made using the process described in the “Manufacturing and Assembly of Tall Sidewall” section above. This post will be screwed to the 2” x 2” x 37-1/2” piece described above using two 2-1/2” wood screws.

One 2” x 2” piece of pine wood will also be cut into a length of 22-1/2” in the same process as the above paragraph for use as the other post of the tall sidewall. There will be a vertical notch with dimensions of 4-1/2” x ¾” x ¾” located at the top end of the piece. There will also be a vertical notch with dimensions of 3” x ¾” x ¾” located at the bottom end of the piece. Two hinges will then be screwed into place at a length of 4” from the top and 6” from the bottom. This bar will be screwed to the 2” x 2” x 37-1/2” piece described above using two 2-1/2” wood screws.

One 1” x 2” piece of pine wood will be cut into a length of 34-1/2”. This will be done using a table saw with a blade speed the same as mentioned above. This piece will be screwed to the two side posts manufactured in the preceding two paragraphs. The top and bottom of the bar will have fillets of ¼” radii. A wood router will be used to obtain these fillets.

Manufacturing and Assembly of End-walls

For ease of manufacturing, both end-walls have exactly the same dimensions and manufacturing plan. Thus, the process described below will be repeated for the fabrication of the second end-wall.

Two 1” x 2” pieces of pine wood will be cut at a length of 25-1/2” using a table saw with a blade speed of 4,000 RPM. These will be the horizontal bars of the end-walls. These bars will have fillets of radius ¼” on every edge. A wood router will be used to obtain these fillets.

Two 1” x 2” pieces of pine wood will be cut at a length of 24-1/2” using a table saw with a blade speed the same as mentioned above. These will be the vertical bars of the end-walls. To reduce weight, a section of each bar will be cut out using a jigsaw. The area that is cut out is shown in Figure G.4 located in Appendix J, along with all other relevant engineering drawings. This will be manufactured by first cutting diagonal to the smaller width of the bar. A 90 degree cut from the length will then be done to remove a triangle of material from the bar. A second diagonal cut will be done at the appropriate length down the bar. Then, a cut will be made lengthwise along the bar removing the material.

Total Assembly

The total assembly will consist of the mating of all the subassemblies, as well as the inclusion of the mesh. First, the tall sidewall assembly will be attached to the frame by two 90 degree hinges with ½” screws. The hinges will be located 7.2” from each end. Next, the short sidewall assembly will be attached to the other side of the frame by two hinges with ½” screws. These hinges will also be located 7.2” from each end of the crib. Then, each end-wall will be attached to each sidewall by two 270 degree hinges with screws. The hinges will be located 3” from the end of the top and bottom of the piece. Regular latches will be added to the bottom frame where the sidewalls fold down. These four latches will prevent the crib from collapsing. They will located 7.2” from each end on the outside of the sidewalls, and attached with ½” screws. There will also be two child proof latches, one at the middle of each sidewall. These are an extra safety feature, and are attached using adhesives. There will also be two child proof latches that will be attached with adhesive where the sidewall and end-wall come together at two corners of the crib. They will be located 3” from the top of the corner bar. There will also be two regular latches at 3” from the bottom of the corner bar for added safety. These latches will be attached using ½” screws. Four pieces of mesh will be stapled to the inside of the frame. Each piece will extend up and rap around the top bar of each wall, and stapled on the outside of each bar.

Validation

In order to verify the safety, durability, affordability, and portability of our final design concept, validation testing was performed on our prototype. To validate the crib's durability, a cycles to failure calculation was performed on what was perceived to be the most vulnerable crib section. Also, the folding mechanism in the final design was tested multiple times to verify if hinges and fits were still working properly. To validate the crib's affordability, a pricing analysis was performed with the assumption of producing above one million cribs in order to achieve the economies of scale to lower costs. To validate the crib's portability, the prototype was weighted and width dimensions were verified. Also the crib was rolled throughout a home and an apartment with varying nominal door sizes. Lastly, to validate the crib's safety, the childproof latches were used multiple times to see if there were still in working order, and the crib was tested using the ASTM crib side latch test as a guide.

Validation of Durability

If there were no time constraints, an actual cycles to failure test would have been performed on the top bar of the sidewall by placing a load of 300 N on the bar until it fractured. Also, our team did not want the prototype to break before the design expo. Therefore, to validate the crib's durability, a cycles to failure analysis was performed. Using our engineering judgment, we determined that the sidewall railings would fail first. These parts are made of the smallest nominal lumber sizes in the design, are long, slender, and would generally be what a child would grab onto while playing, standing up, or keeping its balance. We felt that if these most vulnerable parts resulted in a calculated cycles to failure that was higher than our target, then it would be safe to assume the whole crib would last at least as long.

Based on our estimated point load of 300 N at the center of the railing used in the FEA in the "Parameter Analysis" section, the maximum moment in the railing was found using equation 1 where *P* is the point load, and *L* is the length of the member. The point load at the center of the railing was used because a load at this point produced the maximum moment, and hence, the maximum stress, which would give us a conservative estimate of the lifetime.

$$M_{max} = \frac{PL}{4} \qquad \text{Eq. 1 [6]}$$

Based on this calculation, the maximum stress, σ_{max} was found to be 14.3 MPa using equation 2. The yield criterion was checked, and this stress value was less the yield value of 35.0 MPa for pine wood. The second moment of area, *I*, was found to be $8.78 \cdot 10^{-8}$ m^4, and the distance from the neutral axis, *c*, was 19.05 mm (¾").

$$\sigma_{max} = \frac{M_{max}\, c}{I} \qquad \text{Eq. 2 [6]}$$

As a conservative estimate, we took the daily number of times that the railing would be loaded equal to 10. This was taking into account the fact that the child would not be large enough or strong enough to grip the bar and exert such a force until at least an age of one year. Also, it was taken into account that the child would stress each end and sidewall railing equally. Using 10 cycles of loading per day for 365 days per year for 5 years, we estimated that the total number of cycles the crib would experience would be 18,250. Once this number was obtained, it was seen that the number of cycles was greater than 10^4. This meant we needed to use the formulas for high cycle fatigue. The equation used to calculate the number of cycles to failure, N_f, is seen below in equation 3. The full reversed stress amplitude is σ_{ar}, and the values *C* and *D* are fitting constants.

$$\sigma_{ar} = C + D \log_{10}(N_F) \qquad \text{Eq. 3 [7]}$$

Upon an initial search for the constants C and *D* for wood, which proved difficult, a similar equation of high cycle fatigue was found that specifically was related to wood products. Equation 4 incorporated Modulus of Rupture, *MOR*, and a constant, *H*, based on the wood type.

$$\sigma_{ar} = MOR\left[0.85 - H \cdot \log_{10}(N_f)\right] \qquad \text{Eq. 4 [8]}$$

Before using equation 4 and calculating cycles to failure, the stress pattern described for this analysis needed to be converted from a zero-to-fully loaded stress to a fully reversible stress, σ_{ar}. This was done using Goodman's equation, seen below in equation 5 and was found to be 8.67 MPa. In Goodman's equation, σ_U is the ultimate tensile strength, and for this application, was found to be 40 MPa [9]. Also, σ_a is the amplitude stress and σ_m is the mean stress.

$$\frac{\sigma_a}{\sigma_{ar}} + \frac{\sigma_m}{\sigma_u} = 1 \qquad \text{Eq. 5 [7]}$$

Using the fully reversible stress calculated above and equation 5, the number of cycles to failure, N_f, was found to be 55,406 cycles. Based on the article in *Forest Products Journal* where this equation was found, the value of *H* was taken to be 0.10 as a conservative estimate. The Modulus of Rupture, *MOR,* was found to be 59,000 kPa [10]. The calculated number of cycles to failure far exceeds our estimated lifetime number of cycles the crib would experience. Even when increasing the number of loadings per day by a factor of 2 to 20, the crib has only used approximately 66% of its lifetime.

Validation of Affordability

To validate the crib's affordability, a bulk pricing assessment was conducted. This entailed calling the suppliers for the crib parts, and obtaining a bulk pricing estimate. For a complete bill of materials, see Appendix A. For suppliers that we were unable to contact, or that were unwilling to disclose bulk pricing information generally reserved for large retailers, an average of the bulk price rate to regular price rate ratio was used to form a conservative estimate of a bulk price. When all the individual part's costs are added together, the total crib cost is $82.58. A complete cost estimate can be seen below in table 3.

Table 3: Mass production Cost Estimate

Item	*Quantity*	*Regular Unit Price*	*Bulk Unit Price*	*Cost Per Crib*
Childproof Latches	4	$4.97	$3.40	$14.40
Stability Latches	4	$1.80	$1.29	$5.16
90 degree brackets	12	$0.34	$0.25	$3.00
90 degree hinges	4	$1.98	$1.49	$5.96
270 degree hinges	4	$4.34	$3.47	$13.88
Locking wheels	2	$2.98	$2.08	$4.16
1-1/4" screws	38	1.2 cents	0.9 cents	$0.34
2-1/2" screws	8	1.2 cents	0.9 cents	$0.07
3-1/2" screws	2	1.2 cents	0.9 cents	$0.02
2x4 board (12')	1	$4.03	$2.90	$2.90
2x2 board (8')	2	$1.64	$1.18	$2.36
1x2 board (8')	4	$0.72	$0.48	$1.92
¼" Subfloor board (4'x8')	1	$19.98	$14.98	$4.94
Mesh (60"x36")	1.5	$7.50	$5.48	$8.22
Mattress	1	$19.55	$15.24	$15.24
Total Crib Cost				$82.58

This cost estimate of $82.58 is in the middle of the $100.00 - $60.00 range set forth in our engineering specifications. Note that this cost estimate does not take into account transport and logistics of materials, capital investment overhead for machinery, local taxes, and labor. If this crib were to be mass produced, many of the processes needed to cut pieces to specified lengths, as well as most aspects of assembly, would be automated. Also, a location for production within the United States would need to be chosen to reduce logistical costs and tax burdens. If these things were done, and proper economies of scale were achieved, it is conceivable that logistics, overhead, tax, and labor costs could be greatly reduced, keeping the mass produced price of the crib under the upper cost limit of our engineering specifications, $100.00. A thorough investigation into the exact costs of logistics, overhead, tax, and labor was not performed, as it is outside the scope of ME 450. However, a rough estimate of 10% added cost, based on Lecture #2 of ME 450 Winter 2010, brings the overall cost to $90.83, still within our engineering specifications [11].

Validation of Portability

To validate the crib's portability, weight dimensions, and ease of home usage were verified. First, the crib was weighed using a standard bathroom scale. The bathroom scale was calibrated using 5, 10, and 25 lb exercise weights. Errors seen in calibrations were negligible, and thus ignored. The crib was weighed by first weighing a team member on the scale, and then having that team member hold the crib on the scale, and subtracting the two recorded weights. This was done without the mattress in the crib. The weight of the crib without the mattress was 43.2 lbs. The mattress for use in the final design had a specified weight of 2.0 lbs. Combining these two weights resulted in an overall weight of 45.2 lbs. This weight was within our engineering specification for weight range of 60.0 – 40.0 lbs. Width dimensions of the prototype were also measured and recorded as 27-1/8", 1/8" larger than was specified in our design. This discrepancy can most likely be attributed to human error in manufacturing.

Also, ease of home usage was verified. In order for the crib to be portable, many basic criteria were to be met. The crib must easily fit though doorways, walkways and hallways of apartments and small houses. The crib must be easily rolled from one destination to another. Also, for the foldability of the crib, the folding mechanism designed into the crib must work after multiple uses, so that the crib can be more portable, i.e., be able to be put in a trunk of a standard family sedan, and be transported to another location. The crib was taken to multiple home and apartment locations, and was able to fit through all doorways, walkways, and hallways. The width dimensions of the doorways, walkways and hallways tested ranged from 28" – 48" wide. The folding mechanism of the crib was still in working order after 25 folding and unfolding tests, verifying the crib's foldability and thus its location-to-location portability. However, the rolling ability of the crib was unable to be confidently verified. This was because of the type of wheel purchased for the prototype. The wheel was a locking swivel wheel, which we had originally thought would increase the ease of use by making turns with the crib easier. In reality, the wheel would often turn completely sideways when navigating the crib around a turn, and be stuck in that position due to the locking mechanism on the side of the wheel. This problem is addressed further in the section titled "Discussion."

Validation of Safety

To validate the crib's safety, the main focus of testing the folding mechanism to verify that collapse would not occur. This was done by first testing all latches on the crib to make sure they were still in working order after many uses. This was done in accordance with the ASTM crib side latch test. After 25 uses of each latch, all latches were still in working order. Following guidelines set forth by ASTM designation f1169-09 crib side latch test, a 30lbf was gradually placed on the sidewall [3]. Under the applied loading failure of the sidewall latch did not occur. Also, an FEA was performed as per the ASTM side testing, where an impact of 100 lbs. must be endured. An FEA was done instead of a prototype test due to the fact that we did not have access to the necessary weights or testing equipment, nor wanted to subject the prototype to harm before the design expo. The FEA of the impact resulted in a stress of 8.0

MPa, which is lower than the 35.5 MPa yield strength of the pine wood. For results of the FEA, see Appendix K.

Information Sources

Our group began by holding a teleconference meeting with our sponsor Nancy Cowles, the Executive Director of Kids in Danger, which is located in Chicago, IL. Our sponsor promptly provided us with as list of 12 areas of concern with baby cribs. Our sponsor also sent us ASTM standard f1169-09, which is the standard specification for a full-size baby crib.

After understanding what our customer requirements were, upon the recommendation of our sponsor, our group began researching current issues customers had with cribs by reading the reviews left by customers that purchased cribs on *amazon.com*. We also searched *kidsindanger.org* and *kidsindanger.blogspot.com* in order to look at both portable and standard crib recalls to see what other issues customers were having with their cribs.

After concluding this research, we went to babiesrus.com to research typical prices of cribs, as well as determine what cribs we would choose as the benchmarks for our design. Our group went to Babies R Us® in order look at cribs in person. The purpose of this endeavor was to do field research that would allow us to better understand where the current cribs on the market are at in terms of quality, assembly, and features. Other sources of information can be found in the section titled “References.”

Discussion

Our customer requirements specified that our main challenges were safety, durability, affordability, and portability. Our engineering specifications detailed that guidelines we would follow for our crib design to overcome these challenges. Our crib is meant to be designed for use until a child is two years old. Allowing for the crib being kept to be used for two children (as a safety factor), and taking into account the input from our customer, we decided to design the crib to be durable enough that it is serviceable for a period of five years. After performing calculations for cyclic testing on our design and determining that our design met our durability requirement, we performed several tests to meet the safety requirements, including the Crib Side Latch Test on our design per ASTM standard F1169-09, which is the standard specification for a full-size crib. Our customer requires that this design has a cost of less than $100, with a target price of $60 in order to make the crib affordable for low income families. After establishing bulk pricing for all of the components that were used in the production of our design, we determined that we could mass manufacture our design for a price of $82.58. If we include labor and other operating costs, the price of the crib design will still be below our limit of $100. To achieve portability, our design contains a folding procedure that would greatly decrease the amount of space the crib takes up. This would allow for the crib to be more easily transported from place to place, as well as within your own home.

The biggest strength of our design is the folding mechanism that we have incorporated into it. This folding mechanism could be used to reduce the volume of the crib in order to transport the crib from one household to another. The ease of transportation allows families to purchase only one crib that they can move around instead of purchasing another, most likely secondhand, crib. This not only reduces a family’s cost, but more importantly, improves the safety of the child since they won’t be exposed to an older crib, with less durability and more danger risks.

Our crib design also contains some weaknesses, but we have some recommended solutions that can be performed in the future. A cost analysis with these solutions will have to be performed in order to make sure that we keep the cost of the design below our target price. The biggest concern with our design is the weight of the crib (~40 lb) relative to that of a pack n' play (~20 lb). One way of reducing the bulkiness of the crib would be by using pine wood with smaller dimensions instead of using standard two-by-fours. The height of the crib could potentially be reduced by about an inch and still maintain the structural integrity of the crib.

The structural integrity of the walls of the crib is another weakness in the design. There is no issue with the sidewalls, since screws were used to assemble it, but the end-walls have an issue since finishing nails were used in the assembly. When the end-wall is swiveling around its hinges, it doesn't take very much force to cause the structure to deform. An easy solution for this is to include a crossbar(s) as an engineering change on the walls as well as use screws for the assembly of the end-walls. This would greatly increase the stresses required to cause failure while minimally increasing the weight of the crib.

The safety and durability of the crib can be improved with some key revisions. The mesh on our prototype was attached using a staple gun. Some consumers might have questions about the staples being able to hold up for the lifetime of the crib, as well how to keep babies away from these staples. By attaching the mesh professionally, similar to how it's done on a typical pack n' play, we will address any concerns with the child's safety and the durability of the design. Another revision to improve the durability of the design would be to include an elastic strap that holds the crib together when it's being transported from one location to another. The elastic strap would be attached to the bottom of the crib (underneath the plywood on one side of the frame). The elastic strap would be able to be wrapped around the crib and hook onto the other side of the frame. This new feature would improve the portability of the crib.

The portability of our design can be improved with a couple of key features. When rolling the crib on the swivel wheels, sometimes the wheels will hit the frame of the crib and get stuck in a sideways position. A switch from swivel to non-swivel type caster wheels would be a key improvement to avoid that problem. We would also add a handle that could be hidden into the frame (on the side opposite the wheels that contains the two posts). This handle, along with the non-swivel wheels, would greatly improve the ease of transportation of the crib.

Conclusions

The goal of this project was to design a safe, affordable, durable, and portable crib for low-income families. This crib is meant to replace unsafe hand-me-down cribs or other older model cribs by creating an affordable crib that non-profits may be able to give to people in need. Using our customer requirements, we developed engineering specifications and concepts that would best meet those requirements. These concepts were used to create five different prototypes which can be seen in Appendix H. We then evaluated these concepts using a Pugh Chart, which can be seen in Appendix I. This Pugh Chart allowed us to rate each of the concepts with respect to a datum design. From that, we found that Concept A met our requirements the best and it was chosen for our alpha design.

We revised the alpha concept using finite element analysis, the Cambridge engineering selector, and a new foldable design. This design was modeled in Solidworks, a computer aided drafting program (CAD). A prototype of the final design was fabricated, and went through validation testing. The projected mass production cost of the final design was $82.58. The projected durability of the prototype was calculated to be 15.2 years. The crib side latch test as per ASTM standard was conducted and the prototype passed. The weight of the prototype was 45.2 lbs and final width dimension was 27 ¼". This prototype was shown and the University of Michigan Senior Design Expo on April 15, 2010.

A mass produced final design would include a polyurethane coat on all wood components and professionally attached mesh side and end-walls. To improve the final design, the swivel wheels should be replaced with non-swivel wheels to avoid lock up during transport, and an angled cross member should be added to the end-walls for increased rigidity. Also, the frame should be more closely analyzed to achieve a lower overall crib weight. We recommend the final design improvements be applied to the crib, and further safety testing and validation take place before widespread usage.

Recommendations

We have several recommendations that we believe future teams or organizations can work on to improve our crib prototype.

Design

First, we would recommend including a diagonal support to each of the end-walls of our crib. This addition would greatly increase the rigidity of the crib. Our team did not do this because this would have resulted in a major remanufacture of the prototype, which could not have been completed by the Design Expo date of April 15, 2010.

Secondly, there are more minor changes that we feel would increase the functionality and aesthetic appeal of the crib. We would recommend using different wheels for the crib. The ones we are currently using are able to swivel 360° and have a tendency to get stuck sideways or backwards while the crib is in transport which makes them useless. We recommend wheels that do not swivel to avoid this problem.

Also concerning the aesthetic and safety of the crib, our team recommends that the mesh be attached with professional stitching instead of staples. This eliminates the safety concern of the staples coming loose, and also improves the strength of the fastening of the mesh.

Next, we would recommend using smaller brass latches for the crib because the latches we used in our prototype are large and overhang in some spots which takes away some of the attractiveness of the crib. Also, we recommend the number of latches would also be reduced. There would only be two latches on the bottom of each sidewall instead of the current three. This would reduce cost while maintaining the safety observed in the use of three latches. Lastly, we would recommend using an automatically-locking latch to hold the crib down when it is folded. This would make it easier to move or store the crib.

Material

We recommend performing a stress analysis on the frame of the final design to make it lighter, since excess material will be able to be removed. Also, we recommend looking further into the possibility of using particle board for the crib. Particle board would drop the price of the crib significantly because it is cheap; however particle board is very heavy. If particle board is to be used, it could be worthwhile to look into using four wheels for the crib to make the heavier crib still easy to move around.

Acknowledgements

Team 22 would like to thanks the following for their help on this project: Nancy Cowles, Kids in Danger; Professor Gordon Kraus, University of Michigan; Professor Shorya Awtar, University of Michigan; Philip Bonkoski, Graduate Student Instructor; Bob Coury and Marv Cresssey, Machine Shop, University of Michigan. A special thanks goes our section instructor, University of Michigan Mechanical Engineering Associate Professor Katsuo Kurabayashi, as well as University of Michigan Mechanical Engineering Professor Richard Scott, and Ken at Van Winkle Mattress of Ann Arbor.

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Appendix A

Bill of Materials

Item	Quantity	Source	Catalog Number	Cost	Contact
Latches	4	McMaster-Carr	1766a3	$9.02/5	mcmaster.com
90 degree hinges	4	The Home Depot	15516	$1.98	thehomedepot.com
270 degree hinges	4	Rockler	25741	$8.69/2	www.rockler.com
90 degree brackets	12	McMaster-Carr	1556A24	$0.34	mcmaster.com
360 degree rotating wheels	2	The Home Depot	9509	$3.98	thehomedepot.com
Medium Poly Mesh	1.5 yards	Seattle Fabrics	1571	$7.50/yd	seattlefabrics.com
1/4" subfloor board	4'x8' (1)	Menards	1251910	$19.98	menards.com
2"x4"x12' pine wood	1	The Home Depot		$4.03	In store only: Home Depot
2"x2"x8' pine wood	2	The Home Depot	LU 7161 8	$1.64	In store only: Home Depot
1"x2"x8' pine wood	4	The Home Depot		$0.72	In store only: Home Depot
2.5" screws	1 box	The Home Depot	212CDWS1	$3.88	In store only: Home Depot
1.25" screws	1 box	The Home Depot	114CDWS1	$3.88	In store only: Home Depot
Child Proof Latches	4	KidCo.	3352	$4.95	totsafe.com

Appendix B

Description of Engineering Changes since Design Review #3

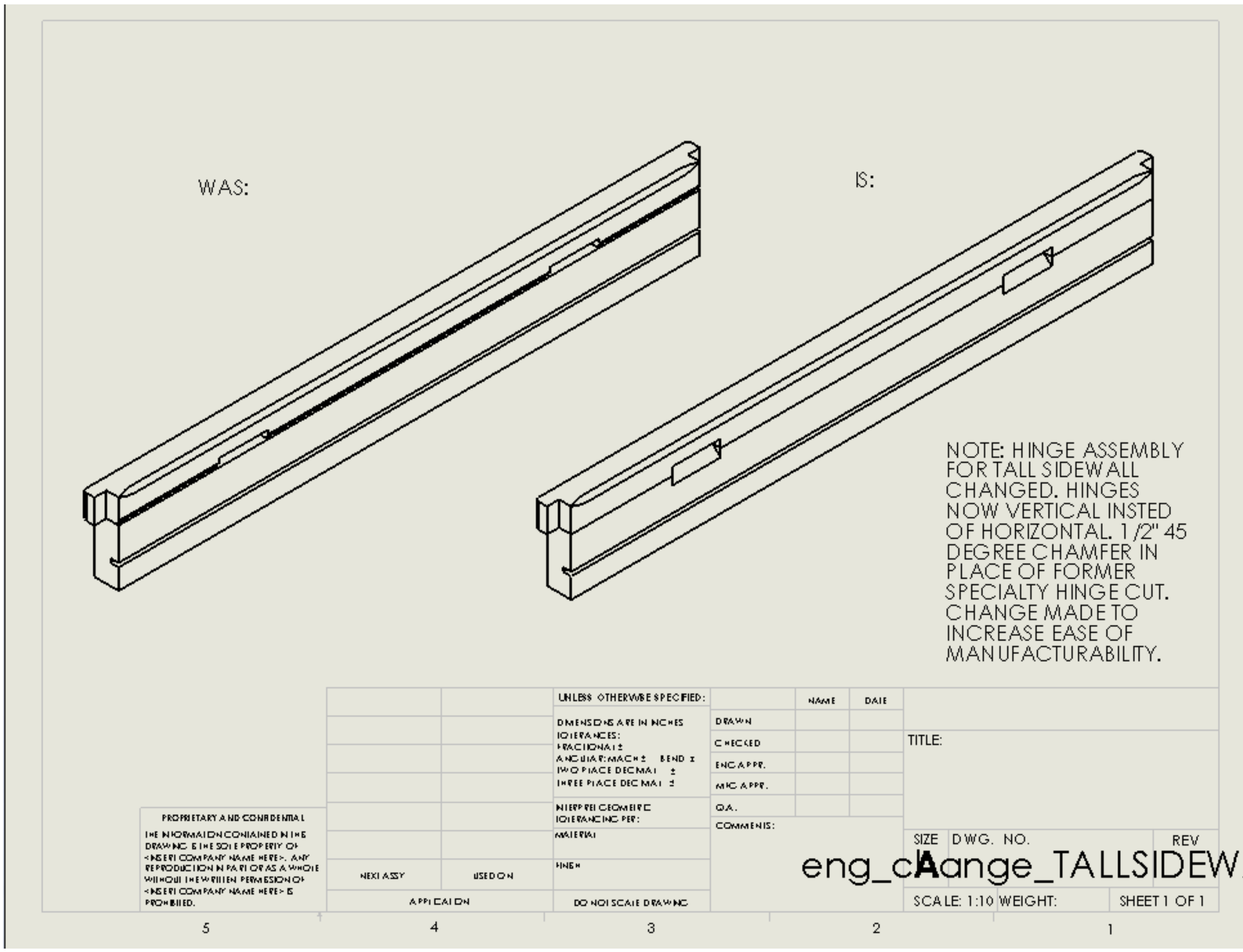


Figure B.1: Tall Sidewall Hinge Assembly Change, 3-21-10

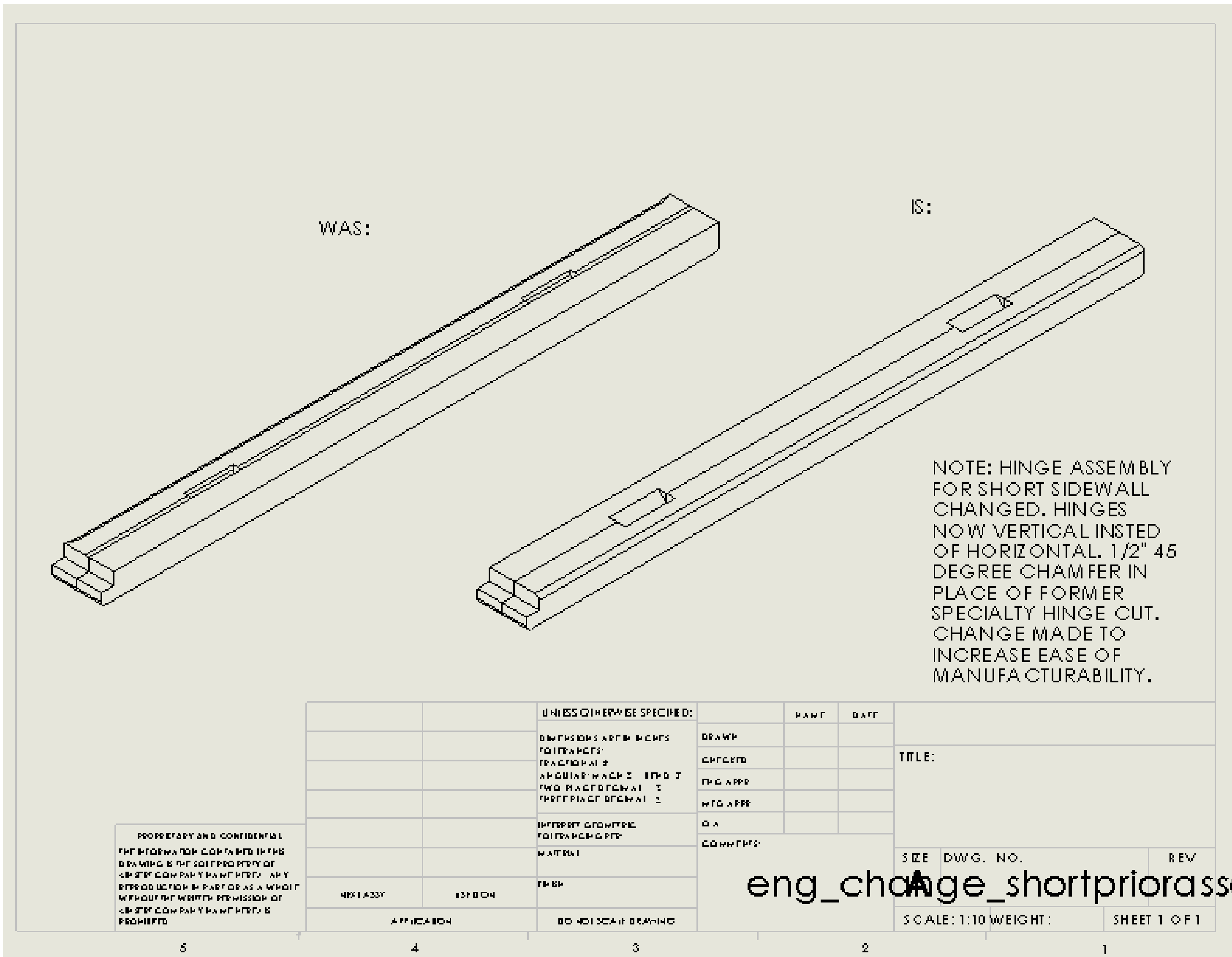


Figure B.2: Tall Sidewall Hinge Assembly Change, 3-21-10

Appendix C

Design Analysis Assignment from Lecture

This appendix contains the three design analysis assignments discussed in lecture: the material selection assignment (functional performance), the material selection assignment (environmental performance), and the manufacturing process selection assignment.

Material Selection Assignment (Functional Performance)

Our group decided the crib prototype will be composed of softwood (pine) after using the multi-criteria search algorithm available in the Cambridge Engineering Selector (CES) software package.

In order to keep costs low, we want to use a material for our crib design that has a high machinablility. Our group decided to consider only materials with a machinability of at least 3 (on a scale of 5), which eliminates all glasses and technical ceramics as shown in Figure C.1 below.

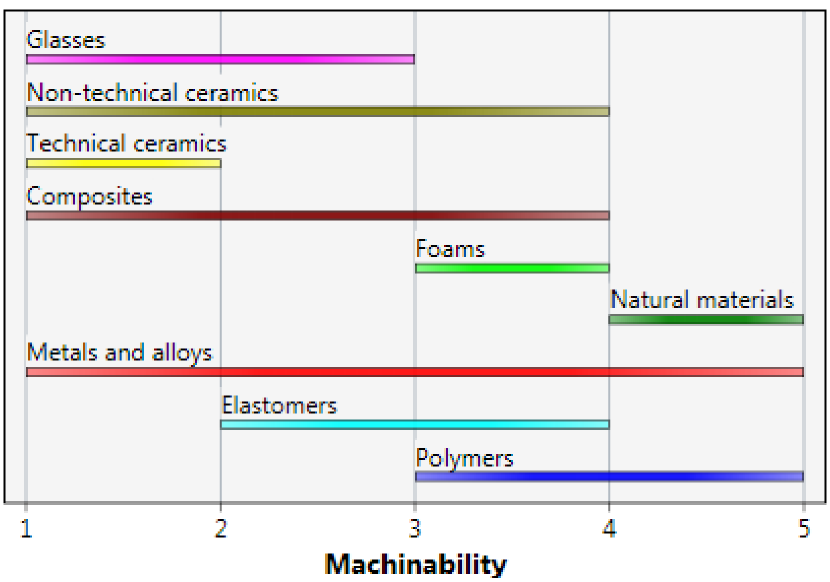


Figure C.1: Machinability of Materials

Our group used the evaluate feature in Solidworks to determine that the volume of the amount of material we would need for our design is 1769.4 in^3, which converts to 1.024 ft^3. If we divide the maximum allowable weight of the crib, which is 60 lbs based on our engineering specifications, by the volume of the crib, we can calculate the maximum density of the material we can use to manufacture the crib. We calculated the maximum allowable density to be 58.60 lb/ft^3. This allows us to eliminate non-technical ceramics, composites, metals and alloys from consideration. To achieve a weight closer to the median of our target range for weight, we will also eliminate elastomers and polymers as they barely qualify as satisfactory materials.

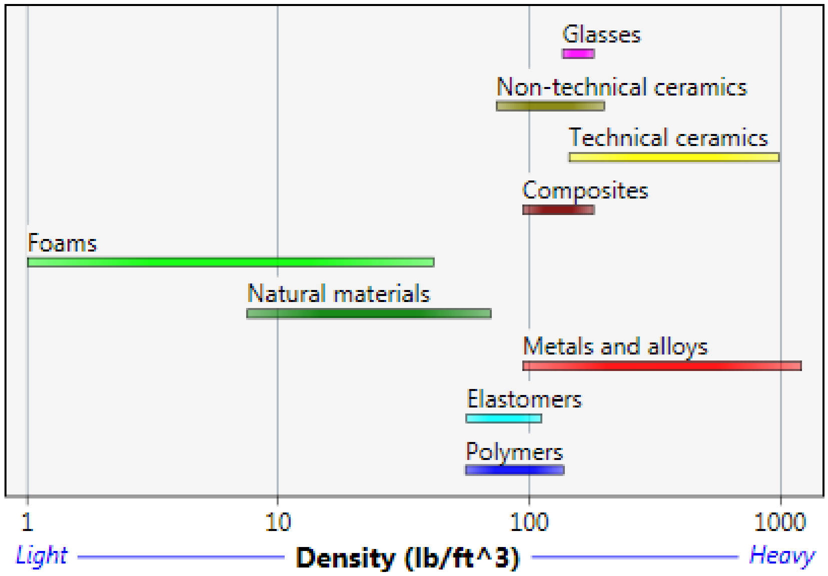


Figure C.2: Density of Materials

This leaves us with only foams and natural materials as options for our crib. When comparing these materials, we see that natural materials are generally stronger, while at the same time being cheaper than foams as shown in Figures C.3 and C.4.

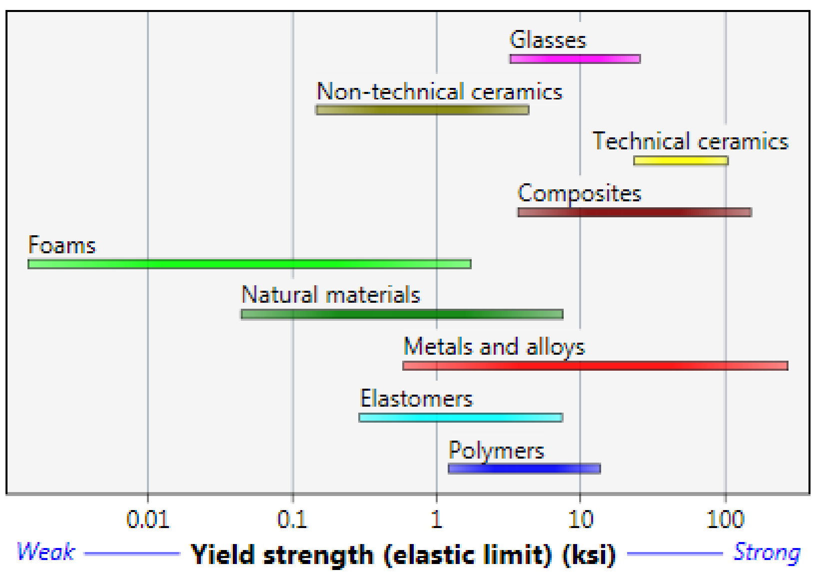


Figure C.3: Yield Strength of Materials

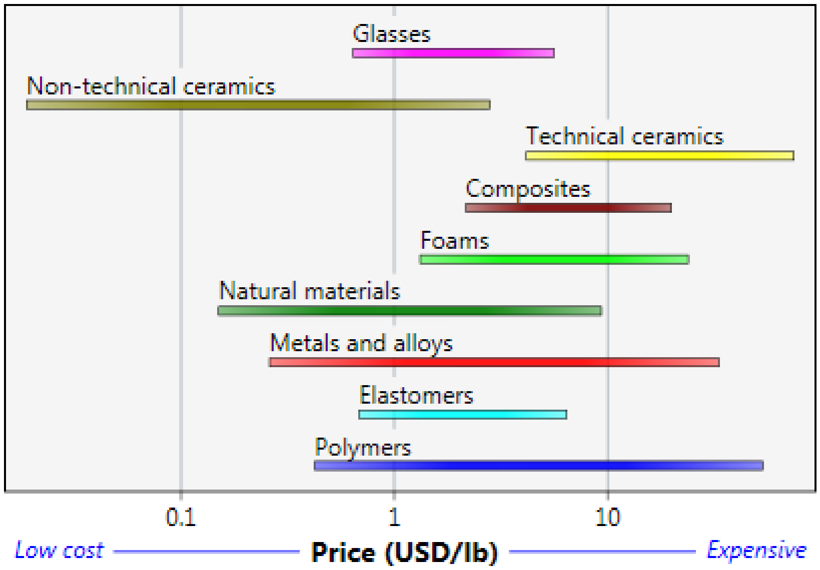


Figure C.4: Price of Materials

Material Selection Assignment (Environmental Performance)

Based on the information from SimaPro, it appears that the Oregon pine will have more of an environmental impact than the Yellow Pine. As seen in Figure C.6, the Oregon pine has a higher EcoIndicator 99 point value than the Yellow pine. Also, Figure C.5 shows that the Oregon pine is highest in all emission and waste categories. When considering the life cycle of the product, neither material will have a higher impact. Both are natural materials, and have the same disposal demands and recyclability. When considering both products, “Ecosystem Quality” is clearly the most affected meta-category, based on the EcoIndicator 99 point values. This can be seen in Figure C.8. While Oregon pine has more of an impact on ecosystem quality than Yellow pine, this value is still relatively small. Furthermore, neither material has large impacts on human health, which brings us to the conclusion that both materials are suitable for our use with respect to the environmental impact.

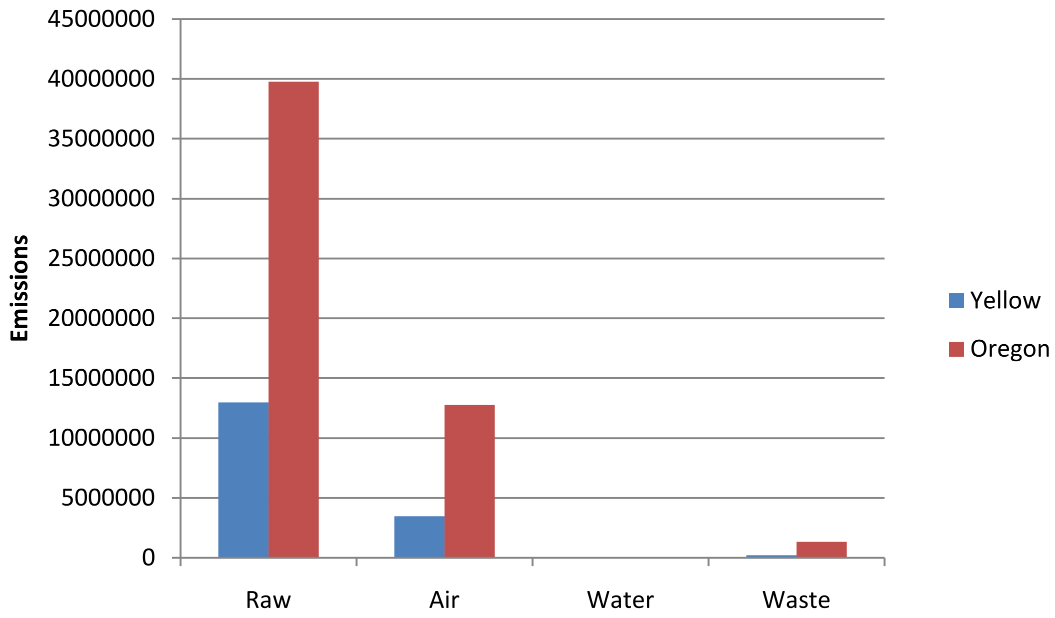


Figure C.5: Total Emissions

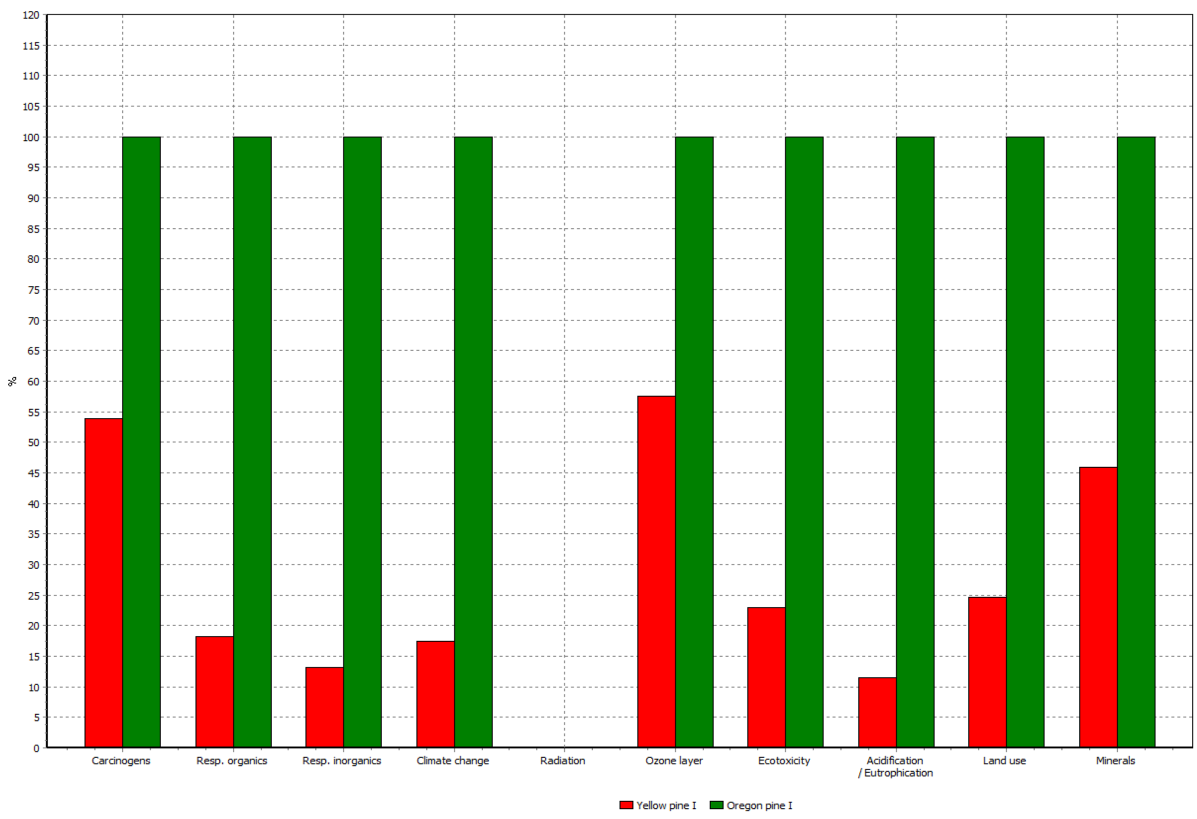


Figure C.6: Relative Impacts in Disaggregated Damage Categories

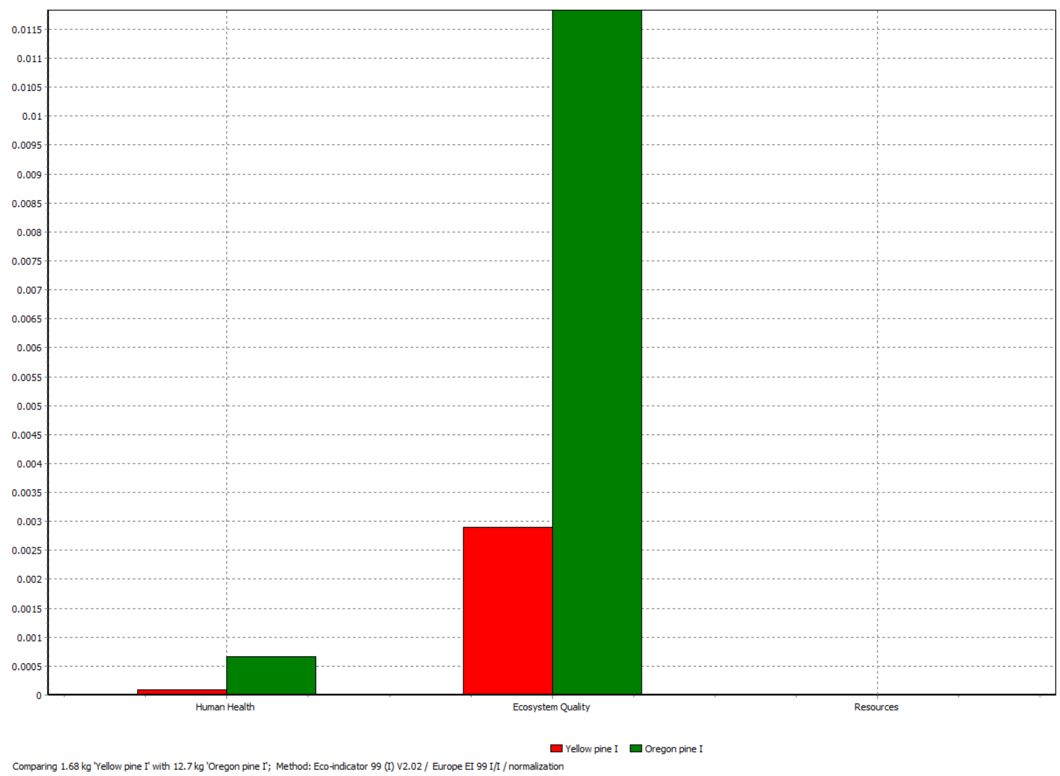


Figure C.7: Normalized Score in Human Health, Eco-Toxicity, and Resource Categories

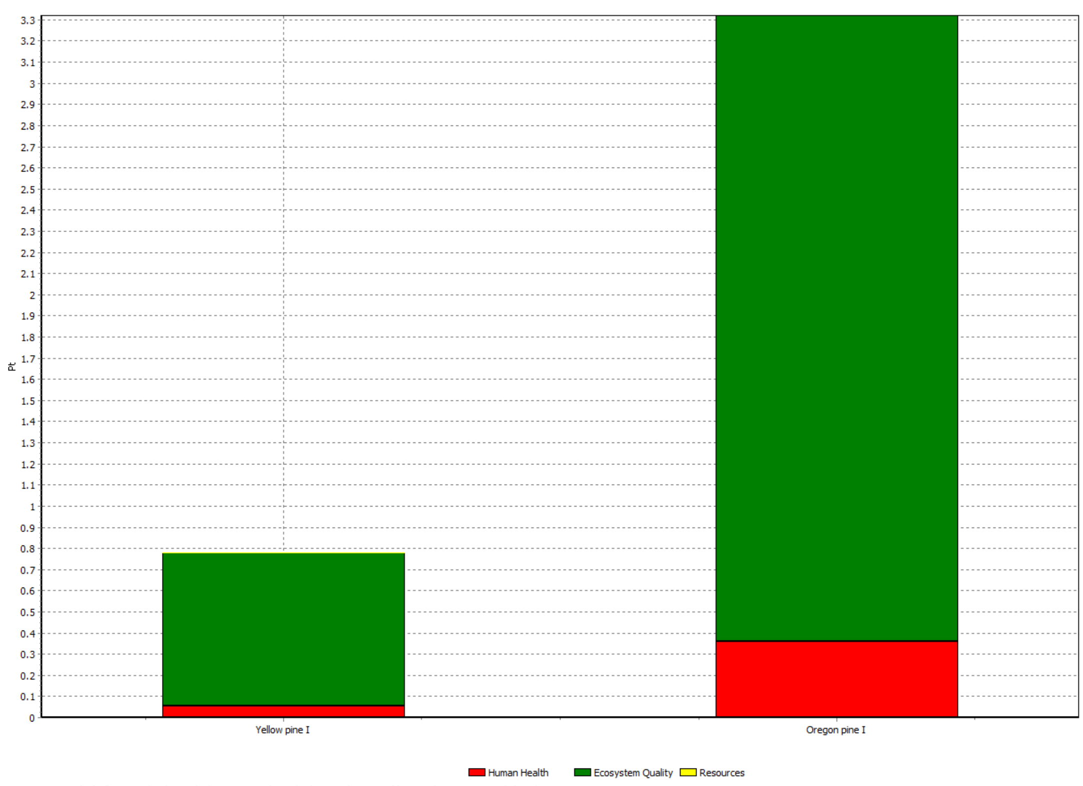


Figure C.8: Single Score Comparison in "Points"

Manufacturing Process Selection Assignment

The US Census Bureau has recorded that 4.2 million children were born in the United States in 2009. [12] According to "Basic Facts About Low-Income Children: Birth to Age 18" by Ayana Douglas-Hall and Michelle Chau [13], 39% of all the children in the US live in low-income families. Using these facts and the customer requirements provided to us by our sponsor, we determined that our product would have a real-world production volume of 1.6 million units per year.

The two materials that were selected using the CES Materials Selector were plywood and softwood (pine, across grain). A 24 ½" x 36" sheet of plywood is placed on the supports in the frame of the crib in order to hold up the mattress, while avoiding any spaces for the child to slip through. Everything else in the crib composed of natural materials is made of pine wood. The pine wood was used for the frame of the crib, the bed supports, the legs of the crib (side without caster wheels), the sidewalls (both large and short), the ten 1" x 2" x 1½" pieces of pine wood, and the endwalls.

Plywood

The plywood will be purchased in the standard size of 4' x 8' that is commonly available. Using an industrial sized table saw, we can cut the plywood along the 4' edge, down to 3' for the 36" length required. Then, we can take this smaller sheet and make multiple passes along the 8' edge, to cut three 24½" wide pieces.

Pine Wood

All the pine wood parts will be manufactured through a highly automated process that will feed the stock wood to the stationary tools required. The stock for the frame will be two-by-fours that are six feet (72") in length. We will feed this stock through to a group of routers (4) that are fixed at the proper height and have ¼" bits in them in order to round the edges for the child's safety. Then, we would transport this wood over to another machine where ideally, we could cut several of these pieces simultaneously (maybe 4 at a time) using an industrial, automated miter saw. A stop wall will rise up at a point 9" past the saw, so that we can feed the two-by-fours in and cut them to a length of 63". An automated hydraulic bar will push the extra material into a scrap bin on the side. At the same time, another stop wall will rise at a point 27" past the saw as the first stop wall recedes into its storage space. Then, we will feed the 63" two-by-fours all the way in to the stop wall and cut them into pieces of 27" and 36", which are the dimensions of the pieces that form the bottom rectangle of the frame. From here, new stock wood will be fed into the machine, so the 27" two-by-fours will be pushed into a storage bin at the end of the line and the 36" two-by-fours will be pushed, by another hydraulic bar into a transfer bin on the side of the machine (next to the scrap bin). The 36" two-by-fours will then be ran through a router that will mill a notch that is 5/16" wide and ½" deep in the center along the whole length of the part.

The setup with the four routers will be adjustable so that at the end of the day, we can run one-by-twos that are eight feet (96") in length. First, we will cut pieces 34½" long that will be used for the top bar of the sidewalls. Next, we will cut pieces 25½" long for both the top and bottom bars on the endwalls. For the vertical bars of the endwalls, we only need to cut 24½" pieces (no routing). These vertical bars for the endwalls will then be ran through an automated jig saw that will be setup up to make the proper cut out shown in Figure J.4.

Some of these one-by-twos will be cut into 1½" pieces that will be used for an adjustment of the height on the side of the crib with the short sidewall. Ten of these pieces are then attached to the frame using a nail gun with finishing nails. The one-by-twos that are located within the frame, and go underneath the plywood for bed support, will only require cutting. We will cut four 24" pieces from each eight foot long one-by-two.

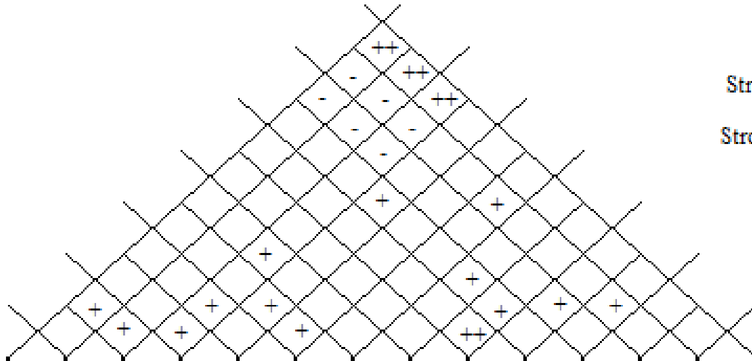
The stock for the remaining pieces of the crib will be manufactured from two-by-twos that are eight feet (96”) in length. The easiest pieces to produce are the legs (2) of the crib. These are made from cutting a two-by-two into 4½” pieces using the automated miter saw. We will also make 1½” pieces from this stock, which will be used for the two pieces of wood that (along with the ten 1½” pieces of one-by-twos) support the piece that is hinged to the short sidewall. We will first use a router to mill out a ¾” x ¾” notch through the length of one of the edges of the two-by-two. Then we will use a miter saw to cut these 1½” pieces, two of which are required per crib. We will also cut two-by-twos to lengths of 22½” for the posts on the tall sidewall and 18¾” for the posts on the short sidewall. Half of the 18¾” pieces for the short sidewall and half of the 22½” pieces for the tall sidewall will be fed to the router setup so that we can create a notch that is ¾” x ¾” for a length of 1½” from the top of the post. The other half of the pieces of both 18¾” and 22½” will be fed to the router setup to create a notch that is ¾” x ¾” and runs through 4½” from the top of the post, as well as a ¾” x ¾” notch that runs 3” from the bottom. Next, we will cut two-by-twos to lengths of 37½”. We will feed some of these pieces through the router setup with a ¾” bit to cut the necessary spaces for the hinges. This piece will sit on top of the ten 1” x 2” x 1½”and two 2” x 2” x 1½” on the side of crib with the short sidewall. We will use screws to hold it in place at the spot where the two 2” x 2” x 1½” pieces are, and use finishing nails at each of the spots above the ten 1” x 2” x 1½” pieces. We will feed the rest of these pieces through the router setup in order to create a round on the two edges facing the inside of the crib for smooth rotation during folding and, more importantly, for the child’s safety. We will then feed all these pieces into the router setup so that it can make a through cut of ¾” x ¾” at one of the ends that contains both the rounded edges. This stock will also be used to cut pieces 22½” in length for the vertical posts of the tall sidewall and 18¾” for the vertical posts of the short sidewall.

All these pieces will be put together using manual labor, as shown in the final assembly drawing in Figure J.23, in groups of two men per crib. After assembly, we will run the cribs in a line through an automated spray machine that will give the cribs a polyurethane finish. All scrap wood can be returned or sold so it’s not a total loss.

We could save some money, by decreasing the width of the plywood piece down to 24” and increasing the length to 36½”. This would allow us to cut the plywood sheet right down the middle of the 4’ edge, which would produce the 24” width required. Then, we could make a couple of passes down the 8’ edge, in order to cut four 36½” length pieces. By doing this, we are maximizing the number of pieces we can get from a single sheet of plywood, by increasing it up to four (from three previously).

Appendix D: QFD Chart

Figure D.1: QFD Chart



Correlation

Strong Positive ++

Strong Negative --

Positive +

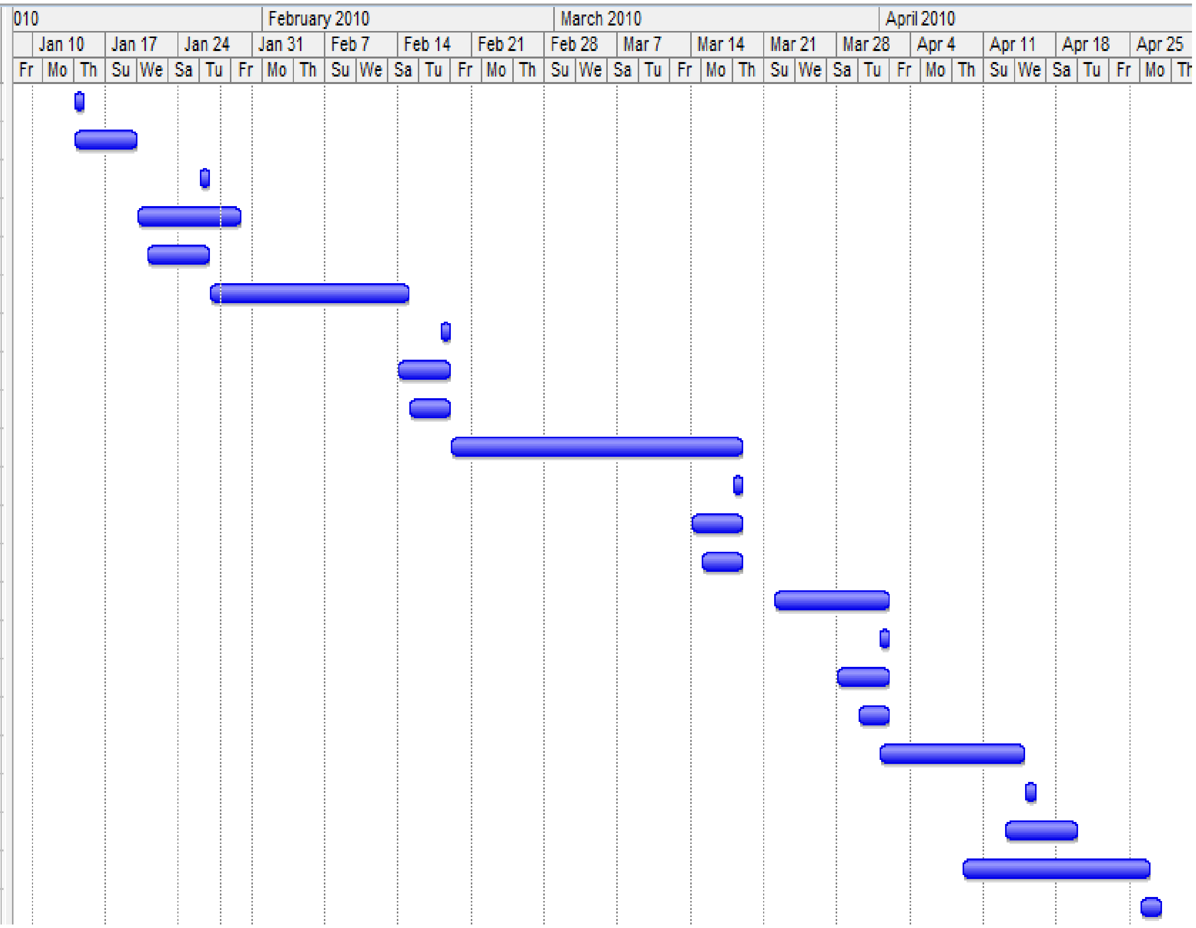
Negative -

	Weight	Length of crib	Height of Crib	Adequate Dimensions	Space between bars	Space between mattress and sides	Porosity of whole crib	Corner radii	Length of time used	Long term durability	Fastener Durability	Cost	Total Weight	Width of Crib	Benchmarks: Portable Crib	Benchmarks: Low Cost Crib	Benchmarks: Standard Crib
Large enough to fit 2 yr old	6	9	3	1						1		1	3	3	5	5	5
Tall enough so 2 yr old cannot climb out	12		9	1			1			1		1	3		5	5	5
Proportional dimensions for stability	9	9	9	9								1	1	9	5	5	5
Proper sidewall bar spacing to avoid limb/head entrapment	14				9		9					1	1		5	3	5
Proper mattress to sidewall spacing to avoid entrapment	13	9		9		9		1				1	3	9	5	5	5
Sidewall material must provide good ventilation	7	1	1		9		9		3	1		3	1	1	5	5	5
No sheets or soft bedding	11					9			3	3		3	3		3	4	4
No sharp corners or edges	8	1	1			1	1	9				3		1	5	5	5
Serviceable up to 24 months	4	9	9	9	9	9	1		9	9	3	3	3	3	2	4	5
Fasteners remain secure	11	1	1	9					9	9	9	3	1	1	3	4	5
Withstand usage throughout the day	5	1	1	1	1	3	1	1	9	9	3	1	1	1	5	5	5
Must be cheap	9	9	9	3	1	1	1	1	3	9	3	9	3	9	1	3	2
Must be lightweight	1	9	9	9	3	3	1					9	9	9	3	4	3
Must be able to fit through standard doorway	2			1		1						1		9	5	3	3
Measurement Unit		in	in	in/in	in	in	%	in	hrs/day	mo.	N	$	lb	in			
Target Value		42	40	tbd	2.5	0.13	70	0.5	20	24	tbd	60	50	30			
Importance Rating		2	4	1	8	5	10	13	7	6	12	9	11	3			
Total		409	364	394	242	289	228	99	261	319	153	274	220	367			
Normalized		0.11	0.10	0.11	0.07	0.08	0.06	0.03	0.07	0.09	0.04	0.08	0.06	0.10			
Portable Crib		39	41				80			12		160	48.5	31.1			
Low Cost Crib		52	40				80					95	32	31			
Standard Crib		55	45.4				75			24		130	74	30			

Appendix E: Gantt Chart

Figure E.1: Gantt Chart

	Task Name	Duration	Start	Finish
1	Sponsor Meeting	1 day	Thu 1/14/10	Thu 1/14/10
2	Research For Project	4 days	Thu 1/14/10	Tue 1/19/10
3	Design Review 1	1 day	Tue 1/26/10	Tue 1/26/10
4	Initial Report	8 days	Wed 1/20/10	Fri 1/29/10
5	DR1 Presentation	4 days	Thu 1/21/10	Tue 1/26/10
6	Initial Alpha Design	14 days	Wed 1/27/10	Sun 2/14/10
7	Design Review 2	1 day	Thu 2/18/10	Thu 2/18/10
8	Report 2	5 days	Sun 2/14/10	Thu 2/18/10
9	DR2 Presentation	4 days	Mon 2/15/10	Thu 2/18/10
10	Create Final Design	21 days	Fri 2/19/10	Thu 3/18/10
11	Design Review 3	1 day	Thu 3/18/10	Thu 3/18/10
12	Report 3	5 days	Sun 3/14/10	Thu 3/18/10
13	DR3 Presentation	4 days	Mon 3/15/10	Thu 3/18/10
14	Create Prototype	10 days	Mon 3/22/10	Thu 4/1/10
15	Design Review 4	1 day	Thu 4/1/10	Thu 4/1/10
16	Report 4	5 days	Sun 3/28/10	Thu 4/1/10
17	DR4 Presentation	3 days	Tue 3/30/10	Thu 4/1/10
18	Final Touches on Prototype	10 days	Thu 4/1/10	Wed 4/14/10
19	DESIGN EXPO	1 day	Thu 4/15/10	Thu 4/15/10
20	FINAL REPORT	6 days	Tue 4/13/10	Mon 4/19/10
21	Prototype Delivered	13 days	Fri 4/9/10	Mon 4/26/10
22	Misc End of Year Activities	2 days	Mon 4/26/10	Tue 4/27/10



Appendix F: Morphological Chart

Morphological Chart					
Function	**Concept 1**	**Concept 2**	**Concept 3**	**Concept 4**	**Concept 5**
Crib Frame Construction	Wood frame	PVC pipe frame	Aluminum frame	Steel frame	
Crib Sidewall Construction	Wood bars	PVC pipe bars	Mesh sidewalls	Clear Plexiglass	
Crib Endwall Construction	Wood bars	PVC pipe bars	Mesh sidewalls	Solid wood	Clear Plexiglass
Crib Portability	FourLocking wheels	Tennis Balls	Rails	Two Locking Wheels & Handle	
Crib Shape	Square	Rectangle	Ovoid	Circle	Octagon
Crib fasterners	Screws	Bolts	Nails	adhesives	notched fittings
Edge protection	Foam Cylinders	Rounded edges	Bubblewrap		
Bedding	Standard Mattress	Foam	Board & Mattress Pad		

Figure F.1: Morphological Chart

Appendix G: Concept Generation Chart

Generated Concept Chart					
Function	**Concept A**	**Concept B**	**Concept C**	**Concept D**	**Concept E**
Crib Frame Construction	Wood frame	PVC pipe frame	Aluminum frame	Steel frame	Wood frame
Crib Sidewall Construction	Mesh sidewalls	Mesh sidewalls	PVC pipe bars	Mesh sidewalls	Clear Plexiglass
Crib Endwall Construction	Mesh sidewalls	Mesh sidewalls	PVC pipe bars	Mesh sidewalls	Clear Plexiglass
Crib Portability	Two Locking Wheels &	Two Locking Wheels &	Four Locking Wheels	Four Locking Wheels	Four Locking Wheels
Crib Shape	Rectangle	Rectangle	Square	Rectangle	Rectangle
Crib fasterners	Notched Fittings & Adhesives	Adhesives	Bolts	Bolts	Notched Fittings & Adhesives
Edge protection	Rounded edges	Rounded edges & foa	Foam Cylinders	Foam Cylinders	Rounded edges
Bedding	Standard Mattress	Standard Mattress	Board & Mattress Pad	Foam	Standard Mattress

Figure G.1: Concept Generation Chart

Appendix H: Concept Drawings

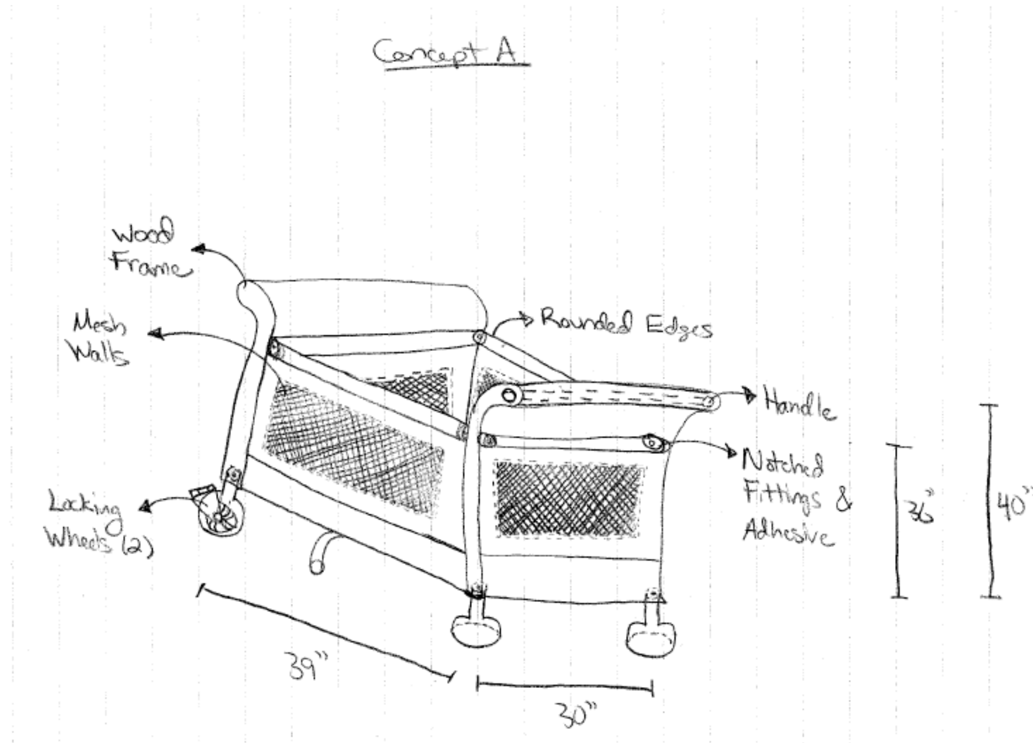


Figure H.1: Concept A

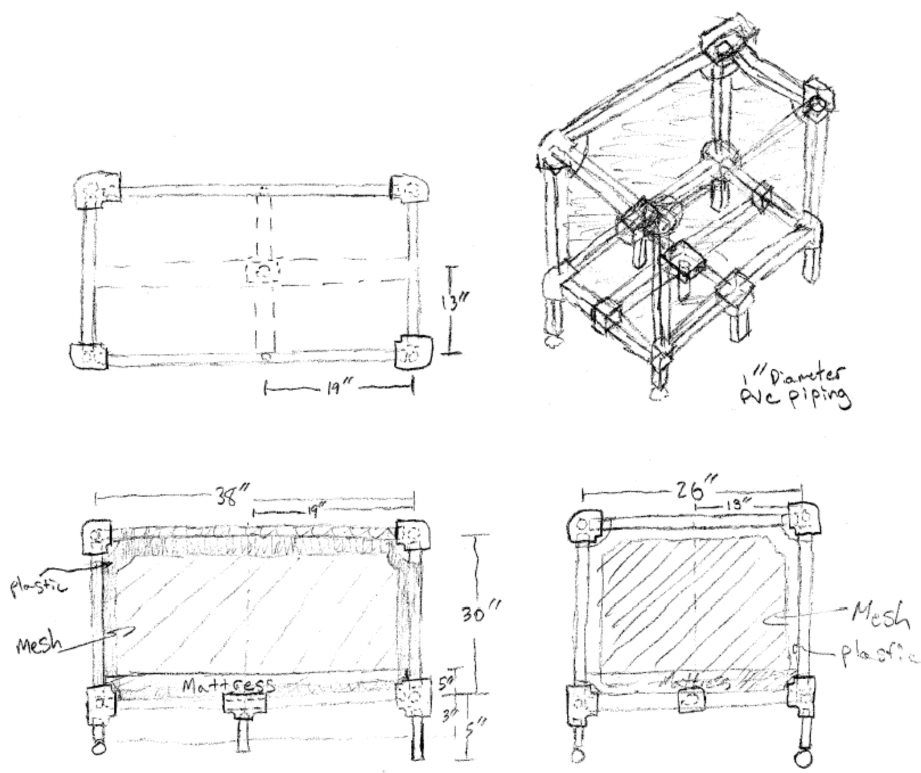


Figure H.2: Concept B

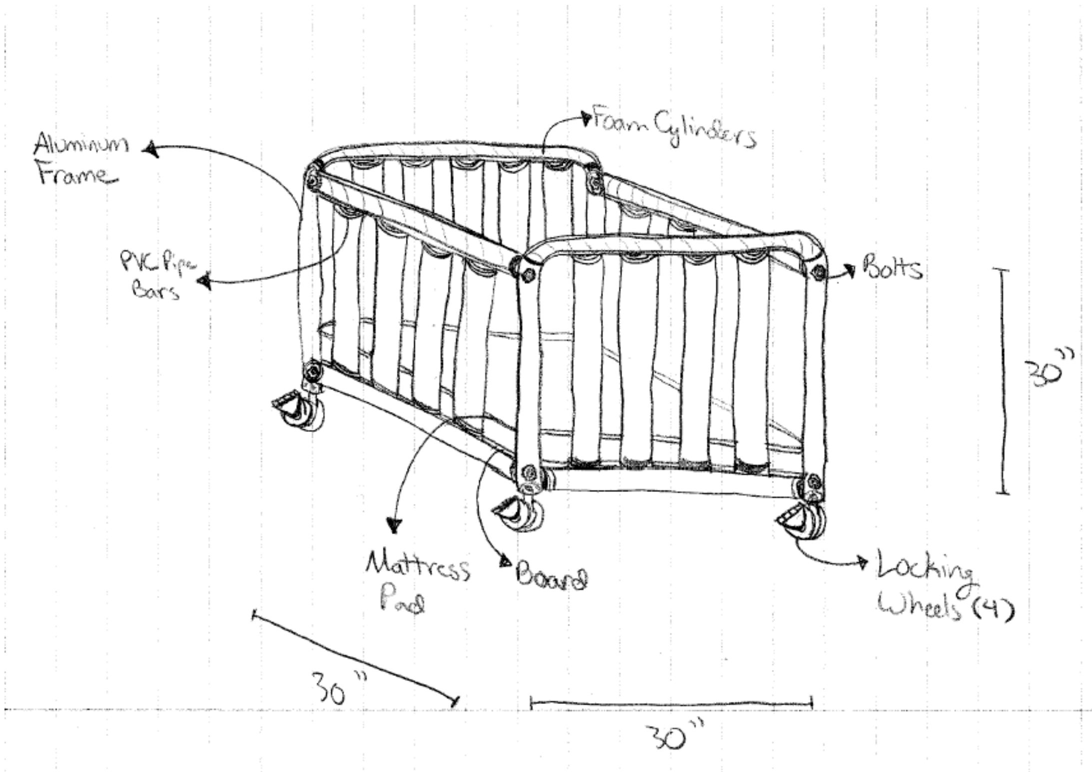


Figure H.3: Concept C

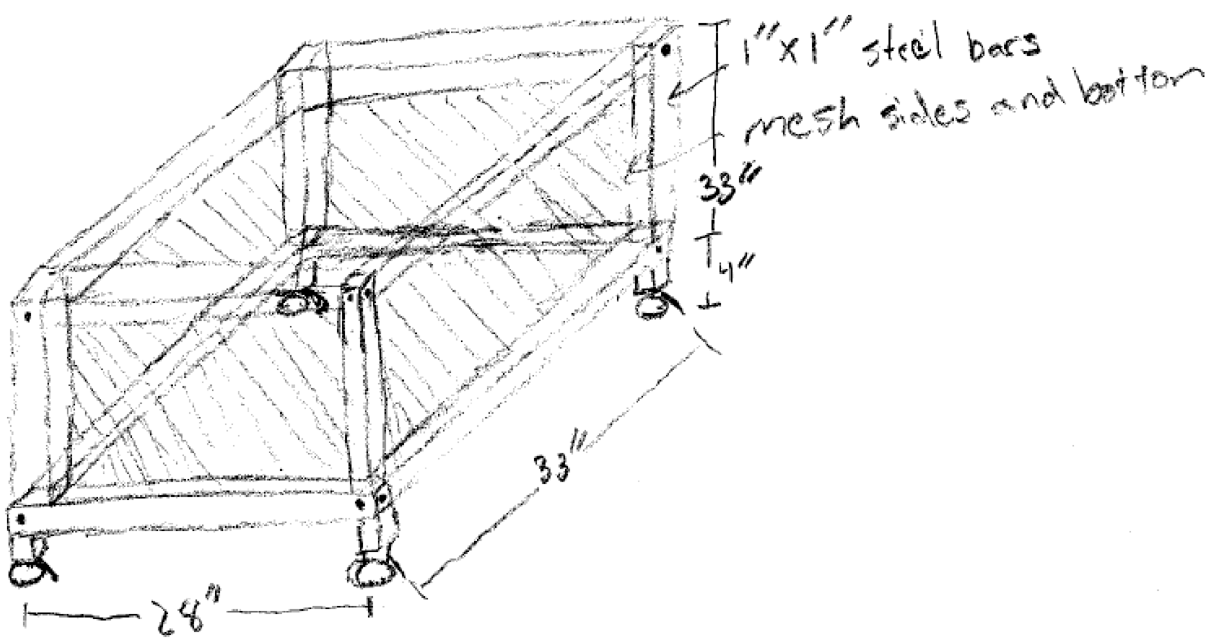


Figure H.4: Concept D

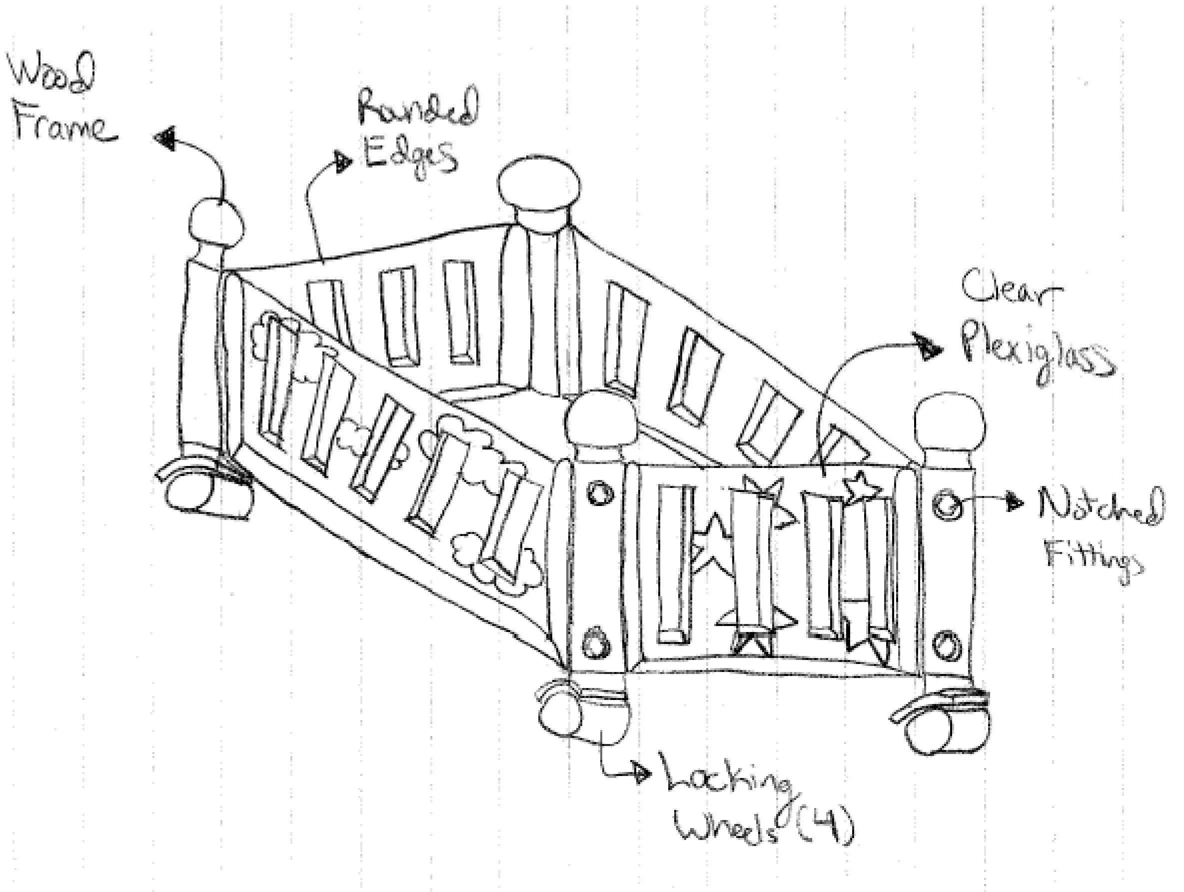


Figure H.5: Concept E

Appendix I: Pugh Chart

Pugh Matrix						
Customer Req.	**Weight**	**Concept E (Datum)**	**Concept A**	**Concept B**	**Concept C**	**Concept D**
Large enough to fit 2 yr old	6	0	0	0	0	0
Tall enough so 2 yr old cannot climb out	12	0	0	0	0	0
Proportional dimensions for stability	9	0	0	0	0	0
Proper sidewall bar spacing to avoid limb/head entrapment	14	0	1	1	0	1
Proper mattress to sidewall spacing to avoid entrapment	13	0	0	0	0	0
Sidewall material must	7	0	1	1	1	1
No sheets or soft bedding	11	0	0	0	0	0
No sharp corners or edges	8	0	0	0	-1	-1
Serviceable up to 24 months	4	0	-1	-1	1	-1
Fasteners remain secure	11	0	0	-1	-1	-1
Withstand usage throughout the day	5	0	1	1	-1	0
Must be cheap	9	0	1	0	-1	-1
Must be lightweight	1	0	1	1	0	-1
Must be able to fit through standard doorway	2	0	0	0	-1	0
	weighted Total	0	32	12	-24	-12

Figure F.1: Pugh Chart

APPENDIX J

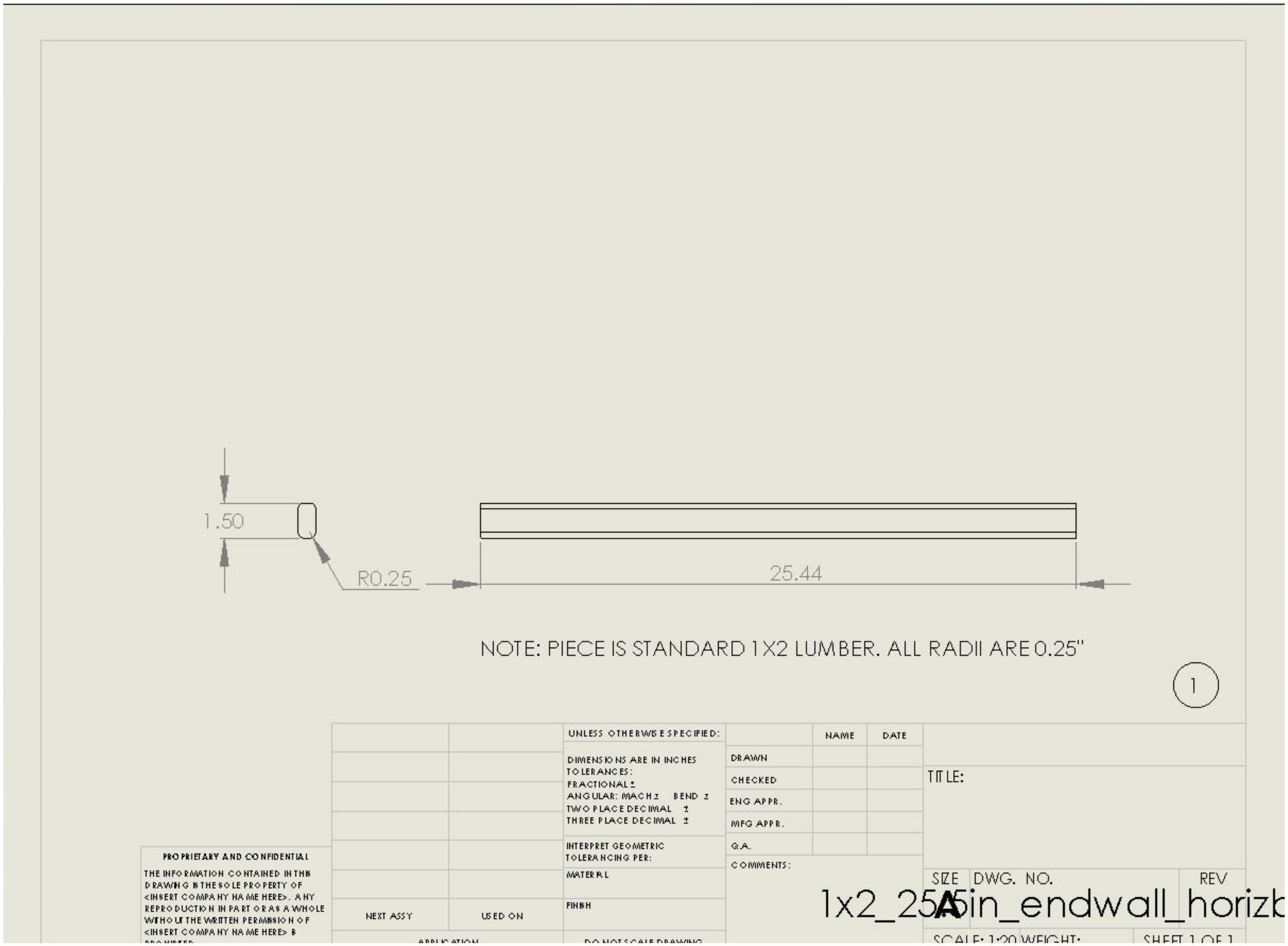


Figure J.1: Part 1

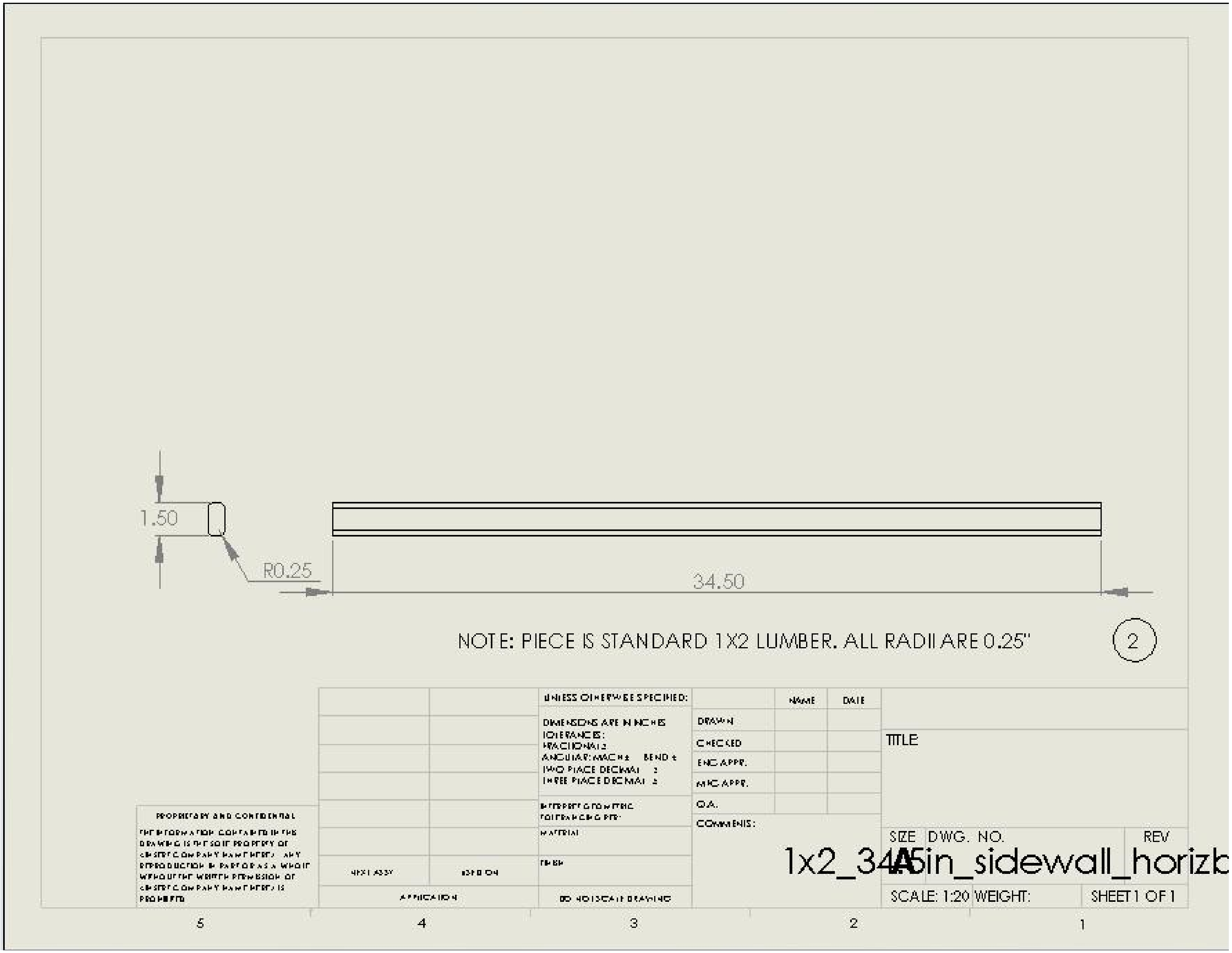


Figure J.2: Part 2

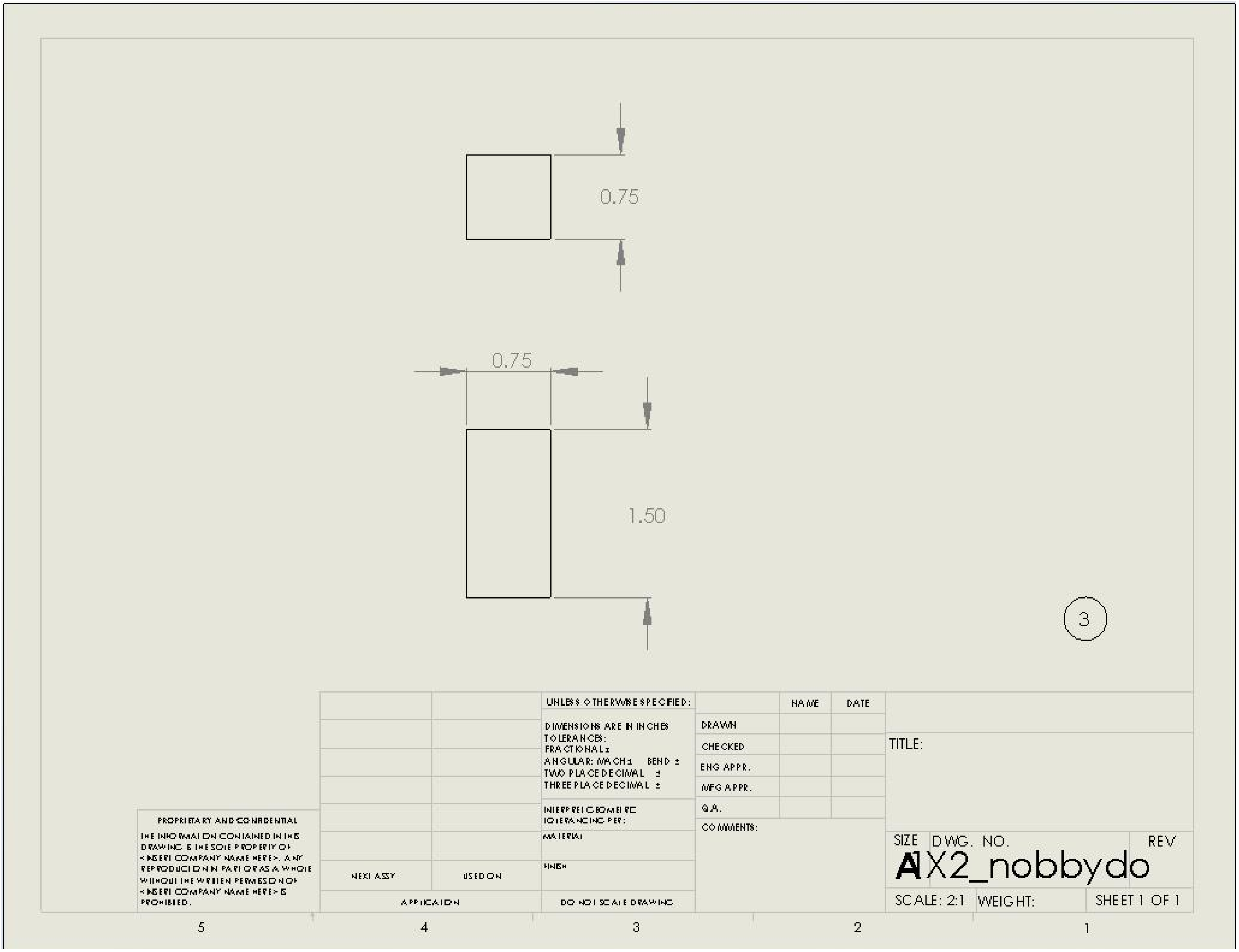


Figure J.3: Part 3

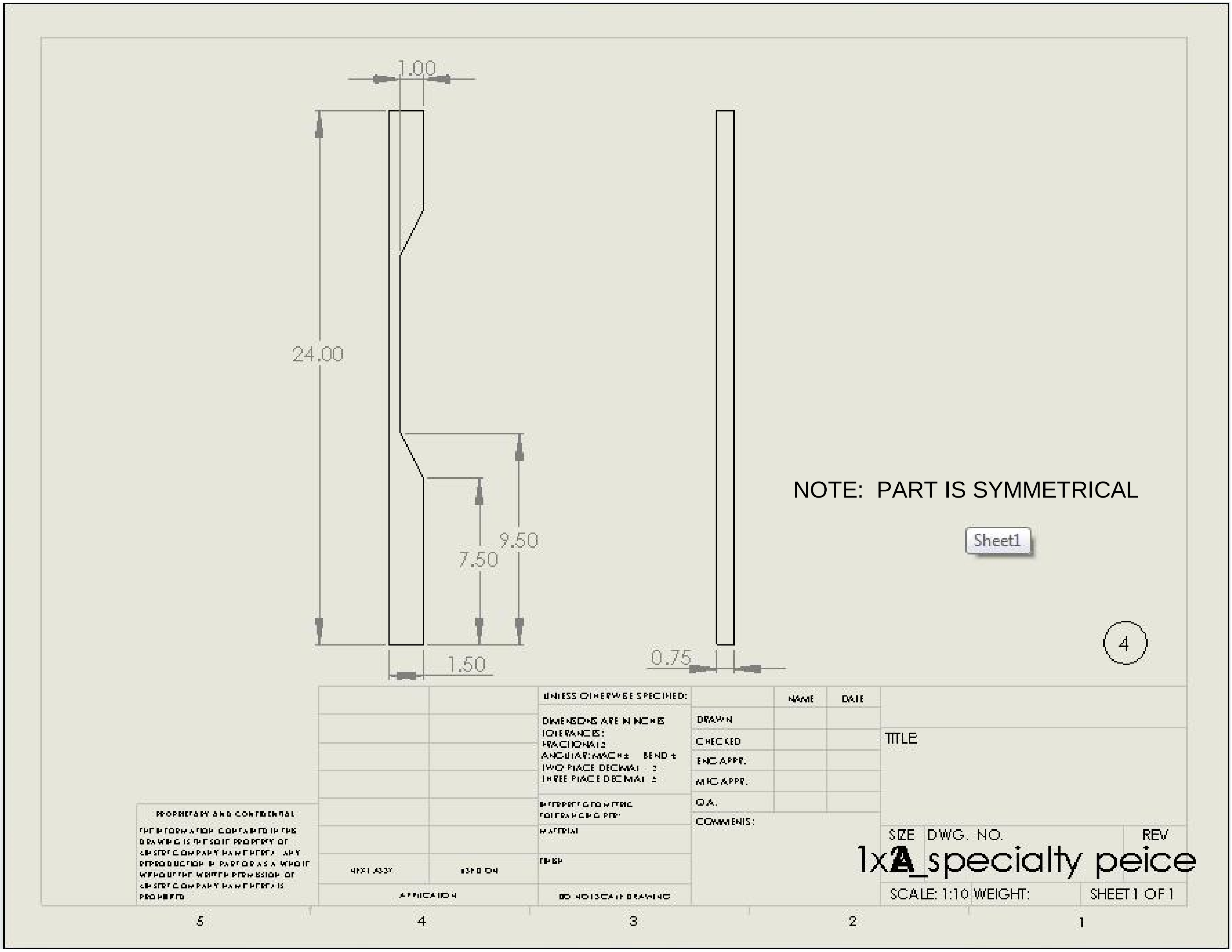


Figure J.4: Part 4

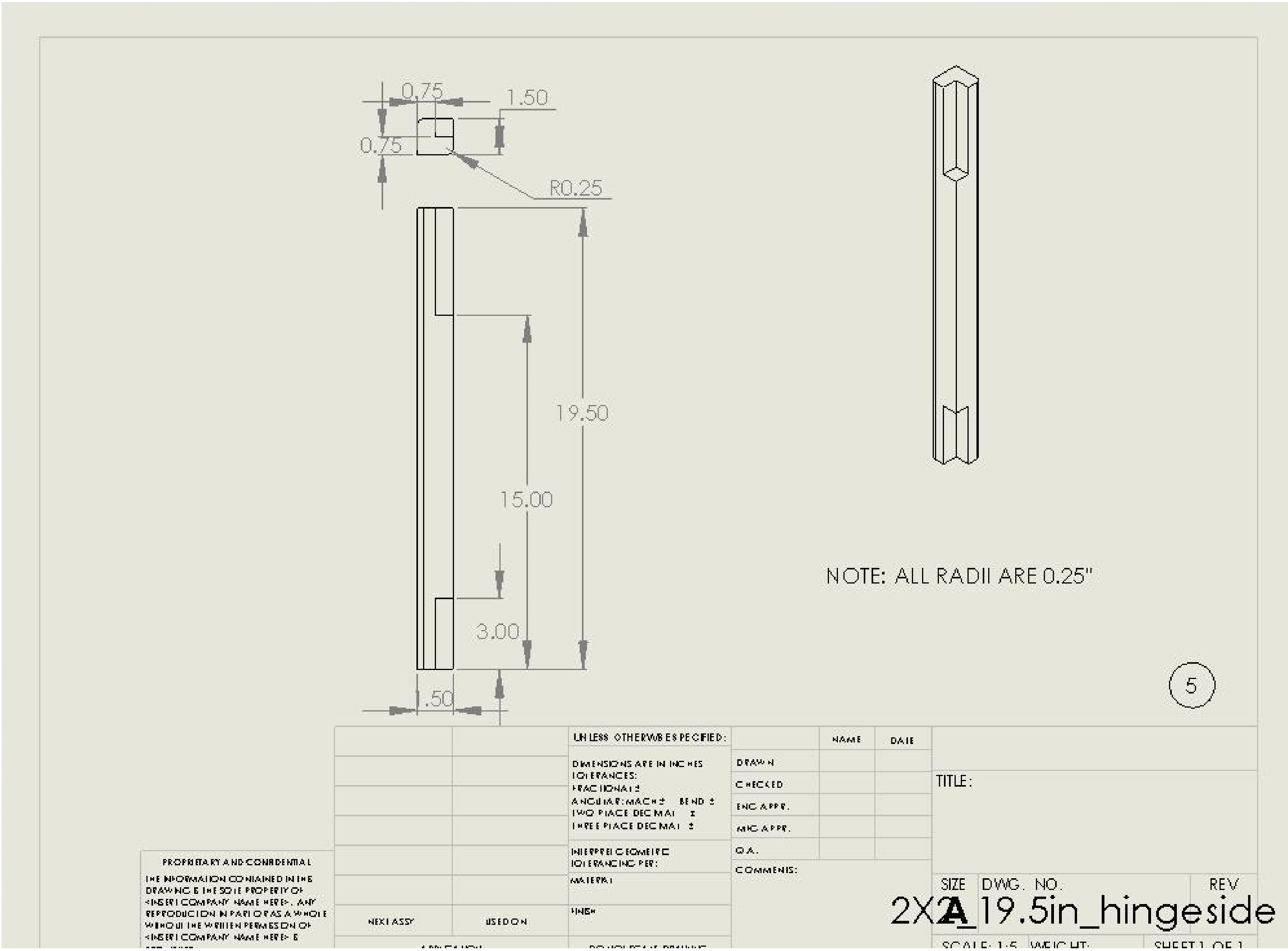


Figure J.5: Part 5

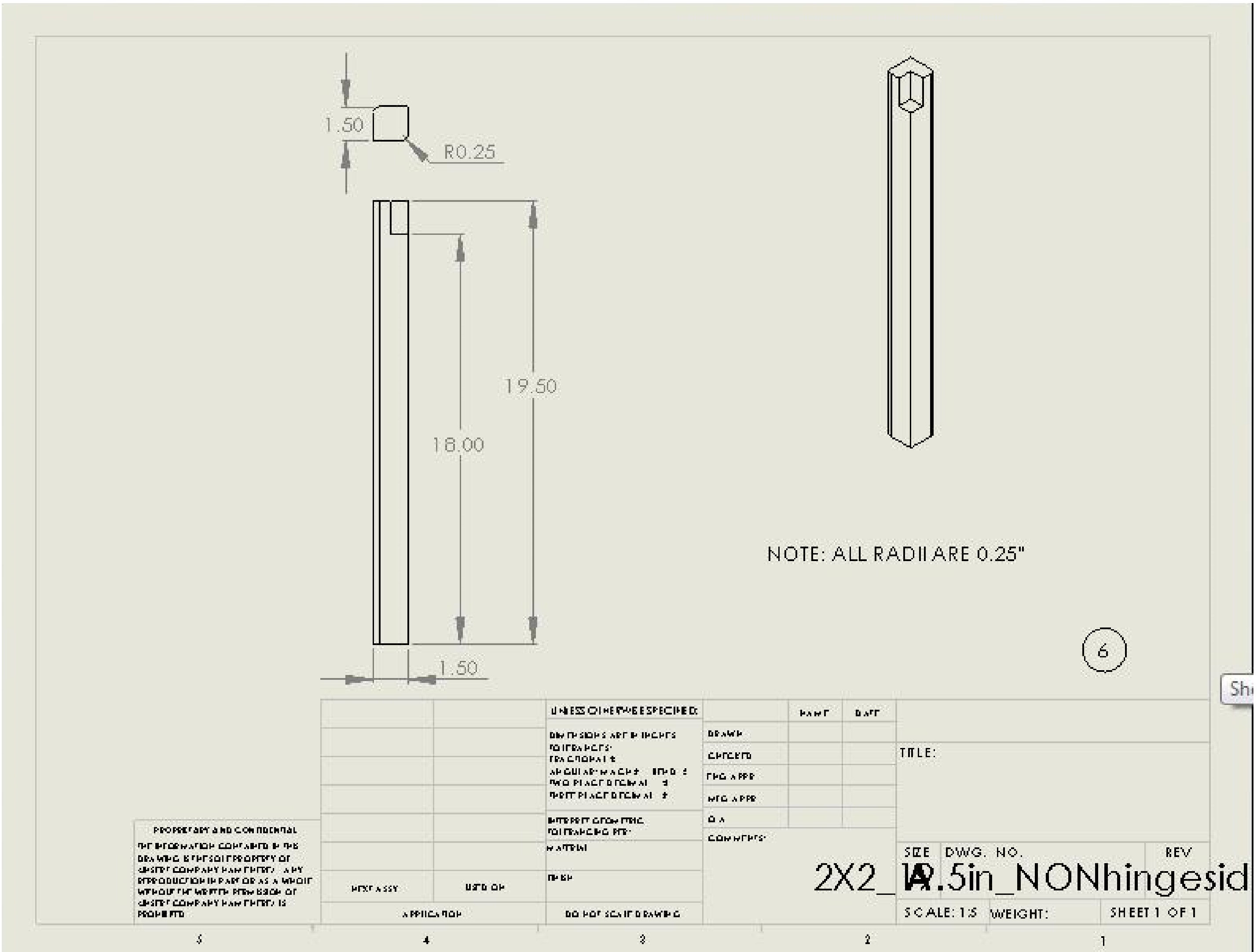


Figure J.6: Part 6

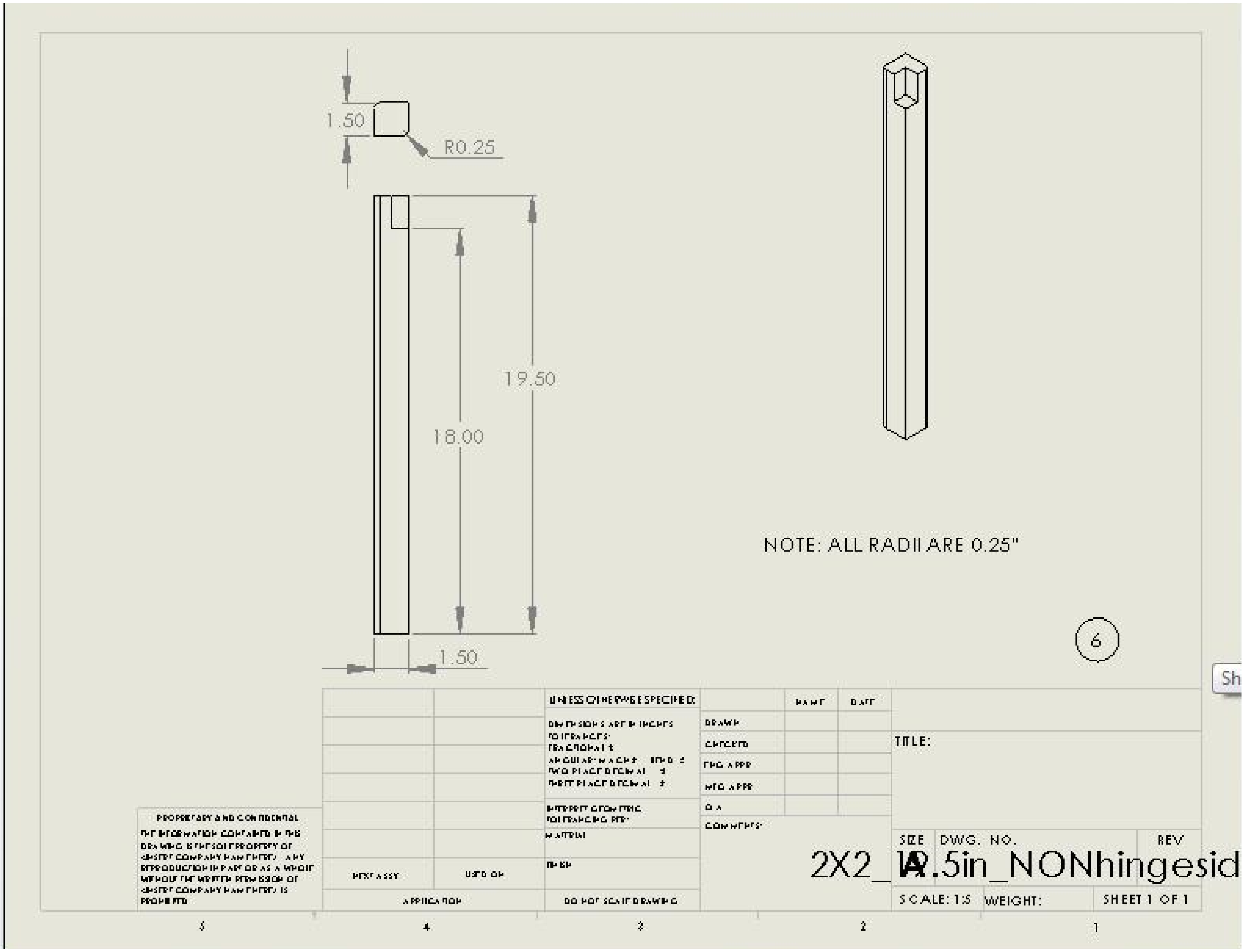


Figure J.7: Part 7

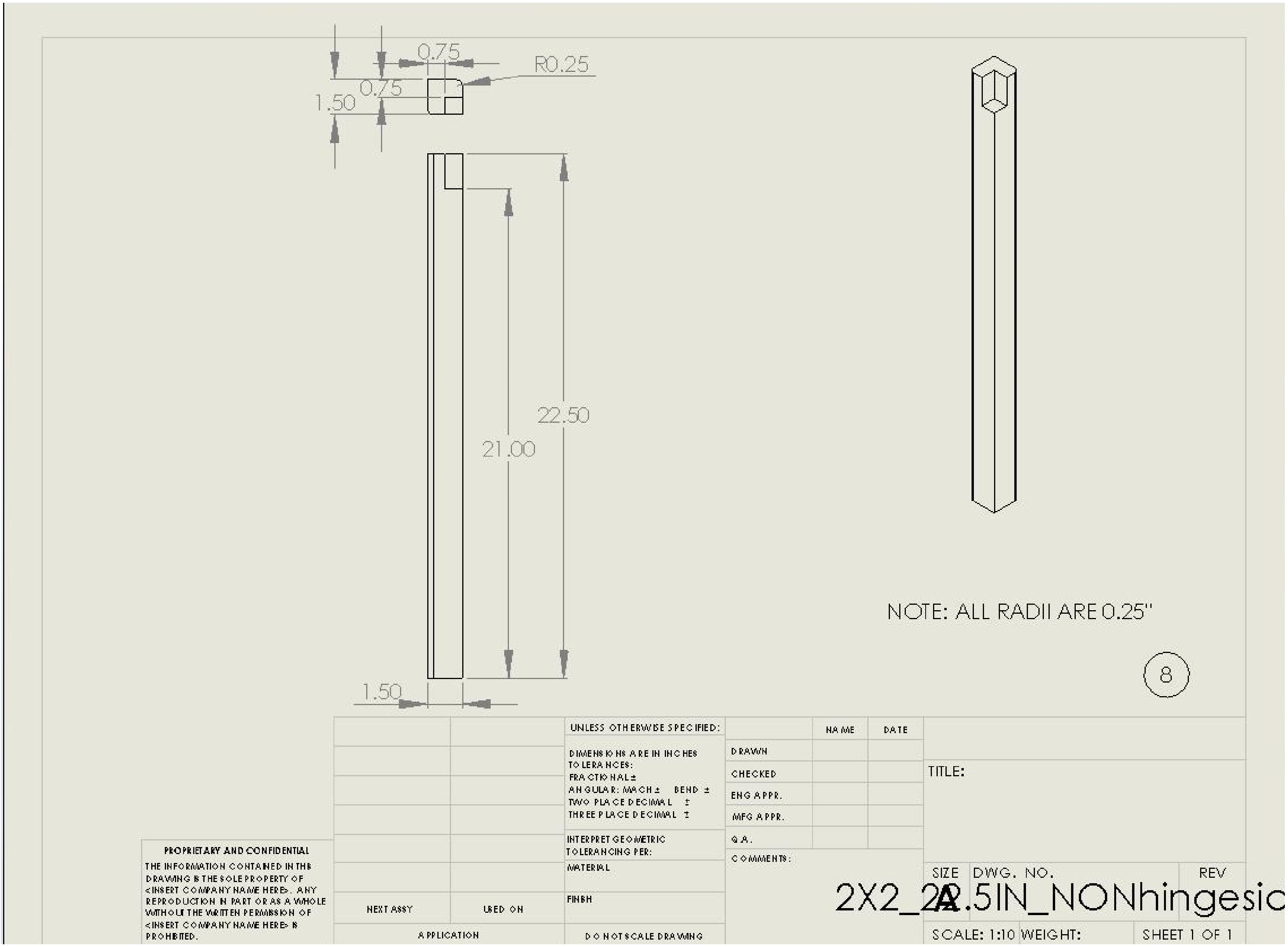


Figure J.8: Part 8

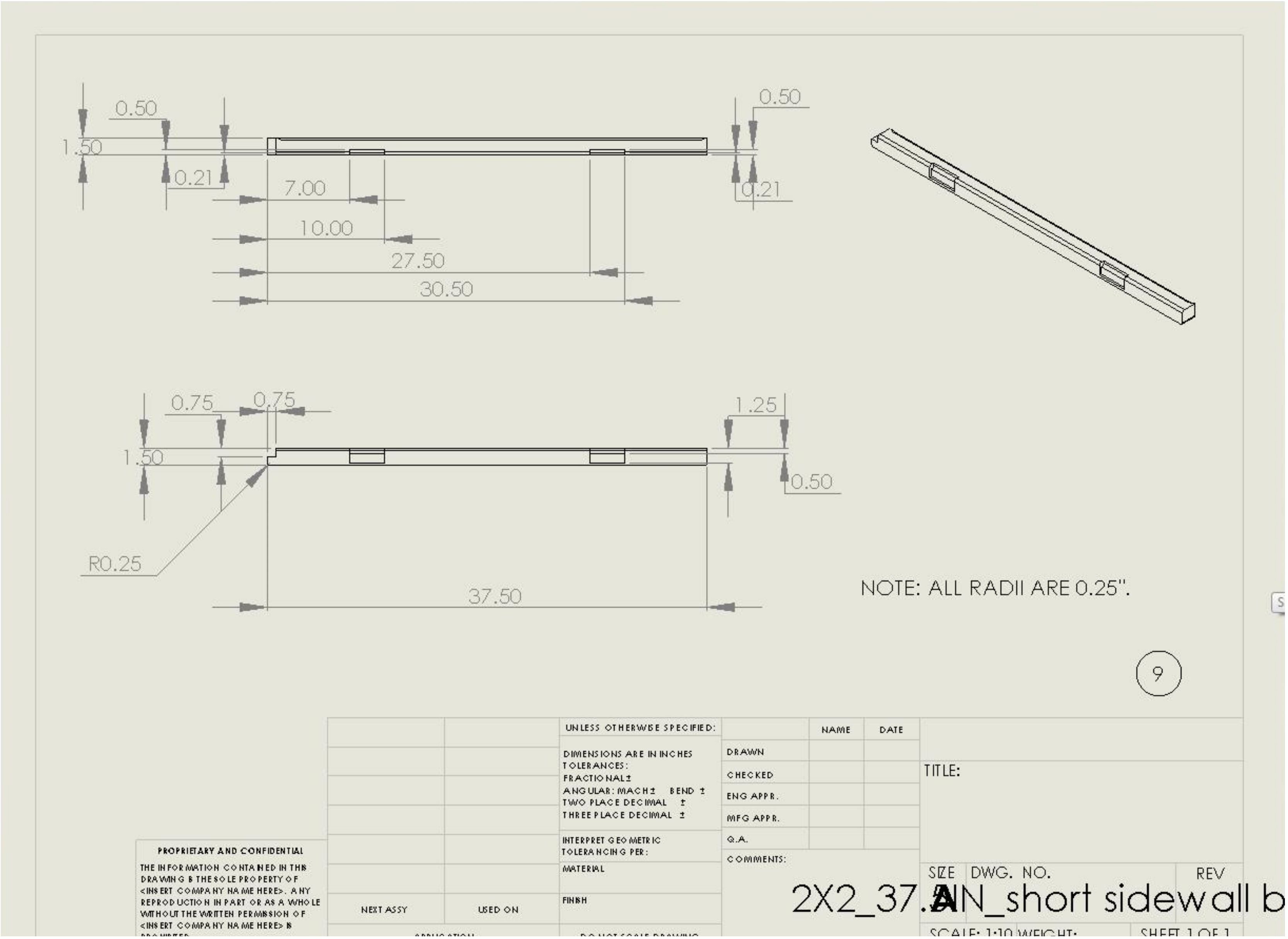


Figure J.9: Part 9

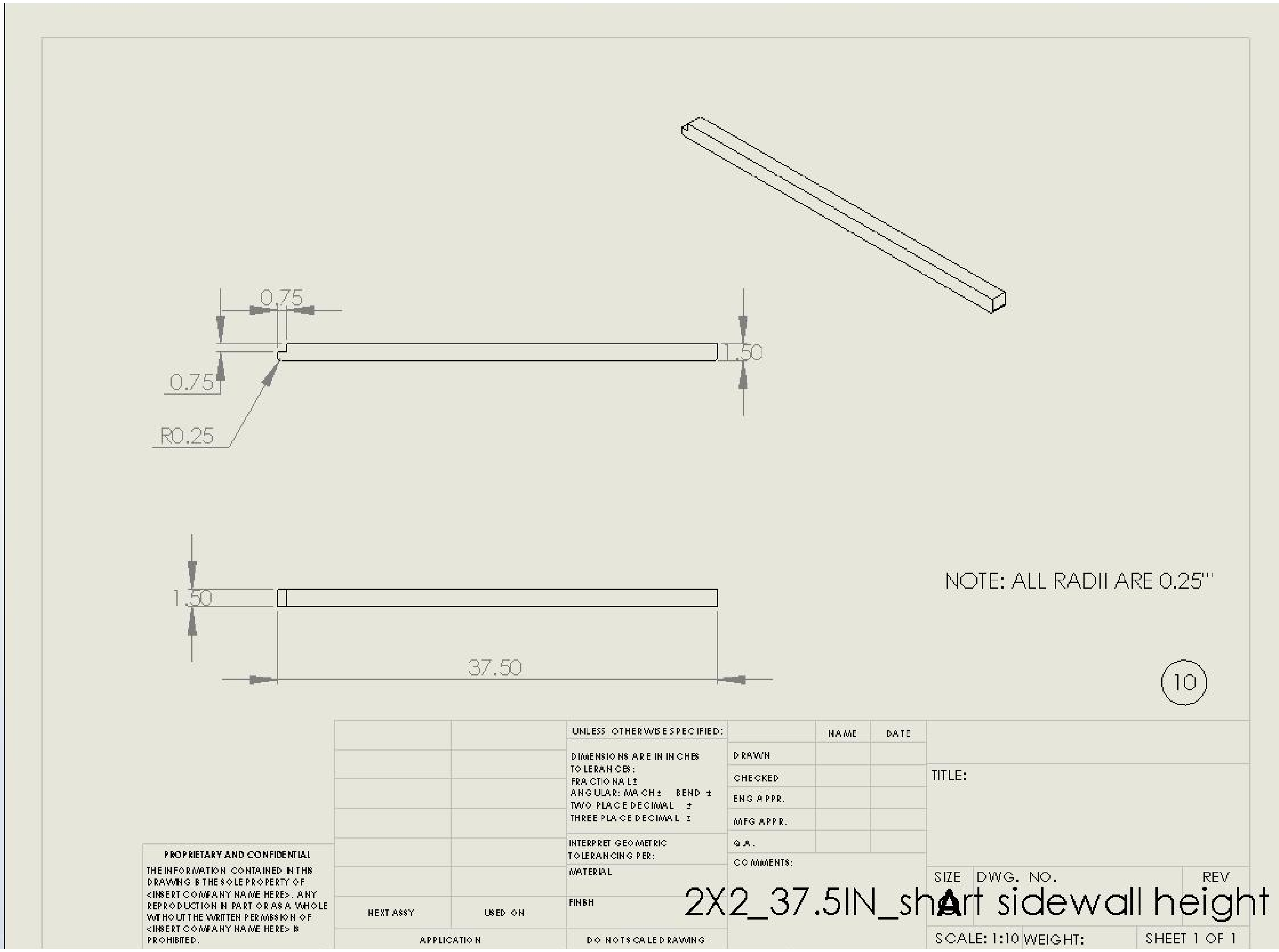


Figure J.10: Part 10

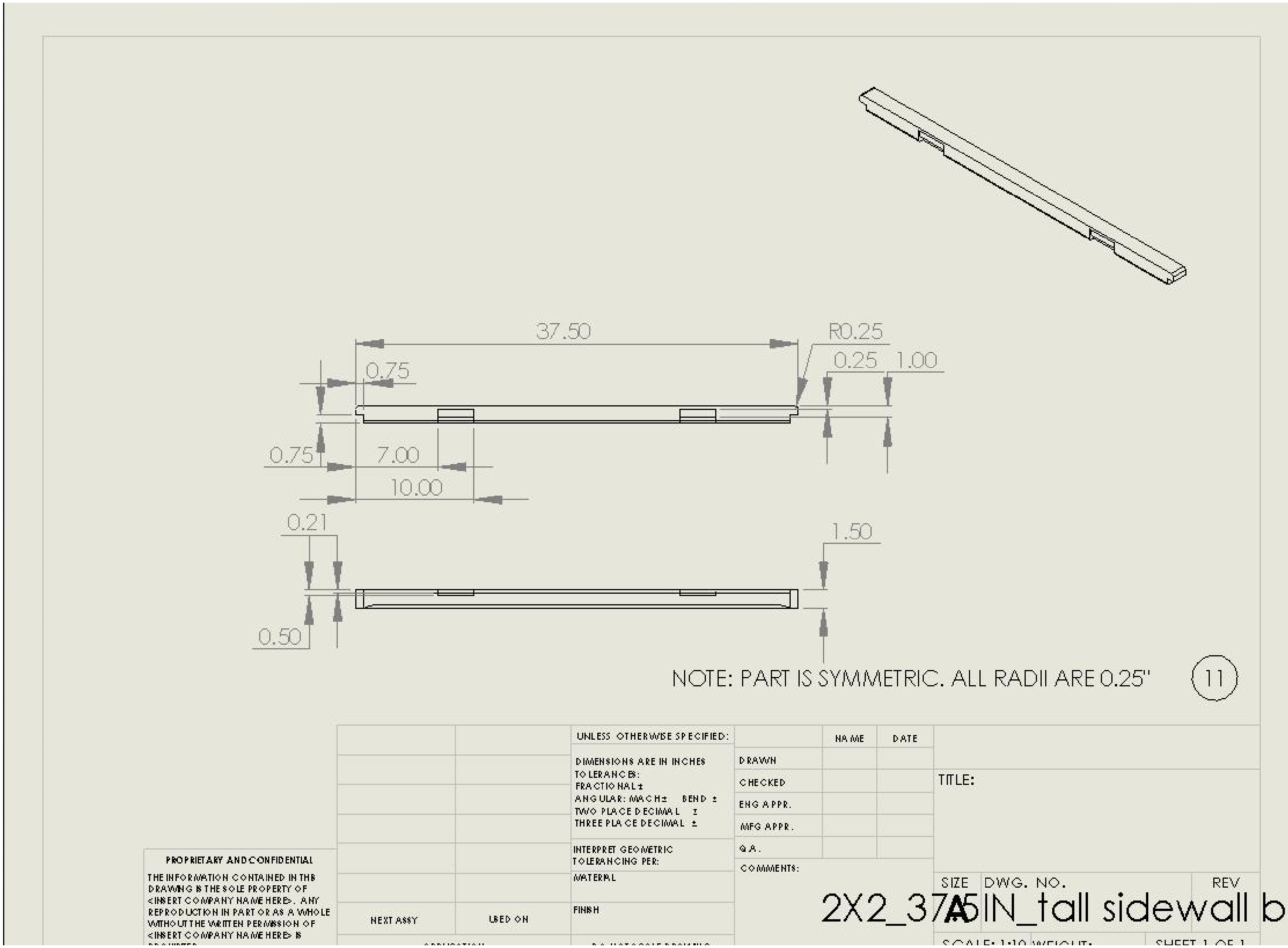


Figure J.11: Part 11

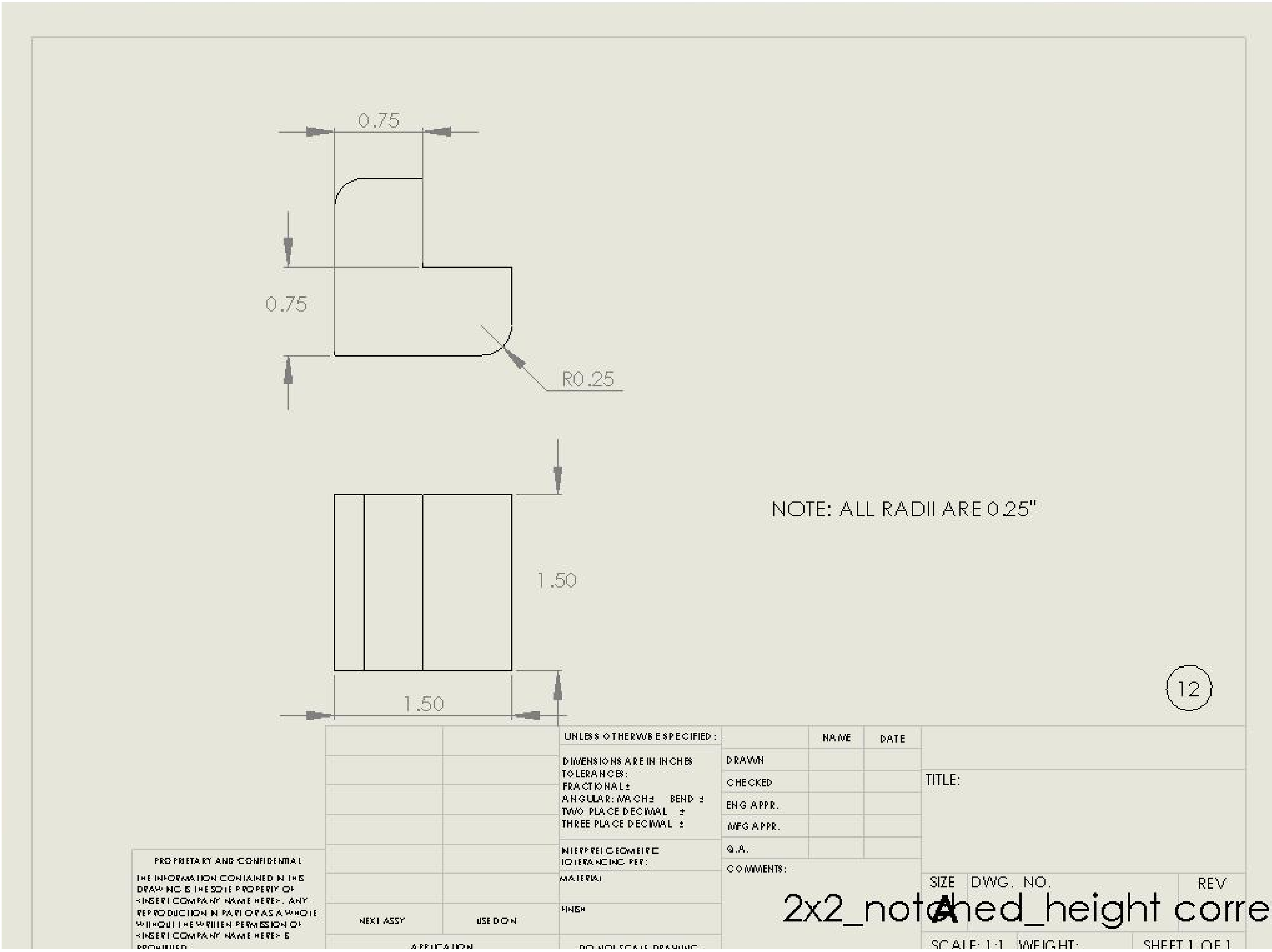


Figure J.12: Part 12

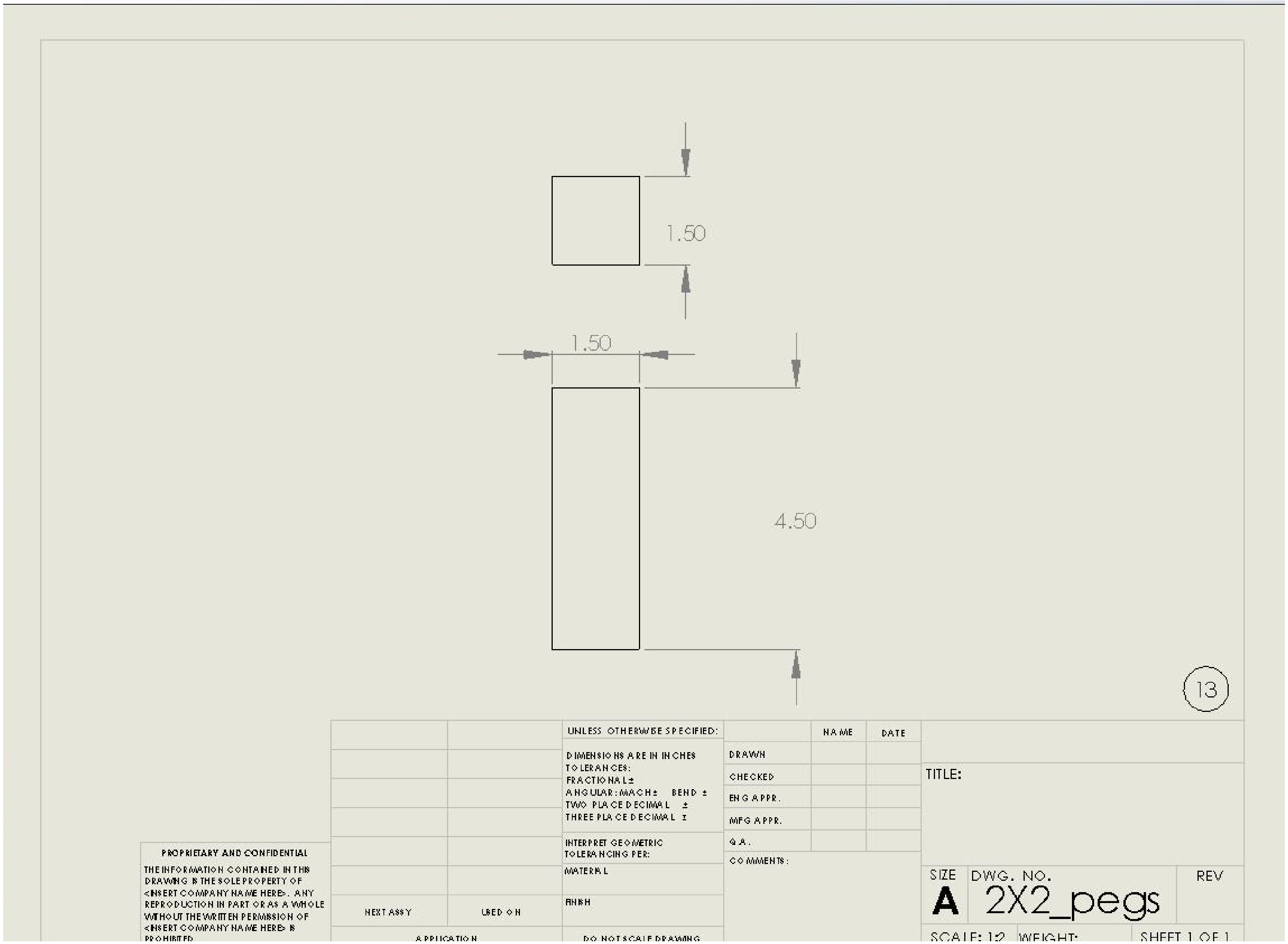


Figure J.13: Part 13

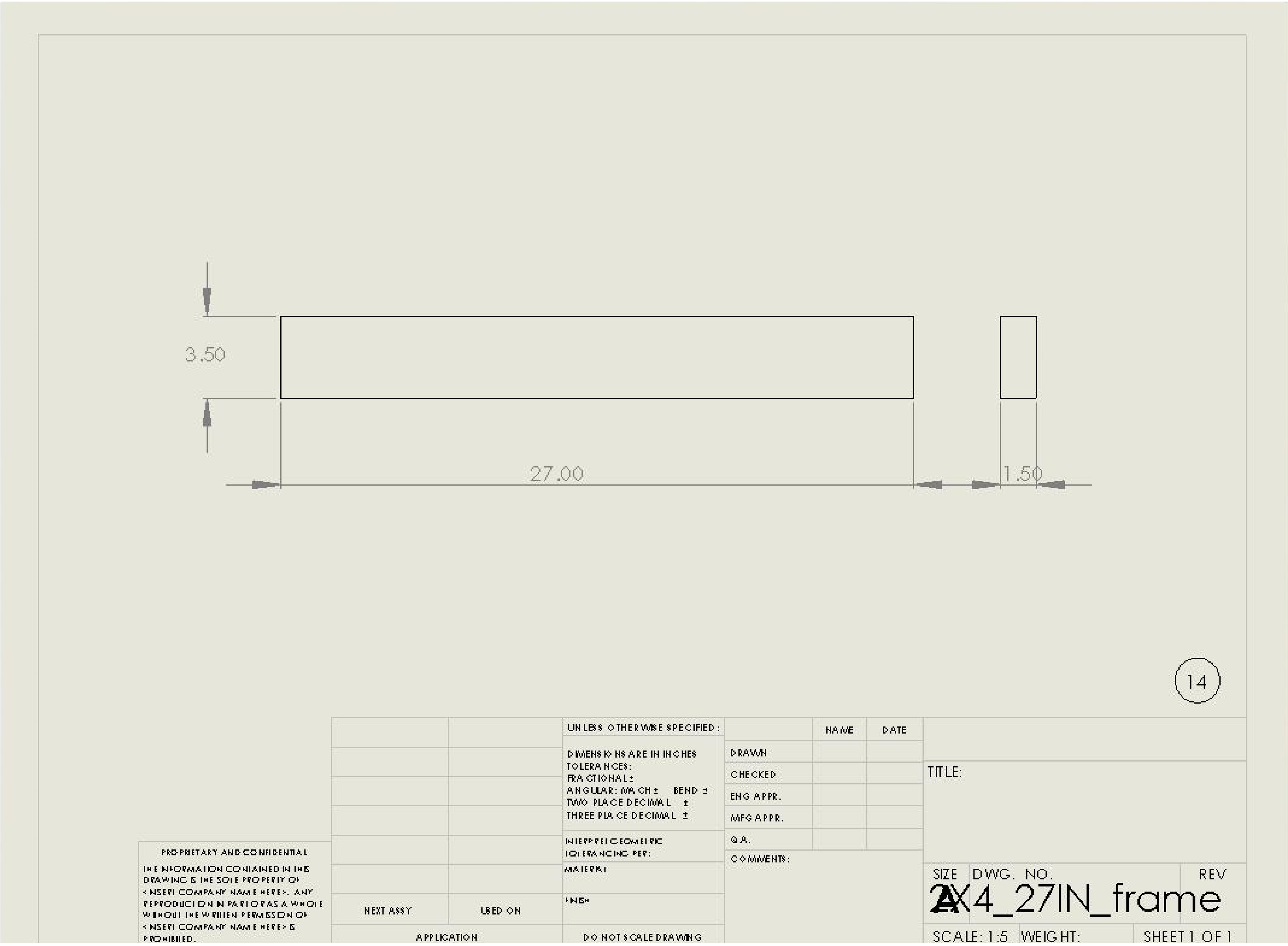


Figure J.14: Part 14

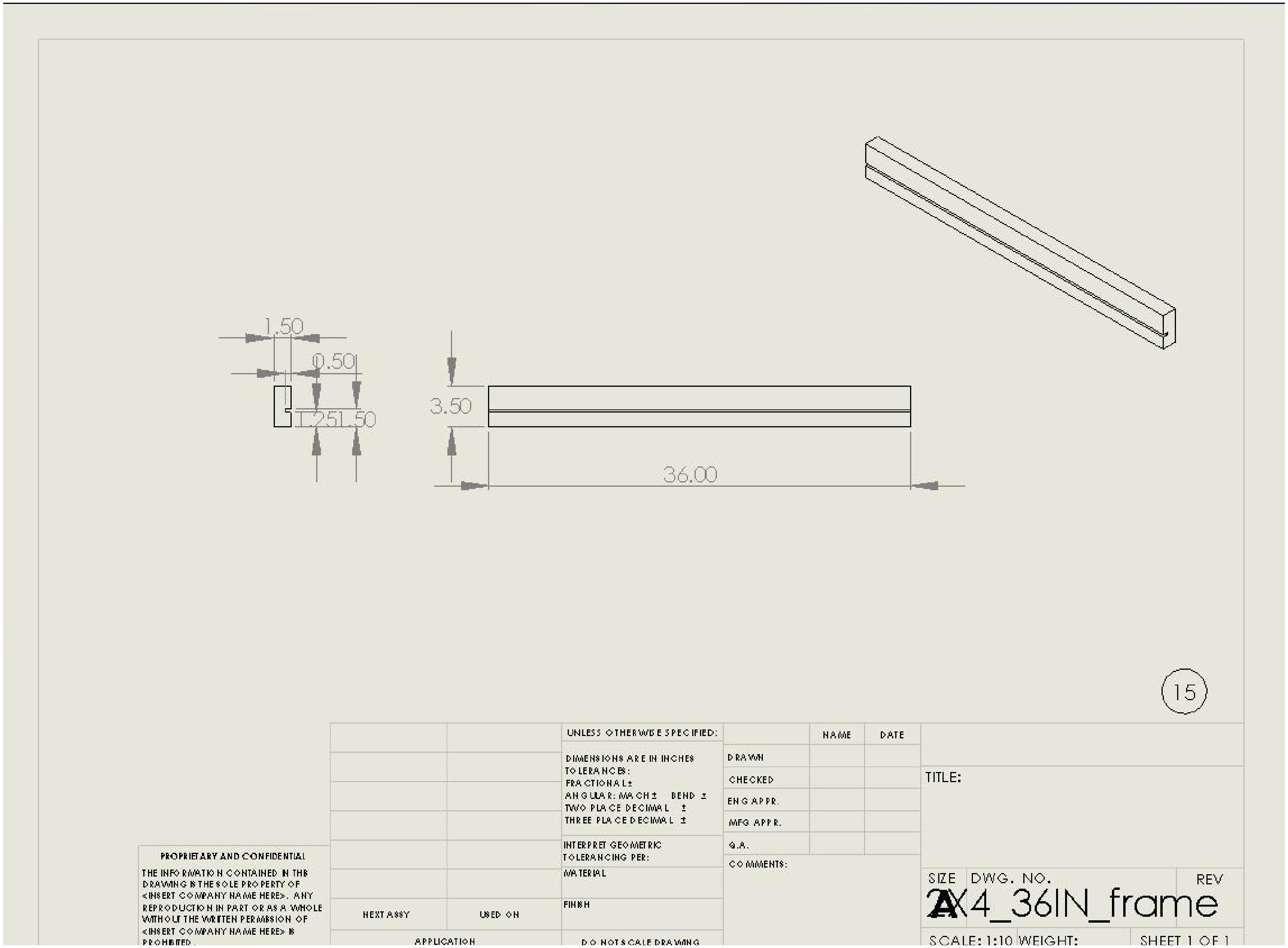


Figure J.15: Part 15

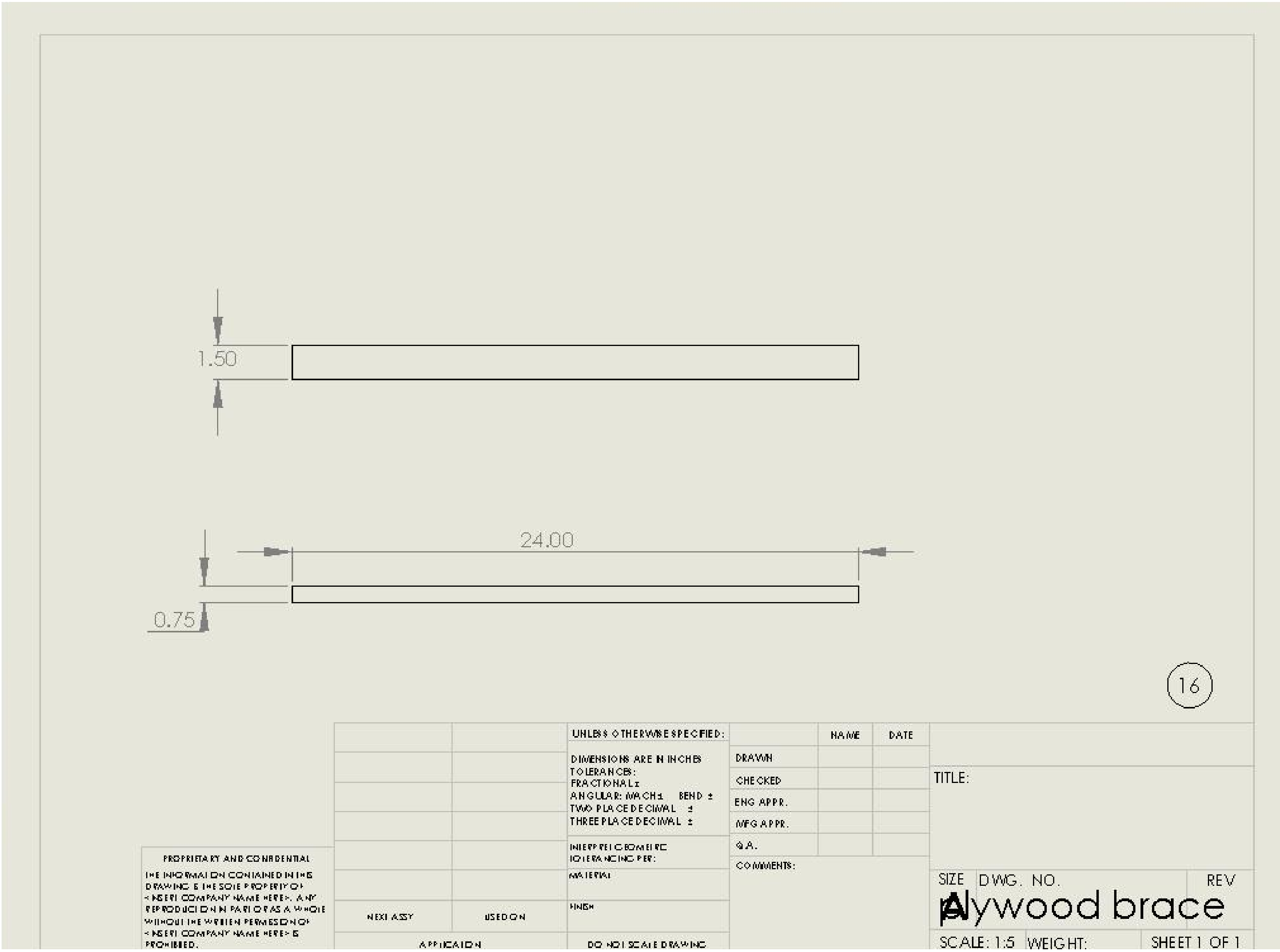


Figure J.16: Part 16

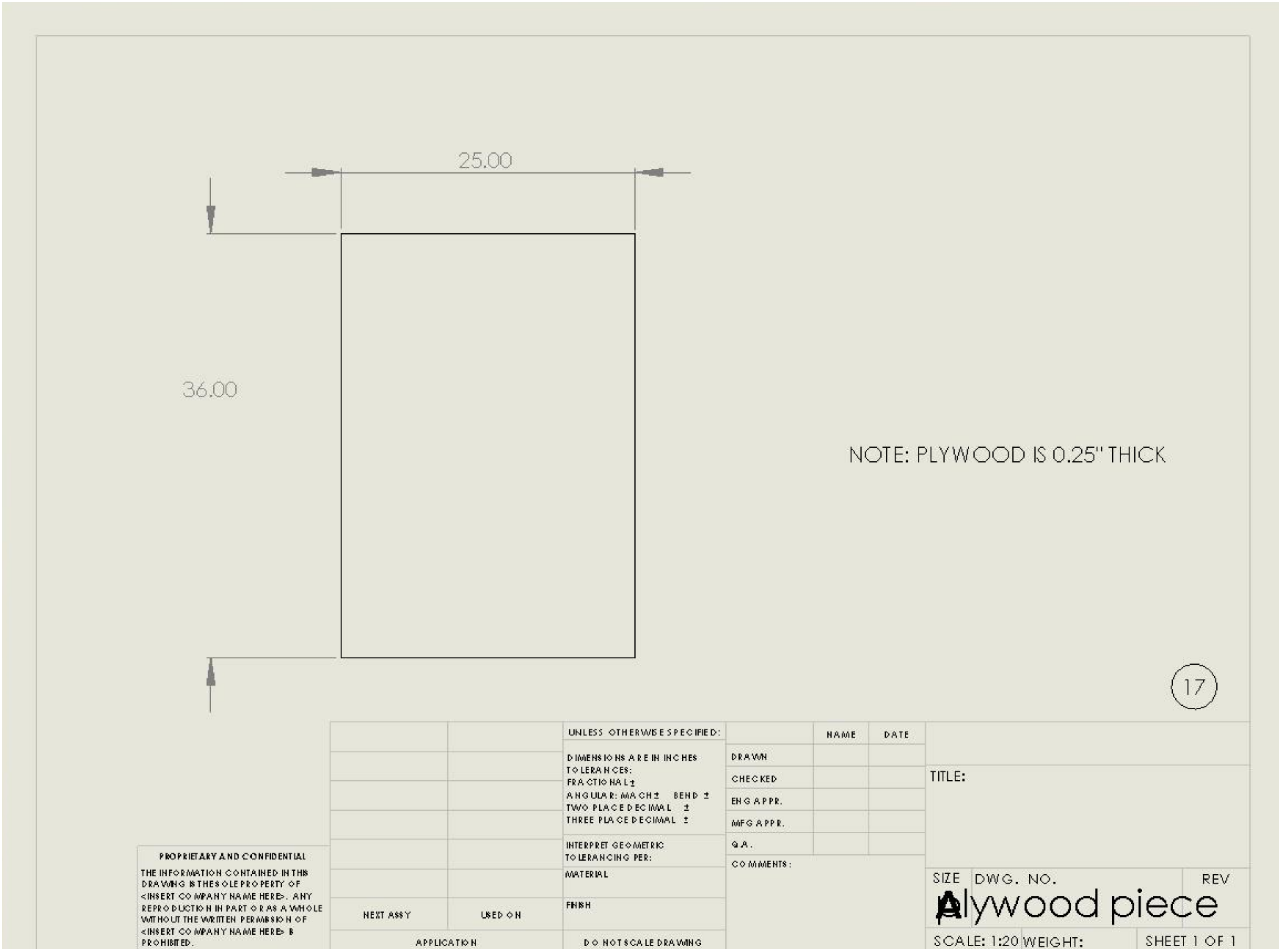


Figure J.17: Part 17

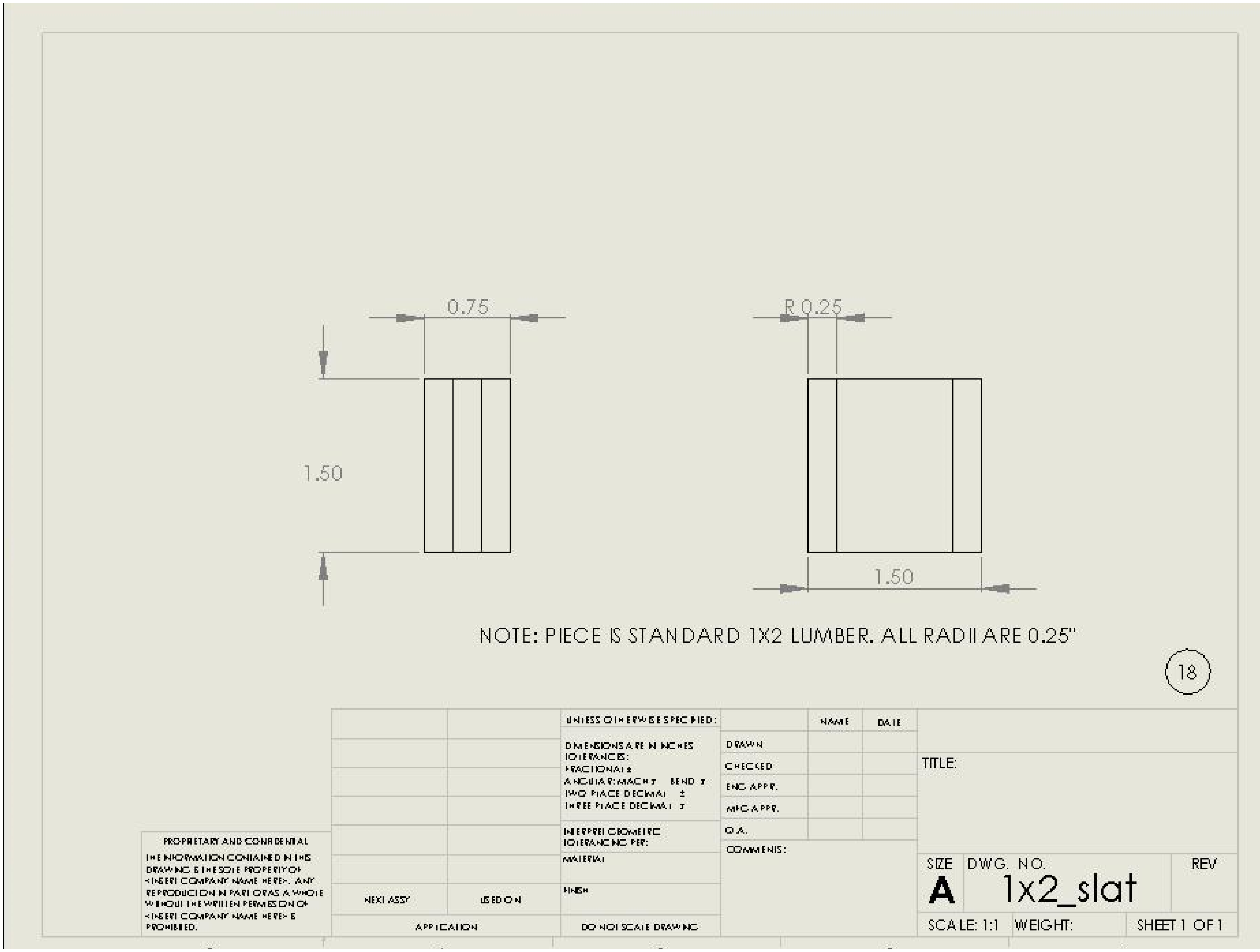


Figure J.18: Part 18

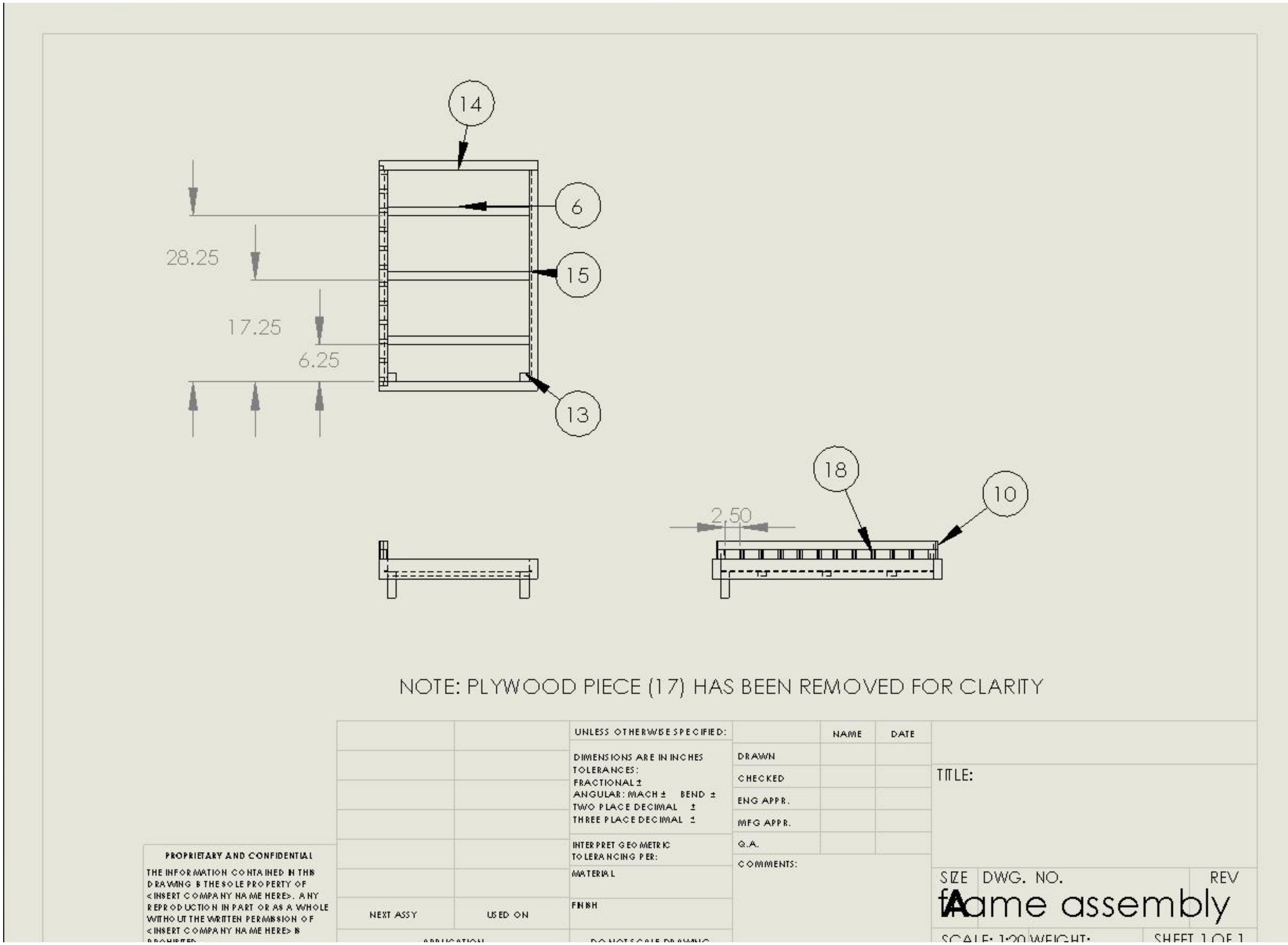


Figure J.19: Frame Assembly

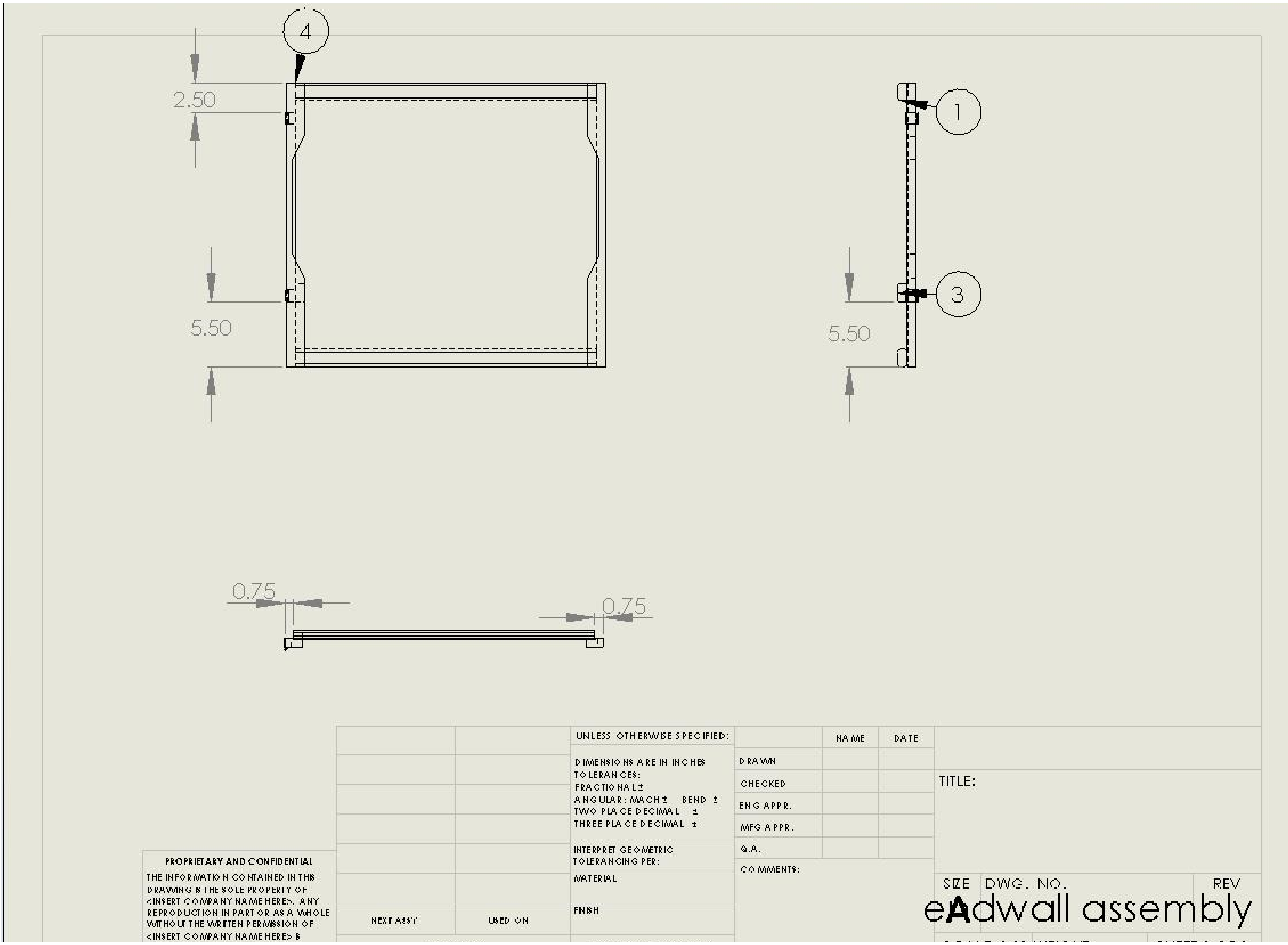


Figure J.20: Endwall Assembly

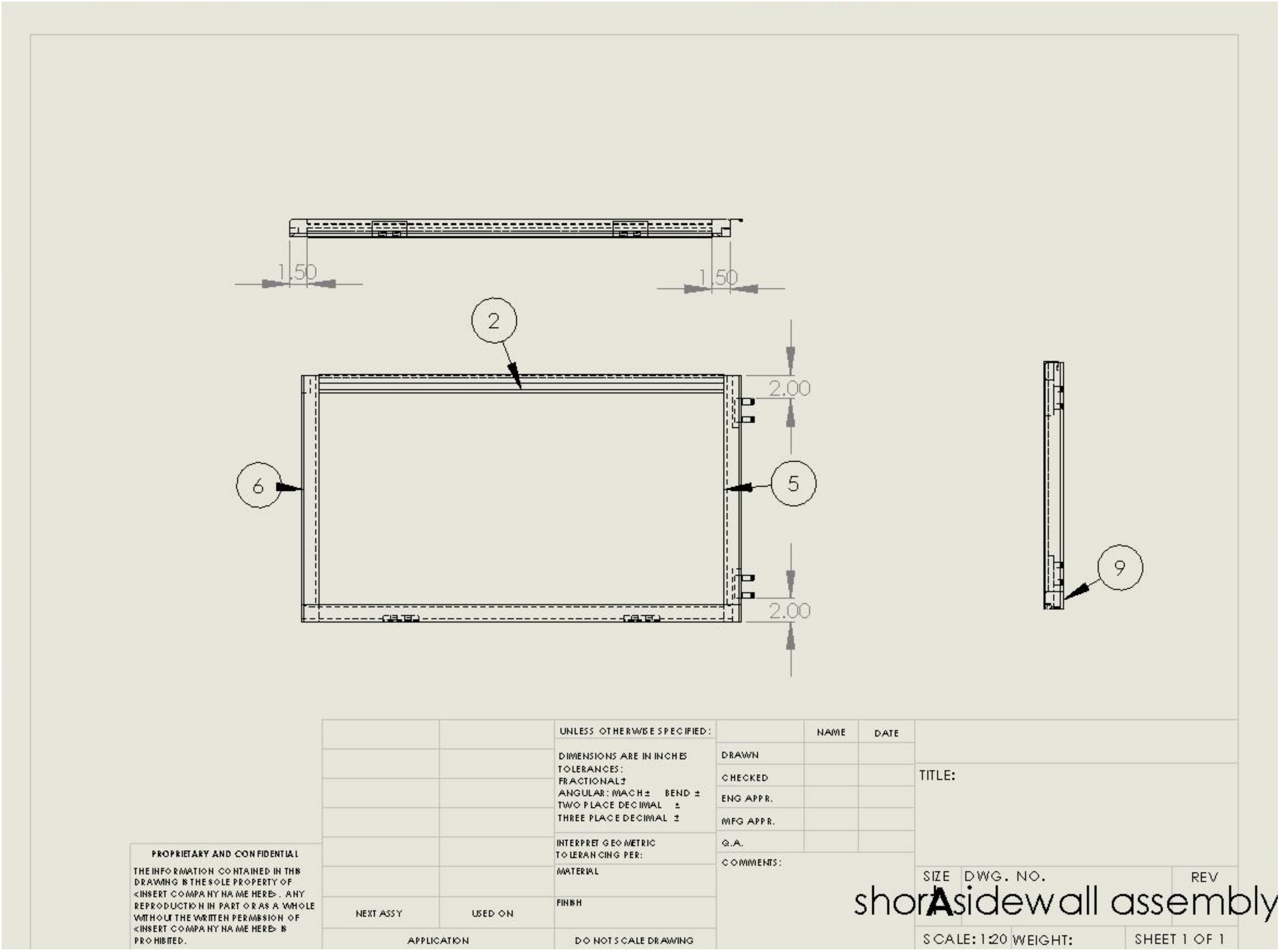


Figure J.21: Short Sidewall Assembly

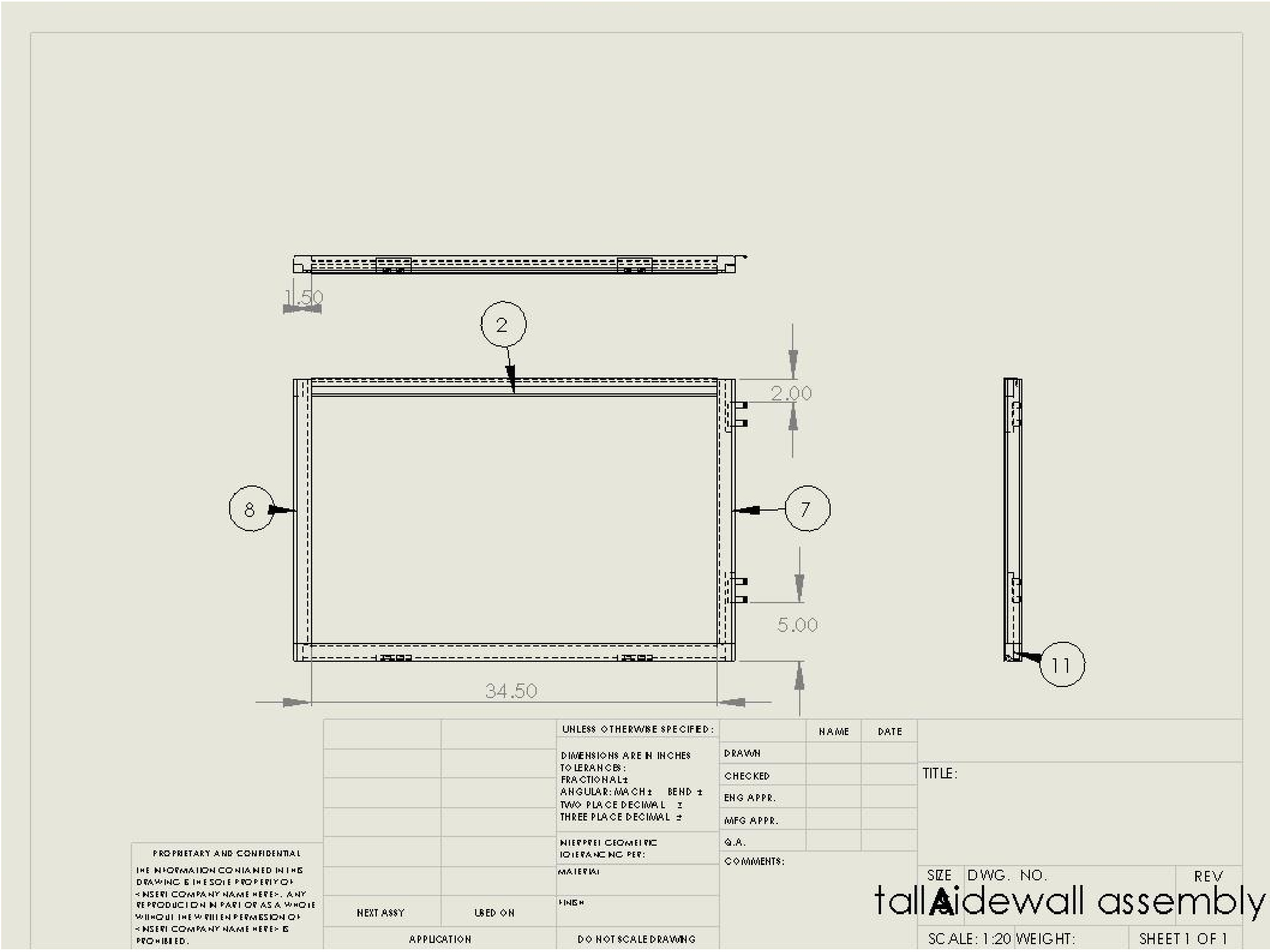


Figure J.22: Tall Sidewall Assembly

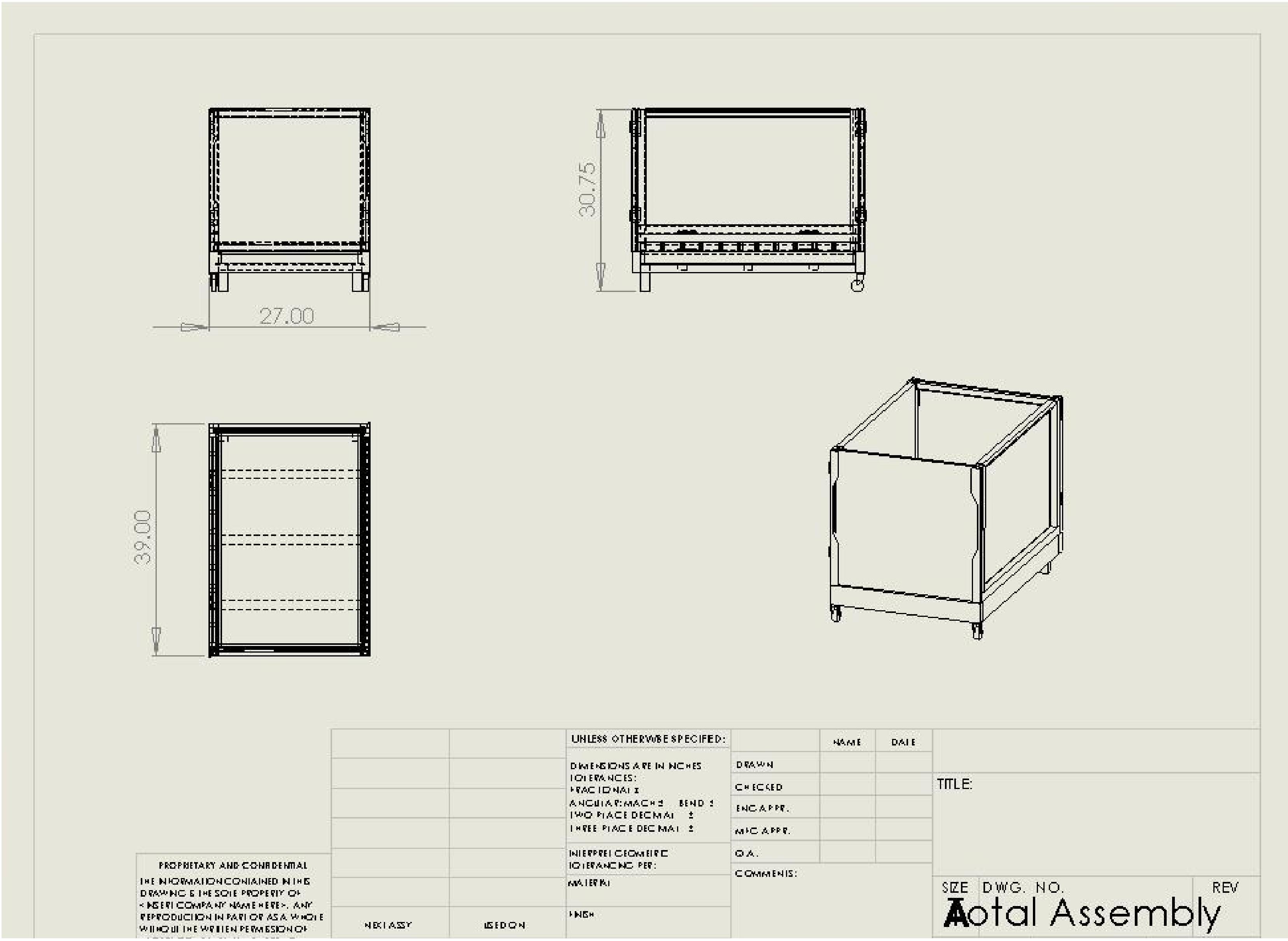


Figure J.23: Total Assembly

Appendix K: Finite Element Analysis

K.1 67 Lbs Sidewall Railing Test (300 N)

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1


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                                         OF MSC.SOFTWARE CORPORATION.

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                                              * *                                * *
                                              * *           MSC.SOFTWARE         * *
                                              * *               CORP             * *
                                              * *                                * *
                                              * *      M D   R 3   N a s t r a n * *
                                              * *                                * *
                                              * *                                * *
                                              * *                                * *
                                              * *         Version 2008.0.4       * *
                                              * *               MD R3            * *
                                              * *                                * *
                                              * *                                * *
                                              * *           JAN 26, 2009         * *
                                              * *                                * *
                                              * *               Intel            * *
                                              * * MODEL PentiumII/4850 (DC3SWP18) * *
                                              * *   Windows XP 6.0 (Build 6002)   * *
                                              * *                                * *
                                              * *                                * *
                                              * * * * * * * * * * * * * * * * * * * *
                                              * * * * * * * * * * * * * * * * * * * *
1                                                                             MARCH  11, 2010   MD NASTRAN  1/26/09   PAGE     1

0        N A S T R A N    F I L E    A N D    S Y S T E M    P A R A M E T E R    E C H O
0


     NASTRAN OP2NEW=0 $ MD NASTRAN .LCL FILE
     NASTRAN BUFFSIZE=8193 $(S:/CAEN/MSC.SOFTWARE/MD_NASTRAN/CONF/NAST2008.RCF[2])
     NASTRAN REAL=532938752 $(PROGRAM DEFAULT)
     $$------------------------------------------------------------------------------
     $$
     $$ NASTRAN INPUT DECK GENERATED BY HYPERMESH VERSION  :10.0BUIL
     $$ GENERATED USING HYPERMESH-NASTRAN TEMPLATE VERSION : 10.0BUILD60
     $$
     $$   TEMPLATE:  GENERAL
     $$
     $$------------------------------------------------------------------------------
     $$------------------------------------------------------------------------------
     $$                      EXECUTIVE CONTROL CARDS
```

```
    $$--------------------------------------------------------------------------------
1                                                                   MARCH  11, 2010   MD NASTRAN  1/26/09   PAGE     2

0       N A S T R A N    E X E C U T I V E    C O N T R O L    E C H O
0


    SOL 101
    CEND
1   LAB4MJWIL                                                       MARCH  11, 2010   MD NASTRAN  1/26/09   PAGE     3

0
0                                    C A S E    C O N T R O L    E C H O
               COMMAND
               COUNT
                1      $$-------------------------------------------------------------------------        --------
                2      $$                        CASE CONTROL CARDS
                3      $$-------------------------------------------------------------------------        --------
                4      TITLE = LAB4MJWIL
                5      $
                6      $HMNAME LOADSTEP               1"LOAD"
                7      SUBCASE       1
                8        LABEL= LOAD
                9        SPC =       1
               10        LOAD =       1
               11        DISPLACEMENT(PRINT,PUNCH) = ALL
               12        STRESS(PRINT,PUNCH) = ALL
               13        SPCFORCES(PRINT,PUNCH) = ALL
               14      $$-------------------------------------------------------------------------        --------
               15      $$                        BULK DATA CARDS
               16      $$-------------------------------------------------------------------------        --------
               17      BEGIN BULK
 *** USER WARNING MESSAGE 324 (XSORSO)
    BLANK ENTRIES ENCOUNTERED WILL BE IGNORED.
0                           INPUT BULK DATA ENTRY COUNT =     113
1   LAB4MJWIL                                                       MARCH  11, 2010   MD NASTRAN  1/26/09   PAGE     4

0
0                                             S O R T E D   B U L K   D A T A   E C H O
               ENTRY
               COUNT        .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
                  1-        CBAR    1       1       1       2       0.7071070.7071070.0
                  2-        CBAR    2       1       2       3       0.7071070.7071070.0
                  3-        FORCE   1       2       0       1.0     0.0     -300.0  0.0
                  4-        FORCE   1       3       0       0.0     1.0     0.0     0.0
                  5-        GRID    1               0.0     0.0     0.0
                  6-        GRID    2               500.0   0.0     0.0
                  7-        GRID    3               1000.0  0.0     0.0
                  8-        MAT1    1       8963.0
                  9-        PBAR    1       1       1290.32 277000.069000.0 0.0     0.0             ++000001
                 10-        ++00000150.8    25.4    -50.8   25.4    -50.8   -25.4   50.8    -25.4    +000002
                 11-        SPC     1       1       123456  0.0
                 12-        SPC     1       3       123456  0.0
                            ENDDATA
0                     TOTAL COUNT=        13

                                   M O D E L   S U M M A R Y
```

```
                                NUMBER OF GRID     POINTS   =        3

                                NUMBER OF CBAR     ELEMENTS =        2

1    LAB4MJWIL                                                        MARCH  11, 2010   MD NASTRAN  1/26/09   PAGE     5

0
 *** USER INFORMATION MESSAGE 7310 (VECPRN)
     ORIGIN OF SUPERELEMENT BASIC COORDINATE SYSTEM WILL BE USED AS REFERENCE LOCATION.
     RESULTANTS ABOUT ORIGIN OF SUPERELEMENT BASIC COORDINATE SYSTEM IN SUPERELEMENT BASIC SYSTEM COORDINATES.
0                                                  OLOAD    RESULTANT
  SUBCASE/    LOAD
  DAREA ID    TYPE       T1            T2            T3            R1            R2            R3
0        1     FX    0.000000E+00     ----          ----          ----       0.000000E+00  0.000000E+00
               FY       ----      -3.000000E+02     ----       0.000000E+00     ----      -1.500000E+05
               FZ       ----          ----      0.000000E+00  0.000000E+00  0.000000E+00     ----
               MX       ----          ----          ----       0.000000E+00     ----          ----
               MY       ----          ----          ----          ----       0.000000E+00     ----
               MZ       ----          ----          ----          ----          ----       0.000000E+00
             TOTALS  0.000000E+00 -3.000000E+02  0.000000E+00  0.000000E+00  0.000000E+00 -1.500000E+05
1    LAB4MJWIL                                                        MARCH  11, 2010   MD NASTRAN  1/26/09   PAGE     6

0     LOAD                                                                                          SUBCASE   1
0                                           G R I D   P O I N T   S I N G U L A R I T Y   T A B L E
0                           POINT    TYPE   FAILED      STIFFNESS       OLD USET           NEW USET
                             ID            DIRECTION      RATIO     EXCLUSIVE  UNION   EXCLUSIVE  UNION
                              2       G      4        0.00E+00          B        F         SB       S    *
1    LAB4MJWIL                                                        MARCH  11, 2010   MD NASTRAN  1/26/09   PAGE     7

0     LOAD                                                                                          SUBCASE   1

 *** SYSTEM INFORMATION MESSAGE 4159 (DFMSA)
     THE DECOMPOSITION OF KLL      YIELDS A MAXIMUM MATRIX-TO-FACTOR-DIAGONAL RATIO OF    1.000000E+00
 *** USER INFORMATION MESSAGE 5293 (SSG3A)
    FOR DATA BLOCK KLL
    LOAD SEQ. NO.            EPSILON              EXTERNAL WORK      EPSILONS LARGER THAN 0.001 ARE FLAGGED WITH ASTERISKS
                1         -1.8947807E-16         9.4401329E+01
1    LAB4MJWIL                                                        MARCH  11, 2010   MD NASTRAN  1/26/09   PAGE     8

0
 *** USER INFORMATION MESSAGE 7310 (VECPRN)
     ORIGIN OF SUPERELEMENT BASIC COORDINATE SYSTEM WILL BE USED AS REFERENCE LOCATION.
     RESULTANTS ABOUT ORIGIN OF SUPERELEMENT BASIC COORDINATE SYSTEM IN SUPERELEMENT BASIC SYSTEM COORDINATES.
0                                                  SPCFORCE RESULTANT
  SUBCASE/    LOAD
  DAREA ID    TYPE       T1            T2            T3            R1            R2            R3
0        1     FX    0.000000E+00     ----          ----          ----       0.000000E+00  0.000000E+00
               FY       ----       3.000000E+02     ----       0.000000E+00     ----       1.500000E+05
               FZ       ----          ----      0.000000E+00  0.000000E+00  0.000000E+00     ----
               MX       ----          ----          ----       0.000000E+00     ----          ----
               MY       ----          ----          ----          ----       0.000000E+00     ----
               MZ       ----          ----          ----          ----          ----       0.000000E+00
             TOTALS  0.000000E+00  3.000000E+02  0.000000E+00  0.000000E+00  0.000000E+00  1.500000E+05
1    LAB4MJWIL                                                        MARCH  11, 2010   MD NASTRAN  1/26/09   PAGE     9

0     LOAD                                                                                          SUBCASE   1
```

```
                                             D I S P L A C E M E N T   V E C T O R

      POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
             1      G      0.0            0.0            0.0            0.0            0.0            0.0
             2      G      0.0           -6.293422E-01   0.0            0.0            0.0            0.0
             3      G      0.0            0.0            0.0            0.0            0.0            0.0
1    LAB4MJWIL                                                                MARCH  11, 2010   MD NASTRAN  1/26/09   PAGE    10

0     LOAD                                                                                                  SUBCASE   1

                               F O R C E S   O F   S I N G L E - P O I N T   C O N S T R A I N T

      POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
             1      G      0.0            1.500000E+02   0.0            0.0            0.0            3.750000E+04
             3      G      0.0            1.500000E+02   0.0            0.0            0.0           -3.750000E+04
1    LAB4MJWIL                                                                MARCH  11, 2010   MD NASTRAN  1/26/09   PAGE    11

0
1    LAB4MJWIL                                                                MARCH  11, 2010   MD NASTRAN  1/26/09   PAGE    12

0     LOAD                                                                                                  SUBCASE   1

                                 S T R E S S E S   I N   B A R   E L E M E N T S         ( C B A R )
  ELEMENT        SA1            SA2            SA3            SA4           AXIAL          SA-MAX         SA-MIN     M.S.-T
    ID.          SB1            SB2            SB3            SB4           STRESS         SB-MAX         SB-MIN     M.S.-C
0       1    6.877256E+00  -6.877256E+00  -6.877256E+00   6.877256E+00   0.0            6.877256E+00  -6.877256E+00
            -6.877256E+00   6.877256E+00   6.877256E+00  -6.877256E+00                  6.877256E+00  -6.877256E+00
0       2   -6.877256E+00   6.877256E+00   6.877256E+00  -6.877256E+00   0.0            6.877256E+00  -6.877256E+00
             6.877256E+00  -6.877256E+00  -6.877256E+00   6.877256E+00                  6.877256E+00  -6.877256E+00
1    LAB4MJWIL                                                                MARCH  11, 2010   MD NASTRAN  1/26/09   PAGE    13

0
1    LAB4MJWIL                                                                MARCH  11, 2010   MD NASTRAN  1/26/09   PAGE    14

0
 * * * *  D B D I C T   P R I N T  * * * *      SUBDMAP = PRTSUM  ,  DMAP STATEMENT NO.     30



0                                   * * * *  A N A L Y S I S  S U M M A R Y  T A B L E  * * * *
0 SEID  PEID PROJ VERS APRCH      SEMG SEMR SEKR SELG SELR MODES DYNRED SOLLIN PVALID SOLNL LOOPID DESIGN CYCLE SENSITIVITY
 --------------------------------------------------------------------------------------------------------------------------
     0     0    1    1 '        '    T    T    T    T    T     F      F      T      0     F     -1            0           F
0SEID = SUPERELEMENT ID.
 PEID = PRIMARY SUPERELEMENT ID OF IMAGE SUPERELEMENT.
 PROJ = PROJECT ID NUMBER.
 VERS = VERSION ID.
 APRCH = BLANK FOR STRUCTURAL ANALYSIS.  HEAT FOR HEAT TRANSFER ANALYSIS.
 SEMG = STIFFNESS AND MASS MATRIX GENERATION STEP.
 SEMR = MASS MATRIX REDUCTION STEP (INCLUDES EIGENVALUE SOLUTION FOR MODES).
 SEKR = STIFFNESS MATRIX REDUCTION STEP.
 SELG = LOAD MATRIX GENERATION STEP.
 SELR = LOAD MATRIX REDUCTION STEP.
 MODES = T (TRUE) IF NORMAL MODES OR BUCKLING MODES CALCULATED.
 DYNRED = T (TRUE) MEANS GENERALIZED DYNAMIC AND/OR COMPONENT MODE REDUCTION PERFORMED.
 SOLLIN = T (TRUE) IF LINEAR SOLUTION EXISTS IN DATABASE.
 PVALID = P-DISTRIBUTION ID OF P-VALUE FOR P-ELEMENTS
 LOOPID = THE LAST LOOPID VALUE USED IN THE NONLINEAR ANALYSIS.  USEFUL FOR RESTARTS.
```

```
 SOLNL = T (TRUE) IF NONLINEAR SOLUTION EXISTS IN DATABASE.
 DESIGN CYCLE = THE LAST DESIGN CYCLE (ONLY VALID IN OPTIMIZATION).
 SENSITIVITY = SENSITIVITY MATRIX GENERATION FLAG.

 No PARAM values were set in the Control File.

1                                        * * * END OF JOB * * *
```

K.2 67 Lbs Plywood Test (300 N)

```
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                                                    OF MSC.SOFTWARE CORPORATION.

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                                              * * * * * * * * * * * * * * * * * * * *
                                              * *                                * *
                                              * *           MSC.SOFTWARE         * *
                                              * *               CORP             * *
                                              * *                                * *
                                              * *      M D   R 3   N a s t r a n * *
                                              * *                                * *
                                              * *                                * *
                                              * *                                * *
                                              * *         Version 2008.0.4       * *
                                              * *              MD R3             * *
                                              * *                                * *
                                              * *                                * *
                                              * *           JAN 26, 2009         * *
                                              * *                                * *
                                              * *              Intel             * *
                                              * * MODEL PentiumII/4850 (DC3SWP18) * *
                                              * *   Windows XP 6.0 (Build 6002)  * *
                                              * *                                * *
                                              * *                                * *
                                              * * * * * * * * * * * * * * * * * * * *
                                              * * * * * * * * * * * * * * * * * * * *
1                                                                     MARCH  11, 2010   MD NASTRAN  1/26/09   PAGE     1

0        N A S T R A N    F I L E    A N D    S Y S T E M    P A R A M E T E R    E C H O
0


    NASTRAN OP2NEW=0 $ MD NASTRAN .LCL FILE
    NASTRAN BUFFSIZE=8193 $(S:/CAEN/MSC.SOFTWARE/MD_NASTRAN/CONF/NAST2008.RCF[2])
    NASTRAN REAL=532938752 $(PROGRAM DEFAULT)
    $$------------------------------------------------------------------------------
    $$
    $$ NASTRAN INPUT DECK GENERATED BY HYPERMESH VERSION  :10.0BUIL
    $$ GENERATED USING HYPERMESH-NASTRAN TEMPLATE VERSION : 10.0BUILD60
    $$
    $$   TEMPLATE:  GENERAL
    $$
```

```
     $$------------------------------------------------------------------------------
     $$------------------------------------------------------------------------------
     $$                      EXECUTIVE CONTROL CARDS
     $$------------------------------------------------------------------------------
1                                                                     MARCH  11, 2010   MD NASTRAN  1/26/09   PAGE     2

0        N A S T R A N    E X E C U T I V E    C O N T R O L    E C H O
0


     SOL 101
     CEND
1    WOOD PLATE ANALYSIS                                              MARCH  11, 2010   MD NASTRAN  1/26/09   PAGE     3

0
0                                   C A S E    C O N T R O L    E C H O
                 COMMAND
                 COUNT
                  1      $$----------------------------------------------------------------------        --------
                  2      $$                      CASE CONTROL CARDS
                  3      $$----------------------------------------------------------------------        --------
                  4      TITLE = WOOD PLATE ANALYSIS
                  5      $
                  6      $HMNAME LOADSTEP               1"MIDDLE FORCE"
                  7      SUBCASE       1
                  8        LABEL= MIDDLE FORCE
                  9        SPC =        1
                 10        LOAD =        1
                 11        DISPLACEMENT(PRINT,PUNCH) = ALL
                 12        STRESS(PRINT,PUNCH) = ALL
                 13        SPCFORCES(PRINT,PUNCH) = ALL
                 14      $$----------------------------------------------------------------------        --------
                 15      $$                      BULK DATA CARDS
                 16      $$----------------------------------------------------------------------        --------
                 17      BEGIN BULK
 *** USER WARNING MESSAGE 324 (XSORSO)
     BLANK ENTRIES ENCOUNTERED WILL BE IGNORED.
0                         INPUT BULK DATA ENTRY COUNT =     161
1    WOOD PLATE ANALYSIS                                              MARCH  11, 2010   MD NASTRAN  1/26/09   PAGE     4

0
0                                           S O R T E D   B U L K   D A T A   E C H O
                 ENTRY
                 COUNT        .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
                    1-        CQUAD4  1       1       10      24      8       9
                    2-        CQUAD4  2       1       24      25      7       8
                    3-        CQUAD4  3       1       25      26      6       7
                    4-        CQUAD4  4       1       26      20      5       6
                    5-        CQUAD4  5       1       11      21      24      10
                    6-        CQUAD4  6       1       21      22      25      24
                    7-        CQUAD4  7       1       22      23      26      25
                    8-        CQUAD4  8       1       23      19      20      26
                    9-        CQUAD4  9       1       12      27      21      11
                   10-        CQUAD4  10      1       27      28      22      21
                   11-        CQUAD4  11      1       28      29      23      22
                   12-        CQUAD4  12      1       29      18      19      23
                   13-        CQUAD4  13      1       13      14      27      12
                   14-        CQUAD4  14      1       14      15      28      27
```

```
                   15-        CQUAD4  15      1       15      16      29      28
                   16-        CQUAD4  16      1       16      17      18      29
                   17-        FORCE   1       22      0       1.0     0.0     0.0     -300.0
                   18-        GRID    5               0.0     0.0     0.0
                   19-        GRID    6               0.0     58.7375 0.0
                   20-        GRID    7               0.0     117.475 0.0
                   21-        GRID    8               0.0     176.21250.0
                   22-        GRID    9               0.0     234.95  0.0
                   23-        GRID    10              158.75  234.95  0.0
                   24-        GRID    11              317.5   234.95  0.0
                   25-        GRID    12              476.25  234.95  0.0
                   26-        GRID    13              635.0   234.95  0.0
                   27-        GRID    14              635.0   176.21250.0
                   28-        GRID    15              635.0   117.475 0.0
                   29-        GRID    16              635.0   58.7375 0.0
                   30-        GRID    17              635.0   0.0     0.0
                   31-        GRID    18              476.25  0.0     0.0
                   32-        GRID    19              317.5   0.0     0.0
                   33-        GRID    20              158.75  0.0     0.0
                   34-        GRID    21              317.5   176.21250.0
                   35-        GRID    22              317.5   117.475 0.0
                   36-        GRID    23              317.5   58.7375 0.0
                   37-        GRID    24              158.75  176.21250.0
                   38-        GRID    25              158.75  117.475 0.0
                   39-        GRID    26              158.75  58.7375 0.0
                   40-        GRID    27              476.25  176.21250.0
                   41-        GRID    28              476.25  117.475 0.0
                   42-        GRID    29              476.25  58.7375 0.0
                   43-        MAT1    1       8963.0          0.32
                   44-        PSHELL  1       1       6.35    1               1
                   45-        SPC     1       5       123456  0.0
                   46-        SPC     1       6       123456  0.0
                   47-        SPC     1       7       123456  0.0
                   48-        SPC     1       8       123456  0.0
                   49-        SPC     1       9       123456  0.0
                   50-        SPC     1       10      123456  0.0
1    WOOD PLATE ANALYSIS                                                      MARCH  11, 2010   MD NASTRAN  1/26/09   PAGE     5

0
0                                        S O R T E D   B U L K   D A T A   E C H O
                 ENTRY
                 COUNT        .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
                   51-        SPC     1       11      123456  0.0
                   52-        SPC     1       12      123456  0.0
                   53-        SPC     1       13      123456  0.0
                   54-        SPC     1       14      123456  0.0
                   55-        SPC     1       15      123456  0.0
                   56-        SPC     1       16      123456  0.0
                   57-        SPC     1       17      123456  0.0
                   58-        SPC     1       18      123456  0.0
                   59-        SPC     1       19      123456  0.0
                   60-        SPC     1       20      123456  0.0
                              ENDDATA
0                       TOTAL COUNT=        61

                                        M O D E L   S U M M A R Y
```

```
                                   NUMBER OF GRID     POINTS   =       25

                                   NUMBER OF CQUAD4   ELEMENTS =       16
```



```
0
 *** USER INFORMATION MESSAGE 7310 (VECPRN)
     ORIGIN OF SUPERELEMENT BASIC COORDINATE SYSTEM WILL BE USED AS REFERENCE LOCATION.
     RESULTANTS ABOUT ORIGIN OF SUPERELEMENT BASIC COORDINATE SYSTEM IN SUPERELEMENT BASIC SYSTEM COORDINATES.
0                                                  OLOAD    RESULTANT
  SUBCASE/    LOAD
  DAREA ID    TYPE       T1            T2            T3            R1            R2            R3
0        1     FX    0.000000E+00     ----          ----          ----       0.000000E+00  0.000000E+00
               FY       ----       0.000000E+00     ----       0.000000E+00     ----       0.000000E+00
               FZ       ----          ----      -3.000000E+02 -3.524250E+04  9.525000E+04     ----
               MX       ----          ----          ----       0.000000E+00     ----          ----
               MY       ----          ----          ----          ----       0.000000E+00     ----
               MZ       ----          ----          ----          ----          ----       0.000000E+00
             TOTALS  0.000000E+00  0.000000E+00 -3.000000E+02 -3.524250E+04  9.525000E+04  0.000000E+00
```



```
0     MIDDLE FORCE                                                                                      SUBCASE   1

 *** SYSTEM INFORMATION MESSAGE 4159 (DFMSA)
     THE DECOMPOSITION OF KLL      YIELDS A MAXIMUM MATRIX-TO-FACTOR-DIAGONAL RATIO OF    2.805918E+00
 *** USER INFORMATION MESSAGE 5293 (SSG3A)
    FOR DATA BLOCK KLL
    LOAD SEQ. NO.             EPSILON              EXTERNAL WORK      EPSILONS LARGER THAN 0.001 ARE FLAGGED WITH ASTERISKS
                1         -2.8779644E-16          7.1599022E+01
```



```
0
 *** USER INFORMATION MESSAGE 7310 (VECPRN)
     ORIGIN OF SUPERELEMENT BASIC COORDINATE SYSTEM WILL BE USED AS REFERENCE LOCATION.
     RESULTANTS ABOUT ORIGIN OF SUPERELEMENT BASIC COORDINATE SYSTEM IN SUPERELEMENT BASIC SYSTEM COORDINATES.
0                                                  SPCFORCE RESULTANT
  SUBCASE/    LOAD
  DAREA ID    TYPE       T1            T2            T3            R1            R2            R3
0        1     FX    0.000000E+00     ----          ----          ----       0.000000E+00  0.000000E+00
               FY       ----       0.000000E+00     ----       0.000000E+00     ----       0.000000E+00
               FZ       ----          ----       3.000000E+02  3.524250E+04 -9.525000E+04     ----
               MX       ----          ----          ----      -4.547474E-13     ----          ----
               MY       ----          ----          ----          ----      -7.048584E-12     ----
               MZ       ----          ----          ----          ----          ----       0.000000E+00
             TOTALS  0.000000E+00  0.000000E+00  3.000000E+02  3.524250E+04 -9.525000E+04  0.000000E+00
```



```
0     MIDDLE FORCE                                                                                      SUBCASE   1

                                                D I S P L A C E M E N T   V E C T O R

      POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
             5      G      0.0            0.0            0.0            0.0            0.0            0.0
             6      G      0.0            0.0            0.0            0.0            0.0            0.0
             7      G      0.0            0.0            0.0            0.0            0.0            0.0
             8      G      0.0            0.0            0.0            0.0            0.0            0.0
             9      G      0.0            0.0            0.0            0.0            0.0            0.0
```

```
          10      G      0.0            0.0            0.0            0.0            0.0            0.0
          11      G      0.0            0.0            0.0            0.0            0.0            0.0
          12      G      0.0            0.0            0.0            0.0            0.0            0.0
          13      G      0.0            0.0            0.0            0.0            0.0            0.0
          14      G      0.0            0.0            0.0            0.0            0.0            0.0
          15      G      0.0            0.0            0.0            0.0            0.0            0.0
          16      G      0.0            0.0            0.0            0.0            0.0            0.0
          17      G      0.0            0.0            0.0            0.0            0.0            0.0
          18      G      0.0            0.0            0.0            0.0            0.0            0.0
          19      G      0.0            0.0            0.0            0.0            0.0            0.0
          20      G      0.0            0.0            0.0            0.0            0.0            0.0
          21      G      0.0            0.0           -2.377482E-01   6.630444E-03   2.385245E-18   0.0
          22      G      0.0            0.0           -4.773268E-01  -4.336809E-19   4.011548E-18   0.0
          23      G      0.0            0.0           -2.377482E-01  -6.630444E-03   2.028754E-18   0.0
          24      G      0.0            0.0           -6.657902E-02   1.517867E-03   1.348694E-03   0.0
          25      G      0.0            0.0           -1.323592E-01  -1.626303E-19   2.742179E-03   0.0
          26      G      0.0            0.0           -6.657902E-02  -1.517867E-03   1.348694E-03   0.0
          27      G      0.0            0.0           -6.657902E-02   1.517867E-03  -1.348694E-03   0.0
          28      G      0.0            0.0           -1.323592E-01  -1.132262E-18  -2.742179E-03   0.0
          29      G      0.0            0.0           -6.657902E-02  -1.517867E-03  -1.348694E-03   0.0
1    WOOD PLATE ANALYSIS                                                MARCH  11, 2010   MD NASTRAN  1/26/09   PAGE    10

0     MIDDLE FORCE                                                                                       SUBCASE   1

                             F O R C E S   O F   S I N G L E - P O I N T   C O N S T R A I N T

      POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
           5      G      0.0            0.0            5.593613E+00  -2.049898E+01  -1.206916E+03   0.0
           6      G      0.0            0.0            2.238463E-01  -6.435706E+02  -1.042109E+02   0.0
           7      G      0.0            0.0           -1.784043E+01   3.765876E-13   2.685994E+03   0.0
           8      G      0.0            0.0            2.238463E-01   6.435706E+02  -1.042109E+02   0.0
           9      G      0.0            0.0            5.593613E+00   2.049898E+01  -1.206916E+03   0.0
          10      G      0.0            0.0            7.872004E+00  -2.514035E+03   2.965437E+02   0.0
          11      G      0.0            0.0            1.404615E+02  -5.495304E+03  -1.364242E-12   0.0
          12      G      0.0            0.0            7.872004E+00  -2.514035E+03  -2.965437E+02   0.0
          13      G      0.0            0.0            5.593613E+00   2.049898E+01   1.206916E+03   0.0
          14      G      0.0            0.0            2.238463E-01   6.435706E+02   1.042109E+02   0.0
          15      G      0.0            0.0           -1.784043E+01  -3.765876E-13  -2.685994E+03   0.0
          16      G      0.0            0.0            2.238463E-01  -6.435706E+02   1.042109E+02   0.0
          17      G      0.0            0.0            5.593613E+00  -2.049898E+01   1.206916E+03   0.0
          18      G      0.0            0.0            7.872004E+00   2.514035E+03  -2.965437E+02   0.0
          19      G      0.0            0.0            1.404615E+02   5.495304E+03  -4.547474E-13   0.0
          20      G      0.0            0.0            7.872004E+00   2.514035E+03   2.965437E+02   0.0
1    WOOD PLATE ANALYSIS                                                MARCH  11, 2010   MD NASTRAN  1/26/09   PAGE    11

0
1    WOOD PLATE ANALYSIS                                                MARCH  11, 2010   MD NASTRAN  1/26/09   PAGE    12

0     MIDDLE FORCE                                                                                       SUBCASE   1

                       S T R E S S E S   I N   Q U A D R I L A T E R A L   E L E M E N T S   ( Q U A D 4 )
  ELEMENT      FIBER               STRESSES IN ELEMENT COORD SYSTEM             PRINCIPAL STRESSES (ZERO SHEAR)
    ID.       DISTANCE           NORMAL-X       NORMAL-Y      SHEAR-XY       ANGLE         MAJOR            MINOR        VON MISES
0       1   -3.175000E+00     4.527358E-01   2.657589E-01  -1.752873E-01   -30.9635    5.579071E-01    1.605875E-01   4.974493E-01
             3.175000E+00    -4.527358E-01  -2.657589E-01   1.752873E-01    59.0365   -1.605875E-01   -5.579071E-01   4.974493E-01
0       2   -3.175000E+00    -2.789218E-01   2.774099E-01  -1.793972E-01   -73.5904    3.302420E-01   -3.317538E-01   5.733057E-01
             3.175000E+00     2.789218E-01  -2.774099E-01   1.793972E-01    16.4096    3.317538E-01   -3.302420E-01   5.733057E-01
0       3   -3.175000E+00    -2.789218E-01   2.774099E-01   1.793972E-01    73.5904    3.302420E-01   -3.317538E-01   5.733057E-01
```

```
           3.175000E+00     2.789218E-01  -2.774099E-01  -1.793972E-01   -16.4096    3.317538E-01   -3.302420E-01   5.733057E-01
0      4  -3.175000E+00     4.527358E-01   2.657589E-01   1.752873E-01    30.9635    5.579071E-01    1.605875E-01   4.974493E-01
           3.175000E+00    -4.527358E-01  -2.657589E-01  -1.752873E-01   -59.0365   -1.605875E-01   -5.579071E-01   4.974493E-01
0      5  -3.175000E+00     2.155961E+00   5.690240E-01  -2.973304E-01   -10.2711    2.209840E+00    5.151451E-01   2.002593E+00
           3.175000E+00    -2.155961E+00  -5.690240E-01   2.973304E-01    79.7290   -5.151451E-01   -2.209840E+00   2.002593E+00
0      6  -3.175000E+00    -2.329775E+00  -1.112193E+00  -3.014404E-01   -76.8289   -1.041651E+00   -2.400316E+00   2.084769E+00
           3.175000E+00     2.329775E+00   1.112193E+00   3.014404E-01    13.1711    2.400316E+00    1.041651E+00   2.084769E+00
0      7  -3.175000E+00    -2.329775E+00  -1.112193E+00   3.014404E-01    76.8289   -1.041651E+00   -2.400316E+00   2.084769E+00
           3.175000E+00     2.329775E+00   1.112193E+00  -3.014404E-01   -13.1711    2.400316E+00    1.041651E+00   2.084769E+00
0      8  -3.175000E+00     2.155961E+00   5.690240E-01   2.973304E-01    10.2711    2.209840E+00    5.151451E-01   2.002593E+00
           3.175000E+00    -2.155961E+00  -5.690240E-01  -2.973304E-01   -79.7290   -5.151451E-01   -2.209840E+00   2.002593E+00
0      9  -3.175000E+00     2.155961E+00   5.690240E-01   2.973304E-01    10.2711    2.209840E+00    5.151451E-01   2.002593E+00
           3.175000E+00    -2.155961E+00  -5.690240E-01  -2.973304E-01   -79.7290   -5.151451E-01   -2.209840E+00   2.002593E+00
0     10  -3.175000E+00    -2.329775E+00  -1.112193E+00   3.014404E-01    76.8289   -1.041651E+00   -2.400316E+00   2.084769E+00
           3.175000E+00     2.329775E+00   1.112193E+00  -3.014404E-01   -13.1711    2.400316E+00    1.041651E+00   2.084769E+00
0     11  -3.175000E+00    -2.329775E+00  -1.112193E+00  -3.014404E-01   -76.8289   -1.041651E+00   -2.400316E+00   2.084769E+00
           3.175000E+00     2.329775E+00   1.112193E+00   3.014404E-01    13.1711    2.400316E+00    1.041651E+00   2.084769E+00
0     12  -3.175000E+00     2.155961E+00   5.690240E-01  -2.973304E-01   -10.2711    2.209840E+00    5.151451E-01   2.002593E+00
           3.175000E+00    -2.155961E+00  -5.690240E-01   2.973304E-01    79.7290   -5.151451E-01   -2.209840E+00   2.002593E+00
0     13  -3.175000E+00     4.527358E-01   2.657589E-01   1.752873E-01    30.9635    5.579071E-01    1.605875E-01   4.974493E-01
           3.175000E+00    -4.527358E-01  -2.657589E-01  -1.752873E-01   -59.0365   -1.605875E-01   -5.579071E-01   4.974493E-01
0     14  -3.175000E+00    -2.789218E-01   2.774099E-01   1.793972E-01    73.5904    3.302420E-01   -3.317538E-01   5.733057E-01
           3.175000E+00     2.789218E-01  -2.774099E-01  -1.793972E-01   -16.4096    3.317538E-01   -3.302420E-01   5.733057E-01
0     15  -3.175000E+00    -2.789218E-01   2.774099E-01  -1.793972E-01   -73.5904    3.302420E-01   -3.317538E-01   5.733057E-01
           3.175000E+00     2.789218E-01  -2.774099E-01   1.793972E-01    16.4096    3.317538E-01   -3.302420E-01   5.733057E-01
0     16  -3.175000E+00     4.527358E-01   2.657589E-01  -1.752873E-01   -30.9635    5.579071E-01    1.605875E-01   4.974493E-01
           3.175000E+00    -4.527358E-01  -2.657589E-01   1.752873E-01    59.0365   -1.605875E-01   -5.579071E-01   4.974493E-01
1    WOOD PLATE ANALYSIS                                                   MARCH  11, 2010   MD NASTRAN  1/26/09   PAGE    13

0
1    WOOD PLATE ANALYSIS                                                   MARCH  11, 2010   MD NASTRAN  1/26/09   PAGE    14

0
 * * * *  D B D I C T   P R I N T  * * * *     SUBDMAP = PRTSUM  ,  DMAP STATEMENT NO.     30



0                                  * * * *  A N A L Y S I S  S U M M A R Y  T A B L E  * * * *
0 SEID  PEID PROJ VERS APRCH      SEMG SEMR SEKR SELG SELR MODES DYNRED SOLLIN PVALID SOLNL LOOPID DESIGN CYCLE SENSITIVITY
 --------------------------------------------------------------------------------------------------------------------------
     0     0    1    1 '        '    T    T    T    T    T     F      F      T      0     F     -1            0           F
0SEID = SUPERELEMENT ID.
 PEID = PRIMARY SUPERELEMENT ID OF IMAGE SUPERELEMENT.
 PROJ = PROJECT ID NUMBER.
 VERS = VERSION ID.
 APRCH = BLANK FOR STRUCTURAL ANALYSIS.  HEAT FOR HEAT TRANSFER ANALYSIS.
 SEMG = STIFFNESS AND MASS MATRIX GENERATION STEP.
 SEMR = MASS MATRIX REDUCTION STEP (INCLUDES EIGENVALUE SOLUTION FOR MODES).
 SEKR = STIFFNESS MATRIX REDUCTION STEP.
 SELG = LOAD MATRIX GENERATION STEP.
 SELR = LOAD MATRIX REDUCTION STEP.
 MODES = T (TRUE) IF NORMAL MODES OR BUCKLING MODES CALCULATED.
 DYNRED = T (TRUE) MEANS GENERALIZED DYNAMIC AND/OR COMPONENT MODE REDUCTION PERFORMED.
 SOLLIN = T (TRUE) IF LINEAR SOLUTION EXISTS IN DATABASE.
 PVALID = P-DISTRIBUTION ID OF P-VALUE FOR P-ELEMENTS
 LOOPID = THE LAST LOOPID VALUE USED IN THE NONLINEAR ANALYSIS.  USEFUL FOR RESTARTS.
 SOLNL = T (TRUE) IF NONLINEAR SOLUTION EXISTS IN DATABASE.
 DESIGN CYCLE = THE LAST DESIGN CYCLE (ONLY VALID IN OPTIMIZATION).
```

```
 SENSITIVITY = SENSITIVITY MATRIX GENERATION FLAG.

 No PARAM values were set in the Control File.

1                                        * * * END OF JOB * * *
   1
```

K.3 100 Lbs Impact Test on Sidewall Top Bar (444 N)

```
                       THIS PROGRAM IS CONFIDENTIAL AND A TRADE SECRET OF MSC.SOFTWARE CORPORATION.  THE RECEIPT OR
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                                              * * * * * * * * * * * * * * * * * * * *
                                              * *                                * *
                                              * *           MSC.SOFTWARE         * *
                                              * *               CORP             * *
                                              * *                                * *
                                              * *      M D   R 3   N a s t r a n * *
                                              * *                                * *
                                              * *                                * *
                                              * *                                * *
                                              * *        Version 2008.0.4        * *
                                              * *              MD R3             * *
                                              * *                                * *
                                              * *                                * *
                                              * *          JAN 26, 2009          * *
                                              * *                                * *
                                              * *              Intel             * *
                                              * * MODEL PentiumII/4855 (DC3SWP33) * *
                                              * *   Windows XP 6.0 (Build 6002)  * *
                                              * *                                * *
                                              * *                                * *
                                              * * * * * * * * * * * * * * * * * * * *
                                              * * * * * * * * * * * * * * * * * * * *
1                                                                                APRIL   9, 2010   MD NASTRAN  1/26/09   PAGE     1

0       N A S T R A N    F I L E    A N D    S Y S T E M    P A R A M E T E R    E C H O
0


     NASTRAN OP2NEW=0 $ MD NASTRAN .LCL FILE
     NASTRAN BUFFSIZE=8193 $(S:/CAEN/MSC.SOFTWARE/MD_NASTRAN/CONF/NAST2008.RCF[2])
     NASTRAN REAL=532676608 $(PROGRAM DEFAULT)
     $$------------------------------------------------------------------------------
     $$
     $$ NASTRAN INPUT DECK GENERATED BY HYPERMESH VERSION  :10.0BUIL
     $$ GENERATED USING HYPERMESH-NASTRAN TEMPLATE VERSION : 10.0BUILD60
     $$
     $$   TEMPLATE:  GENERAL
     $$
     $$------------------------------------------------------------------------------
```

```
    $$------------------------------------------------------------------------------
    $$                      EXECUTIVE CONTROL CARDS
    $$------------------------------------------------------------------------------
1                                                                          APRIL   9, 2010   MD NASTRAN  1/26/09   PAGE     2

0       N A S T R A N    E X E C U T I V E    C O N T R O L    E C H O
0


    SOL 109
    CEND
1   100 LB IMPACT FORCE TEST                                               APRIL   9, 2010   MD NASTRAN  1/26/09   PAGE     3

0
0                                    C A S E    C O N T R O L    E C H O
                COMMAND
                COUNT
                 1      $$------------------------------------------------------------------------        --------
                 2      $$                      CASE CONTROL CARDS
                 3      $$------------------------------------------------------------------------        --------
                 4      TITLE = 100 LB IMPACT FORCE TEST
                 5      $
                 6      $HMNAME LOADSTEP               1"IMPACT"
                 7      SUBCASE       1
                 8        LABEL= IMPACT
                 9        SPC =        1
                10        DLOAD =       4
                11        TSTEP =       5
                12        DISPLACEMENT(PRINT) = ALL
                13        STRESS(PRINT) = ALL
                14      $$------------------------------------------------------------------------        --------
                15      $$                      BULK DATA CARDS
                16      $$------------------------------------------------------------------------        --------
                17      BEGIN BULK
 *** USER WARNING MESSAGE 324 (XSORSO)
    BLANK ENTRIES ENCOUNTERED WILL BE IGNORED.
0                        INPUT BULK DATA ENTRY COUNT =     144
1   100 LB IMPACT FORCE TEST                                               APRIL   9, 2010   MD NASTRAN  1/26/09   PAGE     4

0
0                                             S O R T E D   B U L K   D A T A   E C H O
                ENTRY
                COUNT        .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
                   1-        CBAR    1       1       1       2       0.7071070.7071070.0
                   2-        CBAR    2       1       2       3       0.7071070.7071070.0
                   3-        DAREA   2       2       2       444.0
                   4-        GRID    1               0.0     0.0     0.0
                   5-        GRID    2               0.43815 0.0     0.0
                   6-        GRID    3               0.8763  0.0     0.0
                   7-        MAT1    1       9.04E+08        0.03    520.6
                   8-        PBAR    1       1       0.00129 2.80E-076.90E-080.0     0.0             ++000001
                   9-        ++0000010.0508  0.0254  -0.0508 0.025   -0.0508 -0.0254 0.051   -0.0254  +000002
                  10-        SPC     1       1       123456  0.0
                  11-        SPC     1       2       1345    0.0
                  12-        SPC     1       3       123456  0.0
                  13-        TABLED1 3       LINEAR  LINEAR                                           +000003
                  14-        ++0000030.0     0.0     0.1     0.0     0.2     1.0     0.2     0.0      +000004
                  15-        ++0000040.3     0.0     ENDT                                             +000005
```

```
                 16-        TLOAD1  4       2                       3
                 17-        TSTEP   5       335     0.0015  10
                            ENDDATA
0                      TOTAL COUNT=        18


                                          M O D E L   S U M M A R Y

                                     NUMBER OF GRID     POINTS   =        3

                                     NUMBER OF CBAR     ELEMENTS =        2

 *** USER INFORMATION MESSAGE 7553 (GP1D)
     A TOTAL OF        1 DAREA BULK DATA ENTRIES FOR GRID AND SCALAR POINTS HAVE BEEN CONVERTED TO EQUIVALENT
     FORCE / MOMENT / SLOAD ENTRIES (AS APPROPRIATE)
1    100 LB IMPACT FORCE TEST                                              APRIL   9, 2010   MD NASTRAN  1/26/09   PAGE     5

0
 *** USER INFORMATION MESSAGE 7310 (VECPRN)
     ORIGIN OF SUPERELEMENT BASIC COORDINATE SYSTEM WILL BE USED AS REFERENCE LOCATION.
     RESULTANTS ABOUT ORIGIN OF SUPERELEMENT BASIC COORDINATE SYSTEM IN SUPERELEMENT BASIC SYSTEM COORDINATES.
0                                                OLOAD    RESULTANT
  SUBCASE/    LOAD
  DAREA ID    TYPE       T1            T2            T3            R1            R2            R3
0        2     FX    0.000000E+00     ----          ----          ----       0.000000E+00  0.000000E+00
               FY       ----       4.440000E+02     ----       0.000000E+00     ----       1.945386E+02
               FZ       ----          ----       0.000000E+00  0.000000E+00  0.000000E+00     ----
               MX       ----          ----          ----       0.000000E+00     ----          ----
               MY       ----          ----          ----          ----       0.000000E+00     ----
               MZ       ----          ----          ----          ----          ----       0.000000E+00
             TOTALS  0.000000E+00  4.440000E+02  0.000000E+00  0.000000E+00  0.000000E+00  1.945386E+02
1    100 LB IMPACT FORCE TEST                                              APRIL   9, 2010   MD NASTRAN  1/26/09   PAGE     6

0     IMPACT                                                                                         SUBCASE   1
1    100 LB IMPACT FORCE TEST                                              APRIL   9, 2010   MD NASTRAN  1/26/09   PAGE     7

0     IMPACT                                                                                         SUBCASE   1
 *** USER INFORMATION MESSAGE 7559 (TRLGP)
     THIS TRANSIENT RESPONSE ANALYSIS INVOLVES THE FOLLOWING TYPES OF EXCITATION --

     * APPLIED LOADS
 *** USER INFORMATION MESSAGE 5222 (TRD1)
      COUPLED SOLUTION ALGORITHM USED.
   5.025000E-01     G      0.0            0.0            0.0            0.0            0.0            0.0
1    100 LB IMPACT FORCE TEST                                              APRIL   9, 2010   MD NASTRAN  1/26/09   PAGE     9

0     IMPACT                                                                                         SUBCASE   1
      POINT-ID =         2
                                               D I S P L A C E M E N T   V E C T O R

       TIME       TYPE          T1             T2             T3             R1             R2             R3
   0.0              G      0.0            0.0            0.0            0.0            0.0            0.0
   1.500000E-02     G      0.0            0.0            0.0            0.0            0.0            0.0
   3.000000E-02     G      0.0            0.0            0.0            0.0            0.0            0.0
   4.500000E-02     G      0.0            0.0            0.0            0.0            0.0            0.0
   6.000000E-02     G      0.0            0.0            0.0            0.0            0.0            0.0
   7.500000E-02     G      0.0            0.0            0.0            0.0            0.0            0.0
   9.000000E-02     G      0.0            0.0            0.0            0.0            0.0            0.0
```

1.050000E-01	G	0.0	2.231813E-04	0.0	0.0	0.0	0.0
1.200000E-01	G	0.0	1.213917E-03	0.0	0.0	0.0	0.0
1.350000E-01	G	0.0	2.211728E-03	0.0	0.0	0.0	0.0
1.500000E-01	G	0.0	3.182357E-03	0.0	0.0	0.0	0.0
1.650000E-01	G	0.0	4.103853E-03	0.0	0.0	0.0	0.0
1.800000E-01	G	0.0	4.976516E-03	0.0	0.0	0.0	0.0
1.950000E-01	G	0.0	5.822759E-03	0.0	0.0	0.0	0.0
2.100000E-01	G	0.0	-1.201141E-03	0.0	0.0	0.0	0.0
2.250000E-01	G	0.0	2.460318E-03	0.0	0.0	0.0	0.0
2.400000E-01	G	0.0	5.007656E-03	0.0	0.0	0.0	0.0
2.550000E-01	G	0.0	5.287347E-03	0.0	0.0	0.0	0.0
2.700000E-01	G	0.0	3.172736E-03	0.0	0.0	0.0	0.0
2.850000E-01	G	0.0	-3.786037E-04	0.0	0.0	0.0	0.0
3.000000E-01	G	0.0	-3.758498E-03	0.0	0.0	0.0	0.0
3.150000E-01	G	0.0	-5.436409E-03	0.0	0.0	0.0	0.0
3.300000E-01	G	0.0	-4.652518E-03	0.0	0.0	0.0	0.0
3.450000E-01	G	0.0	-1.761799E-03	0.0	0.0	0.0	0.0
3.600000E-01	G	0.0	1.926726E-03	0.0	0.0	0.0	0.0
3.750000E-01	G	0.0	4.742761E-03	0.0	0.0	0.0	0.0
3.900000E-01	G	0.0	5.411102E-03	0.0	0.0	0.0	0.0
4.050000E-01	G	0.0	3.629101E-03	0.0	0.0	0.0	0.0
4.200000E-01	G	0.0	2.037121E-04	0.0	0.0	0.0	0.0
4.350000E-01	G	0.0	-3.313925E-03	0.0	0.0	0.0	0.0
4.500000E-01	G	0.0	-5.330897E-03	0.0	0.0	0.0	0.0
4.650000E-01	G	0.0	-4.933847E-03	0.0	0.0	0.0	0.0
4.800000E-01	G	0.0	-2.302573E-03	0.0	0.0	0.0	0.0
4.950000E-01	G	0.0	1.371389E-03	0.0	0.0	0.0	0.0
5.025000E-01	G	0.0	-3.077281E-03	0.0	0.0	0.0	0.0

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0 IMPACT SUBCASE 1

1 100 LB IMPACT FORCE TEST APRIL 9, 2010 MD NASTRAN 1/26/09 PAGE 12

0 IMPACT SUBCASE 1

ELEMENT-ID = 1

S T R E S S E S I N B A R E L E M E N T S (C B A R)

TIME	SA1 SB1	SA2 SB2	SA3 SB3	SA4 SB4	AXIAL-STRESS	SA-MAX SB-MAX	SA-MIN SB-MIN	M.S.-T M.S.-C
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	0.0	0.0	0.0	0.0		0.0	0.0	
1.500000E-02	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	0.0	0.0	0.0	0.0		0.0	0.0	
3.000000E-02	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	0.0	0.0	0.0	0.0		0.0	0.0	
4.500000E-02	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	0.0	0.0	0.0	0.0		0.0	0.0	
6.000000E-02	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	0.0	0.0	0.0	0.0		0.0	0.0	
7.500000E-02	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	0.0	0.0	0.0	0.0		0.0	0.0	

9.000000E-02	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	0.0	0.0	0.0	0.0		0.0	0.0	
1.050000E-01	-3.203285E+05	3.203285E+05	3.203285E+05	-3.215896E+05	0.0	3.203285E+05	-3.215896E+05	
	3.203285E+05	-3.203285E+05	-3.203285E+05	3.215896E+05		3.215896E+05	-3.203285E+05	
1.200000E-01	-1.742315E+06	1.742315E+06	1.742315E+06	-1.749174E+06	0.0	1.742315E+06	-1.749174E+06	
	1.742315E+06	-1.742315E+06	-1.742315E+06	1.749174E+06		1.749174E+06	-1.742315E+06	
1.350000E-01	-3.174458E+06	3.174458E+06	3.174458E+06	-3.186955E+06	0.0	3.174458E+06	-3.186955E+06	
	3.174458E+06	-3.174458E+06	-3.174458E+06	3.186955E+06		3.186955E+06	-3.174458E+06	
1.500000E-01	-4.567585E+06	4.567585E+06	4.567585E+06	-4.585568E+06	0.0	4.567585E+06	-4.585568E+06	
	4.567585E+06	-4.567585E+06	-4.567585E+06	4.585568E+06		4.585568E+06	-4.567585E+06	
1.650000E-01	-5.890194E+06	5.890194E+06	5.890194E+06	-5.913383E+06	0.0	5.890194E+06	-5.913383E+06	
	5.890194E+06	-5.890194E+06	-5.890194E+06	5.913383E+06		5.913383E+06	-5.890194E+06	
1.800000E-01	-7.142712E+06	7.142712E+06	7.142712E+06	-7.170834E+06	0.0	7.142712E+06	-7.170834E+06	
	7.142712E+06	-7.142712E+06	-7.142712E+06	7.170834E+06		7.170834E+06	-7.142712E+06	
1.950000E-01	-8.357311E+06	8.357311E+06	8.357311E+06	-8.390214E+06	0.0	8.357311E+06	-8.390214E+06	
	8.357311E+06	-8.357311E+06	-8.357311E+06	8.390214E+06		8.390214E+06	-8.357311E+06	
2.100000E-01	1.723978E+06	-1.723978E+06	-1.723978E+06	1.730765E+06	0.0	1.730765E+06	-1.723978E+06	
	-1.723978E+06	1.723978E+06	1.723978E+06	-1.730765E+06		1.723978E+06	-1.730765E+06	
2.250000E-01	-3.531254E+06	3.531254E+06	3.531254E+06	-3.545157E+06	0.0	3.531254E+06	-3.545157E+06	
	3.531254E+06	-3.531254E+06	-3.531254E+06	3.545157E+06		3.545157E+06	-3.531254E+06	

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0 IMPACT SUBCASE 1
ELEMENT-ID = 1

S T R E S S E S I N B A R E L E M E N T S (C B A R)

TIME	SA1 SB1	SA2 SB2	SA3 SB3	SA4 SB4	AXIAL-STRESS	SA-MAX SB-MAX	SA-MIN SB-MIN	M.S.-T M.S.-C
2.400000E-01	-7.187408E+06	7.187408E+06	7.187408E+06	-7.215704E+06	0.0	7.187408E+06	-7.215704E+06	
	7.187408E+06	-7.187408E+06	-7.187408E+06	7.215704E+06		7.215704E+06	-7.187408E+06	
2.550000E-01	-7.588843E+06	7.588843E+06	7.588843E+06	-7.618720E+06	0.0	7.588843E+06	-7.618720E+06	
	7.588843E+06	-7.588843E+06	-7.588843E+06	7.618720E+06		7.618720E+06	-7.588843E+06	
2.700000E-01	-4.553777E+06	4.553777E+06	4.553777E+06	-4.571705E+06	0.0	4.553777E+06	-4.571705E+06	
	4.553777E+06	-4.553777E+06	-4.553777E+06	4.571705E+06		4.571705E+06	-4.553777E+06	
2.850000E-01	5.434037E+05	-5.434037E+05	-5.434037E+05	5.455431E+05	0.0	5.455431E+05	-5.434037E+05	
	-5.434037E+05	5.434037E+05	5.434037E+05	-5.455431E+05		5.434037E+05	-5.455431E+05	
3.000000E-01	5.394512E+06	-5.394512E+06	-5.394512E+06	5.415750E+06	0.0	5.415750E+06	-5.394512E+06	
	-5.394512E+06	5.394512E+06	5.394512E+06	-5.415750E+06		5.394512E+06	-5.415750E+06	
3.150000E-01	7.802790E+06	-7.802790E+06	-7.802790E+06	7.833510E+06	0.0	7.833510E+06	-7.802790E+06	
	-7.802790E+06	7.802790E+06	7.802790E+06	-7.833510E+06		7.802790E+06	-7.833510E+06	
3.300000E-01	6.677684E+06	-6.677684E+06	-6.677684E+06	6.703974E+06	0.0	6.703974E+06	-6.677684E+06	
	-6.677684E+06	6.677684E+06	6.677684E+06	-6.703974E+06		6.677684E+06	-6.703974E+06	

3.450000E-01	2.528681E+06	-2.528681E+06	-2.528681E+06	2.538637E+06	0.0	2.538637E+06	-2.528681E+06	
	-2.528681E+06	2.528681E+06	2.528681E+06	-2.538637E+06		2.528681E+06	-2.538637E+06	
3.600000E-01	-2.765399E+06	2.765399E+06	2.765399E+06	-2.776286E+06	0.0	2.765399E+06	-2.776286E+06	
	2.765399E+06	-2.765399E+06	-2.765399E+06	2.776286E+06		2.776286E+06	-2.765399E+06	
3.750000E-01	-6.807207E+06	6.807207E+06	6.807207E+06	-6.834007E+06	0.0	6.807207E+06	-6.834007E+06	
	6.807207E+06	-6.807207E+06	-6.807207E+06	6.834007E+06		6.834007E+06	-6.807207E+06	
3.900000E-01	-7.766466E+06	7.766466E+06	7.766466E+06	-7.797042E+06	0.0	7.766466E+06	-7.797042E+06	
	7.766466E+06	-7.766466E+06	-7.766466E+06	7.797042E+06		7.797042E+06	-7.766466E+06	
4.050000E-01	-5.208789E+06	5.208789E+06	5.208789E+06	-5.229296E+06	0.0	5.208789E+06	-5.229296E+06	
	5.208789E+06	-5.208789E+06	-5.208789E+06	5.229296E+06		5.229296E+06	-5.208789E+06	
4.200000E-01	-2.923847E+05	2.923847E+05	2.923847E+05	-2.935358E+05	0.0	2.923847E+05	-2.935358E+05	
	2.923847E+05	-2.923847E+05	-2.923847E+05	2.935358E+05		2.935358E+05	-2.923847E+05	
4.350000E-01	4.756422E+06	-4.756422E+06	-4.756422E+06	4.775148E+06	0.0	4.775148E+06	-4.756422E+06	
	-4.756422E+06	4.756422E+06	4.756422E+06	-4.775148E+06		4.756422E+06	-4.775148E+06	
4.500000E-01	7.651350E+06	-7.651350E+06	-7.651350E+06	7.681473E+06	0.0	7.681473E+06	-7.651350E+06	
	-7.651350E+06	7.651350E+06	7.651350E+06	-7.681473E+06		7.651350E+06	-7.681473E+06	
4.650000E-01	7.081470E+06	-7.081470E+06	-7.081470E+06	7.109350E+06	0.0	7.109350E+06	-7.081470E+06	
	-7.081470E+06	7.081470E+06	7.081470E+06	-7.109350E+06		7.081470E+06	-7.109350E+06	

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0 IMPACT SUBCASE 1
ELEMENT-ID = 1

S T R E S S E S I N B A R E L E M E N T S (C B A R)

TIME	SA1 SB1	SA2 SB2	SA3 SB3	SA4 SB4	AXIAL-STRESS	SA-MAX SB-MAX	SA-MIN SB-MIN	M.S.-T M.S.-C
4.800000E-01	3.304845E+06	-3.304845E+06	-3.304845E+06	3.317856E+06	0.0	3.317856E+06	-3.304845E+06	
	-3.304845E+06	3.304845E+06	3.304845E+06	-3.317856E+06		3.304845E+06	-3.317856E+06	
4.950000E-01	-1.968332E+06	1.968332E+06	1.968332E+06	-1.976082E+06	0.0	1.968332E+06	-1.976082E+06	
	1.968332E+06	-1.968332E+06	-1.968332E+06	1.976082E+06		1.976082E+06	-1.968332E+06	
5.025000E-01	4.416772E+06	-4.416772E+06	-4.416772E+06	4.434160E+06	0.0	4.434160E+06	-4.416772E+06	
	-4.416772E+06	4.416772E+06	4.416772E+06	-4.434160E+06		4.416772E+06	-4.434160E+06	

1 100 LB IMPACT FORCE TEST APRIL 9, 2010 MD NASTRAN 1/26/09 PAGE 15

0 IMPACT SUBCASE 1
ELEMENT-ID = 2

S T R E S S E S I N B A R E L E M E N T S (C B A R)

TIME	SA1 SB1	SA2 SB2	SA3 SB3	SA4 SB4	AXIAL-STRESS	SA-MAX SB-MAX	SA-MIN SB-MIN	M.S.-T M.S.-C
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	0.0	0.0	0.0	0.0		0.0	0.0	
1.500000E-02	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	0.0	0.0	0.0	0.0		0.0	0.0	

3.000000E-02	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0		0.0	0.0
4.500000E-02	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0		0.0	0.0
6.000000E-02	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0		0.0	0.0
7.500000E-02	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0		0.0	0.0
9.000000E-02	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0		0.0	0.0
1.050000E-01	3.203285E+05	-3.203285E+05	-3.203285E+05	3.215896E+05	0.0	3.215896E+05	-3.203285E+05
	-3.203285E+05	3.203285E+05	3.203285E+05	-3.215896E+05		3.203285E+05	-3.215896E+05
1.200000E-01	1.742315E+06	-1.742315E+06	-1.742315E+06	1.749174E+06	0.0	1.749174E+06	-1.742315E+06
	-1.742315E+06	1.742315E+06	1.742315E+06	-1.749174E+06		1.742315E+06	-1.749174E+06
1.350000E-01	3.174458E+06	-3.174458E+06	-3.174458E+06	3.186955E+06	0.0	3.186955E+06	-3.174458E+06
	-3.174458E+06	3.174458E+06	3.174458E+06	-3.186955E+06		3.174458E+06	-3.186955E+06
1.500000E-01	4.567585E+06	-4.567585E+06	-4.567585E+06	4.585568E+06	0.0	4.585568E+06	-4.567585E+06
	-4.567585E+06	4.567585E+06	4.567585E+06	-4.585568E+06		4.567585E+06	-4.585568E+06
1.650000E-01	5.890194E+06	-5.890194E+06	-5.890194E+06	5.913383E+06	0.0	5.913383E+06	-5.890194E+06
	-5.890194E+06	5.890194E+06	5.890194E+06	-5.913383E+06		5.890194E+06	-5.913383E+06
1.800000E-01	7.142712E+06	-7.142712E+06	-7.142712E+06	7.170834E+06	0.0	7.170834E+06	-7.142712E+06
	-7.142712E+06	7.142712E+06	7.142712E+06	-7.170834E+06		7.142712E+06	-7.170834E+06
1.950000E-01	8.357311E+06	-8.357311E+06	-8.357311E+06	8.390214E+06	0.0	8.390214E+06	-8.357311E+06
	-8.357311E+06	8.357311E+06	8.357311E+06	-8.390214E+06		8.357311E+06	-8.390214E+06
2.100000E-01	-1.723978E+06	1.723978E+06	1.723978E+06	-1.730765E+06	0.0	1.723978E+06	-1.730765E+06
	1.723978E+06	-1.723978E+06	-1.723978E+06	1.730765E+06		1.730765E+06	-1.723978E+06
2.250000E-01	3.531254E+06	-3.531254E+06	-3.531254E+06	3.545157E+06	0.0	3.545157E+06	-3.531254E+06
	-3.531254E+06	3.531254E+06	3.531254E+06	-3.545157E+06		3.531254E+06	-3.545157E+06

1 100 LB IMPACT FORCE TEST APRIL 9, 2010 MD NASTRAN 1/26/09 PAGE 16

0 IMPACT SUBCASE 1

ELEMENT-ID = 2

S T R E S S E S I N B A R E L E M E N T S (C B A R)

TIME	SA1 / SB1	SA2 / SB2	SA3 / SB3	SA4 / SB4	AXIAL-STRESS	SA-MAX / SB-MAX	SA-MIN / SB-MIN	M.S.-T / M.S.-C
2.400000E-01	7.187408E+06	-7.187408E+06	-7.187408E+06	7.215704E+06	0.0	7.215704E+06	-7.187408E+06	
	-7.187408E+06	7.187408E+06	7.187408E+06	-7.215704E+06		7.187408E+06	-7.215704E+06	
2.550000E-01	7.588843E+06	-7.588843E+06	-7.588843E+06	7.618720E+06	0.0	7.618720E+06	-7.588843E+06	
	-7.588843E+06	7.588843E+06	7.588843E+06	-7.618720E+06		7.588843E+06	-7.618720E+06	
2.700000E-01	4.553777E+06	-4.553777E+06	-4.553777E+06	4.571705E+06	0.0	4.571705E+06	-4.553777E+06	

TIME	SA1 / SB1	SA2 / SB2	SA3 / SB3	SA4 / SB4	AXIAL-STRESS	SA-MAX / SB-MAX	SA-MIN / SB-MIN	M.S.-T / M.S.-C
	-4.553777E+06	4.553777E+06	4.553777E+06	-4.571705E+06		4.553777E+06	-4.571705E+06	
2.850000E-01	-5.434037E+05	5.434037E+05	5.434037E+05	-5.455431E+05	0.0	5.434037E+05	-5.455431E+05	
	5.434037E+05	-5.434037E+05	-5.434037E+05	5.455431E+05		5.455431E+05	-5.434037E+05	
3.000000E-01	-5.394512E+06	5.394512E+06	5.394512E+06	-5.415750E+06	0.0	5.394512E+06	-5.415750E+06	
	5.394512E+06	-5.394512E+06	-5.394512E+06	5.415750E+06		5.415750E+06	-5.394512E+06	
3.150000E-01	-7.802790E+06	7.802790E+06	7.802790E+06	-7.833510E+06	0.0	7.802790E+06	-7.833510E+06	
	7.802790E+06	-7.802790E+06	-7.802790E+06	7.833510E+06		7.833510E+06	-7.802790E+06	
3.300000E-01	-6.677684E+06	6.677684E+06	6.677684E+06	-6.703974E+06	0.0	6.677684E+06	-6.703974E+06	
	6.677684E+06	-6.677684E+06	-6.677684E+06	6.703974E+06		6.703974E+06	-6.677684E+06	
3.450000E-01	-2.528681E+06	2.528681E+06	2.528681E+06	-2.538637E+06	0.0	2.528681E+06	-2.538637E+06	
	2.528681E+06	-2.528681E+06	-2.528681E+06	2.538637E+06		2.538637E+06	-2.528681E+06	
3.600000E-01	2.765399E+06	-2.765399E+06	-2.765399E+06	2.776286E+06	0.0	2.776286E+06	-2.765399E+06	
	-2.765399E+06	2.765399E+06	2.765399E+06	-2.776286E+06		2.765399E+06	-2.776286E+06	
3.750000E-01	6.807207E+06	-6.807207E+06	-6.807207E+06	6.834007E+06	0.0	6.834007E+06	-6.807207E+06	
	-6.807207E+06	6.807207E+06	6.807207E+06	-6.834007E+06		6.807207E+06	-6.834007E+06	
3.900000E-01	7.766466E+06	-7.766466E+06	-7.766466E+06	7.797042E+06	0.0	7.797042E+06	-7.766466E+06	
	-7.766466E+06	7.766466E+06	7.766466E+06	-7.797042E+06		7.766466E+06	-7.797042E+06	
4.050000E-01	5.208789E+06	-5.208789E+06	-5.208789E+06	5.229296E+06	0.0	5.229296E+06	-5.208789E+06	
	-5.208789E+06	5.208789E+06	5.208789E+06	-5.229296E+06		5.208789E+06	-5.229296E+06	
4.200000E-01	2.923847E+05	-2.923847E+05	-2.923847E+05	2.935358E+05	0.0	2.935358E+05	-2.923847E+05	
	-2.923847E+05	2.923847E+05	2.923847E+05	-2.935358E+05		2.923847E+05	-2.935358E+05	
4.350000E-01	-4.756422E+06	4.756422E+06	4.756422E+06	-4.775148E+06	0.0	4.756422E+06	-4.775148E+06	
	4.756422E+06	-4.756422E+06	-4.756422E+06	4.775148E+06		4.775148E+06	-4.756422E+06	
4.500000E-01	-7.651350E+06	7.651350E+06	7.651350E+06	-7.681473E+06	0.0	7.651350E+06	-7.681473E+06	
	7.651350E+06	-7.651350E+06	-7.651350E+06	7.681473E+06		7.681473E+06	-7.651350E+06	
4.650000E-01	-7.081470E+06	7.081470E+06	7.081470E+06	-7.109350E+06	0.0	7.081470E+06	-7.109350E+06	
	7.081470E+06	-7.081470E+06	-7.081470E+06	7.109350E+06		7.109350E+06	-7.081470E+06	

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0 IMPACT SUBCASE 1
ELEMENT-ID = 2

S T R E S S E S I N B A R E L E M E N T S (C B A R)

TIME	SA1 / SB1	SA2 / SB2	SA3 / SB3	SA4 / SB4	AXIAL-STRESS	SA-MAX / SB-MAX	SA-MIN / SB-MIN	M.S.-T / M.S.-C
4.800000E-01	-3.304845E+06	3.304845E+06	3.304845E+06	-3.317856E+06	0.0	3.304845E+06	-3.317856E+06	
	3.304845E+06	-3.304845E+06	-3.304845E+06	3.317856E+06		3.317856E+06	-3.304845E+06	
4.950000E-01	1.968332E+06	-1.968332E+06	-1.968332E+06	1.976082E+06	0.0	1.976082E+06	-1.968332E+06	
	-1.968332E+06	1.968332E+06	1.968332E+06	-1.976082E+06		1.968332E+06	-1.976082E+06	
5.025000E-01	-4.416772E+06	4.416772E+06	4.416772E+06	-4.434160E+06	0.0	4.416772E+06	-4.434160E+06	
	4.416772E+06	-4.416772E+06	-4.416772E+06	4.434160E+06		4.434160E+06	-4.416772E+06	

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1    100 LB IMPACT FORCE TEST                                                          APRIL   9, 2010   MD NASTRAN  1/26/09   PAGE    18

0     IMPACT                                                                                                   SUBCASE   1
1    100 LB IMPACT FORCE TEST                                                          APRIL   9, 2010   MD NASTRAN  1/26/09   PAGE    19

0     IMPACT                                                                                                   SUBCASE   1
 * * * *  D B D I C T   P R I N T  * * * *      SUBDMAP = PRTSUM  ,  DMAP STATEMENT NO.     30
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Appendix L: Group Biographies

Shane Foley
Shane Foley is from Bay City, MI, part of what is known as the "tri-city area" located approximately 90 miles North of Ann Arbor. He graduated from Bay City Western High School in 2006, and went on to attend the University of Michigan's College of Engineering. Coming into the University, Shane knew his major interest in the broad field of engineering was mechanical engineering. This interest was evident even at a young age, as he was always building with Legos, and took a deeper root with an interest and passion for the American automotive industry. While at the University of Michigan, Shane has earned a Minor in Mathematics, and will graduate with a Bachelor's of Science in Engineering in April 2010. Upon graduation, Shane will begin employment as a Mechanical Design Engineer for the United States Department of Defense.

Justin Rosario
Justin was born in New York City and lived there for the majority of his life. Shortly following his graduation from grade school, his family moved to Grand Rapids, MI. Here he attended Catholic Central High School, where he graduated in the Class of 2006. Since a young age, he has had a keen interest in cars, so he decided to major in Mechanical Engineering upon gaining acceptance to the University of Michigan. This degree is so broad and versatile that it will still be useful should the automotive industry continue to collapse at the current rate. Following graduation, he plans on working for two or three years in the automotive industry before returning to school to further his education in the pursuit of a Masters degree.

Brandon Teller
Brandon is currently from Spring Lake, MI but was born in Morristown, NJ and then lived eight years in both Myrtle Beach, SC, and Richmond, VA. He graduated from Spring Lake High School in 2006 and continued to the University of Michigan. Coming from a family where both of his parents were engineers, it was unsurprising that he went on to declare Mechanical Engineering while enrolled in the College of Engineering. Through internships and courses in college, Brandon discovered a love of mechatronics and controls and hopes to work in one of those fields upon graduation. He will graduate with a Bachelor’s of Science in Mechanical Engineering in May of 2010.

Mark Wilson
Mark has lived in Troy, Michigan, for his entire life. He graduated from Troy High School in 2006, and had planned on obtaining a degree in Mechanical Engineering. Ever since Mark was little he dreamed of attending the University of Michigan, and ecstatic when he was accepted. Mark plans on graduating after this semester and hopefully will obtain a job in an engineering position which will let him apply his knowledge gained here. Mark never intends on getting his masters degree in engineering unless his future employer pays for the schooling. Once Mark retires from engineering, he hopes to obtain a teaching degree and teach high school math. Other hobbies of Mark include going to Rick’s American Café, watching the “Party in the USA” music video, and speaking in redundancies.