Infant Spinal Reflex-Testing Apparatus

ME 450 Fall 2009 Final Paper

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I Revised Abstract

Specialized testing equipment is needed to understand and test the neuromotor reflex development of healthy infants and infants who have spina bifida, cerebral palsy, and Down syndrome. For this purpose, an existing apparatus was developed to test spinal-level reflexes in the primary gait muscles of infants aged 2-10 months. The apparatus consists of a special infant seat and electromyographic sensors to measure the muscle responses to stimuli generated by pulsators. A new apparatus was designed to expand the test range to infants aged from 1 - 36 months and to improve ease of operation and manufacturability for clinical work.

II Executive Summary

The project's sponsors, Dr. Bernard Martin and Dr. Beverly Ulrich, assigned to our team the task of redesigning a seat and test apparatus for clinical and research studies that aimed to increase understanding of infant neuromotor development and to study neurological disorders such as spina bifida, cerebral palsy, Down syndrome, premature birth, autism spectrum disorder, or developmental coordination disorder [1-7].

The stated objective was: to redesign the apparatus in order to accommodate children of age 1 – 36 months and to improve the ease of use for the testers [B. Ulrich, personal communication].

At the time the study commenced, there were two main problems with the existing design: i) it could not physically support and constrain the older children in the proposed future group aged 1 – 36 months old and ii) It was difficult to operate; adjusting the seating angle and pulsator and time-intensive [B. Ulrich, personal communication]. Addressing these major issues will allow the group to move forward toward the long-term goal of marketing the apparatus for use in research and clinics.

The initial stage of the project involved creating a comprehensive list of specifications to meet the redesign requirements. The sponsors and current design provided benchmarks on which some of the specifications were based. One important specification was for an overall setup time of five minutes and a chair back adjustment time of ten seconds. The specifications also included the following measurements: tray (length = 27 cm, width = 29 cm), seat pan (length = 20 cm, width = 23 – 29 cm), belt (length = 0.8m), seat back angle range (60 - 80°) and head support size were created. The proposed specifications for the pulsator were pulsator tip width (0.6 cm), pulsator height (29.2 cm), average pulsator adjustment time (15 – 30 sec), translation (X,Y and Z axes), and rotation (about X, Y, and Z axes). General specifications for overall safety (no latex, no sharp edges), ease of use, and minimizing cost were implemented for all components.

Based on reflex testing research [8], patents [9-11], and communication with the project sponsors, we generated several different concepts for each component of the apparatus. We generated a plan for adjusting the size and angle of the seat, for adding a seatbelt, and for modifying the tray, pulsator, and head support. After eliminating infeasible designs, we compared the designs to the remaining components, based on weighted specifications using Pugh charts. Choosing the best designs based on these charts, we created seven complete apparatus designs. A final Pugh chart of the seven apparatus designs was used to select the alpha design. The alpha design has a motorized angle adjustment, removable tray locked in with bolts, adjustable strap for head support, and pulsator adjustments using a ball joint mounted on an adjustable stand.

After selecting materials, devising a manufacturing plan, and completing a detailed safety analysis, the alpha design was finalized by November 18, 2009. Manufacturing began on November 17, 2009, in parallel with component and assembly testing. The fabrication lasted until December 11, 2009 and validation will be completed by December 14, 2009. The final apparatus will be completed on December 22, 2009.

III Problem Description

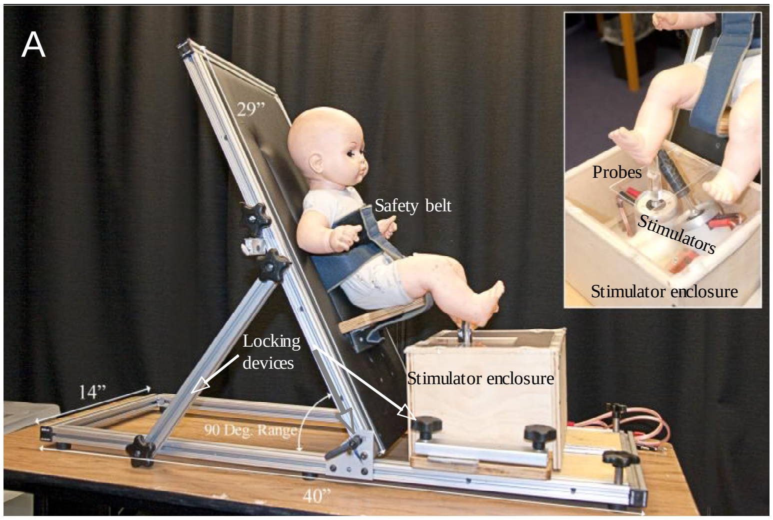


Figure 1: Original prototype design of infant reflex chair [courtesy of B. Ulrich]

Every year in the United States, 650,000 babies are born with spina bifida, cerebral palsy, Down syndrome, premature birth, autism, or developmental coordination disorder [1]. Infants with these developmental disabilities lack the neuromuscular control required for walking [12]. There is limited knowledge in the development of spinal reflexes used for walking in infants under 36 months old [12]. In order to establish clinical benchmarks while improving the understanding of this reflex development, the project sponsors Dr. Beverly Ulrich and Dr. Bernard Martin created a prototype apparatus to test reflexes in infants with normal and disabled development, shown in Figure 1 [12]. This prototype was designed to safely hold infants of only 2 – 10 months old and does not satisfy clinical test functionality [B. Ulrich, personal communication]. Our team is tasked with redesigning the prototype to expand the test range to 1 – 36 months old in addition to improving safety, ergonomics, ease of operation, and adjustability. The final deliverable will be a prototype chair that is close to the quality of the apparatus that will be submitted to clinics.

Research Background

Assessing neuromotor development is important in understanding the emergence of the organization of neural structures and the control of limb movements in healthy babies as well as in infants with neurological disorders. In young infants, stepping patterns are, at first, largely due to *monosynaptic* spinal level response potentials [14]. Beginning in the 1980's, studies showed that afferent reflex pathways play an important role in the development of locomotion in infants [14]. In normal infants, with the development of a more mature gait around the age of four, movements become dominated by *polysynaptic* reflexes [15]. However, in older infants with neurological disorders, movement is often still hampered by the immature monosynaptic reflexes [12].

The standard assessment of reflex function involves analyzing only the monosynaptic or "primitive" reflexes of infants, the most important of which is the *stretch reflex*, also called the *phasic myotatic reflex*. This reflex is a spontaneous muscle contraction that occurs in response to a fast stretching force. Currently, the standard non-invasive clinical test for this is a tendon tap, applied manually with a hammer [14]. Unfortunately, in infants with neurological disorders (and even in some normal infants) responses to this test can be muted and unsatisfactory.

The nature of testing infant neuromotor development can be influenced by a researcher's beliefs about how infants learn to walk. One theoretical approach is that walking simply emerges on its own as the nervous system matures. Researchers who believe this often assist infants in learning to walk by supporting them upright on a motorized treadmill, which tends to engage babies in producing stepping movements. The muscle responses are typically measured using electromyographic sensors. There is evidence that using treadmills can be a valuable therapeutic tool for people with neurological disabilities, although the therapy needs to be to be refined for patients depending on the level of neural damage, muscle tone, and joint problems [16]. However, there is much debate as to the validity of results obtained on treadmills in assessing neurological development [B. Ulrich, personal communication]. This is especially true in young infants who cannot yet walk on their own, but are unnaturally induced into the walking motion.

A prominent alternative theory is that the skill of walking is learned, as infants take advantage of their underlying neural mechanisms, and discover ways to control their muscles and joints in order to move [17]. Scientists who agree with this theory generally concur that there needs to be a more controlled and standardized experimental test to help model neurological development in children [17].

The current tendon “tap tests” used by neurologists to access the peripheral monosynaptic stretch reflex is useful, but the results include variability due to inconsistency in the applied mechanical force. [B. Ulrich, personal communication]. Dr. Ulrich and Dr. Martin’s work proposes a test procedure based on the tap test to study the function of additional neural pathways, including the afferent reflex pathways and their associated polysynaptic responses. The test involves mechanical activation of muscle spindles in the leg using a single electromagnetic pulsator. The use of an electromagnetic pulsator improves repeatability and consistency in the applied force. The test is also much gentler on infants because the stimulators require less force to elicit the same response as a manual hammer. Another feature of the test is that the infant is held stationary in an adjustable chair. This eliminates some of the variability in testing when compared to having a parent physically holding the infant, as some researchers have done in different infant studies [18]. Standardizing a chair for testing infants could also help in the development of special “adaptive” chairs for infants with neurological disorders and could be an additional therapeutic tool [19]. In Dr. Ulrich and Dr. Martin’s studies, reflex responses are detected by electromyographic sensors [20].

The study, which is ongoing and will continue over the next five years, will be the first to map the developmental trajectory of neuromuscular development in infants from 1 to 36 months in age. The device is intended for use as a research tool as well as a clinical device to identify more precisely the extent of nerve damage. The goal is to improve the outcomes of infants with disorders by studying how therapy helps their development with responses to activity and other possible medical treatments, including surgery. These disorders include spina bifida, cerebral palsy, Down syndrome, premature birth, autism spectrum disorder, and developmental coordination disorder.

IV Project Requirements and Engineering Specifications

Specifications were created to descriptively and quantitatively (when applicable) address each requirement for the infant reflex chair project. Multiple specifications were used if necessary to fully describe each requirement. We determined weights for each requirement by systematically comparing requirements with each other and establishing a ranking. Requirements from our sponsors were weighted based on what was stressed during meetings; for instance, child safety and ease of use were weighted heavily, while compactness and marketability were weighted lightly. Many target specifications were based on measurements made from the existing prototype (Figure 1, p. 3). The remaining specifications values were derived from discussions with our sponsors [B. Ulrich, B. Martin, personal communication] and developing appropriate measures. None of our specifications came from competitive products or processes because peer infant reflex researchers use completely different testing methods, as mentioned in the Research Background.

New requirements were created to clearly reflect all sponsor requirements and design considerations, not to just to be inferred by the original requirements. Requirements on cost, maintenance, and complexity of design for the apparatus were added to better define the manufacturing of the project. Requirements on folded volume and marketability were created to address the long-term goals of the project. More detailed requirements for the apparatus design include child comfort and resolution of motion. New specifications were created to address these new project requirements. Additional specifications for adjusting the head support, tray, chair angle, and seat belt were created to measure and minimize test duration. Specifications for resolution of the pulsator height, pulsator tilt, tray height, seat back angle, and head support were added to clearly define the precise motion of the components. To reflect the sponsor need of an automated seat angle adjustment, a specification was created to address this requirement. An additional specification to limit the power consumption was created in correlation to the automated design requirement. A list of specifications is located in Tables 1 - 3, on pp. 7-8. In order to help organize requirements and quantify specifications, our team developed a QFD table, located in Appendix 1. The rest of this section lists each requirement and its corresponding specifications.

- *Safely and securely holds children from ages 1 - 36 months*

Specifications were designed to achieve various safety objectives. Chair design and material selection were oriented toward these goals; exact parameters were specified for safety belt length and head support diameter. The child comfort specification provides that overall safety and security is taken into account. Required maintenance addresses a schedule of reliability against cyclic use and wear. Specifications for dimensions such as seat width, seat length, adjustable seat height, chair back width, and chair back length were determined using standard growth charts to ensure the infants from 1 - 36 months to ensure a safe and secure fit [21]. Additional safety objective that were targeted included avoiding latex, minimizing chair back motion, and restricting sharp edges and crevices.

- *Child cannot see their legs and feet interacting with apparatus*

This requirement pertains directly to the tray built into the test chair. Having a play tray was a clear target to create. To specify further, targets of tray length and width quantify an area to sufficiently obstruct the infants' view of their legs, feet and the interacting device.

- *Child has freedom to move legs and arms*

Targets to guarantee leg movement and arm movement enforce the motion requirement.

- *Have a play surface in front of child to distract them*

A target to install a tray that could have toys to play with was made to address this requirement.

- *Child should not feel closed in by the tray and chair back*

This requirement translates to the size and placement of the tray. The targets of maximum tray height above infant naval and height of lip on tray were created to attend to this issue.

- *Child cannot see any of the apparatus*

The targets of having a play surface and of a maximum height of the pulsator device prevent the infant from seeing the apparatus.

- *No latex present in the entire design, due to an increased chance of allergic reaction with infants who have spina bifida*

A target demanding latex be banned from the prototype guarantees this requirement.

- *Adjustable angle of seating apparatus*

A target quantifying the seat back angle range was created for this specification. Resolution provides a measure of how adjustable the seat apparatus is, and chair angle adjustment time provides a measure of the adjustment duration. Automated seat angle adjustment addresses the function of this requirement. The specification for the design to be user friendly correlates to the adjustable angle requirement as well.

- *Adjustments of pulsator made quickly, so kids remain in chair for under an hour*

For this requirement to be satisfied, several targets were created. Specifications for the motion and rotation of the pulsator head in the X, Y and Z directions allow 6 degrees of freedom. By giving the pulsator head this freedom of movement, you could have the same pulsator perform all three tests. That would reduce the time of the tests because it would not be necessary to switch between the two sets of pulsators. The resolution specifications for pulsator height and tilt take minor adjustments into account, which contribute significantly to total test time.

- *User-friendliness*

A specification stating that the device be self-explanatory covers the user-friendly requirement.
All aspects of design must be considered to achieve this goal. Targets concerning adjustment time and resolution for the head support, tray, chair back, and chair angle also correlate to user-friendliness, which would have quick adjustment by definition. The specification for automated seat angle adjustment addresses the need for user-friendliness.

- *Minimize number of pulsators needed*

The target for the design to be self-explanatory addresses the requirement to minimize the number of pulsators. Targets on the motion and resolution of the pulsator head are related to ensure that the device can reach the orientation needed to perform all three tests.

- *More accurate pulsator tip*

This accuracy requirement is achieved by the target determining pulsator head width and pulsator tilt resolution.

- *Adjusting apparatus made to not startle child*

The major aspect of the design that could upset the infants is the speed of the chair reclining, which is addressed by the target covering the range of degrees per second that the chair back moves. The specification on seat angle resolution also defines the smallest increments of motion, which effects how smoothly the chair back is adjusted. Specifications for adjusting time of components also relates to this requirement.

- *Toys should not fall easily from the tray*

This requirement was satisfied by creating a specification for adding a lip of a given height to the tray.

- *Design is compact*

The specification of folded volume creates a target value to address the compactness requirement.

- *Design does not require constant maintenance*

The target for required maintenance enforces that the apparatus is designed to have minimal maintenance.

- *Cost*

Many specifications indirectly increase the cost for materials, parts, and fabrication. Cost of prototyping creates a target to minimize overall expenses in creating the apparatus. The specification of simplest design correlates to lowering costs.

- *Design is not overly complicated*

This requirement was addressed directly by having a specification dedicated to creating the simplest design. Specification of user-friendliness also dictates a straightforward apparatus design.

- *All adjustments must have good resolution*

Resolution specifications regarding pulsator height, pulsator tilt, head support height, seat angle, and tray height.

- *The design must be marketable*

Specifications ensuring good design meet the marketability requirement; these include no sharp edges or corners, no latex in design, self explanatory, child comfort, having a play tray, and specifications involving the both precision movement and adjustment duration of the pulsator and chair apparati. Automated seat angle adjustment also enhances the marketability. The overall specification of marketability addresses this requirement throughout all design aspects.

- *Automated angle adjustment*

This target is achieved by the specification for automatic angle adjustment. User friendliness correlates to this requirement.

- *Minimal Power Consumption*

Power consumption per test monitors the power used, excluding the power of the pulsator.

Table 1: Specifications for chair portion of apparatus with benchmarks and targets

	Specification	**Benchmark**	**Target**	**Target Source**
Safety	Child Comfort (Held in Securely)	Yes	Yes	Current Design
	Safety Belt (Length)	1 m	1 m	Current Design
	Head Support (Diameter)	N/A	9.9 - 16.9 cm	Estimates using 2000 CDC Growth Charts [21]
	Maximum Load the Apparatus Can Support	N/A	80 lb. *	Estimates using 2000 CDC Growth Charts [21]
	No sharp edges/places to get fingers stuck	Yes	Yes	Current Design
	Play Tray	Yes	Yes	Current Design
Comfort	Height of Lip on Tray	N/A	2.5 cm	Dr. Ulrich
	Length of Tray	27 cm	27 cm	Current Design
	Width of Tray	49 cm	49 cm	Current Design
	Adjustable Tray Height	Yes	Yes	Current Design
	Seat Width	23 cm	23 - 29 cm	Magnecleck [22]
Geometry	Seat Length	15 cm	20 cm	CDC Growth Charts [21]
	Seat Back Angle Range	60 - 80°	0 - 90°	Dr. Ulrich
	Chair Back Width	31 cm	31 cm	Magnecleck [22]
	Chair Back Height	71 cm	105 cm	CDC Growth Charts [21]

	Speed of Chair Back Motion	N/A	5°-20°/sec,	Current Design
	Freedom of Arm Rotation (Forward and Above Tray)	0 - 90°	0-90°	Current Design
	Freedom of Leg Movement (Restricted by Chair, Seat Back, and Tray)	Yes	Yes	Current Design
User-Friendly	User Friendly/Self-Explanatory Operation	No	Yes	Dr. Ulrich
	Average Head Support Adjustment Time	N/A	75 sec.**	Dr. Ulrich
	Average Tray Adjustment Time	N/A	75 sec.**	Dr. Ulrich
	Average Seat Belt Adjustment Time	N/A	75 sec.**	Dr. Ulrich
	Chair Angle Adjustment Time	N/A	75 sec.**	Dr. Ulrich
	Seat Back Angle Resolution	N/A	4°	Dr. Ulrich
	Head Support Height Resolution	N/A	3 cm	Dr. Ulrich
	Tray Height Resolution	N/A	3 cm	Dr. Ulrich
	Seat Angle Adjustment is Automated	No	Yes	Dr. Ulrich

* This weight is double the maximum weight of the test infants (40 lb.), well within the total safety factor load of 264 lb.

** The sum of these must be under 5 minutes; individual adjustment times are arbitrary

Table 2: Specifications for pulsator portion of apparatus with benchmarks and targets

	Specification	Benchmark	Target	Target Source
Reading Quality	Width of Pulsator Tip	1 cm	0.6 cm	Dr. Ulrich
Geometry	Pulsator Apparatus Height	50 cm	37.5 cm	Dr. Ulrich
	Translation of Pulsator Head in X Direction (Lockable)	Yes	Yes	Dr. Ulrich
	Translation of Pulsator Head in Y Direction (Lockable)	Yes	Yes	Dr. Ulrich
	Translation of Pulsator Head in Z Direction (Lockable)	2.5 - 20 cm	5 - 40 cm	Dr. Ulrich
	Rotation of Pulsator Head in X Axis (Lockable)	N/A	360°	Dr. Ulrich
	Rotation of Pulsator Head in Y Axis (Lockable)	N/A	360°	Dr. Ulrich
	Rotation of Pulsator Head in Z Axis (Lockable)	60°	180°	Dr. Ulrich
User-Friendly	Average Pulsator Adjust Time	60 - 120 sec.	15 - 30 sec.	Dr. Ulrich
	Pulsator Height Resolution	N/A	5 mm	Dr. Ulrich
	Pulsator Tilt Resolution	N/A	1°	Dr. Ulrich

Table 3: Specifications for pulsator and chair apparatus with benchmarks and targets

Specification	Benchmark	Target	Target Source
Latex Not Used in Design	Yes	Yes	Current Design
Maintenance Required	N/A	annually	Dr. Ulrich
Cost of Prototyping	N/A	$400	Dr. Ulrich
Not overly complex design	No	Yes	Dr. Ulrich

Marketability	No	Yes	Dr. Ulrich
Power Required per Test	N/A	36 W	N/A

V Concept Generation

A functional decomposition of the infant reflex test apparatus was created to clearly organize the processes and parts of the device and show the component interrelations (App. 2). This chart, combined with research on reflex experimentation [7] and relevant patents, such as car seats [10]and high chairs [11], set the foundation for concept brainstorming. This development section was divided into six major components of the apparatus: (i) seat size adjustment, (ii) seat angle adjustment, (iii) seatbelt, (iv) tray, (v) pulsator, and (vi) head support. The following subsections describe the role of each component and in detail. These designs were carefully selected using weighted selection matrices, pictured and described in full within **Concept Selection** (**VI**). All component designs and drawings are listed in Appendix 3.

(i) Seat Size Adjustment

In order to accommodate children from ages 1-36 months it is necessary to have adjustable sizes of the seat. Some necessary requirements for the seat are that the seat must provide enough support to hold up the child comfortably; however, the seat needs to only support the leg up to the knee allowing for the lower leg to freely swing. The tests cannot be properly administered if this motion is restricted. The other requirement for the seat was that the legs need to be comfortably separated. This is currently achieved by having a built in extrusion from the seat to keep the legs apart.

(ii) Seat Angle Adjustment

The seat angle must safely be adjusted between the angles of 60 and 80°. The mechanism should be user friendly and quick to adjust between the necessary angles with minimal noise while in use. Due to forces from the baby rocking within the chair, the mechanism must be able to support the chair while not in use for adjusting the angle. When the testing is done, the mechanism should be able to compact for storage.

(iii) Seatbelt

The seatbelt has to securely hold the infant in the testing chair while still being comfortable. The seatbelt needs to be adjustable to accommodate for the different sized children. The seatbelt needs to guarantee that the infant cannot fall out of the chair but not feel locked into the chair.

(iv) Tray

The tray provides a surface for the test subjects to play on during testing. This surface must withstand the forces exerted by the subjects and adequately contain the toys on the tray. Additionally, the tray functions as a screen to shield the technical features of the apparatus – pulsator, wires, support and locking mechanisms, etc. – from the infants view. The tray must accommodate the sizes of all test subjects 1 – 36 months old for comfortable testing and simple entry and exit from the apparatus.

(v) Pulsator

The pulsator is needed to provide a tap and vibration motion during the test and it has to be stably supported while providing this function. An adjustable stand is required to allow for one pulsator to test all three sites in the leg.

(vi) Head Support

Some of the children who will be tested in this device will require head support. The children that will require this support are infants less than two months old, whose neck muscles are underdeveloped, and some children with Down syndrome [B. Ulrich, personal communication]. The head support will help hold the head in the upright position, and also not allow the child to make sporadic head movements in the case of a child with Down syndrome. Because the head support needs to be usable with children of different sizes, it needs to be adjustable in height and in size to fit children with different diameter heads.

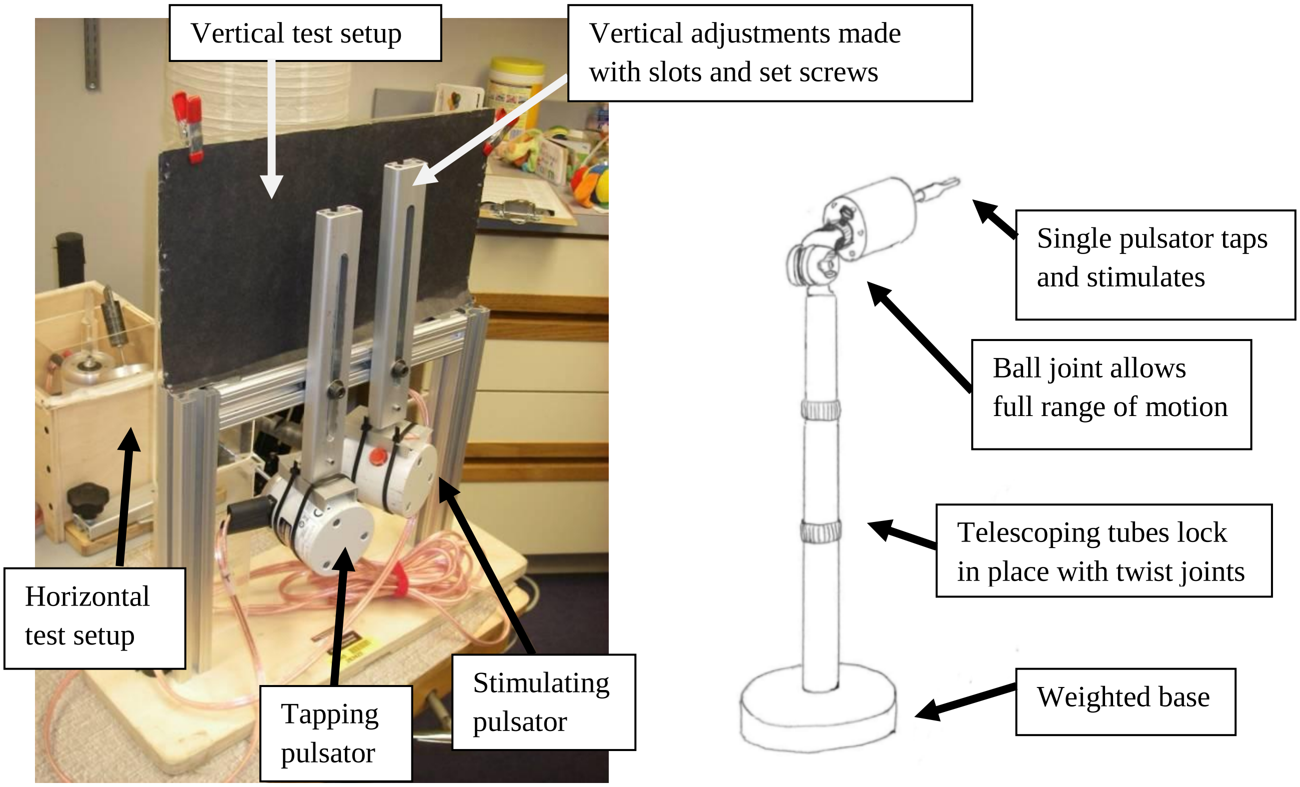
VI Concept Selection

Our first step in developing five concept designs was eliminating infeasible designs generated from our brainstorm session. For example, we eliminated the inflatable headrest design because it required extra equipment and required complicated manufacturing. (For reference, the eliminated designs are shown in Appendix 3). Our next step was categorizing the design features into six categories: seat angle adjustment, seat, seatbelt, tray, pulsator mount, and head support. We determined that the seat angle adjustment was the most critical design choice because the performance of many of the other components depended on the mechanism of seat angle adjustment. The remaining five categories were largely uncorrelated to each other; they did not affect the overall performance, which simplified the process. For example, the choice of pulsator mount design did not affect the performance of any of the seatbelt. Therefore, we chose to compare the individual designs in each of these five categories separately using Pugh charts, and to take the best of each category and implement with our (seven) seat adjustment designs, if possible, for a total of five chair concept designs. The seven chair concept designs were then compared using a final Pugh chart. All Pugh charts are listed in Appendix 4.

Component Selection

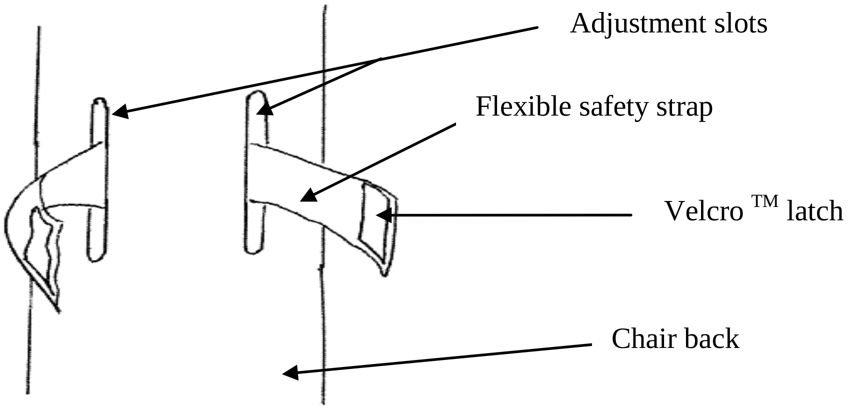
The pulsator mount Pugh chart is shown in Appendix 4.1. The ball joint design was selected based on its flexibility and freedom of movement, relative simplicity, and robustness (Figure 2, p. 11). This design had the fastest adjustment time amongst its competitors; adjustment time is a heavily weighted specification dictated by the sponsor. For the base, the design with a weighted platform was selected. The reasoning is due to the quick adjustment time of the position of the pulsator in addition to the high resistance to the infant kicking. The drawback of the pulsator mount design is the complicated manufacturing process. The ball joint design may be difficult to fabricate, possibly requiring welding. The friction locking mechanism will have to be very robust to handle the weight of the pulsator while the not using any material with latex, found commonly in some rubber. The final seven designs all incorporated the pulsator with a telescoping “microphone” stand for vertical adjustability.

Figure 2: Original prototype uses two pulsator setups, with a tapping and stimulating pulsator at each location (left). The alpha design uses a single tapping and stimulating pulsator developed by our sponsors that has adjustable height and rotation (right). (Photo courtesy of Marco Myerson)



The seat belt Pugh chart is shown in Appendix 4.2. The trunk support seat belt was selected because it provided more trunk support to infants than the other designs due to the large angle between the strap and the infant (Figure 3, p. 12). Additionally, it offered easy and fast adjustability since testers are not required to reach behind the chair or thread the straps through the slots. A drawback of the design is that it will still require slots in the chair back, which increases manufacturing difficulty and cost. All of the final chair designs used the trunk support seat belt.

Figure 3: Safety strap has adjustable height in slotted chair back. Slot design also allows multiple straps to be used for larger children.

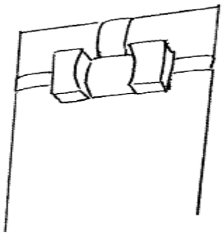


The seat pan Pugh chart is shown in Appendix 4.3. The multiple seat pan concept was selected because its simplicity and user comfort. The current apparatus uses this method, as shown in Figure 4. A drawback of this design is that there are many different sized seat pans needed, which raises cost and storage size. The drawbacks of the other adjustable designs were reduced comfort due to seams and multiple pieces and that they could not accommodate as large a range of infants. All of the final chair designs use the multiple seat pan concept.

Figure 4: Views of seat pan from original prototype: front alignment with chair back (left), isometric view (center), rear attachment with hand-tightened knobs (right) (Photos Courtesy of Marco Myerson)

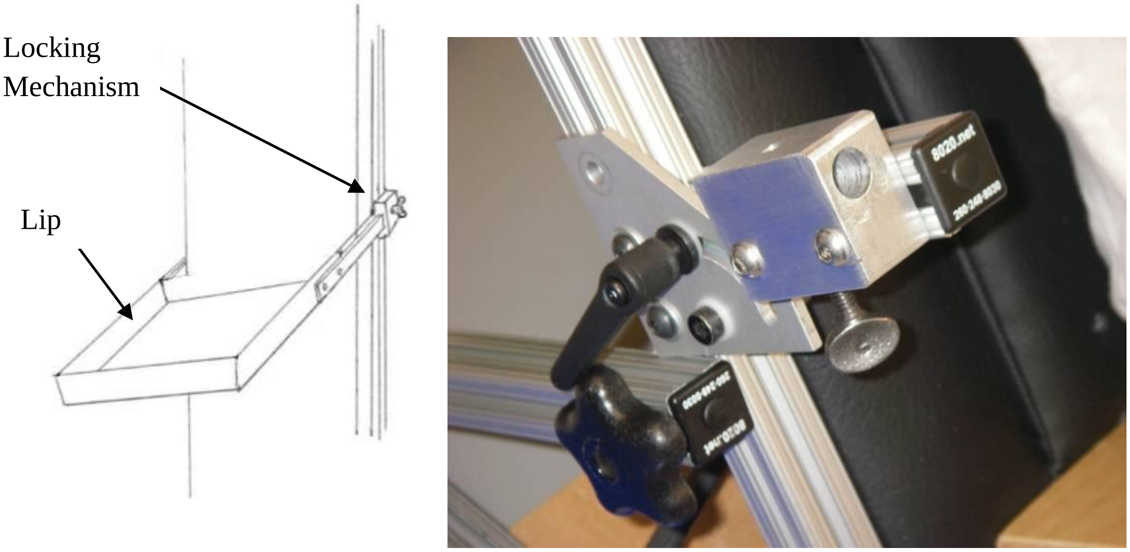
The head support category Pugh chart is shown in Appendix 4.4. The "strap over the top" head support was selected because of its adjustability, security in holding head, and resolution of adjustment (Figure 5). While the design does require slightly more time to adjust than the elastic band head support (which essentially tied with the dentist head support concept), the design also has improved durability. All of the final chair designs use the dentist head support concept.

Figure 5: Head Support



The tray category Pugh chart is shown in Appendix 4.5. The sliding mount design was selected for its simplicity in height and length adjustments (Figure 6). This design is very similar to the current design, but there is a reduced risk of finger traps by placing the locking mechanism behind the chair back. Additionally, the design would be relatively quick to adjust and would not require any tools. The design also allows for high freedom of movement of the infants' arms and legs.

Figure 6: Redesigned tray (left) features a lip to contain toys and hand-tightened locking mechanism behind chair to be out of reach of infants. The locking mechanism will be similarly designed to the one used in the current design (right). (Photo Courtesy of Marco Myerson)



Design Selection for Seat Angle Adjustment

The motorized design, using a "car jack" linkage arrangement could be used for the angle adjustment mechanism, and fitted in two locations. The advantages of using this design are be a high-resolution adjustment and a safe mechanism if designed properly, since the chair back cannot move when the motor is off because of the worm gear. The design is user-friendly, since the angle could easily be adjusted using a remote whether or not an infant is seated. The drawbacks of this design would be the complexity- there are many moving parts, introducing additional failure modes. The many parts and motor requirement means that this design would be relatively expensive. The design is also bulky, which makes storage more difficult. The use of a motor has a negative environmental impact by increasing energy use.

The pneumatic chair angle adjustment system could easily be used to change the angle of the chair, and it could be operated by the simple press of a button. A disadvantage of this system is that it would need frequent maintenance to prevent leaks and the monitor functional valve operation. While manageable, it increases costs. Another disadvantage to the pneumatic design is that its air compressor would require power, thus increasing its environmental impact. Furthermore, the air compressor is extremely loud. The noise generated would upset the infant, which eliminates test accuracy so that the tests cannot be conducted; this effectively ruled out this design.

The "motor at fulcrum" design would be very simple to build. It could be operated with remote control and have a constant motion of the chair back. This design is very compact and could also fold flat for storage without any major adjustments. The amount of torque that this motor would have to apply would be enormous due to the mechanics of its design. The motor required to handle the torque would have such a large volume that it would lose all of the compactness of the design; these demanding load requirements greatly increase the cost compared to all other designs. Another disadvantage to this design would be that there is no safety in the motor; if the motor were brought to a certain angle and left there, one could easily push the chair back and the motor would not be able to hold the chair back in place without constant power supplied. Having constant power applied to the motor: i) needlessly wastes energy, and ii) poses a safety risk during a potential power outage (if there is a power outage while a baby is in the chair, the baby would just fall backwards). This would require us to design a separate mechanical safety, which would decrease ease of operation and increase both cost and bulk.

The rigid bar system could be operated with remote control and have a constant motion of the chair back. This design could use a smaller motor than the "motor at fulcrum" design because it operates using less torque. A drawback to the design is that it does not automatically lock the chair angle in place. The system would need constant power to hold the chair in the correct position. Supplying constant power imposes a worse environmental impact compared to the other designs. This also introduces an increased safety risk in the event of a power outage. A separate mechanical safety to compensate for this would decrease ease of operation, increase cost, and increase overall size.

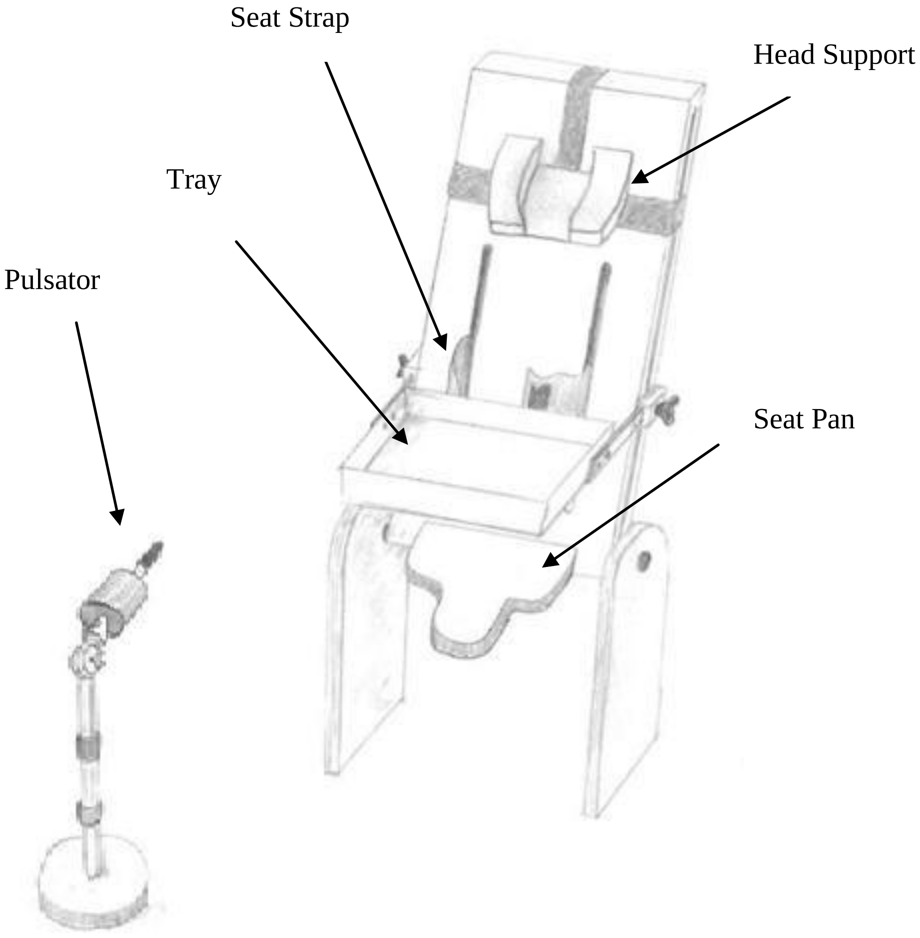
The manual lever design is a very simple design to fabricate and operate. It would require no power source to operate and require very little maintenance on account of its basic functionality. A disadvantage to the design is that the operator to would need to hold up the entire weight of the child and apparatus while adjusting the angle. This would greatly decrease the safety of the apparatus for the operator and test infant in the case the operator were to slip. The adjustment method also greatly decreases the ease of operation.

The static chair design would be extremely simple and require little to no maintenance. Unfortunately our sponsor, Dr. Beverly Ulrich, has informed us that we do need to have an adjustable chair angle in order to test properly; this effectively ruled out this design.

VII Alpha Design

The alpha design consists of our top rated ideas determined from our Pugh charts. Figure 7 (p. 14) shows a schematic of the alpha design assembled with all components, and Figure 8 (p. 16) shows a 3-D CAD model of the alpha design. The rest of this section details the functions of each component.

Figure 7: Alpha design showing head support, seat belt, tray, seat pan, and pulsator



In order to change the angle of the chair, we will use an externally powered mechanical system. This design is powered by a motor that only requires power input to adjust the angle of the chair. While the motor is not powered any force put on the chair back will engage the worm gear into the thrust bearing which will then stop any chair back movement. The “car jack” design uses the motor to power a four bar linkage system, similar to a car jack (Figure 8 (A), p. 16). The linkage system is attached to the back of the chair in the center with a pin-joint and to the ground with another pin-joint. When the motor is engaged it will increase or decrease the length of the linkage system by rotating a worm gear, therefore changing the angle of the chair back. A feature of this design is that when the entire apparatus is not in use, the pin joints can be pulled out and the chair will be able to collapse to save space.

Developing our CAD model (Figure 8, p. 16) helped us to visualize the various components in space relative to each other, and to refine some of the attachment methods. For example, we had to take a much closer look at how our car jack will attach onto the back of our chair and the packaging constraints. Making the CAD has also helped us redefine some of our specifications, such as that the width of our tray needs to be wider than then width of our chair back, allowing it to attach to the outside of the chair back.

Figure 8: CAD Model

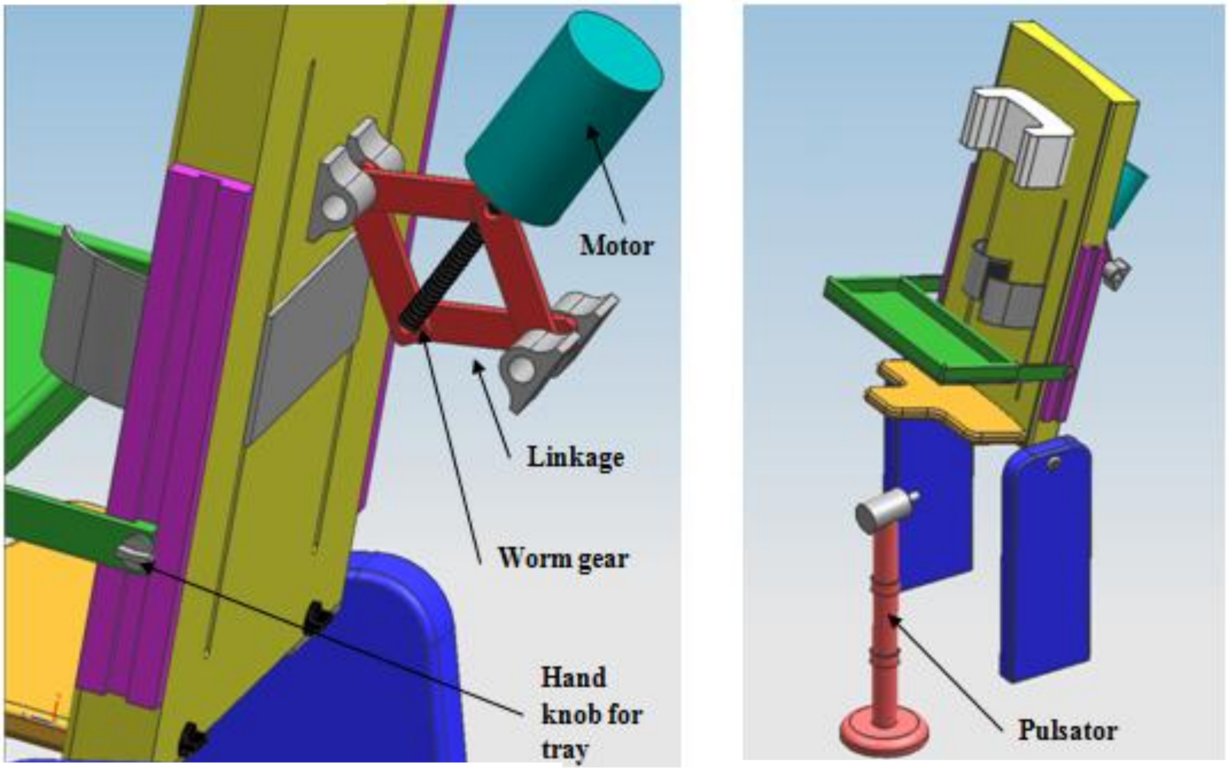


Figure 8 (A): Car jack linkage attachment

Figure 8 (B): Isometric view of alpha design

Figure 8 (C): Mock up of alpha design

To solve the issue of having the seating apparatus fit children from ages 1-36 months, the apparatus will use multiple seat pans. The current design has three seat pans made of wood to fit children from ages 2 – 10 months (Figure 4, p. 12). We will need 5 – 6 seat pans to accommodate the children of our larger age range [B. Ulrich, personal communication]. The original three seat pans function well, and we will use them in our design and make 2-3 larger pans in a similar fashion. The seats will attach on the reverse side of the chair using two hand-tightened bolts. Rough estimates for the range of the seat sizes is length = 16-24 cm and width = 23 – 29 cm.

In order to be able to safely add and remove a play tray for the child we have chosen a design that has the tray lock to the chair by using two hand-tightened bolts. The operator of the chair will place the baby into the chair, secure the child, and then slide the tray into two height adjustable slots. The tray will be tightened into the slots using a hand –tightened bolt. Then the tray will be adjusted vertically for the child's comfort and then locked in also using a hand-tightened bolt. In order to help keep they toys on the tray, we will be adding a lip to the tray. We are also discussing creating multiple trays that would fit into this system that would all provide different features, e.g. a magnetized tray, a Velcro ^{TM} tray, a mirrored tray, a fuzzy tray, and many more possible trays. These extra tray designs can only be manufactured if it fits within our budget.

The device that we have chosen to support the child's head operates on a similar system to a head rest at a dentist's office, with some modifications. Our head support device is attached with a strap from the top of the chair using a bolt. The bolt has an adjustable notch next to it that allow for excess material to slide through thus having a variable height of the head support. When a child does not require the head support it can be flipped over the top so it does not get in the way. Our head support device is also adjustable in its width, in order to be able to support the size range of children's heads. The width of the headrest will be adjusted using a small hand-tightened knob which is recessed in the back of the head rest. This way the knob will not get in the way when the head rest is in use and it will allow the head support to lay flat against the chair back. To help stabilize the child, and not allow motion of the child to either side there will be two Velcro ^{TM} straps attached to either side of the head rest. Once the head rest is in the desired position the operator of the device will take each of these Velcro ^{TM} straps and loop them around the back of the chair to where they will be applied to the contrary side of the Velcro ^{TM}. Having both of these straps taut will help keep the child's head in place. Basic head diameters that are used to estimate the range of the head support is from 9.9 to 16.9 cm.

Our new pulsator design has enough range of motion that we can eliminate the two pulsator setup that is currently in use. The new design incorporates the single pulsator programmed by Dr. Martin to both tap and pulsate, thus creating a setup with one total pulsator that can test all three test locations. Our design consists of mounting the pulsator directly to a ball joint potentially by brazing. The ball joint will allow the pulsator to rotate in all three rotational degrees of freedom. In order to lock the rotational position of this ball joint we will have a hand-tightened bolt which drives a stopper into the ball joint, causing friction and restricting rotational motion. The pulsator must also have a low minimum height to fit below the chair to test the testing zone in the back. A diagram of the four test zones is shown in Figure A.2.1 in Appendix 2. In order to accomplish this task we have decided to put our ball jointed pulsator upon a system of lockable telescoping tubes. The tubes would be broken up into 3 – 6 sections and would use the locking mechanism of a microphone stand. That works by twisting the joint connecting the two sections in a clockwise direction to lock the tubes while turning the joint in the counter-clockwise direction unlocks the tubes to adjust the height. To constrict translational movement on the table, the pulsator apparatus will be attached to a weighted platform by bolts. The platform will be heavy enough so it will resist motion if the child were to nudge it, but still be light enough for the technician to easily slide it to its desired position.

The safety strap design that our team has chosen uses a stretchable material which wraps around the child's abdomen. The strap will run through slots located in the seat back, this way the belt will be adjustable in height to support the child's trunk. In order to cut down on time of operation the proper safety strap will be threaded through the slots in the chair before the child enters the room. The strap will be secured around the child by using Velcro ^{TM}. The belt will be wide enough to hold the smaller children in position while providing good trunk support, which is needed for young infants to remain stable during testing. The strap will also restrict the child's movement to keep them from falling out of the chair.

VIII Parameter Analysis

In designing our chair and testing apparatus, relevant fields to analyze the design include solid mechanics to analyze the forces on the chair and the internal components. The solid mechanics analysis ensures that the chair can withstand the forces due to the weight of the baby, forces caused by the baby kicking or flailing, and moments of the chair so that the baby will not cause the chair to flip over. Appendix 6 is related to the parameter analysis by having detailed analysis and assumptions for each component being reviewed.

Material

For material selection many factors were considered including strength, how easy the surface is to clean, how easy the material can be machined, and how the material can be connected to other materials. This category was also restricted in what materials could be processed in the available facilities and by the price range of the project.

For surfaces that the children rest on or are constantly in contact with, it is important to have an easily cleaned surface that is not porous. PVC and vinyl are easy to wipe down to disinfect and are chosen for the chair back, seat pan, head support shell and foam pad covers. This reduces the children and operator's exposure to accumulated germs.

Strength is a necessary qualification for many materials as the safety of the chair is directly connected to the safety of the child in the chair. The chair base and the bottom of the chair back require metal as it is needed to handle the forces generated by the child's weight and the weight of the other components. The frame materials could be welded together for high strength which reduces the multiple bolts that would be necessary to obtain the same structural support and it requires the frame to be made of metal. To support the chair and child's weight along with allowing for rotational motion, oil-impregnated bronze bushings were selected for having strong radial support and not needing to be lubricated more than once.

Materials that are able to be processed in the shop and have strength to support higher loads include aluminum, steels, and PVC. For the seat pans having the child not sit on metal would give the seat a softer feel which lead to PVC. PVC was analyzed using FEA and also using CES. A full summary of these analyses are in Appendix 6.6. For other processed materials such as sliders for the T-tracks, the stronger material aluminum was chosen because it is stiffer and resists creep better than PVC.

The force required to lock multiple components together also helped decide what materials were chosen. For the head support pieces of light weight foam covered in vinyl need to be easily attached so Velcro ^{TM} was chosen. Velcro ^{TM} can also be sewn to vinyl and glued on the PVC shell because of the lighter forces the head support faces. The Velcro ^{TM} would release before the threads of the glue relinquishes. When tray sliders and the seat pan are locked into place there are moderate loads and forces so hand knobs attached to bolts allow for tight tool free attachment of two components.

Another material requiring a specific strength was the telescoping tubes. Running the CES helped narrow down possible materials that could be used. The analysis of the CES is located in Appendix 6 and required a Young's modulus value of at least 1.9 [GPa]. Mild steel material passed the CES requirements and could be purchased on the market with the included technology of telescoping tubes.

Dimensions

For dimensions, theoretical models were analyzed to see what the resulting forces and ultimately what material properties were needed for each component. Analysis was focused on a safety factor of four in many areas of structure to ensure the safety of the child while seated within the chair. A safety factor of 2 is common in the design of many devices, but since this apparatus has the child within the seat, the safety factor has been doubled to 4 to ensure the child's safety. [D. Johnson, personal communication]

Bolts were modeled using a simple beam with a distributive load as seen in Figure 9. The shear stress and bending moment were then determined using a resolution of forces and moments coupled with Mohr's circle and Von Mises. The full analysis for the determination of the bolt size for the rotating joint is in Appendix 6.1.

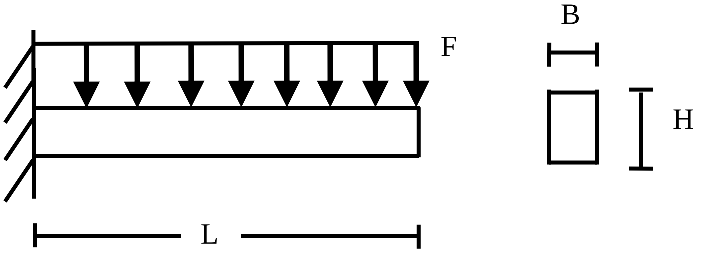


Figure 9: Bolt modeled as a distributed load on a simple support beam at the wall

Tipping calculations were done by summing the center of moments, and are given in Appendix 6.2. This determined what length the legs of the frame needed to be to give a safety factor of four to prevent tipping. A reason the safety factor of four is important here is because a child could use momentum to generate a greater torque by shifting their weight quickly. As a model is unavailable within the time constraints, a safety factor of four is used to ensure that tipping is not a concern.

To decide the linear actuator's position the angular velocity and the safety factor of the weight it could hold were considered. Seen in Figure 12 in Appendix 6.7 is the 2-D CAD design that was used to help render a scale model that reflects how the extension of the linear actuator changes the angle of the chair between the required ranges. The full range of the actuator is used to restrict the operator from moving the chair too far in either direction. From that position a force on the actuator was calculated using by resolving moments and summing them to be zero, and then checked to see if the safety factor of four was upheld on the actuator.

For the thickness on the chair back, hand calculations of a simple beam with two supports and a more detailed FEA were done. Both are listed in Appendix 6.6 and have the assumption of 23.4 in. by 12.2 in. for the PVC piece to accommodate the largest size of a seated three year old. It was determined that a thickness of 0.75 inches is thick enough for a safety factor of four concerning max stress and deflection.

The structure beams had hand calculations determining when the beams would buckle and an FEA calculation helping determine the thickness needed for the frame beams. Full analysis is included in Appendix 6.6.

Shape

The shapes of certain components were chosen for maximum strength and rigidity, while the shapes of some non load-bearing components were designed to save material for compactness.

The head support was designed as a U-shape of PVC blocks with the sides sticking perpendicular to the chair back. Having the chair back contoured in to provide head support was not feasible as children have different sized heads and the lowest contour would make the back of the chair uncomfortable for the tallest children. The U-shape with replaceable foam blocks can be at the correct height and width for each child's head within the age range from 1-36 months old. This U-shape also conserves the space taken up by the head support as it is a shell that has pads attached to its insides.

There were two practical options for the shape of the base of the aluminum frame, a square and a triangle. While a triangle has the advantage that it cannot twist into a different shape while a rectangle can, the square has two advantages over the triangle. First, welding the mounting brackets for the actuator would be difficult at the rearmost point of a triangle. Potentially having a weak setup for the mounts is a high safety concern because if the actuator mount broke the chair back would freely fall backwards. Second, the space under the chair needs to be maximized to allow the pulsator base to freely move under the chair and the square shape provides more room. Therefore, the square shape was chosen.

Our sponsor has also made some specific designs on components that serve a purpose in the testing. The seat pan has a tongue in the middle which helps separate the child's two legs preventing many complications in the test. One complication is the child crossing its legs which prevents the pulsator from correctly reaching the testing zones. Another issue would be the legs bumping into each other while being tested as this could throw off the results. The second specific design is the curved side that is facing the child. This curved tray helps prevent from toys from falling down the near the outer edges of the chair. The toys are used to distract the child so if a toy falls an operator would need to get the toy and it may fall onto lab equipment disrupting the test.

IX Final Design

The final design was modeled in CAD and is shown in Figure 10, below. In the following sections the design and functionality of each component is detailed. For more detailed pictures pertaining to dimensions please refer to Appendix 8, including dimension modifications since design review three.

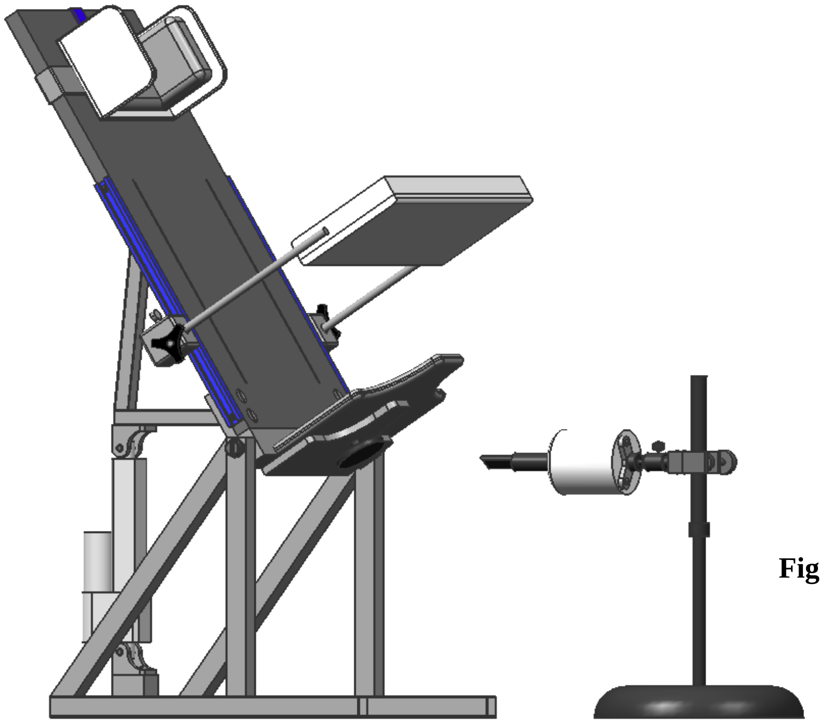


Figure 10: The final design.

Chair Adjustment Angle

To electromechanically adjust the chair back angle, we decided to use a linear actuator for several reasons. First, linear actuators provide the built-in safety since they have use worm gear which holds its position even when unpowered. Second, linear actuators operate at slow speeds below 1 inch/second which is suitable for our application. Third, linear actuators are enclosed so there are no gears or parts exposed to infants and operators. Based on our calculations, we found that we can use a linear actuator with a stroke as small as 3.93 inches and overall length of 9.69” to cover our desired range of motion (desired range of motion: 10˚-30˚ from vertical, actual motion with linear actuator: 8˚-32˚ from vertical). The linear actuator that we purchased, a Creative Werks LACT4, along with a CAD model of the linear actuator in our design is shown in Figures 11 and 12, respectively.

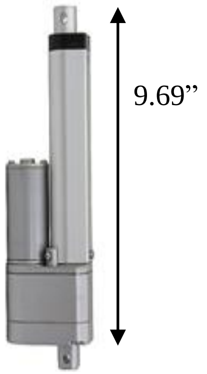


Figure 11: 3.93 inch stroke linear actuator, rated to 107 lb moving [23]

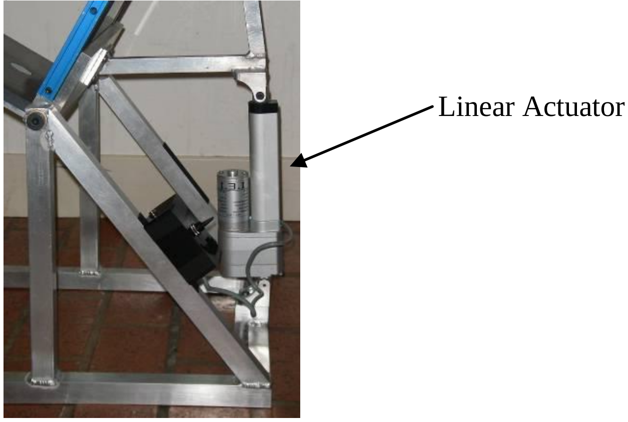


Figure 12: The linear actuator as implemented in the design.

Additional components are necessary to operate the adjustment angle of the chair. The first of these components is specially made brackets for mounting the linear actuator, which were made by the linear actuator manufacturer. An image of these brackets is shown in Figure 13 (below). Machining the brackets would be challenging to precisely position the correct hole sizes while ensuring the same strength as the linear actuator’s mounts. Another component that was purchased is a power transformer, because the linear actuator runs off of 12 VDC, and the sponsor would require it to run on 120 VAC from a wall outlet. The delay for purchasing a transformer is because the designer specifications for how much voltage and amperage are required may be incorrect. The linear actuator is rated for 3.4 A under the largest possible load; however it may need less in our application. Tests will be conducted to determine the voltage and amperage required for the purchased linear actuator. The final component which will be used to adjust the angle of the chair is the switch. To operate the chair, an on-off-on momentary switch is used. In this switch, a button must be held in either a forward or reverse direction in order to move the chair. When the switch is released, the chair will stop moving. There is extra safety in this design as the button is naturally located in the off position. It will also be easier to stop the chair at the desired angle with a momentary switch, than with a position toggle switch as the chair will stop moving when you release the switch with the momentary switch and the position toggle may keep moving. The switch along with the transformer will be mounted on the back support of the chair. A picture of the switch is shown in Figure 13.

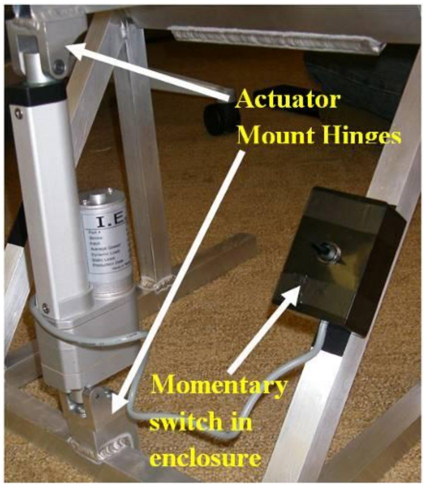


Figure 13: Location of angle adjusting devices.

Frame & Chair Back

The chair frame is made out of 1 inch square solid square aluminum tubing for the vertical bars, and 1 inch square hollow tubes with 1/16 inch wall thickness for all other bars. We have determined through calculations that this tubing will provide a strong enough base to support the child while minimizing weight to help when the apparatus is moved around (see recommendations). The structure of the chair has also been designed against tipping in the forward and lateral directions, based on calculations in section XI, validation testing. Figure 14 (on right) shows the extended support beams added to the front of the chair to help ensure that the infant, along with the seating apparatus, does not tip over.

Figure 14: The extended portions of the support beams reduce the risk of the infant and chair tipping forward.

The chair back and aluminum rotator are shown in Figures 15 – 17 (seen below). We have determined to make the chair back using 0.75 inch thick PVC. In order to reduce the strains on chair back, we designed an aluminum block that is attached to the PVC at the rotating joint. In this setup, the aluminum rotating piece takes majority of the stresses due to the infants' weights in loading the chair. If the PVC were to take most of this load, there would be drastically increased possibility that cracks could propagate or the PVC could creep from the holes in the design. For attaching the PVC chair back to the aluminum rotator, screws are used and threaded into the aluminum. The screws are threaded through the aluminum because it has better materials properties for bolting than PVC: higher yield strength, higher elastic modulus, and higher resistance to creep [B. Coury, personal communication].

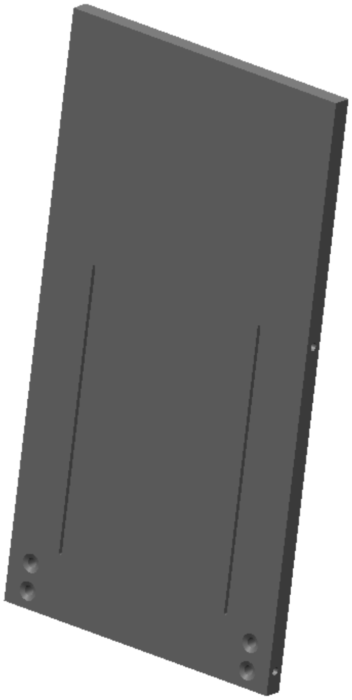


Figure 15: The PVC chair back provides a solid piece for the infant to rest his or her back on.

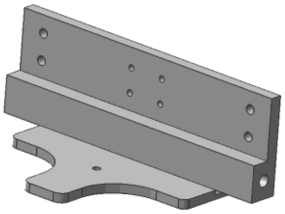


Figure 16: The aluminum rotator piece, welded to the seat pan support, which takes most of the load of the weight of the infant.

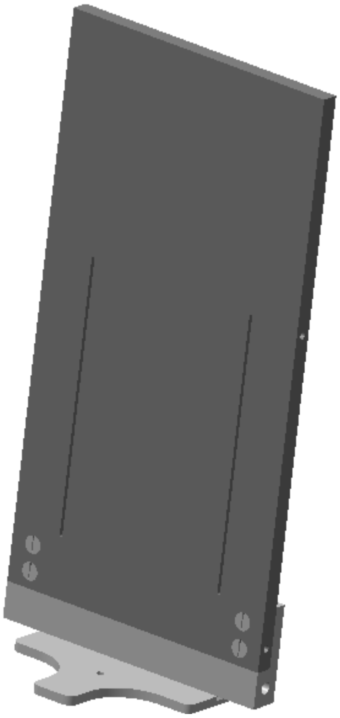


Figure 17: The assembly of the chair back, including the aluminum rotator piece, seat pan support, and the PVC back rest.

Along with the aluminum rotator piece, the other connection between the structure and the chair back is the triangular mount attached to the linear actuator. This mount was designed in order to provide the proper amount of movement of the chair back based on the stroke of our linear actuator. This triangular mount is made out of 0.75 inch square 1/16th inch thick hollow aluminum 6061-T6 tubing and is shown in Figure 18.

Figure 18: The triangular mount connects the linear actuator to the PVC back rest and the aluminum rotator piece. CAD model on left, prototype on right.

Seat Pan

We have designed six different sized seat pans in order to fit our wide range of children, shown in Figure 19, below. These seats are made out of 0.5 inch thick PVC. In order to hold the seat up we have added a support onto the aluminum rotator. This support, made out of aluminum, is slightly smaller than our smallest seat pan, so that it can provide maximum support to the infant without extending beyond the boundaries of the seat pans themselves. Elevator bolts are used to attach the seat pan to the aluminum support. A hand knob threads on the bolts to secure the seat pans against the aluminum support (Figure 20).

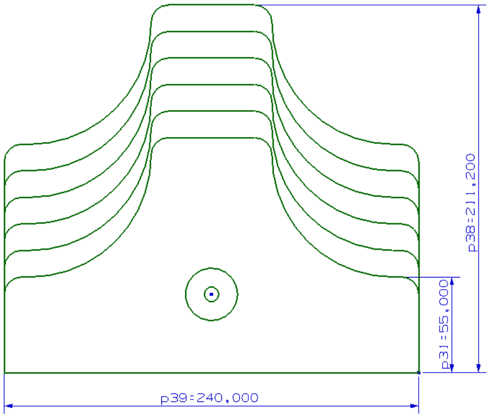


Figure 19: The varying sizes of the six different seat pans, which will be made out of half inch thick PVC.

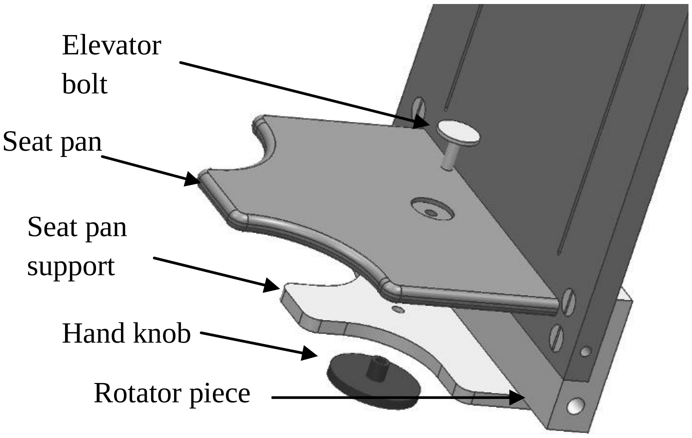


Figure 20: The aluminum seat support is welded to the aluminum rotator to provide extra strength and rigidity to support the infant.

Head Support

The head support design consists of an outer head support frame along with three different sets of head support cushions (Figure 21, on right). Each cushion is composed of three separate pieces of foam or cotton batting which are encased in vinyl and attached to each other. The cushion will be sewn together so that it would lay flat if not propped into position. The three cushions have increasing lengths and decreasing thickness to fit the range of infant head sizes; all pads have the same height to fit inside the support frame (Figure A.12.19, p. 126). Velcro ™ is sewn on the back of each cushion and aligns with the Velcro ™ on the inside of the head support frame.

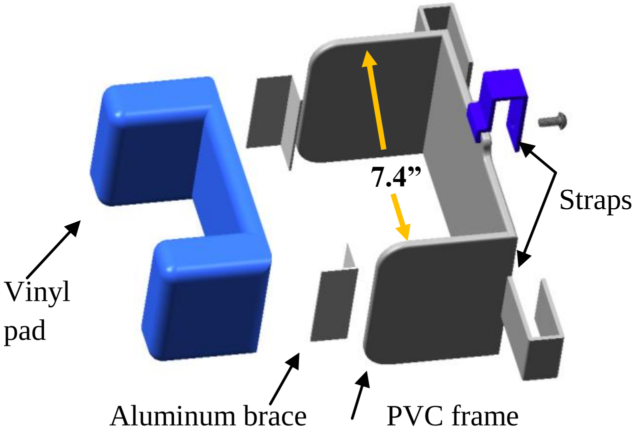


Figure 21: Head support shown with the largest pad size.

The head support frame is made out of 0.25 inch thick PVC, and a Velcro ™ strap is attached across the back, extending to the left and the right side of the head support (Figure 21, above). This strap of Velcro ™ is used to stabilize the head support laterally by securing the Velcro ™ to matching strips of Velcro ™ adhered to back of the PVC chair back. To secure the head support in place vertically, a strap will be attached to the back of the head support through a loop structure and can be draped to the back of the chair where it is attached to a clamp. This clamp will not allow movement of the head support unless the release is held down.

Tray

The play tray that we are using is the same tray used in our benchmark design, developed by our sponsors. The tray is made out of high density polyethylene (HDPE) and has a custom lip added to it (Figure 23, on right). The tray is attached to two aluminum bars which lock into the seating apparatus. The tray is attached to the aluminum bars using counter sunk screws in order to be flush with the tray and provide a smooth play surface. The screws go through the tray into separate aluminum blocks (Figure 23). The four counter sunk screws have their own aluminum block which they screw into. Each aluminum rod slides through a set of two aluminum blocks and are locked into place using set screws.

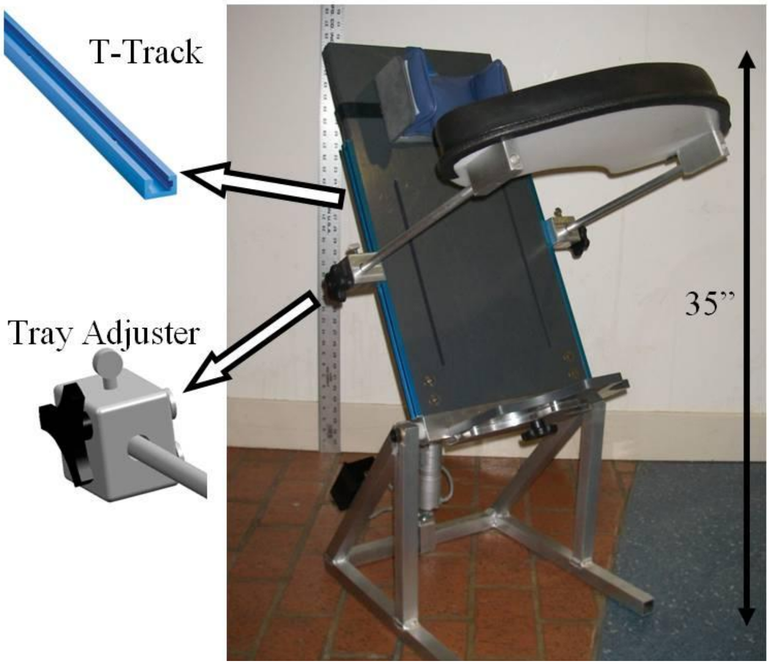


Figure 23: The functions of the tray are to shield the infant from seeing the pulsator apparatus during testing, provide a play surface, and restrict the motion of the infant. The adjustment blocks slide into the T-tracks and lock the tray in the desired position.

The other end of the rod slides through another aluminum block called the tray adjustment block. These aluminum blocks are set in T-Tracks (Figure 23, on right) in order to adjust the height of the tray. A hand knob is located on the side of the tray adjustment block to lock the height of the tray. This is accomplished by turning hand knob, which pushes tray adjustment block against the side of the T-Track, locking it in place using friction. There is also a thumb screw located on the top of the tray adjustment block to extended length of the tray (Figure 23). This position is locked using the friction between the thumb screw and the bar. The target for tray resolution is about 3cm so that a comfortable level for the smallest child can be reached. [B. Ulrich, personal communication]

Pulsator Apparatus

Microphone Stand The pulsator (Ling Dynamics, model number V203) was provided by our sponsor (Figure 24, on right). The pulsator apparatus is mounted on a modified On-Stage M57201B microphone stand to allow for easy vertical position adjustments. The stand includes a cast zinc base and hollow steel telescoping tubes. The tubes are lockable in their vertical position by twisting the mechanism at their interface, a function retained from the original microphone stand (Figure 25, p. 27). The outer tube can be adjusted in height while the inner tube remains fixed to the base, opposite of the original orientation of the microphone stand. The reason for this is so the pipe clamp (Figure 26 , p. 27) only has to be adjusted to fit the outer diameter, which decreases overall adjustment time during testing. With this setup, the pulsator has 15 in of vertical travel range, from 4 in off the ground to 19 in off the ground. Collapsible tubes are necessary because when testing the rear testing zones of the infant (App. A.1, p. 49), the stand must fit entirely under the seat. The microphone stand needed to be modified with a steel connector piece and a nut to allow for clamping to the larger tube (Figure 26). The pulsator can also be seen in Figure 26, as well as an exploded view in Figure 27, pg 27.

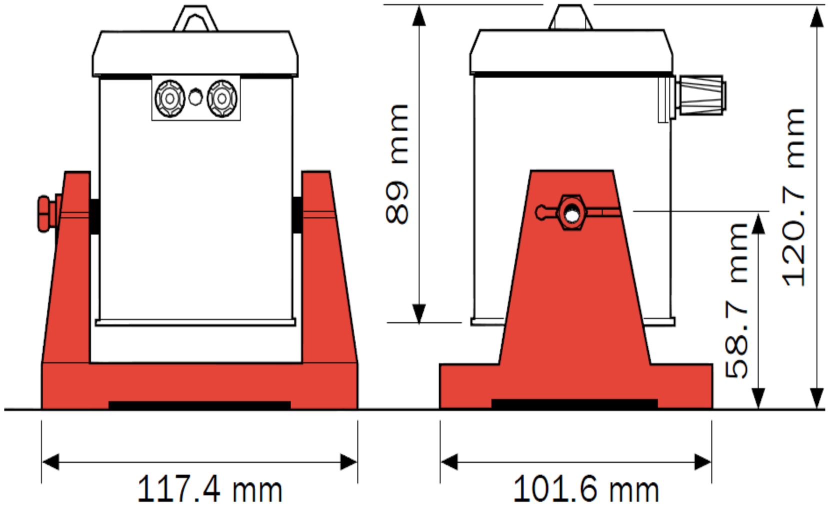
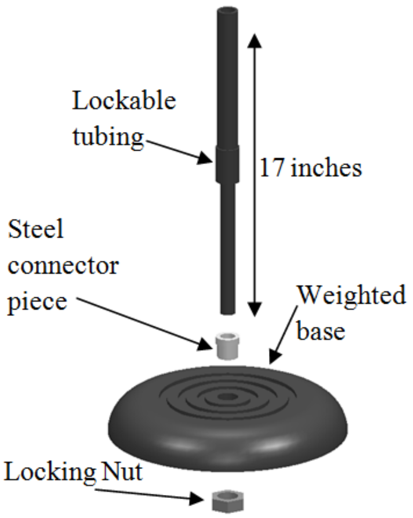


Figure 24: Pulsator V203 from Ling Dynamics (Note: the pulsator does not include the red base seen above)

Ball Joint To control the pulsator orientation, a camera ball joint mechanism was used. The ball joint connects to the pulsator with a aluminum bracket using four screws. The ball joint, a Vanguard BLH-300, it has a rated weight capacity of 70 lbs and has three adjustment knobs, one for course locking, one for fine locking, and one for locking the rolling axis. The large range of motion that the ball joint offers helps us adjust the pulsator to each testing zone, as seen below in Figure 28 . The ball joint is shown in Figure 27. Further operation instructions are in Operation Recommendations.

Figure 28: Ball joint's full range of motion is used to properly place the pulsator at each testing site.

Pipe Clamp To mount the pulsator and ball joint a Manfrotto 035RL pipe clamp was used to secure both in place. The clamp secures around the rod and has a handle which allows for an easier tightening of the testing setup at the desired height. The clamp is rated to a weight of 33 lbs.



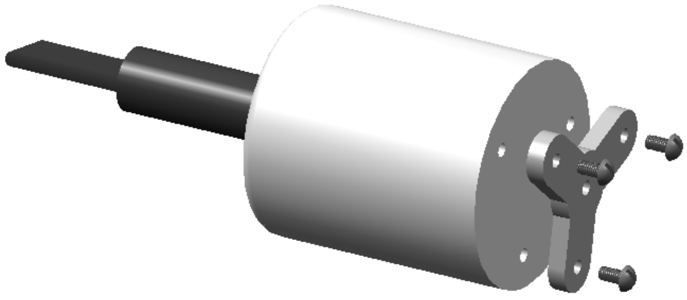


Figure 27: The bolted-in pulsator connection plate attaches via a bolt to the ball joint to the pulsator.

Figure 25: Pulsator stand includes weighted base, lockable telescoping tubing, steel connector piece and nut. Note that the larger of the telescoping tubes is located on top.

The ball joint mechanism allows the pulsator apparatus to reach each testing site from many different angles. Its position is lockable by turning the knob.

The pipe clamp adjusts the height of the pulsator upon the larger of the two telescoping tubes.

Figure 26: The pulsator apparatus fully assembled

X Fabrication Plan

A step-by-step manufacturing plan is detailed in Appendix 11 (p. 98). The first subsection gives brief synopses of the major components and how they were manufactured. The second subsection provides further detail to select, intricate fabrication procedures from the manufacturing plan (App. 11, p. 98). The third subsection describes the assembly. The fourth subsection describes differences between manufacturing the prototype and a full production volume.

Component Manufacturing

Head Support Cushions **-** The manufacturing of the vinyl-covered head support padding for our prototype was outsourced to Joan Courson, of The Parson's Wife Custom Sewing. There are two factors outsourcing this component: (i) the project team did not have skill set required sewing to sew the padding, and (ii) sewing vinyl requires an industrial strength sewing machine in order to sew it, which was unavailable.

Chair Frame - The structure of the chair frame was made out of 1" solid square 6061-T6 aluminum bar and 1" square hollow 6061-T6 aluminum bar 1/16 inch wall thickness. The frame also consists of the aluminum rotator for the PVC chair back to attach to and 3/8 thick 6061-T6 aluminum seat pan support. Additionally, the PVC chair back is supported by a triangular mount, which connects the chair back to actuator; the actuator is also mounted to the chair frame. These parts were milled to size, and holes were drilled for clearance and threaded holes for components to be bolted together. Joining the bars for constructing the frame and joining the aluminum rotator and seat pan support was done with tungsten inert gas (TIG) welding.

Pulsator Stand - The pulsator stand was fabricated by modifying a microphone stand, which has the adjustable height locking mechanism required for the design. The locking telescoping tubes were to the correct length. An adapter piece was made on the lathe to reattach the telescoping tubes to the base in the opposite orientation. The base was also re-tapped to a standard 7/8"-14 thread size compatible with the adapter.

Chair Back - The chair back is made out of rigid PVC sheet with the dimensions 12" x 24" x 0.75". Holes will be drilled and tapped into the chair back to connect it to the aluminum rotator, support frame, tray track, triangular mount, and head support. Slots were milled into the chair back to thread the (purchased) seatbelt through.

Tray Mount **-** Two tray mounts were fabricated to hold the tray and give it two degrees of freedom in the vertical and lateral direction. The mounts were constructed out of aluminum blocks, milled to size. Four holes were then drilled, and two were tapped: (i) hold the rods from the tray, (ii) hold a thumbscrew to lock the tray rods in place, (iii) hold the hand knob for the tray height adjustment, and (iv) a guide screw for the tray track.

Manufacturing Guidelines

Frame welding - For the triangular mount the two bars should first be welded together and then the lower bracket that secures into the rotating piece should be welded into the bottom of the triangular mount. The last bracket should be welded with the use of a wood jig or the chair back itself to ensure that the bracket angles are parallel. A further order of operation recommended about the triangular brace is to drill the holes in the PVC chair back after finishing the welds on the triangular mount. This ensures the holes are in the correct location relative to where the triangular mount is secured into the rotating piece.

Press-fitting bushings into the frame - The bronze bushings should be press fit into the solid vertical aluminum frame bars after welding them to their respective side pieces. This prevents the impregnated oil in the bronze bushing from burning off when the heat from the welding is applied. To use the press fit machine the two side frame supports should not be welded together as they would obstruct the path of the machine and could force an angled press fit. Once the bronze bushings have been press fit, the holes should be hand reamed with a 0.5 in hand reamer to ensure tolerances.

Pulsator adapter welding – The pulsator adapter must be welded to the inner telescoping tube to allow the apparatus to be assembled. All paint must be removed on the telescoping tube during the welding preparatory phase. Fusion welding provides the best results for joining these two components.

Guidelines for Assembly

Assembling Frame and Actuator – First, position the aluminum rotator so that the 3/8”-16 holes (2) on either side are align concentrically with the 0.5 in bushing holes (2) on either side of the aluminum frame. For each side, place a 1/8” thick nylon washer between the aluminum rotator and the aluminum frame, and insert the 3/8”-16 shoulder bolt through the bushing and washer and screw into the aluminum rotator.

Next, place actuator base hinge on top of actuator mount lift on the frame and align the through holes (2) of the actuator hinge with the threaded holes of the actuator mount lift (2). Screw in 1/4”-20 bolts (2) to attach the actuator hinge to the actuator mount lift. Then place the actuator inside of the hinge so that the 0.314 in actuator holes (2) align with the clearance hole of the actuator hinge; once aligned, insert the shoulder bolt (included with actuator hinge purchase) through the clearance holes and fasten the actuator to the hinge. The installment of the shoulder bolt to attach the actuator to the hinge is repeated for attaching the actuator to the welded hinge on the triangular mount.

After attaching (i) the aluminum rotator to the frame, (ii) the base hinge to the frame, (iii) the actuator to the base hinge, and (iv) the actuator to the triangular mount, the triangular mount can be attached to the aluminum rotator. First, align the 0.25 in through holes (4) with the threaded holes (4) located in the back of the aluminum rotator. Fasten the 1/4”-20 bolts (4) through the triangular mount and into the aluminum rotator. This completes the frame assembly.

Installing PVC Chair Back – First, place the PVC chair back on the aluminum rotator, so that 0.4375 in through holes (4) on the chair back and 3/8”-16 threaded holes (4) on the aluminum rotator are aligned. Insert the countersink 3/8”-16 bolts (4) in the chair back through holes and fasten into the threaded aluminum rotator holes until bolts are flush with the front face of the chair back. For an exploded to assembled view please see Figure 29 below.

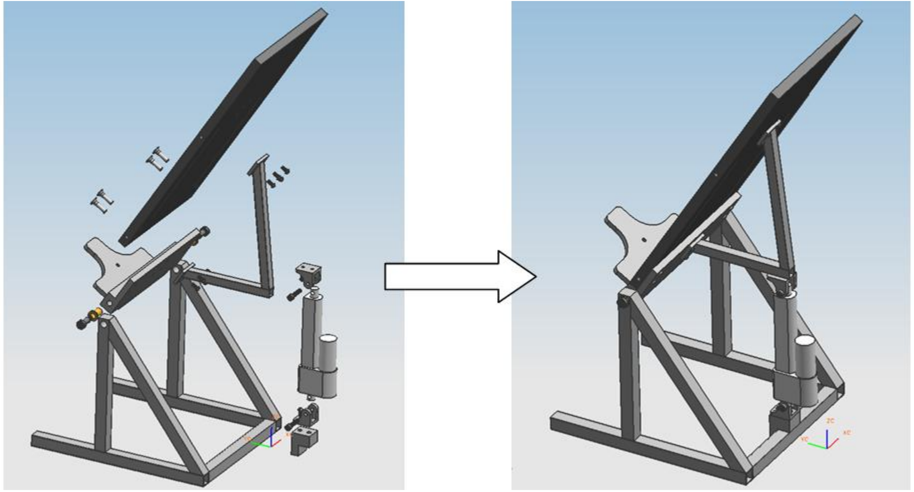


Figure 29: Exploded to assembled view of frame, actuator, and PVC chair back.

Installing Tray and Tray Adjustment System – First, place the bolts (3) into the tray mount: 1/4”-20 thumb screw, 5/16”-18 guide screw, and 5/16”-18 T-bolt (Figure 30, below). Second, screw the hand knob the 5/16”-18 T-bolt. Third, bolt the tray tracks (2) to either side of the PVC chair back using 10-32 socket cap bolts. Fourth, align the sliders to the same position on the PVC chair back, and tighten the hand knobs to lock the position in place. Fifth, insert the rods (2) from the tray into the 0.53125 in clearance holes (2), and tighten thumb screws to lock tray securely.

For proper pad orientation, fold the pad down the middle so that the left and right side are touching, and then attached the back of the pad to the back of the head support shell. Slowly press the pad to the rest of the shell to fully adhere the pad. This method allows the pad to firmly attach to the head support and creates a smooth, comfortable surface for the infant’s head.

Installing Seat Pan – When attaching the seat pan, place the elevator bolt lightly in the recessed hole through PVC seat pan and aluminum seat pan support. Thread the hand knob up to the aluminum seat pan support, and make an additional quarter turn at the onset of resistance. This should properly align the elevator bolt to be level with the seat pan to create a flat surface. Two turns will provide enough stability so that the seat pan will not move; additional turns could cause deformation to the PVC seat pan.

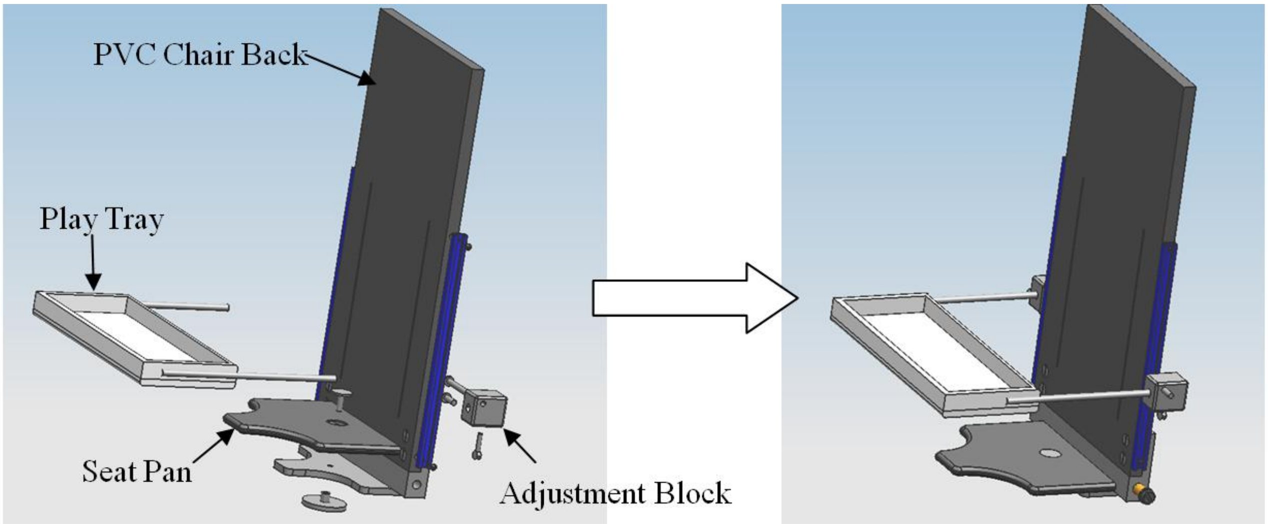


Figure 30: Exploded to assembled view of tray, tray adjustment system, and seat pan.

Assembling Head Support – First, attach the side walls of the head support frame to the back wall using PVC cement. After the walls have dried for 24 hours, attach aluminum brackets to inside joints using epoxy. When the head support frame is fully constructed (Figure 40, p. 43), loop the strap through the top slot, fold onto itself and sew close. Attach Velcro ™ covering the entire back surface of the pad and inside of the head support shell using the adhesive surface on the back of the Velcro ™. Bolt the strap into PVC chair back using a washer and 1/4”-20 bolt.

Assembling Pulsator Apparatus – For the stand assembly, the telescoping tubes with the attached 7/8”-14 adapter are fastened into the rethreaded pulsator base. For attaching the pulsator, place the 3/8”-16 bolt in the pulsator mount opposite the orientation of the 10-32 bolts (3), and then fasten pulsator mount to the pulsator using the 10-32 bolts. With the exposed threading in the 3/8”-16 bolt, fasten the ball joint to this bolt. To attach the ball joint to the pipe clamp, insert a 1/4”-20 set screw into the ball joint, and then thread the ball joint into the pipe clamp using the remaining exposed threads of the set screw. The pulsator angle adjustment mechanism is now intact, and it can be clamped anywhere along the pulsator stand to complete the pulsator apparatus assembly.

For an exploded to assembled view please see Figure 31 below.

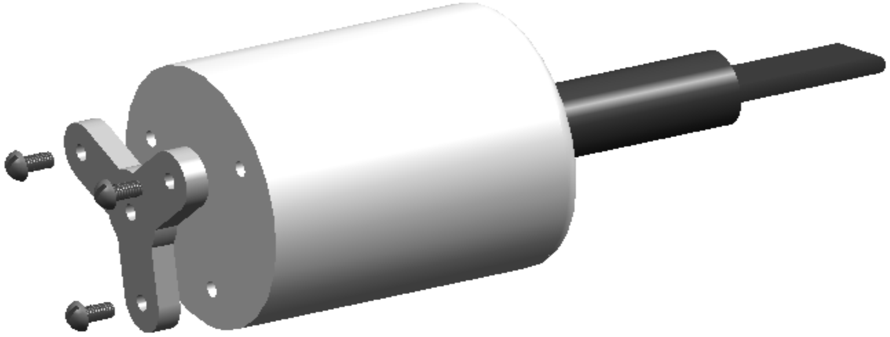


Figure 31: Exploded view for pulsator and pulsator mount plate.

Prototype and Production Assembly Comparison

For a mass produced version of the infant reflex test apparatus, padding could be added the chair back and seat pans to make it more marketable. This padding was not required for the prototype [B. Ulrich, personal communication], but the added comfort for the infants during could create a better test experience. More padding adjustments include having more variations for the head support pads to provide more comfort for infants who fall between the current sizes. Also, designing multiple trays that are more contoured to the range of infant torso sizes would better secure the infant and better prevent toys from falling. Budget would be the limiting factor for the number of different head support pad sizes and contoured tray variations and h.

Having a full enclosure for the back of the chair covering the linear actuator and all moving components would make the apparatus safer and more professional. This housing could provide other functions like holding the power switch for the linear actuator, holding the power converter, and provide a resting place for the head support when not in use.

To optimize the manufacturing for the final design, alternate processes would be used on a mass production scale. In depth analysis of two components, the seat pans and telescoping tubes, are discussed in Appendix 6 (p.67). For material removal on a thin, 2-D plane, features such as (i) as the seat back slots, (ii) cutting the seat pans, (iii) the aluminum connector on the back of the pulsator, (iv) the aluminum frame bars, or (v) the aluminum seat pan support, could be efficiently cut using a water jet cutter. This procedure has the precision required for producing the parts in a cost-effective manner. Additionally, the head support could be made into one piece instead of three pieces using compression molding. The part would be strong enough as one solid piece to not require the aluminum brackets.

XI Validation Testing

The prototype was tested in multiple ways to validate the specifications of the final design. Based on the results, we found that the apparatus meets the specifications that it was tested for and operates as designed. Validation tests are detailed in the following subsections, and summarized in Table 7 (p. 7).

Structural Validation

One of our specifications was for our chair to safely hold children aged up to 36 months; a maximum load of 18 kg (40 lb). The structure of the apparatus was designed for deflection and maximum load safety factors of 4 or greater (A.10.6, p.89), but we decided to only test to a safety factor of 2 to prevent damage to the chair. To conduct weight and deflection tests, the test chair was loaded using hollow, cylindrical bronze tubes weighing 2 kg and 4 kg (Figure 32). A thin-walled aluminum pole of negligible weight allowed the hollow tubes to slide over the rod so that the weights were safely supported when balanced on the angled seat pan (Figure 33). The pole was first balanced on the back of the largest seat pan before weights were added. A counter weight was placed on the back of the chair frame to ensure the chair would not move or tip during testing.

Figure 32: Bronze cylindrical weights

Figure 33: Stacked weights during test

Maximum Load For the maximum load test, the weights were placed through the pole in increments of 4 kg, shown in Figure 33. The chair was loaded from 0 kg to 36 kg (safety factor of 2), and the chair was angled at 5°, the steepest angle allowed by the chair, so that the largest component of the weight was directed downwards on the seat pan. No components in the apparatus were observed to yield or fracture and the results of the test verified the structural integrity of the chair up to 36 kg; a safety factor of 2.

Seat Pan Deflection For the deflection test, the distance between the seat pan bottom and a level surface was first measured using digital calipers (resolution 0.001 in). The weights were then placed through the pole in increments of 4 kg, up to 36 kg. Once the weight was balanced on the seat pan, the weights and pole were slid forward to the tip of the largest seat pan of 21 cm to test the maximum deflection per load. Digital calipers were used to measure the new distance from the tip to the level reference surface (Figure A8.3). The measurements were recorded, and the tip deflections were calculated using the difference between the unloaded and loaded distances. The seat pan was loaded from 0 kg to 80 kg, and safety factor 2 was verified in testing (Table 4, p. 33). As is the maximum load test, to ensure a safe experiment, only a safety factor of 2 was tested.

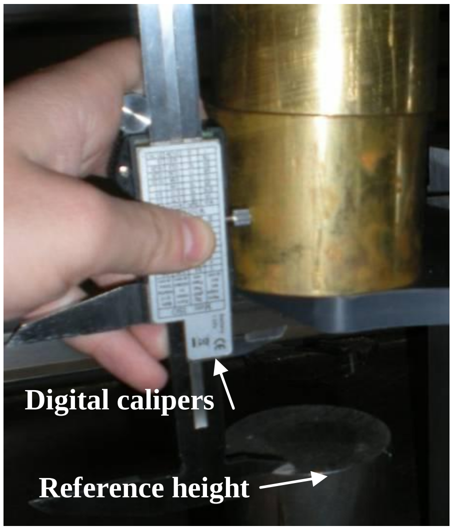


Figure 34: Measuring deflection of seat pan tip against reference height

Table 4: Deflection of Seat Pan versus Applied Weight (4 kg Increments)

Applied Weight	Deflection
0 lb	0 inch
8.82 lb	0.035 inch
17.64 lb	0.06 inch
26.46 lb	0.09 inch
35.28 lb	0.097 inch
44.1 lb	0.121 inch
52.92 lb	0.156 inch
61.74 lb	0.192 inch
70.56 lb	0.209 inch
79.38 lb	0.254 inch

Preliminary Tipping Test

To conduct tests to evaluate tipping risks, we horizontally pulled a rope attached at varying locations on the chair and measured the applied force by attaching a South Bend model DL-2 "fish scale" force gauge (resolution 0.5 lb) to the end of the rope. This way, by pulling on the force gauge, all of the force required to tip the chair went through the force gauge and into the rope that attached to the chair (Figure 8). We conducted tests for forwards, backwards, and sideways tipping. In all cases we did not add weights to the chair as to evaluate the worst-case scenario. For the forwards and backwards tipping test, the rope was attached to the top of the chair back. For the sideways tipping test, the rope was attached next to the pivot bolts on the frame. It was found that the forwards and sideways tipping forces were 3 lb and the backwards tipping force was 2.5 lb. The results are summarized in Table 5.

Figure 35: Force gauge with resolution 0.5 lb

Table 5: Preliminary Tipping Results

Tipping Direction	Force Required	Notes
Forwards	3.0 lb	Worst case scenario: chair 5° from vertical
Sideways	3.0 lb	
Backwards	2.5 lb	Worst case scenario: chair 31° from vertical

Figure 36: Force applied on top rope by pulling on force gauge causing the chair to tip (backwards tipping)

Tipping Test of Production Chair

Given that no weight was added to the chair during tipping tests, the force values were abstract and it was hard to evaluate the real tipping risks. To better understand the results we conducted an identical test using a production desk chair for comparison. This chair is shown in Figure 37. The results of this test showed that our tipping results were very close to the production chair, and were not cause for alarm. They are summarized in Table 6. Our chair was less likely to tip in all directions except for the sideways direction where it tipped at 3 lb and the production chair tipped at 4 lb. We are not very concerned about tipping in the sideways direction, however, because the seat pan is narrower than the chair back width. This means that when an infant is placed on the chair and secured with the seat belt, his or her weight will always be above the footprint of the chair, *reducing* the risk of tipping.

Table 6: Production Desk Chair Tipping Results

Tipping Direction	**Force Required**
Forwards	3.0 lb
Sideways	4.0 lb
Backwards	1.0 lb

Figure 37: Production desk chair tested

Additional Tipping Testing: Extensions

Preliminary testing showed that backwards tipping requires the least amount of force, so backwards tipping was therefore of the most concern, (even though it was safer than the production chair by a factor of three). A follow-up experiment was designed to collect data for the increased resistance to tipping by extending the legs in the back of the chair. In the test, stock aluminum tubes (0.75 in x 0.75 in) were slid through the hollow legs to allow for 1 inch increments of extra material to stick out the back of the chair (Figure 10). The extra length of the bar was measured with digital calipers (resolution 0.001 in) and the bars were held in place with tape in tension, preventing the extra material from sliding back into the base during testing. Results from this test are shown in Table 7. The results show that the force required for backwards tipping can be doubled by adding 5 inches of extensions. This data can be used if increased tipping resistance is desired in the production model to account for forces such as testers leaning on the chair back.

Table 7: Force Required to Tip Chair Backwards versus Extension Length

Extension Length from frame	**Force required to tip**
0 inch	2.5 lb
1 inch	3.0 lb
2 inch	3.2 lb
3 inch	3.6 lb
4 inch	4.4 lb
5 inch	5.0 lb

Figure 38: Extensions on chair back range from 1 to 5 inches

Measured Ranges and Resolutions

A four foot ruler (1/16 inch resolution) and a protractor (1° resolution) were used to measure the initial lengths and angles versus their respective end lengths and angles to determine the ranges of each particular component. To conduct the resolution tests, the initial angle/length was first measured. Then ten small adjustments were made by hand and the new angle/length was measured. That measured value was divided by ten and then taken as the resolution for that component. For speed of the chair back, rotation six tests were timed using a stopwatch (three forward and three backward). These times were averaged and the angle was divided by the average time to generate a speed. The results of the range and resolution measurements are summarized in Table 8.

Weight of chair minus tray = 28 lbs

Table 8: Range and Resolution of Components

Component	**Range**	**Resolution**
Tray Sliders	14 inch	0.05 inch
Head Support	13 inch	0.14 inch
Pulsator Angle	130° (90° to -40°)	0.5°
Chair Back Angle	26° (5° to 31° from vertical)	1.3°
Angle Speed	3.8°/sec forward, 3.9°/sec backward	N/A
Pulsator Height (vertical)*	26.375 inch max	0.038 inch
Pulsator Height (horizontal)*	17.125 inch (when angled it can reach 21 inch) 5.5 inch low (0 inch when angled down)	0.038 inch
Voltage	~12.5 Volts max	N/A
Current	0.96 Amps (at 40 lb load, SF = 1)	N/A
Power	12 Watts (at 40 lb load SF = 1)	N/A

* Measurements were taken on the large pole without going over the top

User Ease Tests

To administer the user ease validation tests, two of the researchers from the kinesiology lab came in to take a series of "can do" tests. They were separated and then provided minimal instruction to adjust one component at a time for an "unlearned" trial. They were then timed at how long it took them to complete the task and then after completing the test they were asked to rate difficulty of the adjustment of that component on a scale from one to ten, (one being the easiest and ten the hardest). When one researcher completed their tests they were asked to leave and the other researcher was tested in a similar manner. After both researchers had completed the first trials of all the tests, they were allowed to practice on the chair and ask any questions about how to adjust a particular component. Each researcher was tested again for a "learned" trial and then they filled out a survey asking questions such as if they thought the design was simple and if they thought the child would be comfortable.

The results of the tests are given in Table 9. Descriptions on how each of the tests was administered are given below.

Change Seat Pan- The initial position of the chair has one seat pan in the chair locked into place. When the time started the task was to take out the seat pan and put in another sized seat pan. Once the second seat pan was locked into place the timer stops and the time is recorded.

Chair Back Angle Adjustment- The initial position of the chair back was reclined at 31° from vertical. The time starts before the switch is activated and the timer stops when the chair back is 5° from vertical. (fully extended linear actuator)

Head Support- The head support strap is initially two inches from the top. The timer begins and the tester has to position the head support as far down as it can go (thus for the youngest child). The time then stops when the head support is fully extended and in position for testing.

Seatbelt- The seatbelt test was broken into two tests timed separately. The first test, not included in the five minutes that the total time of adjustments must be under, was to thread the seatbelt through the slots in the seatback. Once this was done the time was recorded for attaching the two straps together using Velcro.

Tray Adjustments- The tray adjusters were initially in the bottom position and the tray was not attached. The timed section was from the adjusters being repositioned to the correct height and then the tray being put into the correct depth and locked into place.

Pulsator Adjustments- The pulsator started in the bottom position and pointed straight out with the ball joint angled sideways. The instructions were given to reposition the angle of the pulsator to be in the upright or vertical position and to be at the hamstring of the model infant in the chair. When the pulsator was locked into the upright position then the timer was stopped.

Total time average for “unlearned” = 94.5 seconds
Total time average for “learned” = 65.5 seconds

Table 9: User Ease Test Survey Results

Seat Pans (Changing)	Unlearned Difficulty	Time to adjust	Learned Difficulty	Time to adjust
Trial	Scale 1-10 (1=easy, 10=hard)	In seconds	Scale 1-10 (1=easy, 10=hard)	In seconds
Average	1	23.5	1	27

Chair Back Angle Adjustment	Unlearned Difficulty	Time to adjust	Learned Difficulty	Time to adjust
Trial	Scale 1-10 (1=easy, 10=hard)	In seconds	Scale 1-10 (1=easy, 10=hard)	In seconds
Average	1	7	N/A	7

Head Support (Height)	Unlearned Difficulty	Time to adjust	Learned Difficulty	Time to adjust
Trial	Scale 1-10 (1=easy, 10=hard)	In seconds	Scale 1-10 (1=easy, 10=hard)	In seconds
Average	1	4.5	1	3.5

Head Support (Replace)	Unlearned Difficulty	Time to adjust	Learned Difficulty	Time to adjust
Trial	Scale 1-10 (1=easy, 10=hard)	In seconds	Scale 1-10 (1=easy, 10=hard)	In seconds
Average	1	14	1	7

Seatbelt (Threading in)	Unlearned Difficulty	Time to adjust	Learned Difficulty	Time to adjust
Trial	Scale 1-10 (1=easy, 10=hard)	In seconds	Scale 1-10 (1=easy, 10=hard)	In seconds
Average	2	37.5	N/A	N/A

Seatbelt (Attaching)	Unlearned Difficulty	Time to adjust	Learned Difficulty	Time to adjust
Trial	Scale 1-10 (1=easy, 10=hard)	In seconds	Scale 1-10 (1=easy, 10=hard)	In seconds
Average	1	1	1	1

Tray Adjusters	Unlearned Difficulty	Time to adjust	Learned Difficulty	Time to adjust
Trial	Scale 1-10 (1=easy, 10=hard)	In seconds	Scale 1-10 (1=easy, 10=hard)	In seconds
Average	1	43.5	1	20

Pulsator Base x-y Adjustment	Unlearned Difficulty	Time to adjust	Learned Difficulty	Time to adjust
Trial	Scale 1-10 (1=easy, 10=hard)	In seconds	Scale 1-10 (1=easy, 10=hard)	In seconds
Average	2	15.5	2	3.5

Pulsator Height	Unlearned Difficulty	Time to adjust	Learned Difficulty	Time to adjust
Trial	Clamp / telescoping tubes	In seconds	Clamp / telescoping tubes	In seconds
Average	2/2	25.5	2/2	6

Pulsator Angle	Unlearned Difficulty	Time to adjust	Learned Difficulty	Time to adjust
Trial	Scale 1-10 (1=easy, 10=hard)	In seconds	Scale 1-10 (1=easy, 10=hard)	In seconds
Average	2	34.5	2	8

User Ease Trial Results

From the time averages listed above both times fall within the specification of time of adjustment to be under five minutes. With a few minutes of practice and becoming more familiar with the design the time reduced to two thirds of the unlearned trial. Most components were rated at either a one or two as very easy, with the tray adjusters at a three because of the many tightening locations. Also, the adjusting of the pulsator related components was rated as a two because there were also many adjustments dependent on each other.

Results from the surveys were positive and produced helpful recommendations related to user ease. The design was called “user-friendly” and easier to use than the current model. A few suggestions to improve user ease were to add rulers on the chair back to quickly determine the height of each individual slider to help put them at the same height. Also, putting a protractor on the chair back to determine the angle would allow for the testers to record the angle and make tests have consistent angles of chair back. This was not a requirement as the angle of the chair back is mainly for child comfort. (Conversation with Dr. Ulrich) Under child comfort it was considered comfortable for the child (Conversation with Dr. Ulrich) but marketability could be enhanced by more padding on the seat pan and chair back. The easiest adjustment was to change the angle of the chair back while the pulsator setup was also considered easier than the previous model. Lastly, the additional comments were that the lab staff's needs were met to have a "user friendly" chair.

Power Requirements Validation

To test the power requirements, we first tested the motor current draw when the chair was weighted. We loaded the chair with a stack of brass masses to 40 lbs, equal to the weight of the heaviest child tested, and 80 lbs, for a safety factor of 2. To conduct the test, we placed a Cen-Tech 7-Function digital Multimeter in series with one of the power wires. After averaging three trials for each weight, the peak currents were found to be 0.96 A and 1.42 A for 40 lbs and 80 lbs respectively. We also confirmed the voltage of the 12 V power adaptor to be 12.5 V, by measuring the voltage across the power wires. The power requirements for a safety factor of 1 (40 lbs) and for a safety factor of 2 (80 lbs) are calculated using the equation Power = Voltage × Current. The test setup is shown in Figure 39, and the results are summarized in Table 10.

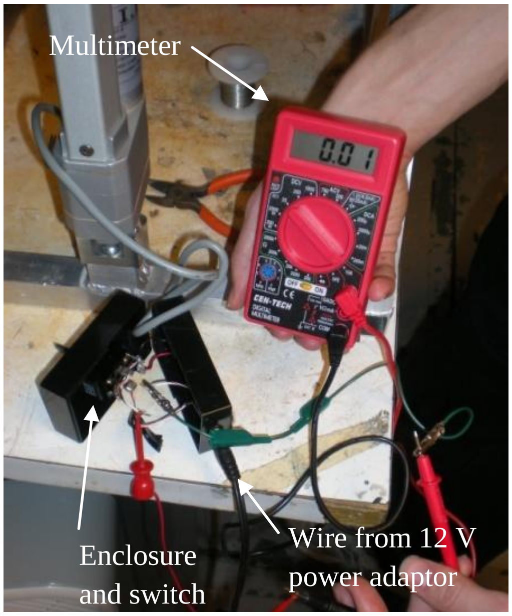


Figure 39: Current Requirement Test

Table 10: Summary of Power Measurements

Voltage of nominal 12 V supply (Volts)	Peak current when loaded to 40 lbs (Amps)	Peak current when loaded to 80 lbs (Amps)	Power Requirement, 40 lbs (Safety Factor = 1), (Watts)	Power Requirement, 80 lbs (Safety Factor = 2), (Watts)
12.5	0.96	1.42 A	12.0	17.8

Based on the results of the current test we found that for a safety factor of 2, a 1.42 A current supply is needed. From our speed validation test in Range and Resolution section, we found that a voltage of 12 V gives us the desired chair back angle adjustment speed. That test combined with our current test allowed us to choose a commonly available 12 V 1.5 Amp AC adaptor made by Enercell™.

Safety Validation

Before the design can be approved for safe use on infants at the University of Michigan, it must be reviewed by the Bio-medical review board at the University of Michigan (BEU). To prepare our product for review by this board and identify potential hazards, we had the apparatus inspected by Ron McCarty, a member of the BEU. Issues that Ron mentioned included putting finger guards near the pinch point near the rotation point, making the electrical enclosure waterproof along with tying the wires down to avoid the covers from wearing down, and to put caps on the ends of the frame bottoms.

Summary, Validation Testing

Validation testing was used to confirm if the new design met the specifications created from the sponsor's requirements. Table 11 provides a summary of all of the validation testing results. Each specification is listed with corresponding goal determined by the sponsor's request or from anthropometric charts about

the size of oldest and youngest infants being tested. If the design meets the target goal, there is a “Y” signifying that the apparatus does meet the specification.
In summary, our prototype nearly fully validated our final design, and we expect that it will meet all of the requirements desired by our sponsors. Our tests validated that our design can accommodate and safely hold the weight of the entire range of infants and children. We validated structure strength, measured deflections, checked tipping, and ensure that the pulsator can reach all of the test zones. We validated the chair angle speed and power requirements and our discussions with a member of the biomedical review board validated the safety of our device for use with infants at the University of Michigan. Our meeting with Dr. Ulrich’s colleagues confirmed the improved user ease and that the time required for testing has been reduced from the old design, however, they likely need to use the device for several months with real infants to fully evaluate our design including the long term maintenance needs. The comprehensive validation of our prototype will allow for preparation for production, which will occur over the next several years.

A few of the specifications were not met for various reasons. Marketability is affected by the ease of use for one operator and not everything in the design is good for a clinic as there are some intensive adjustment components that would be challenging to do with only one operator. This design was planned to have multiple operators where one could be watching the child while other operators were adjusting components for comfort and setting up the pulsator for the next test.

The head support size range is smaller as the original biggest pads were sized to fit the smallest child’s head for the fifth percentile. The would prevent these pads being used on other smaller children who are just bigger than that size so the smallest pads were modified to allow for more space of the children’s heads.

Table 11: Summary of Specification Validation

Specification	**Goal**	**Actual**	**Validated**
Child Comfort (Child is Held Securely)	Y	Deemed Comfortable by Testers	Y
Safety Belt (Length)	0.8 m	0.8 m (stretched)	Y
Head Support (Diameter)	9.9 to 16.9 cm	13 to 16.25 cm	N
Seat Width	23-29 cm	24 cm	Y
Seat Length	16-21 cm	13.5- 21 cm	Y
Length of Tray	27 cm	27 cm	Y
Width of Tray	49 cm	49 cm	Y
Freedom of Arm Rotation (Forward and Above Tray)	0°-90°	0°-90°	Y
Freedom of Leg Movement Restricted by Chair, Seat Back, and Tray	Y	Gives freedom of legs	Y
Play Tray	Y	Include play tray	Y
Adjustable Tray Height	Y	14 in (2.5 to 16. 5 from seat pan)	Y
Pulsator Apparatus Height (Collapsed)	29.2 cm	29.2 cm	Y
Latex Not Used in Design	Y	No latex used	Y
Seat Back Angle Range	60° to 80°	59° to 85°	Y

Average Pulsator Adjustment Time	15 - 30 sec	14 sec	Y
Average Head Support Adjustment Time	75 sec*	16.4 sec	Y
Average Tray Adjustment Time	75 sec*	16.4 sec	Y
Average Seatbelt Adjustment Time	75 sec*	16.4 sec	Y
User-Friendly / Self-Explanatory	Y	Survey Confirmed	Y
Rotation of Pulsator Head in X Axis (Lockable)	360°	360°	Y
Rotation of Pulsator Head in Y Axis (Lockable)	360°	360°	Y
Rotation of Pulsator Head in Z Axis (Lockable)	150°	180°	Y
Translation of Pulsator Head in X Direction (Lockable)	Y	Heavy weighted base	Y
Translation of Pulsator Head in Y Direction (Lockable)	Y	Heavy weighted base	Y
Translation of Pulsator Head in Z Direction (Lockable)	5 - 53.3 cm	0 - 55.9 cm	Y
Width of Pulsator Tip	1.14 cm	1.14 cm	Y
Speed of Chair Back Rotation	2° – 5°/sec	4°/sec	Y
Height of Lip on Tray	2.5 cm	5cm	Y
No Sharp Edges or Crevices which can Catch Fingers	Y	No sharp edges or crevices	Y
Chair Back Width	31 cm	31 cm	Y
Chair Angle Adjustment Time	75 sec*	16.4 sec	Y
Folded Volume	0.53 m^3	0.154 m^3	Y
Maintenance Required	1 per year	N/A	N/A
Cost of Prototype	$800	$580	Y
Pulsator Height Resolution	0.5 cm	0.1 cm	Y
Pulsator Tilt Resolution	1°	0.5°	Y
Seat Back Angle Resolution	4°	1.3°	Y
Head Support Height Resolution	3 cm	0.13 cm	Y
Tray Height Resolution	3 cm	0.36 cm	Y
Maximum Load the Apparatus Can Support	80 lb	80 lb actual, 160 lb theoretical	Y
Seat Angle Adjustment is Automated	Y	Automated	Y
Simple Design	Y	Survey Confirmed	Y
Marketability	Y	N/A	N/A
Power Consumption Per Test (Excluding Pulsator)	40.8 Watts	12 Watts	Y
Chair Back Height	94 cm	94 cm (peak height)	Y

XII Discussion/Critique

Advantages to the New Design

Fits Expanded Age Range - The new design can accommodate and safely support the weight of the extended age range, 1 – 36 months old (old design age range 2-10 months). All of the components can be used for the entire age range of children, as dimensions were chosen using 97% percentile or greater anthropometrics. The new design also incorporates a head support to accommodate younger infants whose neck muscles are not fully developed and infants with Downs syndrome.

Ability to Test New Hamstring Testing Zone - The new pulsator setup allows for the pulsator tip to reach the hamstring test zone as it can be positioned vertically to any height between 26 inches from the ground down to 12 inches. The old pulsator setups were unable to reach this test zone, so this feature allows new testing and research to be conducted with infants and children.

Reduces Operation Time – The new design has a reduced operation time including adjustments of the chair angle, securing a child into the seat, and doing a single pulsator test. An average time for completing these tests on the new apparatus is approximately 1.3 minutes, while those adjustments on the old apparatus were estimated to be about 13 minutes [B. Ulrich, personal communication]. This is due to a multitude of factors. First, our design uses a motorized angle adjustment in place of six manual hand knobs in the old design. Second, no tools are required to make adjustments during testing, and our design has simplified seat pan installation. Third, our design has one extremely flexible pulsator setup to adjust, whereas the old design had two different pulsator sites. The new single pulsator adjustment site is easier to adjust, does not require tools to change its position, and only having one pulsator allows the operators to not have to worry about switching the wires from one pulsator to another.

Easy to Clean – When working with infants and children, cleanliness is an important concern. In our design, all of the surfaces can be easily cleaned because less porous materials such as solid PVC were used. This helps prevent any bacterial or mold buildup.

Disadvantages to the New Design

Less collapsible than original - The previous design could fold flat before being transported and had a folded volume of 840 in^3. The new design requires hex wrenches (0.11 in) to take out the linear actuator pins which then allow for the triangular support to fold down, the PVC chair back can also be removed with a different hex wrench (0.2 in) to fold the design up further for storage. After folding it up, the new rectangular volume of the chair would be 3,284 in^3. (Sponsor requirement less than 30 in × 36 in × 30 in = 32,400 in^3)

Prototype Weight - The total weight of our new prototype is 30 lb (estimated to be greater than weight of current design), and combined with its size the chair would require two people to safely carry the chair if there is no disassembly. However, the chair back can be removed with a hex wrench (0.2 in) to allow for the two heaviest pieces to be carried separately; the PVC chair back with attachments and the aluminum frame with the rotating base attached. By breaking down the components, the design could be carried by one person in multiple trips. If this chair is reproduced, the weight of the chair could be reduced by using hollow tubes for the vertical parts of the aluminum frame. From the FEA calculations it was shown theoretically that a hollow tube would be able to withstand the forces with a safety factor of over four. This method would need some solution to allow for the bronze bushings to be press fit into the vertical supports. With the hollow beams this would not be possible. One solution might be to weld a square inch piece of solid aluminum on top of a hollow beam, thus allowing for a press fit into the solid portion.

Another way to reduce weight would be to contour and taper the PVC chair back which does not need so much material near the top.

Time Intensive Manufacturing - To have the prototype chair replicated would be expensive as many hours were spent machining components that were used on the apparatus. Using the CNC mill for as many similar or complex curved parts helps reduce the milling time.

Expensive Purchased Components - A few of the complex components we used are generally expensive. For example, the ball joint cost $99 and the linear actuator cost $77. While we conducted a thorough search for products on the market that met our specifications and picked the lowest-priced options, there may be other alternatives on the market that emerge that give the same robustness, freedom of movement, etc., and may be less expensive. Furthermore, in production, having custom components manufactured specifically for the application may prove to be less expensive. For instance, in our application we probably did not need the linear actuator to have a position-sensing capability (not utilized in our design) also the ball joint may not have needed a fine-adjustment knob.

Height of Chair - The highest possible point for a child's head in our chair is 36.3 inches above the surface the chair is resting on. This is a concern since if the table is not low enough, the child's eye level may be higher than the testers' eye level which could make the child uncomfortable. For a 5-foot tall tester, this condition would be reached with a 3 foot tall table. Also, the higher that the chair is, the farther the testers will have to reach to adjust certain components such as the head support. The chair is designed to be the minimum height to securely hold a three year old, so having a low enough or an adjustable table would be the solution to keep the child's eye level within a comfortable range. We recommend using a 2 foot tall table, or a table with adjustable height.

Backward Tipping - From the tipping validation tests the four directions of tipping resulted with backward having the least amount of tipping resistance of 2.5 lb. Even thought the chair on its own has been deemed safe for tipping by a biomedical engineering regulatory professional [R. McCarthy, personal communication], modeling tipping using external forces and with an infant in the chair was too complex, so additional precaution for tipping may be advisable. If this is not enough resistance to tipping it is recommended to put extensions on the back at the base of the frame. Table 7 (p. 34) shows the increased resistance preventing backwards tipping as an inch extension is added to the base of the chair.

Pulsator Apparatus Stability – The current pulsator base could be made more stable. When the pulsator is mounted near its maximum height range, the apparatus has a very high center of mass and becomes more prone to tipping over when bumped. A possible solution to this problem is making the base heavier to lower the center of mass of the apparatus, currently the base for the pulsator apparatus is hallow, so by filling in the area inside the stand would allow us to add weight without increasing the usable volume of the base. This is recommended over increasing the diameter of the base, because the apparatus must fit in the area underneath the frame of the chair.

The top of the telescoping tube is currently uncovered. This creates a minor safety hazard for operators' fingers to possibly get caught in that gap. Additionally, the opening allows foreign objects and debris to enter the tube opening, which can lead to the telescoping system to jam or break. Furthermore, the opening presents an unprofessional appearance. The reason the design currently does not have a cap is so that the apparatus will fit underneath the chair. This problem could be solved if the chair was made ¼" higher or the base made ¼" shorter so that a cap could be placed on top of the telescoping tubes.

Tray – The current tray system rotates with the chair back rotation to maintain a perpendicular orientation. By doing so, the tray is not always level with the ground, possibly allowing toys to slide off of the tray. A redesign could have pivots on each tray slider that could be locked using a set screw.

Orienting the tray parallel to the ground would increase set up time for testing, as determining ample amount of space for the infants' legs and torso would be more difficult. The intricacy required to allow the tray to rotate would likely increase fabrication time and lead to higher production cost. Another alternative to the current design would be to modify the existing tray to extend the lip around the rest of the tray so that toys would be less likely to fall off at inclines. These factors would have to be weighed carefully by the research group to determine how to redesign the tray. We attempted to modify our design when we received the specification of the tray being able to rotate angularly. We removed a guidance bolt from each tray height adjustment block. This allowed us to rotate the tray and have it remain in place with no loads on it, unfortunately it could not hold its position when put under loads it would likely see in testing.

To adjust the height of the tray on the current design, a hand knob on the slider is loosened on either side of the tray track and then the tray can be moved and retightened (Figure 30, p. 30). The slider/track method was selected to achieve the resolution specification of 1.5 cm for tray height adjustment [B. Ulrich, personal communication]. Infant high chairs, comparable devices, do not have small height resolution and often use a "peg-and-hole" system [K. Sienko, personal communication]. If it is discovered with further testing that such resolution is not necessary, the "peg-and-hole" system would increase user ease for height adjustments. To drill additional holes and design a locking mechanism (probably using a snap fit) would increase fabrication time and production cost; however, the trade-off to improve user ease and create a more marketable design might justify the design change.

The tray adjustment system is currently on the sides on the PVC chair back. Although the infants are tested by multiple operators carefully monitoring the reflex test and the safety of the child, the adjustment system still creates a potential finger trap. With minor design changes, the adjustment system could be moved to just behind the chair back, making the adjustment completely out of sight for all infants tested and out of reach for the majority of infants tested. This change would also increase the ease of manufacturing by drilling on the back of the PVC chair back, which makes the PVC easier to clamp. Additionally, milling operations on the chair back could be further consolidated by reducing clamping orientations from four down to two; time saved in manufacturing would lead to reduced production cost.

Head Support – The current head support adjustment system uses a strap tightened into the PVC chair back with a hand bolt (Figure 40, on right). The range and resolution of the height adjustment are achieved with the system, but the adjustment clamp and excess strap hang freely from the chair back. This hanging material could potentially impede movement and adjustments necessary for efficient testing; additionally, this system is not very polished in terms of marketability. The current strap system could be modified so the clamp was bolted onto the chair back and that excess strap material could be gathered in a collection spool. This spool could be on a torsion spring, much like a tape-measurer, so it could hold all of the excess material. When it is pulled on it would allow more material to be extended. In order to retract the material back a simple button would have to be pressed.

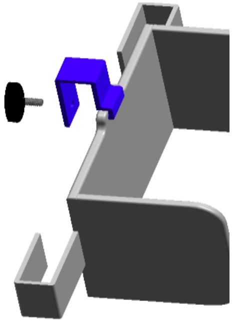


Figure 40: Hand knob connects head support to PVC chair back

The angle adjustment system does not have a way of measuring the angle of the chair back. Angle adjustment is made so that the infant is comfortable during testing. The measurement of the angle is not needed for the actual test. However, collecting data on preferred angles for testing could yield conclusive results, reducing test preparation time in the short term. Attaching a level protractor onto the side of the PVC chair back would allow the operator to record the angle to gather this data

Enclosure – The current enclosure does not have any additional safeguards for waterproofing. In a clinical setting, the enclosure could be penetrated by various fluids which could damage the circuitry.

Although the current model should suffice, adding higher rated connections and seals could increase the longevity of the device.

If the wires powering the linear actuator or the pulsator end up shorting with the chair, possibly from wear over time, or if liquids were spilled upon the wiring, it is possible that the child in seat could get electrically shocked. For this to occur the child would have to be grounded, either through the operator (which would also electrocute the operator) or through some other method (possibly through EMG sensors). In order to help ensure the safety of the child we have four possible recommendations. The first recommendation is to waterproof the enclosure along and the electrical contacts on the pulsator. The next recommendation is to put an electrically insulated material over all of the places where the child could come into contact with metal (seat pan bolt, aluminum rotator, and the tray). Another way to insulate the child is by applying insulated materials in-between all of the contact points from metal to metal. This will restrain the flow of electricity so it can never go through the child. The final recommendation would be to ground the chair; this would provide a route for the electricity directly to the ground, so it would not go through the child.

XIII Recommendations

Current Design provides recommendations for operating, disassembling, and storing the infant reflex apparatus. **Fabrication** explains useful insight and emphasizes specific steps for reproducing the apparatus based on the manufacturing plan created (Appendix 11, p. 98). Recommendations for improving the design are described in detail in **Discussion** (p. 41).

Current Design

Operation

Adjusting Tray – Since the tray is not completely rigid, adjustments made to the tray must be done by simultaneously adjusting both sides. For adjusting the tray height, both sliders should be moved so that the adjustment is smooth and efficient. For adjusting the tray length, both sides of the tray should be pushed or pulled for easier adjustment.

Adjustments to Pulsator – For adjusting the height of pulsator stand with the telescoping tubes, a good method for the operator is for them to place their right hand on the locking mechanism, and their left hand on the outer tube. Rotating each hand so that both elbows are “out” tightens the locking mechanism; rotating each hand so that both elbows are “in” loosens the locking mechanism.

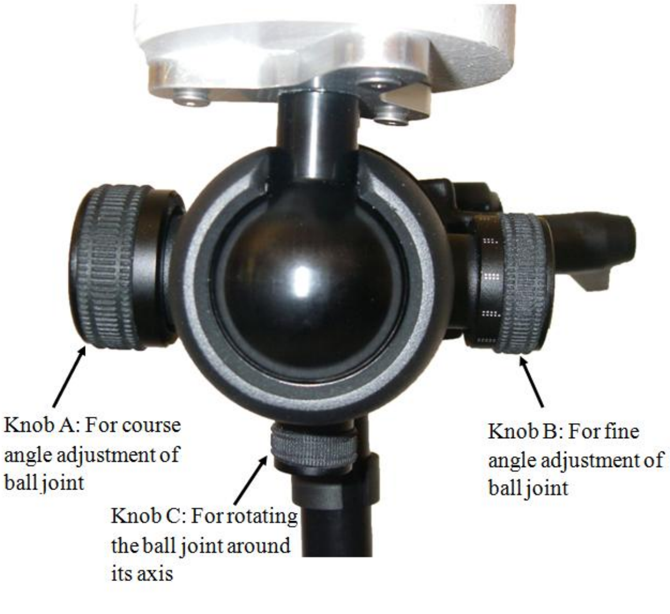


Figure 41: The three adjustment knobs on the ball joint

For adjusting the angle of the pulsator, there are three knobs (Figure 41, on right). The large-sized knob (Knob A) locks the ball joint angle coarsely; the medium-sized knob (Knob B) locks the angle finely; the small-sized knob (Knob C) locks the ball joint about its axis. Depending on the preference of the user, immediate time constraint, and degree of accuracy required, the selection of knobs used to orient the pulsator to the optimal test position will vary. When adjusting the ball joint, support the pulsator with one hand to prevent it from crashing down and causing damage.

Caution of Tipping Pulsator Stand – The stand is stable at all heights and angle orientations when stationary. Due to the combined weight of the pulsator, ball joint, and clamp, the apparatus is top-heavy for certain orientations. The operators should be aware of this and take special precaution not to accidentally hit the pulsator stand to prevent it from falling over. This will ensure the safety of the infant, operators, and equipment. This can be done by keeping one hand on the pulsator base at all times.

Disassembly and Storage

Actuator – The shoulder bolts used to attach the actuator to the frame should be used and not replaced with hand knobs. Although removing these bolts does require an Allen wrench tool, this requirement provides an added safety measure so that the actuator cannot be removed accidentally. If during storage there is a concern for the apparatus being damaged the actuator should be removed and stored separately.

Fasteners – The research team might consider changing the ¼”-20 slot screws (used to bolt the triangular brace to the PVC chair back and aluminum rotator, used to bolt the head support strap to the PVC chair back) to ¼”-20 socket cap screws for assembly purposes. This would allow the entire assembly/disassembly process (that the research group would need to do) to be done with only Allen keys. Additionally, the research team may aesthetically prefer a uniform fastening system.

Storage – For storage, it is recommended that an Allen wrench be used to take out the linear actuator to prevent any damage while the apparatus is being stored. If a need to collapse the apparatus to a smaller volume than the seat back can be removed as well. This also allows for easier transportation.

When transporting the apparatus for storage, the chair apparatus should be carried by the frame only; this includes the aluminum bars composing the base, the vertical posts, and the angled reinforcement bars. The chair apparatus should never be supported by the aluminum rotator or actuator (if it is still attached to the frame). The pulsator apparatus should be carried by the base only.

Fabrication

Pulsator Stand – For connecting the telescoping tube, steel base adapter, and pulsator base, the steel adapter should be welded to the telescoping tube before being threaded into the base. This is so the telescoping rod will then be easily threaded into the base.

Frame – The geometric tolerances of the frame are critical to ensure proper alignment, especially the bars for the triangular support. All bars should be securely clamped down at multiple places to keep geometric alignment during welding. For welding the angled support brace, the following order is recommended:

1) Weld the aluminum rotator bracket (A) to the horizontal bar of the angled support brace (B)
2) Weld the horizontal bar (B) to the angled bar (C) for the angled support brace
3) Weld the angled bar (C) to the PVC chair back bracket (D). When clamping for this operation, clamp the aluminum rotator bracket (A) 0.5” above the level, clamped surface for the PVC chair back bracket (D) to maintain the parallel angle between the aluminum rotator and PVC chair back.

After press fitting the bronze bushings into the vertical posts in the frame, the bushings should be reamed with a ½” reamer. Press fitting slightly distorts the shape of internal diameter, so the bushing needs to be reamed to achieve the high geometric tolerance required for the tight fit between the bushing and the shoulder bolts used as pivots.

Seat Back – For milling the slots in the PVC chair back, we recommend using an end mill with a flute length of ¾” or greater so that the PVC chair back does not need to be flipped. This way the slots can be milled in one operation.

Seat Pans – We recommend fabricating the seat pans using a CNC mill. CNC mills can quickly and accurately cut the intricate contours of the seat pans (Figure A.12.8, p. 116) as well as make the counterbore for the elevator bolts which have a large 1 3/16” diameter head.

XIV Summary and Conclusions

The research from Dr. Beverly Ulrich and Dr. Bernard Martin is aimed to map the neurological developments in lower limb reflexes to facilitate treatment and improved outcomes for infants with conditions such as spina bifida, cerebral palsy and Down syndrome [B. Ulrich, personal communication]. Our goal is to improve the current apparatus (Figure 1, p. 3) for testing infant reflexes in three major ways: i) expand the infant test range from 2 - 10 months to 1 - 36 months, ii) make the apparatus user friendly, and iii) streamline the testing process. From research and contact with our sponsors, we were able to fully understand the project background and determine benchmarks. Requirements came directly from the sponsors, and specifications were created from these and the benchmarks (Table 1-3, pp. 7-8).

From the specifications multiple concepts were generated for each component to fulfill various requirements. These concepts were weighted using Pugh charts and the alpha design was generated from the best components. The alpha design consists of a motorized chair back angle adjustment, 5 – 6 removable seat pans, removable tray, adjustable head support, and a single, fully adjustable pulsator to test all four locations on the infant leg.

From here theoretical calculations and experiments were done to ensure that the design would meet all of the specifications. From further analysis, some of the design’s components have been modified to ensure it can be manufactured to the specifications. The motorized chair back is now controlled by a linear actuator and the attachment methods for the removable seat pans, head support, and tray have been adjusted. These newly designed components were tested to at least have a safety factor of two and in most cases up to a safety factor of four. From the analysis a detailed manufacturing plan was generated to have our final design completed by December 22nd. Validation tests for the safety factors of weight and tests for operator ease were finished by December 14th. Final adjustments to fulfill safety requirements will be completed by December 22nd.

XV Acknowledgements

Without the help of many individuals we would not have been able to complete this project. We would like to sincerely thank Professor Nikos Chronis for advising our team and cheerfully steering us in the right direction. We would like to thank Dr. Beverly Ulrich and her colleagues for taking the time to describe their project requirements and goals and teaching us about a field entirely new to us. We would like to thank Dr. Bernard Martin for sharing his expertise in mechanical design and helping us to improve our designs. We would like to thank Bob Coury and Marvin Cressey for their endless patience and aid in the machine shop and their genuine concern for the outcome of our project. We would like to thank Dan Johnson for meeting us with little notice and for sharing his helpful advice. We would like to thank Joan Courson for her extremely generous help with our project. We would also like to thank the graduate students Girish Krishnan and Jaewon Lee who helped us apply principles that we learned in class to our real-world application. We would also like to thank Professor Volker Sick whose advice early on in our project helped focus our efforts.

XVI Appendices

Appendix 1: QFD

Appendix 2: Bill of Materials

Appendix 3: Description of Engineering Changes since Design Review #3

Appendix 4: Functional Decomposition

Appendix 5: Material Selection

Appendix 6: Manufacturing Process Selection

Appendix 7: Component Designs and Drawings from Concept Selection

Appendix 8: Pugh Charts

Appendix 9: Gantt Chart

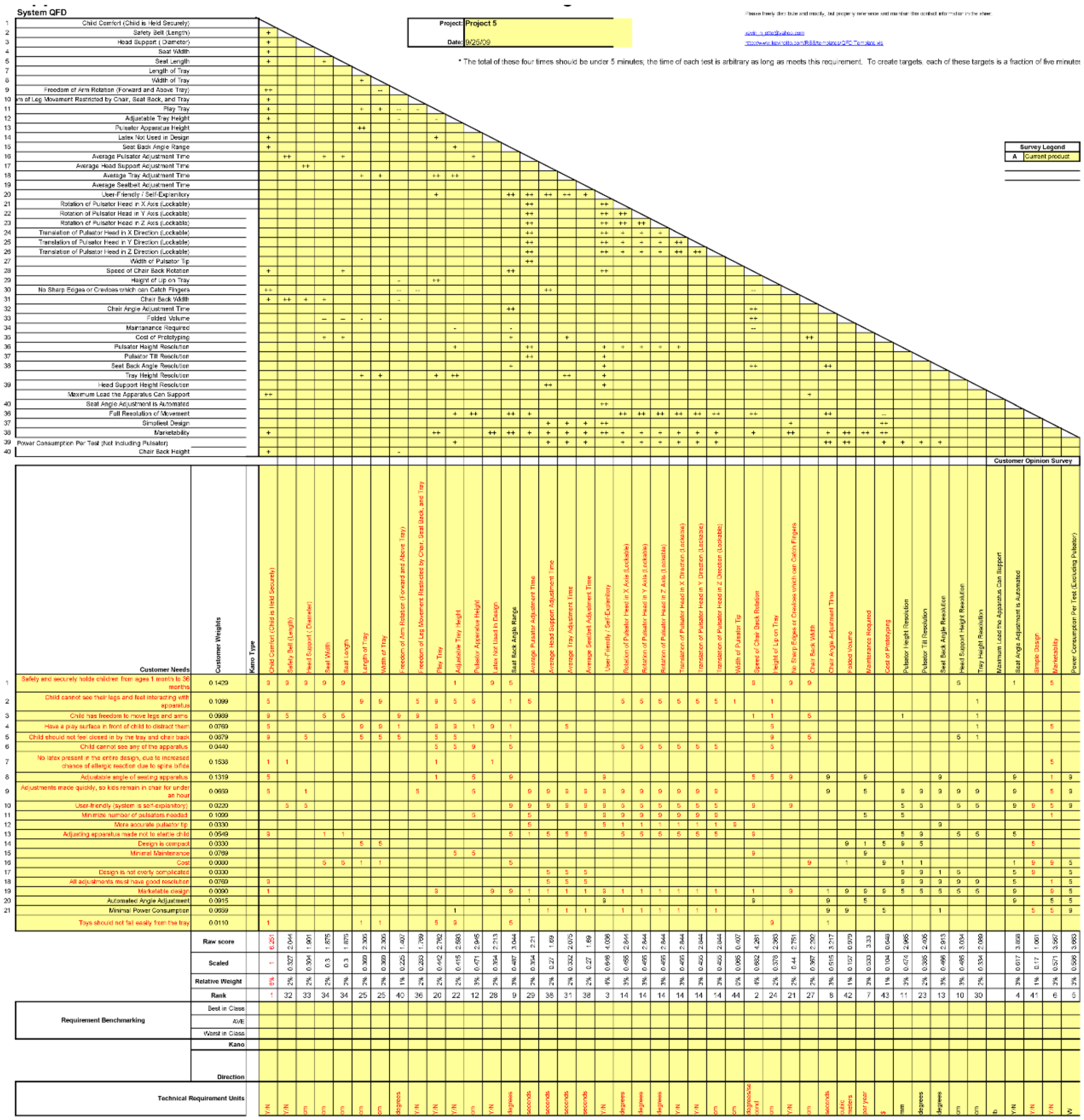
Appendix 10: Parameter Analysis

Appendix 11: Manufacturing Plan

Appendix 12: 2-D Drawings

Appendix 13: Survey Results

Appendix 1: QFD



System QFD

Project: Project 5
Date: 9/25/09

* The total of these four times should be under 5 minutes; the time of each test is arbitrary as long as meets this requirement. To create targets, each of these targets is a fraction of five minutes

Survey Legend
A Current product

1 Child Comfort (Child is Held Securely)
2 Safety Belt (Length)
3 Head Support (Diameter)
4 Seat Width
5 Seat Length
7 Length of Tray
8 Width of Tray
9 Freedom of Arm Rotation (Forward and Above Tray)
10 m of Leg Movement Restricted by Chair, Seat Back, and Tray
11 Play Tray
12 Adjustable Tray Height
13 Pulsator Apparatus Height
14 Latex Not Used in Design
15 Seat Back Angle Range
16 Average Pulsator Adjustment Time
17 Average Head Support Adjustment Time
18 Average Tray Adjustment Time
19 Average Seatbelt Adjustment Time
20 User-Friendly / Self-Explanitory
21 Rotation of Pulsator Head in X Axis (Lockable)
22 Rotation of Pulsator Head in Y Axis (Lockable)
23 Rotation of Pulsator Head in Z Axis (Lockable)
24 Translation of Pulsator Head in X Direction (Lockable)
25 Translation of Pulsator Head in Y Direction (Lockable)
26 Translation of Pulsator Head in Z Direction (Lockable)
27 Width of Pulsator Tip
28 Speed of Chair Back Rotation
29 Height of Lip on Tray
30 No Sharp Edges or Crevices which can Catch Fingers
31 Chair Back Width
32 Chair Angle Adjustment Time
33 Folded Volume
34 Maintanance Required
35 Cost of Prototyping
36 Pulsator Height Resolution
37 Pulsator Tilt Resolution
38 Seat Back Angle Resolution
Tray Height Resolution
39 Head Support Height Resolution
Maximum Load the Apparatus Can Support
40 Seat Angle Adjustment is Automated
36 Full Resolution of Movement
37 Simpliest Design
38 Marketability
39 Power Consumption Per Test (Not Including Pulsator)
40 Chair Back Height

Customer Opinion Survey

	Customer Needs	Customer Weights	Kano Type	Child Comfort (Child is Held Securely)
1	Safely and securely holds children from ages 1 month to 36 months	0.1429		9
2	Child cannot see their legs and feet interacting with apparatus	0.1099		5
3	Child has freedom to move legs and arms	0.0989		9
4	Have a play surface in front of child to distract them	0.0769		5
5	Child should not feel closed in by the tray and chair back	0.0879		9
6	Child cannot see any of the apparatus	0.0440		
7	No latex present in the entire design, due to increased chance of allergic reaction due to spina bifida	0.1538		1
8	Adjustable angle of seating apparatus	0.1319		5
9	Adjustments made quickly, so kids remain in chair for under an hour	0.0659		5
10	User-friendly (system is self-explanitory)	0.0220		
11	Minimize number of pulsators needed	0.1099		
12	More accurate pulsator tip	0.0330		
13	Adjusting apparatus made not to startle child	0.0549		9
14	Design is compact	0.0330		
15	Minimal Maintenance	0.0769		
16	Cost	0.0080		
17	Design is not overly complicated	0.0330		
18	All adjustments must have good resolution	0.0769		9
19	Marketable design	0.0090		1
20	Automated Angle Adjustment	0.0915		
21	Minimal Power Consumption	0.0659		
	Toys should not fall easily from the tray	0.0110		1
		Raw score		6.251
		Scaled		1
		Relative Weight		8%
		Rank		1

Requirement Benchmarking
Best in Class
AVE
Worst in Class
Kano
Direction
Technical Requirement Units

Appendix 2: Bill of Materials

Raw Material Inventory for Manufactured Components

Stock Aluminum
- Material: 6061-T6 Aluminum
- Dimensions: 1 in x 1 in x 36 in
- Quantity: 1
- Cost: $10
- Contact: Alro Steel, http://www.alro.com/

Description: This stock material was for making the frame. **NOTE:** This material was not used in for the final frame. Stock aluminum was provided for the project.

Enclosure
- Material: ABS plastic
- Dimensions: 3.25 in x 1.45 in x 2.16 in
- Quantity: 1
- Cost: N/A (stock material)
- Contact: Box Enclosures & Assembly Services, http://www.boxenclosures.com/

Description:

Seatbelt Material
- Material: Latex Free Elastic
- Dimensions: 6 in x 5 yards
- Quantity: 2
- Cost: $30
- Contact: Save Rite Medical, DE-71422, http://www.saveritemedical.com/index.php

Description: This elastic is used to create the seatbelts for to restrict infant movement during testing. Children with spina bifida are allergic to latex, so the elastic is completely latex free. There are two sizes of seatbelts to accommodate the age range: the larger size is 8 in in width, and the smaller size is 6 in in width.

Chair Back
- Material: PVC
- Dimensions: 12.2 in x 22.6 in x 0.75 in
- Quantity: 1
- Catalog Number: PVC Plate Grey 3/4 4X8
- Cost: $50
- Contact: Colorado Plastic Products, http://www.coloradoplastics.com/

Description:
The chair back is a solid block of PVC that supports the infant's back as they sit in the chair. Many components are drilled into to the chair back, such as the tray support tracks on the side and the head support on the back. Two slots were made to secure a seatbelt around the child during testing to restrain them from falling out of the chair.

Tubing for structure

- Material: 6061-T6 Aluminum
- Dimensions: 1 in x 1 in x 12.2 in
- Quantity: 1
- Cost: N/A (stock material)
- Contact: N/A

Description:
The aluminum bars are welded together to support the chair and position the linear actuator far enough away to safely and slowly adjust the chair angle.

Aluminum Rotator

- Material: 6061-T6 Aluminum
- Dimensions: 1.25 in x 4 in x 12.2 in
- Quantity: 1
- Cost: $30
- Contact: Alro Steel, http://www.alro.com/

Description:
An aluminum block is used to safely support the weight of the chair for the rotating joint between back and frame. This aluminum also supports the seat pans where the child sits and connects to the chair back.

Seat Pan Support

- Material: 6061-T6 Aluminum
- Dimensions: 0.375 in x 8.75 in x 5 in
- Quantity: 1
- Cost: N/A (stock material)
- Contact: N/A

Description:
This is a thin piece of aluminum that the seat pans rest on and are screwed together using an elevator bolt. The elevator bolt is locked into place using a hand knob on the bottom of the chair.

Tray Slider

- Material: 6061-T6 Aluminum
- Dimensions: 1.75 in x 1.5 in x 2 in
- Quantity: 2
- Cost: N/A (stock material)
- Contact: N/A

Description:
The aluminum sliders are located on the sides of the chair and mounted on aluminum tracks. These sliders can move along the track to adjust the height of the tray. The sliders also house the tray arms allowing length adjustment of the tray.

Seat Pan

- Material: PVC

- Dimensions: 9.1 in x 9.4 in x 0.5 in
- Quantity: 6
- Cost: N/A (stock material)
- Contact: N/A

Description:
PVC has the rigidity to support the children and is shaped to separate their legs while providing more support for the bottom of the child. There are six sizes of chairs with the same general design scaled to comfortably fit all test infants.

Head Support Padding

- Material: Foam and batting
- Dimensions: (1) 3.5 in x 1.5 in x 1.25; (1) 4 in x 1 in x 3 in; (1) 4.5 in x 0.5 in x 3.5 in
- Quantity: 1 per size
- Cost: N/A (donation)
- Contact: The Parson's Wife Custom Sewing, theparsonswife@gmail.com

Description:
Foam and batting are covered in vinyl and attached by Velcro™ to the head support to provide support to the children that need help keeping their heads up. Three sizes of foam blocks are created to support the variation in head size of the range of children. The foam is firm to provide a better support for the infant's head.

Head Support Shell

- Material: PVC
- Dimensions: (1) 7.75 in x 5 in x 0.5 in, (2) 4.5 in x 3 in x 0.5 in
- Quantity: 1
- Cost: N/A (stock material)
- Contact: N/A

Description:
The shell is attached to three straps: one adjusts the height of the head support, and the two on the sides restrain the head support from moving laterally. The head support PVC is held together using PVC cement and aluminum brackets.

PVC cement

- Material: Acetone, Tetrahydrofuran, Methyl Ethyl Ketone, Cyclohexanone [http://www.herchem.com/msds/MSDS92_Low_VOC_PVC_CEMENT-CLR,MED_BODY,MED_SET.pdf]
- Dimensions: N/A
- Quantity: 1
- Cost: N/A (stock material)
- Contact: N/A

Description:
PVC cement was used to attach the PVC walls of the head support.

Wires for Electronics

- Material: Insulated Copper wiring

- Dimensions: 18 gauge
- Quantity: 12”
- Cost: N/A (stock material)
- Contact: N/A

Description:
Wires are needed to connect the linear actuator to the switch and power cell.

¼” - 20 Bolts

- Material: Coated Steel
- Dimensions: (6) 0.75 in length, (4) 0.5 in length
- Quantity: 8 total
- Cost: N/A (stock material)
- Contact: N/A

Description:
These bolts are used to connect the angled support bracket to the aluminum rotator and PVC chair back. The longer bolts (4) connect to the PVC; the shorter bolts (4) connect to the aluminum rotator. The longer bolts (2) also bolt the bottom aluminum hinge for the actuator to the mount lift.

Tray

- Material: High Density Polyethylene
- Dimensions: 19.75 in x 10.5 in
- Quantity: 1
- Cost: N/A (provided by sponsor)
- High Density Polyethylene

Description: The tray, provided by the sponsor, it to shield the infant from viewing the test equipment while doubling as a play surface.

Thumb Screws

- Material: 18-8 Stainless Steel
- Dimensions: 1 in length
- Quantity: 18
- Cost: $6.84
- Contact: McMaster-Carr, Item Number 91745A542, http://www.mcmaster.com/#

Description: The thumb screws are used in the tray sliders to lock the length of the tray in place.

Purchased Component Inventory

Ball Joint- Vanguard BLH-300

- Material: Magnesium Alloy
- Dimensions: 6 x 5 x 6.8 inches
- Quantity: 1
- Cost: $99.95

- Contact: Vanguard SBH-300 Large-Format Magnesium Alloy Ballhead with Two Onboard Bubble Levels, http://www.amazon.com/Vanguard-SBH-300-Large-Format-Magnesium-Ballhead/dp/B0016D3H1O

Description: The ball head joint allows for the pulsator to have a great range of movement in angling the pulsator head. The head needs to be able to point in the vertical direction down to a few degrees below horizontal. This helps reach all four test zones on the child and allows for very precise resolution in the angles the pulsator head can be directed. **NOTE:** This ball joint was not used in the final design.

Clamp

- Material: Aluminum
- Dimensions: N/A
- Quantity: 1
- Cost: $34.14
- Contact: Manfrotto 035RL Super Clamp with 2908 Standard Stud, http://www.amazon.com/Manfrotto-035RL-Super-Clamp-Standard/dp/B0018LQVIA/ref=sr_1_1?ie=UTF8&s=electronics&qid=1260722118&sr=8-1

Description: The mounting clamp attaches the ball joint to the telescoping tubes. Clamping the pulsator on different heights of the telescoping tube provides the means to adjust the pulsator height. The clamp can safely hold up to 33 lb.

Hand Knob- ¼"-20

- Material: N/A
- Dimensions: N/A
- Quantity: 1
- Cost: $3.05
    - Contact: Jack's Hardware, 40 Packard St Ann Arbor, MI 48014

Description: This hand knob is for securing the head support strap to the back of the PVC chair back.

3/8 – 16 Bolts

- Material: Stainless Steel
- Dimensions: 1.25 in length
- Quantity: 4
- Cost: $4.40
- Contact: Stadium Hardware, 2177 West Stadium Boulevard, Ann Arbor, MI 48103

Description:
These bolts are used to connect the PVC chair back to the aluminum rotator. They are counter sunk to provide a smooth surface to the PVC while maximizing thread length.

Washers

- Material: Nylon
- Dimensions: 0.5 in ID, 1 in OD, 1/8 in thickness
- Quantity: 2
- Cost: $0.44
- Contact: Stadium Hardware, 2177 West Stadium Boulevard, Ann Arbor, MI 48103

Description: These washers were used as spacers between the aluminum rotator and the frame to reduce friction and prevent lateral sliding of the chair back.

10-32 Bolts for Track Sliders

- Material: Painted Steel
- Dimensions: 0.75 in length
- Quantity: 4
- Cost: $1.04
- Contact: Stadium Hardware, 2177 West Stadium Boulevard, Ann Arbor, MI 48103

Description: These bolts are used to mount the tracks for the tray sliders to the PVC chair back.

Head Support Cover

- Material: Vinyl
- Dimensions: 24 in x 56 in
- Quantity: 1
- Cost: $4.33
- Contact: The Parson's Wife Custom Sewing, theparsonswife@gmail.com

Description:
Vinyl covers the padding used on the head support for the children. This material is easy to clean and provides additional comfort.

Velcro™

- Material: Velcro
- Dimensions: 1 in x 180in
- Quantity: 1
- Cost: $22
- Contact: Create For Less, Item Number 29920895, http://www.createforless.com/

Description:
This Velcro™ was used for the horizontal side straps on the head support, the attachment surface on the back, and for attaching the padding to the back of the head support frame.

Velcro™

- Material: Velcro
- Dimensions: 1 in x 180in
- Quantity: 1
- Cost: $7.78
- Contact: Jo-Ann Fabrics & Crafts, http://www.joann.com/joann/home/home.jsp

Description:
This Velcro™ was used for attaching the padding to the side walls of the head support frame.

Tray Track and Required Bolts and Hand Knobs

- Material: Aluminum
- Dimensions: N/A
- Quantity: 1
- Cost: $29

- Contact: Rockler, Item Number 24063, http://www.rockler.com/index.cfm?ne_ppc_id=776&ne_key_id=4317750&gclid=CMugo7Cv0p4CFRPyDAodrjhUxw

Description:
T-Tracks are bolted on each side of the chair with sliders attached so the height of the tray can be adjusted. The T-track has bolts on the ends of the track to restrict the travel length of the tray from moving too high or too low.

Bushings for Chair Fulcrum Joint
- Material: Bronze
- Dimensions: 5/8 in OD, 1/2 in ID, 1 in length
- Quantity: 2
- Cost: $2.02
- Contact: McMaster-Carr, Item Number 6338K421, http://www.mcmaster.com/#

Description:
The bronze bushings take the radial load and only need to be lubricated once to allow for the rotational movement of the chair around the center joint. The bearings have a smooth center that allows for a shoulder bolt to be screwed into the chair back.

Bolts for Fulcrum
- Material: Steel Alloy
- Dimensions: 1/2 in shoulder DIA, 1.25 in shoulder length, 3/8 – 16 thread
- Quantity: 2
- (stadium hardware)
- Cost: $2.02
- Contact: McMaster-Carr, Item Number 91259A714, http://www.mcmaster.com/#

Description: The bolts are slid through brass bushings and are screwed into the aluminum rotator. The 0.5 in shoulder diameter was selected to fully support the load of the chair.

Bolts for Seat Pan
- Material: Zinc-Plated Steel
- Dimensions: 5/16 – 20 thread, 1.5 in length
- Quantity: 25
- Cost: $7.98
- Contact: McMaster-Carr, Item Number 92670A787, http://www.mcmaster.com/#

Description:
An elevator bolt is used to hold the PVC seat pan onto the aluminum seat pan support. A hand knob is threaded on the bottom of the bolt to hold the PVC in place.

Linear Actuator – Creative Werks LACT4
- Material: N/A
- Dimensions: 3.93 in stroke
- Quantity: 1
- Cost: $76.95
- Contact: Burden Sales Surplus Center, Item Number 5-1577-6,

https://www.surpluscenter.com/

Description:
The linear actuator is the source for the angular movement of the chair back. It is powered by a 12 V and according to the manufacturer's specifications pulls 3.4 A at maximum load. It is mounted to the base structure by two pins on the purchased hinges. It can hold up to 107 lb during movement and 500 lb when stationary.

Enercell™ 12V/1500mA AC Adapter, Model: 273-358

- Material: N/A
- Dimensions: N/A
- Quantity: 1
- Cost: $25.29
- Contact: RadioShack, Item Number 273-358
  http://www.radioshack.com/

Description: The adaptor power cell allows the linear actuator to run off of electricity from the wall. It has an internal transformer which converts the wall voltage to the voltage and current needed for the linear actuator.

Double Pull Double Throw Center Off Momentary Toggle Switch for Linear Actuator

- Material: N/A
- Dimensions: ¾" × 1 3/8" × 1 3/8"
- Quantity: 1
- Cost: $4.99
- Contact: Burden Sales Surplus Center, Item Number 11-2280,
  https://www.surpluscenter.com/

Description:
To control the chair a switch is need with three positions. The neutral position is off and when the button is not being pressed the switch resumes the off position. This provides a safety for when the operator is not intending the chair to move the chair will remain stationary. The other two positions are forward and reverse.

Creative Werks Light Duty Hinges for Linear Actuator

- Material: aluminum
- Dimensions: 1.68 in × 1.5 in × 1.5 in
- Quantity: 2
- Cost: $8.95/each
- Contact: Burden Sales Surplus Center, Item Number 5-1577-B,
  https://www.surpluscenter.com/

Description:
Brackets are required on each side of the linear actuator to connect it to the base frame of the chair. The brackets can allow for the linear actuator to be removed by the use of tools when the chair needs to be stored or transported. These brackets also included the shoulder bolts for the actuator to pivot on.

Task Force Fabric Clamps

- Material: polypropylene strap, steel buckle
- Dimensions: 12 ft. long, 1 in. wide
- Quantity: 1
- Cost: $8
- Contact: Lowe's Hardware, Item Number 2CLS12, http://www.lowes.com/lowes/lkn?action=home

Description:
The fabric clamp is mounted in the back of the chair and has a strap that connects to the head support. The strap can be adjusted for length which allows the head support to reach at any height that is needed to support the head of the child. The clamp mounted on the strap locks the head support height in place.

Telescoping Tube & Weighted Base- On-Stage M57201B Microphone Stand

- Material: Painted Steel
- Dimensions: 9 in DIA, 2 in height for base; tube length 34 – 60 in, 5/8 in ID, 7/8 in OD
- Quantity: 1
- Cost: $32
- Contact: B&H Photo, Item Number MS7201B, http://www.bhphotovideo.com/

Description:
The telescoping tube allows for the pulsator to adjust to a greater range of heights while still being able to fit under the chair. When the tube is fully extended then the clamp for the pulsator can reach the highest test zone on the infant. When the tube is collapsed the pulsator set up can fit under the chair and reach both of the test zones from behind the leg.

Ball Joint

- Material: Painted Aluminum
- Dimensions: 6 in x 1.5 in
- Quantity: 1
- Cost: $15
- Contact: B&H Photo, Item Number ARMCM6, http://www.bhphotovideo.com/

Description:
The ball head joint allows for the pulsator to have a great range of movement in angling the pulsator head. The head needs to be able to point in the vertical direction down to a few degrees below horizontal. This helps reach all four test zones on the child and allows for very precise resolution in the angles the pulsator head can be directed. **NOTE:** This ball joint was not used in the final design.

Mounting clamp to tubes- Manfrotto 035RL

- Material: Painted Aluminum
- Dimensions: N/A
- Quantity: 1
- Cost: $18
- Contact: B&H Photo, Item Number ULUCQ, http://www.bhphotovideo.com/

Description:

The mounting clamp attaches the ball joint to the telescoping tubes. Clamping the pulsator on different heights of the telescoping tube provides the means to adjust the pulsator height. The clamp can safely hold up to 6 lb. **NOTE:** This clamp was not used in the final design.

Loctite

- Material: N/A
- Dimensions: N/A
- Quantity: 1
- Cost: $7.00 (estimate)
- Contact: Stadium Hardware, 2177 West Stadium Boulevard, Ann Arbor, MI 48103

Description:
The Loctite is put on the screws in the pulsator setup that need to be more permanent and secure. Those screws include the mounting clamp to the middle connector, and then from the middle connector to the ball joint.

Hex Nut

- Material: Steel
- Dimensions: Inner Diameter 7/8 - 14
- Quantity: 1
- Cost: $2.10
- Contact: Jack’s Hardware, 40 Packard St Ann Arbor, MI 48014

Description:
The hex nut is placed on the bottom of the telescoping tube connector underneath the pulsator base. This nut helps prevent the rotation of the ball joint during testing and stops the tube from unscrewing when the nut is tightened in.

Total Cost: $580 (estimate – not finalized until final components are purchased)

Appendix 3: Description of Engineering Changes since Design Review #3

Widened Base and Washers

One important design change that we implemented was to add plastic spacers in between the aluminum rotating piece and the frame near the bushings. This was done to avoid having metal rub against metal and to reduce the friction between the parts. We chose to use 1/8th inch nylon spacers on each side of the chair. The spacers had an outer diameter of 1 inch and an inner diameter of ½ inch. A consequence of this design change was that the frame was made ¼ inch wider.

Ball Joint/ Clamp

One major design change was to replace our existing ball joint because it slipped and could not support the load at certain angles, even though it was rated at 10 lbs. We switched to the Vanguard BLH-300 which is a larger ball joint and is rated at 70 lbs. While a weight capacity of 70 lbs may be more than necessary, we decided to be on the safe side because the manufacturer's maximum load specification did not necessarily apply in our unintended application and orientation. We were pleased to find that the new ball joint did not slip and also provided an additional rolling degree of freedom which the old ball joint didn't allow.

Another design change was to replace our existing clamp with a Manfrotto Model 035RL which has a load capacity of 33 lbs. The existing clamp was rated to 5 lbs, which is greater than the supported weight, but we found that it could not sit straightly on the telescoping tubes when loaded. Since the new Vanguard ball joint was heavier, worsening the problem, we decided to switch to the Manfrotto clamp, which was much more secure and sat straightly on the tubes.

The new Vanguard ball joint has a threaded hole at its base, as opposed to having a protruding threaded rod. To attach to the hole we modified the pulsator plate to accept countersunk bolt which connects the two components. The changes to the ball joint and clamp assembly are shown in Figure A.3.1, p. 62.

Figure A.3.1: Change of the old design's ball joint and clamp to the new design

Triangular Bracket

There was also a change in the design of the brackets on the triangular brace. Once we fabricated the brackets, we noticed that the bolt heads would extend off the edges of the brackets. We therefore recommend increasing the size of the brackets to 2 inches by 2 inches, (but leaving the hole spacing the same).

Head Support and Strap

Another minor design change was the connection of the head support, which was not fully detailed before fabrication. In our final design, we burned a hole in the strap for the bolt to go through, using a laser cutter. The dimensions of the final hole after the cut was 0.25 inches.

Appendix 4: Functional Decomposition

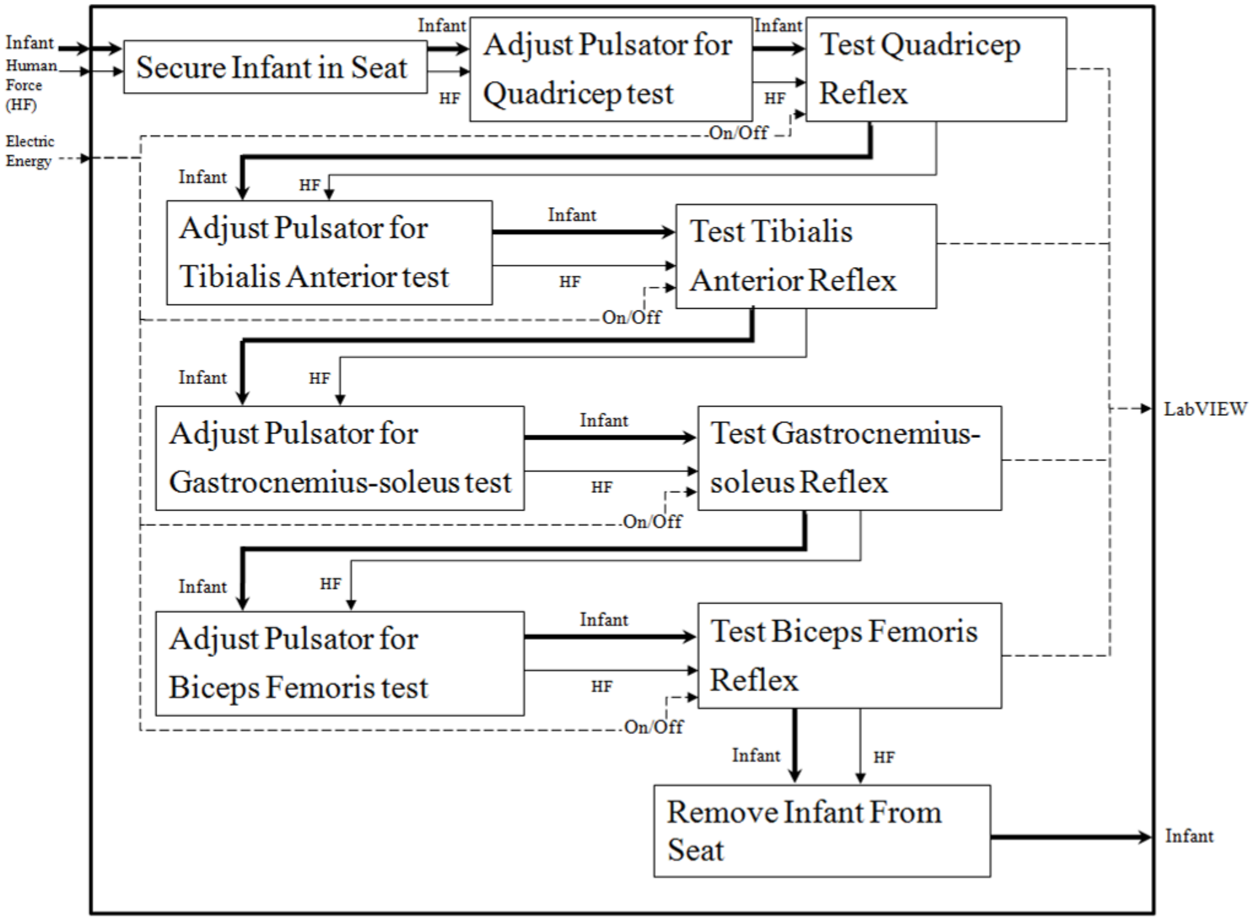


Figure A.4.1: Functional Decomposition

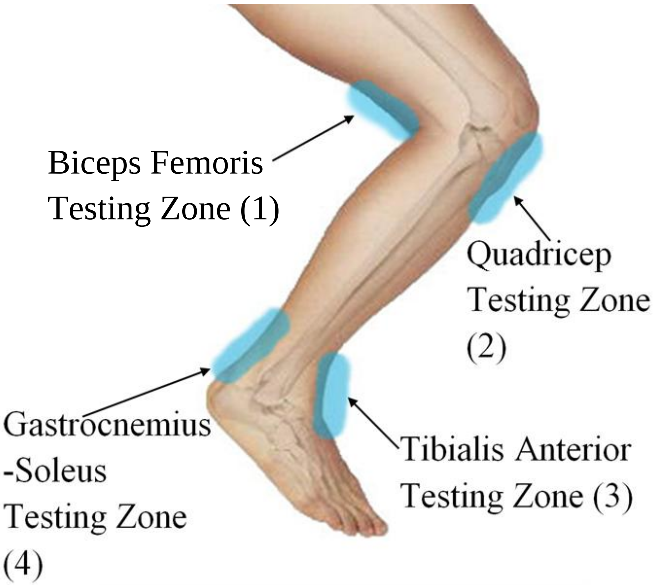


Figure A.4.2: Test Zones [24]

Appendix 5: Material Selection

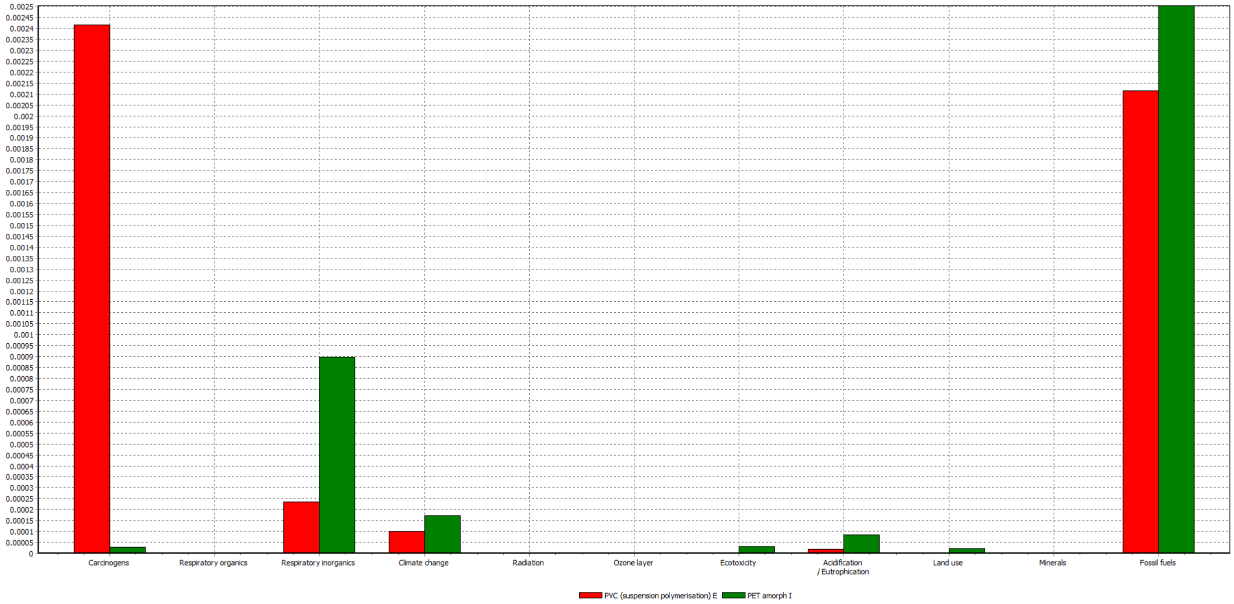
For producing the seat pans for the chair apparatus, polyvinyl chloride (PVC) and polyethylene (PET) were considered. After evaluating the environmental impact of the two materials, it was determined that PET had an overall less detrimental impact. Quantified values assessing the environmental impact were modeling using SimaPro 7 software, and are utilized throughout the rest of this report.

Comparing normalized scores of the two materials (Figure A.5.1, p. 65), the three largest emissions sources in production are fossil fuels (0.00250, PET), carcinogens (0.00218, PVC), and respiratory inorganics (0.0009, PET). Overall, the PET has higher emissions output than PVC in 7 out of the 9 measureable categories (Figure A.5.2, p. 65): respiratory organics, respiratory inorganics, climate change, ecotoxicity, acidification/eutrophication, land use, and fossil fuels. PVC has higher emissions outputs in carcinogens and minerals, but its carcinogen output compared to PET is enormous, as seen in Figure A.5.1 (p. 65). Both materials had negligible emissions for radiation and ozone layer.

In terms of total emissions of raw, air, water, and waste, PVC has an overall output of 190.0 kg and PET has an overall output of 54.3 kg (Figure A.5.3, p. 66). The largest emissions contributor was raw emissions, contributing to 96% of total PVC emissions and 76% of PET emissions. PVC had more total emissions in raw, water, and waste categories. PVC also has an overall higher EcoIndincator 99 (EI99) point value than PET, scoring 1275 mPt and 900 mPt, respectively (Figure A.5.4, p. 66). The contributors to these point totals are seen in Figure A.5.1 (p. 65), where the total amount of PVC emissions exceeds PET emissions.

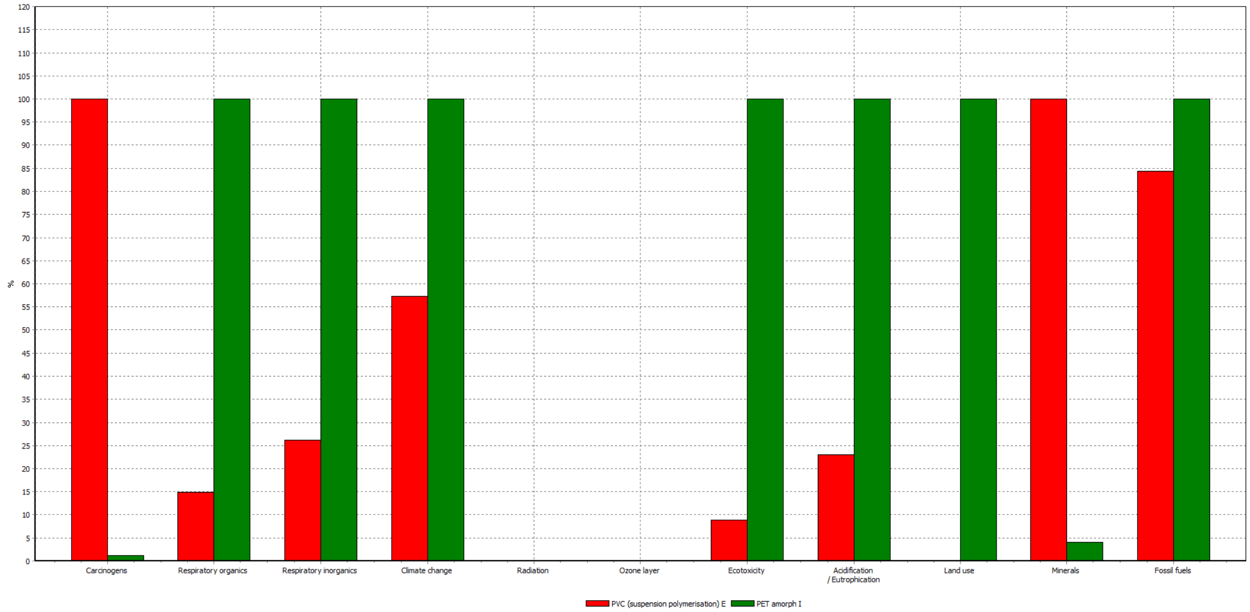
Based on the total emissions and EI99 point score, PVC does have a more severe environmental impact than PET, even though PET had a more negative environmental impact in 7 of 9 measurable emissions categories. When comparing a life cycle analysis, a PVC seat pan would likely have a shorter life cycle than PET because of its weaker mechanical properties [25]; therefore, PET would still remain a more ecologically friendly choice. Based on this thorough analysis, PET would be selected to make the seat pans over PVC in future production. Our group chose PVC because stock material with the correct geometric tolerances was readily available, making it a time and cost efficient selection. The SimaPro 7 analysis does indicate that both materials have significant environmental costs in their respective production, but PET remains the better of the two.

Figure A.5.1: Normalized score in human health, eco-toxicity, and other resources values comparing 2.8 kg of Polyvinyl Chloride (PVC) and 2.8 kg of Polyethylene Terephthalate (PET), created with SimaPro 7.



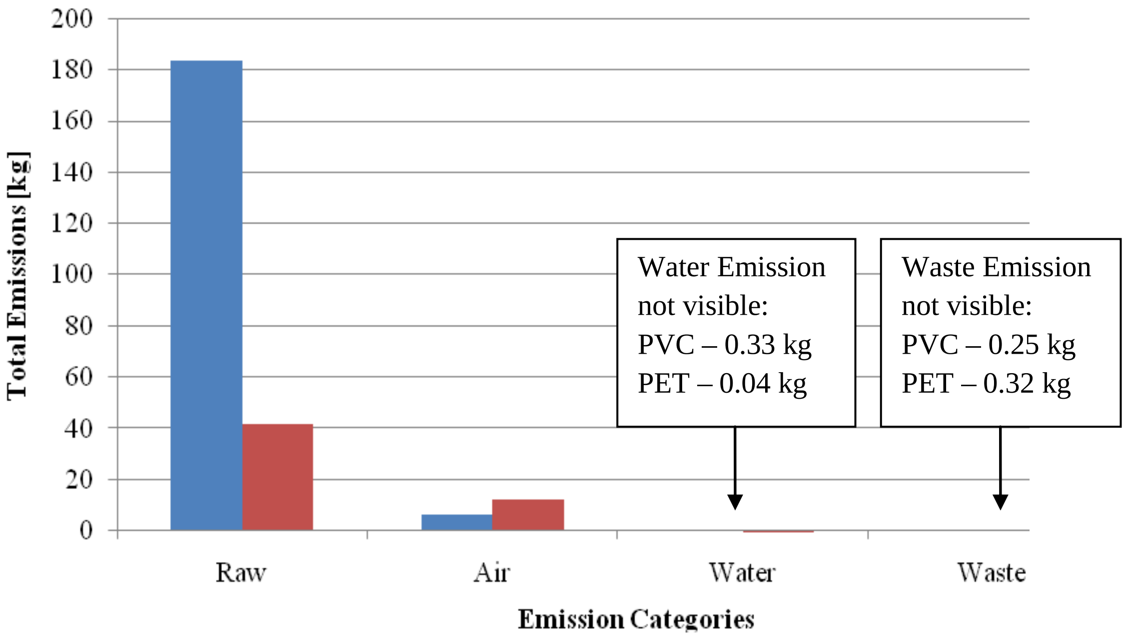
Comparing 2.8 kg 'PVC (suspension polymerisation) E' with 2.8 kg 'PET amorph I'; Method: Eco-indicator 99 (E) V2.04 / Europe EI 99 E/E / normalization

Figure A.5.2: Characterization of emission values comparing 2.8 kg of Polyvinyl Chloride (PVC) and 2.8 kg of Polyethylene Terephthalate (PET), created with SimaPro 7.



Comparing 2.8 kg 'PVC (suspension polymerisation) E' with 2.8 kg 'PET amorph I'; Method: Eco-indicator 99 (E) V2.04 / Europe EI 99 E/E / characterization

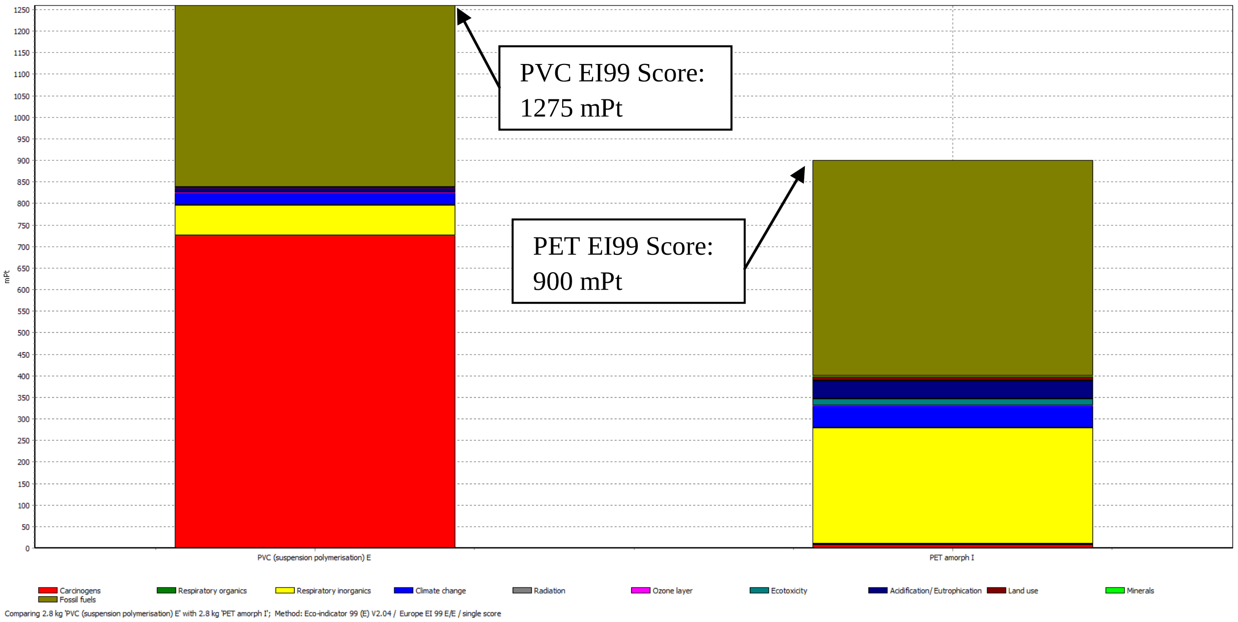
Figure A.5.3: Comparison of total emissions of 2.8 kg of Polyvinyl Chloride (PVC) and 2.8 kg of Polyethylene Terephthalate (PET) in terms of total emissions in raw, air, water and waste



Water Emission not visible:
PVC – 0.33 kg
PET – 0.04 kg

Waste Emission not visible:
PVC – 0.25 kg
PET – 0.32 kg

Figure A.5.4: Comparison of EcoIndicator 99 point values of 2.8 kg of Polyvinyl Chloride (PVC) and 2.8 kg of Polyethylene Terephthalate (PET), created with SimaPro 7



PVC EI99 Score: 1275 mPt

PET EI99 Score: 900 mPt

Comparing 2.8 kg 'PVC (suspension polymerisation) E' with 2.8 kg 'PET amorph I'; Method: Eco-indicator 99 (E) V2.04 / Europe EI 99 E/E / single score

Appendix 6: Manufacturing Process Selection

Production Volume

For a mass production volume of the infant reflex test apparatus, a conservative estimate was estimated made based on several factors. Since the apparatus is not intended to be a diagnostic tool, it would only be used for infants with neuromotor conditions.[B. Ulrich personal communication] The worldwide population of applicable infants is roughly 91,800,000 [1-7, 26, 27]. With additional global data [28] on the number of physicians per capita (13/10,000 people) and number of hospital beds per capita (25/10,000 people) a rough number of clinics worldwide was calculated to be around 575. Due to discrepancies in gross domestic product (GDP) spent on healthcare [28], some regions of the world would more be willing to purchase this testing equipment than others. Based on the assumption that not all available clinics would purchase such a device, a lowered estimate of 500 total units was estimated.

Production Method for Selected Materials

Based on the production volume of 500 apparatus units, the methods for manufacturing were determined using the CES software. Component models for 3,000 seat pans (500 units x 6 seat pan sizes = 3,000 units) and 1,000 telescoping tubes (500 units x 2 tubes = 1,000 units) were determined based on batch size, cost, and various geometric parameters. There were multiple viable methods for each component, and the results are detailed in the following subsections.

Seat pans – Two suitable manufacturing process for making the seat pans were narrowed down based on the batch size (3,000), mass (0.45 kg), and thickness (0.0127 m): polymer casting and compression molding.(values of mass and thickness based on the new design) Both methods have similar roughness ($0.5 - 1.6 \cdot 10^{-6}$ m [25]) and plastic material molding range [25]. Compression molding was selected over polymer casting because it is less expensive (based on relative cost index) and has a higher tolerance level (1 mm compared to 2 mm) [25]. This method is intended for simple molding geometries, which the seat pans are.

Telescoping tubes – Five suitable manufacturing processes for making the telescoping tubes were narrowed down based on the batch size (1,000), mass (0.074 kg), thickness (0.0222 m) and a cylindrical prismatic geometry: plaster mold casting, CLA/CLV casting, centrifugally-aided casting, manual investment casting and automatic investment casting. (values of mass and thickness based on the new design) Plaster mold casting was selected over the other four methods because the other methods were intended for making small, intricate parts [25]. This method also allows for aluminum to be used, which would reduce the weight of the pulsator apparatus, therefore making it easier to move during testing and for storage. Plaster mold casting was the most costly of the choices (based on relative cost index), and had lower tolerances than three of the other casting methods [25]. The tolerances ($2.5 – 7 \cdot 10^{-4}$ m [25]) and roughness ($1.6 – 3.2 \cdot 10^{-6}$ m [25]) of plaster mold casting are within an acceptable range for the telescoping tube application.

Appendix 7: Component Designs and Drawings from Concept Selection

(i) Seat Size Adjustment

Adjustable Bench Seat

In order to accomplish the seating goals is to have a seat that is wide enough to fit any size child inside our age requirements. In order to accommodate the different necessary lengths the bench seat will be able to slide forward and backward through a lockable slot in the chair back. In order to properly separate the infant's legs a retracting slider will be pulled out from a slot in the bench and lock into position. The slider will be tapered in size, so in order to separate the larger child's legs farther apart you would just pull the slider farther out. Depiction of 'Adjustable Bench Seat' is shown in Figure A.2.

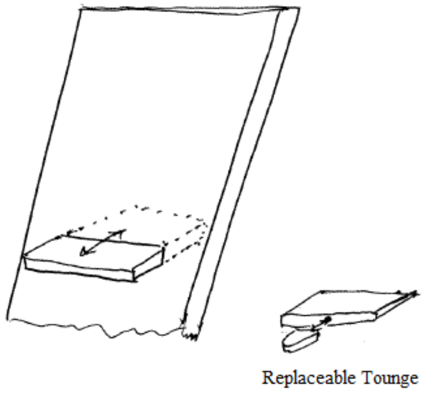


Figure A.2: Adjustable Bench

Flip Out

This design satisfies the aforementioned seating requirements in an adjustable seat size design. This design changes its size by having hinged pieces that would flip out and be locked into place using sliding bars. Because so many different stepped sizes are necessary there would need to be multiple layers which flip out. Having this design would require that the material used for the seat would need to be relatively thin. This is because when the seat was folded up to fit the smallest size child there would be several layers of the seat stacked on top of each other and all of the stacked layers would get in the way of the testing site located on the heel of the child. In order to use a thinner material but still provide a strong base for the child this design would require a stronger material than the previously mentioned designs. Depiction of 'Flip Out' is shown in Figure A.3.

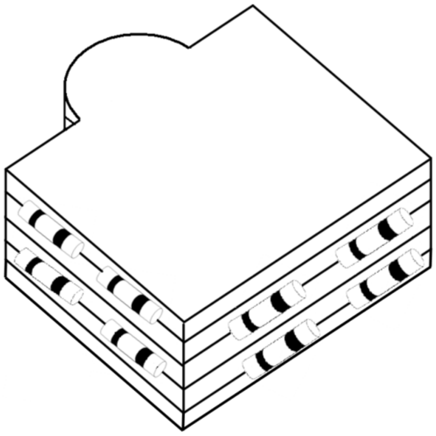


Figure A.3: Flip Out

Canopy Style Canvas Chair

This would include allowing piece of canvas to drape down and provide the support as the back of the chair to the child, the two bottom corners of the canvas would be attached to canopy located above the child's head. The ropes holding the canvas could be raised or lowered in order to change the size of the seat as well as the height. Depiction of 'Canopy Style Canvas Chair' is shown in Figure A.4.

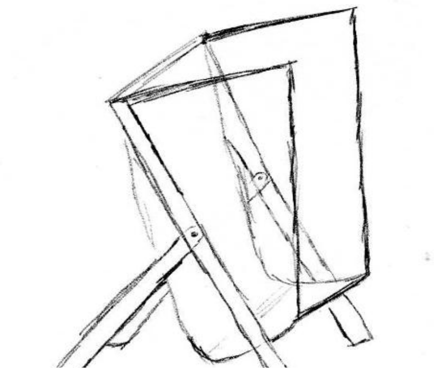


Figure A.4: Canopy Style Canvas Chair

(ii) Seat Angle Adjustment

Exercise Manual (*Assuming that the range of motion required is small*)
The seat angle could be adjusted using a mechanism is a manual design using a knob or crank. An example of this design is shown in Figures A.5. One of the main advantages of these designs is simplicity. There would be no electricity or cables required and the adjustment could be made user-friendly and fast. The angle adjustment could still be fine even if no motor is used. Because of the simplicity, a manual angle adjustment design could also be made very reliable and sturdy because there are fewer parts to fail and fewer moving parts. This means less safety risks. However, wear from friction would have to be accounted for. The design would be relatively inexpensive to manufacture and to maintain. The design could also be made very compact for storage. A drawback of a manual design is that it might not be seen as being professional in a clinical setting. For example, dentist chairs use motorized adjustment.

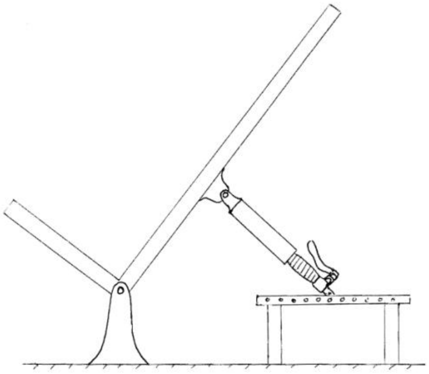


Figure A.5: Exercise Manual

Rigid Bar
A motorized design using a pivoting rigid bar, running on a track, is shown in Figures A.6. This design is simpler than the car jack concept and also offers a high-resolution adjustment and the user-friendliness of a motorized design. The drawbacks of this design include that there is increased risk of failure due to the many parts, and that it would be relatively expensive because of the need for custom gears. Due to the geometry of the mechanism, the seat angle would change at a non-constant angle, which is undesirable. The design may also interfere with some of the other chair components, such as the slots for adjusting the seat or the bench seat concept. The design also would be bulky, making storage more difficult.

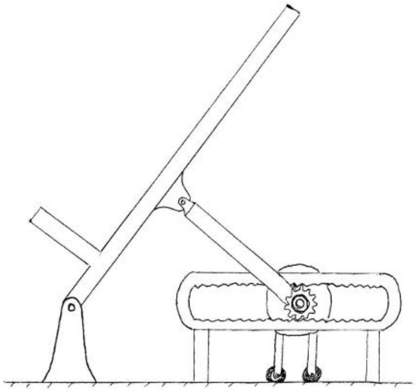


Figure A.6: Rigid Bar

Motor at Fulcrum
A motorized design using a motor at the fulcrum is shown in Figure A.7. This design is offers the advantages in user-friendliness and high resolution in angle adjustment that come with a motor, but comes in a compact form allowing easy storage. The design would also not interfere with other components on the chair, such as the bench seat or the slots. However, for safety the design would probably need an advanced safety mechanism to prevent the seat back from moving, even when the motor is turned off. This could be expensive, for example, if it requires a very large motor or a precision gearbox.

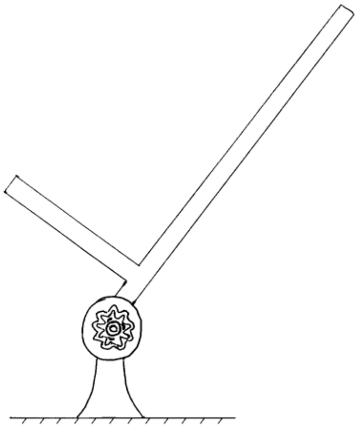


Figure A.7: Motor at Fulcrum

Pneumatic

A pneumatic setup to adjust the chair back angle would be supported up by a powered pressurized tube. The tube would be pressurized on the other side by an air reservoir that would have air pumped into it using a compressor. The reservoir could be depressurized by having a value that could be released to slowly let out pressure. As pressure is released the bar on the compressor side would push down with less force, resulting in the bar on the chair side to come down. This adjustment could accomplish the range of 10 to 30 degrees of angle adjustment from the vertical axis. This design would be relatively quick to adjust as the compressor could be run with just the push of a button. Depiction of 'Pneumatic' is shown in Figure A.8. This design was rejected because the compressor would be very loud during use, which would be unpleasant for infants.

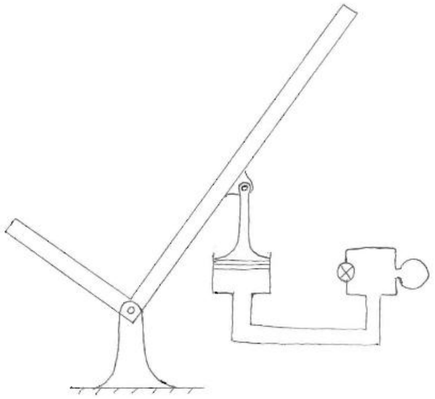


Figure A.8: Pneumatic

Rocking Chair, Clamps (*Assuming that the range of motion required is small*)

Another option for a manual seat angle adjustment mechanism is one using a rocking chair-like motion. This design is shown in Figure A.9. The design would be locked in place using a knob or a stop placed in between the ground and the curved piece. This design offers fast adjustment and user-friendliness, and would be fairly inexpensive. However, there are some safety concerns that are inherent to this design. There needs to be a safe way to prevent the chair from rocking after adjustment, and the chair cannot be allowed to move in either direction. This design could also be motorized. Depiction of 'Rocking Chair' is shown in Figure A.9.

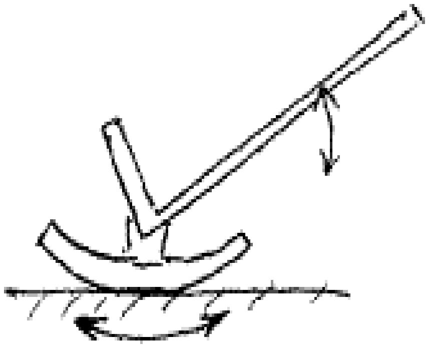


Figure A.9: Rocking Chair, Clamps

Static Chair

The Static Chair design is a standalone chair that would not be placed on a table top as it has fold out legs to reach the ground. The angle on this chair would not adjust be should allow for easier pulsator movement under the chair as the supports to the ground are on the side and back for the chair. This would not have any adjustment time or effort as the chair cannot be adjusted. Depiction of 'Static Chair' is shown in Figure A.10.

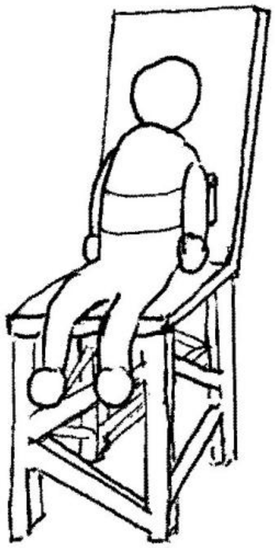


Figure A.10: Static Chair

Manual Knob
As used in the current design, manual knobs can lock the chair angle into place. When the knobs are loosened, the chair angle can be adjusted by the testers supporting the chair weight and the infant while adjusting the angle of the chair. The manual knobs can establish the 10 to 30 degrees of angle adjustment requirement as the bars attached to the knobs run on tracks and can just slide farther back to allow for more angle adjustment. The design is not noisy and does not need to be powered while not being adjusted as it is manual and does not use a motor. Depiction of 'Manual Knob' is shown in Figure A.11.

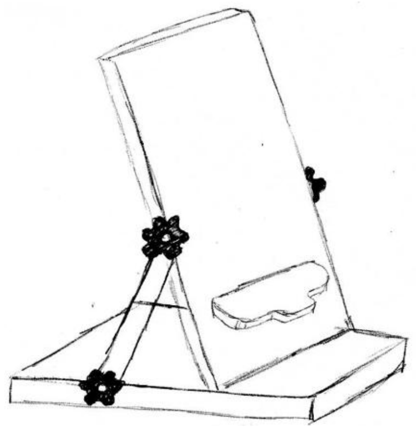


Figure A.11: Manual Knob

(iii) Seatbelt

Hoops on Side of Chair
The hoops are on the side of the chair and can be slid up and down on the bar to fit for any height necessary. The seatbelt would be looped through each side and could then be adjusted for any width needed to wrap around the child. That adjustment could allow for some flexibility of helping the child to not feel locked in to the chair. Depiction of 'Add on Hoops on Side of Chair' is shown in Figure A.12.

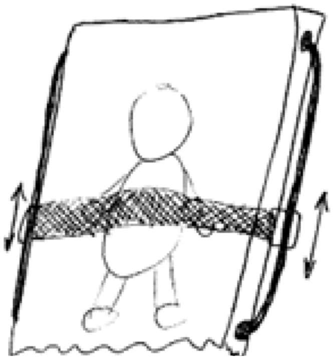


Figure A.12: Hoops on Side of Chair

V-neck Seatbelt
There are three to five points that anchor the belts to the chair. Two possible places are above the child's shoulders, two could be next to the child's sides, and the last point would be between the child's legs. The point between the child's legs has a belt that comes up with a clip which is the central site for the other belts to be clipped into. These clips would make sure the child could not fall out of the chair to either side or forward. Each belt could be adjusted to a different length to accommodate the different sized children. Depiction of 'V-neck Seatbelt' is shown in Figure A.13.

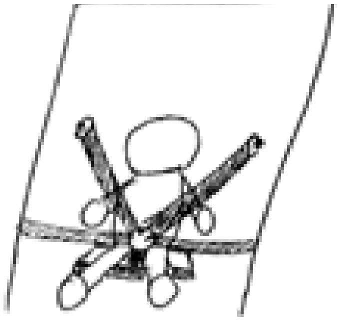


Figure A.13: V-neck Seatbelt

Car or Airplane Seatbelt
With the similar style to a seatbelt in a car or airplane, the seatbelt is anchored on the sides of the infant in the chair. The belt would be adjustable in length at the buckle to allow for the different sized infants. This seatbelt prevents the infant from falling out of the chair by holding them around the waist. Depiction of 'Car or Airplane Seatbelt' is shown in Figure A.14.

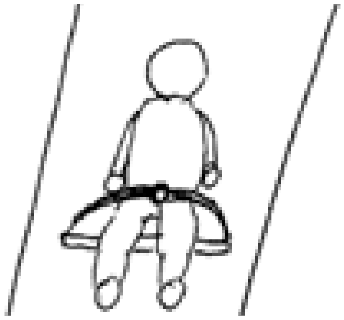


Figure A.14: Car or Airplane Seatbelt

Tethered Vest
The infant is placed in an upper body vest that is attached to the back of the chair by a cord. The infant is allowed some freedom in the chair without being able to fall out because the cord holds them on. Potentially different sized vests would be necessary to accommodate for the different sized infants. Depiction of 'Tethered Vest' is shown in Figure A.15.

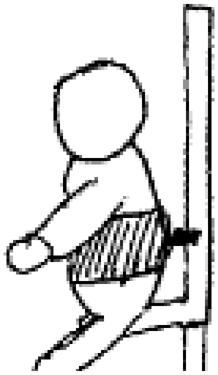


Figure A.15: Tethered Vest

Child Carrying Pack

Another design that we came up with, while discussing seating for the child, was to use a child carrying pack. This entails a cloth torso support which also provides a loop between the child's legs to hold them suspended in the air. The thought was to attach this design to the chair and place the child in the pack. We realized that we would still need multiple sizes of this seating apparatus, but we determined that each pack could hold a larger range of sizes of children, so we would not need as many variations as we would for the multiple sizes of the normal seat. Depiction of 'Child Carrying Pack' is shown in Figure A.16.

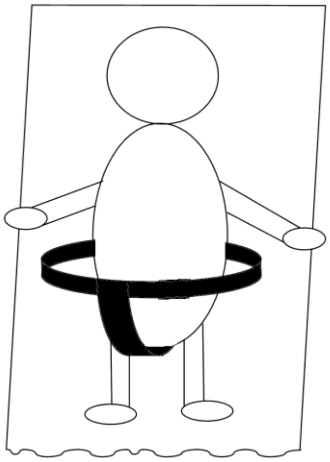


Figure A.16: Child Carrying Pack

(iv) Tray

Tray Type

Velcro ^{TM} or Magnets
Both Velcro ^{TM} and magnetic trays provide means to secure the toys to the tray during testing, including a possible change in test inclination. Compatible Velcro ^{TM} or magnetic toys would need to be used for these designs. Depiction of 'Velcro ^{TM} or Magnets' is shown in Figure A.17.

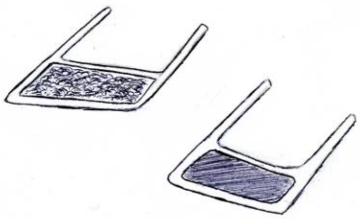


Figure A.17: Velcro ^{TM} or Magnets

Basin
A basin is an exaggerated lip design, having a shallow bin for playing with toys. Each design accomplishes the same goal but caters to different styles of play. Depiction of 'Basin' is shown in Figure A.18.

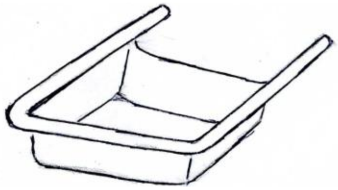


Figure A.18: Basin

Canvas
The surface of the tray is made of canvas and is supported by two armrests. The design allows the canvas tension to be adjustable, creating various play scenarios; the canvas could possibly be hung in a way to create a freeform basin. Depiction of ‘Canvas’ is shown in Figure A.19.

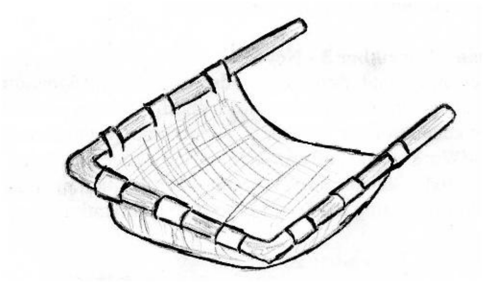


Figure A.19: Canvas

Multiple Tray Layers/Removable Tray Layers
This design allows for interchangeable trays to be inserted into the apparatus. Possible trays include Velcro ^{TM}, magnetic, canvas, and mirror. The apparatus structure could be designed so that inserting the tray creates a lip to contain toys, or that the trays could be inserted into a fixed basin for containing toys. Depiction of ‘Multiple Tray Layers/Removable Tray Layers’ is shown in Figure A.20.

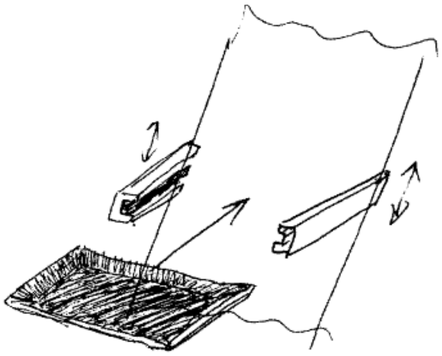


Figure A.20: Multiple Tray Layers/Removable Tray

Tray Structure

Folding Tray and Arms
The tray is able to rotate 90 degrees on the axis of one support arm to allow entry and exit from the apparatus. Additionally, the opposite support arm will fold upright, parallel to the chair back to create more access to enter or exit the apparatus seat. One variation of this design allows the tray to swivel parallel to the support arm after it has been fully rotated, and then have both arms fold upright; this design allows for improved storage for the apparatus while not in use. Another variation includes a tray fixed to two support arms that rotate 90 degrees from horizontal to vertical for entry and exit to the seat and improved storage. Depiction of ‘Folding Tray and Arms’ is shown in Figure A.21.

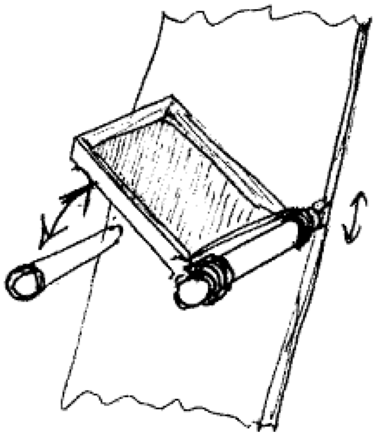


Figure A.22: Folding Tray and Arms

Rotating Arms
The tray is attached to support arms that rotate with the seat back for testing done at different chair inclinations. This design keeps the tray perpendicular to the test subject throughout testing, providing a fixed distance from the chair back to the tray. Depiction of ‘Rotating Arms’ is shown in Figure A.23.

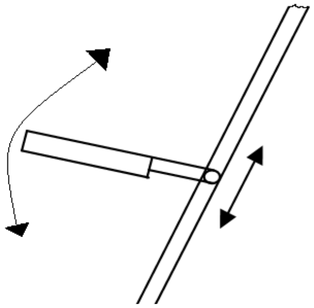


Figure A.23: Rotating Arms

Removable Peg Tray

The tray is designed with built in support arms, and the entire structure is removable from the test chair for entry and exit. The tray structure is secured in place by pegs at the end of each support arm held by close fit slots built into the chair back; the exact locking mechanism may be designed like the spring-loaded lock in an umbrella. This design is intended to be used with a peg system for adjusting the head support and seat. Depiction of 'Removable Peg Tray' is shown in Figure A.24.

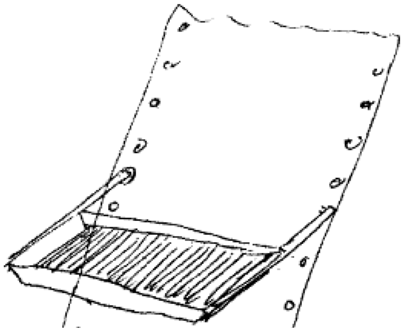


Figure A.24: Removable Peg Tray

(v) Pulsator

Camera Tripod

By modifying a camera tripod to fit with a pulsator, four degrees of motion are possible each with a locking mechanism to hold that degree of freedom in place. The pulsator would rest where the camera normally sits by screwing a camera bottom onto the pulsator. Depiction of 'Camera Tripod' is shown in Figure A.25.

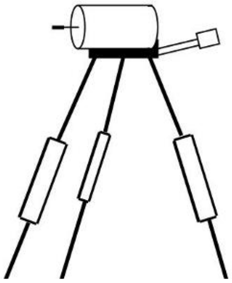


Figure A.25: Camera Tripod

Rotating Pulsator Arm

For a more versatile pulsator apparatus, the pulsator hangs down on a pole attached to a horizontal bar. The horizontal bar is held up by two side bars that are attached to the weighted base on the ground to provide stability to the apparatus. The pulsator can slide on the horizontal bar and also be raised and lowered to reach the potential sites of the various sized infants. If the infant is reclined the pole is able to swing up to reach the final testing site on the back of the leg as the pulsator is positioned vertically. Depiction of 'Rotating Pulsator Arm' is shown in Figure A.26.

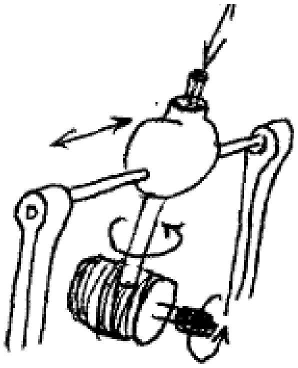


Figure A.26: Rotating Pulsator Arm

Hinged Mount

The basic shape of this set up is a microphone stand with the modification of a V-shaped bar on the top and a horizontal bar with the pulsator attached to it which runs along the top of the V-bar. The pulsator could slide back and forth along the horizontal bar as well as rotate up vertically. This rotation to be able to go vertically should allow for the pulsator to be able to meet any required angle of the three testing sites. Depiction of 'Hinged Mount' is shown in Figure A.27.

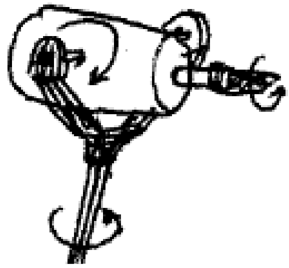


Figure A.27: Hinged Mount

Multi-Joint Arm
The pulsator is attached on the end of an arm that can rotate in many directions from its multiple elbow joints. From multiple locking elbow joints, the arm can position the pulsator in almost every orientation so that it can conduct the three leg tests. Each degree of freedom would be able to be locked to provide the stability also necessary to conduct the tests. Depiction of 'Multi-Join Arm' is shown in Figure A.28.

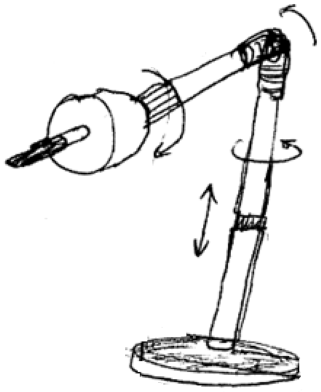


Figure A.28: Multi-Join Arm

Hold the pulsator apparatus in place by 'Locking Wheels'
Attached to the bottom of the upright supporting rods, the wheels would have a locking mechanism built in that could be locked to stop them from sliding. Having the wheels locked in during the test would provide some resistance in two lateral directions while still allowing for the testers to slightly move the apparatus in case of small adjustments made during the test. While unlocked, the wheels would require less force for the testers to adjust the pulsator in the same two lateral directions. Depiction of 'Locking Wheels' is shown in Figure A.29.

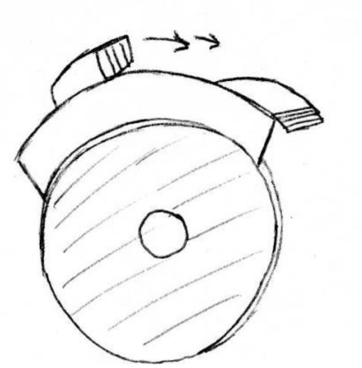


Figure A.29: Multi-Join

Hold the pulsator apparatus in place by 'Suction Cup'
This concerns the stability of the pulsator stand as suction cups support the shorter apparatuses from being knocked out of position. The suction cups need a flat, relatively clean surface to work on and that restricts them from being used to support a stand from the ground. The suction cups themselves are placed loosely on the surface with a small lever arm coming off of side. When the lever arm is pulled up cup suctions down and it is held in place. Depiction of 'Suction Cup' is shown in Figure A.30.

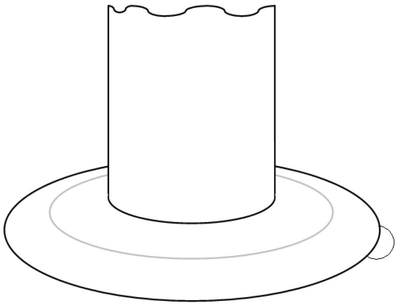


Figure A.30: Suction Cup

(vi) Head Support

Tightening Elastic Strap
Our first idea to accomplish this head support system was to have an adjustable size headrest that is attached to a strap that would slide around the seat back. The headrest would be slid into the correct position behind the child's head and adjusted in width. Once the headrest was in the correct place the straps that hold the headrest in place would be tightened to lock the headrest in place using friction. Depiction of 'Tightening Elastic Strap' is shown in Figure A.31.

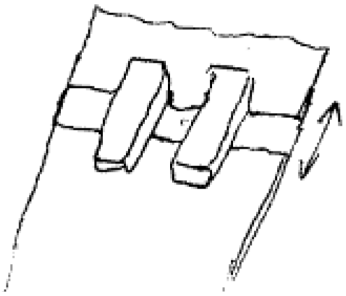


Figure A.31: Tightening Elastic Strap

Pegged Headrest
Our third design is to have a headrest, adjustable in size, which would fit into a peg slot system located on the chair back. Our final idea for the head support is to have it be inflatable. This head support idea could be used with any of the other designs to vary the height of the head rest. This design is intended to be used with a peg system for adjusting the tray and seat. Depiction of 'Pegged Headrest' is shown in Figure A.32.

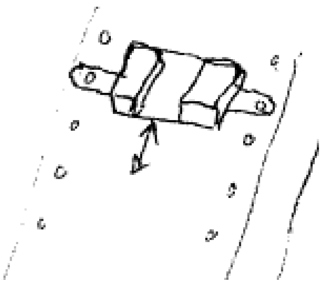


Figure A.32: Pegged Headrest

(vii) Seat Height Adjustment (Ruled out after further discussions with sponsor)

Our Sponsor, Beverly Ulrich, originally asked us to include the ability to adjust the seat height in our final project. After a discussion at a later date we all decided that by increasing the range of the pulsator height we could eliminate this design feature. This discussion took place after had already brainstormed the idea. The results from this brainstorm are included below.

Slot Manual Adjustment
Our first design to meet these requirements is to hold the chair up by using friction, it would accomplish this by having a slot going through the back of the chair which is attached to the seat. A hand tightenable bolt or a pressure relieve grip would be used to allow motion to the seat. Depiction of 'Slot Manual Adjustment' is shown in Figure A.33.

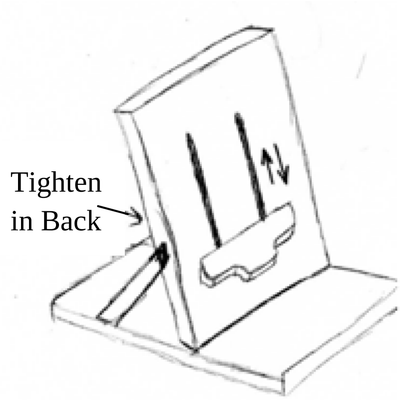


Figure A.33: Slot Manual Adjustment

Pegged Chair
The next concept that we generated was to have many aligned peg slots located up and down the entire chair, you would be able to take your seat and place it in at the desired height that was preferred for the current child. This design is intended to be used with a peg system for adjusting the tray and head support. Depiction of 'Pegged Chair' is shown in Figure A.34.

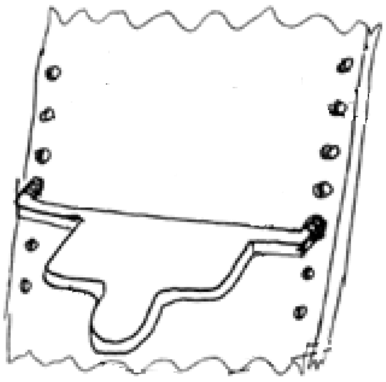


Figure A.34: Pegged Chair

Motor Lift

Our final idea to vary the height of the seat for the child is to adjust the height using a motor or hydraulic lift. By using one of these more automated systems the height that the child is sitting at could be easily varied by the push of a button. Depiction of 'Motor Lift' is shown in Figure A.35.

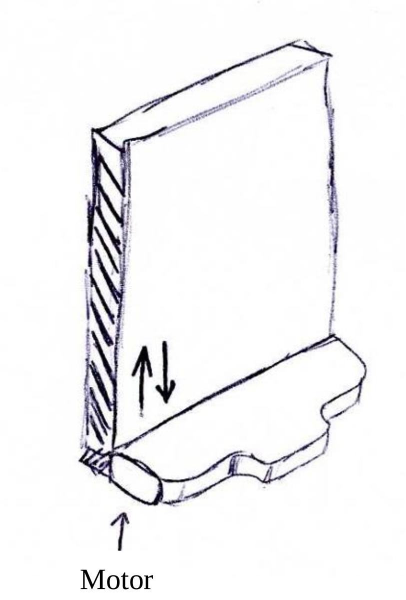


Figure A.35: Motor Lift

Appendix 8: Pugh Charts

A.8.1 – Pulsator

	Weight	Ball Joint	Camera Tripod	Multi-Joint Arm	Hinged Mount	Rotating Pulsator Arm
Average Pulsator Adjustment Time	1	1	1	-1	1	-1
Self-Explanatory/ User Friendliness	0.7	1	0	0	1	0
Full Range of Motion (Translational and Rotational)	0.7	1	1	1	1	1
No Sharp Edges or Crevices which can Catch Fingers	0.7	0	0	-1	0	-1
Cost	0.1	0	0	-1	0	-1
Maintenance Required	0.7	0	0	0	0	0

Total Score	**2.4**	1.7	-1.1	2.4	-1.1

	Weight	Suction Cups	Weighted Platform	Locking Wheels
Self-Explanatory/ User Friendliness	1	0	1	-1
Cost	0.1	-1	0	0
Average Pulsator Adjustment Time	0.7	1	0	-1
Full Resolution of Movement	0.5	-1	0	0
Maintenance Required	0.3	0	1	0

Total Score	0.1	**1.3**	-1.7

A.8.2 – Seat Belt

	Weight	Hoops	V-neck	Airplane	Vest with Tether	Trunk Support
Holds Child in Securely	1	0	1	0	1	1
Freedom of Arm Rotation	0.7	1	0	1	0	1
Self-Explanatory/ User Friendliness	0.7	-1	0	1	-1	0
No Sharp Edges or Crevices	0.7	1	0	0	1	0
Chair Back Width Range	0.3	0	0	1	1	1
Chair Back Length Range	0.3	0	-1	0	0	0
Time for Adjustment	1	0	-1	1	-1	0
Cost	0.1	1	0	1	-1	0
Complexity to Make	0.3	1	0	1	0	0
Trunk Support	1	1	1	-1	0	1
	Total Score	2.1	0.7	2.1	0.2	**3**

A.8.3 – Seat Pan

	Weight	Flip Out	Adjustable Bench Seat	Multiple Seats
Seat Width	1	0	0	0
Seat Length	1	0	0	0
Self-Explanatory/ User Friendliness	0.7	-1	0	0
No Sharp Edges or Crevices which can Catch Fingers	0.7	0	0	1
Child Comfort (Child Held Securely)	0.7	-1	0	1
Cost	0.1	-1	0	-1
Maintenance Required	0.7	0	0	0
Total Adjustment Time	0.7	-1	0	-1
Simplest Design	0.5	-1	0	1
Folded Volume	0.3	0	0	-1
	Total Score	-2.6	0	**0.9**

A.8.4 – Head Support

	Weight	Tightening Elastic Band	Strap with Pillow	Pegged Head Support
Self-Explanatory/ User Friendliness	0.6	0	0	-1
No Sharp Edges or Crevices which can Catch Fingers	0.8	0	0	-1
Child Comfort (Child is Held Securely)	1	0	0	1
Cost	0.1	0	0	-1
Maintenance Required	0.5	0	1	1
Full Resolution of Movement	0.6	0	0	-1
Total Adjustment Time	0.5	0	-1	-1
	Total Score	**0**	**0**	-1.1

A.8.5 – Tray

	Weight	Velcro ™ / Magnet	Basin	Canvas Tray	Lip
Failure	0.7	0	0	0	0
Life Cycle	0.5	-1	1	0	0
Seat Length	0.2	0	0	0	0
Adjustable Seat Height	0.3	0	-2	0	0
Length of Tray	0.2	0	0	0	0
Freedom of Arms	0.4	0	0	0	0
Freedom of Legs	0.4	0	-1	0	0
Self-Explanatory/ User Friendliness	0.6	0	1	0	1
Ability to Hold Toys	0.5	2	1	0	1
No Sharp Edges, etc.	0.5	0	0	0	0
Chair Back Width	0.1	0	0	0	0
Cost	0.1	-1	0	0	0
Overall Safety	1	0	0	0	0
Time of Adjustment	0.7	0	0	0	0
	Total Score	0	0	0	**2**

Tray (continued)

	Folding Tray/Arms	Clamped Tray (Knob)	Peg	Folding Tray Above Head
Failure	-1	-1	0	-1
Life Cycle	0	1	1	0
Seat Length	0	0	0	-1
Adjustable Seat Height	-1	0	-1	-1
Length of Tray	0	-1	-1	-1
Freedom of Arms	0	0	0	0
Freedom of Legs	0	0	0	0
Self-Explanatory/ User Friendliness	-1	0	0	-1
Ability to Hold Toys	0	0	0	0
No Sharp Edges, etc.	-1	0	-1	-1
Chair Back Width	1	0	0	-1
Cost	-2	0	0	0
Overall Safety	-1	0	0	-1
Time of Adjustment	0	-1	0	-1
Total Score	-6	**-2**	-2	-9

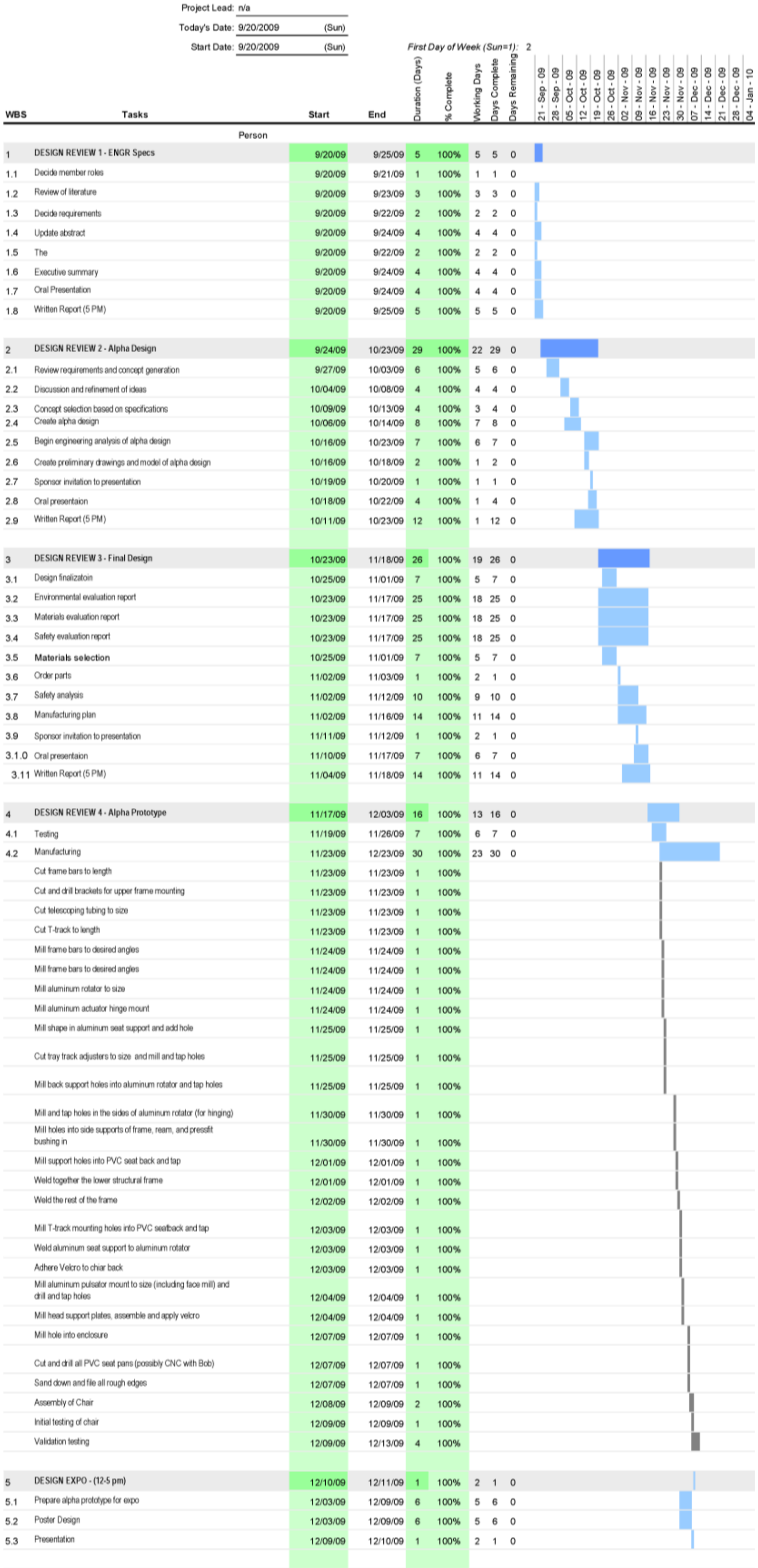
A.8.6 – Alpha Design Selection

	Weight	(1) Motorized Motion (worm gear)	(2) Rigid Bar	(3) Motor at Fulcrum	(4) Pneumatic	(5) Exercise Manual	(6) Pegs	(7) Stand Alone
Child Held Securely	1.0	0	0	0	0	0	0	0
Finger Traps/Sharp Edges	0.8	0	0	0	0	0	-0.5	0
Safety of Chair back	1.0	0.5	0	0	0.5	-0.5	0.5	0.5
Ease of Use	0.8	0	0	0	0	-0.5	-0.5	0
Cost	0.1	0.5	0	0	0.5	1	0.5	-0.5
Time for Test	0.5	0	0	0	0	-0.5	0.5	0
Complexity to Make	0.2	-0.5	-0.5	0	-0.5	0.5	-0.5	-1
Durability	0.5	0	0	0	0	1	-0.5	-0.5
Compactness	0.3	0	0	0	0	0.5	0	-1
Comfort of Child	0.6	0	0	0	0	0	-0.5	0
Freedom of Arm(s)	0.4	0	0	0	0	0	0	0
Freedom of Leg(s)	0.4	0	0	0	0	0	0	0
Self-Explanatory/ User Friendliness	0.5	-0.5	-0.5	0	-0.5	0	-0.5	-1
Marketability	0.2	0	0	0	0	-0.5	0	-0.5
	Total Score	0.20	-0.35	0.00	0.20	-0.30	-.90	-0.80

A.8.7 – Prototype Design Selection

	Weight	1-Motorized Motion (worm gear)	2-Rigid Bar	3-Motor at Fulcrum	4-Pneumatic	5-Exercise Manual	6-Pegs	7-Stand Alone	8 - Linear Actuator
Child Held Securely	1.0	0	0	0	0	0	0	0	0
Finger Traps/Sharp Edges	0.8	0	0	0	0	0	-0.5	0	0
Safety of Chair back	1.0	0.5	0	0	0.5	-0.5	0.5	0.5	0.5
Ease of Use	0.8	0	0	0	0	-0.5	-0.5	0	0
Cost	0.1	0.5	0.5	0	0.5	1	0.5	-0.5	0.5
Time for Test	0.5	0	0	0	0	-0.5	0.5	0	0
Complexity to Make	0.2	-0.5	-0.5	0	-0.5	0.5	-0.5	-1	-0.5
Durability	0.5	0	0	0	0	1	-0.5	-0.5	0
Compactness	0.3	0	0	0	0	0.5	0	-1	0
Comfort of Child	0.6	0	0	0	0	0	-0.5	0	0
Freedom of Arm(s)	0.4	0	0	0	0	0	0	0	0
Freedom of Leg(s)	0.4	0	0	0	0	0	0	0	0
Self-Explanatory/ User Friendliness	0.5	-0.5	-0.5	0	-0.5	0	-0.5	-1	0
Marketability	0.2	0	0	0	0	-0.5	0	-0.5	0
Resolution	0.3	0	-1	0	-0.5	-1	-1	0	0
Design is Not Overly Complicated	0.6	0	-0.5	0	-0.5	0	0	-0.5	0
Environmentally Friendly	0.2	0	1	0	-0.5	1	1	0	0
	Total	0.20	-0.70	0.00	-0.35	-0.50	-1.00	-1.20	0.4

Appendix 9: Gantt Chart



Project Lead: n/a
Today's Date: 9/20/2009 (Sun)
Start Date: 9/20/2009 (Sun)

WBS	Tasks	Person	Start	End	Duration (Days)	% Complete	Working Days	Days Complete	Days Remaining
1	**DESIGN REVIEW 1 - ENGR Specs**		9/20/09	9/25/09	5	100%	5	5	0
1.1	Decide member roles		9/20/09	9/21/09	1	100%	1	1	0
1.2	Review of literature		9/20/09	9/23/09	3	100%	3	3	0
1.3	Decide requirements		9/20/09	9/22/09	2	100%	2	2	0
1.4	Update abstract		9/20/09	9/24/09	4	100%	4	4	0
1.5	The		9/20/09	9/22/09	2	100%	2	2	0
1.6	Executive summary		9/20/09	9/24/09	4	100%	4	4	0
1.7	Oral Presentation		9/20/09	9/24/09	4	100%	4	4	0
1.8	Written Report (5 PM)		9/20/09	9/25/09	5	100%	5	5	0
2	**DESIGN REVIEW 2 - Alpha Design**		9/24/09	10/23/09	29	100%	22	29	0
2.1	Review requirements and concept generation		9/27/09	10/03/09	6	100%	5	6	0
2.2	Discussion and refinement of ideas		10/04/09	10/08/09	4	100%	4	4	0
2.3	Concept selection based on specifications		10/09/09	10/13/09	4	100%	3	4	0
2.4	Create alpha design		10/06/09	10/14/09	8	100%	7	8	0
2.5	Begin engineering analysis of alpha design		10/16/09	10/23/09	7	100%	6	7	0
2.6	Create preliminary drawings and model of alpha design		10/16/09	10/18/09	2	100%	1	2	0
2.7	Sponsor invitation to presentation		10/19/09	10/20/09	1	100%	1	1	0
2.8	Oral presentaion		10/18/09	10/22/09	4	100%	1	4	0
2.9	Written Report (5 PM)		10/11/09	10/23/09	12	100%	1	12	0
3	**DESIGN REVIEW 3 - Final Design**		10/23/09	11/18/09	26	100%	19	26	0
3.1	Design finalizatoin		10/25/09	11/01/09	7	100%	5	7	0
3.2	Environmental evaluation report		10/23/09	11/17/09	25	100%	18	25	0
3.3	Materials evaluation report		10/23/09	11/17/09	25	100%	18	25	0
3.4	Safety evaluation report		10/23/09	11/17/09	25	100%	18	25	0
3.5	**Materials selection**		10/25/09	11/01/09	7	100%	5	7	0
3.6	Order parts		11/02/09	11/03/09	1	100%	2	1	0
3.7	Safety analysis		11/02/09	11/12/09	10	100%	9	10	0
3.8	Manufacturing plan		11/02/09	11/16/09	14	100%	11	14	0
3.9	Sponsor invitation to presentation		11/11/09	11/12/09	1	100%	2	1	0
3.1.0	Oral presentaion		11/10/09	11/17/09	7	100%	6	7	0
3.11	Written Report (5 PM)		11/04/09	11/18/09	14	100%	11	14	0
4	**DESIGN REVIEW 4 - Alpha Prototype**		11/17/09	12/03/09	16	100%	13	16	0
4.1	Testing		11/19/09	11/26/09	7	100%	6	7	0
4.2	Manufacturing		11/23/09	12/23/09	30	100%	23	30	0
	Cut frame bars to length		11/23/09	11/23/09	1	100%			
	Cut and drill brackets for upper frame mounting		11/23/09	11/23/09	1	100%			
	Cut telescoping tubing to size		11/23/09	11/23/09	1	100%			
	Cut T-track to length		11/23/09	11/23/09	1	100%			
	Mill frame bars to desired angles		11/24/09	11/24/09	1	100%			
	Mill frame bars to desired angles		11/24/09	11/24/09	1	100%			
	Mill aluminum rotator to size		11/24/09	11/24/09	1	100%			
	Mill aluminum actuator hinge mount		11/24/09	11/24/09	1	100%			
	Mill shape in aluminum seat support and add hole		11/25/09	11/25/09	1	100%			
	Cut tray track adjusters to size and mill and tap holes		11/25/09	11/25/09	1	100%			
	Mill back support holes into aluminum rotator and tap holes		11/25/09	11/25/09	1	100%			
	Mill and tap holes in the sides of aluminum rotator (for hinging)		11/30/09	11/30/09	1	100%			
	Mill holes into side supports of frame, ream, and pressfit bushing in		11/30/09	11/30/09	1	100%			
	Mill support holes into PVC seat back and tap		12/01/09	12/01/09	1	100%			
	Weld together the lower structural frame		12/01/09	12/01/09	1	100%			
	Weld the rest of the frame		12/02/09	12/02/09	1	100%			
	Mill T-track mounting holes into PVC seatback and tap		12/03/09	12/03/09	1	100%			
	Weld aluminum seat support to aluminum rotator		12/03/09	12/03/09	1	100%			
	Adhere Velcro to chiar back		12/03/09	12/03/09	1	100%			
	Mill aluminum pulsator mount to size (including face mill) and drill and tap holes		12/04/09	12/04/09	1	100%			
	Mill head support plates, assemble and apply velcro		12/04/09	12/04/09	1	100%			
	Mill hole into enclosure		12/07/09	12/07/09	1	100%			
	Cut and drill all PVC seat pans (possibly CNC with Bob)		12/07/09	12/07/09	1	100%			
	Sand down and file all rough edges		12/07/09	12/07/09	1	100%			
	Assembly of Chair		12/08/09	12/09/09	2	100%			
	Initial testing of chair		12/09/09	12/09/09	1	100%			
	Validation testing		12/09/09	12/13/09	4	100%			
5	**DESIGN EXPO - (12-5 pm)**		12/10/09	12/11/09	1	100%	2	1	0
5.1	Prepare alpha prototype for expo		12/03/09	12/09/09	6	100%	5	6	0
5.2	Poster Design		12/03/09	12/09/09	6	100%	5	6	0
5.3	Presentation		12/09/09	12/10/09	1	100%	2	1	0

Appendix 10: Parameter Analysis

All the following equations are from basic statics and mechanics. [29]

A.10.1 Bolts in Joint Rotation

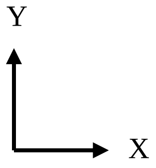
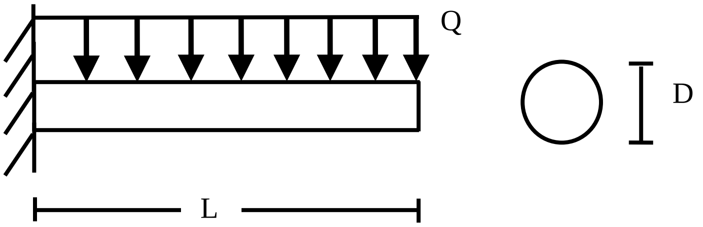


Figure A.10.1 Free body diagram of bolt



Length of bolt (L) = 0.5 in = .0127meters

Diameter of bolt (D) = 0.4995 in = .01269 meters

Mass	[kg]
Aluminum	1.7
Child [kg]	18
PVC chair back [kg]	6.6
Seat [kg]	0.9
Tray [kg]	2.5
Head Support [kg]	1
Miscellaneous [kg]	3
(seat belt, bolts, head support strap and clamp)	
SUM =	33.7

The sum of all of the forces weighing down on the chair with a safety factor of 4 is 1321.6N

$$F = \int_0^L Q dx = Q \cdot L = 1321.6$$

Force total (F) = 1321.6 N

$$A = \pi \left(\frac{D}{2}\right)^2$$

Area = .0001264 [m^2]

$$SF = \frac{F}{A}$$

Shear Stress = 10.45 MPa

Summing the moments factoring in that there are two bolts so only half the force applies to one bolt. Also the force is applied halfway of length L.

$$M = \frac{F}{2} \cdot \frac{L}{2} = \frac{1321.6 \cdot .0127}{4} = 4.20$$

M = 4.2 [Nm]

$$I = \frac{\pi D^4}{64} = \frac{\pi \cdot 0.0127^4}{64} = 1.27 \cdot 10^{-9}$$

I = $1.27 \cdot 10^{-9}$ [m^4]

$$\sigma_{yield} = \frac{My}{I} = \frac{4.2 \cdot \frac{0.0127}{2}}{1.27 \cdot 10^{-9}} = 2.09 \cdot 10^7$$

σ_{yield} = $2.09 \cdot 10^7$ [Pa]

Mohr's Equations

$$\frac{M}{2} \pm \sqrt{\left(\frac{M}{2}\right)^2 + {\sigma_{yield}}^2}$$

σ_1 =Principle Stress 1 = $2.53 \cdot 10^7$

σ_2 =Principle Stress 2 = - $4.33 \cdot 10^6$

Maximum Stress

$$\sigma_M = \sqrt{0.5 \cdot [(\sigma_1)^2 + (\sigma_2)^2 + (\sigma_1 - \sigma_2)^2]}$$

σ_M = 27.7 [MPa]

This is below the minimum tensile strength of a bolt this size. The tensile strength is 620.5 [MPa] which is greater than 27.7 [MPa] so the bolt will hold over the safety factor of four.

A.10.2 Tipping Calculations

Part # [in figure]	Center of Mass [m]	Weight [kg]	Moment [kg·m]
1	0.1215	0.1852	0.0225
2	0.2430	0.2362	0.0574
3	0.1215	0.1852	0.0225
4	0.0127	0.2477	0.0031
5	0.0127	0.2477	0.0031
6	0.0810	0.3093	0.0250
7	0.0810	0.3093	0.0250
8	0.2430	2.30	0.5589
9	0.1215	0.1852	0.0225
10	0.2430	0.2576	0.0626
11	0.150	6.0	0.90
12	0.0127	7.7281	0.0981
13	0.290	1.0	0.290
14	-0.3047	2.50	Excluded
15	-0.2110	72.0	-15.1920
16	-0.0914	0.910	-0.0831
17	-0.0762	0.1161	-0.0089
18	-0.0762	0.1161	-0.0089
SUM		95.07	-13.20

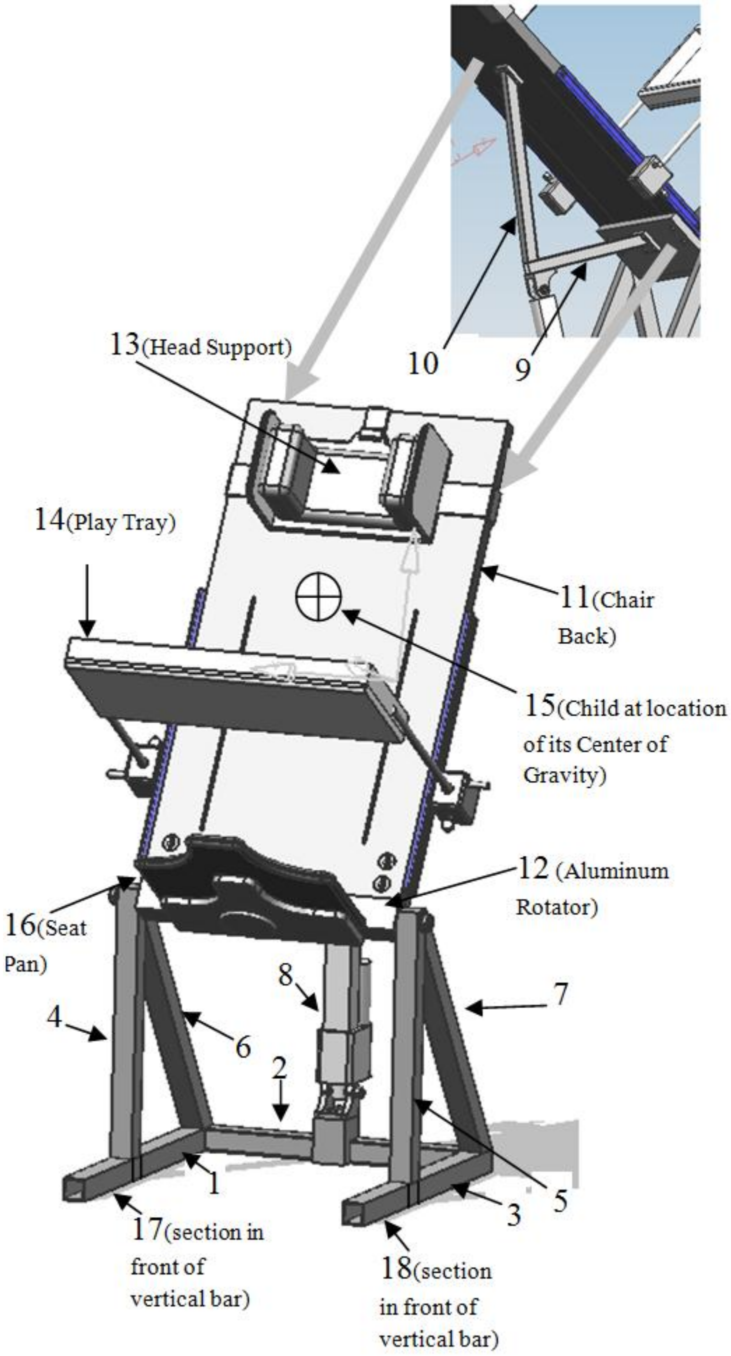


Figure A.10.2 Part Numbers of Chair Masses

The moment is generated by the weight multiplied by the distance the center of mass is away from the axis.

$$M = W \cdot x$$

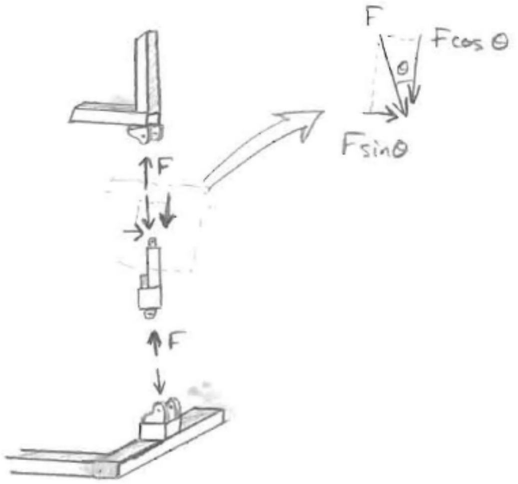
The sum of the moments divided by the total mass will give the center of mass location for the whole chair.

$$COM(x) = \frac{\Sigma M}{\Sigma W} = \frac{-13.20}{95.07} = -0.1388$$

With the center of mass of the system with a safety factor of four is at -0.1388[m] from the axis it is still within the edges of the chair as the front legs at the base of the chair go to -0.1524[m]. Having the center of mass of the system within the legs of the chair means it will not tip.

A.10.3 Linear Actuator Forces

Figure A.10.3 Free body diagram of linear actuator



part # [in figure]	distance [meters]	weight [kg]	Moment [kg·m]
9	0.1465	0.2233	0.0327
10	0.2930	0.2576	0.0755
11	0.150	6.0	0.90
12	0.0127	7.7281	0.0981
13	0.290	1.0	0.290
14	-0.3047	2.50	-0.7617
15	0.120	72.0	2.160
16	-0.0914	0.910	-0.0831
SUM			2.712

From the sum of the moments the remaining force is the linear actuator that can be controlled on where it is placed. A safety factor of four is important as this is one of the main supports that if it failed, the child would be quickly rotated around the joint and could be injured.

$$F = \frac{Moment}{distance}$$

The force that would have a safety factor of four is the maximum load while moving 107lbs divided by four equaling 26.75lbs. This occurs when the pulsator is located 0.102[m] away. However a position of 0.243[m] away was chosen to prevent too much non-axial force on the mounting pins of the linear actuator. Also, it avoids the linear actuator from going through the vertical direction to change the angle of the chair as the linear actuator extends. The safety factor of the selected position is 9.5 which is safely over the safety factor of four.

A.10.4 Buckling Calculations

We found the critical load for aluminum and steel beams of solid and hollow square cross sections. It was found that buckling was not a concern in our design, even in the main vertical beam. Even in the least stiff cross section that we considered, the 3/4 inch square 1/16th thick aluminum, the critical load was 9200 N (2059 lbs). The formula used was:

$$P_{cr} = \frac{\pi^2 EI}{(kL)^2}$$

Where
P_{cr} = critical load on a column before buckling
E = elastic modulus
I = section polar moment of inertia
k = constant for boundary condition
L = length of beam

The polar moment of inertia of a solid square section is:

$$I = \frac{B^4}{12}$$

Where B is the outside section length.

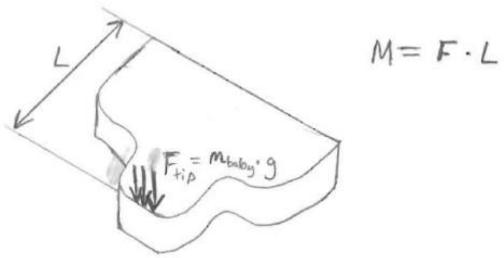
The polar moment of inertia of a solid square section is:

$$I = \frac{B^4 - b^4}{12}$$

Where b is the inside section length.

10.5 Seat Pan Calculations

Figure A.10.4 Free body diagram of seat pan



We added a slope to our CES of $\sigma_{yield}/\rho = Constant$ because we wanted to maximize our yield strength to density ratio. This ratio was important to us because we knew we wanted a strong material for our seat pan, however, we also did not want to add to the weight of the overall chair by choosing a material that was too heavy. Using the length of the seat pan along with the maximum force of the child applied directly to the tip of the edge of the seat we were able to get a maximum σ_{yield} our seat would experience. Using maximum length of our seat pan to be L=.2112m, our force to be F=18Kg×9.81m/s^2=176.58N and a safety factor of four we determined our Moment M=149.17Nm using the following equation:

$$M = F \times L$$

We then determined that our maximum yield stress should be $\sigma_{yield} > 24.3$MPa by using the following equation:

$$\sigma_{yield} = \frac{My}{I}$$

We also added a slope of $E^{1/2}/\rho = Constant$, this ratio helped us determine what material would best help us achieve a minimum deflection, again without adding too much excess weight. Our team also decided that we would not want the edge of the seat pan to deflect more than 3mm. To make sure our design would accomplish this we used the following equation along with a safety factor of four and determined that our young's modulus $E > 3\times10^3$.

$$E = \frac{FL^3}{3\delta I}$$

Along with the previous two equations limiting related to density we also estimated that we did not want each seat pan to weigh more than m = 1.361 Kg (3 lbs). Because we already had an estimated volume of $V = 7.88\times10^{-4}$ m^3 from our initial CAD design of the largest of the six seat pans we were able to use the following equation:

$$\rho = \frac{m}{V}$$

To determine that our ρ<1727.2 kg/m^3.

A.10.6 1-D/2-D Finite Element Analysis

It was decided that Finite Element Analysis was needed to find the stresses and deflections in the structure due to the complex loading conditions and the many elements. A model was created in HyperMesh using 1-D and 2-D elements. The frame, back brace and linear actuator were modeled as CBAR elements, which model axial and bending stresses. Results were obtained using the linear elastic solver in Nastran. The chair back and seat pans were modeled as 2-D quad shell elements. To model the effect of the slots, which could act as stress risers, the elements at the slot locations were detached from their neighboring elements.

Forces and Boundary Conditions

To model the force of a 97th percentile weight three year old infant, we used mass data from infant anthropometrics. The mass was taken to be 18 kg. From the same source, we obtained the center of gravity of a seated three year old infant: 39%. From this information we modeled the weight force as having a component, F_{back}, normal to the chair back, and F_{seat}, a component normal to the seat pan, both originating from the seated center of gravity. This is shown in Figure 6.1. Using the anthropometric data again, the surface area of the seat pan and chair back that was in contact with the infant was estimated. In the FEA model, a uniformly distributed pressure (where Pressure = Force / Area) was created on both the seat pan and the chair back contact areas to model the sitting infant. For the boundary conditions, the bars touching the ground were left unconstrained for all three moments since the chair is not fixed to the ground. All corners of the chair were constrained in the z-axis because of the ground and one corner was constrained in the x and y axes, respectively, to prevent rigid body modes. A diagram of the loading model is shown in Figure A.10.5 and a diagram of the FEA model is shown in Figure A.10.6.

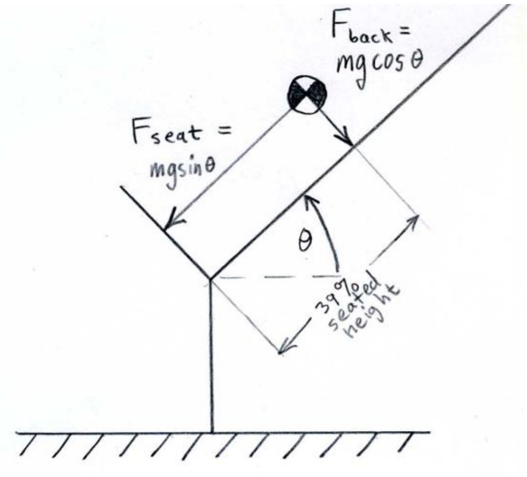


Figure A.10.5: Loading model

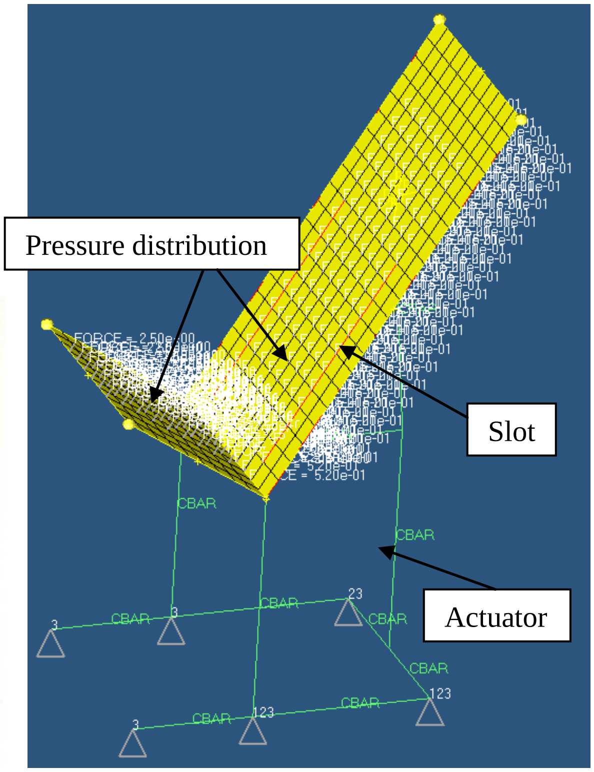


Figure A.10.6: Diagram of FEA model

Test Cases

The material of the CBAR elements was taken to be 6061-T6 aluminum, which is a strong and weldable aluminum alloy that was available to us in several sizes. Since we were tried to use the materials available to us given the limited budget, we modeled our test cases using the following cross sections: a solid 1 inch square bar, a hollow 1/16th inch thick square bar, and a ¾" square hollow bar. The polar moments of inertia were calculated using the following formula:

$$I = \frac{B^4 - b^4}{12}$$

Where *B* is the outside section length and *b* is the inside section length. The calculated values for the cross section areas and polar moments of inertia which were inputted into the program are shown in following table.

B (in.)	b (in.)	B (mm)	b (mm)	I (mm^4)	Area (mm^2)
0.75	0.625	19.05	15.875	5682	110.89
1	0.875	25.4	22.225	14354	151.21
1	0	25.4	0	34686	645.16

RESULTS

The results showed that both the stresses in the smallest (3/4 inch square, 1/16th inch thickness) cross-section aluminum were well within a safety factor of four and the bar deflections were very low. A contour of the Von Mises stresses in the chair with all beams of this cross section is shown in Figure 4, representing the highest stresses of all cases. It is shown that the maximum stress is in the seat pan from the bending stress of the infant. Although the stresses were still only 5% of the yield strength of the PVC material, this was improved by implementing an aluminum support, which was designed as a safety factor against creep in the plastic.

The only appreciable stresses in the welded structure were in the vertical bars which had a stresses as high as 1.4 MPa. This was considered to be negligible since aluminum 6061-T6 has a yield stress greater than 240 MPa. However, as an extra safety factor these bars will be made from solid 1 inch square aluminum bar because it provides a safer, stiffer and easier way of mounting our fulcrum bushings and also us to use a large diameter, stiff shoulder bolt for the connection. Based on that decision, we also decided to use the stronger 1 inch square 1/16th inch aluminum bars for the rest of the frame structure (at a 27% weight penalty for frame) so that the solid vertical beam made contact with a frame of bars of the same diameter, to make welding the pieces easier and for aesthetic reasons.

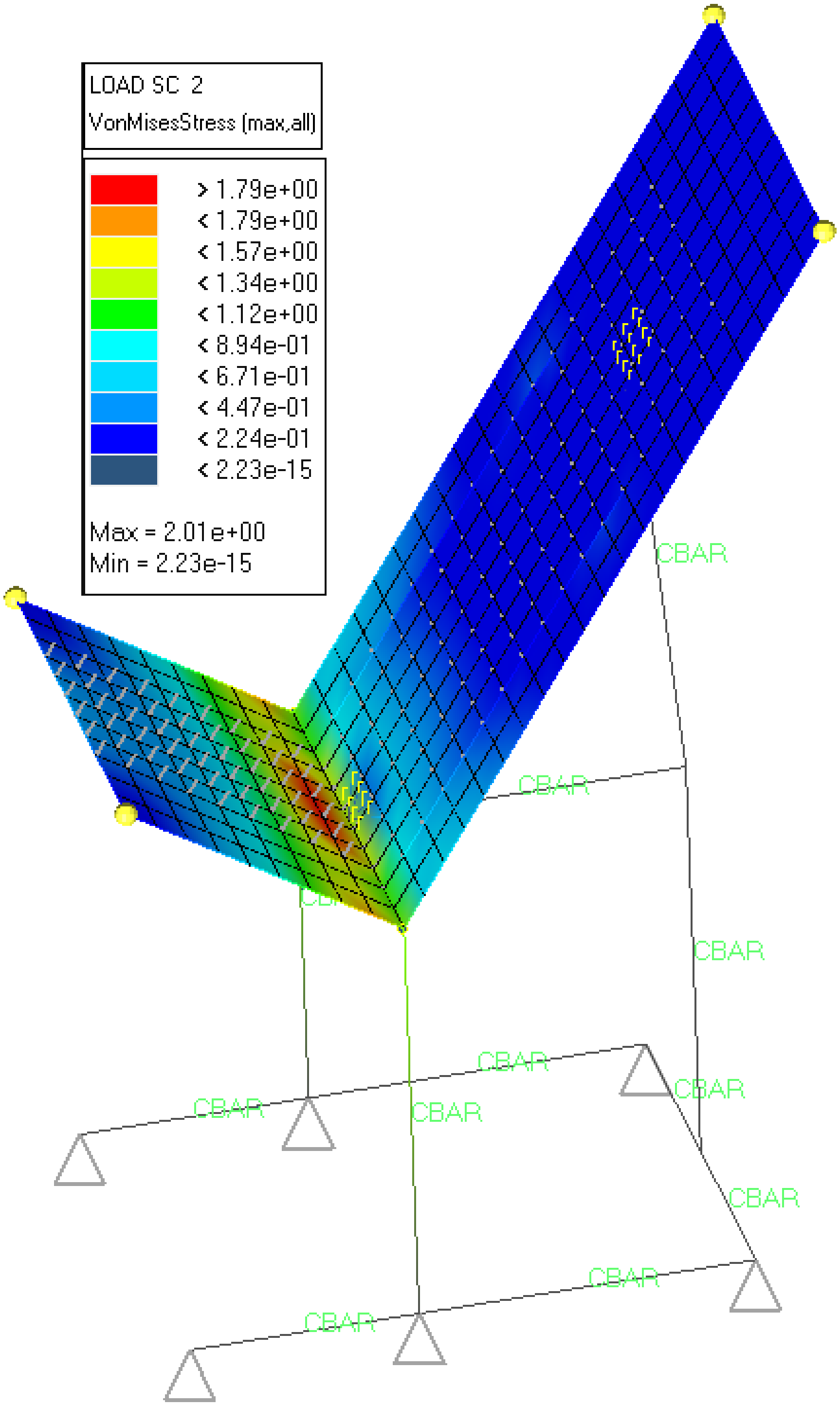


Figure A.10.7: Von Mises Stresses in the ¾ inch square 1/16th inch thickness beam structure

The deflections of the structure are shown in Figure A.10.8. The structure was very stiff, with deflections less than 0.5 mm. The chair back did not have appreciable deflections even with the large slots running through the PVC back. The seat pan did have a 2 mm deflection at the very tip. Although this is not very concerning, this was improved greatly through the use of an aluminum support under the seat pan, as used in our final design.

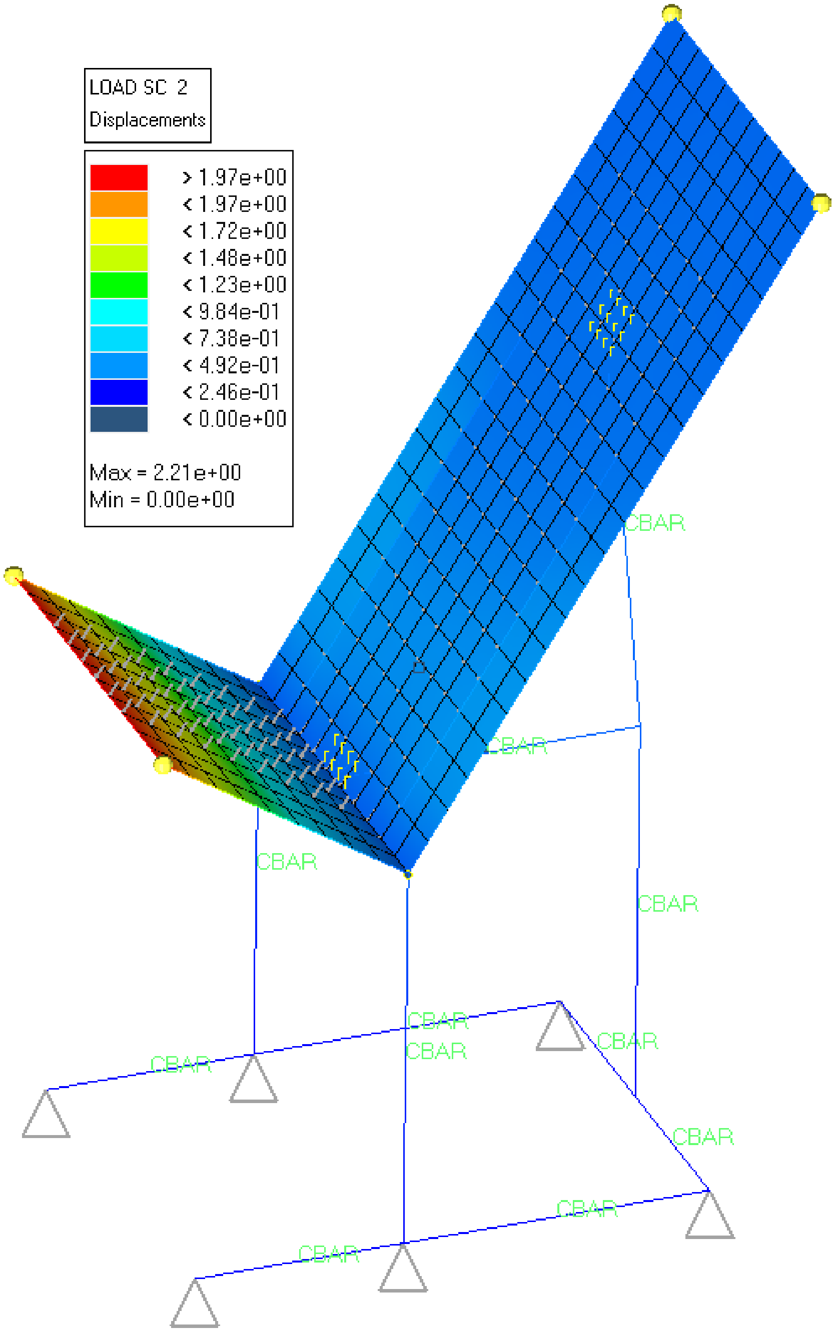


Figure A.10.8: Deflections in the ¾ inch square 1/16th inch thickness beam structure

1) 3-D Crush Load Test

Another 3-D FEA test was desired to validate that the "crushing" force of the solid vertical beam on the hollow horizontal aluminum beam would not cause yield. To model this, an aluminum 6061-T6 1 inch square hollow aluminum section was modeled in SolidWorks with a uniform pressure on its surface equating the maximum weight force of a three year old infant, and a rigid restraint on its lower surface. This is shown in Figure A.10.9. The stress results showed a maximum Von Mises stress of 25.5 MPa which gave a safety factor of over 10.0, and a maximum deflection of well below 1 mm.

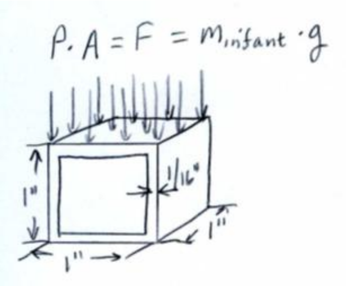


Figure A.10.9: Crushing force diagram

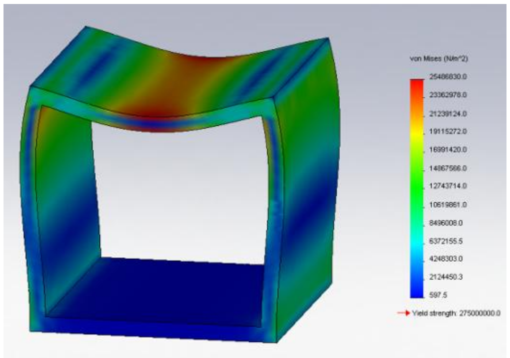


Figure A.10.10: Results of FEA

2) **3-D Bushing Load Test**

In selecting our bushings and bolts for the chair fulcrum, a 5/8 inch outer diameter bronze bushing at the fulcrum of the chair, with ½ inch diameter steel shoulder bolts. This is shown in Figure 8. To validate that the stresses did not approach yield, a 3-D FEA simulation was run in SolidWorks on an aluminum 6061-T6 vertical beam fixed at the bottom and with a 5/8 inch hole in it. A vertical force of the entire maximum infant's weight (-176.6 N) was applied on the surface of the inside of the hole in the beam.

It was found that the stresses reach 1 MPa, well below the yield of aluminum; a safety factor over 200. The maximum Von Mises stress distribution is shown in Figure 9. The maximum deflection was below 0.55 μm. These results validated our use of the 5/8" outer diameter bronze bushings. Furthermore, because the aluminum rotating piece had the same size hole mounted in an even thicker 1.25 inch square section, the stress in that bolt hole can also be considered negligible. The stresses in the four 3/8 inch diameter steel bolts in the aluminum rotating piece can be validated by our bolt stress calculations in Appendix 10.1 (Bolt).

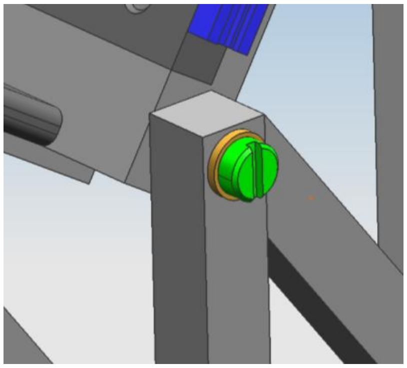


Figure A.10.11: Fulcrum bushing and bolt

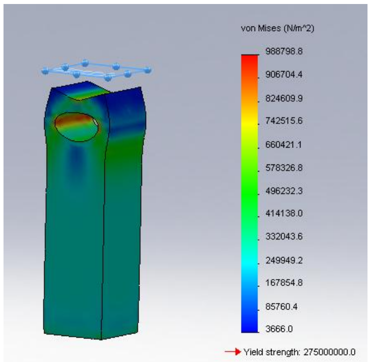


Figure A.10.12: Maximum Von Mises Stress in beam

3) 3-D Seat Pan Load Test

To determine that the deflection in the PVC seat pan was not too high, even with the aluminum support piece, another 3-D FEA model was constructed in SolidWorks. The ½ inch thick PVC was restrained along the contact area of the 3/8" aluminum support, and the entire infant's weight was applied to the tip of the PVC seat pan; a worst case scenario. It was found that the maximum Von Mises stresses were below 6 MPa (SF = 40), and the maximum deflection was about 1 mm, which was considered acceptable.

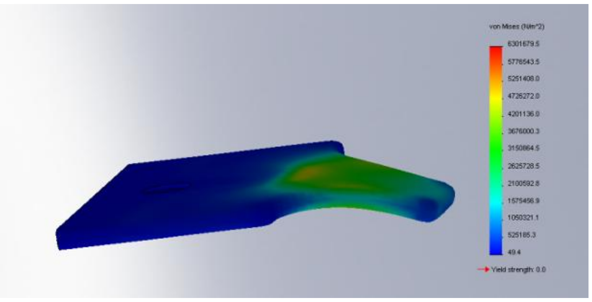


Figure A.10.13: Stress of seat pan

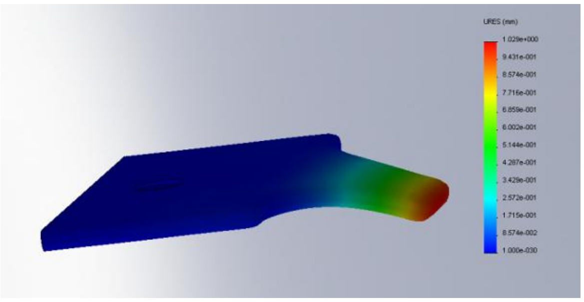


Figure A.10.14: Deflection of seat pan

10.7 Chair Back Kinematics

To validate that the actuator met our specification of 2-5°/sec, we modeled the kinematics of the chair in 2-D CAD. We made a linear interpolation of the linear motor speed as a function of the load based on the manufacturer's specifications to get a speed of 0.46 in/sec. We then varied the moment arm length of the linear actuator to the fulcrum, at distances above 100 mm to keep our actuator force safety factor above 4.0 as discussed in the safety report. We attempted to use the full travel of the actuator in the range of 10-30°, so that we could use the smallest actuator possible for compactness and lower overall mass. However, we added a safety margin of 2° on each side in case there were manufacturing errors which would prevent the chair from reaching the full 10-30° range. Using the methodology of setting the travel of the linear actuator equal to the distance travelled through the range of 8-32° based on moment arm length, we found that a distance of 243 mm allowed us to use a linear actuator two sizes smaller and still maintain our safety factor of 4.0. Our final calculated speed with this moment arm length is 3°/sec, well within our specifications. The final 2-D kinematics diagrams with the 243 mm moment arm length are shown in Figures A.10.15.

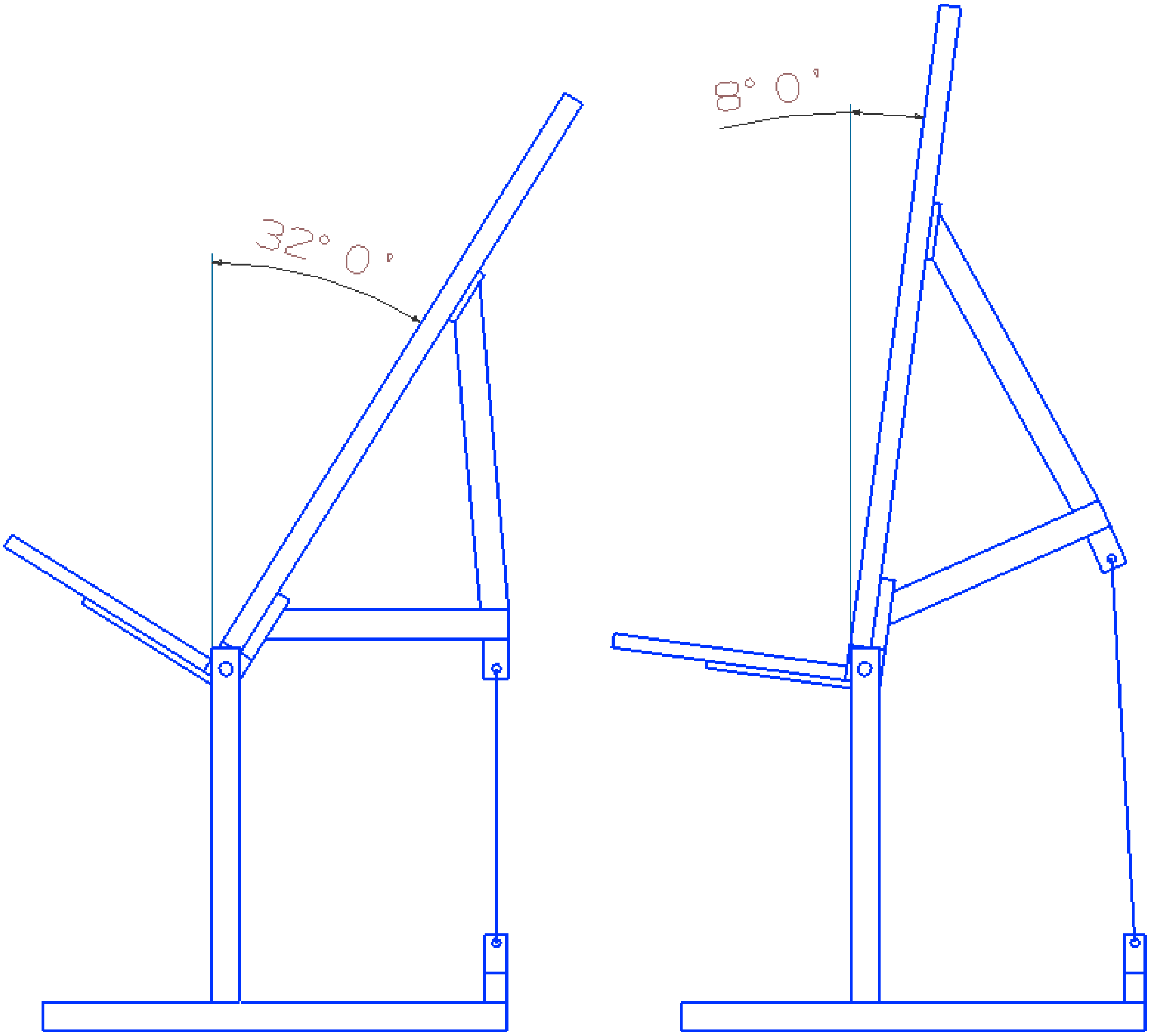


Figure A.10.15: The chair in its highest angle and the chair at its most upright position

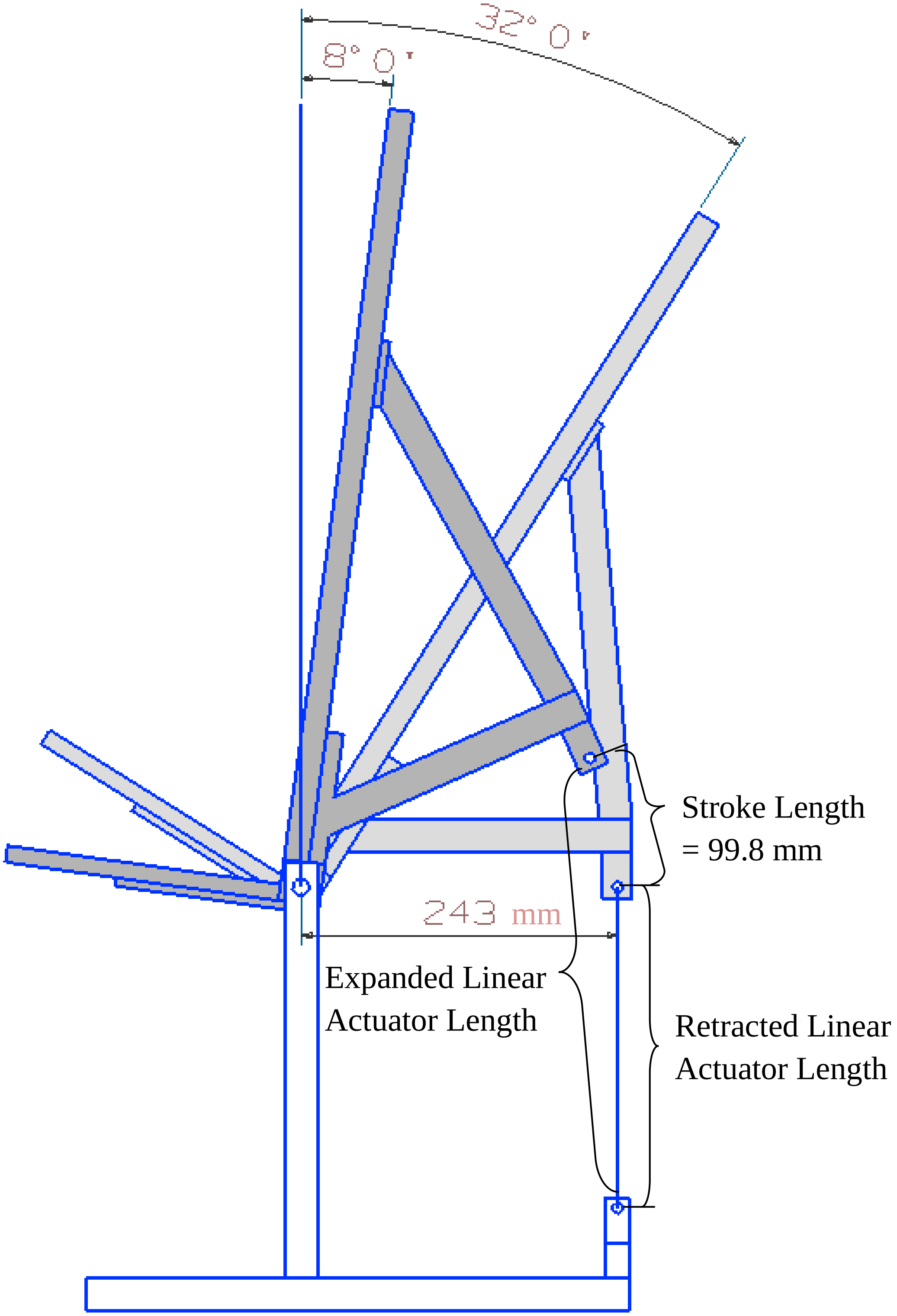


Figure A.10.16; The two most extreme positions superimposed. In design, the change in linear actuator travel was made equal to the entire stroke through the 8 - 32° motion at the 243 mm moment arm length.

Appendix 11: Manufacturing Plan

Operation	Machine	Cutting Tool	Cutting Speed	Comments	Estimated Time
Rough cut Al 6061-T6 bars (7) to length for chair frame base	Ideal-Werk D-59557 (Band Saw)	N/A	300 ft/s	7 bars cut to length: 16.5” (2) (base) 30” (2)(vertical) 15.5” (2) (angle) 14.5” (1) (back)	30 min
Rough cut Al 6061-T6 bars (2) for chair back frame support	Ideal-Werk D-59557 (Band Saw)	N/A	300 ft/s	2 bars to length: 9” (1) (level) 12” (1) (angle)	15 min
Cut bracket to size for frame	Ideal-Werk D-59557 (Band Saw)	N/A	300 ft/s	Dimensions [in]: 1.5 x 2 x 0.25 (1 of 2)	15 min
Drill through holes (4) for bracket	US Electric Motors Model F537A (Mill)	#7 drill	1800 rpm	Through hole dimensions [in]: 0.25 x 0.25 (1 of 2)	30 min
Cut bracket to size for frame	Ideal-Werk D-59557 (Band Saw)	N/A	300 ft/s	Dimensions [in]: 1.5 x 2 x 0.25 (2 of 2)	15 min
Drill through holes (4) for bracket	US Electric Motors Model F537A (Mill)	F dril	1800 rpm	Through hole dimensions [in]: 0.25 x 0.25 (2 of 2)	30 min
Cut T-Track to length	Ideal-Werk D-59557 (Band Saw)	N/A	300 ft/s	Length [in]: 16.8 Measure out the length to allow 4 pre drilled holes on the track so the pre drilled holes on the ends have an extra .4” on each side (1 of 2)	15 min
Cut T-Track to length	Ideal-Werk D-59557 (Band Saw)	N/A	300 ft/s	Length [in]: 16.8 Measure out the length to allow 4 pre drilled holes on the track so the pre drilled holes on the ends have an extra .4” on each side (2 of 2)	15 min
Re-Drill holes (2) on T-track	Delta 70-200 (Drill Press)	# 7 Drill	1150 rpm	The top and bottom hole are drill pressed to be through holes for a 10-32 bolt, dimension: .2010” (1 of 2)	10 min

Operation	Machine	Cutting Tool	Cutting Speed	Comments	Estimated Time
Re-Drill holes (2) on T-track	Delta 70-200 (Drill Press)	# 7 Drill	1150 rpm	The top and bottom hole are drill pressed to be through holes for a 10-32 bolt, dimension: .2010” (2 of 2)	10 min
Final cut Al 6061-T6 bars (5) to length for chair frame base	US Electric Motors Model F537A (Mill)	0.5” two flute end mill	1800 rpm	7 bars cut to length: 28.715”(2)(vertical) 15.489” (2) (angle) 14.208” (1) (back)	20 min
Final cut Al 6061-T6 bars (2) for chair frame base	US Electric Motors Model F537A (Mill)	0.5” two flute end mill	1800 rpm	2 bars to length: 8.297” (1) (level) 11.507” (1) (angle)	20 min
Angle cut Al 6061-T6 bars (2) for chair frame base	Ideal-Werk D-59557 (Band Saw)	0.5” two flute end mill	300 ft/s	37.45° end and 52.54° end for both angle bars	30 min
Angle cut Al 6061-T6 bars (2) for chair back frame support	Ideal-Werk D-59557 (Band Saw)	N/A	300 ft/s	58° end (level) 5.13° end 37. 08° end (angle)	30 min
Mill Al 6061-T6 to size for aluminum rotator	US Electric Motors Model F537A (Mill)	0.5” two flute end mill	1800 rpm	Dimensions [in]: 12.205 x 1.25 x 4	1 hour
Mill ledge in Al 6061-T6 to size for aluminum rotator	US Electric Motors Model F537A (Mill)	0.5” two flute end mill	2400rpm	Dimensions of material removed [in]: 0.75 x 2.5 x 12.205	1 hour 30 min
Mill 45˚ angle on back of aluminum rotator	US Electric Motors Model F537A (Mill)	45˚ two flute end mill	1800 rpm	Only milled on the back bottom ledge, where it is in contact with the aluminum seat support	20 min
Mill Al 6061-T6 actuator mount lift to size for frame	US Electric Motors Model F537A (Mill)	0.5” two flute end mill	1800 rpm	Dimensions [in]: 1.68 x 1.5 x 2.035	45 min
Mill ledge in Al 6061-T6 to size for actuator mount lift	US Electric Motors Model F537A (Mill)	0.5” two flute end mill	1800 rpm	Dimensions of material removed [in]: 1 x 1 x 1.5	30 min
Drill through holes (2) for actuator mount lift	US Electric Motors Model F537A (Mill)	#7 drill	1800 rpm	Through hole dimensions [in]: 0.25 x 1.035	30 min

Operation	Machine	Cutting Tool	Cutting Speed	Comments	Estimated Time
Tap holes (2) for actuator mount lift*	Hand tap	¼” – 20 tap	N/A		20 min
Cut Al 6061-T6 plate to size for aluminum seat support	Ideal-Werk D-59557 (Band Saw)	N/A	300 ft/s	Dimensions [in]: 9.412 x 6.922 x .375	30 min
Mill aluminum seat support to shape	VZHT Bridgeport (CNC Mill)	0.5” two flute end mill	1800 rpm		45 min
Drill aluminum seat support	VZHT Bridgeport (CNC Mill)	Q Drill	1800 rpm	Dimension [in]: .3320 x 3/8 (through hole)	10 min
Mill 45˚ angle on aluminum seat support contact areas	US Electric Motors Model F537A (Mill)	45˚ two flute end mill	1800 rpm	Angled ledge only milled where aluminum seat support contacts aluminum rotator, not including the front edge	30 min
Rough cut Al 6061-T6 blocks to size for tray to tray track mounts	Ideal-Werk D-59557 (Band Saw)	N/A	300 ft/s	Dimensions [in]: 2 x 1.5 x 1.75 (1 of 2)	30 min
Rough cut Al 6061-T6 blocks to size for tray to tray track mounts	Ideal-Werk D-59557 (Band Saw)	N/A	300 ft/s	Dimensions [in]: 2 x 1.5 x 1.75 (2 of 2)	30 min
Final cut Al 6061-T6 blocks to size for tray to tray track mounts	US Electric Motors Model F537A (Mill)	0.5” two flute end mill	1800 rpm	Dimensions [in]: 2 x 1.972 x 1.75 (1 of 2)	1 hour
Drill holes (1) for Al 6061-T6 tray to tray track mount	US Electric Motors Model F537A (Mill)	F drill	800 rpm	Guide hole dimensions [in]: 0.2570 x 0.908 (1 of 2)	15 min
Drill hole (1) for Al 6061-T6 tray to tray track mount	US Electric Motors Model F537A (Mill)	Q drill	800 rpm	Dimensions [in]: 0.3320 x 1.5 (1 of 2)(through hole)	15 min
Drill hole (1) for Al 6061-T6 tray to tray track mount	US Electric Motors Model F537A (Mill)	17/32 drill	800 rpm	Bar hole dimensions [in]: 0.5 x2 (1 of 2) (through)	15 min
Drill hole (1) for Al 6061-T6 tray to tray track mount	US Electric Motors Model F537A (Mill)	#7 drill	800 rpm	Thumb screw hole dimensions [in]: 0.2010 x 0.875 (1 of 2)	15 min

Operation	Machine	Cutting Tool	Cutting Speed	Comments	Estimated Time
Final cut Al 6061-T6 blocks to size for tray to tray track mounts	US Electric Motors Model F537A (Mill)	0.5” two flute end mill	1800 rpm	Dimensions [in]: 2 x 1.972 x 1.75 (2 of 2)	1 hour
Drill holes (1) for Al 6061-T6 tray to tray track mount	US Electric Motors Model F537A (Mill)	F drill	800 rpm	Guide hole dimensions [in]: 0.2570 x 0.908 (1 of 2)	15 min
Drill hole (1) for Al 6061-T6 tray to tray track mount	US Electric Motors Model F537A (Mill)	Q drill	800 rpm	Dimensions [in]: 0.3320 x 1.5 (1 of 2)(through hole)	15 min
Drill hole (1) for Al 6061-T6 tray to tray track mount	US Electric Motors Model F537A (Mill)	17/32 drill	800 rpm	Bar hole dimensions [in]: 0.5 x2 (2 of 2) (through)	15 min
Drill hole (1) for Al 6061-T6 tray to tray track mount	US Electric Motors Model F537A (Mill)	#7 drill	800 rpm	Thumb screw hole dimensions [in]: 0.2010 x 0.875 (2 of 2)	15 min
Tap hole (1) into tray to tray track mount (1 of 2)*	Hand tap	5/16” - 18	N/A	(guide hole)	10 min
Tap hole (1) into tray to tray track mount (1of 2)*	Hand tap	¼-20” tap	N/A	(thumb screw)	10 min
Tap hole (1) into tray to tray track mount (2 of 2)*	Hand tap	5/16” - 18	N/A	(guide hole)	10 min
Tap hole (1) into tray to tray track mount (2of 2)*	Hand tap	¼-20” tap	N/A	(thumb screw)	10 min
Drill holes (4) into Al 6061-T6 block for aluminum rotator	US Electric Motors Model F537A (Mill)	#7 drill	1800 rpm	Hole dimensions [in]: 0.2010 x 0.50 (through)	30 min
Tap holes (4) into Al 6061-T6 block for aluminum rotator*	Hand tap	½” -20 tap	N/A		30 min
Drill holes (4) into Al 6061-T6 block for aluminum rotator	US Electric Motors Model F537A (Mill)	5/16 drill	1800 rpm	Hole Dimensions [in]: .3125 x 2 (through holes)	30 min
Tap (4) holes into aluminum rotator*	Hand tap	3/8” - 16 tap	N/A		25 min

Operation	Machine	Cutting Tool	Cutting Speed	Comments	Estimated Time
Drill holes (2) into Al 6061-T6 block for aluminum rotator	US Electric Motors Model F537A (Mill)	5/16 drill	1800 rpm	Holes dimensions [in]: .3125 x 2 (pivots for shoulder bolts)	30 min
Tap (2) holes into aluminum rotator*	Hand tap	3/8” - 16 tap	N/A		25 min
Drill hole into Al 6061-T6 post for chair frame	US Electric Motors Model F537A (Mill)	39/64 drill	1800 rpm	Hole dimensions [in]: 0.5 x 1 (1 of 2) (pivot for shoulder bolts) (through)	20 min
Drill hole into Al 6061-T6 post for chair frame	US Electric Motors Model F537A (Mill)	39/64 drill	1800 rpm	Hole dimensions [in]: 0.5 x 1 (2 of 2) (pivot for shoulder bolts) (through)	20 min
Ream hole into Al 6061-T6 post for chair frame	US Electric Motors Model F537A (Mill)	5/8” reamer	450 rpm	Holes are exact for tight fit of bushing (1 of 2)	15 min
Ream hole into Al 6061-T6 post for chair frame	US Electric Motors Model F537A	5/8” reamer	450 rpm	Holes are exact for tight fit of bushing (2 of 2)	15 min
Drill (4) holes into PVC slab for chair back	US Electric Motors Model F537A (Mill)	Q drill	1000 rpm	Hole dimensions [in]: 0.3320 x 0.75 (through) (for bolting welded brace from actuator to chair back)	30 min
Countersink bore (4) holes into PVC slab for chair back	US Electric Motors Model F537A (Mill)	29/64	1000 rpm	Hole dimensions [in]: 7/16 x 0.25 (for 4 support bolts)	20 min
Drill (1) holes into PVC slab for chair back	US Electric Motors Model F537A (Mill)	#7 drill	1000 rpm	Hole dimensions [in]: 0.25 x 0.5 (for bolting head support clamp to chair back)	15 min
Tap holes (4) into PVC chair back*	Hand tap	¼-20” tap	N/A	(for bolting welded brace from actuator to chair back)	20 min
Tap hole (1) into PVC chair back*	Hand tap	¼-20” tap	N/A	(for bolting head support clamp to chair back)	10 min
Tack weld vertical post to base bar**	DIALARC HF RFC-23A (TIG WELDER)	N/A	N/A	Side 1 of 2	25 min
Tack weld angle bar to base and to vertical post**	DIALARC HF RFC-23A (TIG WELDER)	N/A	N/A	Side 1 of 2	25 min

Operation	Machine	Cutting Tool	Cutting Speed	Comments	Estimated Time
Weld vertical post to base bar pan**	DIALARC HF RFC-23A (TIG WELDER)	N/A	N/A	Side 1 of 2	20 min
Weld angle bar to base and to vertical post**	DIALARC HF RFC-23A (TIG WELDER)	N/A	N/A	Side 1 of 2	20 min
Tack weld vertical post to base bar**	DIALARC HF RFC-23A (TIG WELDER)	N/A	N/A	Side 2 of 2	25 min
Tack weld angle bar to base and to vertical post**	DIALARC HF RFC-23A (TIG WELDER)	N/A	N/A	Side 2 of 2	25 min
Weld vertical post to base bar pan plate to aluminum rotator**	DIALARC HF RFC-23A (TIG WELDER)	N/A	N/A	Side 2 of 2	20 min
Weld angle bar to base and to vertical post**	DIALARC HF RFC-23A (TIG WELDER)	N/A	N/A	Side 2 of 2	20 min
Press fit bronze bushing into side 1 of 2 of the frame	Drake 2 ½ (Arbor Press)	N/A	N/A	Side 1 of 2	10 min
Hand ream bronze bushing	N/A	½” hand reamer	N/A	Side 1 of 2 Ream inside of bonze bushing until shoulder bolt will fit	10 min
Press fit bronze bushing into side 1 of 2 of the frame	Drake 2 ½ (Arbor Press)	N/A	N/A	Side 2 of 2	10 min
Hand ream bronze bushing	N/A	½” hand reamer	N/A	Side 2 of 2 Ream inside of bonze bushing until shoulder bolt will fit	10 min
Tack weld block to back frame**	DIALARC HF RFC-23A (TIG WELDER)	N/A	N/A		20 min
Weld actuator mount lift to back frame**	DIALARC HF RFC-23A (TIG WELDER)	N/A	N/A		20 min

Operation	Machine	Cutting Tool	Cutting Speed	Comments	Estimated Time
Tack weld frame sides to back bar**	DIALARC HF RFC-23A (TIG WELDER)	N/A	N/A		30 min
Weld frame sides to back bar**	DIALARC HF RFC-23A (TIG WELDER)	N/A	N/A		20 min
Tack weld bracket to angle bar**	DIALARC HF RFC-23A (TIG WELDER)	N/A	N/A	(1 of 2)	20 min
Weld bracket to angle bar**	DIALARC HF RFC-23A (TIG WELDER)	N/A	N/A	(1 of 2)	10 min
Tack weld angle bar to level bar**	DIALARC HF RFC-23A (TIG WELDER)	N/A	N/A		20 min
Weld angle bar to level bar**	DIALARC HF RFC-23A (TIG WELDER)	N/A	N/A		10 min
Tack weld bracket to angle bar**	DIALARC HF RFC-23A (TIG WELDER)	N/A	N/A	(2 of 2)	20 min
Weld bracket to angle bar**	DIALARC HF RFC-23A (TIG WELDER)	N/A	N/A	(2 of 2) Completing triangular mount	10 min
Tack weld rotator bracket to triangular mount**	DIALARC HF RFC-23A (TIG WELDER)	N/A	N/A		15 min
Weld rotator bracket to triangular mount**	DIALARC HF RFC-23A (TIG	N/A	N/A		10 min
Drill (4) holes into PVC slab for chair back	US Electric Motors Model F537A (Mill)	21 drill		Hole dimensions [in]: 0.19 x 0.375 (for mounting T-track to chair back)	25 min
Tap (4) holes into PVC chair back*	Hand tap	10-32 tap	N/A	(for mounting T-track to chair back)	20 min

Operation	Machine	Cutting Tool	Cutting Speed	Comments	Estimated Time
Tack weld seat pan plate to aluminum rotator**	DIALARC HF RFC-23A (TIG WELDER)	N/A	N/A		30 min
Weld seat pan plate to aluminum rotator**	DIALARC HF RFC-23A (TIG WELDER)	N/A	N/A		20 min
Lathe steel adapter tube for pulsator mount	Monarch 10” EE (Lathe)	N/A	1800 rpm	Lathed diameter [in]: 2.125 Center hole dimensions [in]: 0.5 x 1.25	45 min
Thread adapter tube	Monarch 10” EE (Lathe)	N/A	1800 rpm	Thread: 7/8” - 14	15 min
Re-thread pulsator stand base	US Electric Motors Model F537A (Mill)	7/8 “ – 14 tap	N/A		15 min
Cut inner diameter tube to size for pulsator stand (microphone stand)	Hacksaw	N/A	N/A	9.65	20 min
Cut outer diameter tube to size for pulsator stand (microphone stand)	Hacksaw	N/A	N/A	9.25” from bottom of tightening knob, in locked position, to top of tube	20 min
Press fit smaller pulsator tube into steel adapter tube for pulsator mount	Drake 2 ½ (Arbor Press)	N/A	N/A	Press smaller pulsator tube until bottom is flush with steel adapter tube	10 min
Fusion weld steel adapter and smaller pulsator tube **	DIALARC HF RFC-23A (TIG WELDER)	N/A	N/A	Before preparing the inner diameter tube for pulsator stand for welding the paint should first be ground off Only weld at bottom of tube and adapter	15 min
Mill slots into PVC slab for chair back	US Electric Motors Model F537A (Mill)	0.25” two flute end mill	600 rpm	Slot dimensions [in]: 0.759 x 13 (for seatbelt)	30 min
Adhere Velcro to chair back	N/A	N/A	N/A	Velcro is to stabilize head support with straps	10 min

Operation	Machine	Cutting Tool	Cutting Speed	Comments	Estimated Time
Cut aluminum pulsator mount to size	Ideal-Werk D-59557 (Band Saw)	N/A	300 ft/s	Dimensions [in]: 3.09 x 3.09	20 min
Mill aluminum pulsator mount to shape	VZHT Bridgeport (CNC Mill)	0.5” two flute end mill	1800 rpm	Mount base dimensions[in]: 3.071 x 0.25	30 min
Drill hole (1) into pulsator mount	VZHT Bridgeport (CNC Mill)	#7 drill	1000 rpm	Hole dimensions [in]: 0.25 x 0.25	10 min
Drill (3) holes into pulsator mount	VZHT Bridgeport (CNC Mill)	#9 drill	1000 rpm	Hole dimensions [in]: 3.071 x 0.279 (through)	10 min
Chamfer back of pulsator mount	US Electric Motors Model F537A (Mill)	Chamfer	500 rpm	Chamfer hole though from back of the plate until bolt used to connect to ball joint lays just below flush	15 min
Cut PVC plates (3) to size for head support	Ideal-Werk D-59557 (Band Saw)	N/A	165 ft/s	Plate dimensions (2) (for sides) [in]: 3.5 x 4.488 x 0.25 Plate dimension (1) (for back) [in]: 7.74 x 4.488 x 0.25	30 min
Mill out contour and hole of back plate	VZHT Bridgeport (CNC Mill)	3/16 end mill		Hole dimension (1) (for back) [in]: 1.1 x 3/16 x 0.25	45 min
Cut aluminum L bracket to size (2)	Ideal-Werk D-59557 (Band Saw)	N/A	300 ft/s	Cut 4” long, with L bracket of 1”x1”x1/16”	10 min
Epoxy aluminum L bracket into PVC head support, and PVC cement PVC head support	N/A	N/A	N/A	L brackets are to be epoxied on so they are centered in height	20 min Curing Time 24 Hours
Adhere Velcro to side plates	N/A	N/A	N/A	Velcro attached to the head support is for securing to chair back	10 min
Drill hole (1) into enclosure for switch	Delta 70-200 (Drill Press)	15/32” drill	550 rpm	Hole dimensions [in]: .4687 x .0625 (through hole through top of enclosure)	20 min
Drill hole (1) into enclosure for switch	Delta 70-200 (Drill Press)	#7 drill	550 rpm	Hole dimensions [in]: .2010 x .0625 (through hole through side of enclosure)	20 min

Operation	Machine	Cutting Tool	Cutting Speed	Comments	Estimated Time
Drill hole (1) into enclosure for switch	Delta 70-200 (Drill Press)	5/16" drill	550 rpm	Hole dimensions [in]: .3125 x .0625 (through hole through side of enclosure)	20 min
Cut PVC seat pan	VZHT Bridgeport (CNC Mill)	0.5" two flute end mill	1000 rpm	6 seat pans are made in total; 1 of 6 seat pans completed	45 min
Drill PVC seat pan counter bore	VZHT Bridgeport (CNC Mill)	0.5" two flute end mill	1000 rpm	Dimension [in]: 1.153 x .125 (1 of 6)	15 min
Drill PVC seat pan	VZHT Bridgeport (CNC Mill)	F Drill	1000 rpm	Dimension [in]: .3320 x .5 (through hole) (1 of 6)	10 min
Cut PVC seat pan	VZHT Bridgeport (CNC Mill)	0.5" two flute end mill	1000 rpm	6 seat pans are made in total; 2 of 6 seat pans completed	45 min
Drill PVC seat pan counter bore	VZHT Bridgeport (CNC Mill)	0.5" two flute end mill	1000 rpm	Dimension [in]: 1.153 x .125 (2 of 6)	15 min
Drill PVC seat pan	VZHT Bridgeport (CNC Mill)	F Drill	1000 rpm	Dimension [in]: .3320 x .5 (through hole) (2 of 6)	10 min
Cut PVC seat pan	VZHT Bridgeport (CNC Mill)	0.5" two flute end mill	1000 rpm	6 seat pans are made in total; 3 of 6 seat pans completed	45 min
Drill PVC seat pan counter bore	VZHT Bridgeport (CNC Mill)	0.5" two flute end mill	1000 rpm	Dimension [in]: 1.153 x .125 (3 of 6)	15 min
Drill PVC seat pan	VZHT Bridgeport (CNC Mill)	F Drill	1000 rpm	Dimension [in]: .3320 x .5 (through hole) (3 of 6)	10 min
Cut PVC seat pan	VZHT Bridgeport (CNC Mill)	0.5" two flute end mill	1000 rpm	6 seat pans are made in total; 4 of 6 seat pans completed	45 min
Drill PVC seat pan counter bore	VZHT Bridgeport (CNC Mill)	0.5" two flute end mill	1000 rpm	Dimension [in]: 1.153 x .125 (4 of 6)	15 min
Drill PVC seat pan	VZHT Bridgeport (CNC Mill)	F Drill	1000 rpm	Dimension [in]: .3320 x .5 (through hole) (4 of 6)	10 min
Cut PVC seat pan	VZHT Bridgeport (CNC Mill)	0.5" two flute end mill	1000 rpm	6 seat pans are made in total; 5 of 6 seat pans completed	45 min
Drill PVC seat pan	VZHT Bridgeport (CNC Mill)	F Drill	1000 rpm	Dimension [in]: .3320 x .5 (through hole) (5 of 6)	10 min
Drill PVC seat pan counter bore	VZHT Bridgeport (CNC Mill)	0.5" two flute end mill	1000 rpm	Dimension [in]: 1.153 x .125 (5 of 6)	15 min

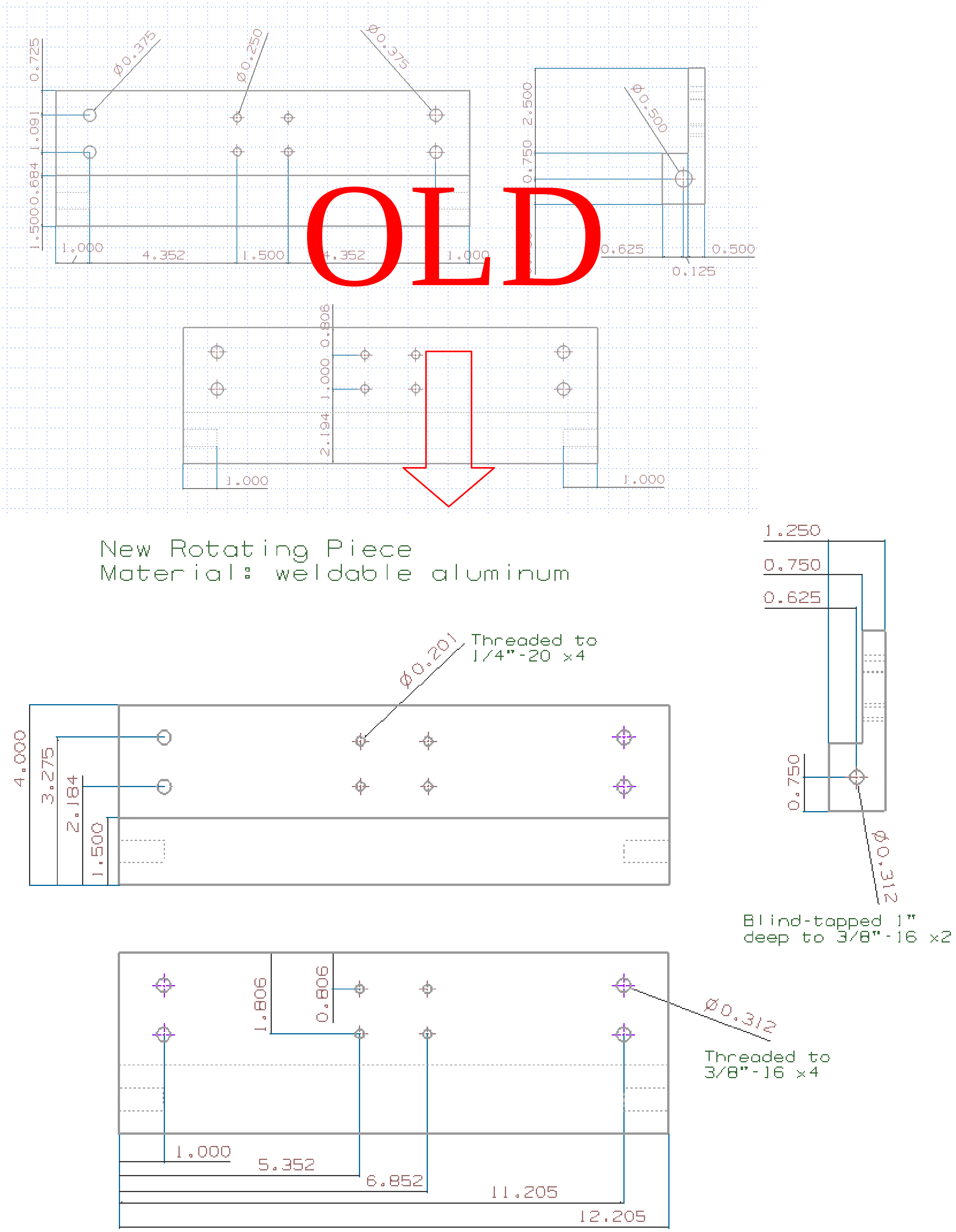
Operation	Machine	Cutting Tool	Cutting Speed	Comments	Estimated Time
Cut PVC seat pan	VZHT Bridgeport (CNC Mill)	0.5” two flute end mill	1000 rpm	6 seat pans are made in total; 6 of 6 seat pans completed	45 min
Drill PVC seat pan	VZHT Bridgeport (CNC Mill)	F Drill	1000 rpm	Dimension [in]: .3320 x .5 (through hole) (6 of 6)	10 min
Drill PVC seat pan counter bore	VZHT Bridgeport (CNC Mill)	0.5” two flute end mill	1000 rpm	Dimension [in]: 1.153 x .125 (6 of 6)	15 min
LASER cut hole and length of head support strap	Universal Laser Systems X6200 (Laser Cutter)	N/A	All of the LASER cutting was run at 90% power	Hole cut into support strap is located 1” away from steel strap clamp, with strap folded over so to double the strength of the hole The length the support strap is cut should be determine after LASER cutting the hole. The strap should be screwed into the back of the chair back and draped over the front of the chair, and marked to be cut 13” down from the top of the chair back.	30 min
Sand and file all rough edges	N/A	N/A	N/A		1 hour

*All holes were chamfered using a chamfer tool on a drill press run at 150 rpm

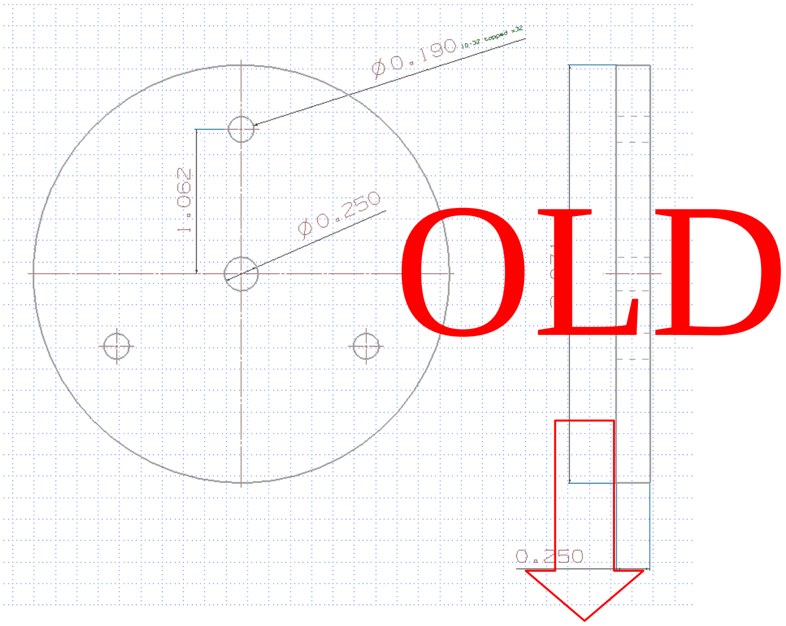
**All pieces being welded should first be submerged in solvent, rubbed down with acetone, and then brushed with the proper bush based on what material is being welded

Appendix 12: 2-D Drawings

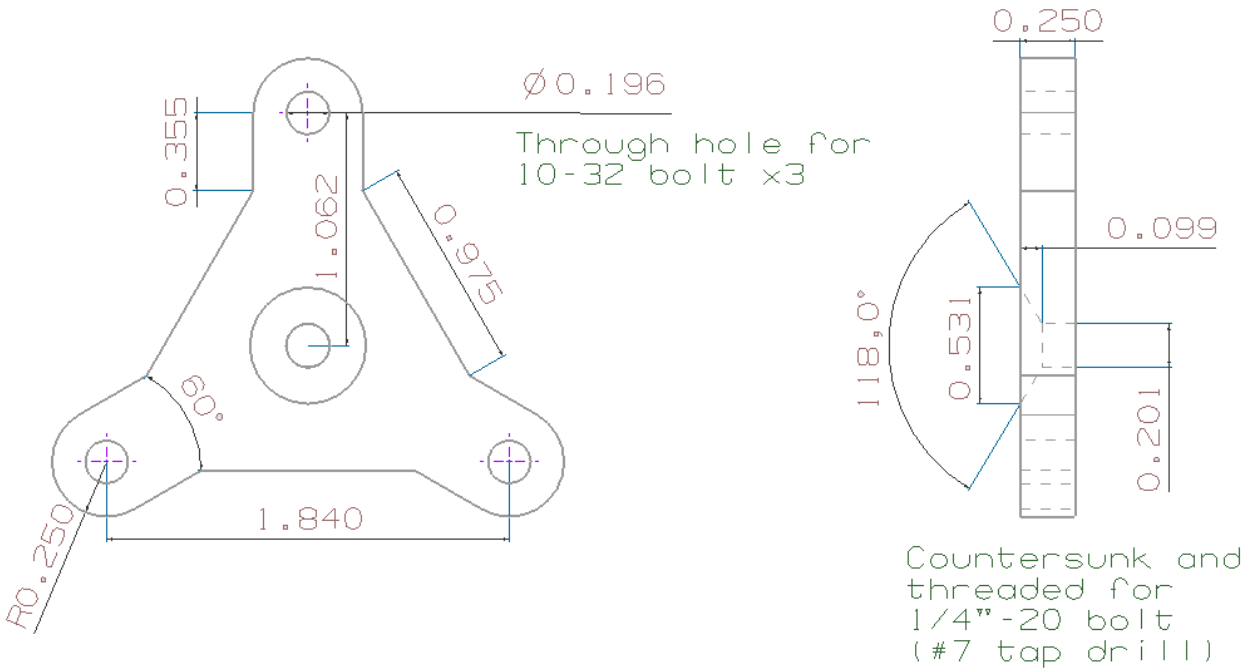
A.12.1 Rotating Piece



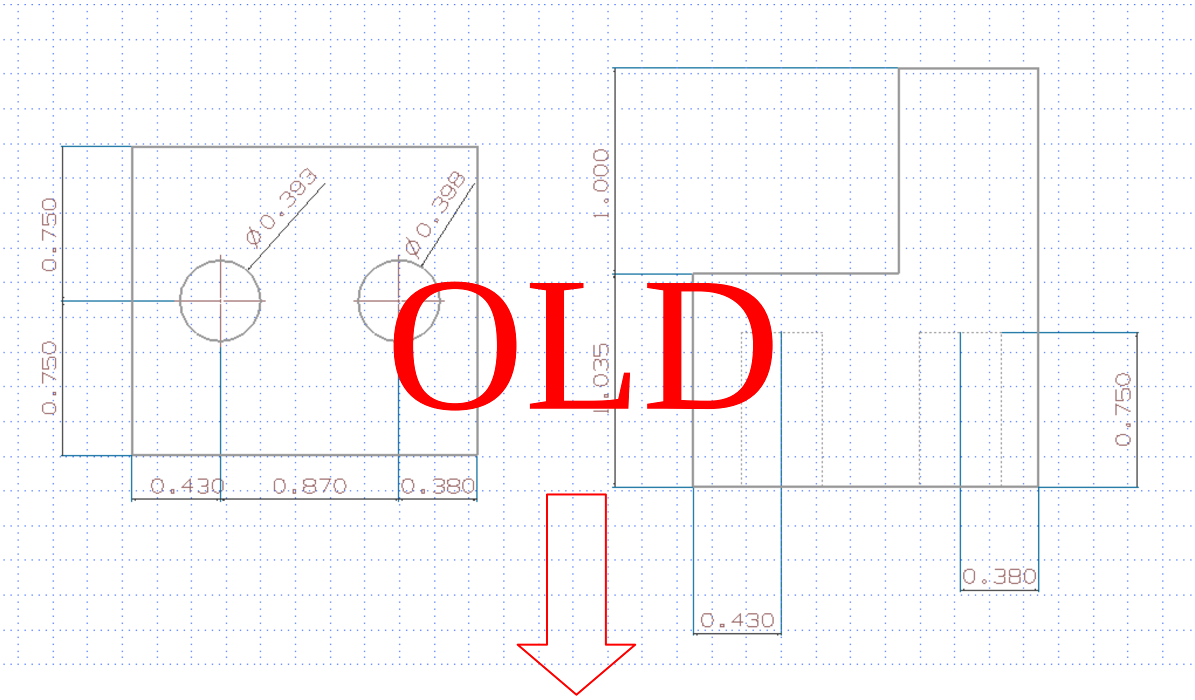
A.12.2 Pulsator Bracket Plate

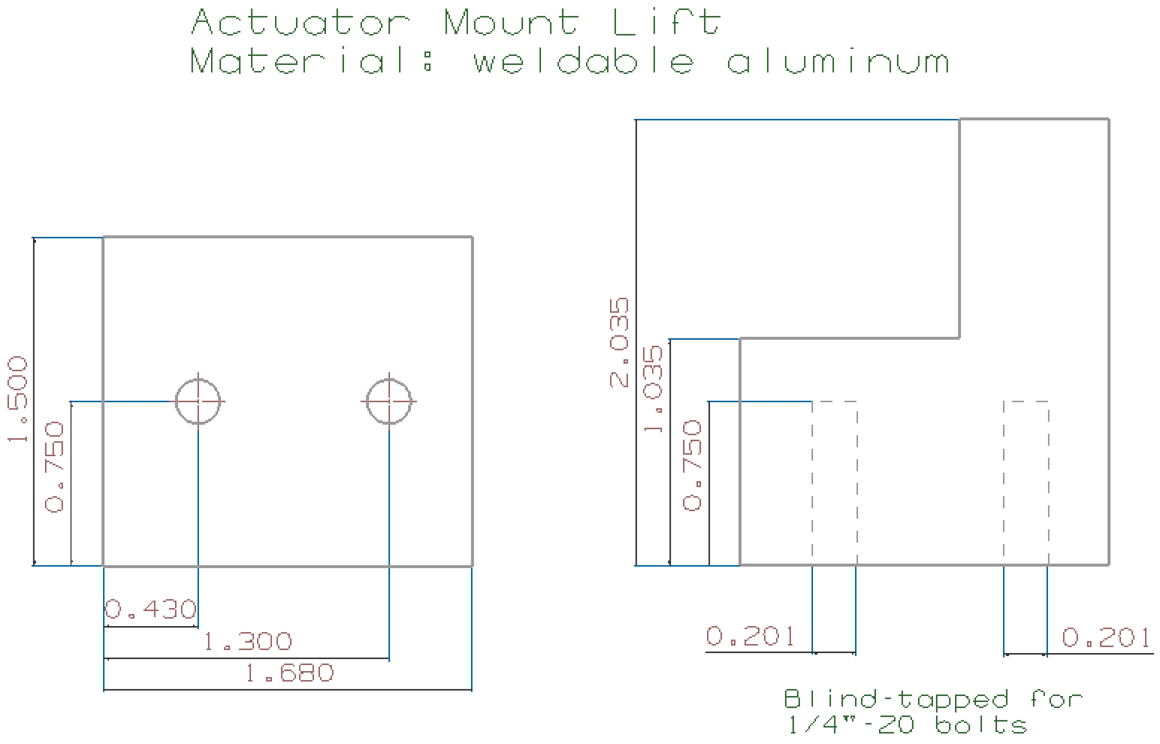


Final Pulsator Plate
Material 1/4" thick aluminum

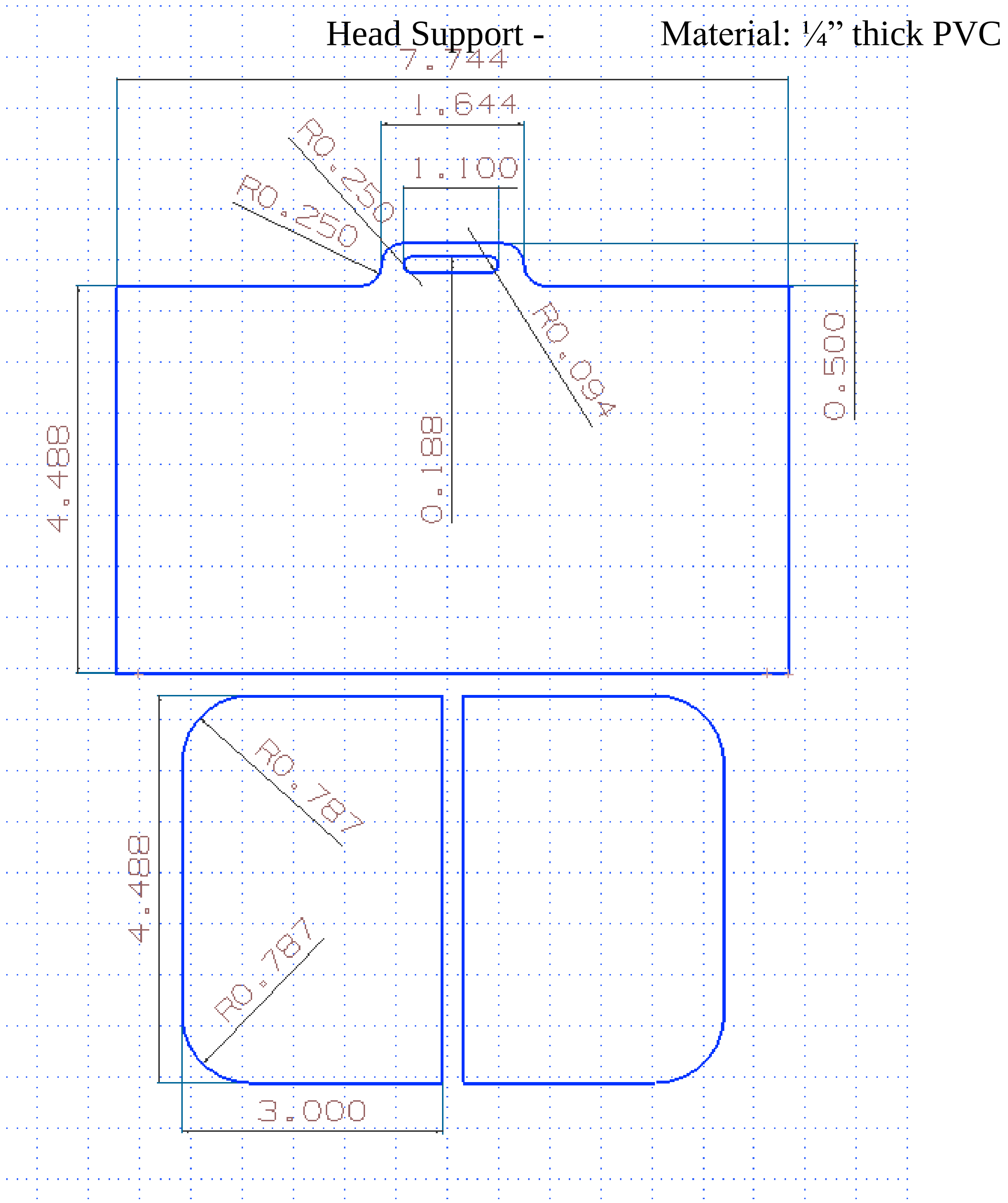


A.12.3 Linear Actuator Mount Lift

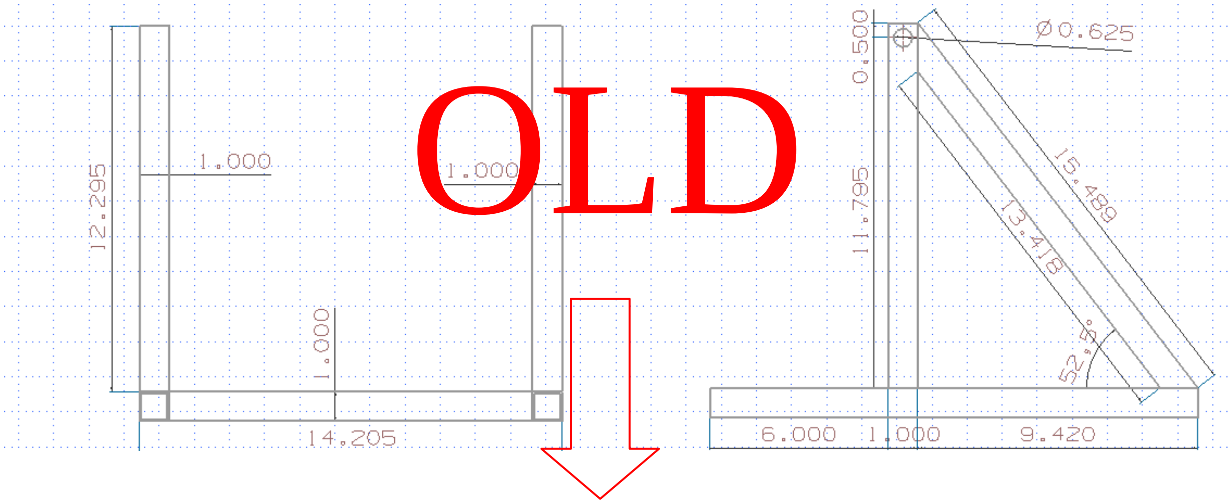


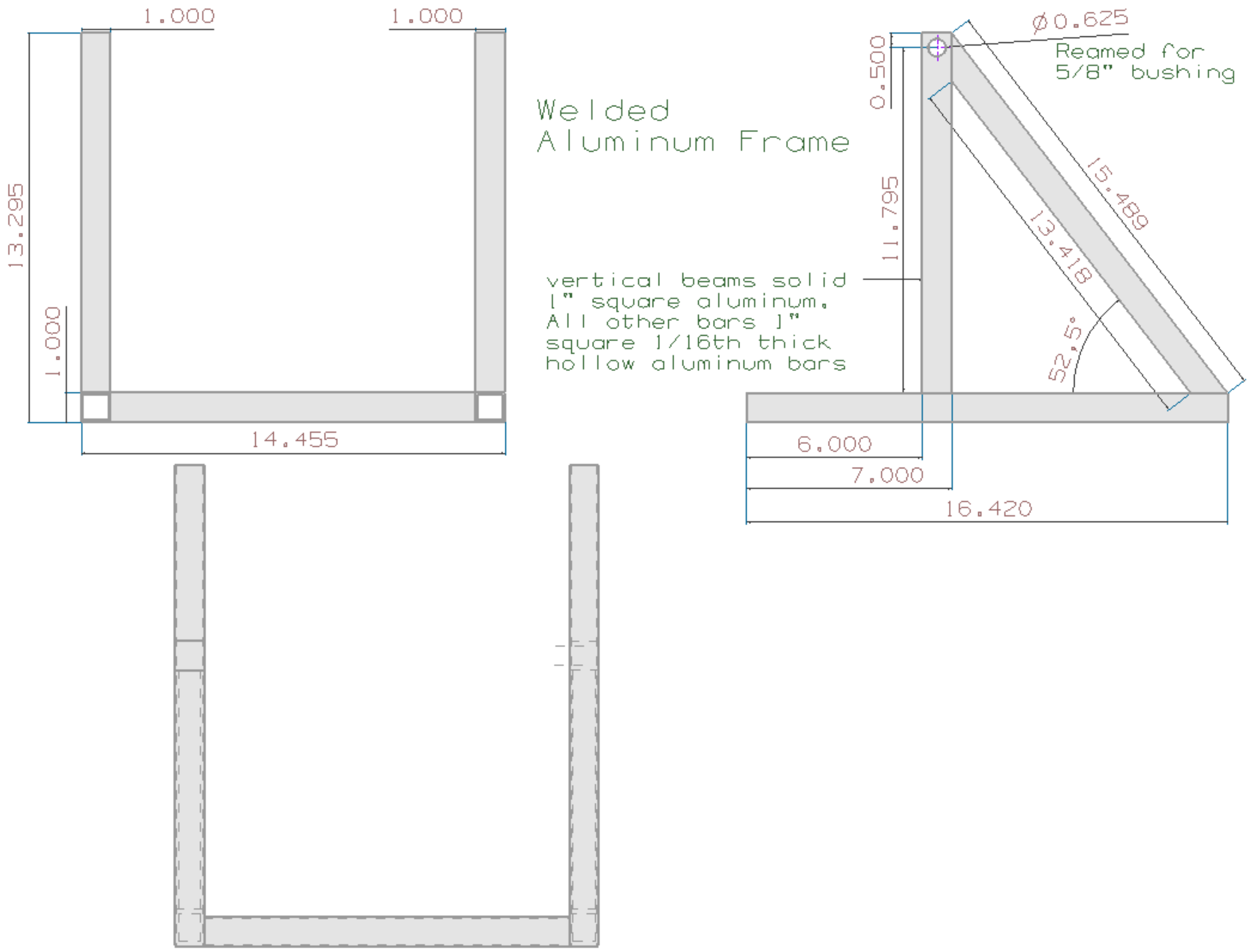


A.12.4 Head Support

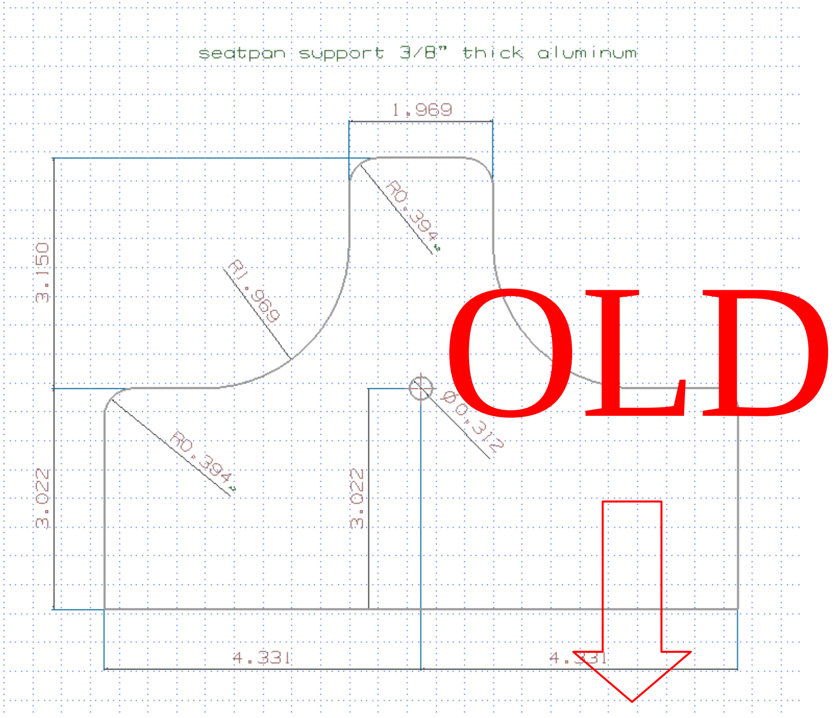


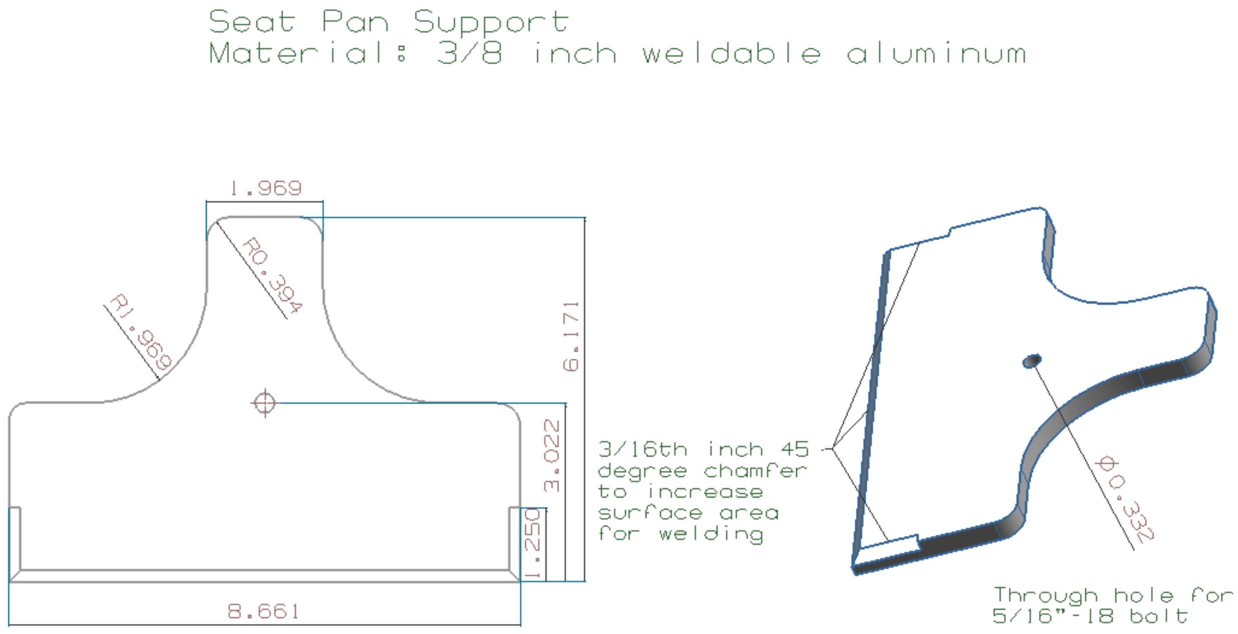
A.12.5 Welded Aluminum Frame



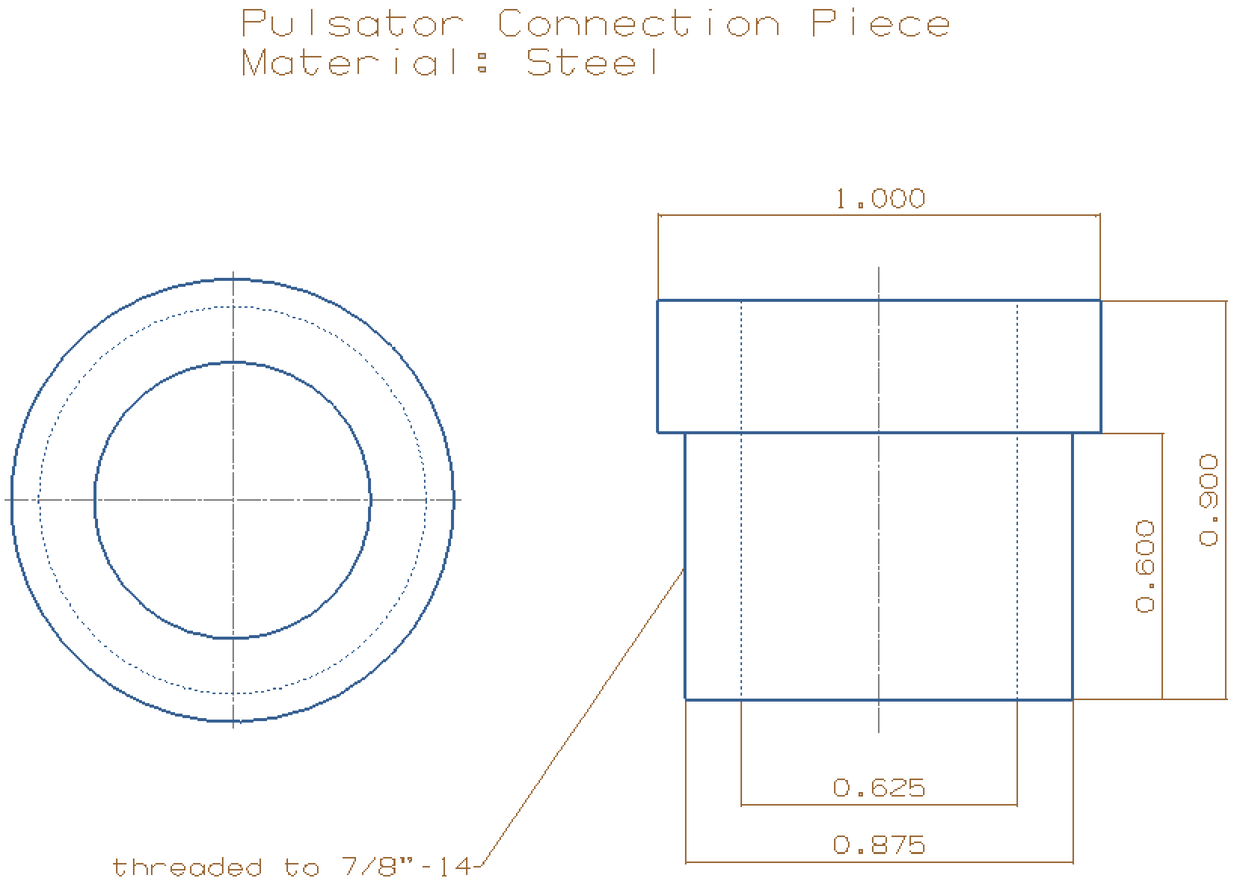


A.12.6 Seat Pan Support

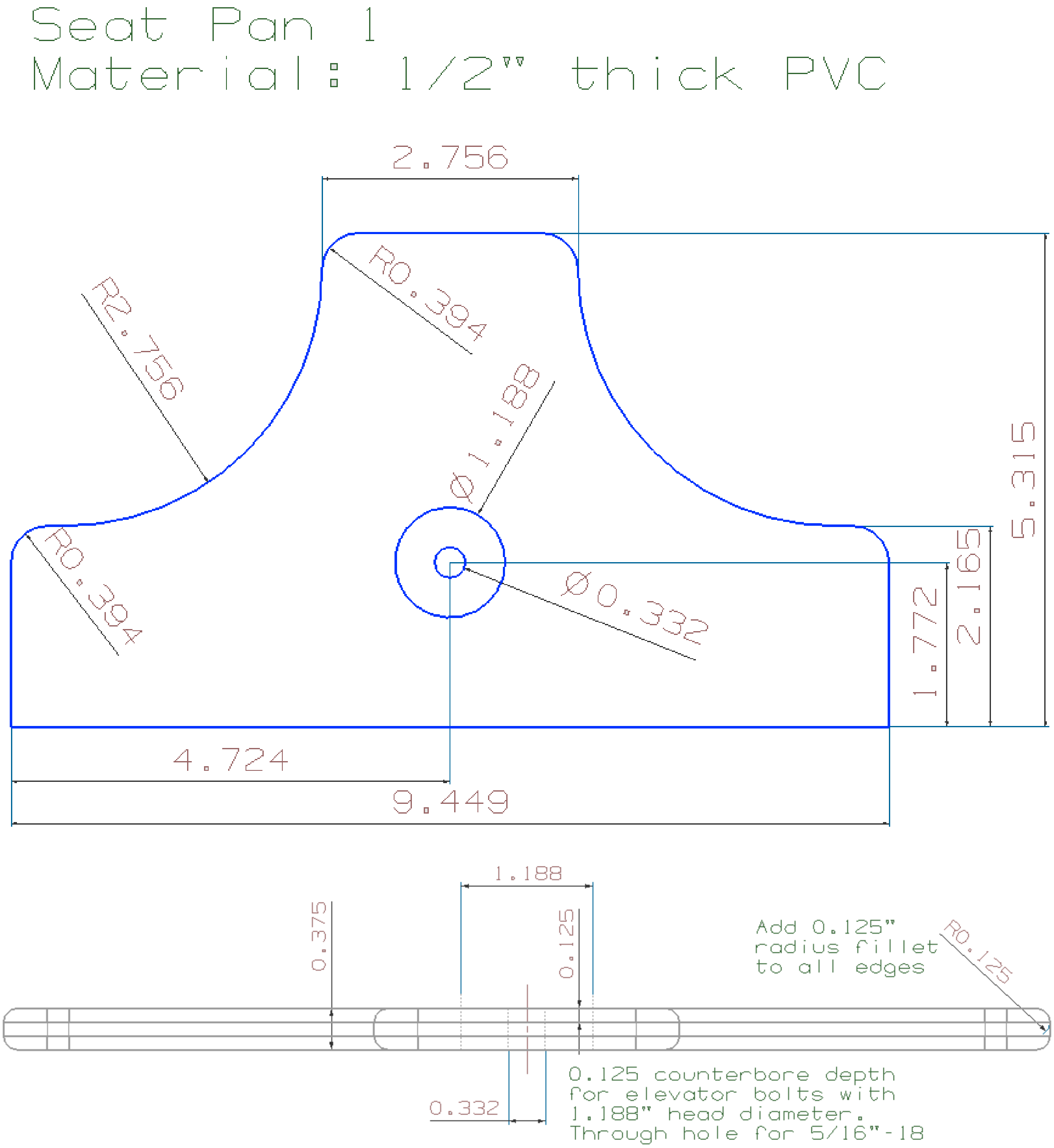




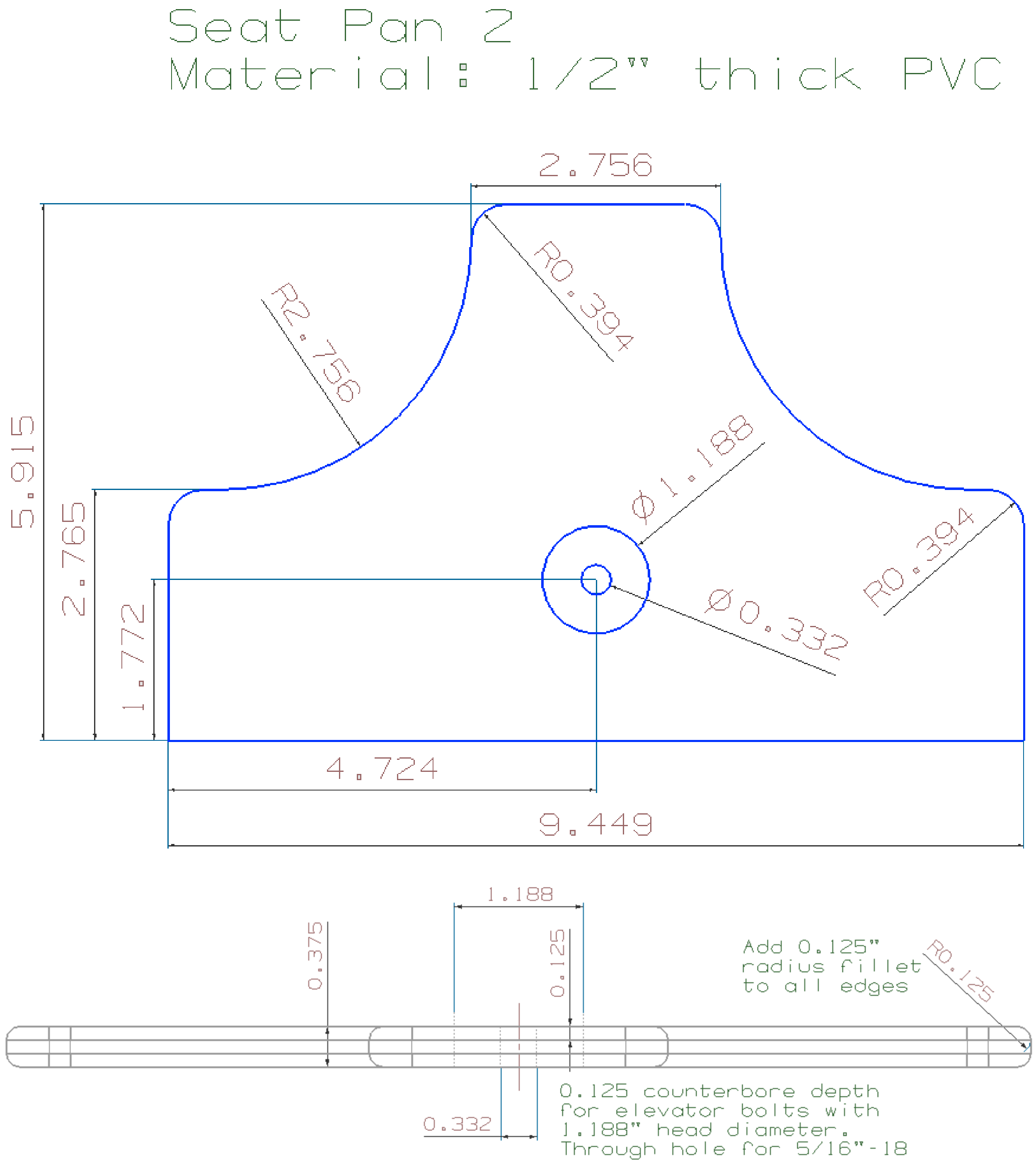
A.12.7 Pulsator Connection Piece



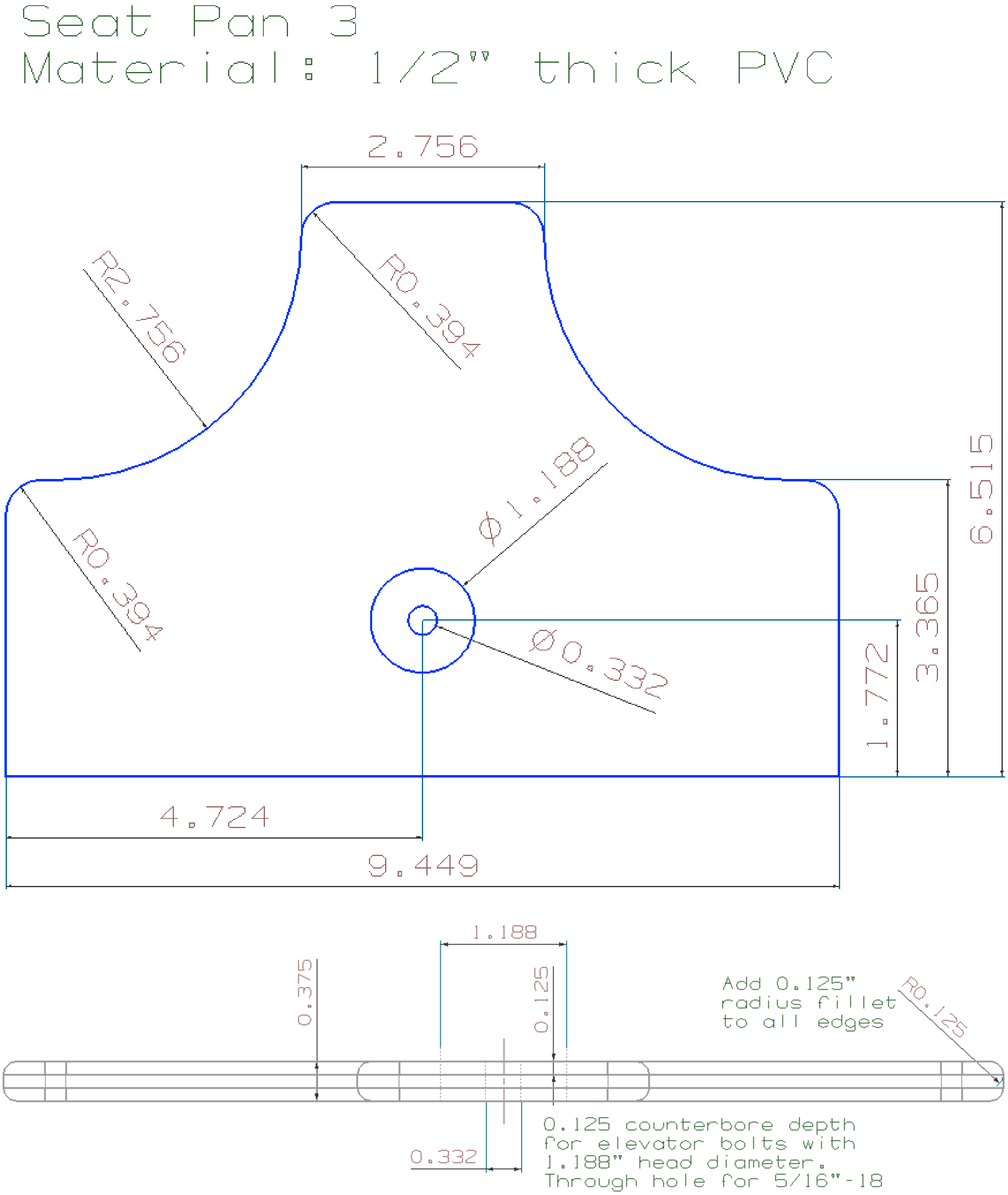
A.12.8 Seat Pan 1



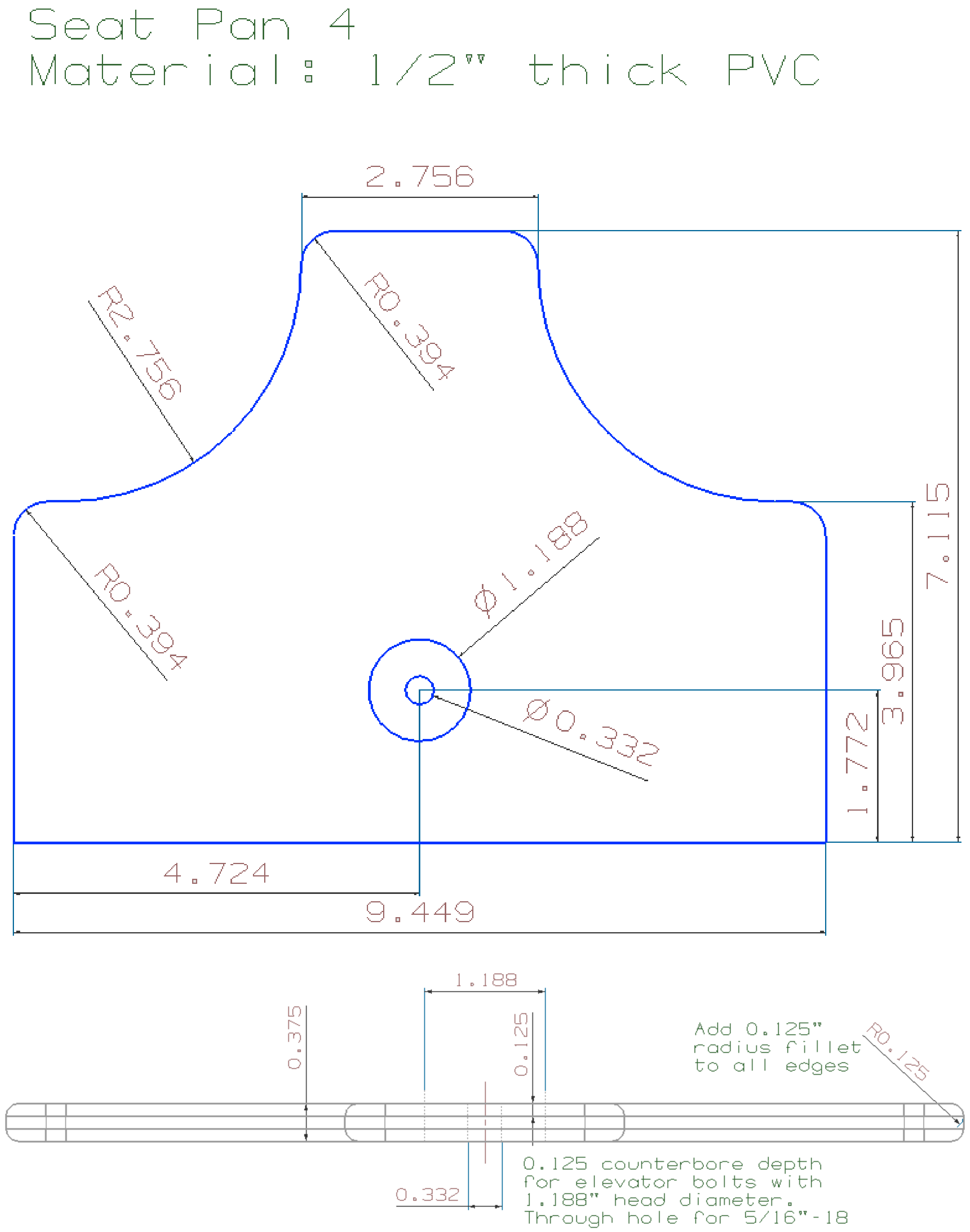
A.12.9 Seat Pan 2



A.12.10 Seat Pan 3



A.12.11 Seat Pan 4

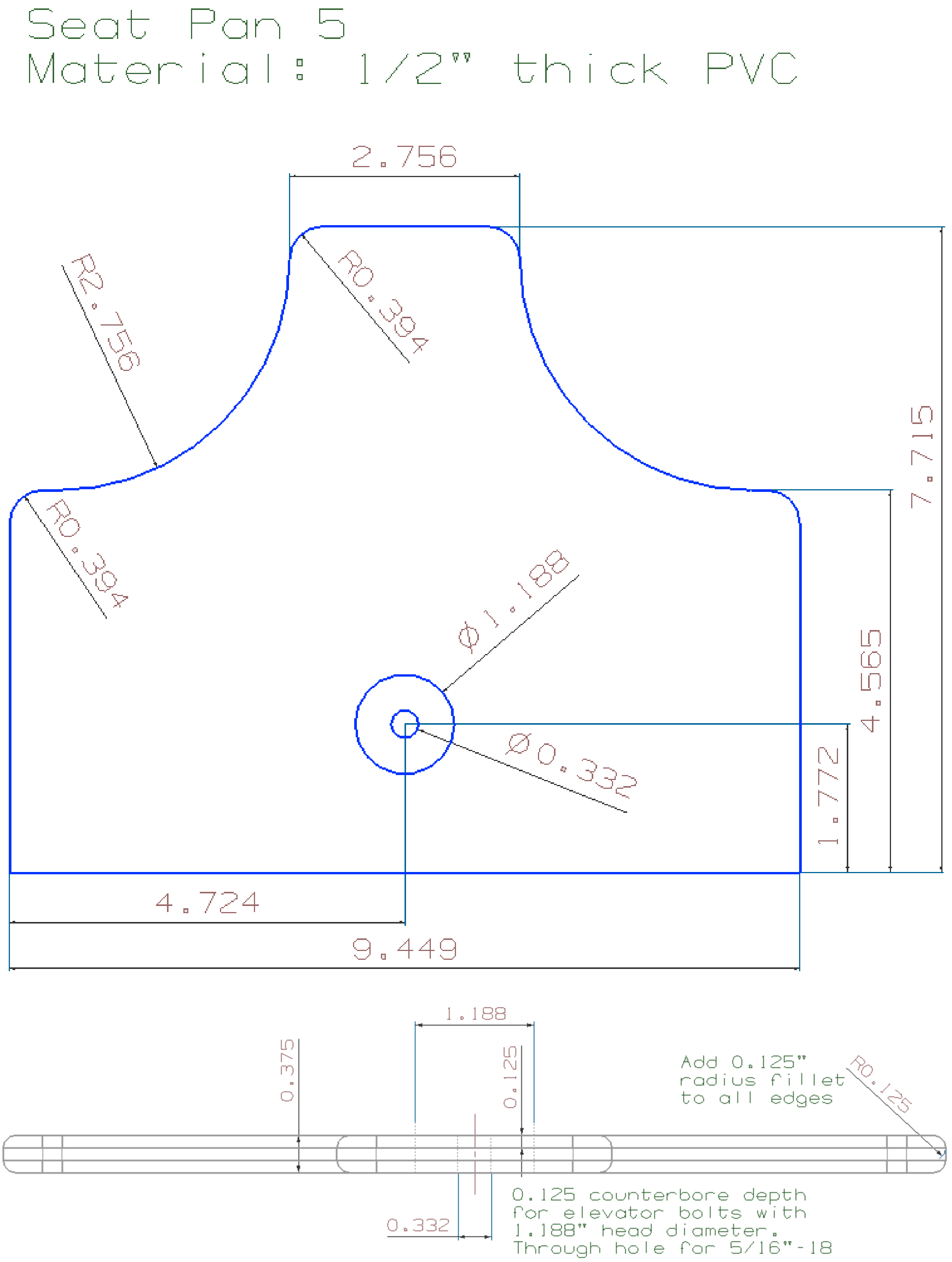


Seat Pan 4
Material: 1/2" thick PVC

Add 0.125" radius fillet to all edges

0.125 counterbore depth for elevator bolts with 1.188" head diameter. Through hole for 5/16"-18

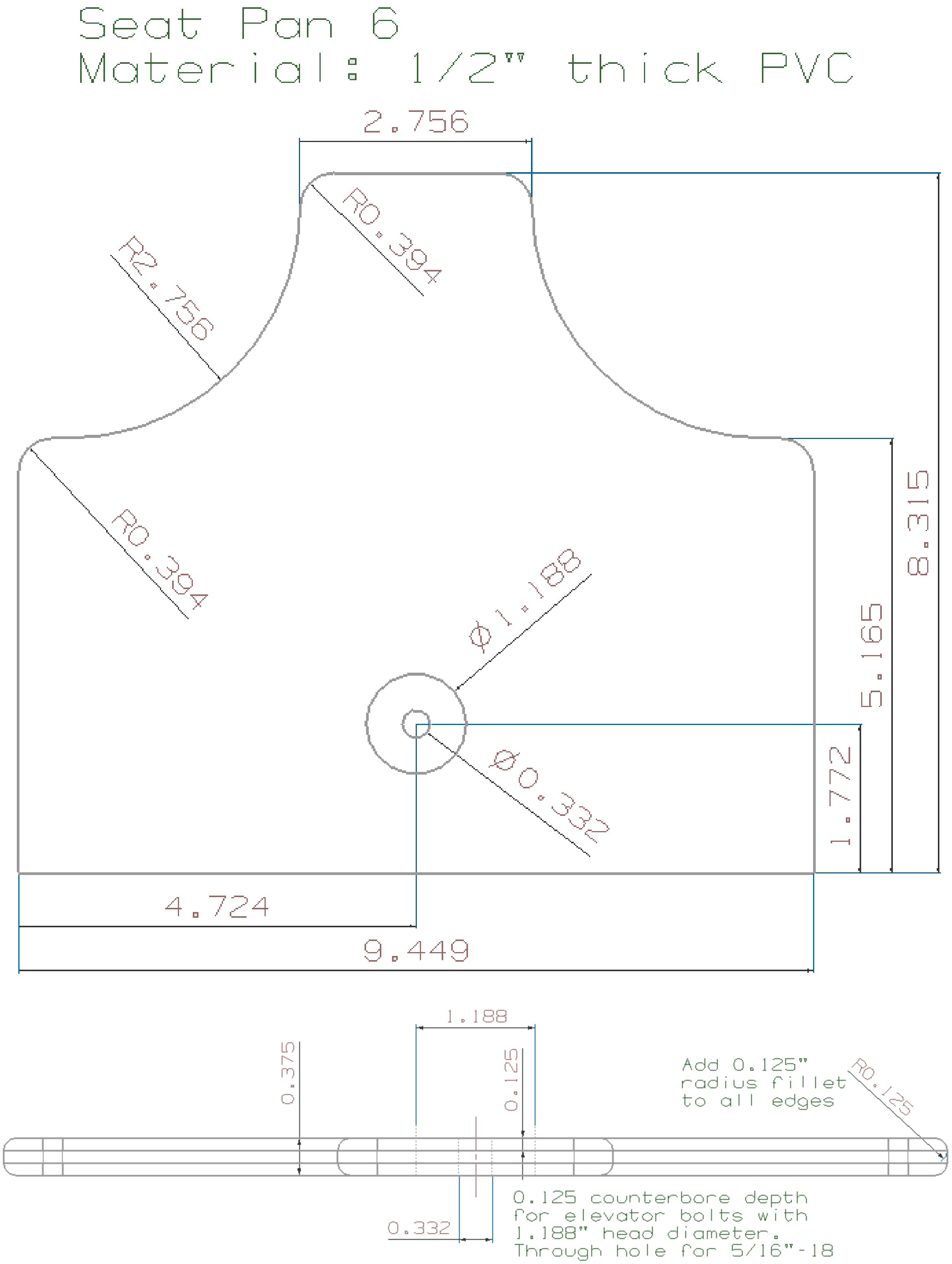
A.12.12 Seat Pan 5


Seat Pan 5
Material: 1/2" thick PVC

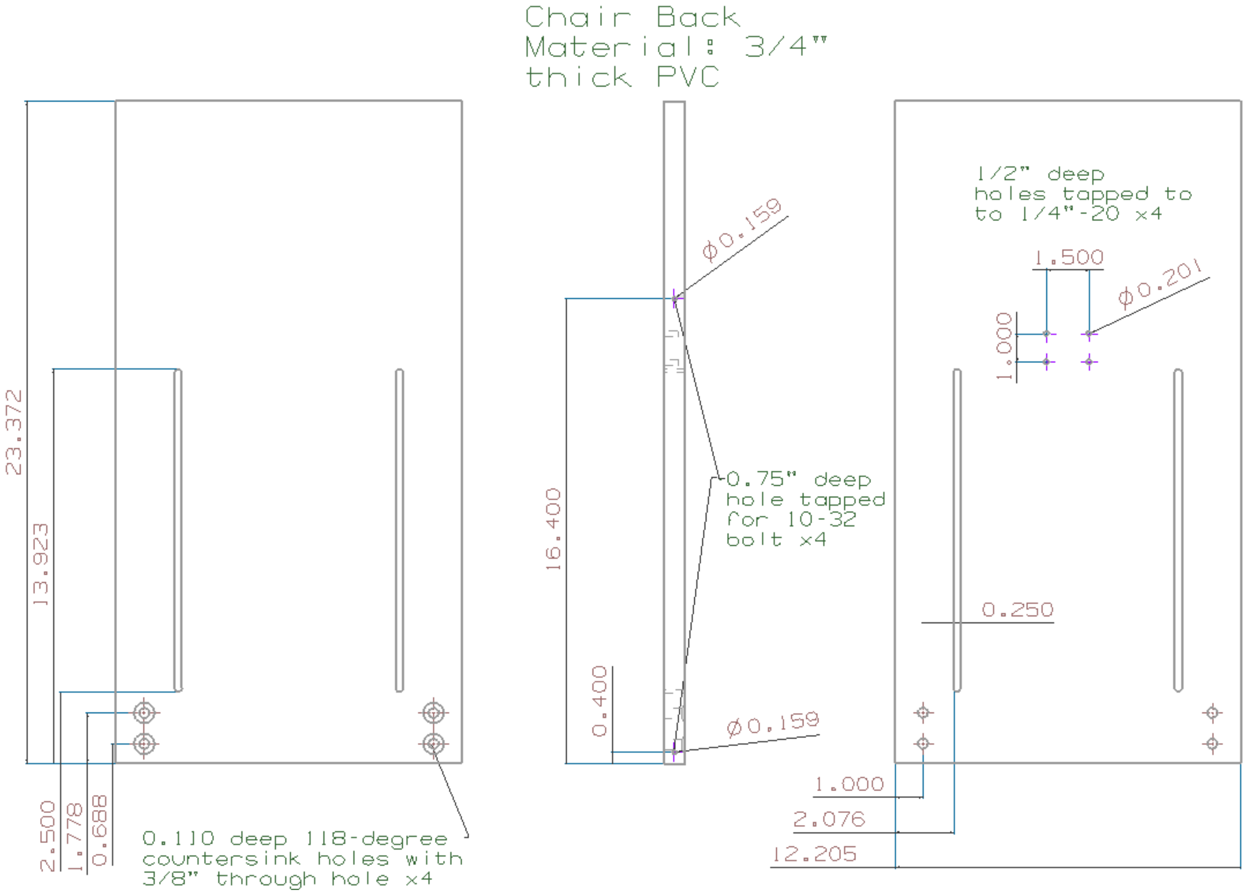
Add 0.125" radius fillet to all edges

0.125 counterbore depth for elevator bolts with 1.188" head diameter. Through hole for 5/16"-18

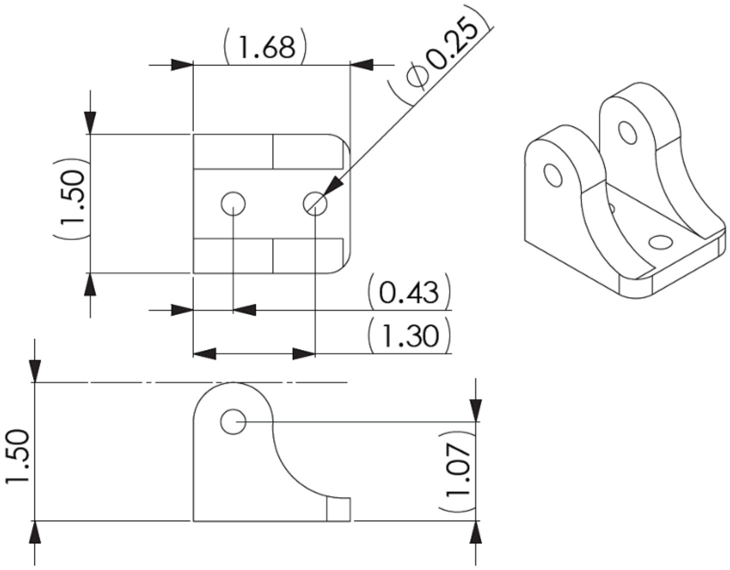
A.12.13 Seat Pan 6



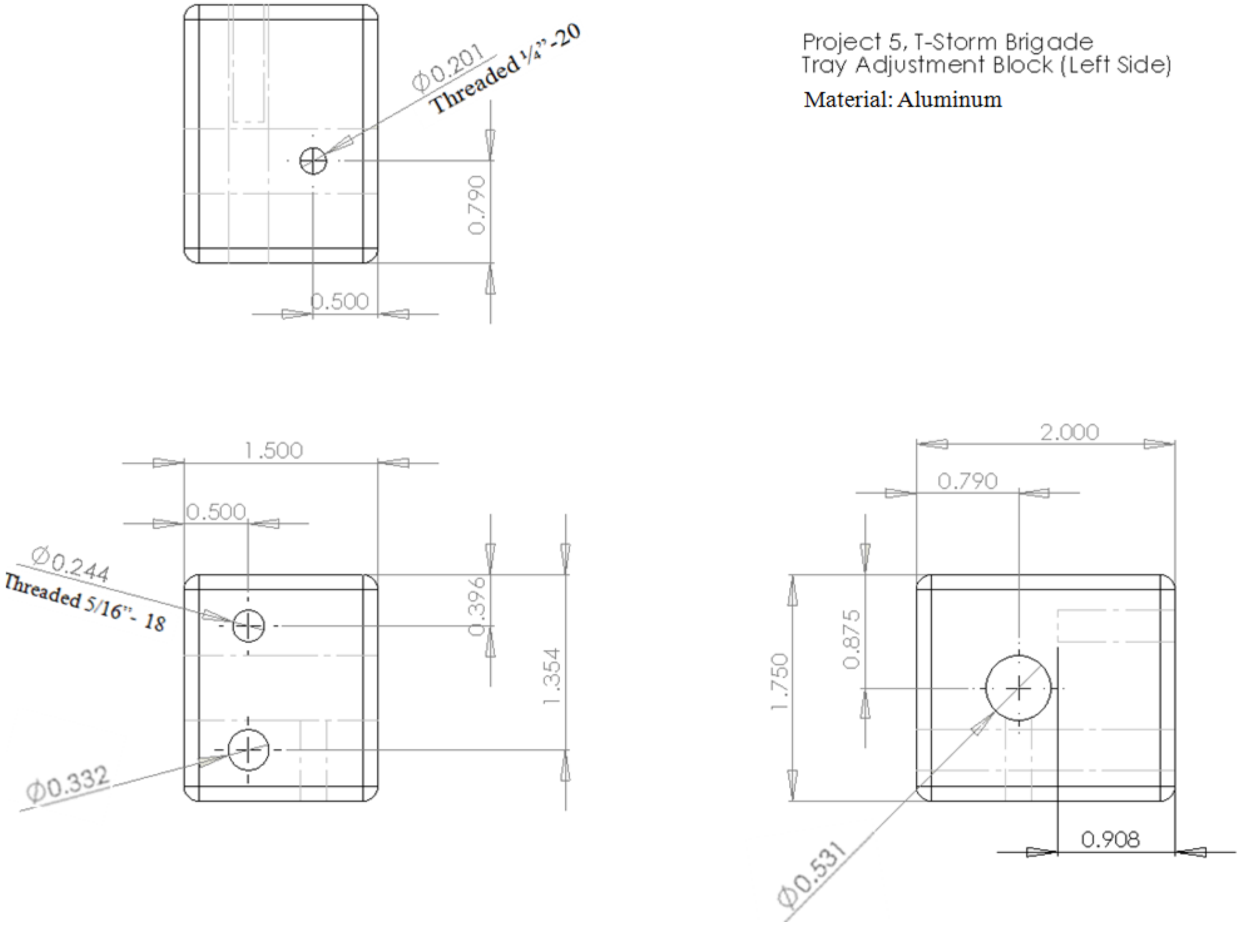
A.12.14 Chair Back



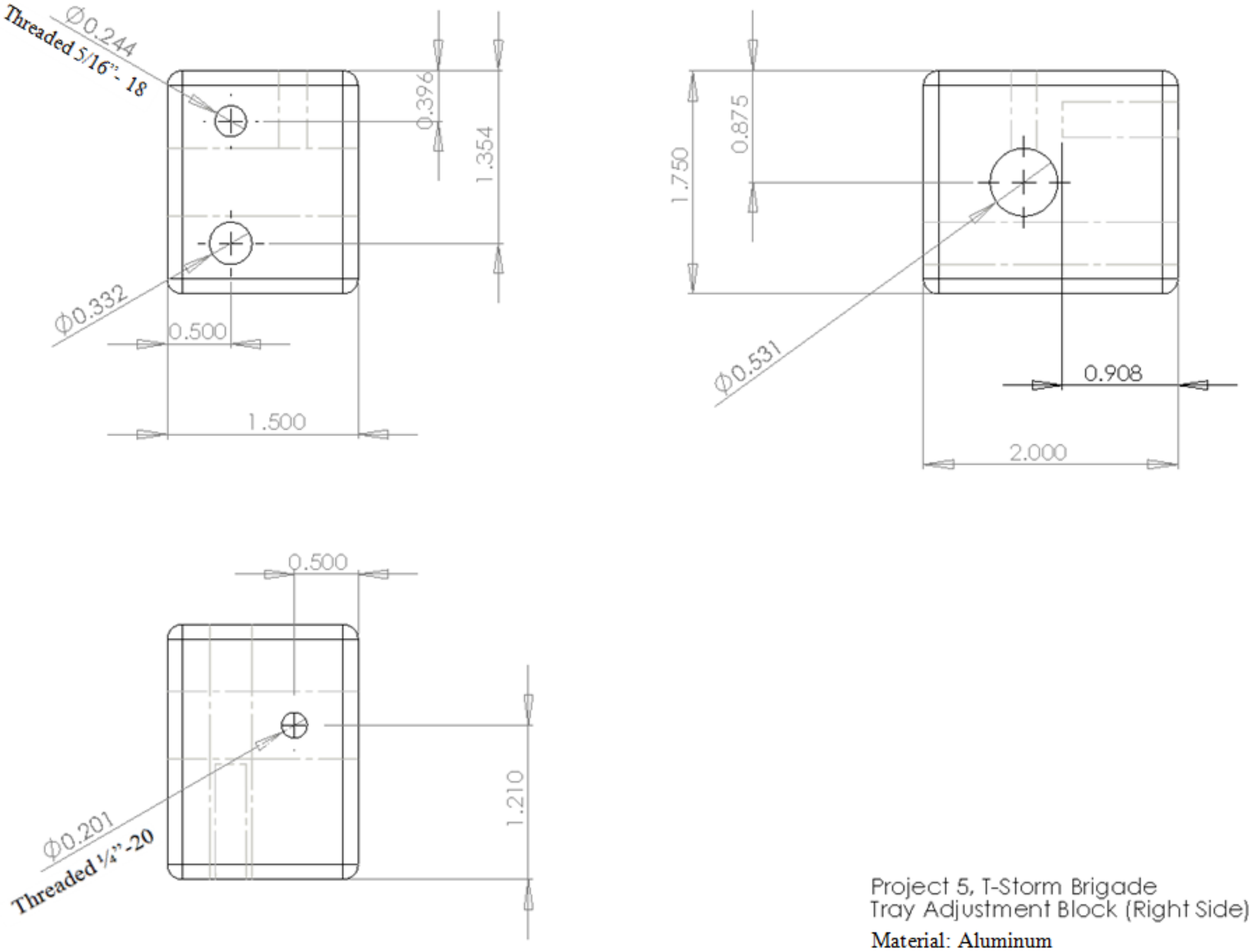
A.12.15 Linear Actuator Bracket (Creative Werks LA-LD-BRACKET)



A.12.16 Tray Adjustment Block (Left Side)

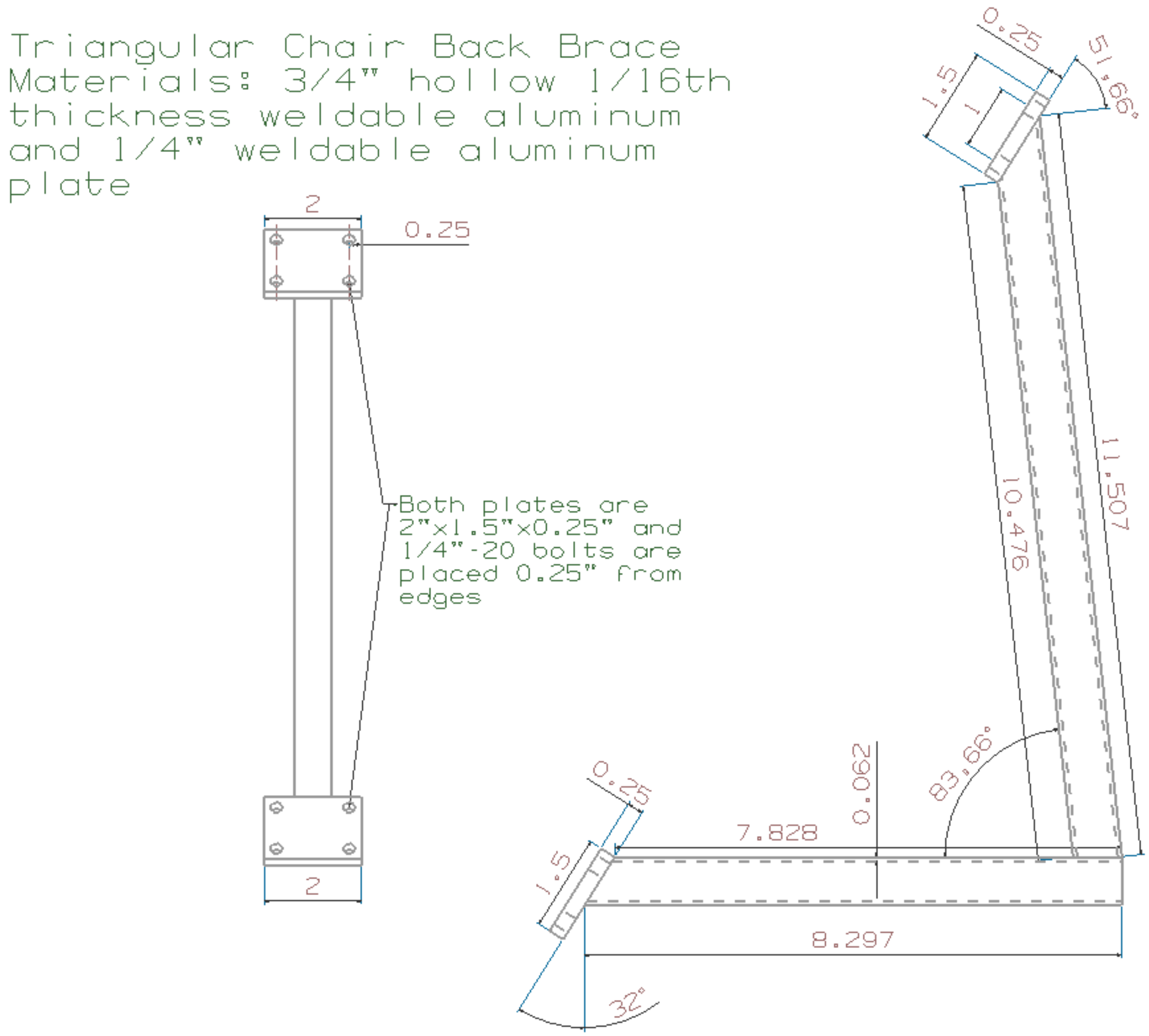

Project 5, T-Storm Brigade
Tray Adjustment Block (Left Side)
Material: Aluminum

A.12.17 Tray Adjustment Block (Right Side)



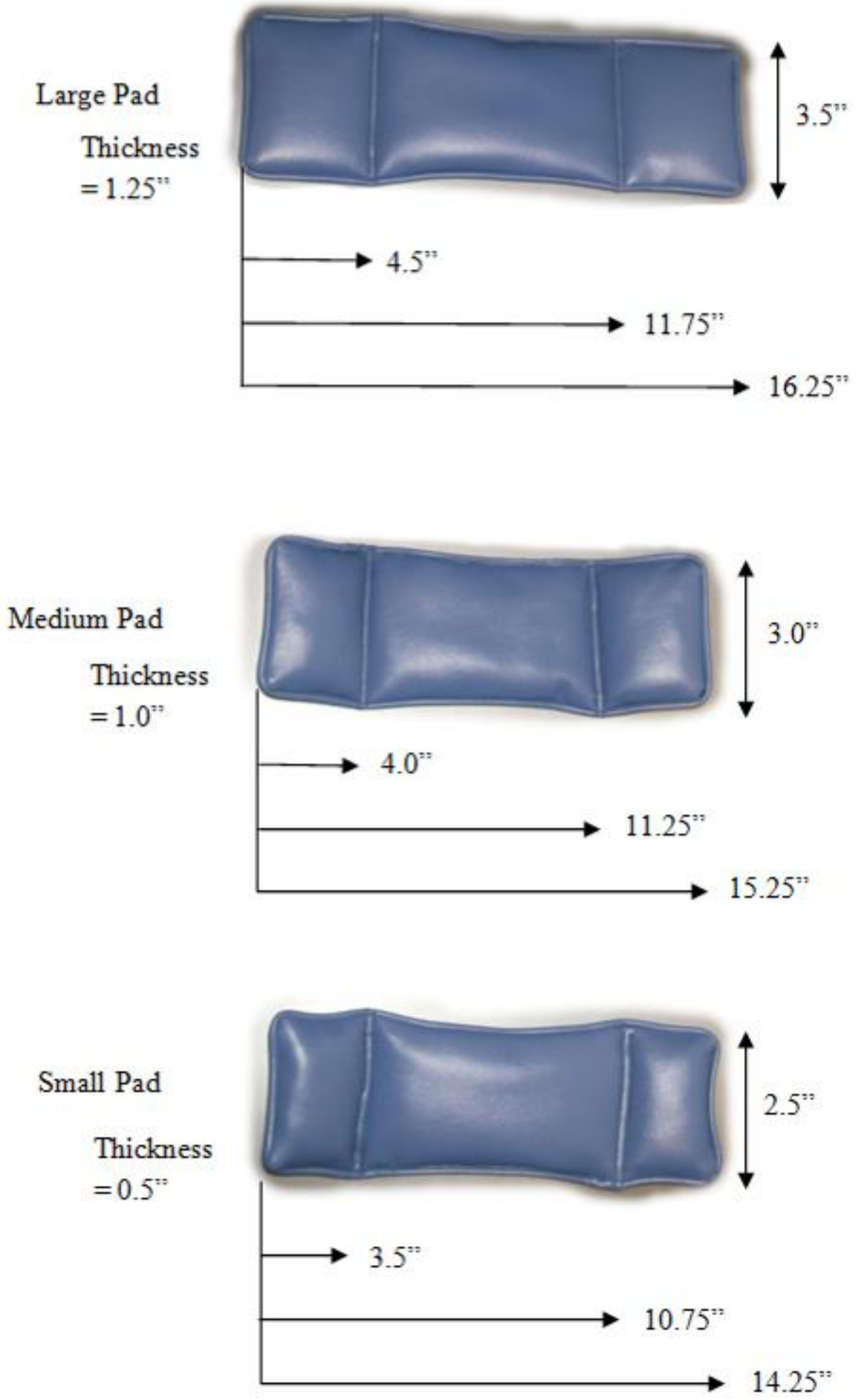
Project 5, T-Storm Brigade
Tray Adjustment Block (Right Side)
Material: Aluminum

A.12.18 Triangular Mount



A.12.19 Head Support Pads

Head Support Pads
Material: Vinyl and cotton batting
Add Velcro on back surfaces as desired



Appendix 13: Survey Results

Seat Pans (Changing)	Unlearned Difficulty	Time to adjust	Learned Difficulty	Time to adjust
Trial	Scale 1-10 (1=easy, 10=hard)	In seconds	Scale 1-10 (1=easy, 10=hard)	In seconds
Average	1	23.5	1	27

Chair Back Angle Adjustment	Unlearned Difficulty	Time to adjust	Learned Difficulty	Time to adjust
Trial	Scale 1-10 (1=easy, 10=hard)	In seconds	Scale 1-10 (1=easy, 10=hard)	In seconds
Average	1	7	N/A	7

Head Support (Height)	Unlearned Difficulty	Time to adjust	Learned Difficulty	Time to adjust
Trial	Scale 1-10 (1=easy, 10=hard)	In seconds	Scale 1-10 (1=easy, 10=hard)	In seconds
Average	1	4.5	1	3.5

Head Support (Replace)	Unlearned Difficulty	Time to adjust	Learned Difficulty	Time to adjust
Trial	Scale 1-10 (1=easy, 10=hard)	In seconds	Scale 1-10 (1=easy, 10=hard)	In seconds
Average	1	14	1	7

Seatbelt (Threading in)	Unlearned Difficulty	Time to adjust	Learned Difficulty	Time to adjust
Trial	Scale 1-10 (1=easy, 10=hard)	In seconds	Scale 1-10 (1=easy, 10=hard)	In seconds
Average	2	37.5	N/A	N/A

Seatbelt (Attaching)	Unlearned Difficulty	Time to adjust	Learned Difficulty	Time to adjust
Trial	Scale 1-10 (1=easy, 10=hard)	In seconds	Scale 1-10 (1=easy, 10=hard)	In seconds
Average	1	1	1	1

Tray Adjusters	Unlearned Difficulty	Time to adjust	Learned Difficulty	Time to adjust
Trial	Scale 1-10 (1=easy, 10=hard)	In seconds	Scale 1-10 (1=easy, 10=hard)	In seconds
Average	1	43.5	1	20

Pulsator Base x-y Adjustment	Unlearned Difficulty	Time to adjust	Learned Difficulty	Time to adjust
Trial	Scale 1-10 (1=easy, 10=hard)	In seconds	Scale 1-10 (1=easy, 10=hard)	In seconds
Average	2	15.5	2	3.5

Pulsator Height	Unlearned Difficulty	Time to adjust	Learned Difficulty	Time to adjust
Trial	Clamp / telescoping tubes	In seconds	Clamp / telescoping tubes	In seconds
Average	2/2	25.5	2/2	6

Pulsator Angle	Unlearned Difficulty	Time to adjust	Learned Difficulty	Time to adjust
Trial	Scale 1-10 (1=easy, 10=hard)	In seconds	Scale 1-10 (1=easy, 10=hard)	In seconds
Average	2	34.5	2	8

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