Child Carrier : Senior Project

by

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Statement of Disclaimer

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This report details the redesign of MORPHTECH's foldable child carrier. Although there are numerous strollers available with a variety of features, very few can be considered portable. It is believed that there is a sizeable market of parents with a need for a compact, portable stroller. Fred Park, the inventor of the MORPHTECH foldable child carrier, has created a product to meet this need. The stroller's design is very good; it is sturdy, folds nicely and is well engineered. There are a few problems, though. The stroller is easy enough to assemble given that one is familiar with the design. For the average consumer, however, the process is not intuitive. It is difficult to connect the latching mechanism and the structure tends to flop around until the latch has been secured. In addition, there are improvements that can be made and additional refinement is required in order for the product to be ready for manufacturing.

The project began with an initial analysis of the current design. Problem areas were noted and the focus was placed on two main components: the latching mechanism and the central hub that connected the legs. The first quarter of this project was dedicated to ideation. Possible solutions were presented and analyzed. Ultimately, a single idea was chosen for prototyping. It was decided that a sliding latch would be pursued as an alternative to the current two-piece construction, and a geared hub would be developed to aid in folding and unfolding.

During the second quarter of the project, the initial prototypes of the modified components were rapid prototyped using a 3D printer. The hub was the primary focus and successive iterations refined not only the rigidity of the hub itself, but also the interface of the gears.

The final quarter consisted primarily of manufacturing a complete prototype. In addition to the components being modified, an entirely new structure was also necessary. This included replicating the frame, legs, and all required joints and components. Copper piping was chosen for the primary structure and the rest of the components were 3D printed. Once the prototype was assembled, the modified components were then evaluated. Problems were once again identified and successive iterations were designed and manufactured.

The conclusion of this project resulted in a completed prototype that matches its predecessor's size, but contains some much needed improvements. The new prototype is a proof of concept that demonstrates that the modified components improve the overall functionality of the stroller. Although the stroller is still not ready for mass-production manufacturing, only slight modifications and refinements are required to make it so. The rest of this report documents, in detail, the process of this project from the ideation stage, to the completion of the final prototype.

1 Introduction

There is a need for a lightweight stroller that can easily be assembled and disassembled by the customer, and be compact enough to fit into a small space for storage. The current prototype, invented by Fred Park of MORPHTECH LLC, does not suitably satisfy this need and therefore is not ready for the competitive child carrier market. This senior project team has been assigned the task of improving the design, building a prototype, and testing the stroller according to the relevant standards and specifications in order to ultimately increase the marketability of the product. To address the current problem, it is required that the tensioning system of the stroller and any accompanying and necessary frame components be redesigned to allow the customer to use the stroller in an easy and intuitive manner. There are several requirements that must be met for this design. These requirements include, but are not limited to: the ability to fit in an airline carry-on overhead while folded up, which is currently limited to 22" X 14" X 9" by the FAA; pass US and European safety requirements ASTM F833-07 and EN 1888:2012, which include stability requirements, no pinch points or entrapment hazards, etc.; be intuitive for the user to assemble and pack down, ideally with one hand; retail at a competitive price; and be competitive in performance to other strollers on the market.

1.1 Requirements and Objectives

The objective of this project is to design, build, and test an innovative stroller frame to be marketed for consumer use. From researching the market's needs, a list of several customer requirements was developed in order to define our engineering specifications. The following is a list of the key requirements for a compact stroller:

- Intuitive for the user
- Lightweight
- Fits into an airline overhead compartment
- Safe for both the passenger and the operator
- Maneuverable
- Durable
- Affordable
- Weather Protection

To provide a successful solution to the problem, the design must effectively satisfy these requirements. Parameters have been set and testing will be conducted in order to verify that each requirement is met. Below is a table with the ideal engineering specifications, used to quantify the customer requirements, and the relative importance of each.

Table 1-1 Customer requirements, research and weights

Spec. #	Parameter Description	Target	Tolerance	Importance
1	Linear Dimensions (L"+W"+H")	45"	Max.	High
2	Assembly Steps	2	+2 Steps	Medium
3	Ease of Assembly	Assemble Stroller While Holding 15 lb of Weight	N/A	High
4	US and European Safety Standards	Pass	N/A	High
5	Weight	12 lb	Max.	Medium
6	Price	$200	$100	Medium
7	Weather Protection	Waterproof, Provides Shade From Sun/Wind	Meets at Least 1 Requirement	Medium

Quality Function Deployment (QFD) was used to set targets for the project by identifying the customer requirements and their associated engineering specifications. The QFD is displayed in a House of Quality format (see Appendix A) which is used to compare the interrelation of specifications and their effect on the customer requirements. This method weighs the importance of certain aspects of the design and shows how relevant the parameters are when related to one another.

1.2 Management Plan

The primary responsibilities of each team member will be as follows:

Cordell: Cordell is the group's treasurer and will be in charge of keeping an eye on the group's finances. His administrative responsibilities include: maintaining the teams material budget, tracking the group's overall spending, and approving purchases made by group members. When it comes to the technical aspects of this project, Cordell is the lead CAD modeler and in charge of testing plans. As the lead CAD modeler, he is in charge of modeling all designs and concepts for the group in Solidworks.

Jake: Jake is the Communications Officer. He is the main point of contact and is responsible for all forms of communication with Jeff Goettman, Fred Park and other outside parties. Other managerial responsibilities include organizing meetings with the group and sponsors as well as maintaining communication between group members. Jake is also the manufacturing and prototyping lead for the group.

Drew: Drew is the secretary of the group and will be the primary information researcher. He will be in charge of recording what is discussed during meetings, conference calls, and any other group related events. He will also maintain an updated record of project progress in order to keep sponsors and advisors

informed. In addition, it will be his responsibility to organize all aforementioned documents and any others pertaining to the project.

In order to organize and schedule the tasks required for the entire span of the project, a Gantt Chart (see Appendix A) was created. Other tasks completed during the course of the project include: creating models of the initial top concepts, explorations of additional solutions to address the problem or satisfy the specifications, creation of a final prototype stroller or the redesigned components that solve the problem, testing to verify that the specifications and requirements have been met, and any necessary iterations of the aforementioned tasks. The preliminary models were created using 3D printing technology and common, inexpensive hardware to model how the components work together and verify that the concepts are feasible. Once modeled, tweaks to the designs were made as necessary to better represent the solution to the problem until a final design was decided upon. The final design prototype was a combination of 3D printed components and customized hardware to demonstrate how a marketable product will look and operate. Testing on the final prototype and any intermediate models throughout the design and build process were conducted to assure the engineering team and the customer that the requirements have been met.

2 Background

Conventional strollers currently available on the market have locking mechanisms that, when released, allow the sides of the stroller frame to be pushed inward. This drastically reduces the height and width, but not the length (distance measured from front wheels to handles) of the stroller. This length constraint prevents the user from storing the folded stroller in many tight areas, such as a small closet or the overhead carry-on of an airplane.

There are several competitive products on the market today that operate as effective strollers, but none of them meet all of the requirements laid out by this project, most notably the 22” X 14” X 9” dimension requirement. A couple of these competitive stroller models include the Quinny Zapp and the Quicksmart Easy Fold. The Quinny Zapp, pictured in Figure 2-1, features relatively easy pack-down and reassembly, but requires two hands and only achieves collapsed dimensions of 27” X 11” X 10”. In addition, the entire assembly weighs roughly 25 pounds, which is quite heavy relative to other models on the market.

Figure 2-1 Quinny Zapp

The Quicksmart Easy Fold, pictured in Figure 2-2, is inexpensive at only $129 and pretty light-weight at 12.5 pounds. The Easy Fold features very effortless pack-down and reassembly, but is fairly large in its most collapsed state, with dimensions of 21” X 9” X 21”.

Figure 2-2 Quicksmart Easy Fold

In an attempt to address the problem with the currently available stroller market, U.S. Patent No. 8172254 B2 was obtained in May of 2012 which details the design of a collapsible stroller support frame, as seen below in Figure 2-3, that satisfies the dimension requirements when folded. According to the document, the support frame comprises a front frame, rear frame, and locking mechanism. Both the front and rear frames are constructed with several tubular members. The rear frame's members connect at a central hub, with at least two of the members extending outward from this hub and connecting pivotably to the opposite side of the front frame. The locking mechanism consists of two independent components, a lever and base member, which cooperate to lock and unlock the frame. The base member pivotably connects to the hub, while a pair of tension members extends from the lever to connect it to the front frame. In the locked position, the lever and base member pull the frames toward each other to put them in tension and hold them open in the unfolded position. In the unlocked position, the lever and base member separate from each other to release tension on the frames and allow the structure to collapse into a folded position.

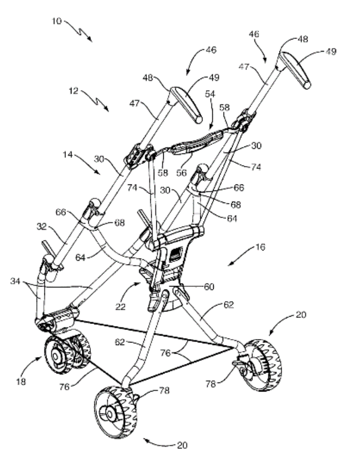
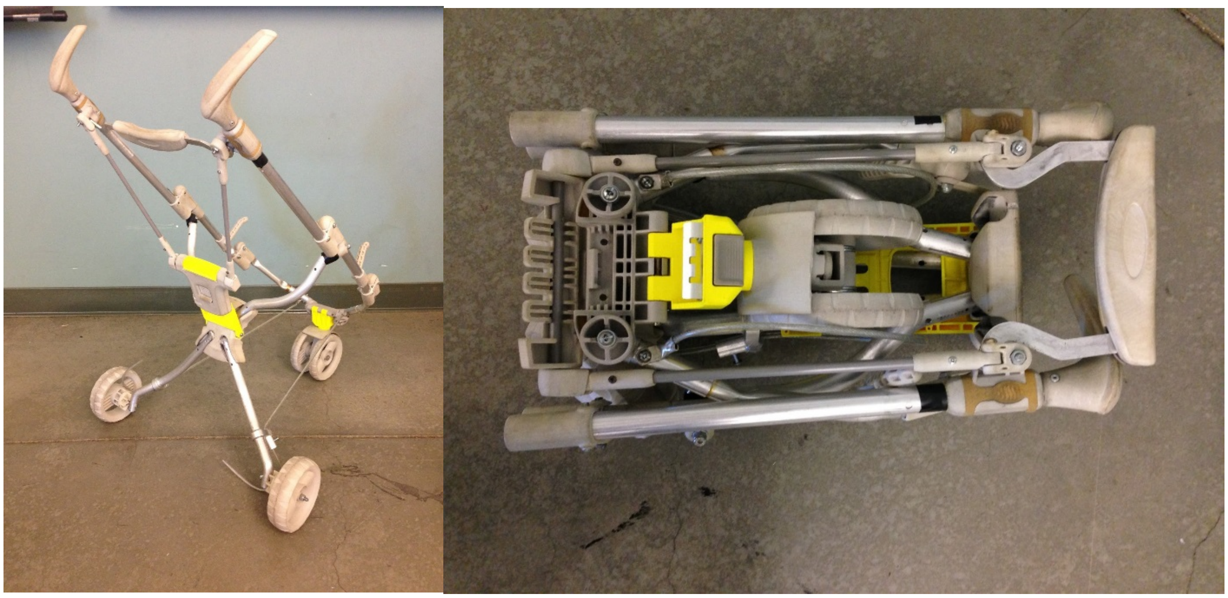


Figure 2-3 Rear view of current invention (U.S. Patent No. 8172254 B2) frame structure design

Further research was conducted on the ASTM standard F833-07 for strollers, which the current patent has met the requirements of. These standards mainly focus on stability requirements of the structure, as well as the absence of pinch points and entrapment hazards. The stability testing is easily done with the stroller placed on a tilt table that is angled to a specified number of degrees. If the stroller does not tip over when the equivalent weight of a child is added, then it passes the stability requirements. Additionally, anthropometric data was obtained from the US Department of Health and Human Services to help constrain the size requirements of the stroller design. Since the stroller is designed to hold toddlers, data from the 95th percentile of male 4 year olds was recorded to accommodate the higher end of the spectrum. This data includes weight at 56.3 pounds and height at 45.2 inches.

3 Design Development

One of the biggest problems with Fred Park's current stroller design is that, as he put it, the stroller is "like a bag of bones." Fred's prototype, seen in Figure 3-1, contains over nineteen hinged joints, none of which are spring assisted and only one of which has a mechanical latch to lock it in place. The result is that when the user attempts to unfold the stroller, none of the legs or hinges want to stay in one place. The four spider legs that extend from the hub, best pictured in Figure 3-1 or 3-2, do not pivot simultaneously which makes for a very difficult unfolding process. Only once the user reaches the final step of assembly, applying tension to the stroller, are the legs and hinges fully-constrained. This makes for a very difficult and complicated assembly process. With the addition of spring and gear assistance to the hub, these difficulties can be drastically reduced.



Figures 3-1(a) Current Unfolded Prototype, **Figure 3-1(b)** Current Folded Prototype

Figure 3-2 Current hub model with pivoting spider legs

Another problem with the current design is the tensioning system itself and the manner in which the frame is held together in the unfolded, usable position. The current design features a two piece latch system, as seen in Figure 3-3, that requires the user to engage the teeth of the upper latch into the lower latch and lever it down to lock them together. Once these latch pieces are locked together, the entire frame structure is appropriately in tension to support the weight of a child passenger. The problem with the way that these latches are engaged and locked together is in the fact that they are separated from each other. This inherently makes assembly of the stroller not intuitive to the user, especially when the several hinges mentioned previously do not allow for the latch pieces to be consistently in the same location during assembly. The ideal solution to this problem is to redesign the latching components and the overall method of applying the critical tension to the frame structure. The general idea to approach this issue is to keep the two latching components together or in some way aligned so that the locking mechanism is obvious and intuitive to the user. The design ideas for the new locking mechanism are discussed later in this section of the report.

Figure 3-3 Current two piece latch mechanism, shown separated

Additionally, there are several other minor issues with the current prototype that require attention in order to improve the usability and marketability of the stroller. One issue is the lack of any kind of locking mechanisms, besides the latch, to keep the many hinges in place to make it easier for the user during assembly. Another component that could use redesign is the front wheel. In order to completely pack-down the stroller, it is necessary that the front wheel's hinge is released with a push button to allow it to fold in on the frame. This is an extra undesired step that is required to fold the stroller, and ideally will be omitted with a redesigned feature. Also, an increased axle length between the two wheels that comprise the front caster wheel would be beneficial to increase the stability of the frame structure. Further issues include ease of use and stability of the extendable handles, as well as tweaks to the geometry of the frame's components to allow for possible improved ease of compaction and overall collapsed dimensions. There are not yet any definitive design ideas to solve these additional issues, however,

the concepts thus far are discussed later in this section of the report and the issues will be revisited in future stages of the project.

3.1 **Hub Concepts**

3.1.1 Torsional Spring Loaded Hub

One idea to improve the hub is to add torsional springs to its hinge joints. The torsional springs would be biased to the unfolded position. By the addition of these springs, the four spider legs will naturally stay unfolded. By forcing these four legs into place, almost all of the stroller's other hinges will also be fully-constrained. To unfold the legs, all that the user will have to do is release four latches that lock the spider legs in the folded position. However, there are a few problems with this design. Firstly, the legs are independent and will have to be folded down individually when packing up the stroller; this will add significant time to the stroller disassembly. The legs, being independent, may also affect the assembly of the stroller. Depending on how the user is holding the stroller, some of the legs may not be able to unfold, causing difficulties with assembly. It is unclear how big of a problem this would actually be without first trying it, but it is a definite concern.

3.1.2 Two-Way Spring Loaded Hub

This is the simplest of the hub alternatives. A two-way spring design is almost identical to the torsional spring design, except it includes no latches and utilizes compression springs rather than torsional springs. A conceptual picture of the two-way spring is shown below in Figure 3-4. The basic idea behind the two-way spring is that the spring is biased to the folded and unfolded positions rather than just one in the case of the torsional spring. With the two-way spring there are three zones: 1) Folded Bias, 2) Critical (halfway) Angle, and 3) Unfolded Bias. In the "Folded Bias" zone the compression spring pulls on the leg, creating a moment that pulls it into the folded position. The "Unfolded Bias" zone is exactly the same, except the moment pulls the leg to the unfolded position. The critical angle is the angle where the spring is directly in line with the spider leg and no moment is created. Advantages for this design over the torsional spring design are that it does not require the use of latches. However, the user will have to provide force to the legs to fold and unfold the stroller to get the legs past their critical angle. Additionally, mounting compression springs in this manner will take up more room than putting compression springs on the hinges.

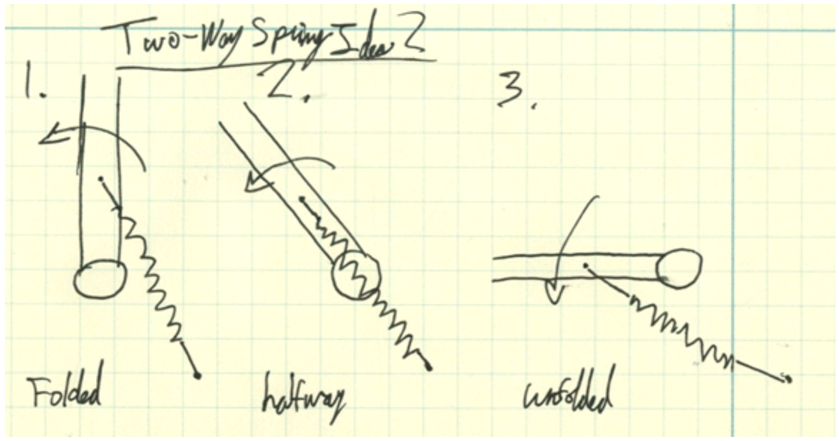


Figure 3-4 Two-Way Spring Loaded Hub Concept

3.1.3 Geared Hub

The geared hub design takes the spring loaded design one step further and makes the spider legs fold and unfold in unison. The design, seen below in Figure 3-5, revolves around the idea of connecting the four spider legs with a gear train, allowing one leg to drive the motion of the other three legs in perfect synchrony. Initial designs place a pair of spur-bevel combination gears between the pairs of upper and lower spider legs. The spur-bevel combination gears could be one custom gear as illustrated in the left-hand drawing or three separate gears fused together or keyed onto the same shaft, as shown in the right-hand drawing. The hinges of the spider legs would be modified to have integrated gear faces as in the picture on the left or an offset gear keyed to the hinges as on the right. These designs would also ideally include the use of either the torsional spring concept, or the two-way spring concept. With the Geared Hub design using torsional springs there would be a need for no more than one latch. When folding the stroller, the user would be able to fold up the legs simultaneously rather than individually. Also with the legs unfolding simultaneously this would reduce the risk of parts getting caught on each other while unfolding. As mentioned in the Two-Way Spring Hub section, utilizing a two-way spring would yield similar benefits to utilizing torsional springs. The main benefit of using the two-way spring is that it would not require a lock to keep everything in position.

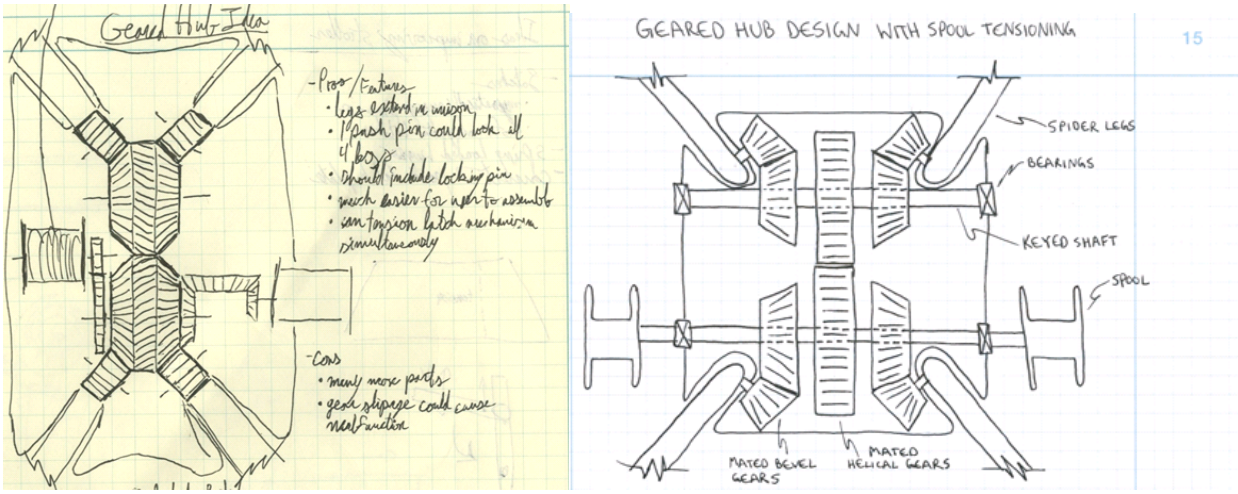


Figure 3-5(a) and **Figure 3-5(b)** Geared hub design ideas

3.2 Tensioning/Latch Concepts

3.2.1 Reverse Latch

The basis behind this idea begins with the fact that the two latch components in the current design are separated, which makes it very difficult to intuitively guide them into each other and engage the latch to put the stroller into its tensioned, upright position. The current general solution to this problem is to simply keep the two latch components together at all times, most likely with a simple pinned hinge. However, the issue with this is that when the stroller is in its folded position there is approximately 5-7 inches (as seen below in Figure 3-6) separating the two pieces due to the rigidity and geometry of the frame.

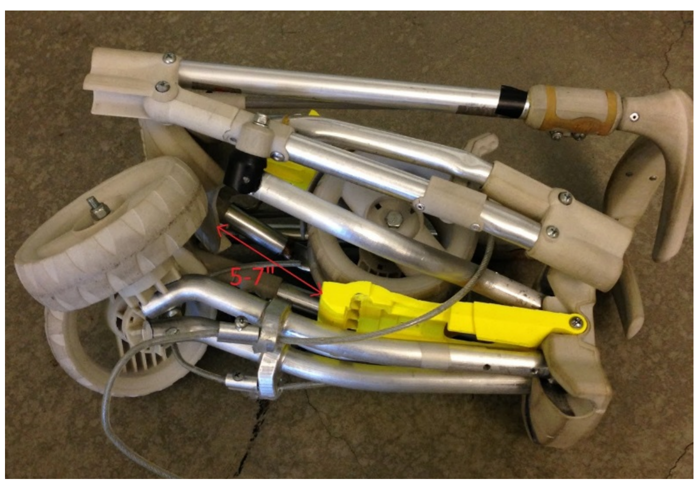


Figure 3-6 Gap between Latch Components when Stroller is folded

One idea to improve the ease of assembly of the stroller without over-complicating the tensioning system is with a mechanism like the reverse latch shown below in Figure 3-7. To facilitate the gap between the two latch components, the rigid bars that attach from the upper frame (just below the handles) to the upper latch would need to be replaced with flexible cables that are roughly 5-7 inches longer to accommodate the distance

required to have the latch components hinged together. With this extra cable length added, there would be a large amount of slack in the cables when opening the stroller for assembly. To eliminate this slack, the cables would be attached at the opposite end of the upper latch, thus creating the reverse latch. Therefore, to engage the latch, the user will pivot the upper latch about the hinge connecting it to the lower latch and effectively flip it over to snap it into a locking mechanism on the lower latch. In doing this, the extra cable slack is taken away and now runs up from the bottom of the lower latch (near the hub) to put the entire structure in tension. The benefit of this idea is that it is not a drastically different design than the current design, and if implemented correctly it could significantly improve the user friendliness of the stroller. The main drawbacks, however, are that in order to engage the reverse latch, there will be a large amount of extra force necessary to move the upper latch through the midpoint of the lever motion. It is likely that this extra force would at least require two hands to apply, and may require too much force for the average user to get the stroller into its properly tensioned structural position.

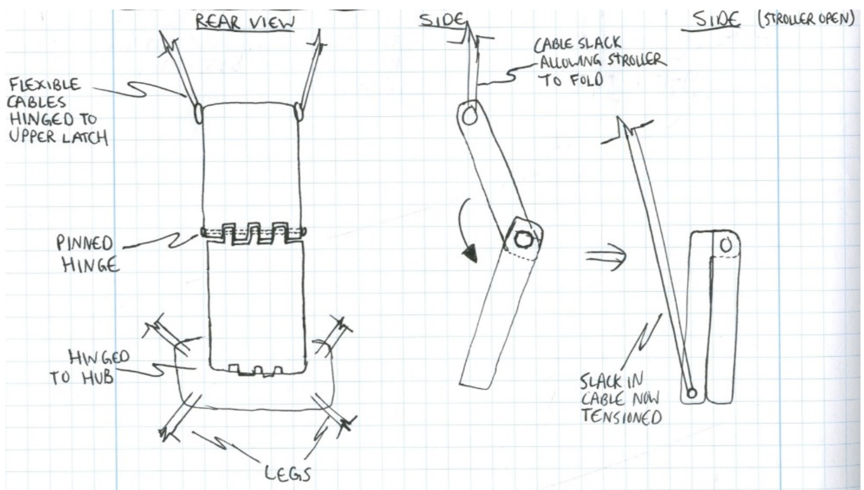


Figure 3-7 Reverse Latch Tensioning Concept

3.2.2 Boa-style Tensioning

With the current design, one of the biggest problems is the latch that tensions the stroller. The fact that it is two separate pieces makes assembly difficult and unintuitive. The process would be much simpler if the two pieces were combined into one. The problem with this, though, is that the latch provided the mechanical advantage to add in the final tension. A simple and elegant solution to both of these problems would be to add a Boa-type device. The Boa system, shown in Figure 3-8, works using cables and applies tension using a small knob, or reel. This technology can be found on snowboard boots, cycling shoes, helmets, and many other products. It provides a quick and easy way to tighten the cables. Tension is then easily released by simply pulling the knob up and allowing the reel to rotate freely. By implementing a device like this on the stroller, it would allow for the two latch pieces to become one and provide enough slack in the cables to maintain the current folding size, but there are some things to consider. There would need to be a clearly defined point where the device has been fully tensioned, otherwise the user could possibly apply too little tension and the stroller would be at risk

of collapsing. It would also have to be determined whether a device similar to this could be developed, or if licensing the technology would be necessary.

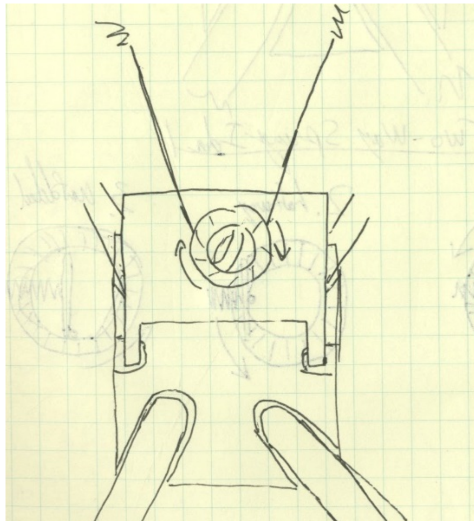


Figure 3-8 Boa-style Tensioning Concept

3.2.3 Sliding Latch

Sticking with the idea of keeping the latching pieces together, another possible solution could be in the form of a sliding mechanism, as seen in Figure 3-9. The idea is to make a flexible slider, somewhat similar to a cable carrier, that could bend and fold with the current design. The pieces could then line up linearly in order to slide down and lock into place when the stroller is upright. A handle would be placed on the bottom part of the slider to provide the mechanical advantage. This would allow for minimal changes to the current design, but there would be more manufacturing of parts. In order to have an adequate amount of length to overcome the distance necessary to fold, as well as being able to fold with the current geometry of the stroller, there would have to be at least three or four pieces for the slider to work. The strength of the pieces would also have to be considered as they would experience the most fatigue and would be prone to breaking or malfunctioning. However, this idea is much more intuitive for the user and little modification is needed to be done to the current design.

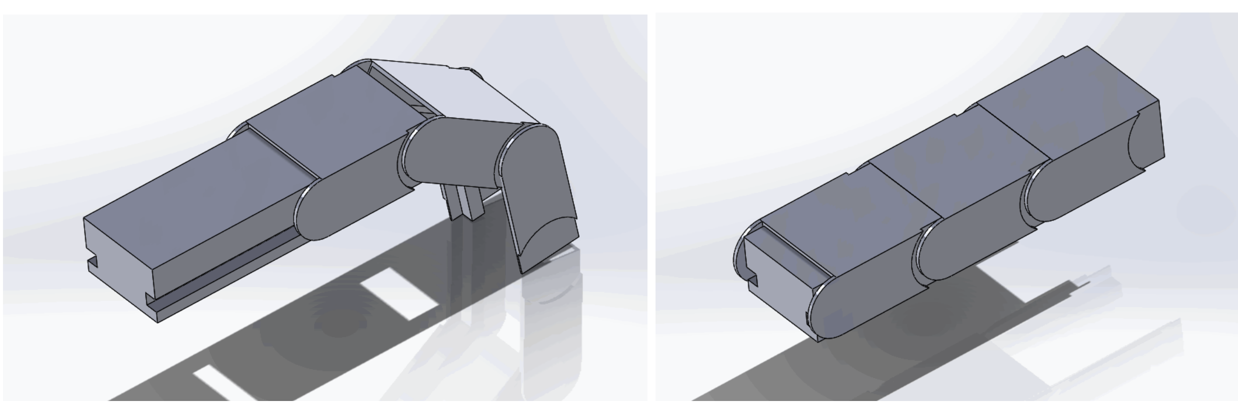


Figure 3-9(a) Concept Sliding Latch in “unfolded” position, **Figure 3-9(b)** Concept Sliding Latch in “folded” position.

3.2.4 Linear Bearing

Another idea that will be explored further is the use of a linear bearing. The idea is to put linear bearings on the handle poles and make an attachment for a cable to hook on to. The cable would run from the bearings, down the length of the frame, through the front wheel latch and back to the rear wheels. The idea is to use one motion to pull the handles up and out, and doing so will tighten the cables and cause the frame to unfold and lock out. A latch, similar to the current design, could be used to lock the stroller in the upright position. The latch could also be hinged together for added convenience. This design would work really well with the geared hub idea, because the uniform motion of the arms could really assist in the ease of pulling the cables. There are some obstacles to overcome, though. The main issue is the material. Having a sliding piece on the same surface where the material attaches poses a problem. The solution would be to either: redesign the material, or create a new surface for the material to secure to, but one that also allows the bearings to move uninhibited.

3.2.5 Gear Spool

The Gear Spool tensioning concept, pictured below in Figure 3-10, is an extension of the geared hub design discussed previously. The idea is that spools would be attached to one of the gear shafts, but on the outside of the hub. This design would include cables attached to the upper latch component and would run down through the lower latch and get wound up by the spools adjacent to the hub. When the gears rotate to extend the spider legs simultaneously, the spools also rotate to wind in the cable slack that separates the two latch components. With the cables attached to the upper latch and running through slots in the lower latch, these two components would not be connected permanently, but would be attached by the cables which act as guides to bring the pieces together when the cable slack is removed by winding up the spools. The benefit of this design is that all the necessary steps required to assemble the stroller would be completed with one mechanism that requires little user interaction. Once the gears are activated to extend the spider legs and bring the latch components together, all that would be required of the user is to lock the latch components together, putting the whole structure in tension. The drawbacks of this idea are adding extra components on the outside of the hub, which may take up extra space that is not available in the current design. Also, the gears may not provide enough strength to wind in a sufficient amount of slack, and it would require a significant gear ratio to wind the spools at a drastically different rate than the leg extension.

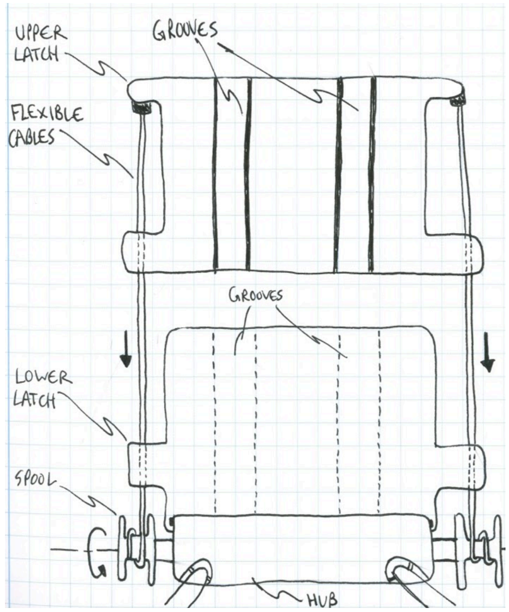


Figure 3-10 Gear Spool Tensioning Concept

3.2.6 Lever-Slider

Another latching mechanism design is a sort of combination between the Boa-style tensioning system, the gear spool design, and the current latching mechanism on Fred Park's prototype. This design replaces the rigid bars between the handlebars and upper latch with two cables that join at a rigid plastic Y-joint and continue down as one cable. This single cable runs through a torsion spring device that acts to be constantly winding in the cable's slack and thus pulling the stroller toward its assembled position. This device is mounted on the lower latch, which is hinged at the hub. As the cable is wound in, the Y-joint descends down toward the lower latch. When it is in position, the user is able to pull a lever that simultaneously grabs the top of the Y-joint and pulls it down just a bit further to apply the final tension to the system, much like the clamp-top lids found on glass jars. Everything is held in position similar to the lever latch on Fred Park's prototype, and is only released when the user disengages the lever to fold up the assembly. Since the torsion spring cable winding device acts in favor of the assembled position, the user must push against its resistance in order to fold the stroller. This requires an additional locking mechanism to keep the stroller from unfolding while it is disassembled, but accompanies the geared hub well in aiding the user to assemble the stroller when they desire.

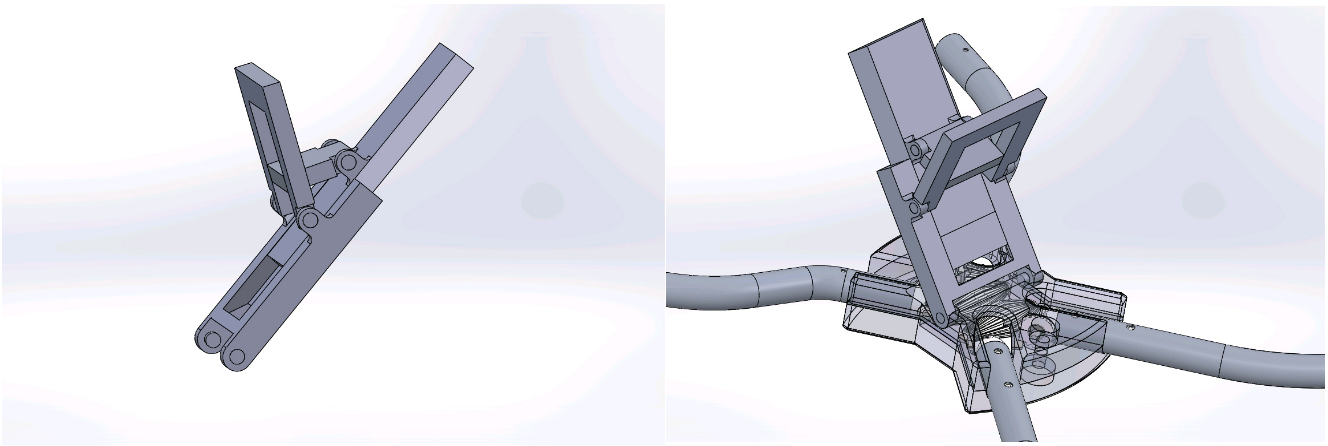


Figure 3-11(a) Concept Lever-slider design, **Figure 3-11(b)** Concept Lever-slider with geared hub.

3.3 Concept Selection

A decision matrix, seen in Table 3-1, was created in order to evaluate the top ideas. The preliminary requirements for the stroller design were used as categories, and each idea was given a value from 1 to 10 based on how well it satisfied the requirement. The categories were also given a weight based on the relative importance of their function to the overall design of the stroller. The point values were then totaled and the ideas were ranked. Given the results, three of the top ideas were chosen to be further analyzed and developed.

Table 3-1 Latch/Tensioning Ideas Decision Matrix

Tensioning											
Weight	4	6	2	10	5	8	10	5	7		
Ideas	**Cost**	**Manufacturability**	**One Handed?**	**Assembly Time**	**Safe**	**Intuitive**	**Effort**	**Durablility**	**Number of Steps**	**Total**	**Rank**
Gear Spool	2	2	5	8	6	8	8	5	8	365	1
Boa	6	5	3	6	7	7	6	7	7	355	2
Ratchet	6	5	3	3	4	3	3	7	5	234	6
Reverse Lever	8	6	2	7	3	4	2	4	6	271	4
Slider	4	3	3	7	3	7	5	4	7	300	3
Handle Tensioning	7	5	1	5	5	5	4	4	4	263	5
Current Design	9	6	1	3	6	2	3	3	3	216	7

The final concept is the culmination of the best solutions for the hub, the tensioning and the latch mechanisms.

The Geared Hub is the best hub design because it is the most user friendly. As was stated in the geared hub section, the legs of the geared hub move in unison, making it possible for the user to fold and unfold all the legs while only having to move one leg. The designs with just spring loaded legs will be much easier to manufacture, however, this is not worth the downgrade to usability.

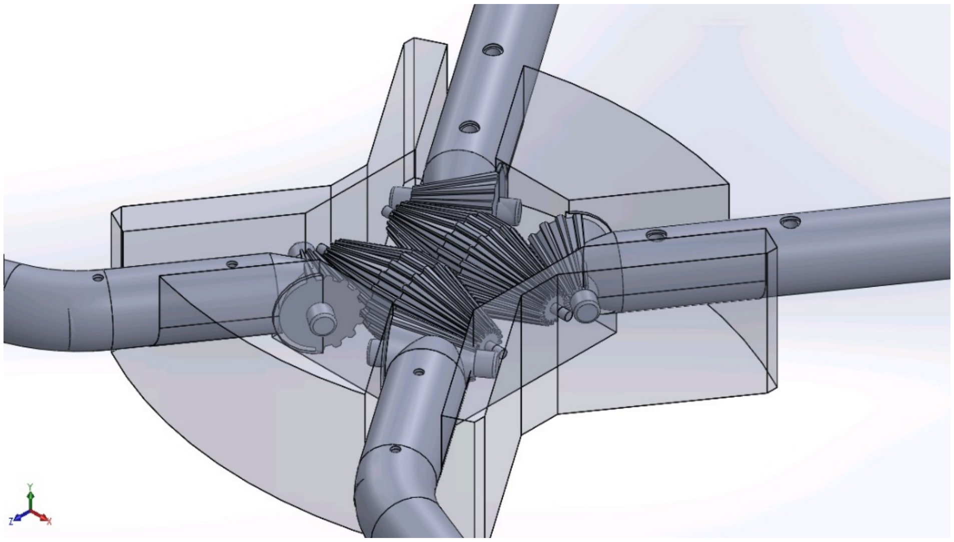


Figure 3-12 Initial SolidWorks concept of Geared Hub

In order to verify that small, custom designed gears could be printed with reasonable resolution, an initial rapid prototype job was conducted. As seen in Figure 3-13, the result was satisfying. The gear teeth meshed together quite well, and the resolution on the small teeth was impressive. The teeth clearly needed some involute redesign in order to mate more cleanly, but the fact that they came out with some reasonable accuracy gave the confidence to move forward with the design process on this particular idea.

Figure 3-13 Preliminary 3D print test of gear teeth resolution

The slider latch, seen in Figure 3-14, is currently the best solution to both the tensioning and latch design problems. The slider latch concept is designed to be very intuitive for the user and solves the major issue of the two latch components being detached from one another. With the slider fully extended, it is able to fold up with the stroller and fit among the other parts without taking up much more space in its compacted position.

When assembling the stroller, the slider latch acts as the component that both removes the excess slack between the two latching pieces and applies the final tension needed to hold the whole assembly together.

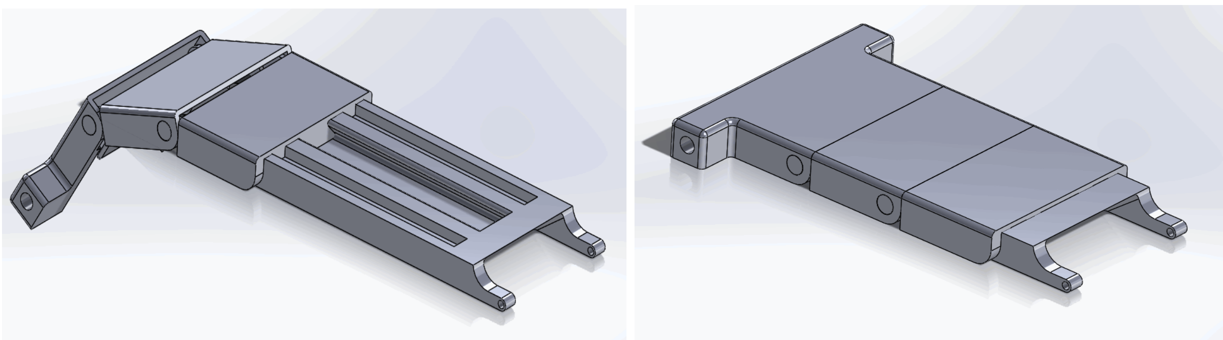


Figure 3-14(a) First iteration Slider Latch in extended (folded) position, **Figure 3-14(b)** First iteration Slider Latch in collapsed (unfolded) position.

3.4 Additional Concepts

In addition to the main ideas mentioned above, there are also other improvements that could be made to satisfy the design objectives such as improving the overall function and ease of use of the stroller. One of these ideas is to place small magnets in the joints of the stroller. This would assist in keeping the lower, middle, and upper legs semi-locked in place when trying to assemble the stroller. The magnets would provide just enough force to keep the joints together temporarily, but not so much force that it makes folding the stroller more difficult.

Another improvement that could be made is an increase to the length of the axle between two front wheels, or an increase to the wheel size. The current wheelbase is adequate, but there is definitely room to improve the stability. Extension of the front wheel forward a couple of inches or an increase in axle length of a few inches will add extra stability to the frame while still remaining within the size requirements of the design.

3.5 **Final Concept Model**

The final concept is a combination of several different components working together with Fred Park's current prototype to create a better-functioning and easier to use stroller. The two most significant newly designed components are a solution to the hub functionality, and a solution to the tensioning mechanism.

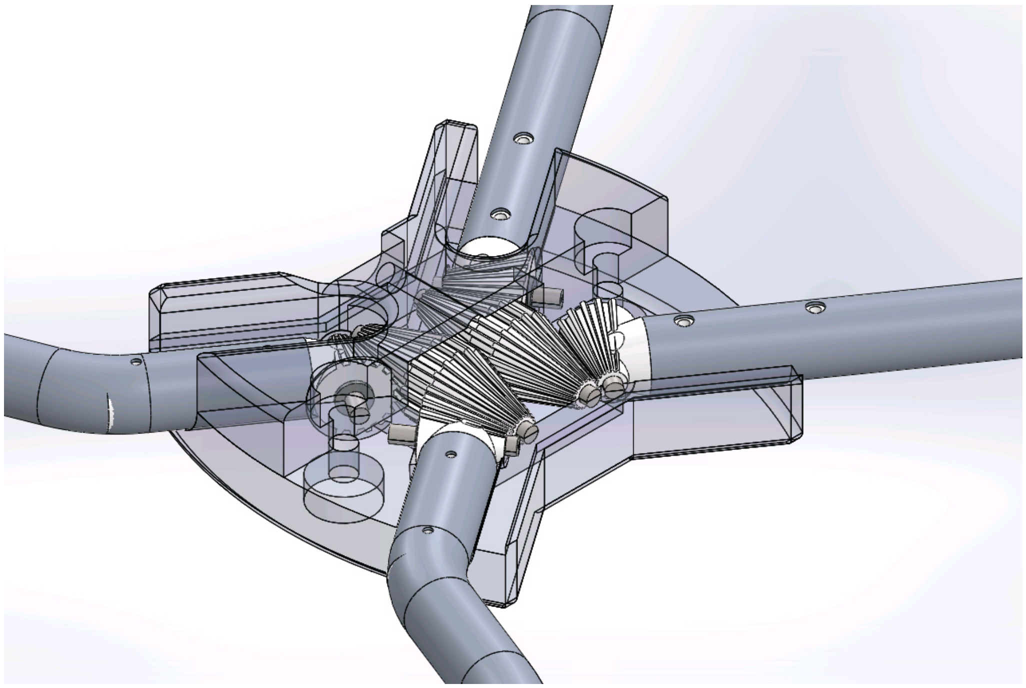


Figure 3-15 Geared hub with upper hub cross section

The geared hub (see Figure 3-15) is a partial solution to the problem that Fred described as causing the stroller to act like "a bag of bones." In other words, this is essentially an unstable assembly that the user must fuss with while attempting to unfold the stroller. The final design for the geared hub utilizes very intricately specified dimensions for custom gears that work together to extend all four spider legs simultaneously. There are four plugs, each topped with a segment of bevel gearing, that are inserted into the tubing of the spider legs. Each pair of the spider legs' bevel gear plugs mates with one bevel/spur combination gear that is located within the hub. These bevel/spur gears mate with one another to complete the gear train. All six of the geared components have 18 teeth and identical involutes, which creates a 1:1 gear ratio among them. Therefore, when just one of the spider legs is displaced, the gears are engaged and the other three legs are forced to move in unison with the first. This makes it significantly easier for the user because naturally all four legs will want to be either extended or collapsed. The gears are each mounted on a 3/16" steel axle which rests between the top and bottom sections of the hub. The hub is held together with two ¼-20 screws, which help to keep the axles in place and the gears from slipping. To make everything a bit more snug and take away any unnecessary clearances, a washer is placed on the axle of each of the four spider leg plug gears. Since size is a main constraint, the hub is designed to have just enough space to fit all of the gears. The grooves of the hub that the spider legs sit in when fully extended (in the stroller's

assembled position) help to hold them in place and also take a majority of the load off of the gear teeth when the stroller is in use.

The latching mechanism is an additional portion of the desired solution to keeping the entire stroller assembly together and intuitive to use for the customer. Since it is hard to tell which components will work without prototyping and testing them, there are currently two main contenders for the latching mechanism. The first is an improvement to the earlier discussed slider latch. After comparing carefully measured dimensions of the stroller's current geometry with the initial slider latch concept, it was determined that the design was not feasible in its current state. The concept was solid, but the design of the links were too long and thus left too much slack when fully assembled, but could not be shortened because they would not allow for the stroller to fold up completely. Therefore, a new telescoping design (see Figure 3-16) was created to achieve the same results as the original slider latch, but fix the issue of length in the links. This design is a modification of the lower latch to include a female dovetail groove down the middle of the top of the piece. This allows for the middle link of the latch mechanism, which has a male dovetail groove, to slide along the surface of the lower latch and decrease the length between the stroller's handlebars and the hub, thus removing some slack and aiding the user to assemble the stroller. The middle link also has two female grooves on either side of it. These grooves allow for the inward-facing male pins on the upper link to slide over the middle link and telescope down with it toward the hub. This new design allows for the entire latch to be three times as long as the lower latch when fully extended and in the folded position, but consolidate down to roughly the length of just the lower latch when in the unfolded position. The upper link can then be used as a lever by the user and pulled down to telescope the links on top of one another, making them rigid and linear as they mate with each other and approach the hub. Once the links are fully telescoped, a lock engages to keep everything in place and the stroller in its unfolded position until the user is ready to disassemble it.

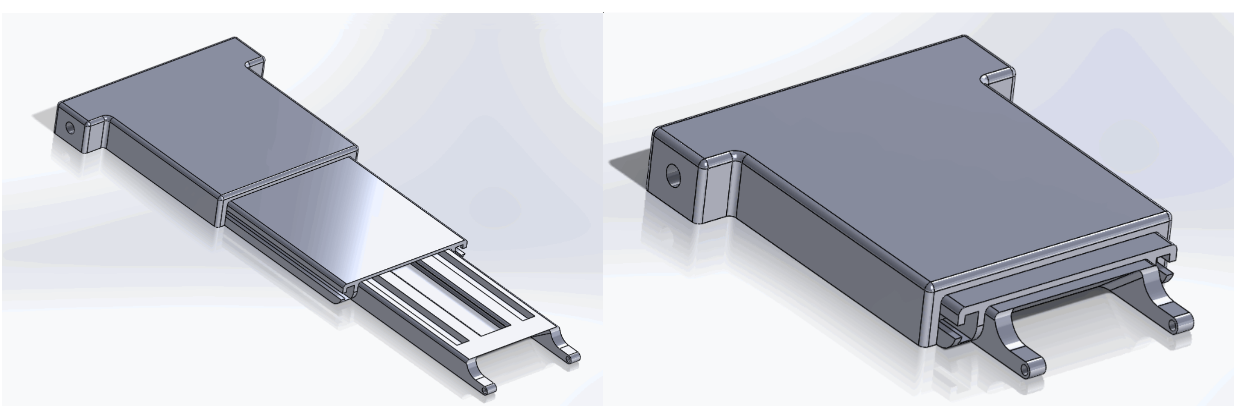


Figure 3-16(a) Second iteration Slider Latch in extended (unfolded) position, **Figure 3-16(b)** Second iteration Slider Latch in collapsed (folded) position.

3.6 Preliminary Analysis Results

Analysis was conducted in order to properly size the gears that fit within the hub. Since the size tolerances are very tightly constrained, the gears must be relatively small but still have large enough teeth to properly mate with one another. Additionally, for the legs to be fully vertical when folded and extending from the hub at the proper angle when unfolded, the bevel gears must have a precise contact angle to achieve this desired movement. To save some complication, the bevel portions of all the gears are designed to be identical, so that the teeth calculations can be consistent among all the gears. The calculations for gear sizing were done using equations from Shigley's Mechanical Engineering Design book. An Engineering Equation Solver (EES) file was created to perform the calculations and output the specific numbers needed to accurately design the gear teeth (see Appendix F). The results of the calculations provided the precise addendum, dedendum, and pitch circle values needed to create the necessary involutes for the gear teeth. The minimum number of teeth which can exist without interference was also calculated to be 13 teeth. This, in addition to all the other sizing values obtained, verifies that the gears are indeed possible to create and are able to mate together without interference.

4 Final Design

The final design of the foldable child carrier is a culmination of several design development and concept ideas with several revisions and iterations. The telescoping slider latch was chosen as the latching mechanism to be used in combination with the geared hub design.

4.1 Prototype Iterations

In order to obtain a final prototype design, several iterations were necessary to test the feasibility and functionality of each component. The initial designs and iterations were modeled in SolidWorks (as seen in the Chapter 3) before a design was decided upon for rapid prototyping.

The second iteration 3D print of the telescoping slider latch (see Figure 4-1) utilizes three pieces that slide together on dovetail grooves. The lower piece which is hinged directly to the hub has a female groove that the middle joint slides in linearly. It also has two snap-fit clips on either side that lock into the upper piece once all three pieces are collapsed and in the unfolded stroller position. The upper piece slides along the middle piece and is able to rotate once it is fully extended, allowing for the stroller to be folded easily while keeping all the tensioning (hub and latch) components attached. The middle piece also adds a third stage to the telescoping design, giving it a longer extended length to accommodate the necessary geometry in the folded position.

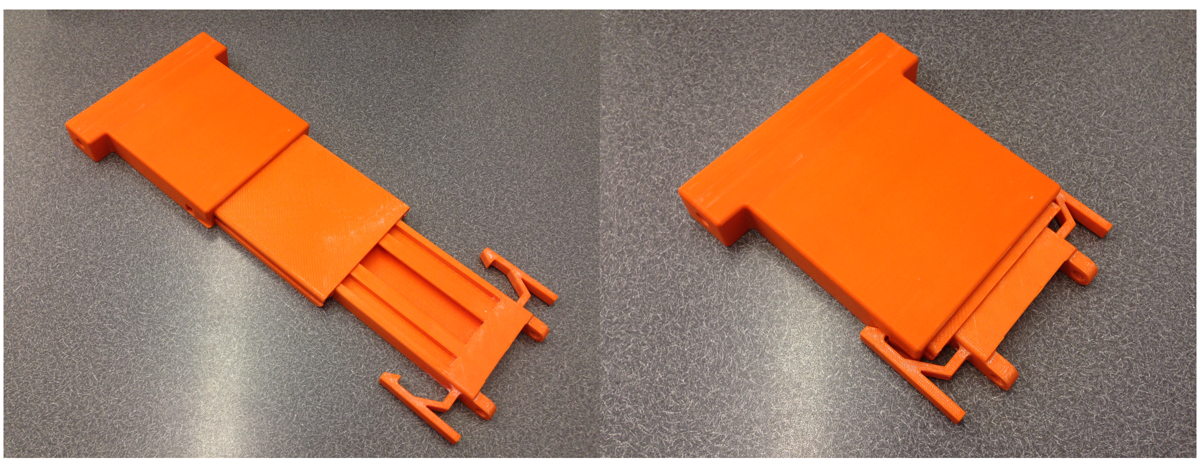


Figure 4-1(a) 3D printed Telescoping Slider Latch in extended (unfolded) position,
Figure 4-1(b) 3D printed Telescoping Slider Latch in collapsed (folded) position

The geared hub, as described earlier, uses six interfacing gears within a customized hub to aid the spider legs in moving simultaneously. The initial 3D printed prototype can be seen in Figure 4-2.

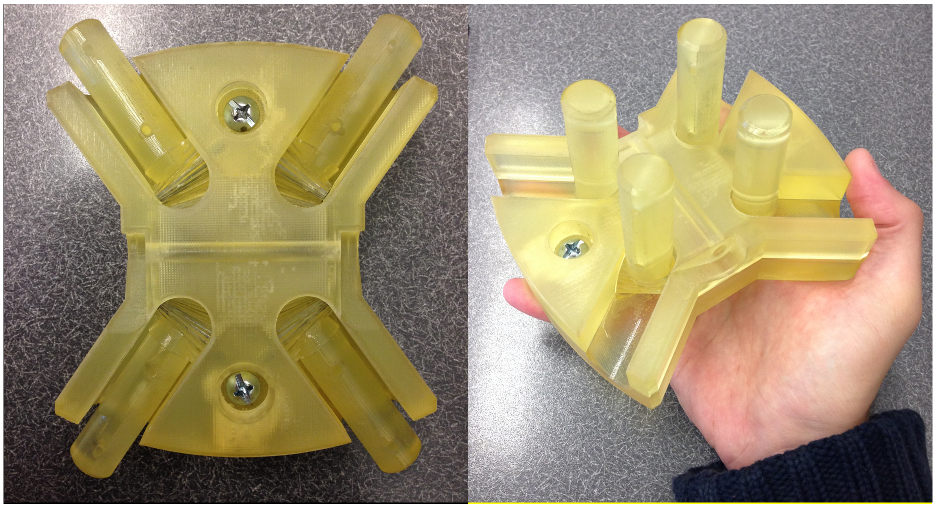


Figure 4-2(a) 3D printed geared hub with spider legs in unfolded position, **Figure 4-2(b)** 3D printed geared hub with spider legs in folded position.

The geared hub and telescoping slider latch components work together to make the stroller assembly more user friendly. When combined (see Figure 4-3), they help the legs move simultaneously and also keep all the components attached during folding and unfolding, which is more intuitive for the user.

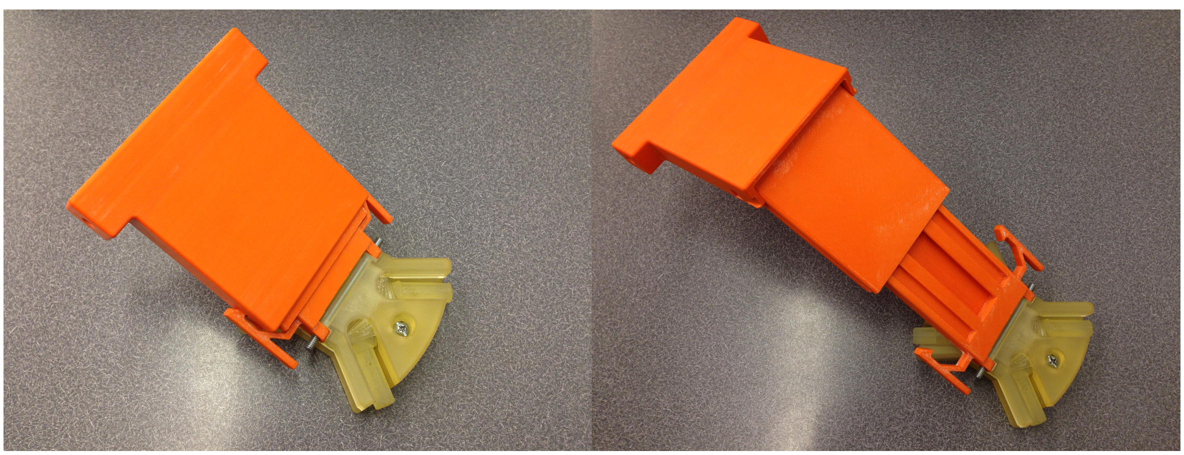


Figure 4-3(a) 3D printed Hub and Slider in collapsed (unfolded) position, **Figure 4-3(b)** 3D printed Hub and Slider in extended (folded) position

4.2 Detailed Design Description

After testing the hub and latch component combination (seen in Figure 4-3) for functionality, the general design was verified to be effective, but it quickly became evident that further redesign was necessary.

The slider latch design, after functionality testing with the first 3D model, worked just as intended with just a few minor modifications necessary in order to optimize its performance. First, the overall extended length was just a little short, which would restrict the stroller from being fully packed down. Also, the bottom link was determined

to be a bit too wide, which caused interference problems with the spider legs when attempting to compact the stroller. The FullCure720 resin material used to print the first iteration geared hub quickly failed under applied loads. The resin material was too soft, which caused the gear teeth to shear when a load was applied to rotate the spider legs. Additionally, the two fasteners used to connect the hub together proved to be insufficient. They did not provide enough clamping force, so the two halves of the hub actually began to warp and separate at the edges, causing further issues with the gear teeth meshing.

After evaluation of the initial prototype and more iterations of the base design, final iteration models were created in SolidWorks, as seen in Figures 4-4 and 4-5.

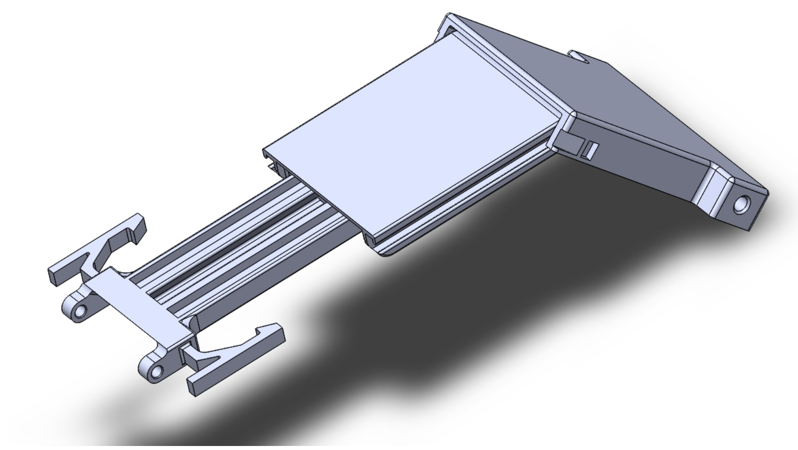


Figure 4-4 Final iteration model of Slider Latch

The final slider latch design (Figure 4-4) was slightly modified from the second iteration (Figure 4-1) in order to make it narrow enough and long enough to allow the stroller to fully fold and compact to its smallest size. The bottom link was decreased in width such that the interference with the spider legs when folding is minimized, without compromising the latch's strength or sliding capabilities.

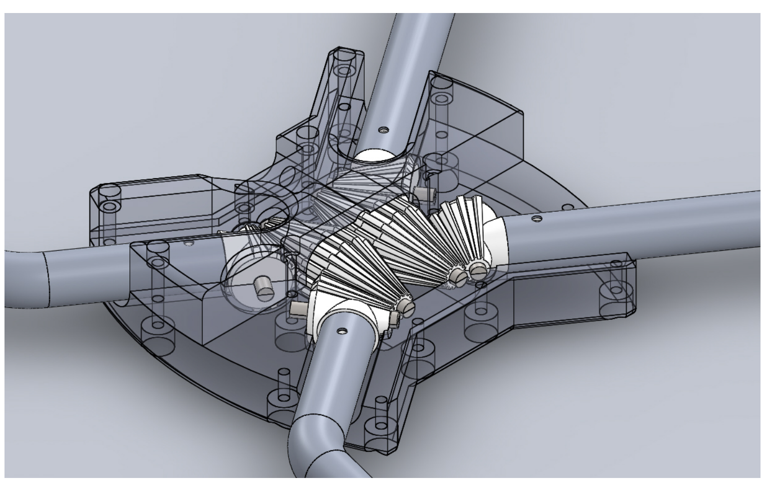


Figure 4-5 Final iteration model of Geared Hub

The final geared hub design (Figure 4-5) was modified quite drastically from the first iteration print (Figure 4-2) in which it failed due to material properties and insufficient gear and hub design. The hub was redesigned with several more fasteners along the edges of the hub to ensure proper clamping force which is required to keep the gears from moving around within the hub's cavity. The gears' involute profile was also slightly redesigned (see Appendix F) so that the teeth can mesh together better, allowing less potential for shearing. In addition to these redesigns, the hub's final prototype iteration model was printed using ABS material, rather than the FullCure720 resin as before. The ABS material is a bit stronger and more rigid, which solved the problem of broken teeth and a warping hub.

In order to accurately test the redesigned hub and latch components, the entire stroller frame was prototyped. Several manufacturing processes (addressed later) were utilized to recreate a variation of the original prototype designed by Fred Park. Some basic modifications were made in order to simplify manufacturing and utilize the limited available resources. Once the entire frame was put together with the intended geometry, including the newly designed hub and latch components, verification testing became feasible. Since the folded/unfolded sizes and tension on the system are critical to the overall operation of the stroller, it needed to be entirely prototyped to verify that the new components actually worked as intended. This entire prototype, with the fully functioning hub and latch components, can be seen in Figure 4-6.

Figure 4-6(a) Rear view of final prototype stroller with redesigned hub and latch, **Figure 4-6(b)** Close-up of hub and latch on final prototype

The new hub and latch components, when assembled with the rest of the recreated stroller frame, effectively replaced the old design of Fred Park's hub and latching system. They proved to provide proper tension on the frame components by holding up when in the unfolded position, and packing up nicely when in the folded position.

4.3 Material Selection

Ideally, the final result of this design will be mass-produced for consumer use. The design process, however, is far different than the mass-production process because it requires multiple trial and error runs before the product is finalized and ready to be repeatedly produced quickly and cost-effectively. Most components of the marketable design will be injection molded, which requires a large up-front cost for the tooling, but is effective for producing mass quantities with tight tolerances. The purpose of this project, though, is mainly to achieve a design and create a prototype that is worthy of transitioning to the marketable phase.

Most of this project's prototyping needs were achieved with the use of 3-dimensional printing technology. 3D printing is extremely beneficial for this kind of project because it is very iteration-friendly; a design can go from a drawing in CAD software to a solid part in a few hours with just the press of a button, and then tweaked and back through the iterative process relatively easily. This avoids the necessity to spend hours with extra software and program a CNC or other manufacturing process to create a part. For things like complex custom gears and precise components, 3D printing proved to be really the only feasible and efficient method for accurate prototyping.

The most affordable and available resources for these needs are two on-campus 3D printers, one which extrudes a thermoplastic layer-by-layer, and one which uses light to cure a resin with very high resolution. Since the geared hub design requires very small intricate gear teeth and tight tolerances, the photo-cured resin printer, which uses a material called FullCure720 (see Appendix C) seemed like the best option. This material is a bit more expensive, but the layers are hardly noticeable and therefore were thought to be good for producing precise gears. After several pieces were produced with the FullCure720 resin material, however, it was discovered that this material is not actually as good as once thought. The resin material after several weeks began warping and became very soft. This caused many parts to fail after extended use, most notable the gear teeth in the hub design. Besides the geared hub, there were several other pieces of the assembly that were 3D printed using the FullCure720 material. Many of the pieces were taken from Fred Park's original design and tweaked slightly to accommodate the new features and components (see Figure 4-7).


Figure 4-7 Some of the 3D printed joint and connector pieces using FullCure720 material

Several of these FullCure720 printed pieces ended up failing once more of the assembly was put together, which required reprinting using the alternate 3D printer, detailed below.

The other 3D printer, which extrudes a material called acrylonitrile butadiene styrene (ABS) ended up being used for most of the rapid prototyping needs for this project (see Appendix C for material properties). There are several reasons that ABS proved to be superior for prototyping the stroller components. First, it does not allow as tight of tolerances as the resin material, but it was discovered that the 0.010” layer thickness that it provides is sufficient for this project’s needs. Next, it is much more rigid than the FullCure720 material, which is desired for areas that take large loads such as the gear teeth. Also, is a bit more flexible than FullCure720, which is required for the snap-fit locking mechanism on the sliding latch. Finally, ABS is much cheaper to print with than the FullCure720 resin material.

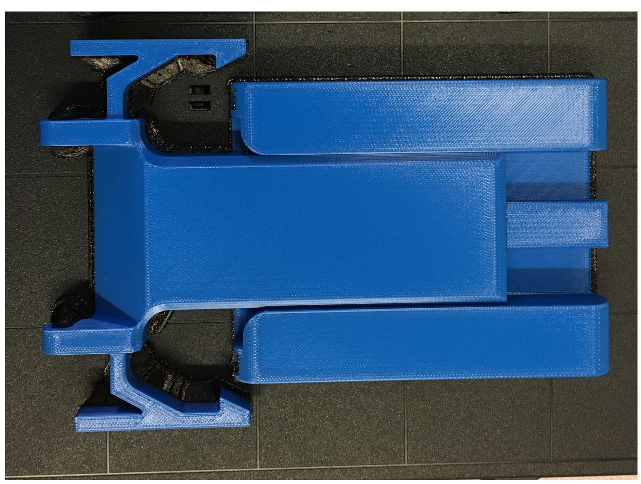


Figure 4-8 A portion of the 3D printed Slider Latch in ABS on the print tray

The other portions of prototyping are done with easily sourced stock material such as EMT conduit tubing and copper pipe for the spider legs and frame, steel rods for the gear axles, and basic hardware to hold the components together. These materials were selected because they are readily available at a local hardware store for a reasonable price, and can be easily customized by the team in a machine shop for no labor costs. Initially, thin-walled copper pipe was thought to be the easiest to bend to create the complex geometry for the spider legs. However, after several attempts with an EMT conduit bender, the thin wall proved to be too difficult to accurately bend and often kinked and crushed. Therefore, a thicker walled copper pipe was opted for and after some struggling, ended up working for the bends for two of the spider legs found on the final prototype. The best material for precise bending, however, ended up being steel EMT conduit. Although it appeared thick and rigid, it shaped nicely around the curves of the conduit bender and effectively created the desired spider leg geometry for the other two legs. The steel rods as axles were chosen because their rigidity allows for the gears to stay in place and mate consistently, and their relatively low friction against the ABS material allows for smooth gear rotation.

4.4 Cost Analysis

Since 3D printing is the quickest and easiest way to create a design for prototyping and testing purposes, a majority of this project's costs are dedicated to 3D printing components. The cost of 3D printing is not exactly cheap, but it is worth it for the time saved by attempting to create the same high-precision pieces with an alternate manufacturing technology. The biggest cost for the 3D printer that is readily available for use is simply the start-up cost. It is a flat rate of $120 just to turn on the machine, with an additional up to $0.40 per gram of printed material, depending on which material is used. For example, the geared hub subassembly (seen above in Figure 6-2) cost around $250 to print all the parts in one job. With several iterations of each design taken into consideration, an estimated $2,000 is required for 3D printing needs. Besides the 3D printing, a limited amount of other materials and stock items are required to complete the project. A bill of materials for these items can be found in Appendix D, and will cost no more than a few hundred dollars to source.

Beyond the scope of this project is the design for mass-production and market sales. The cost analysis for this is obviously much more complex and requires more specific tooling and material analysis to save on cost. Since most of the pieces will be injection molded, as discussed earlier, the cost will increase slightly for the new design when compared to Fred Park's new design simply because there are more pieces in the new design. The stroller, when mass-produced, will likely have one master mold that can produce all the molded pieces for the assembly in one job. Therefore, adding the newly designed extra pieces to this master mold will increase the upfront costs significantly, but in the long run when thousands of parts are created, the cost per part will not change much. The tooling cost for a master mold will be tens of thousands of dollars upfront, but if the product is successful this initial investment should pay for itself in time. Besides the injection molded pieces, there will be limited other custom manufactured components such as the tubing for the frame, the fasteners, the wheels, and the fabric seat. These components, when purchased and manufactured in bulk, will not make up a

majority of the total cost for production. Even with manufacturing and assembly costs, the stroller should be able to host a competitive price on the market and still return a profit.

A rough cost analysis can be found in Appendix E, outlining the approximate cost for mass production of one stroller unit. It is estimated to cost around $55 to manufacture one stroller and the upfront tooling cost is assumed to be $150,000. Then, with an arbitrarily decided profit margin of $45, which assumes a stroller unit sale price of roughly $100, it is required that around 3,300 stroller units are sold before breaking even.

4.5 Safety Considerations

The fact that this stroller is created to be used by parents with young children inherently indicates a strong focus on safety as a design consideration. Each component of the design is intended to be as safe as possible for both the user and the occupant, and any component deemed to be unsafe, regardless of its effectiveness at solving the given problem, shall not be considered in the final design. For the United States stroller market, unsafe designs are illegal and therefore unmarketable. The final design is to pass the ASTM F833 Standard Consumer Safety Performance Specifications for Carriages and Strollers. The standards relevant to the specified design goals of this project, in summary, require that there are no hazardous pinch points or hole openings for the user and occupant to access, as well as a latching mechanism to prevent unintentional folding. Additionally, the stroller assembly must pass a stability test which restricts the stroller from tipping over when used as intended on a sloped surface. These requirements have been thoroughly considered in the design of each component in order to keep both the user and occupant safe during normal use of the product.

The geared hub, which contains some of the most obvious potential pinch point locations, is safely encased within the hub such that no fingers can be exposed to the meshing gear teeth. Additionally, all components that are directly exposed to the user and the occupant have been designed such that there are no sharp corners or edges that can cause harm. The latch mechanism is designed such that there are no pinch points that a finger can get caught in while folding or unfolding the assembly.

The main concern with the final design are pinch points. The most likely place for pinch points to occur include the joints, wheel latch, and the main latch on the hub. Ideally, the fabric will prevent the child from accessing most of these pinch points, but given the unique manner in which the stroller folds, extra measures may be necessary.

Material strength does not appear to be a concern, but a static analysis will be necessary to ensure that the material can support the possible loads. The stability of the stroller may also be a concern. As stated above, the device does pass the testing standards, but there is room to improve. In order to make the stroller successful in the market, stability should be improved so that there are no worries about the stroller tipping over when on an incline or uneven surface.

4.6 Maintenance and Repair Considerations

In its marketable state, this product will be much like any other stroller on the market today in terms of functionality and longevity. The individual components are designed to have a long life and should not break under normal intended use. The maintenance considerations are typical of any other consumer product; the user is encouraged to take care of their product to maintain its integrity and reliability. If specific parts of the stroller fail, however, replacement parts will be easily available because of nature of mass-produced injection molded pieces. When replacement parts are obtained from the manufacturer, the user should be able to easily replace the broken part and repair the product with common household tools. Many of the components of the stroller are simply screwed together, which allows for easy assembly and disassembly of specific components.

5 Product Realization

5.1 Manufacturing Processes Employed

For this project, 3D printing was the main manufacturing process that was employed. Much of the design relied on rapid prototyping in order to verify that the component functioned well with the overall design. Using rapid prototyping techniques, components could be modified and improved very quickly to satisfy the iterative design process. This process was used extensively for the production of the hub and latch components.

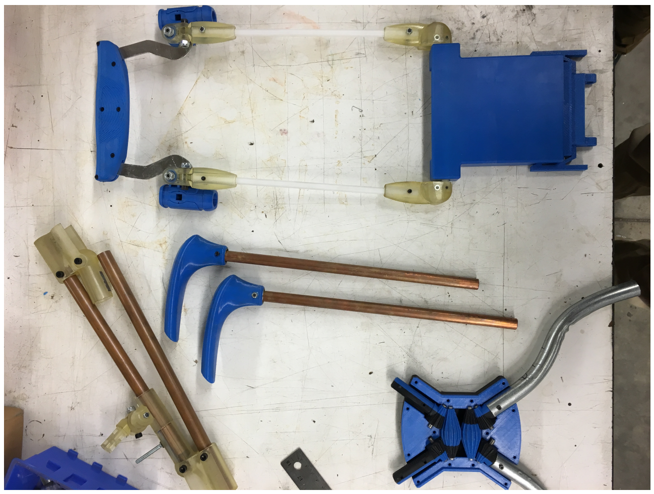


Figure 5-1 Final Prototype assembly build in process

Besides the rapid prototyping utilized for the main design components of this project, several other manufacturing techniques were required to produce an entire stroller frame for testing and design verification of these components. One of these manufacturing technique used throughout the project was pipe bending. The “spider” legs on the stroller require fairly accurate bend geometry and angles in order to maintain functionality and overall dimensions when collapsed. A ½’’ Conduit Bender, similar to what an electrician would have, was used to create the bends in both the frame and the legs of the stroller. After several attempts, it was discovered that wall thickness was critical in regards to the pipe kinking and being crushed beyond use. Using a thin-walled (type M) copper pipe, it was nearly impossible to avoid kinking the pipe. However, when the wall thickness was increased (such as with type L copper pipe or EMT steel conduit), it was much easier to produce the required bends without compromising the integrity of the pipe.

A number of other manufacturing processes were employed throughout the duration of the project including, but not limited to: drilling, sawing, cutting sheet metal and threading holes.

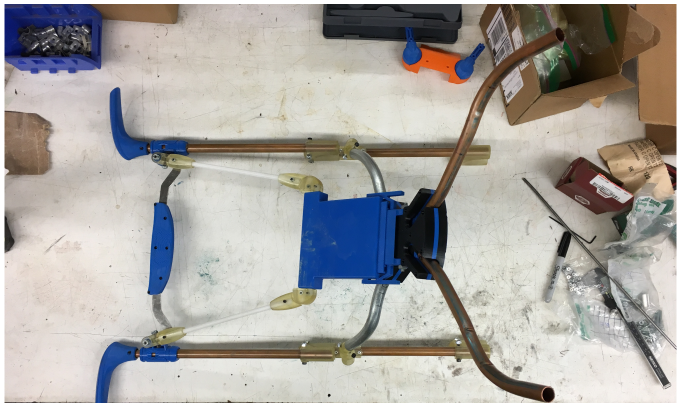


Figure 5-2 Final Prototype assembly testing structure

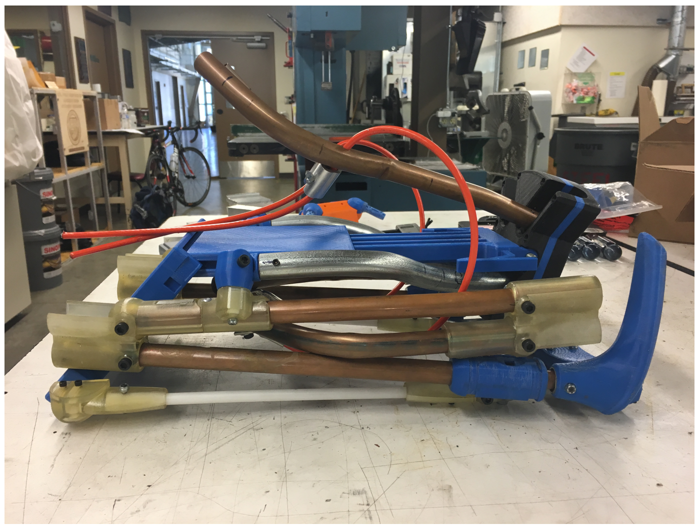


Figure 5-3 Final Prototype assembly build near completion

5.2 How Prototype Differs from Planned Design

The final prototype for this project was very close to what was originally planned, however, some of the materials and dimensions were modified. Fred's original prototype used a much stronger pipe for the frame, as well as extruded aluminum legs. The pipe that was chosen for the final prototype was a decision based on the effort needed to bend it as well as the material cost. The copper pipe and conduit were much easier to bend with hand tools and they were also more readily available in case a mistake was made. As for the legs, the extruded aluminum allowed for very strong structures with complex 3D bends. For ease of manufacturing and with the limited resources available, it was necessary to simplify the geometry of these bends to 2D for this project's prototype. This was not ideal, but given budget and time constraints, it was adequate enough to demonstrate proof of concept. As stated before, many of the components were 3D printed. While this allowed for easy modification and rapid production, the components really are not capable of handling loads. This prevents any realistic loading testing to be conducted, but again, effectively demonstrates proof of concept.

5.3 Recommendations for Future Manufacturing of Design

As this project progresses and continues into later stages of development, there are a few manufacturing considerations that should be addressed. The majority of the components are fully developed, so aiming toward mass production is the next step. For most of the 3D printed parts on the prototype, injection molding is likely the easiest and most effective method for mass production, so this should be planned accordingly. The frame and legs should be bent professionally by machine. The best solution would most likely be a jig that is set to replicate the required bends consistently. Casting the legs or contracting custom pipe extrusions is possible, but may not be the most cost effective route. The main manufacturing concern is the latch. As it stands, the bottom two pieces are entrapped. While this is easily accomplished using 3D printing methods, this presents certain challenges from a manufacturing standpoint. There are two possible options to address this problem. The first is to find a solution that allows for easy manufacturing of the part. This would require more research and development in manufacturing techniques, or even a new innovation. The second option is to completely redesign the latch. It may be easier to develop a new design that employs the same concept and has similar functionality. From an engineering perspective, the latch performs beautifully. However, it is not a feasible design to be employed in a marketable product.

6 Design Verification

The main goal was to make the design easier and more intuitive to use. This was a confirmed success. With the addition of the geared hub, the stroller's spider legs are now much easier to control. Instead of flopping around during assembly and disassembly, the spider legs can now be held in either the folded or unfolded position with a single hand, as well as be moved open and closed with a single hand. This is a major improvement to the ease of use. With the geared hub, the user will no longer struggle with trying to hold down multiple spider legs, while simultaneously attempting to apply the latch. In addition to these benefits to the user, the geared hub does not take up any more space than the hub in the original design. Overall, the new hub design is an obvious upgrade with very few drawbacks.

Figure 6-1(a) Final Prototype design verification process (folding), **Figure 6-1(b)** Final Prototype design verification process (unfolding)

The slider latch design was also a success. The main benefit of the slider latch is that the whole latch mechanism remains connected. This was effective in addressing a confusing problem users faced when assembling the stroller. With the original two-piece latch, users were very confused as to how the latch was supposed to work when assembling the stroller for the first time. The slider latch eliminates this confusion by leaving both parts of the latch permanently connected. With regards to saving time during assembly, there was not a significant increase. Users familiar with both the slider latch and the two piece latch can assemble the strollers in a similar amount of time. The slider latch still requires two hands to use. Despite the fact that the slider latch is larger in the stroller's folded position than the original two piece latch, the latch manages to fit entirely into the stroller's original folded envelope. This results in no net increase in the stroller's folded footprint. In the unfolded position, the slider latch almost exactly matches the original latch's footprint, thus contributing no net increase to the footprint of the stroller in the folded position either.

Figure 6-2(a) Testing Final Prototype latch mechanism (extending), **Figure 6-2(b)** Testing Final Prototype latch mechanism (collapsing)

Another small improvement to the stroller design was the addition of magnets to the hinges of the rest of the stroller's frame. Although only a limited amount of time was spent on this addition, it was an improvement worth pursuing. With the addition of the magnets, it becomes much easier to keep parts of the frame in the locked position. This was an obvious improvement to the stroller, but it still needs some refinement.

After much design verification, it is safe to say that both the geared hub and the slider latch are improvements to the stroller's design. The geared hub directly improves ease of assembly and assembly time, and the slider latch eliminates a major design flaw that could cause potential buyers to never even consider trying the stroller.

7 Conclusions and Recommendations

One idea that was not able to be tested was a gear-linkage hybrid design. Instead of the spider pole legs being linked together by two bevel gears and a combo-bevel-spur gear (as done in this project's design) they would be linked together by a rotating three-piece linkage. The two linkages on the bottom and top of the hub would be connected by two spur gears. The main advantage of a gear-linkage hybrid hub over the current gear hub design is that there would be fewer points of failure for the hub. The initial iteration of the geared hub experienced failure of the spider pole gear teeth. This was probably due to the gears being printed on the Eden printer, whose resin material was softer than expected under load. Eliminating the spider pole gears from the design would drastically improve the reliability of the hub.

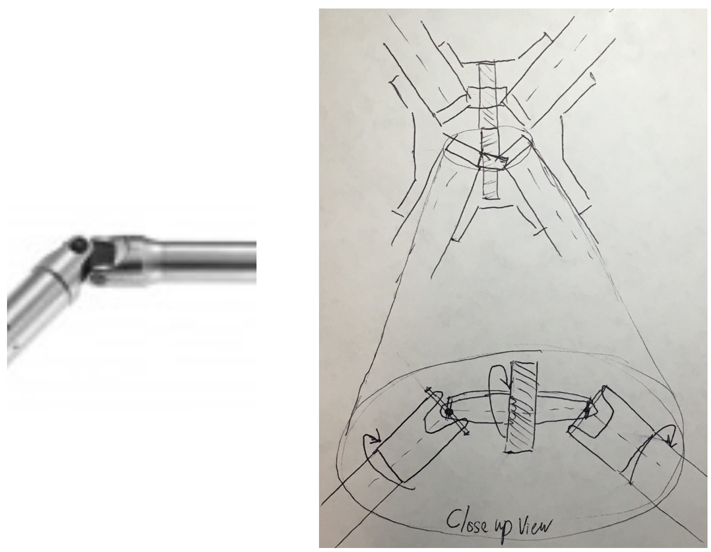


Figure 7-1 Possible alternate hub design idea

Another idea worth exploring is the two way spring idea that was presented in the initial design development. However, this was not one of the designs that the group went ahead with due to the fact that there were so many other ideas that were a higher priority.

The clips on the side of the latch design were not meant as a final solution, but simply intended to work well enough so that the slider aspect of the latch could be tested. With the material used, fatigue failures are imminent on the clips after many cycles of locking and unlocking the latch. A more robust locking mechanism would be necessary for a market ready product.

In the same vein, as previously mentioned, the lower and middle components of the slider latch were made as entrapped parts to speed along manufacturing time and minimize printing costs. An entrapped design is simply not practical for a manufactured product, and will likely need modifications to be easily produced.

Another potential area of focus to improve the overall design for the stroller is the front wheel. This portion of the stroller design was not a main point of focus during the design process of this project. An initial area of concern from Fred Park regarding safety was the stability requirement of the stroller. He noted that testing different axle lengths between the front two wheels may increase the stability of the overall frame, but change the geometry. This is definitely an idea worth pursuing for the future success of the product on the market. Also, the front wheel hinge, in its current state, is an extra step required when folding and unfolding the stroller. It would be ideal if this step could somehow be made easier or even eliminated, to make the entire assembly process quicker for the user.

One of the biggest time sinks in the project was re-creating a new stroller prototype to test the hub and latch designs. One big recommendation would be to use EMT conduit, exclusively, when bending legs for a new prototype. EMT conduit is much easier to bend than copper pipe. It is also much less likely to kink and works with standard pipe benders.

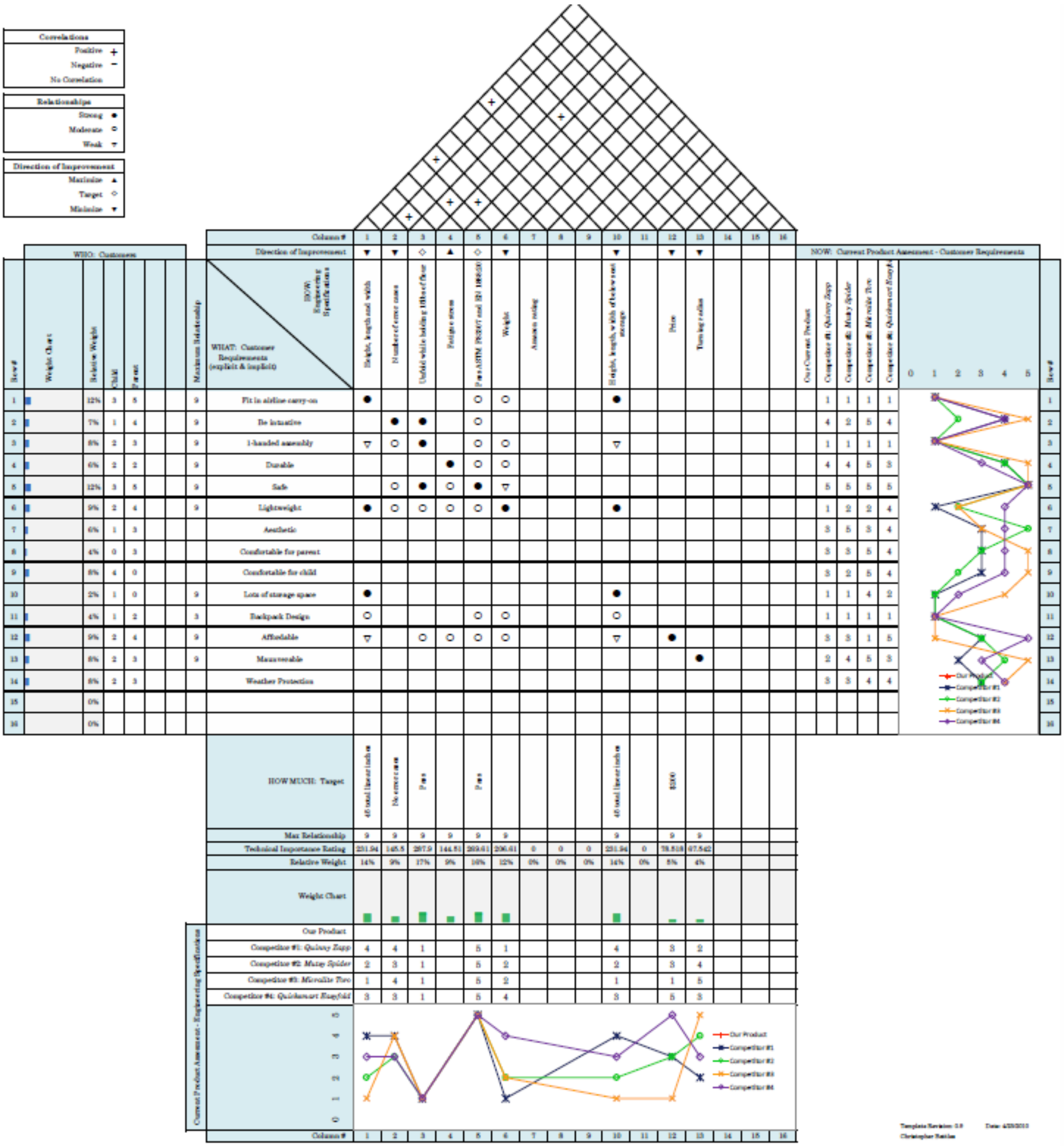
Another important tip for future prototypes is to not use the Eden 3D printer for prototyping. The resin that the Eden prints with is very soft and becomes brittle and shrinks with age. Many of the parts on the prototype that were printed out of resin broke and were reprinted in ABS. The ABS printed parts are much stronger than the resin parts and only one of them broke during prototyping. The only reason that the initial prints were done in resin was for the superior resolution of the models, which was of particular concern when printing the gears. However, the high resolution proved to be unnecessary, as the ABS printer was sufficient enough. Lastly, printing in ABS is much faster and cheaper.

References

ASTM Standard F833-13b, "Standard Consumer Safety Performance Specification for Carriages and Strollers," ASTM International, West Conshohocken, PA, 2013, www.astm.org.

Budynas, Richard G, J K. Nisbett, and Joseph E. Shigley. *Shigley's Mechanical Engineering Design*. New York: McGraw-Hill, 2011. Print.

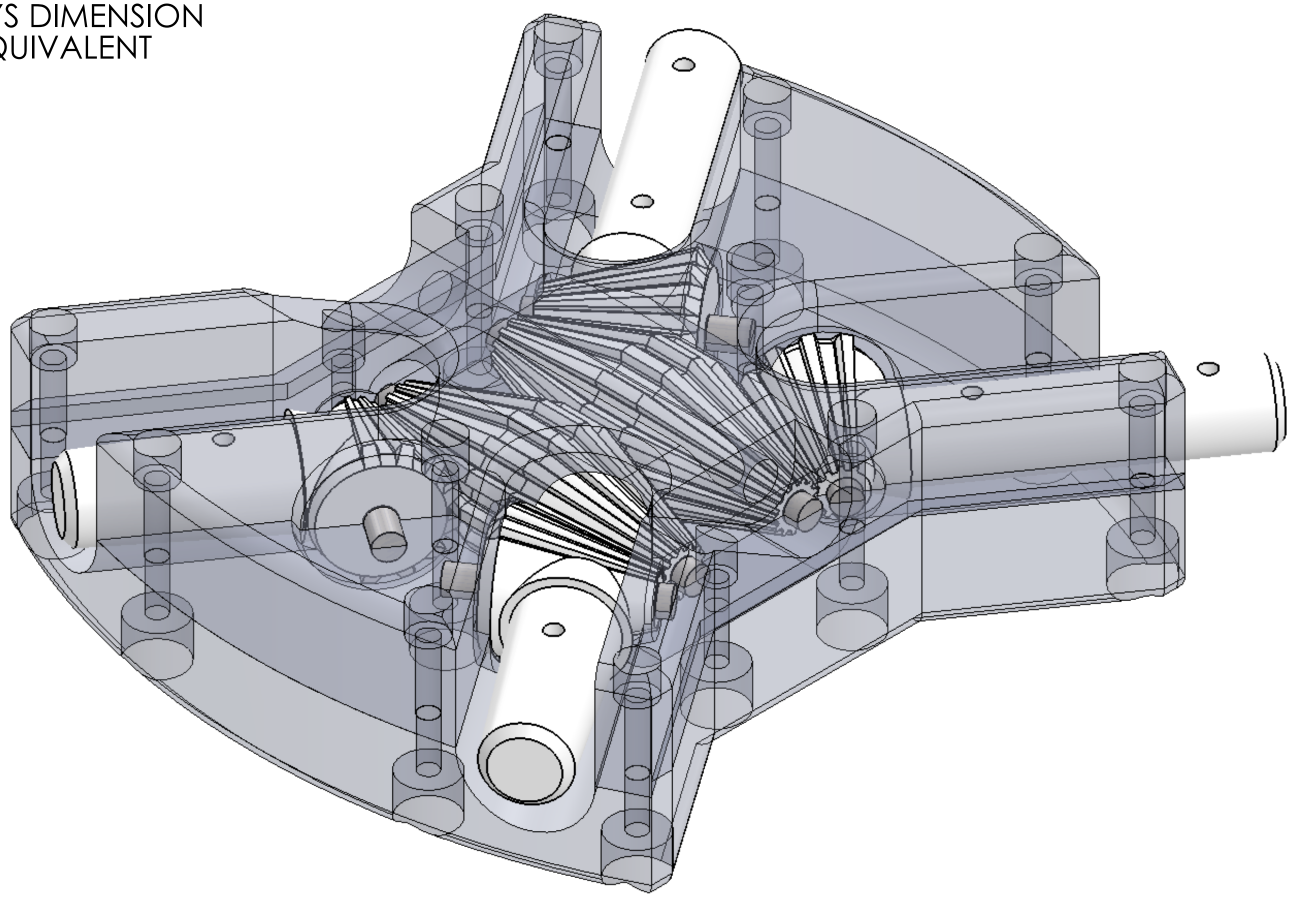
Appendix A. Quality Function Deployment (QFD)



Appendix B. Drawings

- Geared Hub Assembly
- Geared Hum Bottom
- Geared Hub Top
- Spider Pole Gear 1
- Spider Pole Gear 2
- Center Hub Gear
- Slider Latch Top Link
- Slider Latch Middle Link
- Slider Latch Bottom Link

ALL DIMS. AND TOLS. ARE AS
PER STRATASYS DIMENSION
1200ES OR EQUIVALENT
PRINTER



SCALE 1 : 1

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SCALE: 1:1	TOLERANCE: NA	TITLE: GEARED HUB ASSEM	
UNITS: Inches	NEXT ASSY: NA	MATERIAL: NA	
DATE: 10/7/2015	DWG #: NA	GROUP: MORPHTECH CHILD CARRIER	

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5 4 3 2 1

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1200ES OR EQUIVALENT
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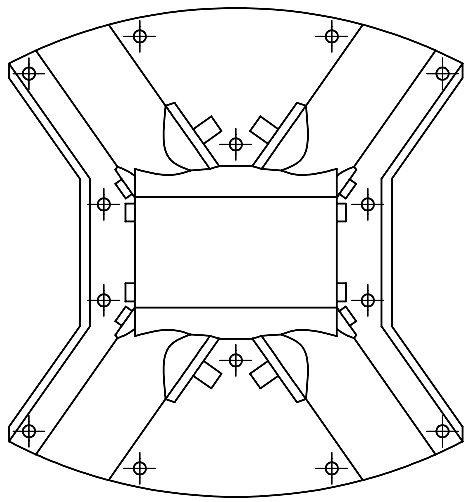

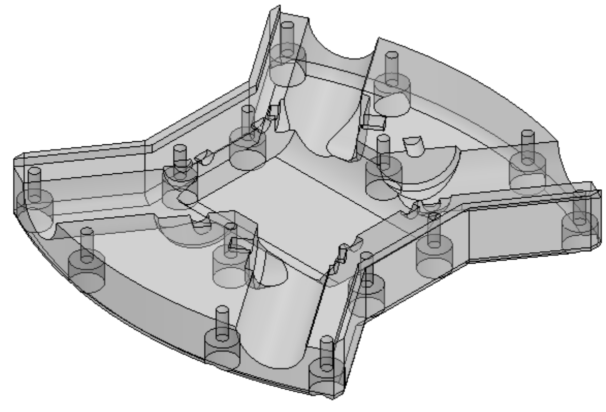

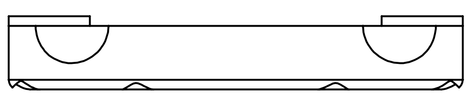

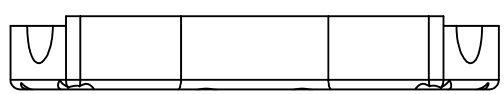

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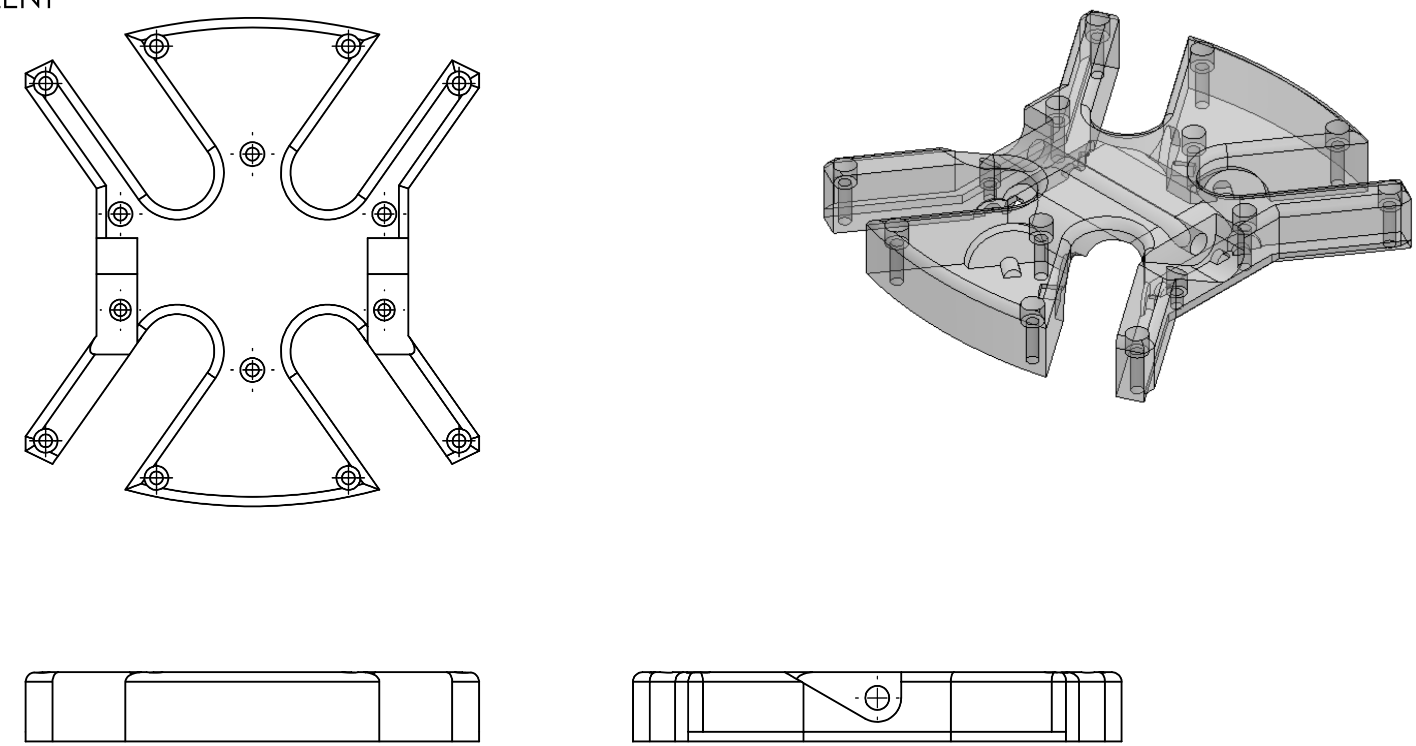
DATE: 10/7/2015	DWG #: NA	GROUP: MORPHTECH CHILD CARRIER	

5 4 3 2 1

ALL DIMS. AND TOLS. ARE AS
PER STRATASYS DIMENSION
1200ES OR EQUIVALENT
PRINTER



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UNITS: Inches	NEXT ASSY: NA	MATERIAL: NA	
DATE: 10/7/2015	DWG #: NA	GROUP: MORPHTECH CHILD CARRIER	

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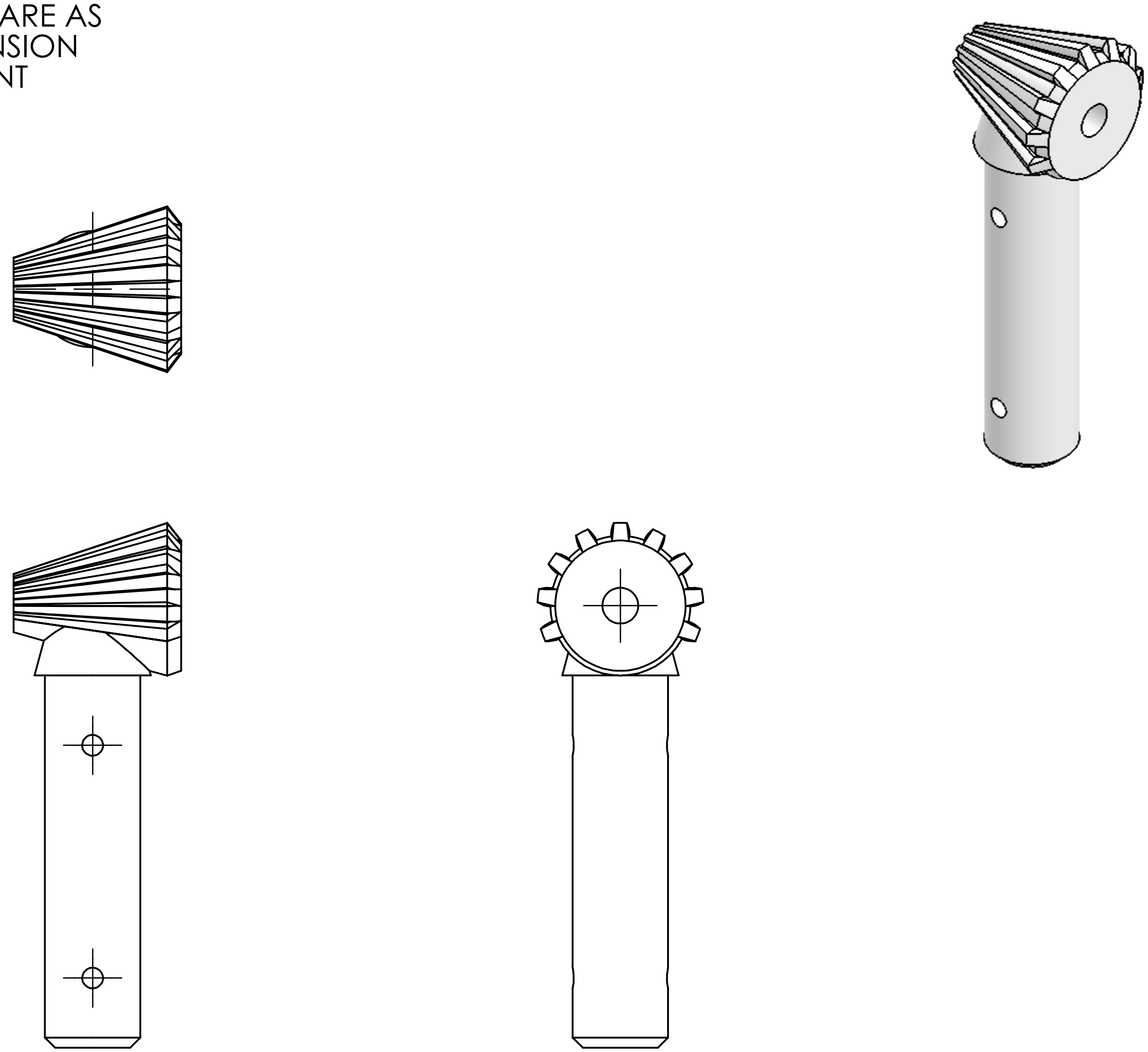
ALL DIMS. AND TOLS. ARE AS PER STRATASYS DIMENSION 1200ES OR EQUIVALENT PRINTER



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UNITS: Inches	NEXT ASSY: NA	MATERIAL: NA	
DATE: 10/5/2015	DWG #: NA	GROUP: MORPHTECH CHILD CARRIER	

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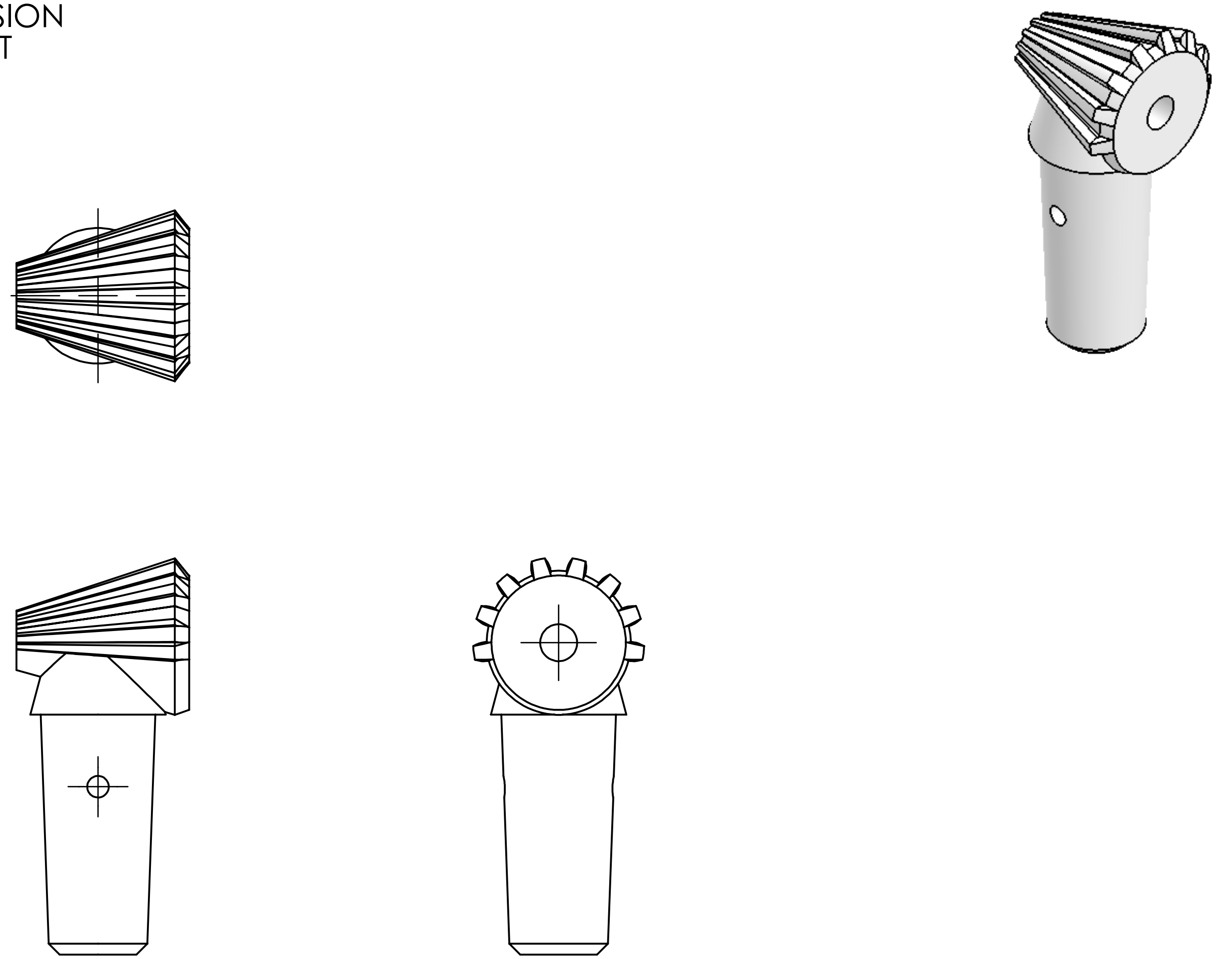

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DATE: 10/7/2015	DWG #: NA	GROUP: MORPHTECH CHILD CARRIER	

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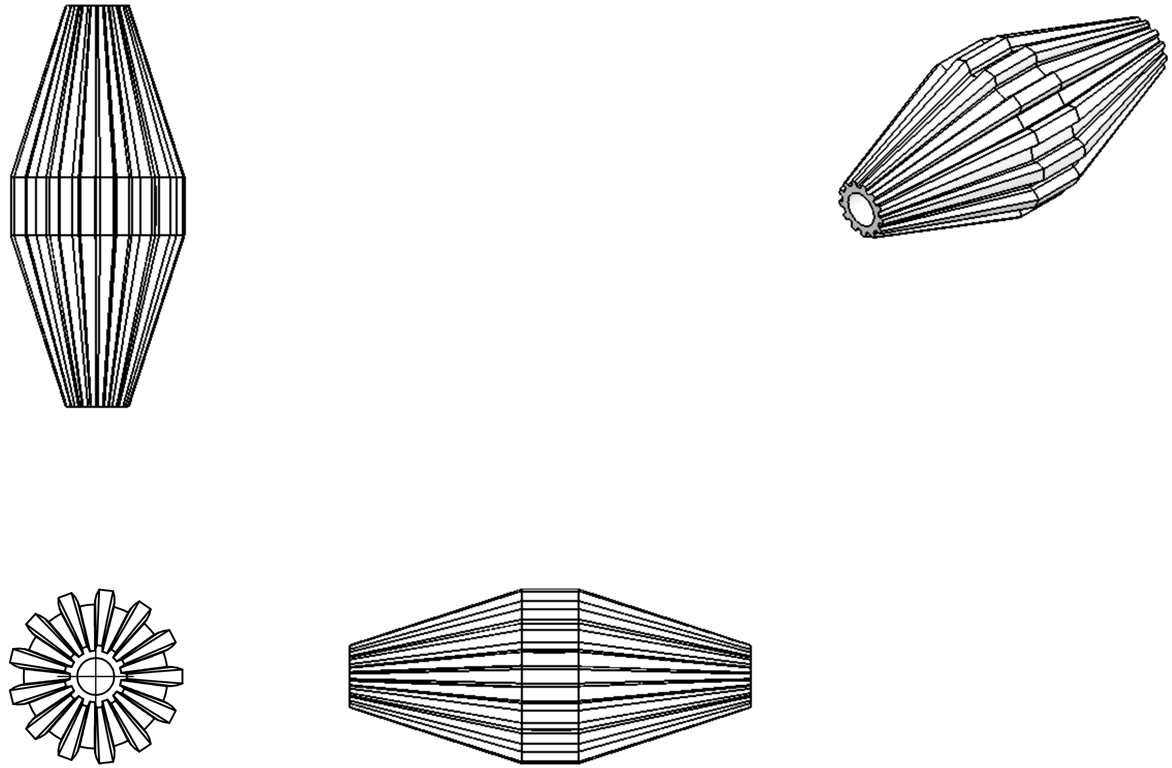
PER STRATASYS DIMENSION
1200ES OR EQUIVALENT
PRINTER



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NOTE: DIMENSIONS AND
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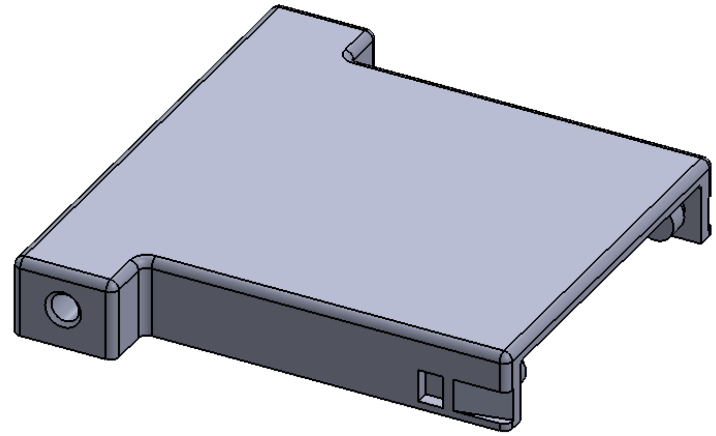
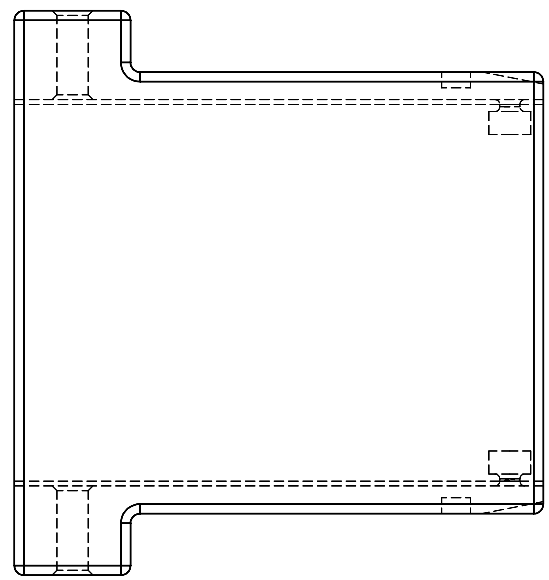
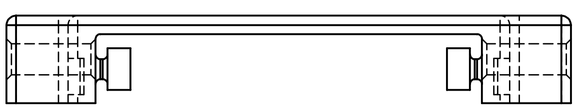
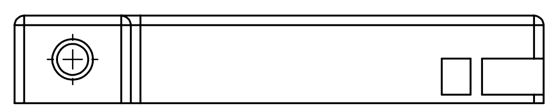
OR EQUIVALENT 3D PRINTER.



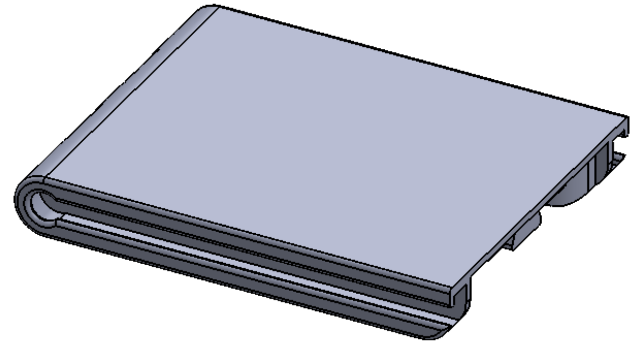


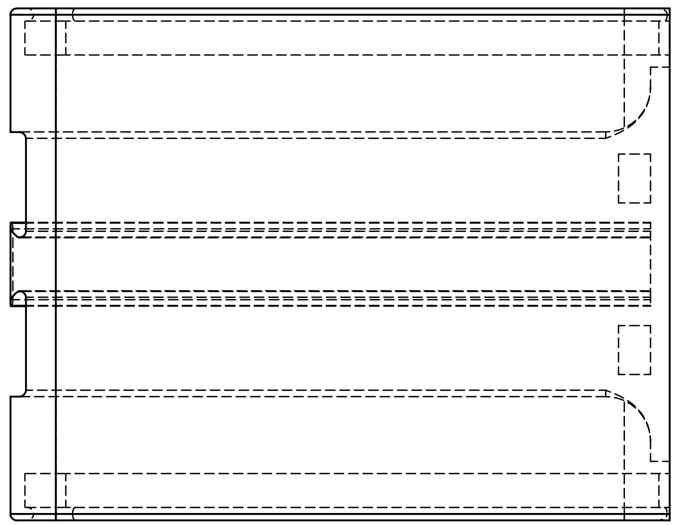


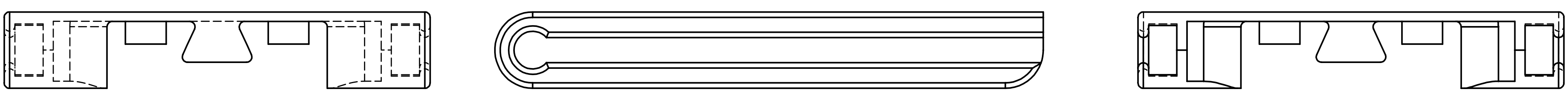


Cal Poly Mechanical Engineering	SPONSOR: JEFF GOETTMAN	TITLE:FINAL LATCH: TOP	DRWN. BY:DREW SAPP
SENIOR PROJECT - FALL 2015	ADVISOR: DR. TOM MASE	DATE:12/4/2015	CHKD. BY: DR. TOM MASE

NOTE: DIMENSIONS AND TOLERANCES TO BE CONTROLLED BY STRATASYS DIMENSION 1200ES, OR EQUIVALENT 3D PRINTER.

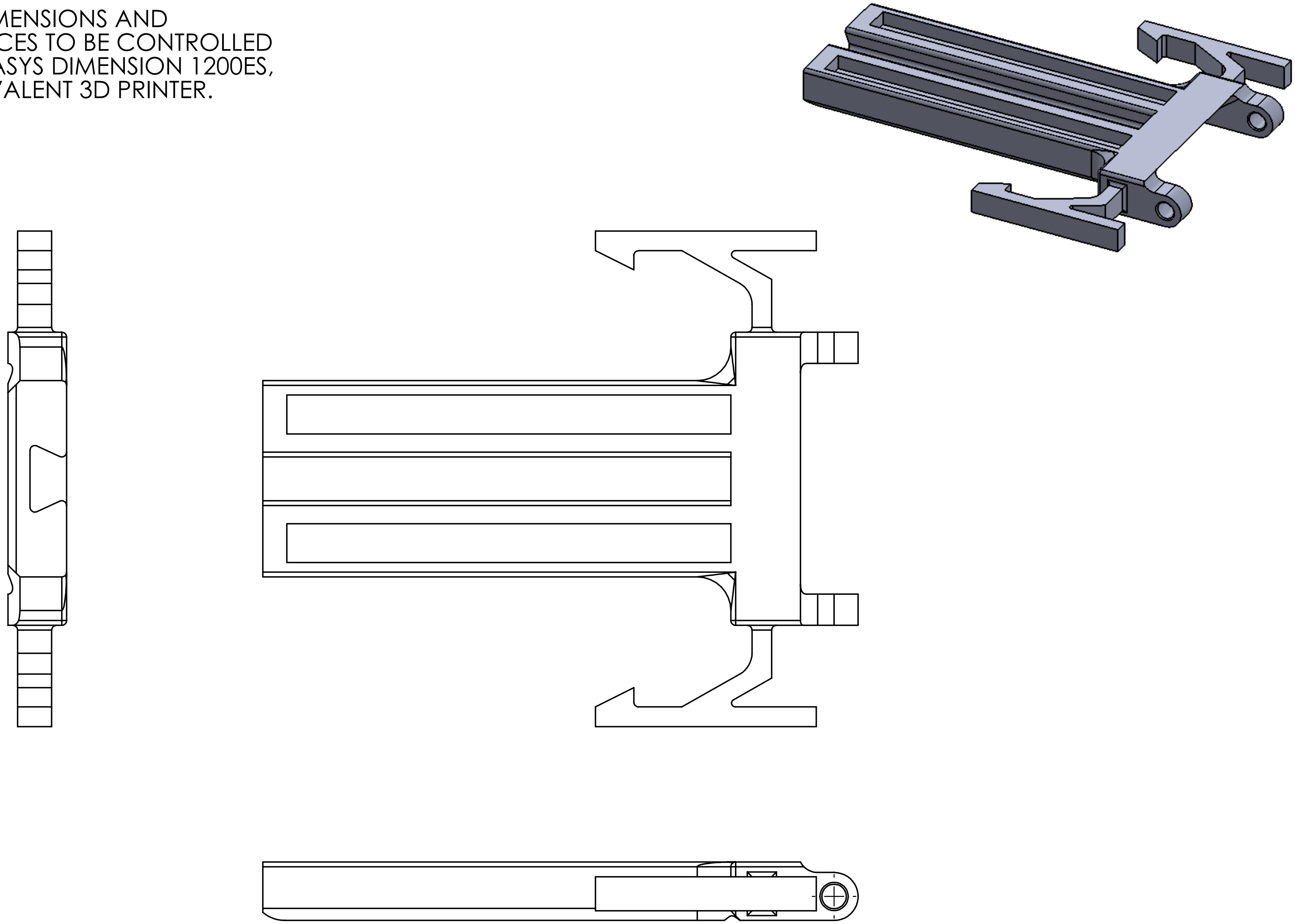






Cal Poly Mechanical Engineering	SPONSOR: JEFF GOETTMAN	TITLE:FINAL LATCH: MIDDLE	DRWN. BY:DREW SAPP
SENIOR PROJECT - FALL 2015	ADVISOR: DR. TOM MASE	DATE:12/4/2015	CHKD. BY: DR. TOM MASE

NOTE: DIMENSIONS AND TOLERANCES TO BE CONTROLLED BY STRATASYS DIMENSION 1200ES, OR EQUIVALENT 3D PRINTER.



Cal Poly Mechanical Engineering SENIOR PROJECT - FALL 2015	SPONSOR: JEFF GOETTMAN	TITLE:FINAL LATCH: BOTTOM	DRWN. BY:DREW SAPP
	ADVISOR: DR. TOM MASE	DATE:12/4/2015	CHKD. BY: DR. TOM MASE

Appendix C. Material Data Sheets

› FullCure®720

FullCure720 Transparent is the original material developed for Objet PolyJet-based 3-Dimensional Printing Systems.

Please, find the complete FullCure® General Purpose Family Data Charts Below:

Property	ASTM	Results in Metric Units		Results in Imperial Units	
Tensile Strength	D-638-03	MPa	60.3	psi	8744
Modulus of Elasticity	D-638-04	MPa	2870	psi	416150
Elongation at Break	D-638-05	%	20	%	20
Flexural Strength	D-790-03	MPa	75.8	psi	10991
Flexural Modulus	D-790-04	MPa	1718	psi	249110
Compressive Strength	D-695-02	MPa	84.3	psi	12224
Izod Notched Impact	D-256-06	J/m	21.3	ft lb/in	0.40
Shore Hardness	Scale D	Scale D	83	Scale D	83
Rockwell Hardness	Scale M	Scale M	81	Scale M	81
HDT at 0.45 MPa	D-648-06	ºC	48.4	ºF	119
HDT at 1.82MPa	D-648-07	ºC	44.4	ºF	112
Tg	DMA, E"	ºC	48.7	ºF	120
Ash Content	NA	%	<0.01	%	<0.01
Water Absorption	D570-98 24 Hr	%	1.53	%	1.53

ABSplus™-P430

Production-Grade Thermoplastic for Design Series 3D Printers

ABS*plus* is a true production-grade thermoplastic that is durable enough to perform virtually the same as production parts. When combined with Design Series 3D Printers, ABS*plus* is ideal for building 3D models and prototypes in an office environment.

Mechanical Properties	Test Method	English	Metric
		XZ Axis	XZ Axis
Tensile Strength, Ultimate (Type 1, 0.125", 0.2"/min)	ASTM D638	4,700 psi	33 MPa
Tensile Strength, Yield (Type 1, 0.125", 0.2"/min)	ASTM D638	4,500 psi	8 MPa
Tensile Modulus (Type 1, 0.125", 0.2"/min)	ASTM D638	320,000 psi	2,200 MPa
Tensile Elongation at Break (Type 1, 0.125", 0.2"/min)	ASTM D638	6%	6%
Tensile Elongation at Yield (Type 1, 0.125", 0.2"/min)	ASTM D638	2%	2%
IZOD Impact, notched (Method A, 23°C)	ASTM D256	2.0 ft-lb/in	106 J/m

Mechanical Properties	Test Method	English		Metric	
		XZ Axis	ZX Axis	XZ Axis	ZX Axis
Flexural Strength (Method 1, 0.05"/min)	ASTM D790	8,450 psi	5,050 psi	58 MPa	35 MPa
Flexural Modulus (Method 1, 0.05"/min)	ASTM D790	300,000 psi	240,000 psi	2,100 MPa	1,650 MPa
Flexural Strain at Break (Method 1, 0.05"/min)	ASTM D790	4%	4%	2%	2%

Thermal Properties[2]	Test Method	English	Metric
Heat Deflection (HDT) @ 66 psi	ASTM D648	204°F	96°C
Heat Deflection (HDT) @ 264 psi	ASTM D648	180°F	82°C
Glass Transition Temperature (Tg)	DSC (SSYS)	226°F	108°C
Melt Point	- - - - - - - - -	Not Applicable[3]	Not Applicable[3]
Coefficient of Thermal Expansion	ASTM E831	4.90E-05 in/in/°F	8.82E-05 mm/mm/°C

Electrical Properties[4]	Test Method	Value Range
Volume Resistivity	ASTM D257	2.6E15 - 5.0E16 ohm-cm
Dielectric Constant	ASTM D150-98	2.3 - 2.85
Dissipation Factor	ASTM D150-98	0.0046 - 0.0053
Dielectric Strength	ASTM D149-09, Method A, XZ Orientation	130 V/mil
Dielectric Strength	ASTM D149-09, Method A, ZX Orientation	290 V/mil

Stratasys | Design Series

Appendix D. Bill of Materials for Complete Prototype

The following is for the final stroller unit, excluding iteration costs

Item	Supplier	Dimensions/Units	Product Number	Qty	Unit Price	Item Cost
Rapid Prototype Use/Labor Cost	Cal Poly ME dept.	-	-	3	$ 120.00	$ 360.00
Stratysis Modeling Material	Cal Poly ME dept.	cubic inches (est.)	-	40	$ 7.28	$ 291.20
Stratysis Support Material	Cal Poly ME dept.	cubic inches (est.)	-	15	$ 7.01	$ 105.15
Wheel	Previous Prototype	each	-	4	-	-
Seat Fabric	Previous Prototype	unit	-	1	-	-
Lock Nut	McMaster-Carr	10-24	90631A411	20	$ 0.03	$ 0.60
Lock Nut	McMaster-Carr	4-40	90631A005	34	$ 0.03	$ 1.02
Socket Head Cap Screw	McMaster-Carr	10-24 X 1"	91251A247	6	$ 0.13	$ 0.78
Socket Head Cap Screw	McMaster-Carr	10-24 X 1.25"	90044A114	14	$ 0.22	$ 3.08
Socket Head Cap Screw	McMaster-Carr	4-40 X 3/4"	91251A113	26	$ 0.09	$ 2.34
Socket Head Cap Screw	McMaster-Carr	4-40 X 1"	90044A111	8	$ 0.30	$ 2.40
Aluminum Blind Rivet	McMaster-Carr	1/8" dia. X 0.275" lg.	97447A015	2	$ 0.03	$ 0.06
Plain Steel Round Rod	Home Depot	3/16" dia. X 3'	202183494	1	$ 2.77	$ 2.77
Threaded Rod	Miner's Ace Hardware	1/4-20 X 6"	98750A436	1	$ 2.18	$ 2.18
Copper Type M Straight Pipe	Home Depot	1/2 X 10' lg.	100354198	1	$ 9.97	$ 9.97
Copper Type L Straight Pipe	Home Depot	1/2 X 10' lg.	100354232	1	$ 14.73	$ 14.73
Copper Type M Straight Pipe	McMaster-Carr	3/8 X 5' lg.	5175K133	1	$ 7.66	$ 7.66
Acetal Rod	McMaster-Carr	5/16" dia. X 1' lg.	8497K151	2	$ 0.65	$ 1.30
Vinyl Coated Wire Rope	McMaster-Carr	3/16" dia. X 1' lg.	8912T51	4	$ 0.68	$ 2.72
Neodymium Block Magnet	K&J Magnetics	1" X 1/4" X 1/8" thick	BX042	4	$ 1.24	$ 4.96
Neodymium Block Magnet	K&J Magnetics	1" X 1/4" X 1/16" thick	BX041-N52	4	$ 0.95	$ 3.80
Copper Compression Lug	McMaster-Carr	4 AWG, 1/4" stud	6926K51	2	$ 2.71	$ 5.42
Aluminum Cable Crimp	Miner's Ace Hardware	for 3/16" dia. cable		4	$ 1.27	$ 5.08
					Total Cost:	**$ 827.22**

Appendix E. Mass Production Cost Analysis

Item	Unit	Qty	Unit Price	Item Cost
HDPE Injection Molded Material	pounds	2	$ 3.00	$ 6.00
Hardware	screws, nuts, rivets	80	$ 0.03	$ 2.40
Wheels	item	4	$ 1.00	$ 4.00
Tubing for Frame	feet	13	$ 1.00	$ 13.00
Seat Fabric	item	1	$ 10.00	$ 10.00
Labor and Overhead	per stroller	1	$ 20.00	$ 20.00
			Total Stroller Cost:	**$ 55.40**

Expected Stroller Sale Price:	$ 100
Profit Margin Per Stroller:	$ 44.60
Upfront Custom Tooling Cost:	$ 150,000
Required Stroller Sales to Break Even:	**3,364**

*NOTE: Table Values are Estimates

Appendix F. Supporting Analysis

Gear Calculations

$N = 18$ Number of Teeth

$\theta = 17$ [deg] Contact Angle of bevel gears

$d = 0.83$ [in] pitch circle diameter. Given, based off of sketch

$P = \frac{N}{d}$ Pitch (diametral), teeth per inch

$\phi = 20$ [deg] Pressure angle

$r = \frac{d}{2}$ pitch circle radius

$r_b = r \cdot \cos(\phi)$ Base circle radius

$a = \frac{1}{P}$ Addendum distance from pitch circle

$b = \frac{1.25}{P}$ Dedendum distance from pitch circle

$p_{circ} = \frac{\pi}{P}$ Circular Pitch

$t = \frac{p_{circ}}{2}$ Tooth thickness at pitch circle

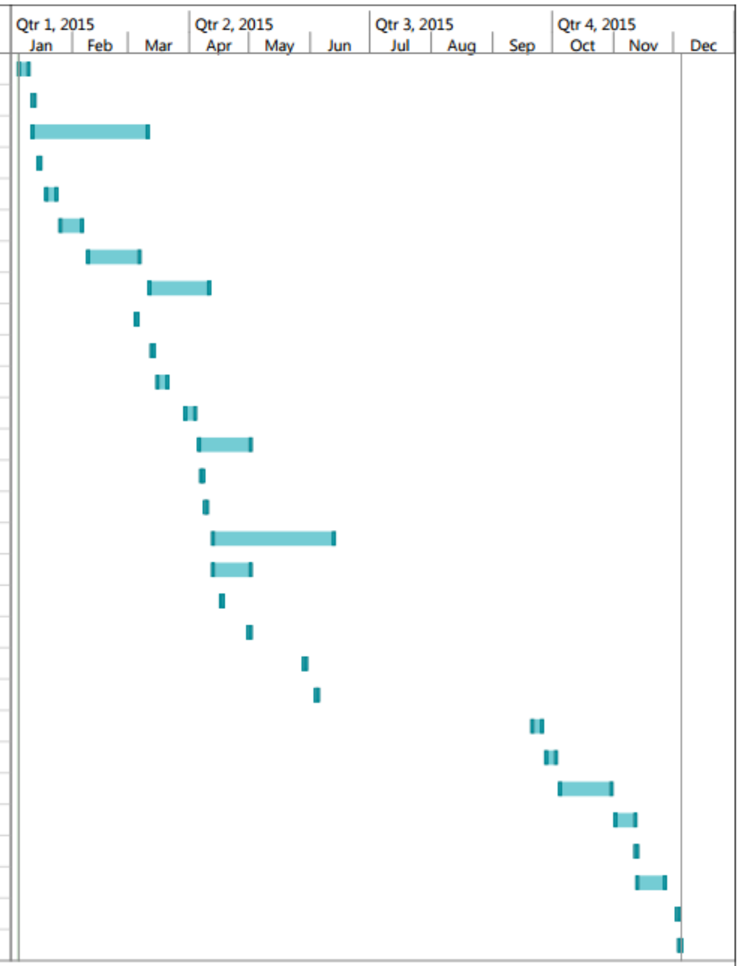
$N_p = \frac{2}{3 \cdot \sin^2(\phi)} \cdot \left[1 + \sqrt{1 + 3 \cdot \sin^2(\phi)}\right]$ smallest number of teeth which can exist without interference

Unit Settings: Eng F psia mass deg

$a = 0.04611$ [in]	$b = 0.05764$ [in]	$d = 0.83$ [in]	$N = 18$ [-]	$N_p = 12.32$ [-]
$P = 21.69$ [1/in]	$\phi = 20$ [deg]	$p_{circ} = 0.1449$ [in]	$r = 0.415$ [in]	$r_b = 0.39$ [in]
$t = 0.07243$ [in]	$\theta = 17$ [deg]			

Appendix G. Gantt Chart

ID	Task Name	Duration	Start
1	Project Preference Decision	5 days	Mon 1/5/15
2	Project and Team Assignment	1 day	Mon 1/12/15
3	Background Research	42 days	Mon 1/12/15
4	Letter of Introduction to Sponsor	1 day	Thu 1/15/15
5	Initial Problem Definition	5 days	Mon 1/19/15
6	Project Proposal Report	9 days	Mon 1/26/15
7	Concept Generation	20 days	Mon 2/9/15
8	Concept Modeling	22 days	Thu 3/12/15
9	Concept Design Review (in Lab)	1 day	Thu 3/5/15
10	Conceptual Design Report Due	1 day	Fri 3/13/15
11	Concept Design Review (with Sponsor)	5 days	Mon 3/16/15
12	Concept Selection	5 days	Mon 3/30/15
13	Detailed Design and Analysis	20 days	Mon 4/6/15
14	Critical Design Review (in Lab)	1 day	Tue 4/7/15
15	Critical Design Review (with Sponsor)	1 day	Thu 4/9/15
16	Fabrication	45 days	Mon 4/13/15
17	Test Plan Development	15 days	Mon 4/13/15
18	Final Design Report Due	1 day	Fri 4/17/15
19	Draft Design Status Report Due	1 day	Fri 5/1/15
20	Prototype and Test Plan Review	1 day	Fri 5/29/15
21	Project Update Report to Sponsor	1 day	Thu 6/4/15
22	Prototype Assembly	5 days	Mon 9/21/15
23	Prototype Testing	5 days	Mon 9/28/15
24	Prototype Modifications	20 days	Mon 10/5/15
25	Final Assembly	8 days	Mon 11/2/15
26	Final Hardware Demo	1 day	Thu 11/12/15
27	Final Assembly Testing	10 days	Fri 11/13/15
28	Senior Project Design Expo	1 day	Thu 12/3/15
29	Final Project Report Due	1 day	Fri 12/4/15



Child Carrier Gantt Chart