Universal Play Frame VI

Final Project Report

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Statement of Disclaimer

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Executive Summary

This design report details the design process utilized by Adaptive Exercise Designs (AED) in creating the sixth design of the Universal Play Frame (UPF). The UPF is an adaptive frame which supports a variety of devices that allows athletes in wheelchairs with limited ranges of motion to participate in physical activity. The past five frame designs do not meet the needs of the Friday Club due to complications with function and time constraints. To ensure all of Fridays Clubs needs were met, the problem was better defined by converting the customer requirements into engineering specifications. The design process our team followed was guided by the engineering specifications and is presented in detail in this report.

The final dimensions of the UPF VI varied from the original anticipated design are summarized as follows. The UPF VI utilizes four 12’’ wheels instead of two wheels like the previous UPFs. The additional and larger wheels will improve the frames ability to maneuver over different terrains. The final design of the frame weights approximately 50 lbs. The frame is 40’’ wide (fixed width) to provide clearance for the user’s wheelchair and the UPF wheels to rotate. The height adjusts between the range of 34’’ and 42’’ and has a maximum length of 74” in order to accommodate different height and length wheelchairs. The Cargo Buckle ratchet tie-down was selected as a new method of attachment in order to allow for a quick and easy connection of the UPF to the wheelchair. The UPF VI cost a total of $1,239.65, which includes an estimated $130.00 for a powder coat to improve the visual aesthetics of the UPF.

I. Introduction

A. Project Definition

The Universal Play Frame (UPF) is a multi-year Senior Project developed by Mechanical Engineering and Kinesiology students at California Polytechnic State University, San Luis Obispo. Over the past decade, five prototypes have been designed and built for the Friday Club on Cal Poly's campus. Friday Club is an organization at Cal Poly that provides Cal Poly Kinesiology students the opportunity to work with Special Olympics to structure physical activities for both child and adult athletes with varying disabilities. The UPF supports a variety of adaptive devices to participate in various sports and activities. Many of these athletes have limited ranges of motion and use either manual or motorized wheelchairs. The current model (UPF V) is able to support the adaptive devices but needs improvement with adjustments, attachments, and stability. The goals of the UPF VI project are to decrease attachment time, increase stability and safety, improve all-terrain mobility, and decrease storage volume. A multi-disciplinary group of Mechanical Engineering and Kinesiology students are working together to understand the problem and needs of the new UPF design and reach a best solution. The project is funded and sponsored by Dr. Kevin Taylor of the Kinesiology Department at Cal Poly San Luis Obispo.

B. Motivation

Volunteers in the Friday Club often have difficulty attaching the UPF to athletes' wheelchairs and waste valuable exercise time struggling with its adjustments. A UPF design that is easier to attach and adjust would allow for more use by athletes during each club session. Also, a successful UPF VI design would allow for the UPF program to be out-reached into the community at other clubs similar to Cal Poly's Friday Club.

C. Justification

Although the UPF has been designed and built five times through Cal Poly's Mechanical Engineering Senior Project, the current frame does not provide for the Friday Club's needs. A redesign is necessary to evaluate the sponsor's needs and provide an effective solution. Also, the current market does not produce or sell any product that is similar to the UPF's structure or capability.

II. Background

A. The Athletes

The athletes using the UPF often have paraplegia or partial quadriplegia which can limit the range of motion of their limbs. Dr. Taylor has explained partial quadriplegia as an athlete having partial use of their arms, but may not be able to extend them further than 12 inches from their torso. To help include athletes with limited mobility, the UPF needs to be adjustable to accommodate all users and their unique abilities. Currently Cal Poly's Friday Club is the only local San Luis Obispo County organization for athletes with a disability that provides an opportunity to use the UPF. However, the goal is to design a UPF that may be lent to other organizations to allow more people with disabilities to exercise and enjoy physical activities.

B. Current Market

The current market does not provide products that perform as an adaptive system to allow athletes with disabilities to compete in sport activities. The original design of the UPF was based off Sportime International's "Equalizer" as shown in **Figure 1**. The concept is a rigid frame that attaches to a wheelchair's framing to support sport adaptations and allow the user to engage in adapted physical activity. However, the Equalizer's limitations and problems did not serve the needs of the Friday Club athletes and led to development of the UPF series.

Figure 1. "The Equalizer"

Figure 2. FreeWheel Wheelchair Attachment

A wheelchair's terrain maneuverability is often limited due to the smaller front wheels. Several third-wheel attachments are available in the current market that lift the front wheels off the ground and allow users to traverse tougher terrain. Incorporation of products such as the FreeWheel into the UPF would allow athletes to enjoy physical activities outdoors and in a more independent setting. **Figure 2** shows the FreeWheel's capacity for traversing terrain that would otherwise be difficult in a regular wheelchair. However, certain adaptive equipment requires space directly in front of the athlete and would interfere with the FreeWheel. A similar wheel style could be utilized in a frame off to the side of the wheelchair to avoid interference and allow athletes to travel on grass and dirt easily.

C. Universal Play Frame V

The UPF V is the current prototype of the UPF family and is used on a weekly basis by the Friday Club. The framing consists of stainless steel circular tubing that utilizes slip joints for adjustment to the user's wheelchair and securing the sports attachments. Set-screw clamps secure the UPF arms to the wheelchair and rubber caster wheels allow 360 degree motion. **Figure 3** shows the UPF V attached to a manual wheelchair and supporting a Tee-ball attachment.

Figure 3. UPF V with Tee Ball Attachment

Although the current model of the UPF V is functional, many improvements can be made. **Table 1** lists the observed strengths and weaknesses of the UPF V.

Table 1. Observed Strengths & Weaknesses of the UPF V

Strengths	Weakness
Frame is collapsible	Heavy attachments & frame
Frame allows user to participate in physical activity	Difficult to fold & transport
Frame supports heavy devices user could otherwise not	Attachment to wheelchair takes too much time
Adjustments to user are possible	Attachment locations not always available in front of wheelchair
	Attachment clamps loosen easily
	Wheels do not traverse rough terrain

D. Objectives and Specifications

Our goal is to design and construct the next generation of the UPF. Meetings with Friday Club and sponsors have allowed us to develop an accurate customer needs list to guide our development of the UPF VI.

User input on previous UPF models allowed us to formulate design objectives focused on improving past design flaws. It is important that the needs of the customer are clearly quantified and measured in order to evaluate whether or not they have been fulfilled. Quality Function Deployment (QFD) was used to help transform customer requirements into engineering specifications. The QFD table relates the importance of all user requirements to technical engineering specifications as well as analyzes how well past designs have satisfied these needs. The result of the QFD table delivers a relative importance scoring for each specification for past designs, as well as the intended new design. The importance scoring is marked by 1, 3, & 9 in increasing importance and relevance for each specification. Our QFD table is provided in **Appendix A: QFD Analysis** and demonstrates the importance of each specification in the new design. The results demonstrate the following criteria have high importance in the new design: frame shape, frame material, strength and deflection, and life span.

Table 2 represents a summary and risk assessment of the specifications from the QFD table and shows a requirement or target value for each. The UPF VI needs to be light enough so it can maneuver well and be easily transported, so a target weight of 30 lbs was selected. The target volume represents the space the frame should fit within are a generalized approximation from American Disabilities Act (ADA) wheelchair standards. The adjustment ranges were derived from the UPF V specifications and are a basis for the general adjustment ranges. Further research and analysis will provide more specific ranges suited for the UPF VI. The target chair attachment height allows for a wide range of attachment locations and options. The frame diameter must be large enough to be strong but small enough so the frame isn't excessively bulky and heavy. The load supported is based off of adaptive device weights to ensure the frame does not fail. Although the devices do not weight 100 pounds, this weight was chosen to ensure that excess loads would not cause failure. A lifespan of 5 years is the desired life required by the project sponsor. The design factor ensures loads up to 200 pounds will not damage the frame and is significantly related to the life span of the product. To make the device quick and easy to use, no loose parts or tools should be involved and any removable pins will be secured to the frame by lanyards. Large wheels will ensure maneuverability over various terrains. An approximate project cost was derived from the project budget estimate, but there is a considerable amount of tolerance due to uncertainty. In addition to a target value, each parameter has a tolerance, risk assessment, and compliance. There are three levels of risk associated with each specification: High (H), Medium (M) and Low (L). High risk denotes the tolerance must be met to ensure safety for the user while low risk denotes less important tolerance. Compliance is the method in which the parameter is evaluated; (A) for Analysis, (T) for Testing, (S) for Similarity to Existing designs, and (I) for Inspection.

Table 2. Assessment of Technical Specifications for UPF VI

Parameter Description	Requirement or Target	Tolerance	Risk	Compliance
Weight	30 lbs	MAX	H	A,S,T
Volume (folded)	3 cubic feet	MAX	M	A,S,I
Volume (unfolded)	9 cubic feet	MAX	L	A,S,I
Vertical Adjustment Range	34-42"	± 6"	M	A,S,I
Width Adjustment Range	24-36"	± 6"	M	A,S,I
Chair Attach Height	4"-12"	± 1"	L	A,S,I
Frame Diameter	.75"-2.00"	± 0.25"	L	A,S,I
Load Supported	100 lbs	± 25 lbs	M	A,S,T
Lifespan	5 years	MIN	H	A,I
Design Factor	2	MIN	H	A
Loose parts	0	MAX	L	I
Tools required	0	MAX	H	S,I
Lightweight material	Aluminum	N/A	H	A,I
Table interface constant	Male-Female Joint	N/A	H	A,S,I
Large, free moving wheels	6-10"	MIN	M	A,I
Deflection	0.5"	MAX	H	A,T
Cost	$500 ea	± $150	M	A

III. Final Design

A. Design Description

The final frame concept selected was the Angle Frame design, as shown with a wheelchair in **Figure 4**. The design is similar to the previously proposed A Frame but utilizes a different orientation to allow for better adjustability while still offering the benefit of collapsibility provided by the A Frame. The dimensions of the simulated wheelchair are standardized dimensions from the American Disability Association for a manual wheelchair. The design is comprised of two identical assemblies on each side which are connected by the table top and cross supports. The table top is the interface for the adaptive equipment and holds the weight, which is transferred through the arms and distributed to the four wheels on the frame. The cross supports provide stability when the frame is attached to an athlete's chair via the Cargo Buckle nylon straps. Each side assembly is constructed with two telescopic aluminum tubes, a pivoting joint, a support bar, and two wheels. The table top and cross support are removable to allow for collapsible storage as shown in **Figure 5**. The Angle Frame uses telescopic tubing to adjust the height along the angled supports and the length around the user's wheelchair along the horizontal supports. When removing the UPF from storage and preparing for use, all components will be pinned together while the user enters from the rear. The rear cross support is then pinned into place and Cargo Buckles secured before use. Additional assembly images are shown in. A complete parts list is detailed in **Appendix H: Design Drawing Packet**.

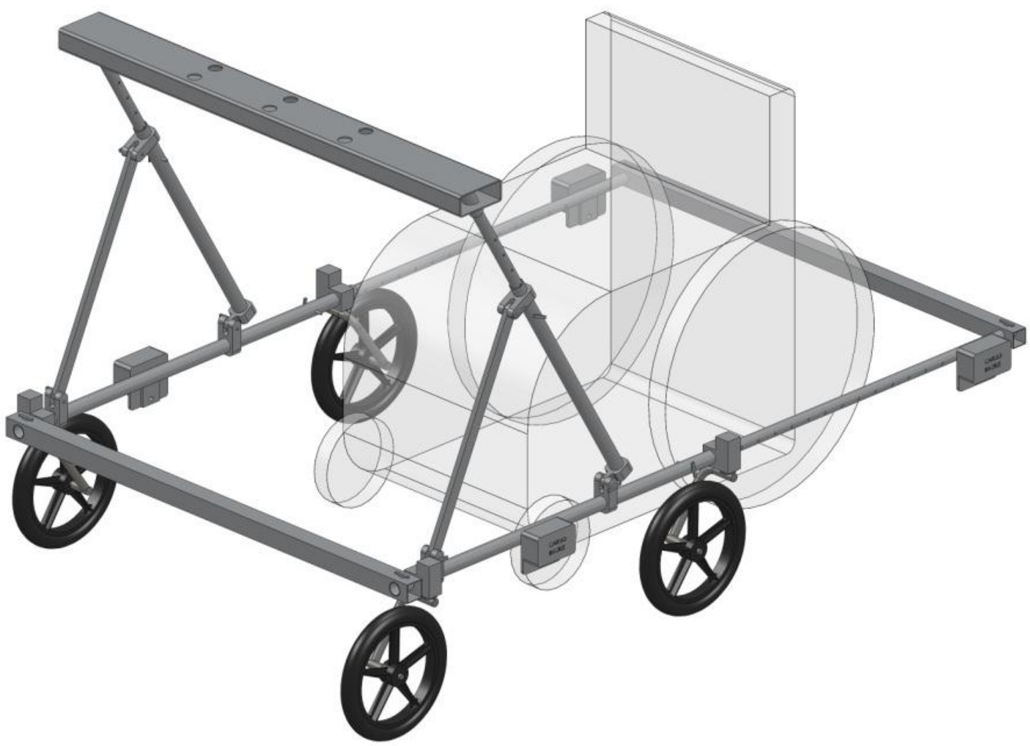

Figure 4. Isometric View with Wheelchair Computer Design

Figure 5. Collapsing Process of UPF VI

Testing of the built prototype will evaluate whether the UPF VI design satisfies the sponsor requirements and engineering specifications. However, the final prototype was not built immediately and other indications of the design's properties were needed. A physical model built with PVC piping and other parts helped model the physical space of the frame while providing a 3-dimensional visual to help ensure all UPF specifications were met. SolidWorks also provided weights and dimensions for each part based on the specified material. **Table 3** is a summary of the approximated values of critical specifications of the UPF VI design.

Table 3. Approximated Design Specifications Based on Solid Model

Specification	Target Value	Actual Value
Weight	30 lbs	45 lbs
Volume (folded)	3 cu. ft.	3.95 cu. ft.
Volume (unfolded)	60 cu. ft.	77 cu. ft.
Chair attach height	4-12"	Cargo Buckles at 12"
Vertical adjustment range	34-42"	32-40”
Width	24-36"	Fixed at 40"
Wheel size	6-10"	12"

B. Part Description

1. Wheels

In order to maintain maneuverability on all types of terrain, larger wheels (approx 6 to 12 inches) that distribute the weight of the frame and attachments were used. The wheels also needed to rotate 360 degrees in order to allow athletes to maneuver while attached to the UPF. Wheel selection on past UPF models have limited the use of certain adaptive devices to indoors because the frame was unable to traverse terrain other than smooth flooring. Analysis shown in **Appendix E: Wheel Selection Analysis** offers a comparison between available wheels and casters on the current market. A major concern for the sponsor was wheel diameter as it will affect performance on various surfaces, and they have insisted at least an 8” wheel diameter be used. Although the 6” pneumatic wheel scored well, it is rejected due to the sponsor requirement. Utilizing a wheel that had built in locks could make the UPF versatile as a dynamic and static frame, but was not of high importance and ultimately ruled out. In addition to a large wheel, the wheel was requested to be relatively thin in width. Through extensive research between our team and Dr. Taylor it was ultimately decided to use the Phil & Ted’s 12” jogger wheel. The larger wheel had been used in other adaptive exercise projects and was quite successful in maneuvering and traversing uneven terrain. Having the larger wheel raised the overall height of the UPF a few inches but does not negatively affect its performance.

2. Telescoping Tubes

The arms of the Angle Frame are telescoping, allowing for a greater range of adjustments for the adaptive device. Each athlete often has custom wheelchairs that vary in height and size, and the adjusting arms would bring the adaptive device to the appropriate height of the user. Currently, the minimum distance an athlete can sit from a device is 36”, which greatly removes the athletes from the interaction of the device. The new design would support the adaptive device closer to the athlete to allow them to be more involved with the activity. Testrite Visual specializes in non-rotational telescoping tubing with locking systems built-in. The telescopic feature provides adjustment while the non-rotation feature provides stability and prevents the UPF from twisting loose during use. Several types of Testrite systems (below in **Figure 6**) were analyzed to determine which system best suits the needs of Friday Club.

Figure 6. Adjustment Mechanisms (L-to-R): Clutch, Split Collar, Non-Locking, Spring Button w/Clutch

Table 4. Analysis of Testrite Adjustment Mechanisms

Concept / Criteria	A-NR: Clutch Lock	B-NR: Split Collar Lock	E-NR: Non-Locking w/Added Pins	FA-NR: Spring Button w/Clutch
Non-rotational	+	+	+	+
Set Distances	-	-	-	+
Ergonomic Handles	-	+	+	S
Speed of Adjustment	+	+	+	-
Durability	-	-	+	+
Σ +	2	3	4	3
Σ -	3	2	1	1
Σ S	0	0	0	1

Analysis of the various Testrite products available for use on the UPF VI suggests the non-locking with post-purchase manufacturing is best. This style still provides easy telescoping and non-rotational tubes, but will require drilled adjustments to allow a quick-release pin (**Figure 7**) for locking the settings. Utilizing pins ensures no internal plastic components will slip or wear over time and ensure the quality of the frame. The split collar lock also scored fairly well in retrospect, but utilizes plastic components that might break and does not have set distances. Also, the spring button with clutch scored well but was specifically denied as a viable option by the sponsor and will not be used.

Figure 7. Quick-Release Pin for Telescope Adjustments

3. Table Top Interface

The sports attachments interface with the UPF through a six-hole system (two rows of three). The system has worked on current UPF prototypes and does not need significant evaluation. Changes to the system would also require all adaptive devices to be modified and would require a lot of additional work. The proposed support structure on the UPF VI will change from a cylindrical bar to a flat plate. Most attachments have a wide base that impairs the assistant from seeing if they are properly interfacing the holes. The bar and adaptive device interaction made it difficult to blindly align the connection holes. By using a plate, the adaptive devices would be placed on the plate and slid into place, a far easier endeavor that would reduce attachment time. In addition to difficultly to place the adaptive devices, the friction clamps in do not sufficiently hold the table top interface level as devices are used, and they have a propensity to rotate the entire frame. After time, the device will fall toward the ground (or sky) and require re-adjustment. Utilizing the flat plate interface will prevent the adaptive devices from rotating and falling. Should the square table top interface become a problem in use, a cylindrical version could be easily fabricated to replace it.

4. Cargo Buckle

The wheelchair will attach to the UPF via four ratcheting tie downs. In order to simplify the process of ratcheting and to minimize the amount of loose material currently present in ratcheting ties down systems, the Cargo Buckle was selected. The Cargo Buckle is a self-ratcheting system tie down system that is self-containing. By going with this system, the learning curve necessary to operate the tie down would be drastically cut when compared to common ratcheting systems.

5. Cross Support

The cross support in the front and rear is a quickly removable part that provides a more solid structure to the UPF during use. The table top is the main linking component between the two sides of the UPF but is unable to support the load of the Cargo Buckles in tension from each side. The rear cross support is un-pinned and removed while the user enters the UPF space and then is pinned back into place once the user is secured with the Cargo Buckles.

B. Analysis Results

Relevant engineering analysis was conducted in order to verify whether the Angle Frame would be able to hold the load of the adaptive devices without breaking. These analyses are similar to the preliminary analysis previously discussed but have finalized materials and dimensions that accurately represent the design. The various modes of failure can be seen in **Table 5** and calculations can be found in **Appendix F: Final Design Analysis**. Design factor represents the number of times the anticipated load of 200 pounds (maximum) can be increased before failure of that part. Design factors above 2 ensure the design is safe and efficient.

Table 5. Final Analysis Summary

Failure Mode	Part	Result	Design Factor
Bending (σ)	Telescopic Support	14656 psi	3.4
Shear (τ)	Pin	1360 psi	67.0
Deflection (δ)	Table Top	6×10^{-6} in	N/a
Deflection (δ)	Table Top Due to Attachment	0.075 in	N/a
Deflection (δ)	Bottom Side Tube	0.044 in	N/a

C. Cost Analysis

A detailed cost analysis is shown in **Appendix C: List of Vendors & Bill of Materials**. The proposed project budget was $1000 and the goal was to build a UPF VI for about $500, with a medium tolerance of $150. The final project cost came to $1,239.65 including an estimate for a powder coating of the UPF, which the sponsor has expressed interest in completing. Although it would be ideal to build several UPFs, our goal was to develop the best frame possible within the main budget cost to ensure Friday Club had a quality product. Building additional frames could attain new budgeting after the UPF VI prototype has proven successful. Details on the manufacturers utilized for the UPF VI are also listed in this Appendix.

D. Safety Considerations

The safety of the user and assistants while using the UPF and its attachments is crucial to the project's success. In order to prevent injury during use, the UPF must support the weight of adaptive devices and any additional loads applied by users. Testing with weights larger than those anticipated will verify the UPF frame is safe for use with adaptive devices. Because the UPF utilizes moving parts to collapse the frame, it is important users are careful as to not pinch their fingers in moving parts or to drop the table top onto their feet. All anticipated causes of injury such as sharp edges will be addressed and minimized during fabrication. These minor injuries cannot be removed completely from the design but can be prevented with proper warning before the UPF is used.

E. Material Selection

Special considerations were given to the materials selected in order to keep the UPF VI as light as possible. The UPF V utilized stainless steel tubing to construct their frame, which resulted in a heavy overall weight. Because the UPF V did not disassemble or fold into a manageable volume, transportation was a critical issue. By designing the UPF VI with high-strength aluminum (6061-T6), the overall weight is reduced significantly without losing the strength of stainless steel. Also, the UPF VI is collapsible into individual pieces, which are easily carried if the combined weight is unmanageable. A major problem however with using aluminum is the difficulty of welding. For parts that need welding, we will utilize the skill of professional pipe-fitters that have worked with aluminum and have the proper equipment to ensure quality in the production. All other materials will be purchased components.

F. Fabrication and Assembly

In order to ensure quality, many of the UPF VI parts will be purchased rather than manufactured by our group (i.e.-caster wheels). Some parts will be modified by drilling holes for pins or other purposes but will not require extensive machining experience or expertise. The major factor of fabrication is welding aluminum, which will be done by a professional welder to ensure it is done properly. Section

IV. Product Realization details the process taken by our team to fabricate and assemble the UPF VI.

G. Maintenance and Repair

Failure of major components in the aluminum is not anticipated due to the small loads the table top will be subject to. Smaller components such as a caster wheel or pin might wear down due to fatigue and cause performance issues over time. These components are easily removable and replaceable. The manufacturers are provided in **Appendix C: List of Vendors & Bill of Materials**, which can be contacted if extra parts need to be ordered. The only components that might require replacement with time include the pins and Cargo Buckles due to fatigue loading. No extensive repairs that require machining skills should be necessary. The Bill of Materials also details all parts used in the project (hyperlinks to website included) and provides exact costs should replacement parts be necessary in the future.

IV. Product Realization

A. Fabrication Process

The UPF VI was fabricated entirely on Cal Poly's campus by the AED team in the provided engineering shops. The various equipment most utilized for fabrication included a mill, horizontal band saw, drill-press, and CNC mill. Stock for the UPF parts arrived throughout the Fall quarter as changes were made to the UPF design on an almost weekly basis and prevented our team from being completely prepared for fabrication at the beginning of the quarter. However, utilizing the method of stop-and-go ordering and fabricating allowed our team to effectively solve any design issues as they presented themselves. The remainder of this section will detail the process utilized to fabricate the UPF VI.

The first parts completed were the main tubing sections and support bar. The stock was cut to length using a horizontal band saw and de-burred as shown in **Figure 8**.

Figure 8. Tubing & Support Bar Cut to Length

Each pipe required adjustment holes drilled in precise locations to ensure the adjustment system was easy to align and operate. The mill provided a stable platform to drill each hole in the pipes and allowed us to obtain perfectly aligned holes. **Figure 9** shows a telescopic pipe with an adjustment pin holding them together.

Figure 9. Telescopic Pipe with Adjusting Pin

After each of the four (two upper, two lower) sections of telescopic pipe were completed, the next step were the joints that hold the parts of the frame together. Our team utilized the CNC mill provided in the Mustang ’60 shop in Bonderson Projects Center. Although our parts were delayed for a couple weeks due to unforeseen software issues, the joints were completed and successfully formed one side of the frame. The completed joints and assembled side are shown below in **Figure 10** and **Figure 11**, respectively.

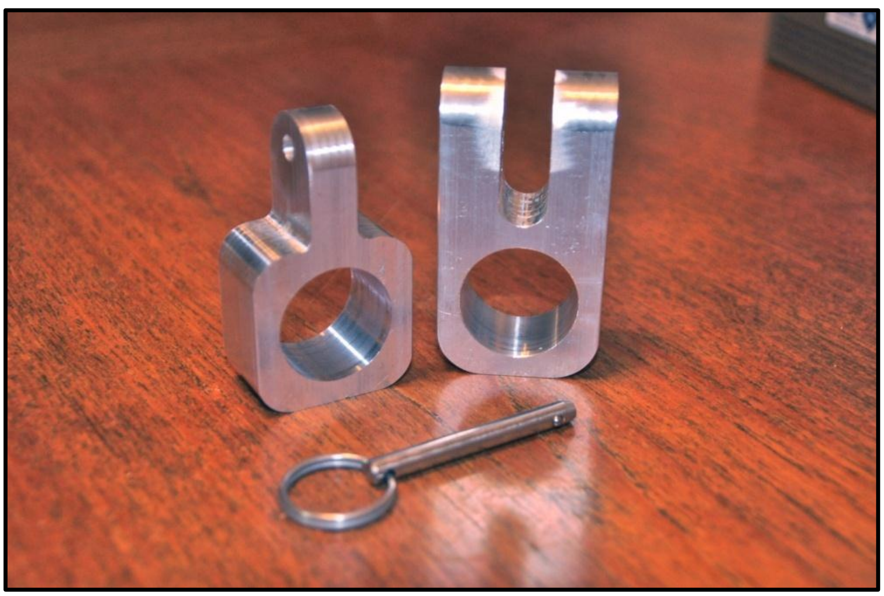

Figure 10. Inner & Outer Joint with Connecting Pin

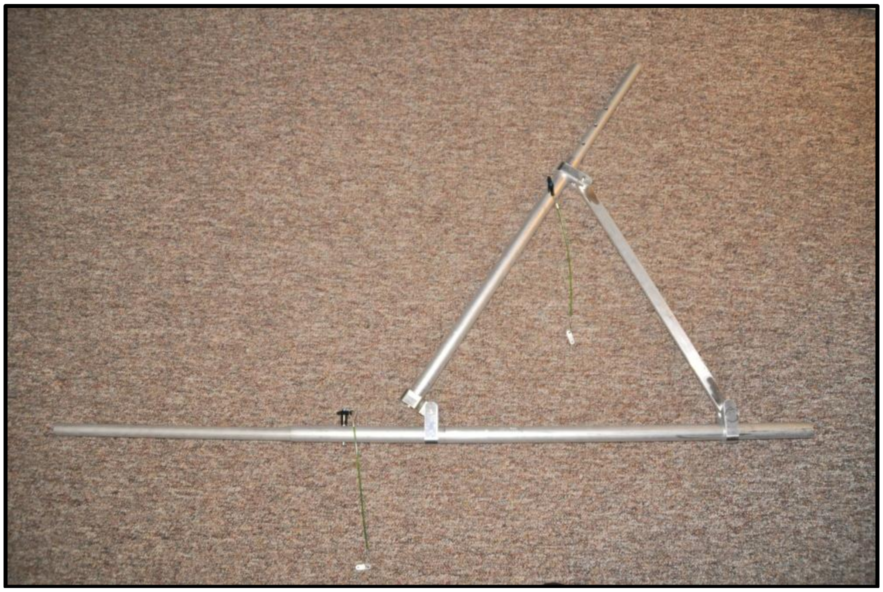

Figure 11. Completed Side of UPF

The table top was completed utilizing a mill for the interface holes and a 3-axis vice for the angled pipe holes. It was difficult to setup the 60-degree angle cut to ensure the hole would align properly with the angled pipe sleeve. Luckily, the 3-axis vice allowed us to mount the table top at the proper angle to drill the hole with precision. The wheel mounts were also completed during this time from a large billet of aluminum. The four parts were cut to length and de-burred before drilling holes for the pipe and wheel bushing. Two of the four parts were also milled to remove excess material but time constraints prevented us from finishing the other two. Removing the excess material was not necessary but provided a slight weight reduction and aesthetic appeal. Rather than trying to mount the Cargo Buckles as a sleeve over the pipe sections, mounting plates were cut from excess stock and drilled for the mount hole. After all these components were completed, the frame was transported to Orange County to be welded by a professional welder. The AED team utilized this connection rather than trying to weld the frame themselves because aluminum is a very difficult metal to weld and requires a very specific technique. Prior to welding, the frame was assembled as shown in **Figure 12** and **Figure 13** to ensure the dimensions and layouts were accurate.

Figure 12. Assembled UPF (without Wheels & Cargo Buckles)

Figure 13. Side Assembly Layout for Welding

Figure 14 shows a side-view of the frame which simulates a person sitting in a wheelchair and details their distance from the table top (adjustable). Note: the height of the chair relative to the table top is not accurate due to wheels not being attached. In the picture, the cross supports had not yet been drilled but were not necessary for welding, so they were completed back in San Luis Obispo. The cross supports required holes for the front and rear tubing and the securing pins and were drilled on a drill press and mill.

Figure 14. Side View of Frame with Approximated User

The welding process was very successful considering the difficulty and only resulted in one error. One side of the upper outer pipes was rotated and welded at an incorrect angle, resulting in the inner pipe being misaligned with the table top. The problem was simply resolved by drilling an additional hole at the correct angle and alignment. However, an additional hole was drilled on the other side to ensure proper height adjustment between the two sides of the table top. The result is an extra set of holes in the upper pipes that will not be used.

The frame was transported back to San Luis Obispo and assembled as shown in **Figure 15** with all parts except the wheels and Cargo Buckles. All dimensions and alignment was checked to ensure the frame will perform as designed. Lanyards for the pins were not attached yet since the frame is to be powder coated and cannot contain any plastic components during the process. The key-ring grip pins are not used as often as adjustment pins and therefore do not have lanyards. Also, they may provide some resistance during use due to tight clearance holes but are safer than having larger holes with slop that do not hold the frame together.

Figure 15. Post-Weld Frame Assembly (without Wheels & Cargo Buckles)

We attached the Cargo Buckles and disassembled the frame to show the amount of storage space necessary. As shown in **Figure 16**, the frame occupies a relatively small area. A standard broom and hammer were laid in the figure to show a relative scale of the frame. The frame is easily transported with two people holding a couple pieces each. Transportation could be further eased and simplified using a proper sized duffle bag with wheels to roll it rather than carry.

Figure 16. Disassembled Frame

The wheel bushings were then press fit into the wheel mounts with the magnets above to hold the wheels in place. The UPF was then assembled and layout verified with an attached wheelchair as shown in **Figure 17**.

Figure 17. Full-Assembly of UPF w/Wheelchair

B. Discrepancies from Planned Design

1. Wheels
The wheels were initially analyzed to be between 6 and 8 inches in diameter. However, as discussed in the wheel part description, the client Dr. Taylor desired large wheels that were reliable as per another adaptive project experience. The larger wheels raised the UPF height a couple inches and required a wider frame to allow the wheels 360 degree rotation to not interfere with the user's wheelchair. Wheel mounts were also additional parts fabricated to provide a housing for the mounting magnet and bushing.

2. Telescopic Tubing
The major component of the UPF that changed from the planned design was the telescopic tubing. Testrite Visual was not cooperative in providing quotes promptly for our project's needs so our team researched elsewhere. The non-rotational feature was no longer to be included in the design unfortunately as it would have kept adjustment holes aligned during adjustment. Ultimately, the tubing was purchased from Tube Services as they were able to cooperate with our needs. The most difficult aspect was finding two outer diameters that fit within one another but also minimized slop clearance. We ultimately used 1.00 and 1.25 inch outer diameter tubing with 0.065 inch thickness, which provided 0.060 inches of clearance. Adjustment holes were drilled after ordering to provide the adjustment system in the tubing.

3. Table Top & Cross Supports
Due to 12" diameter wheels being used, the table top and cross supports were extended to a 40" width to ensure the wheels could fully rotate and not interfere with user's wheelchair.

4. Welding Errors
There was one minor weld error attributed to the third party who aided our team in welding the UPF. The upper pipe was misaligned to the joint pieces during welding but was remedied by re-drilling the adjustment hole in each side. The minor draw-back is an additional hole that is not used will be showing.

C. Recommendations for Future Prototypes

The UPF accomplished a majority of high importance customer requirements and engineering specifications our team set out to meet. Additional parts that were not anticipated added additional weight and material costs but ultimately provided for a much higher quality and durable product. We were lucky to have the connection for welding the thin-wall aluminum tubing since it was extremely challenging according to professional welders with over 20 years of experience. In hindsight, aluminum may be a light-weight material but it can extremely difficult to weld and work with. Future UPFs may look to different methods of securing parts that aren't removable or adjustable to avoid welding should aluminum be used again. Also, if the design can be reduced in parts or weight, steel may be a viable material and could simplify the welding process. Tolerances on every interfacing part also caused some "slop" in the frame and were very difficult to manage. It wasn't until the frame was assembled we noticed some tolerance slop. More precise machining could reduce slop and provide tighter fits. The additional of larger than anticipated wheels resulted in a slightly high table top in comparison to a manual wheelchair. However, most wheelchairs being used with the UPF will be powered and might stand higher in comparison with the table top, placing it closer to the user's waistline. Future UPFs should reduce the minimum adjusting height of the table top.

V. Design Verification

A series of tests were used to ensure the final design met the specifications originally developed. Weight and size were easily measured using a scale and tape measure. The project originally had an anticipated cost per frame of $500 but has changed significantly since. The detailed bill of materials is shown in **Appendix C: List of Vendors & Bill of Materials** and shows the exact cost of the UPF VI. By using the Cargo Buckle as the method of attachment, the frame will be able to attach over a much larger range of points on the chair than originally specified. The actual range will be verified using a standard tape measure. The proposed frame tubing diameters are 1.25 inches and 1.00 inches, well within the established range shown in **Table 2**.

The frame will be load tested by applying at least 100 lbs of weight at possible adaptive device locations, guaranteeing the frame can safely support loads of this magnitude. While none of the current adaptive devices actually weigh 100 pounds, we have greatly increased the anticipated load to account for additional stress induced by users or the device when in use. Also, analysis completed utilized a design factor of 2, meaning the analysis ensures a load of 200 pounds will not cause the frame to break. The frame will also be attached to a wheelchair and tested for maneuverability on all potential terrains. Because the performance of the frame in this area will not be easily quantifiable, user testing and feedback will be used to verify whether the maneuverability of the frame is acceptable. During testing, the UPF easily rotated 360 degrees and traversed concrete, loose gravel, and thick grass. It definitely excels in this area.

Time is an important consideration in the use of the UPF by Friday Club. Assembly and attachment time will be measured for a two person assembly. The total assembly and attachment time will take no more than five minutes and confirmed by a timed test which resulted in about 3 minutes. Detachment and disassembly are similar to assembly time and also took around 3 minutes. Listed below are the equipment items necessary to conduct all tests. **Table 6** is a checklist to display whether or not a specification has been met.

Necessary Test Equipment:

- Tape Measure
- Scale
- 100 pound weight
- Stop Watch

Table 6. Testing Verification of Specifications

Parameter Description	Requirement or Target	Met	Result
Weight	30 lbs	N	50 lbs
Volume (Disassembled)	3 cubic feet	N	4.34 cubic feet
Volume (Assembled)	30 cubic feet	N	65.69 cubic feet
Vertical Adjustment Range	34-42"	N	42-50”
Width Adjustment Range	24-36"	N	40” (Fixed)
Chair Attach Height	4"-12"	Y	12”
Frame Diameter	.75"-2.00"	Y	1.25” & 1.00”
Load Supported	100 lbs	Y	175 lbs
Lifespan	5 years	N/A	N/A
Design Factor	2	Y	+2
Loose parts	0	Y	0
Tools required	0	Y	0
Lightweight material	Aluminum	Y	Aluminum
Table interface constant	Male-Female Joint	Y	Same
Large, free moving wheels	6-10"	N	12”
Deflection	0.5"	Y	0.75” in Table Top
Cost	$500 ea	N	$1239.65
Assembly/Disassembly time	5 min	Y	3 min
Changing Users	3 min	Y	2 min
Terrain maneuverability	Acceptable	Y	Flat, Dirt, Grass

In summary, the UPF excels in categories important to the Friday Club: it is highly maneuverable, able to adjust to any wheelchair, can adjust to various sized wheelchairs, and time saving from the previous UPF. Recommended changes to the UPF design are listed in section **C. Recommendations for Future Prototypes**.

VI. Design Development

A. Conceptual Designs

In order to meet the requirements of Friday Club and our sponsors, our team developed a variety of frames and styles ideas through brainstorming. We focused on a completely new design rather than improving the UPF V because many issues have been carried through previous models. The following figures discuss our major brainstorm concepts (those which were completely impractical are not shown).

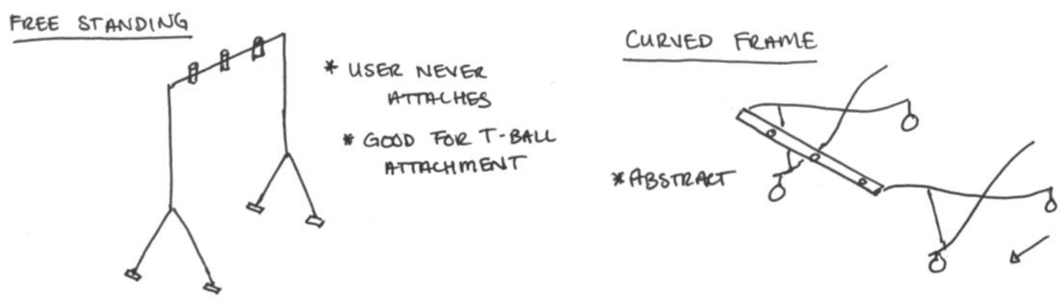

Figure 18. Concepts Group 1

Figure 18 shows the Free Standing and Curved Frame concepts that were among the first ideas brainstormed. Many problems are involved with the attachment to wheelchair system so eliminating the necessity to attach would simplify the UPF greatly. This however would only work with certain adaptive devices and greatly limit its use. The Curved Frame is similar to a box-style frame that encloses the athlete and wheelchair, but utilizes curved geometries for aesthetic appeal. Other curved geometry concepts were developed but are not shown. Concerns with manufacturing curved beams may make production difficult and expensive.

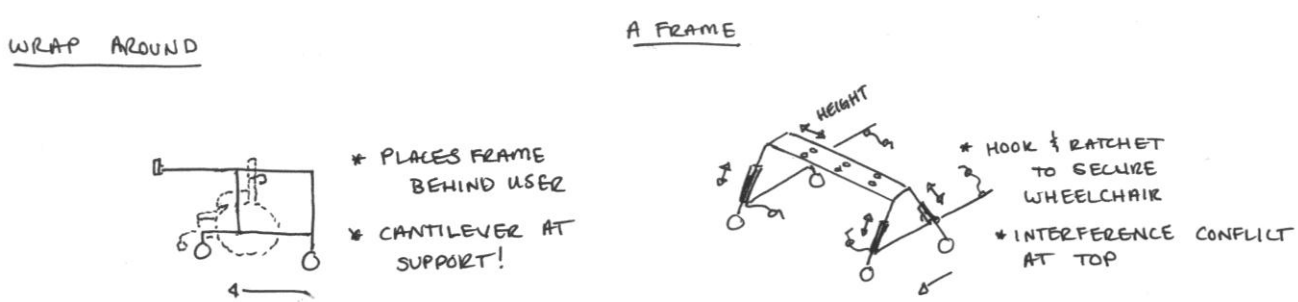

Figure 19. Concepts Group 2

Figure 19 shows the Wrap Around and A Frame concepts that focused on practical solutions. The Wrap Around concepts focuses on placing the support framing behind the athlete so the adaptive equipment is the only thing in their focal view and allows for a more direct feeling. However, the adaptive equipment would be hanging from an unsupported end and therefore require a lot of material to ensure safe use. More material in turn makes the frame heavier and more expensive. The A Frame is a much more rigid and simple design that allows for simple adjustability. Rather than having a rigid secure point

to attach a wheelchair, hook and ratchet systems similar to cargo tie-downs would be used to allow any wheelchair to attach securely. Although telescoping legs would allow the height to adjust, there are four points that need to simultaneously adjust while the adaptive device is supported and would require a few assistants to accomplish the task.

B. Concept Selection

One of the primary focuses in generating new ideas was not to be constrained by past prototypes. In all previous UPFs, the design was based from the market product the "Equalizer" (shown in **Figure 1**). In order to avoid a simple re-design of a failed concept, many frame configurations were brainstormed and explored, as shown in the previous section. In order to select a brainstorm concept, we utilized an evaluation technique called a Pugh matrix that evaluates concepts in comparison to a datum or benchmark (in this case the UPF V). The matrix also helps focus on the strengths and weaknesses of each concept and delivers relative scores. A copy of the Pugh matrix generated can be seen in **Table 7** below.

Table 7. Pugh Matrix Analysis of Concepts

Concepts / **Criteria**	2 Wheel (UPF V)	3 Wheel	4 Wheel	Curved Frame	A-Frame	Free Standing	Floating (no wheels)	Wrap Around
Maneuverable	D	S	+	+	+	-	+	+
Attaches to chair	D	S	S	S	+	+	-	+
Adjustable	D	S	S	-	+	+	S	+
Compatibility	D	-	S	S	S	S	S	S
Safe	D	S	+	S	+	+	-	+
Lightweight	D	+	-	S	+	S	-	S
Collapsible	D	S	S	-	+	+	-	+
Durable	D	-	-	S	+	+	-	+
Stable	D	-	-	+	+	+	-	+
Construction	D	S	S	-	+	+	-	S
Repair	D	S	S	-	+	S	S	S
Σ +	D	1	2	2	9	7	1	6
Σ -	D	3	3	4	0	1	7	0
Σ S	D	7	6	5	2	3	3	5

The results of the Pugh matrix analysis clearly favor the A Frame design, but the Wrap Around and Free Standing concepts also scored fairly well in respect to the UPF V. The A Frame design offers improved adjustment capabilities as well as a strong rigid structure to support the sport attachments. The A Frame would also extend further back along the wheelchair to allow for more attachment points for the frame to the wheelchair (extension not shown in model figures). In addition, this concept also has four wheels (wheels not shown in model figures) compared to two on all previous models of the UPF which would allow for greater maneuverability. A mockup of the A Frame concept is shown in **Figure 20**.

Although the Free Standing frame (one that would simply rest on the ground) scored well relative to the datum, the frame would not attach to the wheelchair and prevent certain adaptive devices from being used with the new design. In order to include the features of the Free Standing frame into the A Frame, the wheels could be anchored to soft ground or locked into place to perform as the Free Standing frame would, eliminating the need for a separate frame. Both the A Frame and Wrap Around frame offer many more locations for attachment as well as different methods of attachment to accommodate each athlete's unique wheelchair. The new concepts also both have four wheels which would allow for improved maneuverability especially when used on different terrains such as grass.

Figure 20. A Frame Concept Design (wheels and extensions not shown)

The Wrap Around frame however was not pursued as a concept due to its large amount of material required to properly design the frame. More material makes the system heavier and more costly, both of which are important specifications for the UPF design. Also, the design would utilize the interface support as a cantilever beam, which is usually avoided in design. Applying loads to the end of the support would create large stresses and result in failure of the design, which does not satisfy the requirements of durability and a 5 year minimum life.

A major concern with the A Frame geometry was that the adjustment points requiring synchronized precision to prevent misaligned angles in the user interface. We continued developing A Frame design concepts by varying geometries and how the UPF would function with respect to the user. If the A Frame has a stationary bottom frame (adjustments extend upward), the adjustments would interfere with each other and make the UPF useless. However, if the upper frame was stationary and the bottom frame adjusted (adjustments extend downward), assistants would have to support the frame while simultaneously adjusting the legs. These methods require multiple adjusters and consume too much time. Additional brainstorm ideas to solve this problem were developed and are shown below in **Figure 21**.

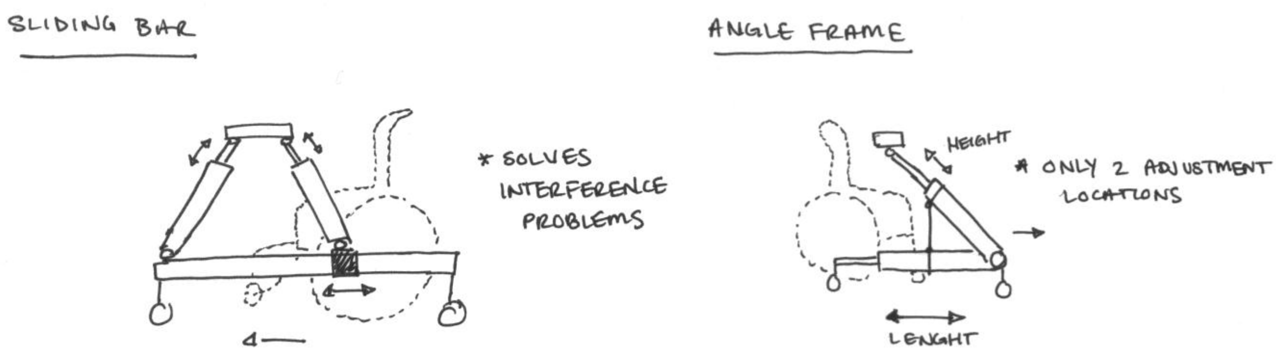

Figure 21. Secondary Brainstorm Concepts

Figure 21 shows the Sliding Bar and Angle Frame concepts. These concepts eliminate complex adjustment systems and resolve the problem of interfering telescope tubes. The Sliding Bar is similar to the A Frame but utilizes a fixed and sliding end to adjust the height of the system. Although the adjustment problem is solved, the component to which the sliding bar is attached must be very long and would be difficult to store. The Angle Frame utilizes a pivoting elbow and two arms with telescoping tubes to adjust the height and length to the athlete. The frame sits around the wheelchair and athlete and requires only two adjustment locations. Stability in the frame is accomplished with stability bars that are removable for storage.

Previous prototypes have used a clamping system to attach the UPF to the wheelchair with limited success. The clamp loses grip during use with the adaptive devices and causes the UPF to shift and rotate in relation to the user. In order to correct the shifting, the frame needs to be constantly readjusted and the clamps retightened, both time consuming operations. Due to the rigidity of the clamp (which is bolted to the arm), the attachment location to the wheelchair is limited by the dimensions and shape of the frame. In order to make the attachment more versatile and easier to attach, we would implement a system of 4 hooks attached to vinyl straps. The straps would be tensioned by either standard tie-downs or ratchet tie-downs (**Figure 22**). By having four corners of the UPF tensioned to the wheelchair, the attachment system acts like a 4-point harness and keep the UPF from interfering with the wheelchair. Utilizing bungee cords in place of the hooks and nylon straps is also being considered, which is what the Foam Wars project currently uses. Assistants who secure athletes into the Foam Wars device have consistently said that the bungee cord method is simple and easy. However, the Foam Wars device is only used indoors. The variable tension in bungee cords could cause the problem of the UPF interfering with the wheelchair's function when used on rough terrain, which is why nylon straps are being primarily considered. Also, nylon straps have higher load strengths and can handle tension loads better than a bungee cord. In order to maintain a secure attachment to the wheelchair, especially on rough terrains, the lower portion of the Angle Frame telescopes to extend beyond the rear of the athlete's wheelchair and provides an attachment location. This system was experimentally tested using the Foam Wars frame and simple nylon truck tie downs as seen in **Figure 23**. The wheelchair was easily maneuvered by the athlete and the Foam Wars frame followed without noticeable lag. However, solution to the excess straps and setup time will be pursued to ensure the attachment system is quick and simple to use for Friday Club assistants.

Figure 22. Vinyl Strap Tensioning System

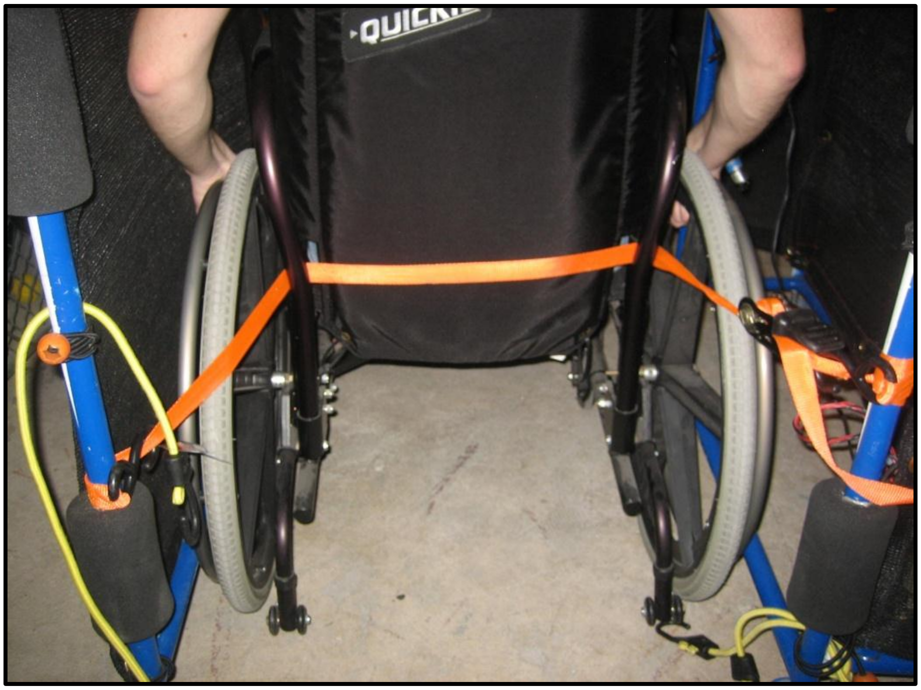

Figure 23. Testing Nylon Strap System on Foam Wars Frame to Wheelchair

In order to select among the refined concept designs shown in **Figure 21**, a similar Pugh Matrix analysis was conducted with the A Frame and Angle Frame concepts. As seen in **Table 8**, the two frames have very similar strengths and weakness. It was ultimately decided that the Angle Frame was the best concept since it was easier to adjust and used less material, therefore lighter in weight and lower costs.

Table 8. Secondary Pugh Matrix Analysis

Concepts **Criteria**	2 Wheel (UPF V)	Sliding Bar	Angle Frame
Maneuverable	D	+	+
Attaches to chair	D	+	+
Adjustable	D	+	+
Compatibility	D	S	+
Safe	D	S	+
Lightweight	D	+	+
Collapsible	D	-	+
Durable	D	+	+
Stable	D	+	+
Construction	D	+	+
Repair	D	+	+
Σ +	D	8	11
Σ -	D	1	0
Σ S	D	2	0

C. Concept Justification

Initial concept analysis demonstrated the A Frame was a valid solution to the UPF V's design problems. The A Frame itself is a triangular shaped frame and was developed from the "A-Bike" as seen in **Figure 24**. The sides of the triangle would consist of telescoping tubing while the support bar would be a small rod or tube with a locking hinge on either side. When in use, the base would be locked into place and the silhouette of the frame would be a triangle (or "A" shaped with the wheels.) When not in use, the small rod's hinge would be unlocked and allow for the base of the triangle to fold inwards. The sides of the frame telescope into itself, similar to a camera tripod and allow the frame to collapse to a very small volume. The entire UPF would be made of two A Frames connected at the apex by an attachment plate. After more consideration, the A Frame orientation would cause problems with adjustment and use so we decided to rotate the frame on its side to create the Angle Frame. This orientation makes the adjustments independent of each other so that height and length only requires one adjustment on each side of the frame and thus can be performed with fewer assistants. Overall, the Angle Frame provides significant improvement from the UPF V and satisfies the sponsor's requirements of adjustment, attachment, collapsibility, and durability.

Figure 24. A-Bike Product That Utilizes "A Frame" Structure

D. Preliminary Analysis

Before spending valuable time developing a final design, it is necessary to complete preliminary design analysis to ensure the Angle Frame concept will function without failure. Although exact materials and dimensions have not been finalized, the analysis results in large enough design factors that minor changes will not affect the performance. Design factor is an engineering concept that ensures a design will not fail when loads in excess of the anticipated regular load are applied. In the case for the UPF, the anticipated weight of an adaptive device is at maximum 100 pounds, so the analysis is conducted utilizing a load of 200 pounds, which results in a design factor of 2. Primary failure modes examined were ensuring the supports didn't buckle or bend, and that any pin wouldn't break. More detailed analysis is outlined in **Appendix D: Preliminary Analysis**. Summarized results from the appendix are shown in **Table 9**.

Table 9. Summary of Preliminary Analysis

Failure Mode	Part	Result	Design Factor
Buckling (Pcr)	Support Bar	1967 lbf	9.8
Buckling (Pcr)	Circular Tubing	2248 lbf	11
Bending (σ)	Telescopic support	17717 psi	4.6
Shear (τ)	Pin	159 psi	29
Deflection (δ)	Table Top	0.1207 in	N/a

Sizing the frame was also a critical issue. Various geometries were tried and evaluated to provide the best orientation of the frame relative to the athlete. Utilizing online research regarding standard wheelchair dimensions and past UPF analysis, **Figure 25** represents the anticipated dimensions of the UPF VI. As the project progresses, these dimensions might be changed if problems arise during fabrication.

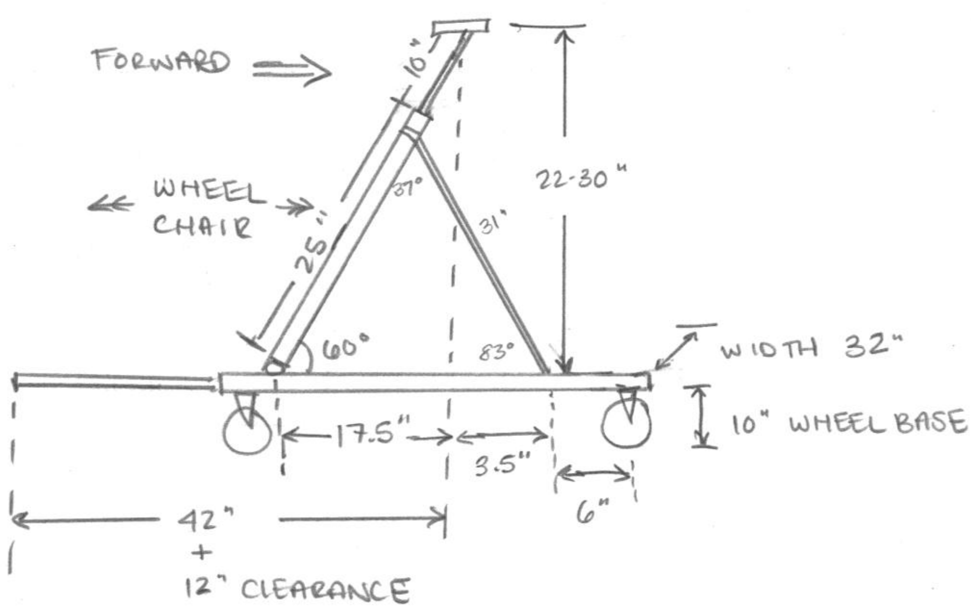

Figure 25. Anticipated Frame Dimensions

VI. Conclusion

A design process has been used to help define the problem of re-designing the Universal Play Frame and turn the Friday Club's needs into engineering specifications. After extensive brainstorming, the Angle Frame design was selected because it best satisfies the defined specifications. The Angle Frame offers the benefits of being easily collapsible and adjustable, while maintaining a weight within the specifications set. By utilizing the Cargo Buckle as the method of attachment, the main issue of universal attachment to all wheelchairs was resolved. The new method of attachment will allow for much easier and quicker setup of the UPF, allocating more time for the UPFs to be used by the athletes at Friday Club. The improved collapsibility of the frame also allows for the UPF VI to be transported to other locations for use at day clubs in the local San Luis Obispo area. Testing of the UPF VI show the design met the majority of customer requirements within accepted ranges, although a few specifications were not met. However, these discrepancies do not affect the performance of the UPF and were difficult to avoid. Overall, the project succeeded in providing the Friday Club with a collapsible, adjustable, and universal play frame that is quick and easy to use.

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Appendix A: QFD Analysis

Universal Play Frame VI
AED: Adaptive Exercise Designs
"Friday Club"

Engineering Requirements

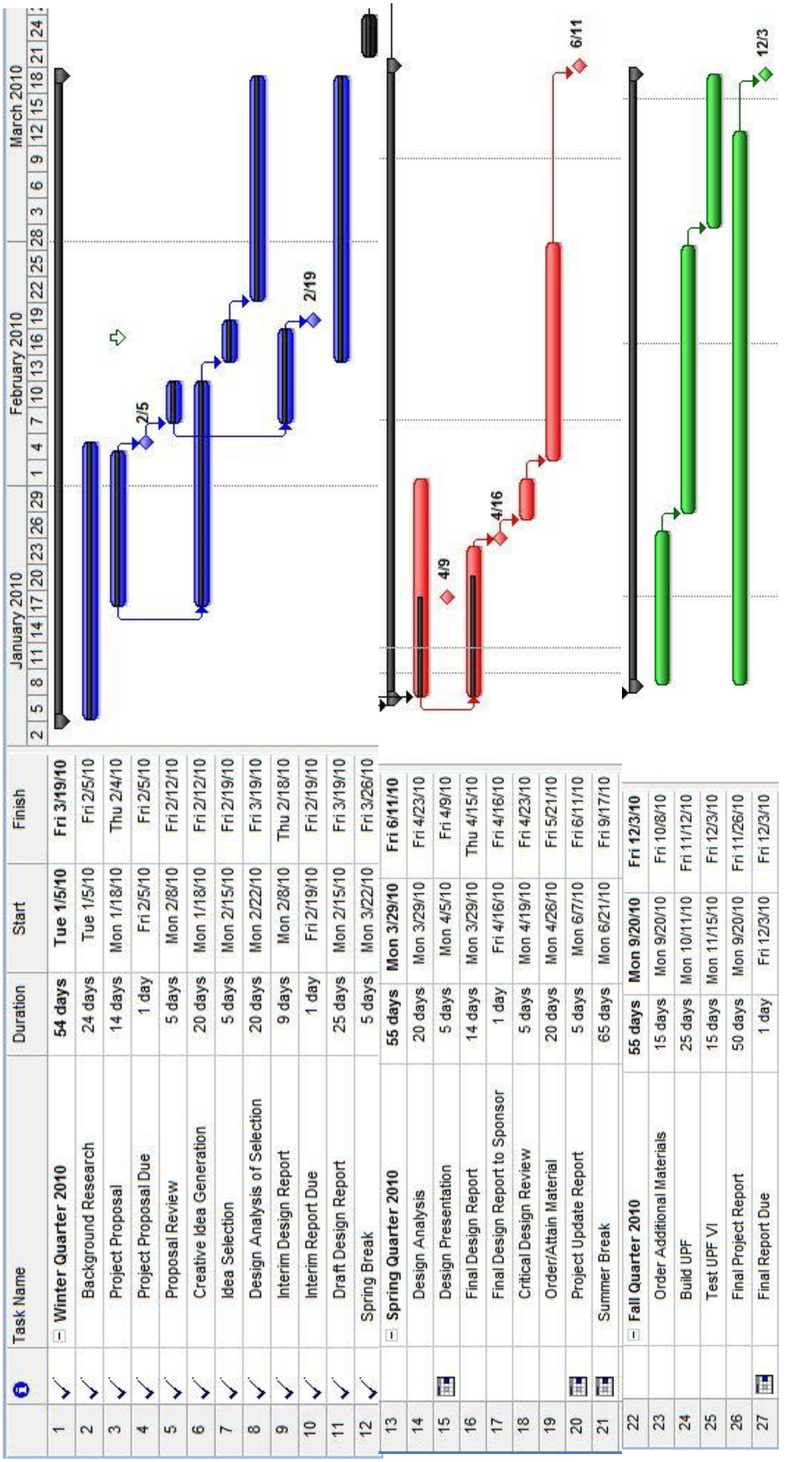
Customer Requirements	Weighting (1 to 5)	Frame Shape	Under 30 lbs	Volume w/in 9 cu.ft	No detaching parts	Free-moving wheels	Steel or Aluminum Framing	Female attach mounts	No tools for use	Chair attach height 4-12"	Chair attach diam. 0.75-2"	Adjust vertically 34-42"	Deflection < 0.5"	Telescope adjust 18-24"	Width adjust 24-36"	Life span 5 years	No special fabrication	Large wheels	Support 50-100 lbs	UPF V (Benchmark)	UPF IV (Benchmark)
Function																					
Maneuverable	5	3	9			9												9		4	3
Attaches to chair	4	3							9	3	9									3	2
Multi-terrain capable	4					9												9		2	1
Adjustable	5	1	1	3				3	9	9	3	9		9	9					3	2
Compatibility	5	3						9	1			3		3						4	2
Limited loose parts	3				9				3											4	4
Safe	5		3		1		3	1					1		1	1		1	9	3	3
Physical Design																					
Lightweight	4		9				3													3	3
Collapsible	4	3		9																3	3
Storage volume	4	3		9																3	3
Durable	5	3				1	9						9			9				2	3
Stable	5	9				3	3			3	3		9					3	9	2	1
Manufacturing																					
Materials	3						9						3			9	3		3	4	4
Construction	4	1			1		3						3			9	9		3	2	2
Repair	3	3			1		3		3				1			3	9			2	2
UPF V		98	75	63	43	62	90	84	80	42	42	51	59	51	30	81	48	63	63		
UPF IV		84	77	60	82	72	108	37	69	30	30	27	75	27	22	109	66	73	78		
Importance Scoring		144	101	87	39	101	135	65	104	72	66	60	119	60	50	122	72	101	111		
Importance Rating (%)		100	70	60	27	70	94	45	72	50	46	42	83	42	35	85	50	70	77		

Quality Function Deployment (QFD) helps transform customer requirements into engineering specifications. The QFD table relates the importance of all user requirements to technical engineering specifications as well as analyzes how well past designs have satisfied these needs. The result of the QFD table delivers a relative importance scoring for each specification for past designs, as well as the intended new design. The importance scoring is marked by 1, 3, & 9 in increasing importance and relevance for each specification. The results demonstrate the following criteria have high importance in the new design: frame shape, frame material, strength and deflection, and life span.

Appendix B: Project Timeline

In order to optimize organization and time management, a Gantt chart (next page) was constructed to appropriate sections of the project to each of the three quarters. Our team will equally work on each task and rotate responsibility on additional tasks as necessary. While not a definite schedule, it provides a general idea of our expected progress. The major goals of each academic quarter are as follows:

- Fall Quarter 2009: Compose a Project Proposal, Interim Design Report, and Draft Final Design Report
- Spring Quarter 2010: Deliver Design Report and begin material purchase and prototype construction
- Fall Quarter 2010: Finish building and testing of prototype. Deliver Final Project Report and completed product



ID		Task Name	Duration	Start	Finish
1	✓	**Winter Quarter 2010**	**54 days**	**Tue 1/5/10**	**Fri 3/19/10**
2	✓	Background Research	24 days	Tue 1/5/10	Fri 2/5/10
3	✓	Project Proposal	14 days	Mon 1/18/10	Thu 2/4/10
4	✓	Project Proposal Due	1 day	Fri 2/5/10	Fri 2/5/10
5	✓	Proposal Review	5 days	Mon 2/8/10	Fri 2/12/10
6	✓	Creative Idea Generation	20 days	Mon 1/18/10	Fri 2/12/10
7	✓	Idea Selection	5 days	Mon 2/15/10	Fri 2/19/10
8	✓	Design Analysis of Selection	20 days	Mon 2/22/10	Fri 3/19/10
9	✓	Interim Design Report	9 days	Mon 2/8/10	Thu 2/18/10
10	✓	Interim Report Due	1 day	Fri 2/19/10	Fri 2/19/10
11	✓	Draft Design Report	25 days	Mon 2/15/10	Fri 3/19/10
12	✓	Spring Break	5 days	Mon 3/22/10	Fri 3/26/10
13		**Spring Quarter 2010**	**55 days**	**Mon 3/29/10**	**Fri 6/11/10**
14		Design Analysis	20 days	Mon 3/29/10	Fri 4/23/10
15		Design Presentation	5 days	Mon 4/5/10	Fri 4/9/10
16		Final Design Report	14 days	Mon 3/29/10	Thu 4/15/10
17		Final Design Report to Sponsor	1 day	Fri 4/16/10	Fri 4/16/10
18		Critical Design Review	5 days	Mon 4/19/10	Fri 4/23/10
19		Order/Attain Material	20 days	Mon 4/26/10	Fri 5/21/10
20		Project Update Report	5 days	Mon 6/7/10	Fri 6/11/10
21		Summer Break	65 days	Mon 6/21/10	Fri 9/17/10
22		**Fall Quarter 2010**	**55 days**	**Mon 9/20/10**	**Fri 12/3/10**
23		Order Additional Materials	15 days	Mon 9/20/10	Fri 10/8/10
24		Build UPF	25 days	Mon 10/11/10	Fri 11/12/10
25		Test UPF VI	15 days	Mon 11/15/10	Fri 12/3/10
26		Final Project Report	50 days	Mon 9/20/10	Fri 11/26/10
27		Final Report Due	1 day	Fri 12/3/10	Fri 12/3/10

Appendix C: List of Vendors & Bill of Materials

Best in Auto
1739 Cassopolis Street
Elkhart, IN 46514
1 (866) 491-7437
http://www.bestinauto.com/

Full Spectrum Powder Coats
825 Buckley Road #400
San Luis Obispo, CA 93401
(805) 543-2596
http://fullspectrumpowdercoating.com/

McMaster-Carr
6100 Fulton Industrial Blvd. SW
Atlanta, GA 30336-2853
(404) 346-7000
http://www.mcmaster.com/

Online Metals
1138 West Ewing
Seattle, WA 98119
(800) 704-2157
http://www.onlinemetals.com/

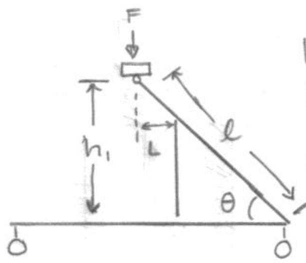
Phil & Teds
http://philandteds.com/en/home
(Brick & Mortar Location):
Chicken Little
1236 State Street
Santa Barbara, CA 93101
(805) 962-7771

Tube Service
9351 South Norwalk Blvd
Santa Fe Springs, CA. 90670
(562) 695-0467
http://www.tubeservice.com/

No.	Part Name	UPF Part No.	Vendor	Part No.	Unit Price	Qty.	Part Cost	Shipping & Tax	Subtotal
1	Cargo Buckle	1800	Best In Auto	IMMF18800	$59.99	2	$119.98	$0.00	$119.98
2	6061-T6 Tubing: 1.25" & 1.00" OD x.065 W x 12' L	1101, 1102, 1201, 1202	Tube Service	N/A	$120.72	1	$120.72	$29.32	$150.04
3	Aluminum Rect. Bar: 0.5" Thk x 1" W x 6' L	1600	Mc Master	4490T22	$31.83	1	$31.83	$26.97	$58.80
3	T-Handle Pin: 0.25" D x 1.25" Length	1900	Mc Master	93750A308	$20.49	4	$81.96		$81.96
4	Ring Grip Pin: 0.25" D x 1.8" Length	1900	Mc Master	98404A138	$1.93	6	$11.58		$11.58
5	6061-T6511 Bare Aluminum: 1"x1.75"x3' L	1103, 1203	Online Metals	N/A	$25.69	1	$25.69	$12.56	$38.25
6	HSS 3-Flute End Mill for Aluminum	N/A	Mc Master	2716A53	$15.13	1	$15.13	$8.86	$23.99
7	Hi-Performance Carbide End Mill for Aluminum	N/A	Mc Master	8829A82	$38.79	1	$38.79		$38.79
8	6061 Aluminum Tube: 1.25" OD x 1.084" ID x 1' L	1700	Mc Master	9056K773	$13.68	1	$13.68	$5.54	$19.22
9	Front Wheel with J-Bar	1304	Phil & Teds	N/A	$59.99	4	$239.96	$26.00	$265.96
10	Aluminum Rect. Bar: 1.5" Thk x 3" W x 1' L	1301	Mc Master	8975K315	$34.51	1	$34.51	$15.24	$49.75
11	T-Handle Pin: 0.25" D x 1.75" Length	1900	Mc Master	93750A312	$21.48	2	$42.96		$42.96
12	T-Handle Pin: 0.25" x 1.5" Length	1900	Mc Master	93750A310	$21.00	2	$42.00		$42.00
13	Aluminum Rect: 2" H x 5" W x .125" Wall x 6' L	1700	Mc Master	88935K716	$50.67	1	$50.67	$18.08	$68.75
14	Teflon PTFE: 1" OD x .75" ID x 2' L	1302	Mc Master	8547K15	$13.82	2	$27.64	$12.06	$39.70
15	Disc Magnet: 1" D x .125" Thick	1303	Mc Master	58605K43	$14.48	4	$57.92		$57.92
16	Powder Coating (Estimate)	N/A	Full Spectrum	N/A	$130.00	1	$130.00	$0.00	$130.00
								Total Cost	$1,239.65

Appendix D: Preliminary Design Analysis

ANALYSIS | A-FRAME | 3/10/10



h_1 - LOWEST SETTING HEIGHT
h_2 - HIGHEST SETTING HEIGHT
L - MOMENT LENGTH
θ - ANGLE DURING USE
l - ARM LENGTH

TARGETS:

* WEIGHT < 30 lb_f
* HEIGHT RANGE OF 34" – 42"
* WIDTH 36"
* SUPPORT 50 - 100 lb_f
* $n_s \geq 2$

HEIGHT:

WHEELS ABOUT 6" IN DIAMETER, ∴ $h_1 = 34 - 6 = 28"$

VARY ANGLE FOR h_1

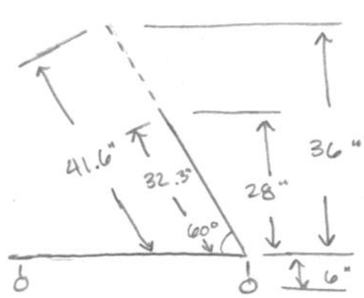
$\theta = 45° \Rightarrow l = 39.6"$

$\theta = 55° \Rightarrow l = 34.2"$

$\theta = 65° \Rightarrow l = 30.9"$

$\theta = 75° \Rightarrow l = 28.99"$

USE $\theta = 60°$



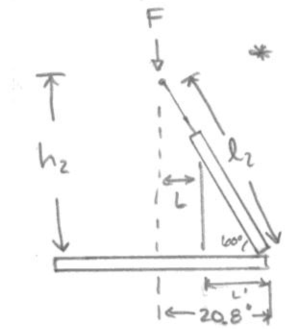
$h_1 = 28"$, $l_1 = 32.33"$

$h_2 = 36"$, $l_2 = 41.57"$

$\Delta l = 9.24"$ OF TELESCOPING

BENDING:

WANT TO REDUCE MOMENT ARM AS MUCH AS POSSIBLE



* MOST CONCERNED FOR BENDING AT MAX HEIGHT

F - LOAD APPLIED

l_2 - TELESCOPE LENGTH

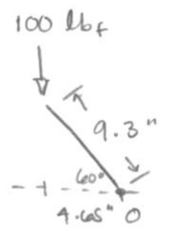
h_2 - HEIGHT FROM FRAME LEG

θ - ANGLE

L = MOMENT ARM

L' = SUPPORT BAR LOCATION

L' IS CONSTRAINED BY h_1 AND THEREFORE IS MAXIMUM AT 16.15". THUS, L = 4.65"



$$\Sigma M_o = (n_s F) L$$
$$= (2)(100\ lb_f)(4.65\ in)$$
$$= 930\ lb\text{-}in$$

$$\sigma = \frac{My}{I}$$

ASSUME d = 1.5", t = 0.065"

2024-T3 ALUMINUM $S_y = 50038$ psi

$$\sigma = \frac{930\ lb\text{-}in \left(\frac{1.5}{2} in\right)}{\frac{\pi}{64}(1.5^4 - 1.37^4)\ in^4} = 9228.37\ psi$$

$$n_s = \frac{50038}{9229} = 5.4$$ ✓

PIN SHEAR STRESS

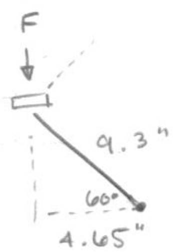
$V = n_s F = 2(100) = 200\ lb_f$

$d = 1''$

$A = \frac{\pi}{4}(1'') = 0.785\ in^2$

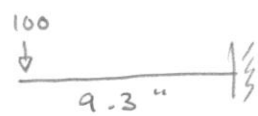
$$\tau = \frac{4V}{3A} = \frac{4(200)}{3(.785)} = 339.7\ psi < S_y = 50038\ ✓$$

DEFLECTION



200 cos 60 = 100

MODEL AS:



$$\delta = -\frac{F\ell^3}{3EI}$$

$$= -\frac{100\ lb_f(9.3\ in)^3}{3(10600000\ psi)(0.0209\ in^4)}$$

$$= -0.1207\ in$$ (SMALL ENOUGH!)

BUCKLING IN SUPPORT BAR

$b = 1''$

$h = 0.7''$

$L = 28''$

$C = 1$

$I = \frac{1}{12}(1)(0.7)^3 = 0.0285 \text{ in}^4$

$A = (1)(.7) = 0.7 \text{ in}^2$

$$k = \sqrt{\frac{I}{A}} = \sqrt{\frac{.0285}{.7}} = 0.202 \text{ in}$$

$$\frac{L}{k} = \frac{28}{.202} = 138.56$$

CRITERIA:

$$\left(\frac{L}{k}\right)_1 = \left[\frac{2\pi^2(1)(10600000)}{50038}\right]^{1/2} = 64.63$$

$\frac{L}{k} > \left(\frac{L}{k}\right)_1$ SO USE EULER EQN

EULER:

$$P_{CR} = \frac{C\pi^2 E I}{L^2}$$

$$= \frac{(1)\pi^2(10600000 \text{ psi})(.0285 \text{ in}^4)}{(28 \text{ in})^2}$$

$$= 3810.3 \text{ lb}$$

$$n_s = \frac{3810}{200} = 19.1 \checkmark$$

Appendix E: Wheel Selection Analysis

Model: 6”x2” Pneumatic Swivel Caster w/Brake (E.R. Wagner)	
Pros	**Cons**
Brake locks roll and swivel	6” diameter
4.8 pound overall weight	Tire can go flat
Won’t damage flooring	$40 + SH
Can traverse grass	

Model: 8”x2” Solid Rubber Swivel Caster w/Brake (Harbor Freight)	
Pros	**Cons**
Brake locks roll and swivel	Brake often drags
Tire cannot go flat	Very heavy
Might mark/damage flooring	Very large
$20 no SH	

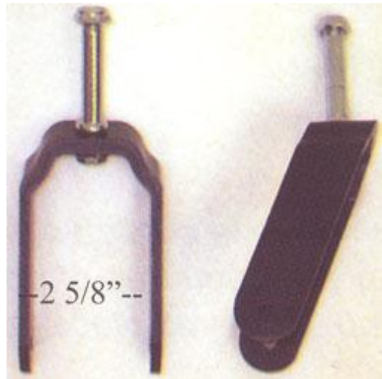
(Brakes not shown)

Model: 8”x2” Super Cushion Swivel Caster w/add-on brakes (Caster City)	
Pros	**Cons**
Doesn’t get flat	$70 + SH
Won’t damage flooring	Rotation and swivel locks additional costs
Can traverse grass	Weight unknown

Model: 8”x2” Pneumatic Swivel w/Tire Brake (Film Tools)	
Pros	**Cons**
Tire brake	$45 + SH
Might mark/damage flooring	Tire can go flat
Can traverse grass	Weight unknown

Model: 8”x2” Rubber Wheel/Fork Assembly (Nova Mack)	
Pros	**Cons**
Used on personal walkers	$40 + SH
Lightweight	Plastic Housing and rim (shorter lifespan)
4 Wheels support 400lbs	No locking system

Model: 8”x2” Semi-Pneumatic Swivel Caster (Mabis)	
Pros	**Cons**
Used on personal walkers	No locking system
Lightweight	Plastic rim (shorter lifespan)
$27.33 + SH	
3 Wheels support 250 lbs	

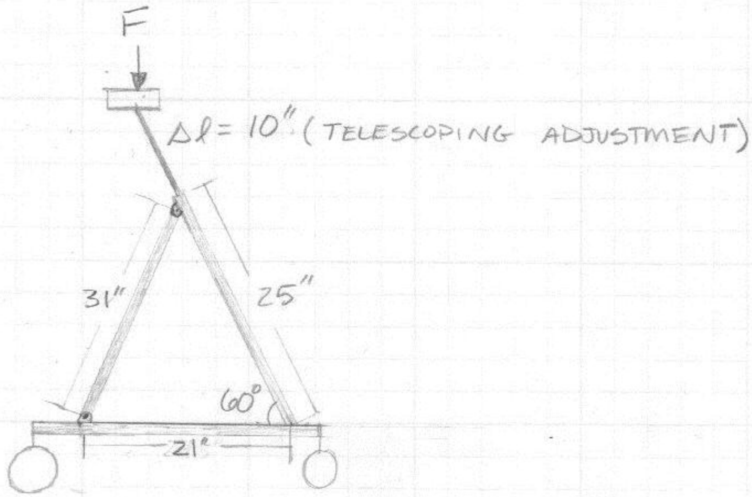


Model: 8”x1” Rubber Wheel/Fork/Axle Assembly (Edmond Wheelchair)	
Pros	**Cons**
Tire won’t go flat	Plastic rim
Won’t damage flooring	Cost $45 each
Lightweight	Not a pre-built assembly
Thin wheel width	

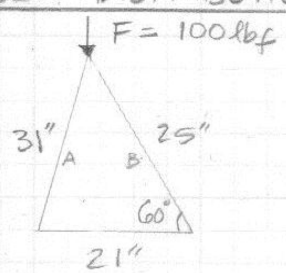
Model: 8”x1.25” Pneumatic Wheel (Chih-Young)	
Pros	**Cons**
Lightweight	Not a pre-built assembly
Won’t damage flooring	Unknown cost & oversea shipping
Thin wheel width	Need to buy rest of parts elsewhere
Aluminum spokes	

Manufacturer	E.R. Wagner	Harbor Freight	Caster City	Film Tools	Nova Mack	Mabis	Edmond	Chih-Young
Concept / **Criteria**	6" Pneumatic w/Total Lock	8" Rubber w/Total Lock	8" Super Cushion w/Total Lock	8" Pneumatic w/Tire Lock	8" Rubber Wheel/Fork	8" Semi-Pneumatic Wheel/Fork	8" Rubber Wheel & Assembly	8" Pneumatic Wheel
Traverse Uneven Ground	+	-	+	+	+	+	+	+
Cost (< $30 ea)	-	+	-	-	-	S	+	-
No Floor Damage	+	-	+	-	+	+	+	+
Tire Lock	+	+	+	+	-	-	-	-
Swivel Lock	+	+	+	-	-	-	-	-
Lightweight	+	-	-	-	+	+	+	+
Wheel Width (< 2")	-	-	-	-	-	-	+	+
Strength of Parts	+	+	+	+	-	-	-	+
Air-less Tire	-	+	+	-	+	+	+	-
Σ +	6	5	6	3	4	4	6	5
Σ -	3	4	3	6	5	4	3	4
Σ S	0	0	0	0	0	1	0	0

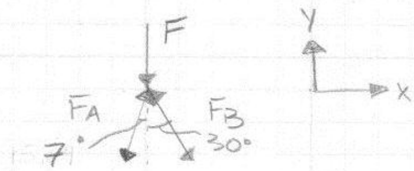
Appendix F: Final Design Analysis



FORCE DISTRIBUTION ANALYSIS



* EACH SIDE ONLY SEES HALF THE LOAD BUT A 100 lbf INCLUDES A $n_s = 2$.



ΣF_y: $F = F_A \cos 7° + F_B \cos 30°$

$100\,lbf = F_A (0.993) + F_B (0.866)$

ΣF_x: $F_A \sin 7° = F_B \sin 30°$

$F_A = F_B \dfrac{\sin 30°}{\sin 7°}$

$F_A = (4.10) F_B$ * SUB INTO ΣF_x EQ.

$100\,lbf = (4.10 F_B)(0.993) + 0.866 F_B$

$100\,lbf = 4.937 F_B$

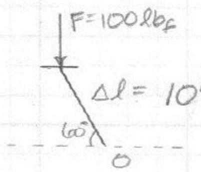
$F_B = 20.3\ lbf$

$F_A = 83.0\ lbf$

* FORCE IS MUCH MORE DISTRIBUTED COMPARED TO A VERTICAL SUPPORT LOWERING THE CHANCES OF FAILURE

* NEED TO CHECK BENDING AND DEFLECTION IN TELESCOPING PORTION OF THE UPPER TUBE

BENDING



$$M_o = (F)(10'' \cos(60°))$$

$$M_o = 500.0 \text{ lb}_f\text{-in}$$

$$\sigma = \frac{My}{I}$$

* USE PIPE DIAMETER $d = 1\,1/8''$ & WALL THICKNESS $t = 0.038''$

$$\sigma = \frac{(500.0 \text{ lb}_f\text{-in})\left(\frac{1.125}{2}\text{in}\right)}{\frac{\pi}{64}(1.125^4 - 1.049^4)\text{ in}^4}$$

$$\sigma = 14,656.5 \text{ psi}$$

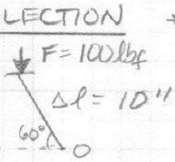
YIELD STRENGTH OF ALUMINUM $S_y = 50,038$ psi
$E = 10,600$ ksi

$$n_s = \frac{S_y}{\sigma}$$

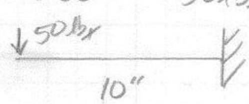
$$n_s = \frac{50,038 \text{ psi}}{14,656.5 \text{ psi}}$$

$$\boxed{n_s = 3.4}$$ * FACTOR OF SAFETY

DEFLECTION * DUE TO SPORTING ATTACHMENT



MODEL AS CANTILEVER BEAM
$100 \cos 60° = 50 \text{lb}_f$



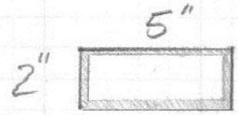
$$\delta = -\frac{Fl^3}{3EI}$$

$$= \frac{-(50 \text{ lb}_f)(10 \text{ in})^3}{3(10,600 \text{ ksi})(0.0209 \text{ in}^4)}$$

$$\boxed{\delta = -0.075 \text{ in}}$$ * VERY SMALL ESPECIALLY CONSIDERING THE WEIGHT WILL NEVER BE THIS LARGE

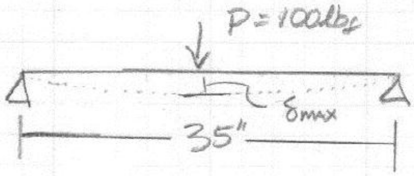
DEFLECTION OF TABLE TOP

- USE 2" x 5" HOLLOW ALUMINUM TUBING



THICKNESS = 1/8"
LENGTH = 35"

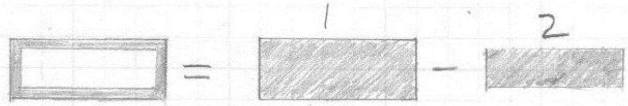
* MODEL AS A SIMPLY SUPPORTED BEAM W/ A POINT LOAD OF 100 lbf APPLIED AT THE MIDDLE



$E_{AL} = 10{,}000$ ksi

$$\delta_{max} = \frac{P\ell^3}{48EI}$$

* NEED I



$$I_{TOTAL} = I_1 - I_2$$

$$I = \frac{b_1 h_1^3}{12} - \frac{b_2 h_2^3}{12}$$

$$I = \frac{(5")(2")^3}{12} - \frac{(5" - 1/4")(2" - 1/4")^3}{12}$$

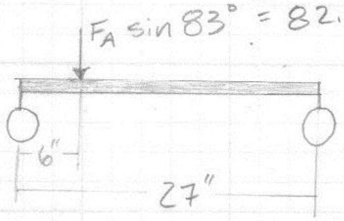
$$I = 1.212 \text{ in}^4$$

$$\delta_{max} = \frac{(100 \text{ lbf})(35 \text{ in})}{48\left(10{,}000 \frac{\text{kips}}{\text{in}^2}\right)\left(1.212 \text{ in}^4\right)}$$

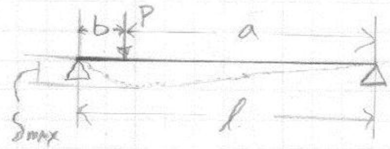
$$\boxed{\delta_{max} = 6.01 \times 10^{-6} \text{ INCHES}}$$

* THE DEFLECTION OF THE TABLE TOP CAUSED BY A 100 lbf FORCE IS VERY SMALL AND NOT A CONCERN FOR THE UPF APPLICATION.

DEFLECTION IN BOTTOM TUBE



* MODEL AS SIMPLY SUPPORTED BEAM



WHERE:

$E_{AL} = 10{,}600\,ksi$

$$I = \frac{\pi}{64}\left(1.25^4 - 1.174^4\right) in^4$$

$$I = 0.0266\,in^4$$

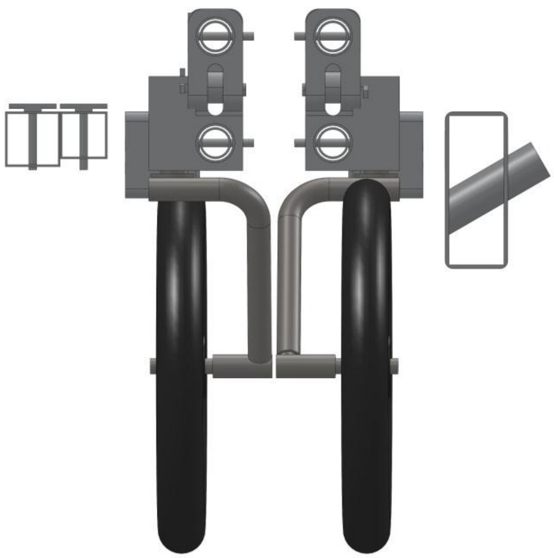
$$\delta_{max} = \frac{Pb\left(\ell^2 - b^2\right)^{3/2}}{9\sqrt{3}\,\ell E I}$$

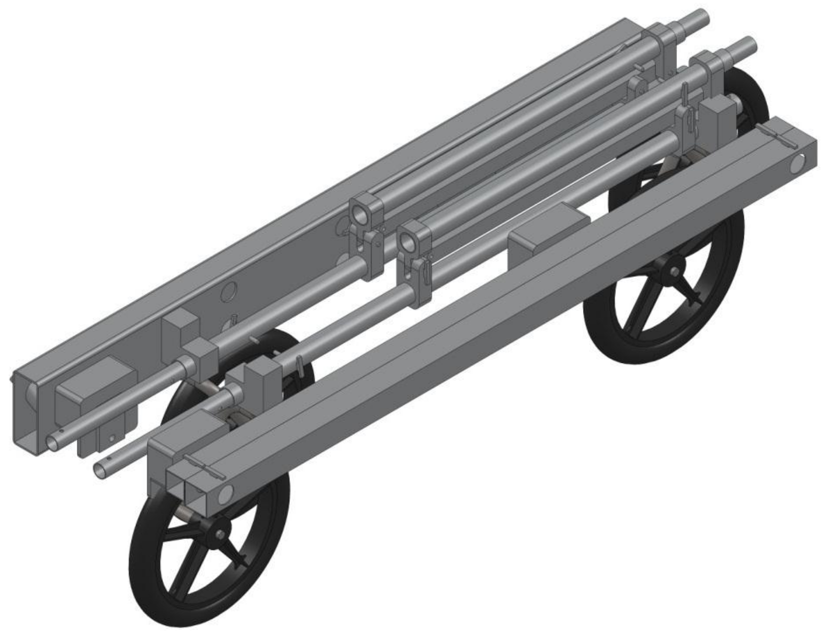
$$\delta_{max} = \frac{(82.4\,lb_f)(6\,in)\left(21\,in^2 - 6\,in^2\right)^{3/2}}{9\sqrt{3}\,(21\,in)(10{,}600\,ksi)(0.0266\,in^4)}$$

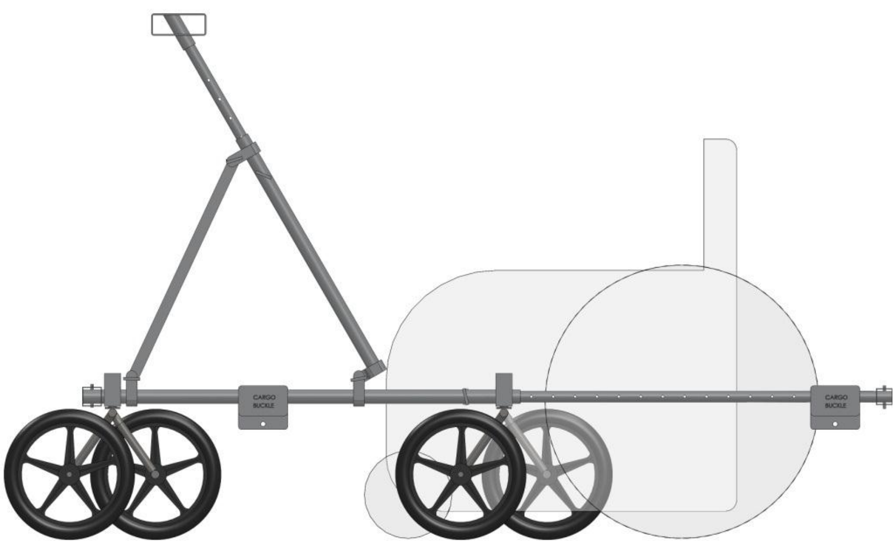
$$\boxed{\delta_{max} = 0.044\,in}$$

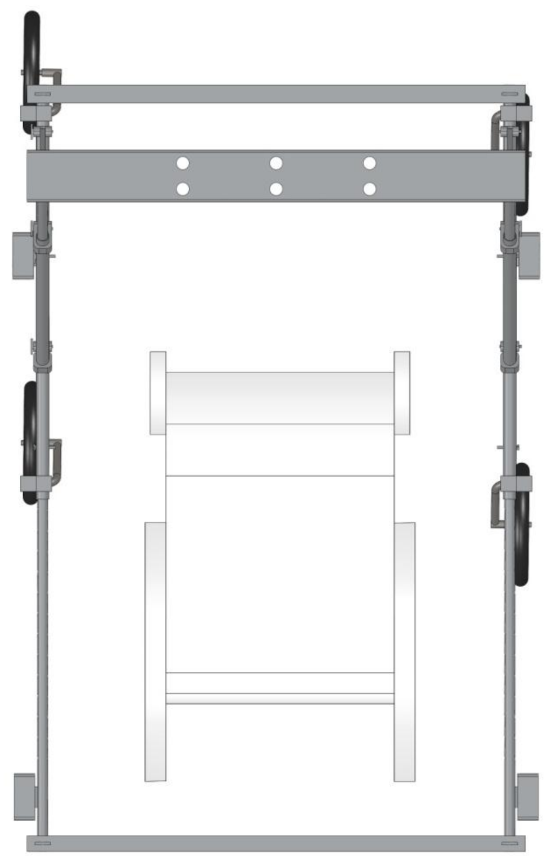
Appendix G: Assembly Images

The following images are from SolidWorks and simulate the dimensions of the UPF and a standard manual wheelchair.







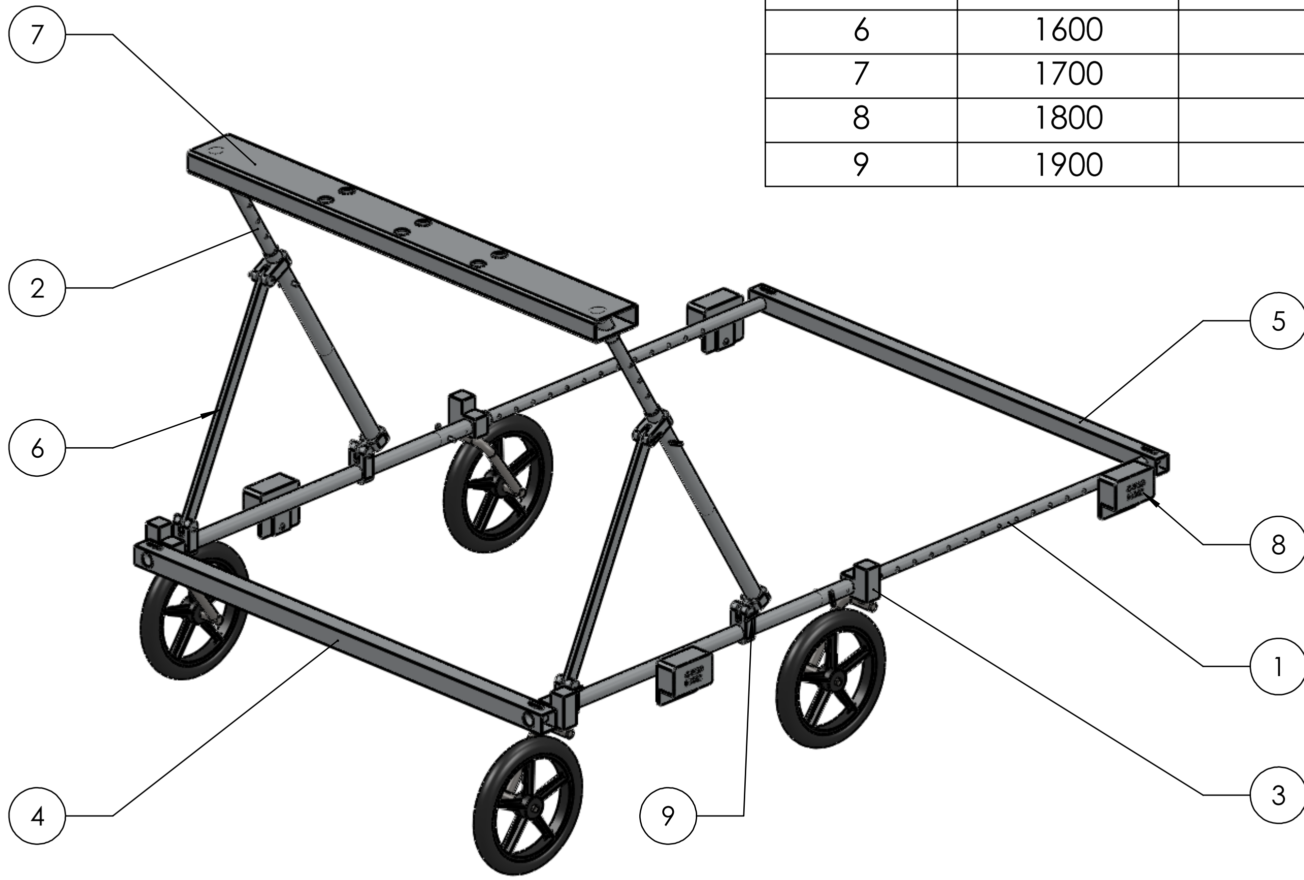


Appendix H: Design Drawing Packet

Please see the attached drawing packet. The following table outlines the complete parts list and associated drawing numbers.

Part Number	Part Description
1000	Master Assembly
1100	Bottom Leg Subassembly
1101	Bottom Max Pipe
1102	Bottom Min Pipe
1103	Slide Joint Outer
1200	Upper Leg Subassembly
1201	Upper Max Pipe
1202	Upper Min Pipe
1203	Slide Joint Inner
1103	Slide Joint Outer
1300	Wheel Mount Subassembly
1301	Wheel Mount
1302	Bushing
1303	Magnet
1304	Wheel
1400	Front Cross Support
1500	Rear Cross Support
1600	Support Bar
1700	Table Top
1800	Cargo Buckle Mount
1900	Joint Pin

ITEM NO.	PART NUMBER	Description	QTY.
1	1100	Bottom Leg Subassembly	2
2	1200	Upper Leg Subassembly	2
3	1300	Wheel Mount Subassembly	4
4	1400	Front Cross Support	1
5	1500	Rear Cross Support	1
6	1600	Support Bar	2
7	1700	Table Top	1
8	1800	Cargo Buckle Mount	4
9	1900	Joint Pin	14



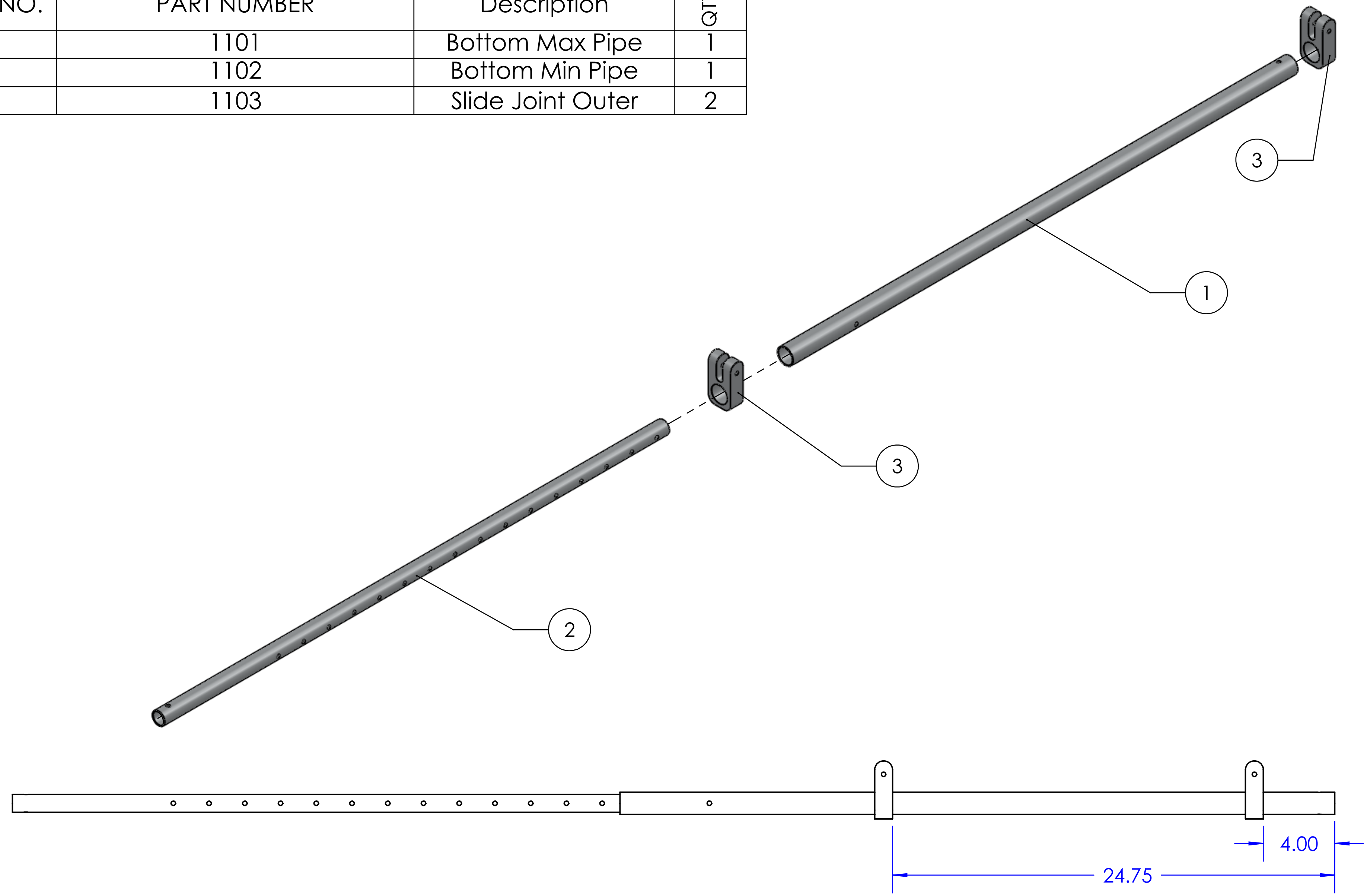
Adaptive Exercise Designs

Mechanical Engineering
CAL POLY

CKD BY: Cullen Crackel	INIT:	DRAWN BY: Justin Bazant	INIT:
NEXT ASSY: N/A	DRAWING #: 1000	MATERIAL: N/A	
TOLERANCE: N/A	SCALE: 1/16	GROUP: Adaptive Exercise Designs	
DATE: Oct 8, 2010	UNITS: Inches	TITLE: Master Assembly	

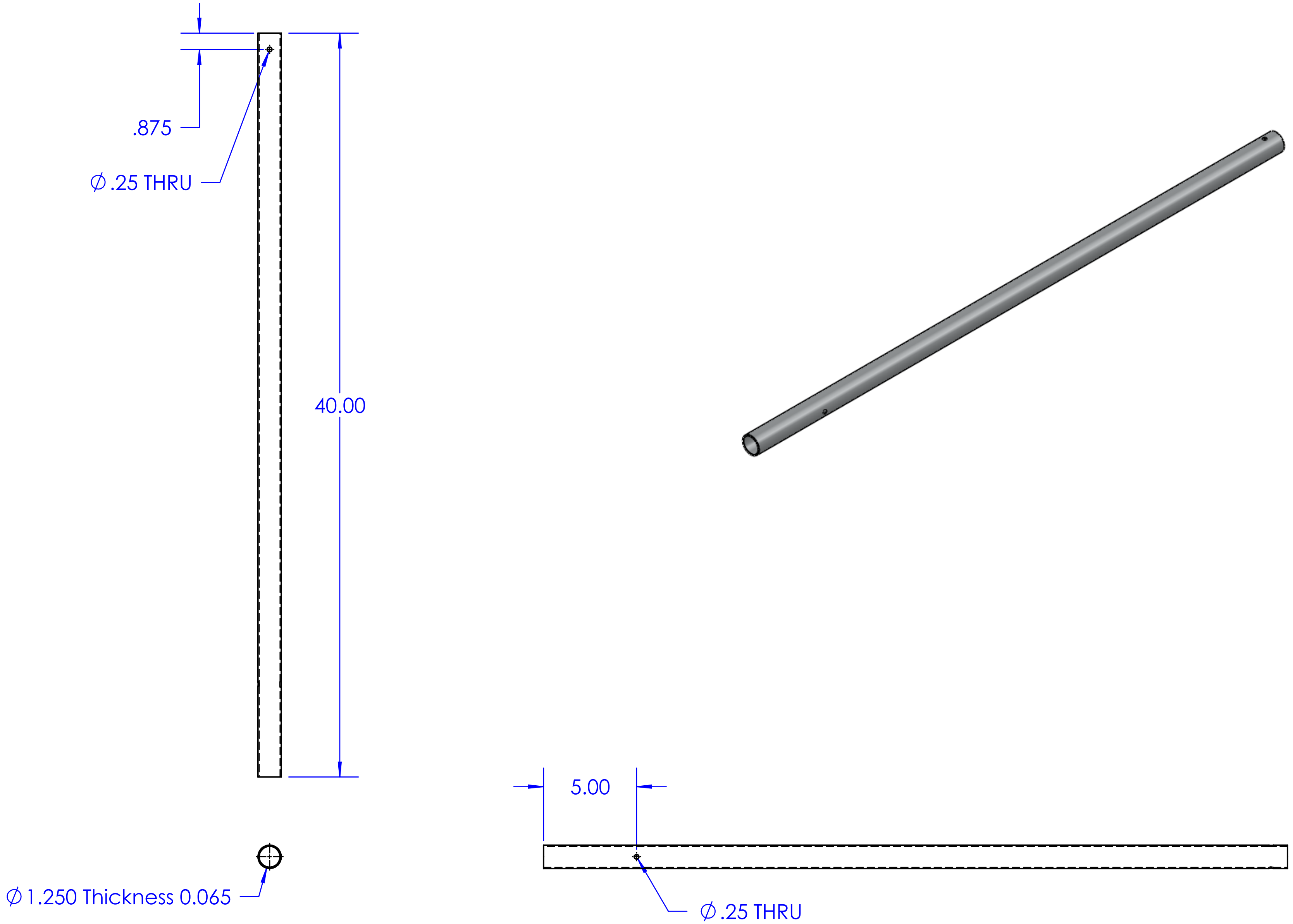
5 4 3 2 1

ITEM NO.	PART NUMBER	Description	QTY.
1	1101	Bottom Max Pipe	1
2	1102	Bottom Min Pipe	1
3	1103	Slide Joint Outer	2



Adaptive Exercise Designs	CKD BY: Cullen Crackel	INIT:	DRAWN BY: Justin Bazant	INIT:
Mechanical Engineering CAL POLY	NEXT ASSY: 1000	DRAWING #: 1100	MATERIAL: 6061-T6 Aluminum Alloy	
	TOLERANCE: ±0.01	SCALE: 1/8	GROUP: Adaptive Exercise Designs	
	DATE: Oct 8, 2010	UNITS: Inches	TITLE: Bottom Leg Subassembly	

5 4 3 2 1

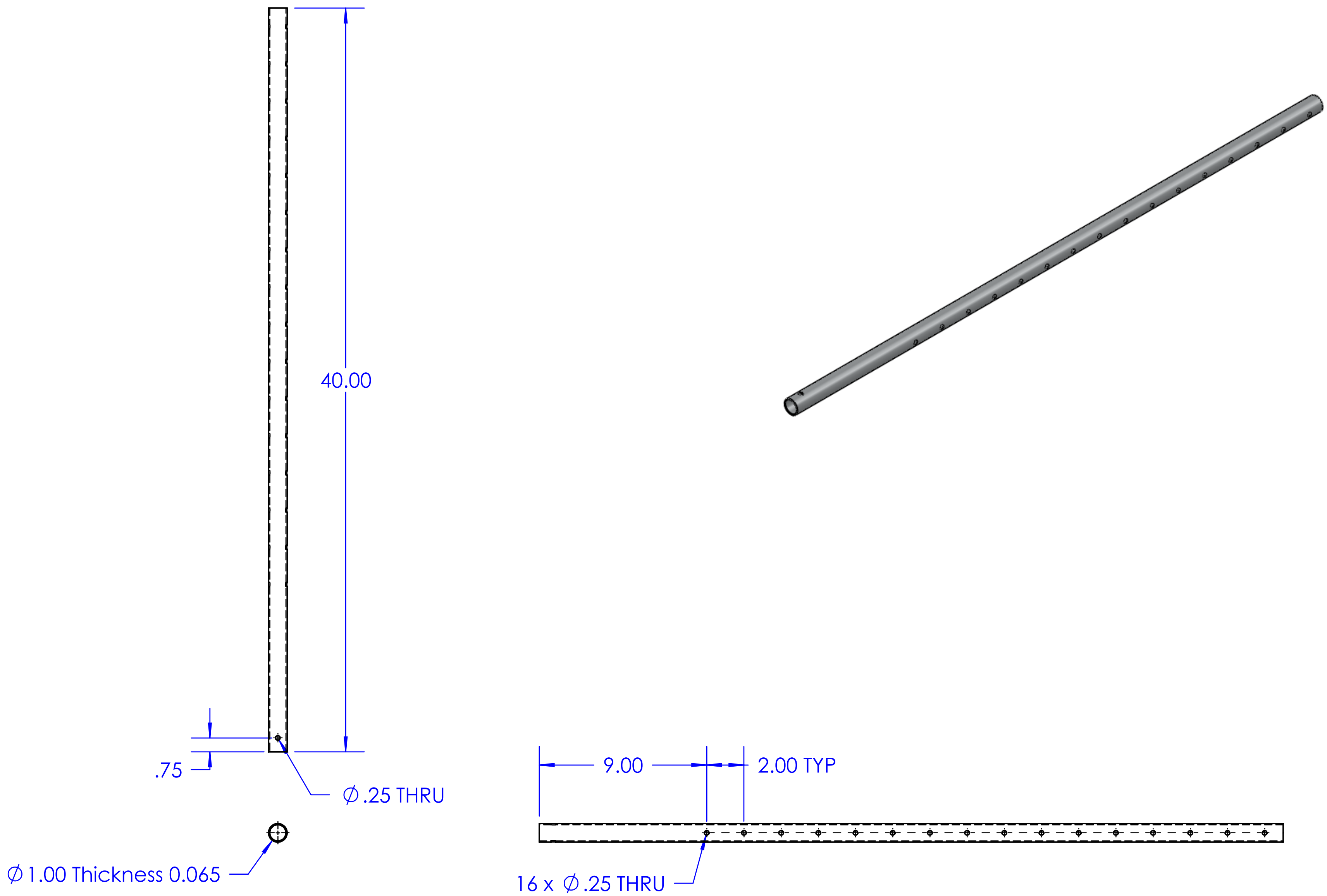


Adaptive Exercise Designs

Mechanical Engineering
CAL POLY

CKD BY: Cullen Crackel	INIT:	DRAWN BY: Justin Bazant	INIT:
NEXT ASSY: 1100	DRAWING #: 1101	MATERIAL: 6061-T6 Aluminum Alloy	
TOLERANCE: ±0.01	SCALE: 1/8	GROUP: Adaptive Exercise Designs	
DATE: Oct 8, 2010	UNITS: Inches	TITLE: Bottom Max Pipe	

5 4 3 2 1

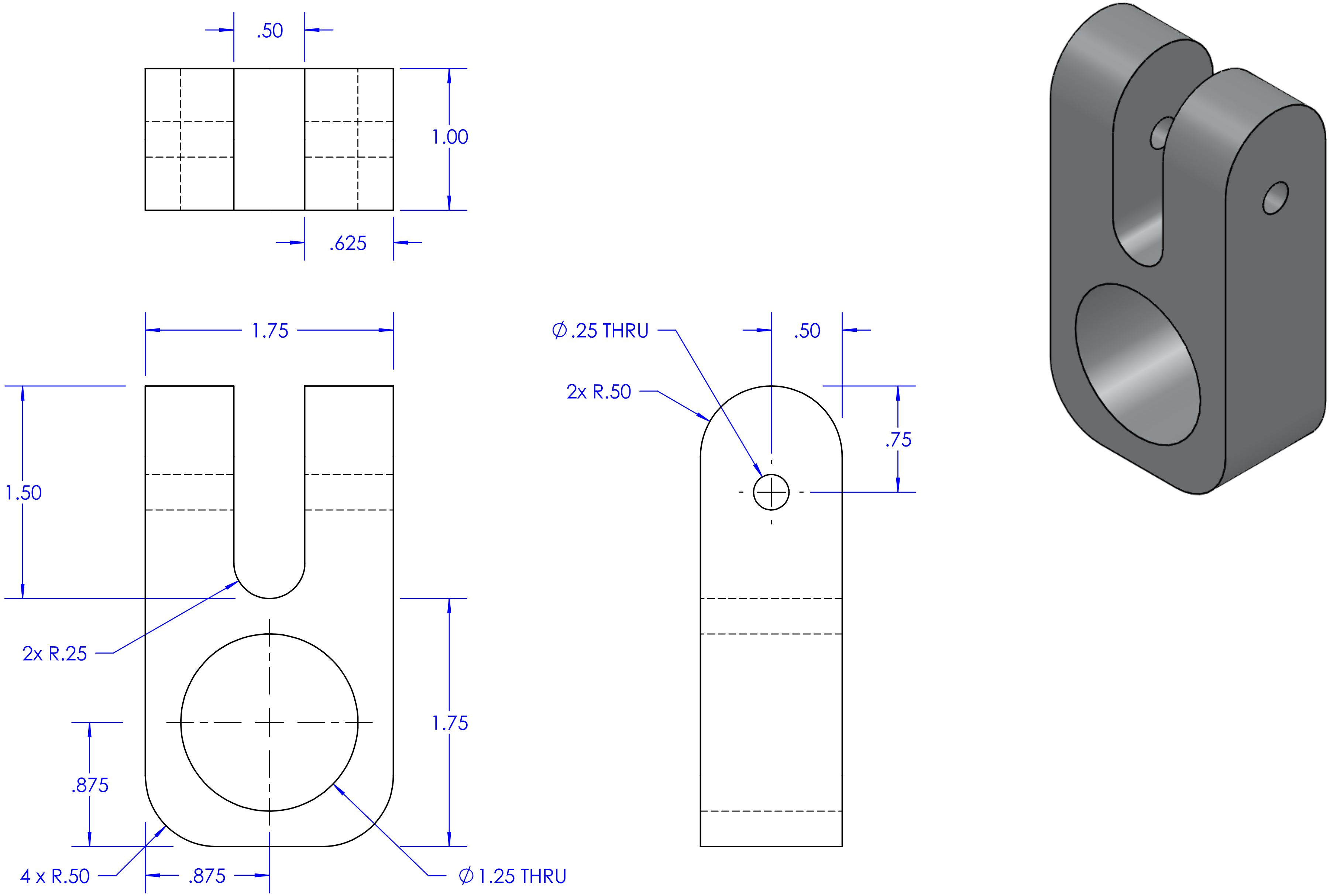


Adaptive Exercise Designs

Mechanical Engineering
CAL POLY

CKD BY: Cullen Crackel	INIT:	DRAWN BY: Justin Bazant	INIT:
NEXT ASSY: 1100	DRAWING #: 1102	MATERIAL: 6061-T6 Aluminum Alloy	
TOLERANCE: ±0.01	SCALE: 1/8	GROUP: Adaptive Exercise Designs	
DATE: Oct 8, 2010	UNITS: Inches	TITLE: Bottom Min Pipe	

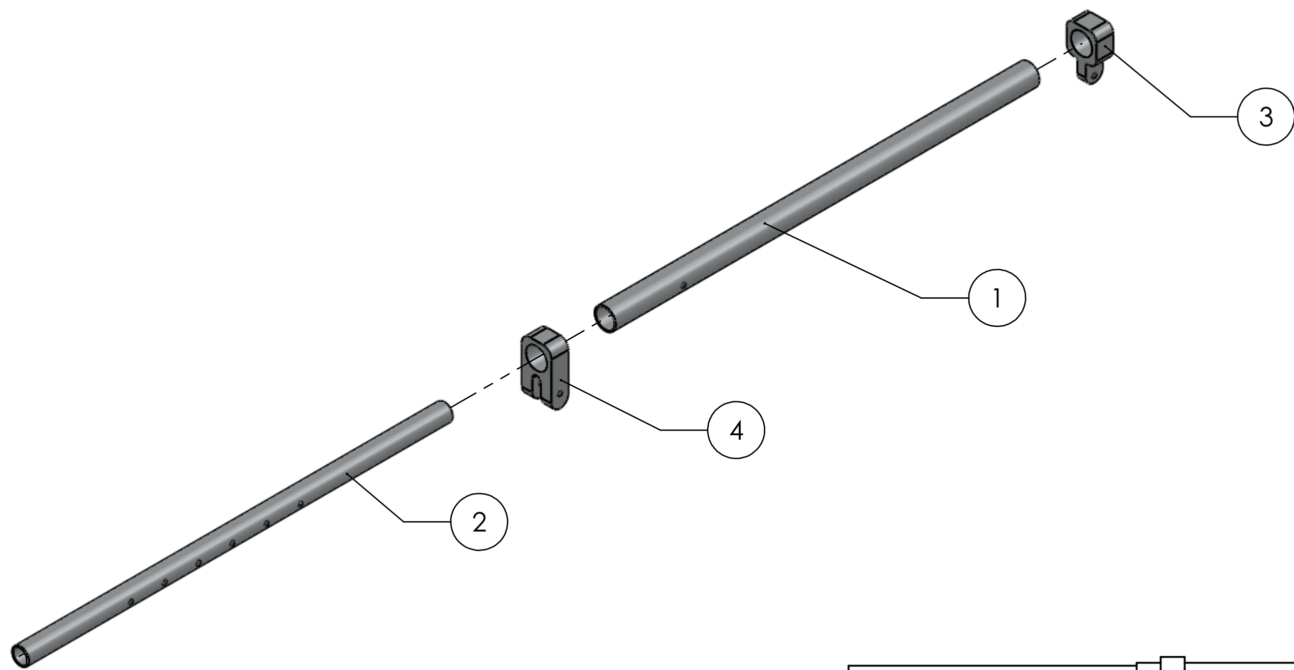
5 4 3 2 1

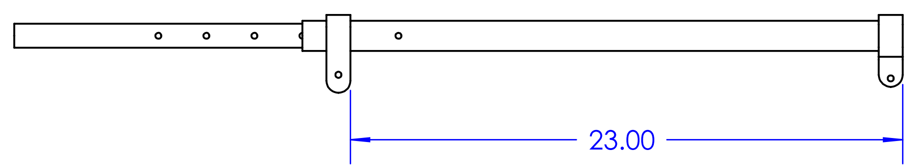


Adaptive Exercise Designs	CKD BY: Cullen Crackel	INIT:	DRAWN BY: Justin Bazant	INIT:
Mechanical Engineering CAL POLY	NEXT ASSY: 1100, 1200	DRAWING #: 1103	MATERIAL: 6061-T6 Aluminum Alloy	
	TOLERANCE: ±0.01	SCALE: 1/1	GROUP: Adaptive Exercise Designs	
	DATE: Sep 24, 2010	UNITS: Inches	TITLE: Slide Joint Outer	

5 4 3 2 1

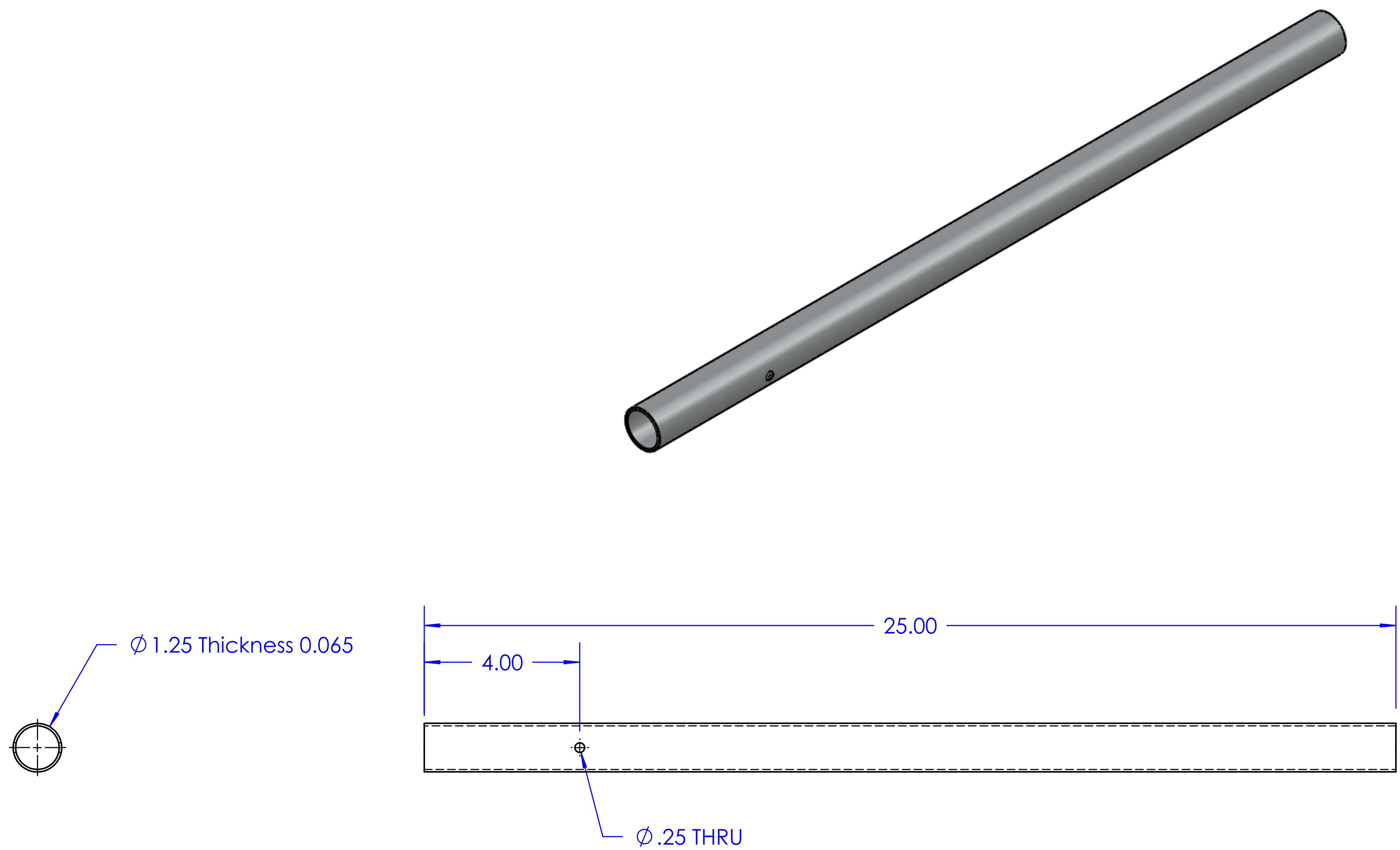
ITEM NO.	Description	PART NUMBER	QTY.
1	Upper Max Pipe	1201	1
2	Upper Min Pipe	1202	1
3	Slide Joint Inner	1203	1
4	Slide Joint Outer	1103	1





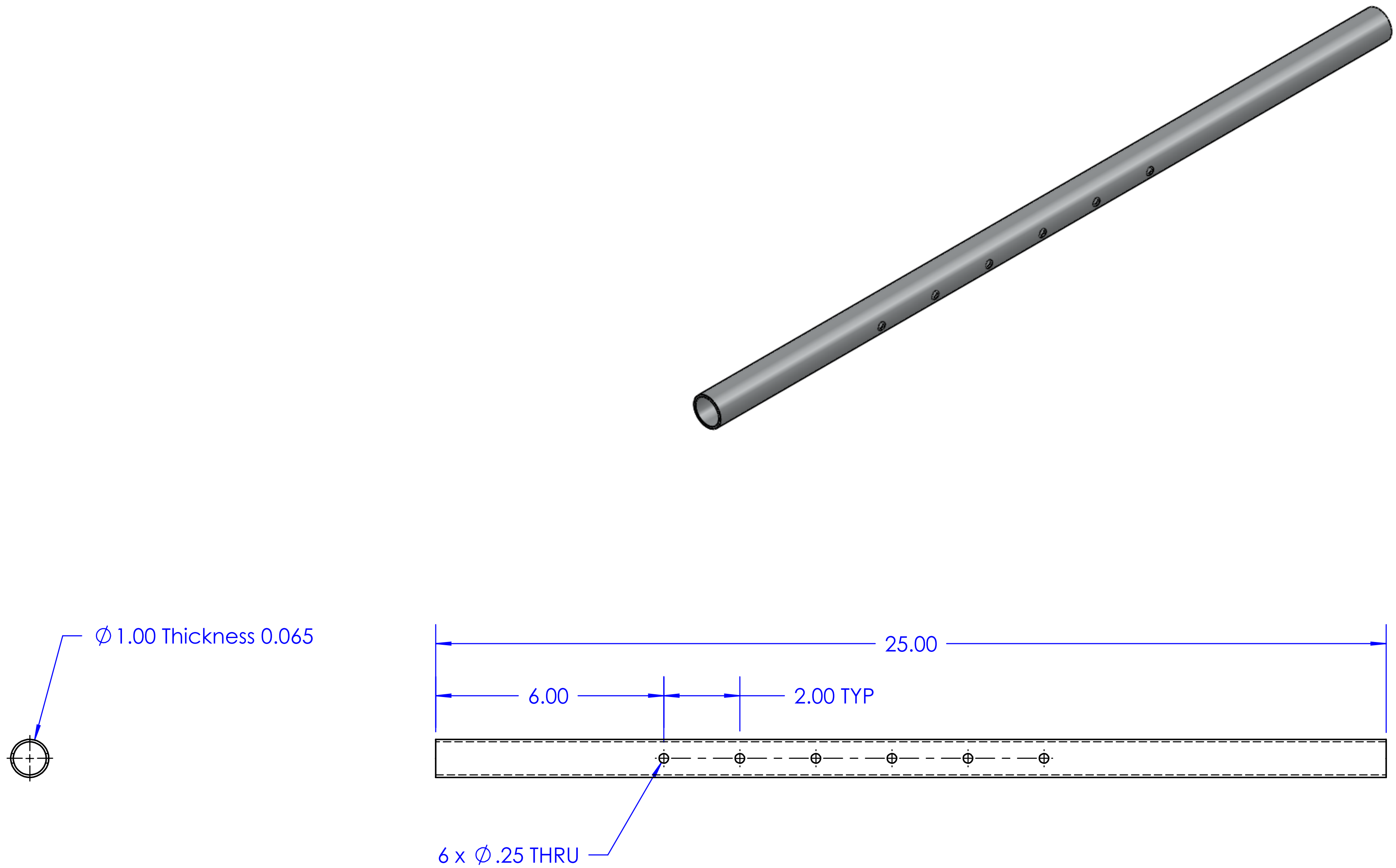
Adaptive Exercise Designs	CKD BY: Cullen Crackel	INIT:	DRAWN BY: Justin Bazant	INIT:
Mechanical Engineering CAL POLY	NEXT ASSY: 1000	DRAWING #: 1200	MATERIAL: 6061-T6 Aluminum Alloy
	TOLERANCE: ±0.01	SCALE: 1/8	GROUP: Adaptive Exercise Designs
	DATE: Oct 8, 2010	UNITS: Inches	TITLE: Upper Leg Subassembly

5 4 3 2 1



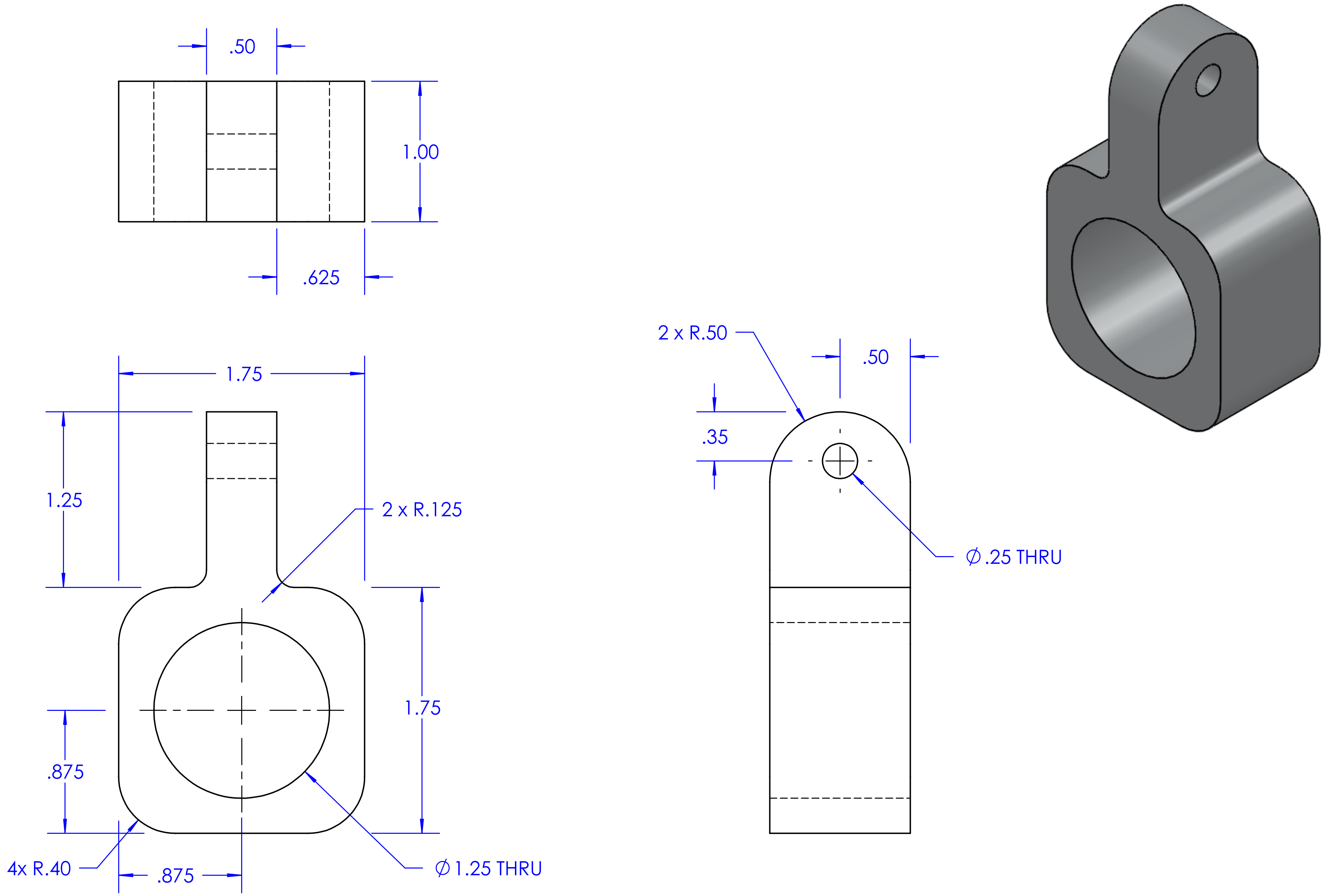
Adaptive Exercise Designs	CKD BY: Cullen Crackel	INIT:	DRAWN BY: Justin Bazant	INIT:
Mechanical Engineering CAL POLY	NEXT ASSY: 1200	DRAWING #: 1201	MATERIAL: 6061-T6 Aluminum Alloy	
	TOLERANCE: ±0.01	SCALE: 1/4	GROUP: Adaptive Exercise Designs	
	DATE: Oct 8, 2010	UNITS: Inches	TITLE: Upper Max Pipe	

5 4 3 2 1



Adaptive Exercise Designs	CKD BY: Cullen Crackel	INIT:	DRAWN BY: Justin Bazant	INIT:
Mechanical Engineering CAL POLY	NEXT ASSY: 1200	DRAWING #: 1202	MATERIAL: 6061-T6 Aluminum Alloy	
	TOLERANCE: ±0.01	SCALE: 1/4	GROUP: Adaptive Exercise Designs	
	DATE: Oct 8, 2010	UNITS: Inches	TITLE: Upper Min Pipe	

5 4 3 2 1



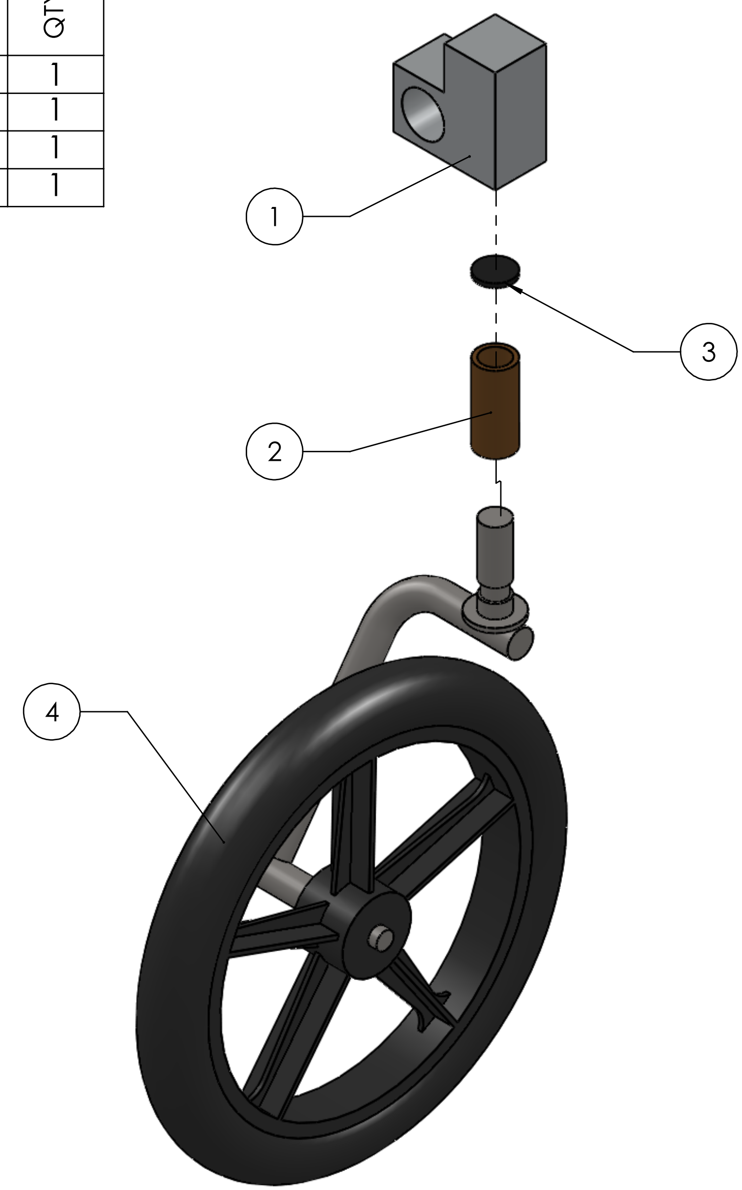
Adaptive Exercise Designs

Mechanical Engineering
CAL POLY

CKD BY: Cullen Crackel	INIT:	DRAWN BY: Justin Bazant	INIT:
NEXT ASSY: 1200	DRAWING #: 1203	MATERIAL: 6061-T6 Aluminum Alloy	
TOLERANCE: ±0.01	SCALE: 1/1	GROUP: Adaptive Exercise Designs	
DATE: Sep 24, 2010	UNITS: Inches	TITLE: Slide Joint Inner	

5 4 3 2 1

ITEM NO.	PART NUMBER	Description	QTY.
1	1301	Wheel Mount	1
2	1302	Bushing	1
3	1303	Magnet	1
4	1304	Wheel Subassembly	1

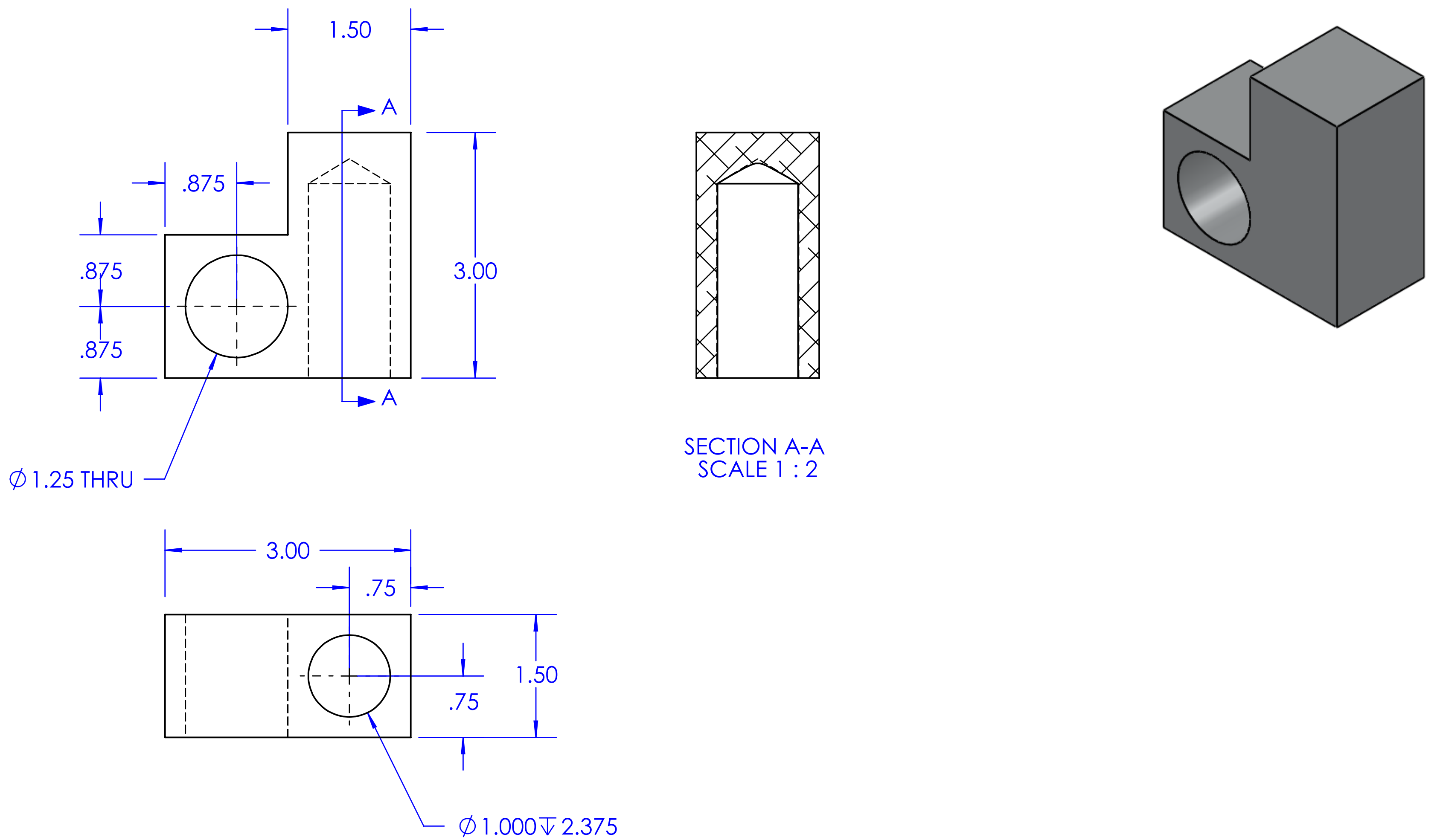


Adaptive Exercise Designs

Mechanical Engineering CAL POLY

CKD BY: Cullen Crackel	INIT:	DRAWN BY: Justin Bazant	INIT:
NEXT ASSY: 1000	DRAWING #: 1300	MATERIAL: N/A	
TOLERANCE: N/A	SCALE: 1/4	GROUP: Adaptive Exercise Designs	
DATE: Oct 8, 2010	UNITS: Inches	TITLE: Wheel Mount Subassembly	

5 4 3 2 1

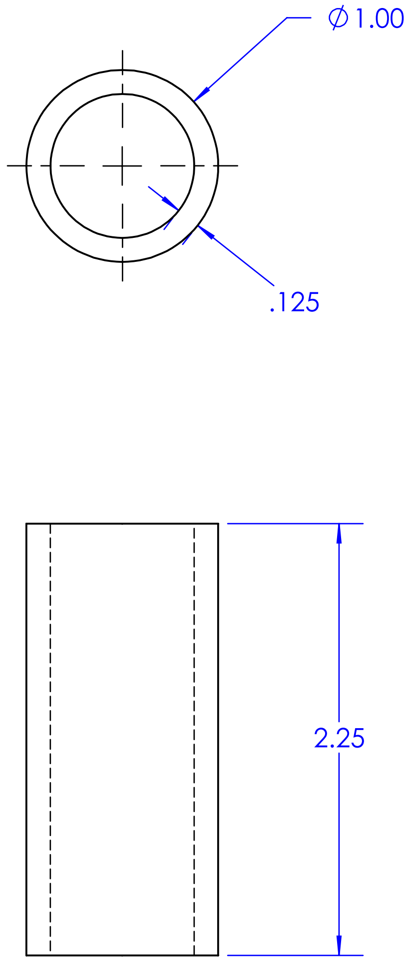


Adaptive Exercise Designs

Mechanical Engineering
CAL POLY

CKD BY: Cullen Crackel	INIT:	DRAWN BY: Justin Bazant	INIT:
NEXT ASSY: 1300	DRAWING #: 1301	MATERIAL: 6061-T6 Aluminum Alloy	
TOLERANCE: ±0.01	SCALE: 1/2	GROUP: Adaptive Exercise Designs	
DATE: Oct 8, 2010	UNITS: Inches	TITLE: Wheel Mount	

5 4 3 2 1

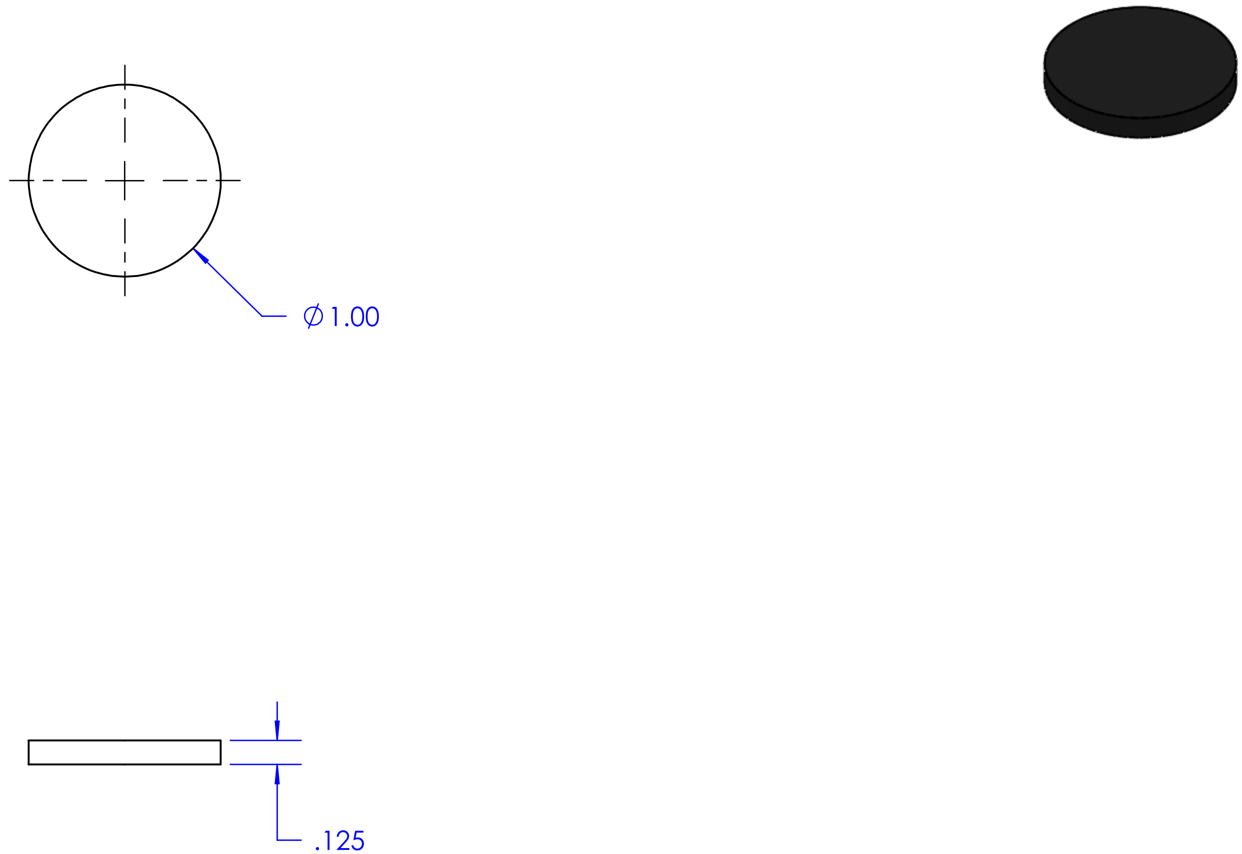


Adaptive Exercise Designs

Mechanical Engineering
CAL POLY

CKD BY: Cullen Crackel		INIT:	DRAWN BY: Justin Bazant	INIT:
NEXT ASSY: 1300	DRAWING #: 1302		MATERIAL: Delrin	
TOLERANCE: ±0.01	SCALE: 1/1		GROUP: Adaptive Exercise Designs	
DATE: Oct 8, 2010	UNITS: Inches		TITLE: Bushing	

5 4 3 2 1

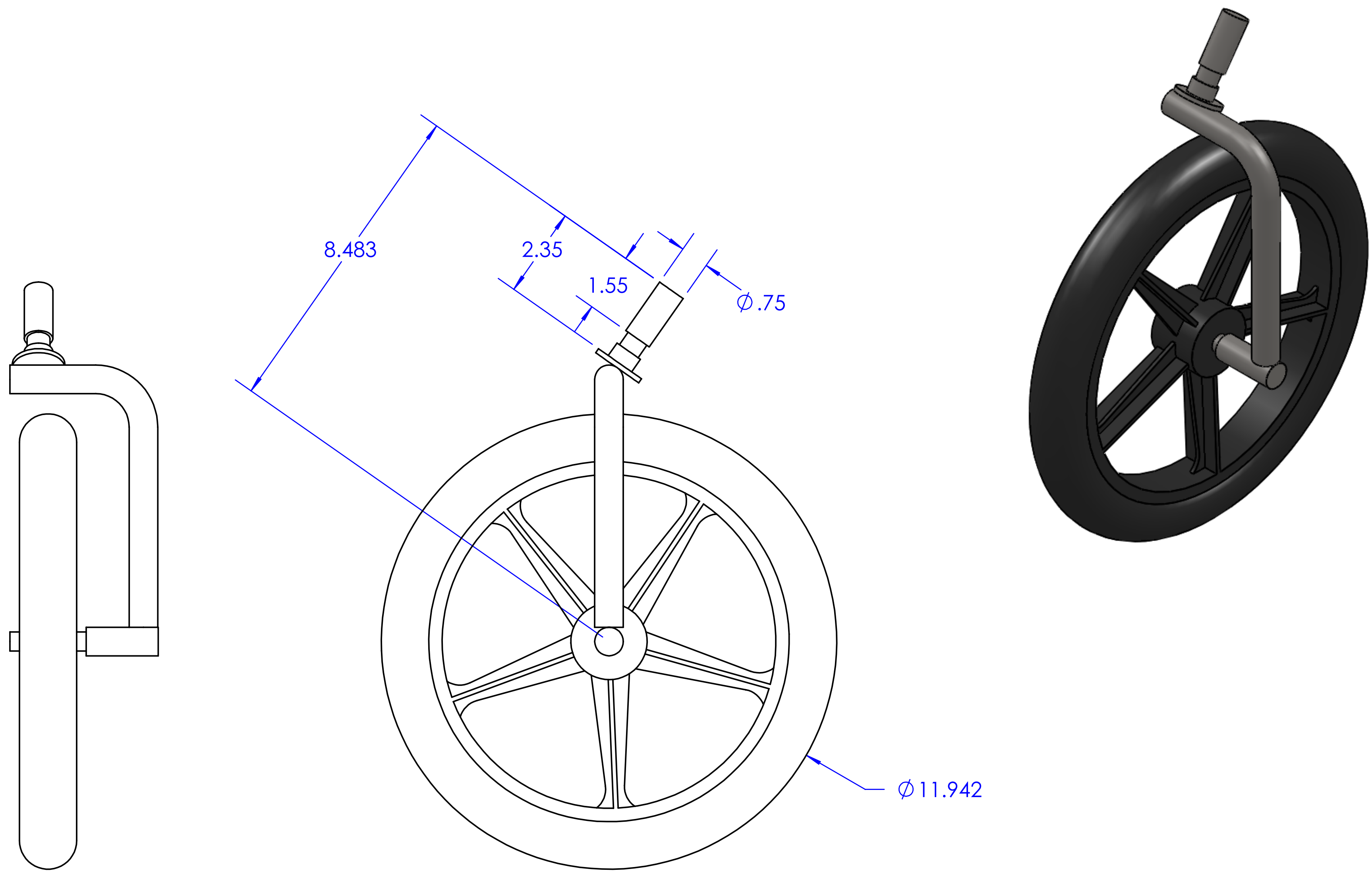


Adaptive Exercise Designs

Mechanical Engineering
CAL POLY

CKD BY: Cullen Crackel	INIT:	DRAWN BY: Justin Bazant	INIT:
NEXT ASSY: 1300	DRAWING #: 1303	MATERIAL: Ductile Iron	
TOLERANCE: ±0.01	SCALE: 1/1	GROUP: Adaptive Exercise Designs	
DATE: Oct 8, 2010	UNITS: Inches	TITLE: Magnet	

5 4 3 2 1



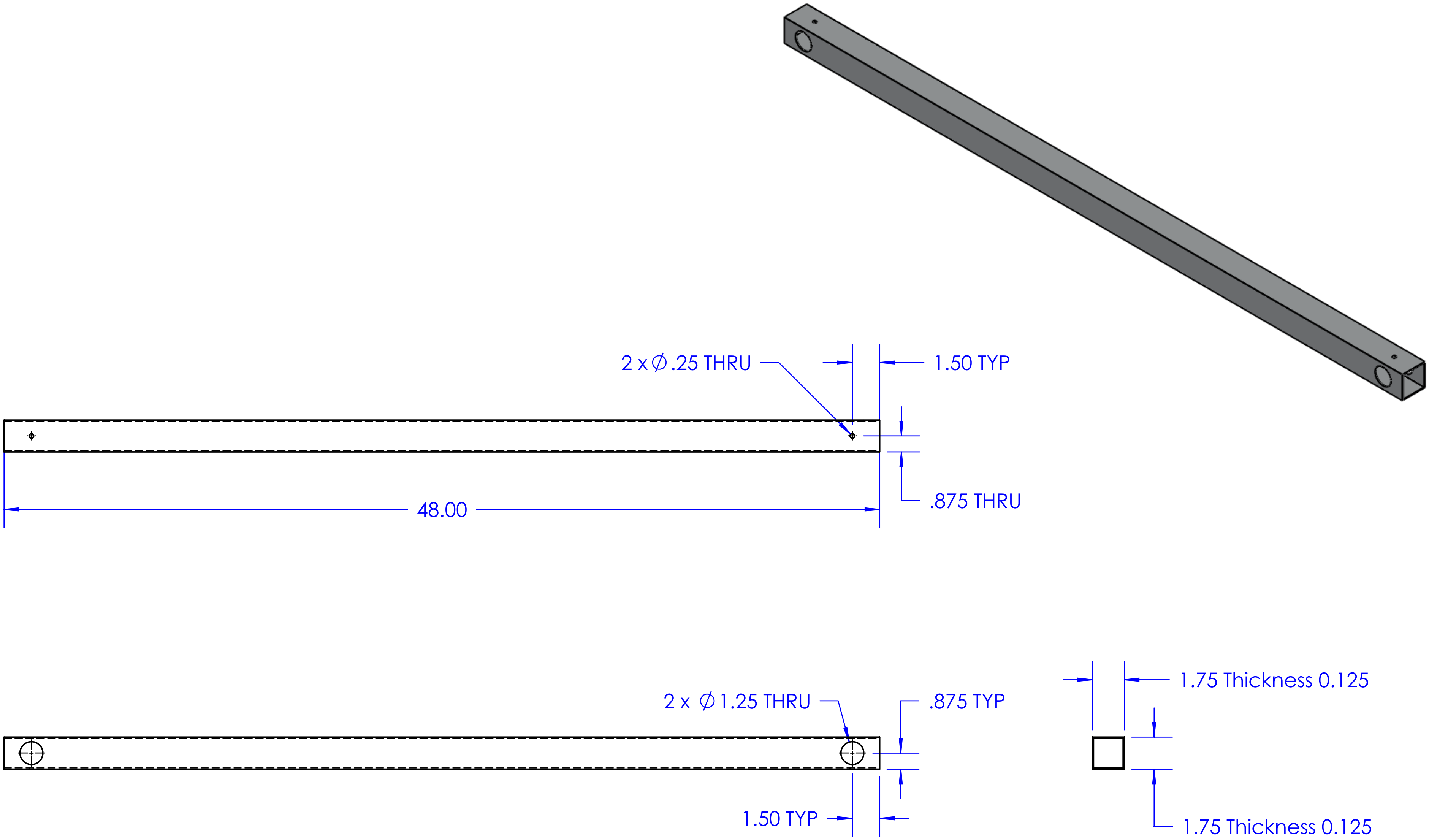
NOTE: Part will be purchased as unit

Adaptive Exercise Designs

Mechanical Engineering
CAL POLY

CKD BY: Cullen Crackel	INIT:	DRAWN BY: Justin Bazant	INIT:
NEXT ASSY: 1300	DRAWING #: 1304	MATERIAL: N/A	
TOLERANCE: N/A	SCALE: 1/4	GROUP: Adaptive Exercise Designs	
DATE: Oct 8, 2010	UNITS: Inches	TITLE: Wheel	

5 4 3 2 1

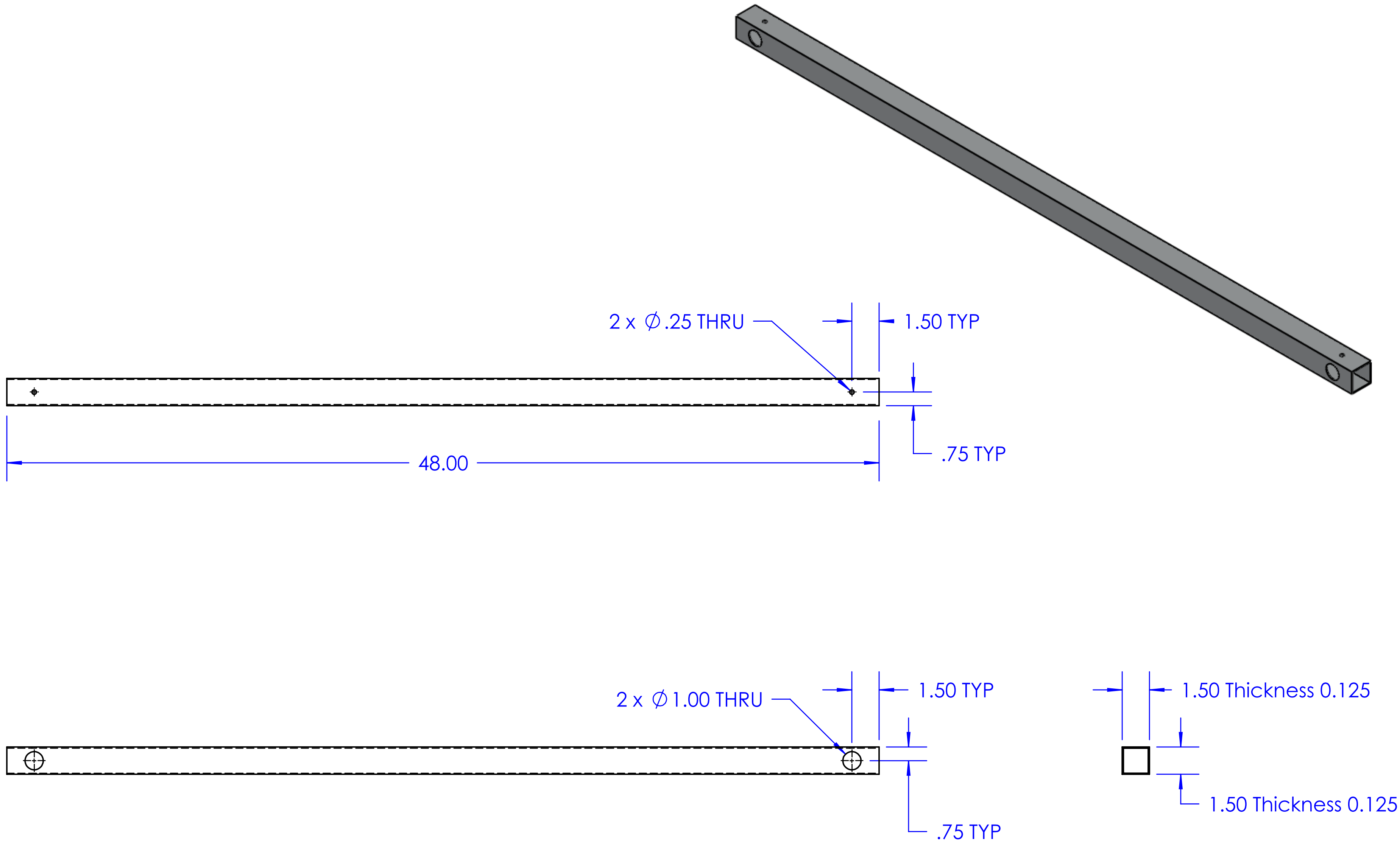


Adaptive Exercise Designs

Mechanical Engineering CAL POLY

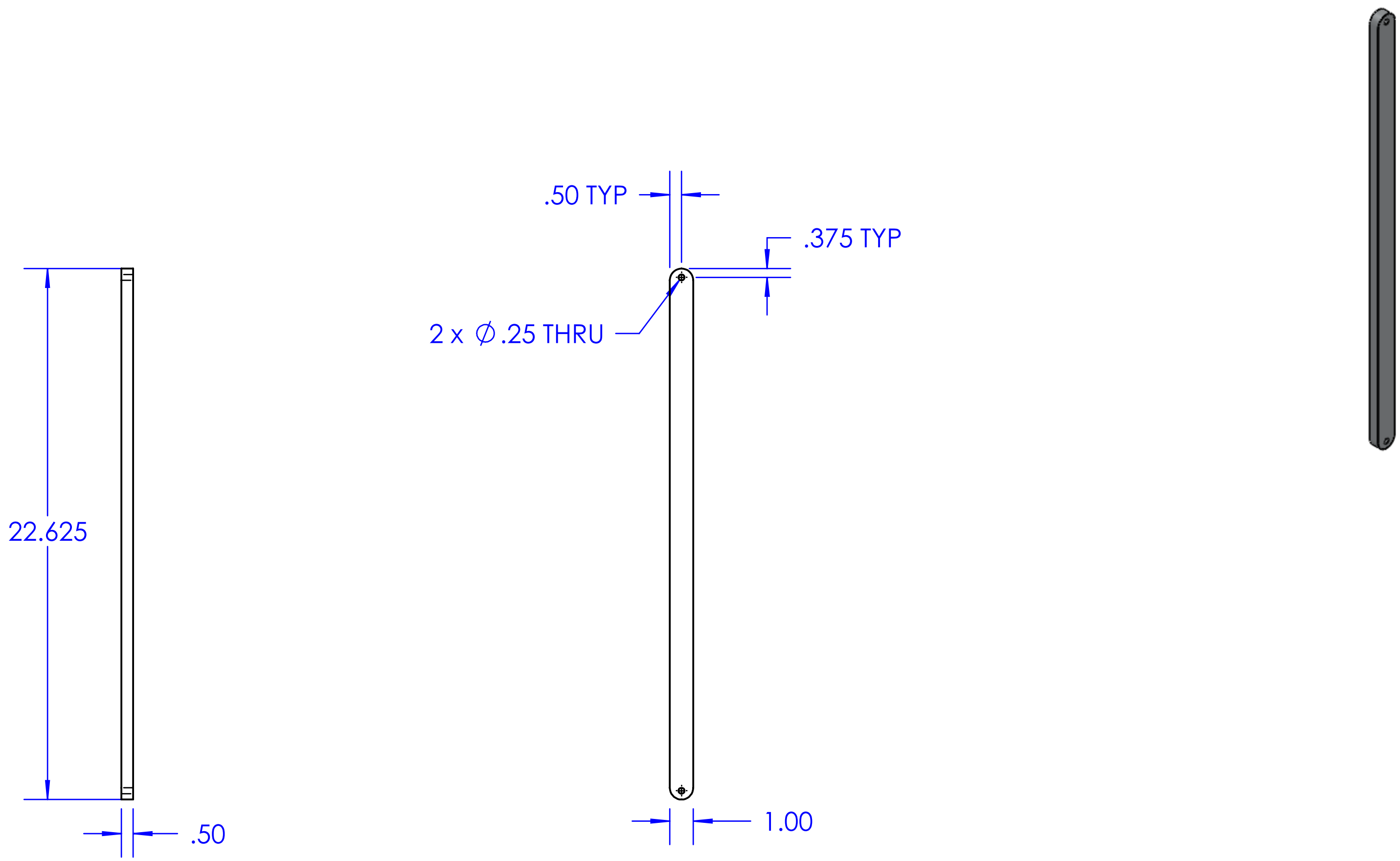
CKD BY: Cullen Crackel	INIT:	DRAWN BY: Justin Bazant	INIT:
NEXT ASSY: 1000	DRAWING #: 1400	MATERIAL: 6061-T6 Aluminum Alloy	
TOLERANCE: ±0.01	SCALE: 1/8	GROUP: Adaptive Exercise Designs	
DATE: Oct 8, 2010	UNITS: Inches	TITLE: Front Cross Support	

5 4 3 2 1



Adaptive Exercise Designs	CKD BY: Cullen Crackel	INIT:	DRAWN BY: Justin Bazant	INIT:
Mechanical Engineering CAL POLY	NEXT ASSY: 1000	DRAWING #: 1500	MATERIAL: 6061-T6 Aluminum Alloy	
	TOLERANCE: ±0.01	SCALE: 1/8	GROUP: Adaptive Exercise Designs	
	DATE: Oct 8, 2010	UNITS: Inches	TITLE: Rear Cross Support	

5 4 3 2 1

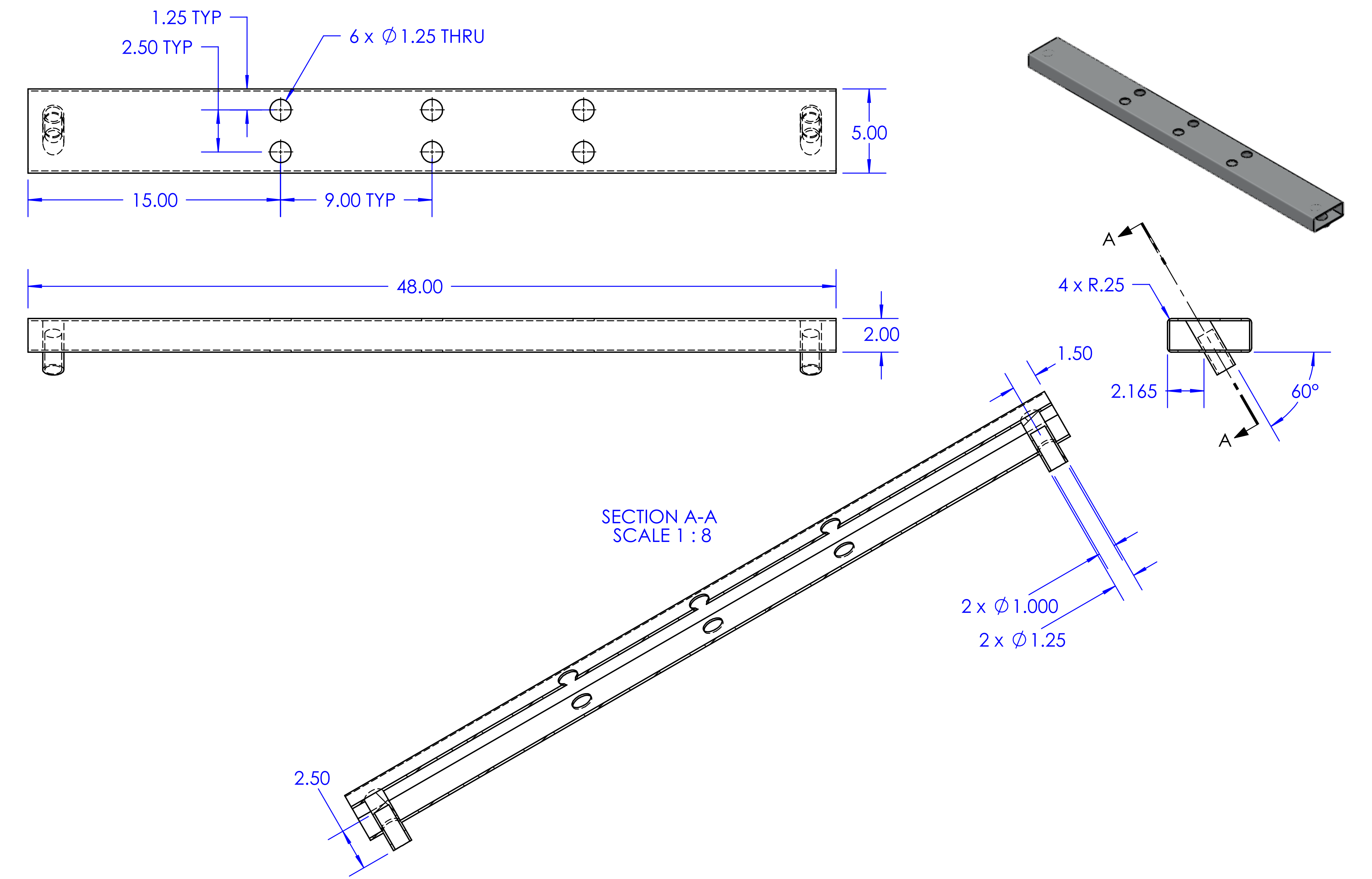


Adaptive Exercise Designs

Mechanical Engineering
CAL POLY

CKD BY: Cullen Crackel	INIT:	DRAWN BY: Justin Bazant	INIT:
NEXT ASSY: 1000	DRAWING #: 1600	MATERIAL: 6061-T6 Aluminum Alloy	
TOLERANCE: ±0.01	SCALE: 1/8	GROUP: Adaptive Exercise Designs	
DATE: Oct 8, 2010	UNITS: Inches	TITLE: Support Bar	

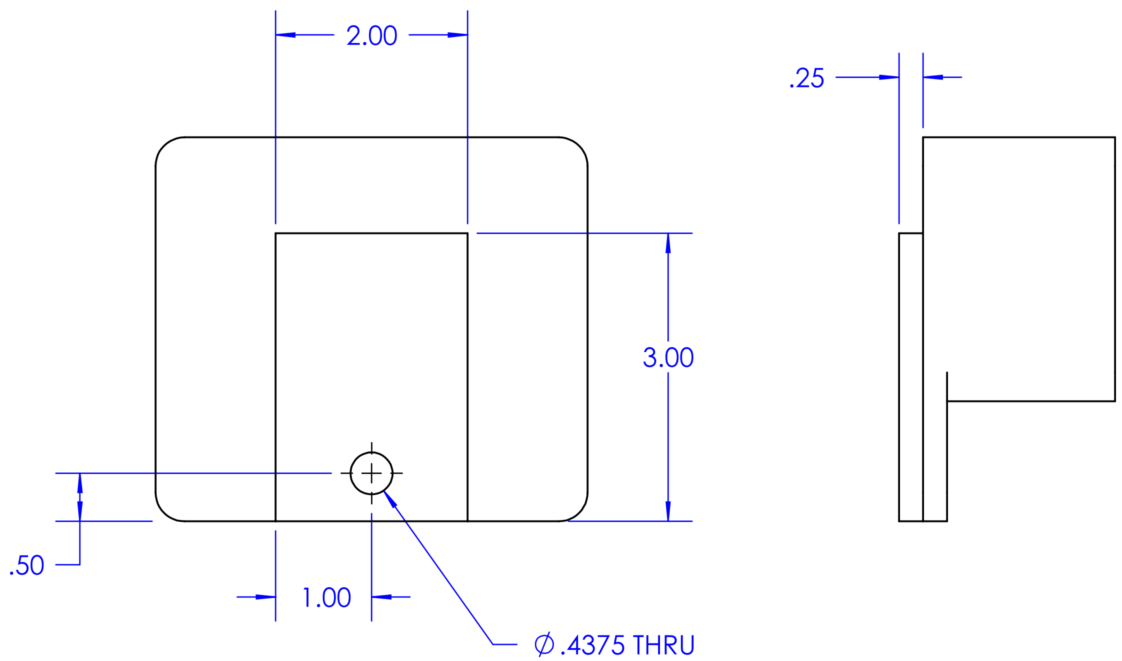
5 4 3 2 1

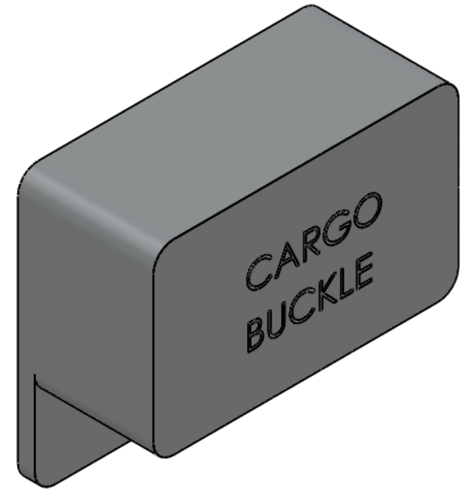


Adaptive Exercise Designs	CKD BY: Cullen Crackel	INIT:	DRAWN BY: Justin Bazant	INIT:
Mechanical Engineering CAL POLY	NEXT ASSY: 1000	DRAWING #: 1700	MATERIAL: 6061-T6 Aluminum Alloy	
	TOLERANCE: ±0.01	SCALE: 1/8	GROUP: Adaptive Exercise Designs	
	DATE: Oct 8, 2010	UNITS: Inches	TITLE: Table Top	

5 4 3 2 1

NOTE: Drawing is only describing the mounting plate - Cargo Buckle is purchased as complete unit

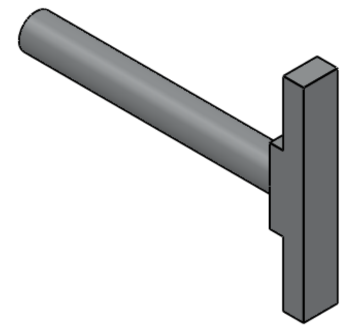




Adaptive Exercise Designs Mechanical Engineering CAL POLY	CKD BY: Cullen Crackel	INIT:	DRAWN BY: Justin Bazant / INIT:
	NEXT ASSY: 1000	DRAWING #: 1800	MATERIAL: 6061-T6 Aluminum Alloy
	TOLERANCE: ±0.05	SCALE: 1/2	GROUP: Adaptive Exercise Designs
	DATE: Oct 8, 2010	UNITS: Inches	TITLE: Cargo Buckle Mount

5 4 3 2 1

NOTE: All pins used in Master Assembly have a 0.25" diameter but their usable length and pin type varies



Adaptive Exercise Designs

Mechanical Engineering
CAL POLY

CKD BY: Cullen Crackel	INIT:	DRAWN BY: Justin Bazant	INIT:
NEXT ASSY: 1000	DRAWING #: 1900	MATERIAL: Stainless Steel & Plastic	
TOLERANCE: ±0.01	SCALE: 1/1	GROUP: Adaptive Exercise Designs	
DATE: Oct 8, 2010	UNITS: Inches	TITLE: Joint Pin	

5 4 3 2 1