Adjustable Mount Skate Blade

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ABSTRACT

Figure skating requires precise blade/foot placement to maximize efficiency, which is made difficult when a person suffers from over pronation or supination. Only around 30% of people have normal foot placement, meaning the other 70% suffer from some degree of over pronation or supination (Leading Edge Physiotherapy), which has a significant effect on a person's ability to skate. To overcome this problem, skaters have been mounting and re-mounting their blades to the boot, experimenting with different angles until the optimal angle is achieved. While this solution addresses the problem, it is time consuming and skate boots are often ruined in the process.

The primary goal of this project is to develop a device which allows a figure skater to simply and easily adjust the angle of a skate blade to the optimal position without ruining the boot in the process. The project consisted of a design stage in which the individual components were developed, a rapid prototyping stage in which designs were physically examined before being refined, and a prototyping stage in which the final design was machined. The final design utilizes a worm to allow for an infinitely adjustable blade placement angle and set screws at the rear and clamps at the toe to secure the blade in position.

EXECUTIVE SUMMARY

Numerous people suffer from pronation and supination problems. Only 30% of people have what would be considered a normal stride, meaning 70% of people have problem with their foot placement to some degree. When left untreated, these problems can permanently alter a person's stride and effect the way the foot strikes the ground, known as the placement angle. This is the angle at which the foot lands relevant to the normal line/direction of travel.

Figure skating requires precise placement of the blade. In order to maximize power and efficiency, it is important that the skater positions the skates properly. This ability is hindered when a person has a placement angle greater than 7.5°. The skater will have to force their feet into an unnatural position when they wish to glide forward as the blades would not be parallel when placed in their normal position. This is only one example of how a skater's ability to move is effected by the placement angle of their foot. Wear and tear on the joints in the knee is permanent such that the foot will continue to land in the same position (Tiberio), meaning that it cannot be fixed by orthotics alone.

In order for a skater to correct their placement angle, the blades need to be re-mounted to correct for the placement angle of the skater. Currently, the only method by which this can be accomplished is by first removing the old blade, filling the mounting holes, and re-mounting the blade in an adjusted position. This solution doesn't always work the first time, however. If the skater tests the configuration and finds it has not adequately addressed the problem, it will need to be redone. Even if the second correction is successful, there will be twenty unused holes in the bottom of the boot, rendering it useless.

The goal of the project is to develop a mechanism that will allow the placement angle of the blade to be adjusted numerous times without needing re-mount it after each change.

The first decision that was made was determining the pivot location. It was eventually decided that the heel should be used as the pivot location as there was more room for the toe to be mounted. In

addition, the heel placement location is constant for all people, regardless of their placement angle. As a result, the decision was made to place the pivot location at the heel.

From the beginning, the design featured a mechanism involving three plates and a worm to be used for adjustment. One plate would be positioned at the front to allow the toe to be secured and the remaining two are positioned at the heel allowing for adjustment. The worm is the component through which the user adjusts the angle of the blade.

The front plate was not given much consideration in the early stages of the design, but ended up being a crucial component of the overall mechanism. The importance of this component stemmed from the need for a locking mechanism for the toe of the blade. A great deal of consideration was given to this, and the final design of the front plate features two holes for mounting and four slots allowing hold down clamps to be slid into place. When tightened, the hold down clamps secure the toe of the blade, and minimize the force transferred to the rear plates.

The static plate is designed to be rigidly mounted to the heel of the boot. This component serves as a mounting location for the worm as well as a pivot for the adjustable plate. It also features two tapped holes to be used to secure the adjustable plate in place, once the blade position has been set. The front of the plate allows for the worm to be mounted such that it is in line with the midplane of the adjustable plate.

The adjustable plate, as mentioned above, pivots around the static plate and serves as a mounting location for the heel of the blade. In addition, this plate features gear teeth at the front which are designed to interact with the worm mounted to the static plate above. An adjustment of the worm will correlate with a change in angle of the adjustable plate, and since the blade is rigidly mounted to it, the placement angle of the blade will be adjusted as well.

The worm was one of the most important aspects of the project, and was also the source of the most major setback in the project. The machining capabilities at WPI are limited to 1/8in. for milling operations and a worm with a pitch of the required size was not able to be purchased within the budget restrictions of the project. To accommodate this, a worm was designed and printed using the rapid prototype machines available on campus.

The machining process for prototyping involved in this project was not simple. Because the parts were designed to be as small as possible, special methods needed to be used to secure the aluminum stock during machining. The solution involved the use of adhesive sheets used to bind the stock to "sacrificial stock." The process is not used often and was not expected to work. The operations were successful, however, and a working prototype was produced.

A tearout analysis using a factor of safety of two was done to determine if there would be failure at positions on the adjustable plate and on the static plate. The analyses indicate that both locations are safe when forces from stopping are applied, but there would be failure if the device experienced the forces from jumping.

The final prototype successfully allows for the skate blade to be adjusted without the need to re-mount it to the boot after each configuration. Certain aspects of the design need to be improved before it can be considered complete, but it does function well in its current state. Additional recommendations include testing in a lab and on ice before considering the device to be a completed product.

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INTRODUCTION

Figure skating requires precise position of the blade in order to ensure efficiency while skating. For people whose feet do not naturally land parallel to each other, achieving this precise blade positioning can be difficult and uncomfortable if not impossible. The current solution to this problem is to position the blades on the boot to correct for a person's foot placement. This solution is not simple, however, and can be time-consuming and expensive.

In order to re-position the blade of a skate, the blade must first be removed and the old mounting holes must be filled. At this point, new mounting holes can be drilled and the blade can be re-mounted to the boot ensuring that the blade is secure. The skater will not know if the position is comfortable or not until they have tested the configuration. If the change in angle was not correct, the blade will need to be removed and re-mounted. At the end of this process, the bottom of the boot may have 20-30 holes in it.

The objective of this project is to design a device that will require being mounted only once and will allow the angle of the blade to be easily and precisely adjusted.

This project was focused on the design of the mechanism in order to produce a prototype at the end of the project period. The design went through numerous iterations before arriving at a finalized solution. The final design consists of three aluminum plates and a worm for adjustments. One plate is mounted at the toe of the boot and is used to secure the toe of the blade. The remaining two plates and worm are positioned at the rear and are used to adjust the angle of the blade before securing it.

BACKGROUND

Skating on ice may seem impossible for someone with no experience, but for someone who has spent years on the ice, the motions of skating are second nature. These familiar motions are developed from years of practice. It has long been known that figure skaters are the best skaters on ice. They have a great deal more skill than hockey players, and much more maneuverability than speed skaters. There are many people, however, who have difficulty skating due to the biomechanics of their knees and feet.

Pronation and Supination

Only around 30% of people have normal foot placement, meaning the other 70% suffer from some degree of over pronation or supination (Fedoruk, 2013). Over pronation is characterized by the collapsing of the arch when the foot is placed on the ground, resulting in the inward roll of the foot. Supination, on the other hand, is the inverse of pronation and means a person’s roll to the outside (Maffetone, 2011). These conditions are shown in Figure 1 below.

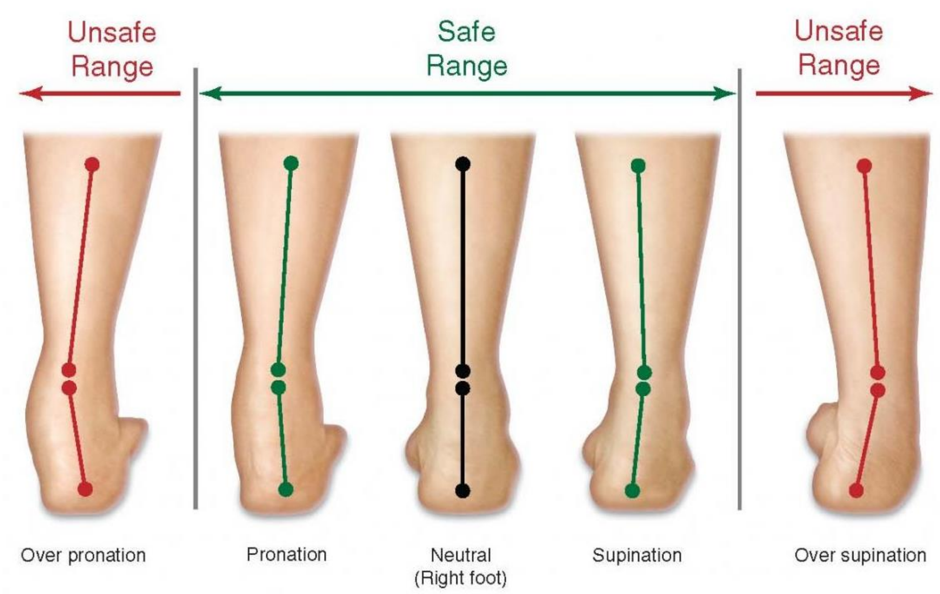


Figure 1: Foot Roll Types
Source: Team Doctors Blog

Orthotics can be used to treat this problem if it is noticed early, but when this problem is left untreated, it will eventually lead to uneven wear in the knees (Tiberio).

Foot Placement Angles

Untreated pronation/supination problems can result in a change in a person's foot placement angle. Many people are familiar with the terms bow-legged or knock-kneed. These are simply common terms used to describe a condition in which the foot placement is outside "normal" conditions. The placement angle of the foot is defined as the angle at which the center axis of the foot deviates from the direction of travel as shown in Figure 2.

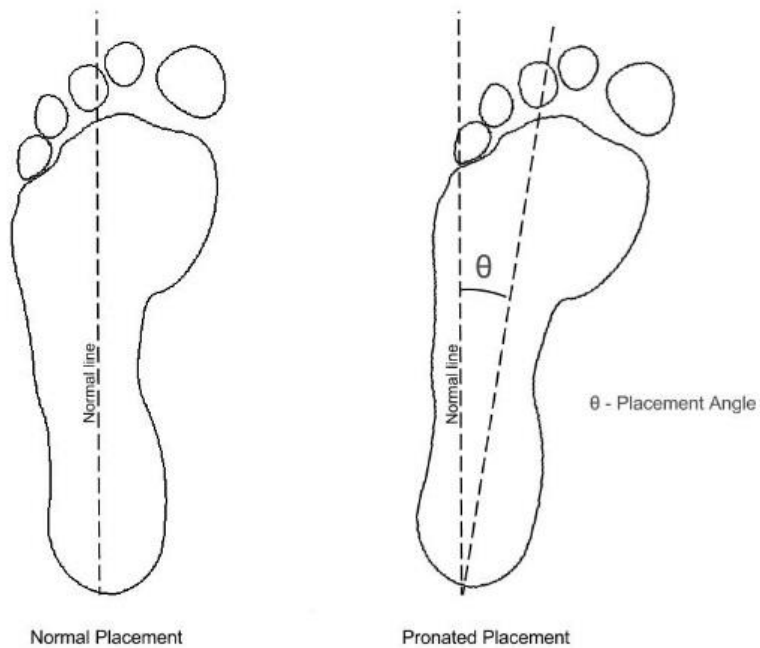


Figure 2: Placement Angle Diagram

A placement angle of +/- 7.5^{o} is considered normal, but for people who have problems with pronation or supination, placement angles can be as significant as +/- 17^{o} (Kernozek, Ricard, 1990). The placement angle of the foot is very difficult if not impossible to reverse, and if a person's condition is allowed to worsen, their placement angle will increase.

Placement angle effects in skating

For individuals with large placement angles, skating can become a difficult task. The neutral stance, when skaters place their feet in their natural locations, will result in problems for persons with larger placement angles as their skate blades will not be parallel. When the skater tries to glide, for example, they will have to put their feet into what feels like an unnatural position in order to avoid their skates drifting apart or colliding. Skating in this situation can be difficult and sometimes dangerous.

When the blade is not positioned properly, the skater can lose a great deal of power from their stride. If the placement angle is such that the foot is angled inward (from pronation), the skater will be forced to take much narrower strides. This is due to the fact that the skater will not be able to angle their feet wide enough to allow their skates to be placed parallel to the direction the force is applied as shown in Figure 3 below. When pushing off of a blade while gliding, the skater will not be able to be apply force perpendicular to their blades to accommodate their adjusted angle.

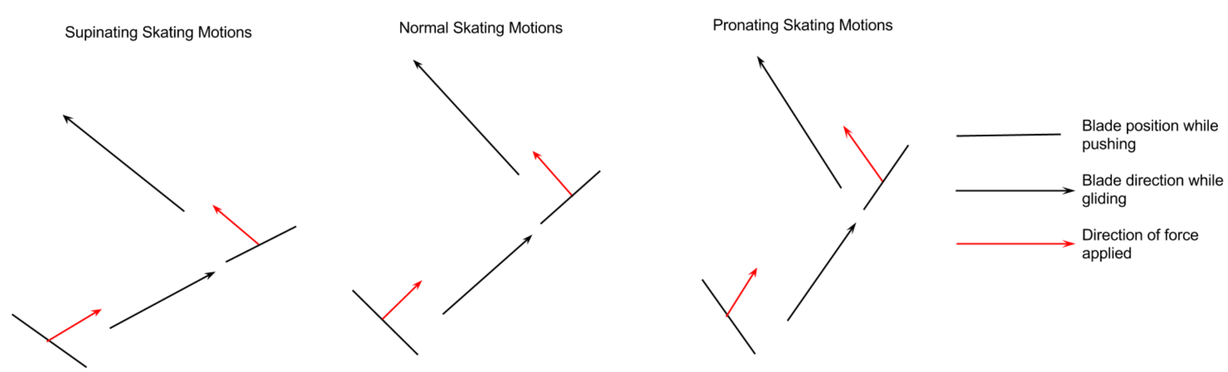


Figure 3: The supinating, normal, and pronating motions of skating

This means that some of the force is pushing alone the direction of the blade, meaning the skater loses power and efficiency in their stride. In addition, certain skating maneuvers require a very large intentional placement angle. For individuals whose feet already have an increased placement angle, achieving the proper positioning can be difficult or impossible if their range of motion has deteriorated.

The positioning of the blade is important in order to maintain an efficient stride and comfortable stride. If a skater is forced to make the adjustment by consciously angling their foot to correct for their problem, skating can become uncomfortable for the user. In order to make skating more efficient and comfortable for people with significant placement angles, the angle of the blade on the boot must be adjusted.

Current Solution

The current solution to address the issue of placement angles is to re-mount the skate blade on the boot at an angle. This process involves removing the current blade and drilling new mounting holes, or purchasing new boots without blades and having them mounted later. Both options are simply adjusting the mounting position of the blade on the boot.

In the first case, where the blade is removed and remounted, several steps must be followed. The current blade must first be removed by removing the rivets followed by drilling new holes into the bottom of the boot. At this point, the old holes must be filled to avoid ice and water getting into the boot. If the adjustment angle isn’t correct, the process will need to be repeated and eventually the bottom of the boot will have too many old holes and the blade will no longer be able to be safely secured.

The second case involves acquiring a new boot that has not yet had a blade mounted on it. This adds significant cost as the boots and blades must be purchased separately. In addition, if the mounting is not done correctly the first time, the situation is similar to the first scenario where the bottom of the boot becomes perforated.

Once the blade has been positioned correctly, it will work well for the skater for a time. But since the placement angle cannot be fixed, people with pronation problems will often find that their condition continue to worsen as time goes on. Eventually, the adjusted blades will need to be adjusted and the process repeats.

DESIGN SPECIFICATIONS

The following Design Specifications were developed and used to govern the design.

- Device must allow user to repeatedly adjust the placement angle of the blade without re-mounting.
- Device must require mounting only once.
- Device must allow the user to adjust the blade with a minimal number of tools (1-3).
- Device must be able to be secured in place to allow user to test the configuration.
- Device must be able to withstand forces from figure skating.

Allowing the blade to be repeatedly adjusted without remounting and requiring the device to only require mounting once ensures that the design will provide a solution that addresses the issue of adding numerous holes to the bottom of the boot. Limiting the number of tools that the adjustment mechanism requires ensures the device is simple to use and minimizes the time required to make adjustments. Securing the blade in place and designing the device to withstand the forces from skating ensures that any configuration can be safely tested by the user.

DESIGN DESCRIPTION

The goal of this project is to design a system that would allow for infinite blade angle adjustments to accommodate persons with pronation or supination problems. The design consists of two plates at the rear of the boot and one at the front. The angle of the blade is adjusted using a worm connected to the static plate (mounted to boot) and interacting with the adjustable plate (mounted to blade). The adjusted position is fixed by tightening bolts in the static and adjustable plates as well as tightening clamps holding the toe of the blade to the front plate.

General Design Features

There were several aspects of the design were considered during development. These ideas were not included in the design specifications as they were only desirable, but were strongly considered at various points during the design process.

Choosing the Pivot Location

The heel was chosen as the pivot location for several reasons. The primary of these is that regardless of placement angle, the heel always lands in the same location. This means that the placement of the heel is the only location that is consistent between people with pronation problems and those without. Since the heel is placed correctly, placing the pivot mechanism at the heel results in the blade being positioned along the normal line. If the pivot location were to be located at the toe, the blade would be parallel to the normal line, but offset to the side. It was decided that for the purposes of this project, placement of the blade along the normal line (as opposed to offset) would be ideal.

An additional advantage to using the heel as a pivot location is that it makes skating more natural. Proper skating technique involves bringing the heels close together (often touching) before pushing off. If the blade were to pivot from the toe, the heel would not be over the blade. This would result in the blades colliding when the heels are brought together or during crossovers.

The final advantage to locating the pivot at the heel deals with weight and force distribution. The toe of the boot is much wider than the heel which means that as the blade is adjusted, there is a greater chance that the boot will still be positioned over the blade mounting plates if the blade pivots at the heel.

It was recognized that there were disadvantages to using the heel as a pivot as well. The primary of these disadvantages is the compromised use of toe picks. When using the toe picks for jumping or spinning, weight is transferred to the toes. With the pivot position at the heel, there is potential for the blade to be angled in such a way that it is not under the toes. This would make it difficult to balance on the toe and would require a change in body position. This is one of the reasons the device was designed to be used only temporary.

Usage

Because of the issue of using the toe pics and because many of the forces involved in skating are variable and high during some motions (stopping/jumping), it was decided that the purpose of the device should be only to determine the ideal blade placement angle. In essence, the device would be temporarily used by the user to determine the ideal angle at which point the device would be removed and the blade would be permanently mounted to the boot.

Marketing

The purpose of this project was not focused on turning the design into a marketable product, but it was considered throughout the design process. These considerations took two forms: cost and ease of use. It was desired to keep the manufacturing/material cost of the design minimal. Since the design was not intended to be a permanent solution, customers would likely be hesitant to spend a lot on what could be considered as a calibration instrument.

Rear Adjustable Plate

The 1.X series of the adjustable plate design shows the initial thoughts for the component. The design started with a simple rectangle with a raised track for gear teeth. The track was included to allow the plate to be adjusted by a worm mounted on the rear static plate above. The slots were designed to allow for 30° of adjustment on either side and were positioned to ensure that there would be no interference when pivoting. Iteration 1.1 features curved edges to accommodate the rotation of the plate. Without angling the sides in this way, adjusting the plate would result in the edges extruding from the side of the boot and potentially create a hazard for skaters. Iteration 1.4 added the mounting holes for the skate blade. The holes include a counterbore to ensure that the rear plates will be able to slide smoothly over each other. It should be noted that the thickness of the plate had not been considered at this point, so the counterbore would not have been effective. Also at this time in the project, there was no skate blade available to determine proper dimensions or placement locations of the blade mounting holes.

The 2.X series of the Rear Adjustable Plate featured the most significant changes in design. The lip for the gear teeth was removed in order to simplify the design. Having a raised gear track, as shown the previous iterations, would have greatly complicated the design of the worm as it would have required complex geometry including a continuously varying pitch. The revision of this design was inspired by the more traditional worm-gear relationship and is reflected in the design. The gear teeth shown in the initial versions were arbitrarily drawn to show the function of the plate. The resulting change in the interaction between the worm and the plate meant lowering the worm mounting location in order to be properly aligned with the new gear teeth. At this point in the design process, a skate blade and boot had been obtained, so dimensions for the mounting holes were able to be accurately determined. This is reflected in the sizes of the blade mounting holes. It was also decided at this time to that helical gear teeth would not be incorporated into the design. Although these are standard for a gear interacting with a worm, including this feature would add unnecessary complexity since the design would still function without them. Design iteration 2.5 finalized the thickness of the plate. It was decided that the counterbore features were necessary and the thickness of the plate would have to be significant enough to allow for them. Iteration 2.6 adjusted the size of the plate. The radius was increased to equal that of the static plate design (at that time) and heel of the boot to avoid high stress/strain locations.

The 3.X series of the adjustable plate design focused on finalizing dimensions. Until this point in the project, the manufacturability of the plates had not been closely considered. These versions reflect the manufacturing limitations of the WPI Machine shops. The main area that was considered was the teeth at the end of the plate that would interact with the worm. Through an inquiry at the machine shops, it was determined that the smallest available milling bit was 1/16in. Additional changes in these versions include the positioning of the mounting slots to allow for clearance between the mounting bolts and the blade. The final change in the 3.X series as in version 3.4 where the inner corners of the gear teeth were rounded as square features of this sort cannot be manufactured.

The 4.X series of the adjustable plate designs were intended to be final versions, ready to be manufactured. The major changes in these designs from previous versions include adjustments of the gear teeth dimensions. During design review with manufacturing personnel, it was noted that the minimum milling capabilities of the machine shop were not 1/16in. as previously thought, but were instead limited to 1/8in. No worm could be obtained to accommodate the change in pitch, so one was designed and printed using the rapid prototyping machines at WPI. The design is explained in the section below. Since the worm was now being designed instead of being purchased, there was freedom to determine the size of the gear teeth so long as the smallest feature was 1/8in or larger. It was decided to make the gear teeth as small as possible as it would allow for more precise adjustments of the blade placement angle. With all changes made, iteration 4.1 was chosen as the final design to be manufactured. It was used to determine material selection as well as analyzed for failure.

Worm Selection and Design

A worm was selected early on as an ideal mechanism to allow for the adjustment of the skate blade. It would allow the user to make small adjustments while simultaneously providing a locking mechanism. One of the unique traits of a worm system is that it is cannot be back driven meaning that turning the gear while not turn the worm. The available machine shops do not have the capability to manufacture a worm so it would need to be ordered as a pre-made unit.

The selection of the gear teeth was not a simple process. There are very few suppliers that carry worms of the size needed for design. Eventually, several potential gears were found and had CAD models provided. They were imported into the SolidWorks assembly to determine if they would function with the design. Many of the gears had a very small pitch, which limited the number of viable gears. It was believed at this time that the manufacturing capabilities of the machine shop allowed for cut features as small as 1/16”. As a result, a gear with a 1/16” pitch was selected.

It was decided that the worm would not be ordered until the designs had been validated by the machine shop in the event that there were any factors that would restrict the selection of the worm. Unfortunately, such an event occurred when it was realized that the minimum size milling bit was 1/8", which already had limitations. This change was reflected in the design of the gear teeth on the rear adjustable plate, which the worm would need to interact with.

The change in gear teeth meant that the previously selected worm would not function with the revised design as the pitch was too small. The gear teeth would need to be designed around the gear that was purchased as availability of worms was the limiting factor in this iteration of the design. As a result, a new worm with larger pitch needed to be found. A gear of the required dimensions was unavailable, however, and was too expensive to have manufactured. As a result, it was decided that the gear would need to be manufactured in-house using the rapid prototyping machines.

The design of the worm was not complicated. The pitch was determined by the design of the rear static plate and was determined to be 1/4". The design was created using a profile of the gear tooth wrapped along a helix. This features was merged with a cylindrical body with a hole and key slot to allow it to be rotated by rotating a pin. The pin was designed to just be a cylindrical piece with a key feature to allow the worm to be rotated. The ends of the pin would have hex cuts in them to allow the pin to be rotated using a standard Allen key. With the design finalized, it was submitted to the rapid prototyping personnel at WPI to be printed.

Rear Static Plate Design

The purpose of the rear static plate is to provide a mounting location for the rear static plate and to hold the worm used for adjustments.

Initial designs consisted of only a rectangular plate and a feature extruded up to provide a mounting location for the worm. The retained this general profile through the 1.X iteration series. It was decided at this time that mounting holes to attach the plate to the boot would not be decide on at this point. This was due to the fact that these positions were not as necessary as the mounting locations for the adjustable plate.

The change to 2.X was prompted by a change in design of the adjustable plate. All designs from this point on included a feature extruded below the top plane of the plate. The purpose of this feature was to allow the worm to sit lower such that the teeth of the worm and the adjustable plate would interact along the midplane of the adjustable plate. This feature included a slot which was sized varied through remaining iterations according the worm that was being considered at the time. Similar to the 1.X series, the 2.X iterations were rectangular in shape and did not include boot mounting holes.

The next major change to the designs was the profile of the plate. The most notable change in the 3.X series is the conversion to a rounded profile to follow the heel of the boot instead of remaining rectangular. The purpose of this change was to avoid unnecessary extrusions from the side of the boot and to avoid the sharp corners of the rectangular plate.

Another change in the 3.X series was in iteration 3.1 which added a cylindrical extrusion to the bottom of the plate. The inspiration for this feature came from a review of the manufacturing process. Since the plate would need to be ¼in. to accommodate the worm mounting feature, there would be enough material to include the pivot. This feature would eliminate the need for a pin to be added after the manufacturing process greatly simplifying the assembly process.

Additionally, the 3.X series was the first to include mounting locations for the rear static plate as well as boot mounting holes. Iteration 3.3 was the first design to include the mechanism through which the adjustable plate would be secured. This was accomplished through tapped holes. The tapped holes would allow bolts to be placed through the slots in the adjustable plate and threaded into the tapped holes. By tightening the bolts, the adjustable plate could be secure in place to the static plate. These hole locations were adjusted to avoid interference between the bolts and the blade found during the early prototyping stages.

The next feature to be added is seen in iteration 3.7, which changes the boot mount holes to slots. This feature was added to allow the user to adjust the lateral position of the blade on the boot.

Adjusting the angle of the blade would mean the toe of the boot would have less support. Changing the boot mounting holes to slots would allow the user to move the heel of the blade slightly to the side, moving the toe of the boot closer to the toe of the blade. This would mitigate some of the balance issues created by adjusting the blade angle.

The 4.X series of the static plate design includes iterations that had addressed all known issues and are, in theory, ready to be manufactured. These designs were used to determine mass properties for material selection as well as dimensioning used in analyses.

Front Plate and Toe Locking Mechanism

The front plate was not originally considered as a major component of the design for this system but was eventually realized to be a major aspect. The main reason for the high level of importance of this part is its purpose, a mounting location for the toe of the blade.

Toe Locking Mechanism

The locking mechanism for the toe of the blade was the largest determining factor for the design of the front plate, and so was considered closely. Original design considerations involved pivoting bars to be mounted to the front plate and the to the mounting holes of the blade itself. This idea was based on the bars from an erector set, which was used for prototyping in the early stages of the design. The idea was that using two bars would provide a rigid structure and secure the toe in place. The issue with this design was that the bars from the erector set had set hole positions meaning that the blade would only be able to be secured at certain locations (figure of erector set components). This was unacceptable for the design and was dismissed. The next design was based on the previous idea, but instead of mounting holes along the bar, a slot was considered. The issue with this design was that it would rely on friction between the mounting bolt, nut, and bar to secure it in place. The next design consideration focused on using the cavity on the front mounting plate of the blade. Using this feature as the mounting location would provide more versatility in mounting, but it was eventually ruled out as an option as it would be impossible to use if the cavity was under the boot. The next option was to use a hold down clamp to anchor the blade in position. This option would also rely on friction to hold the blade in position, but it was determined at this time that a solution that didn't rely on friction would be difficult to design, and it was important for the design to move forward.

In order to use the hold down clamps with the front plate there would need to be holes to secure the pins. It was realized in previous iterations that unused mounting mechanisms would be a hindrance if they could not be removed. After some deliberation over the design, it was realized that using slots would allow the user to remove unused clamps or place them where they would be needed. The major problem with this design is that it would require a portion of the blade to be in contact with the front plate at all positions. It was still chosen as the locking mechanism because it was easily adjustable by the user and easily removable in the event it was needed at a different location. The design of the front plate was based on the necessary mounting locations for the hold down clamp. In order to maximize the clamping force on the blade, the center portion on the bottom face of the plate was designed to be recessed such that the plate would sit flush with features at front and back of the plate. On the top, pocket features were created around the slots to act as counter bores for the washers that would be used by the hold down clamps. The only remaining features of the front plate are the mount holes. It was decided that the holes should be counterbored and placed in the middle to avoid any interference with the existing mount holes.

ANALYSIS

There were a few analyses done on the design used to determine material selection and check for failure. The first of these analyses was is shown in a table used to determine the optimal material for the design and is shown below in Table 1: Component Weight by Material.

Table 1: Component Weight by Material

Component Weights for Material Selection		
	6061 Aluminum	1020 Steel
Part	Weight (lbs)	Weight (lbs)
Rear Stat.	0.1064	0.3101
Rear Adj.	0.0715	0.2084
Front	0.2219	0.6469
Total:	**0.3998**	**1.1654**

This table shows that 6061 is the optimal material by weight. Additionally, aluminum will not corrode, which is an important property considering the mechanism will likely get covered in ice shavings. The second analysis that was performed on the design was a tearout calculation. These calculations were conducted using equations 1-4 listed below.

(1) $$\sigma_{allow} = \frac{\sigma_{yield}}{FS}$$

(2) $$A_{tearout} = 2 * d * T$$

(3) $$\sigma_{actual} = F * A_{tearout}$$

(4) $$F_{stopping} = \frac{v^2}{2x} * m$$

σ_{allow} is the allowable stress for the system, σ_{yield} is the yield strength of the material, and FS is the factor of safety used in the design. $A_{tearout}$ is the effective area examined for tearout calculations, d is the shortest distance from the location of applied force to the edge of the material, and T is the thickness of the plate. σ_{actual} is the actual stress from tearout and F is the load or applied force. $F_{stopping}$ is the force on the blade from stopping, v is the velocity before stopping, x is the distance over which the force is applied or the stopping distance, and m is the mass of the skater.

The tearout analyses were calculated using maximum force from jumping and from stopping assuming a 150lb person. The maximum expected force from jumping is five to eight times the body weight. The force from stopping was calculated assuming 10 miles/hour (4.5 meters/second) and is shown in Table 6: Force From Stopping Calculation in Appendix B. Tearout Calculations were done using Excel and are shown in Table 3: Tearout Calculation and the calculations for allowable stress can be seen in Table 4: Allowable Stress Calculation found in Appendix B.

Using the calculated force value from stopping and 8x bodyweight for jumping, tearout stress was calculated at two locations and are shown in Appendix B. The first of these is the rear slot on the adjustable plate and the second is the hole for the worm pin on the static plate shown in Figures 5 and 6 below.

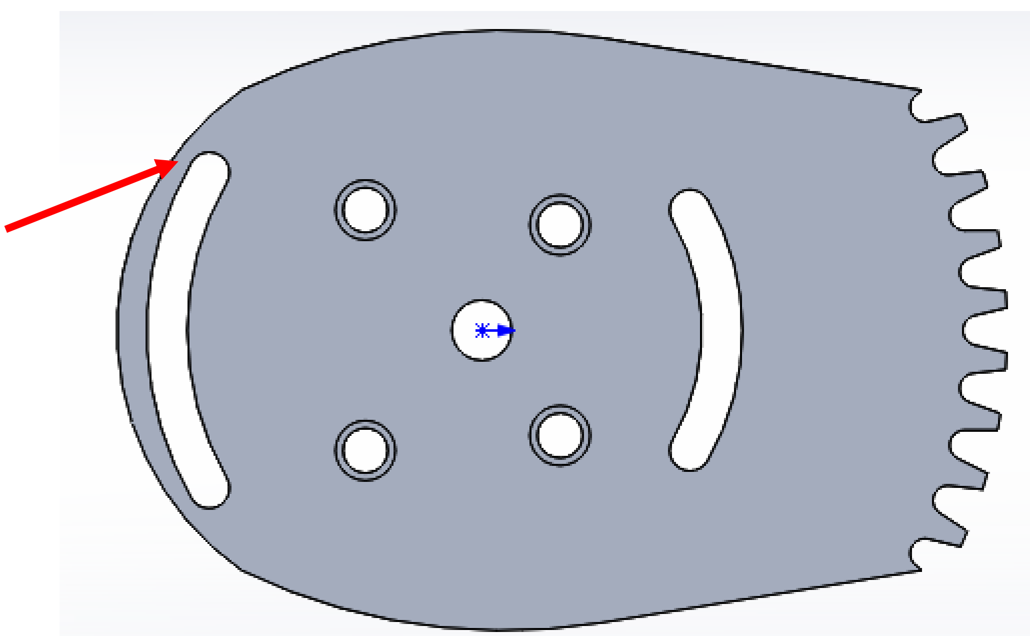


Figure 4: Adjustable Plate Tearout Calculation Location

Figure 5: Static Plate Tearout Calculation Location

The design utilized a factor of safety of 2 to ensure the design would not suffer from failure under normal operating conditions. The calculations show that the design is safe within the given factor of safety when the forces of stopping are considered, but the force from jumping, however, is significantly higher, and the plate would fail at both locations under these forces as shown in Table 5: Safe/Failure Calculation.

PROTOTYPING

One of the key aspects in the development of the project was the various prototyping stages of the project. Because of the restrictions of the budget, it was desired to create only the final order prototype out of metal. As a result, it was important to do zeroth and first order prototypes out of cheaper materials.

Zeroth Order Prototype

The zeroth order prototype was constructed using Erector Set components and cardboard and was used for the sizing and positioning of various features. Drawing files of the parts were printed and used as outlines to cut out cardboard profiles. The locations for the mounting holes could then be identified, as shown in Figure 6, to be placed later in the SolidWorks models.

Figure 6: Cardboard Prototypes

Using various Erector Set components and screws, the cardboard cutouts and blade were mounted to the boot in such a way that its placement angle could be adjusted. After changes to the design had been made, it was a simple task of printing a new drawing and cutting out the profile in cardboard. At this point, the hole locations could be punched out allowing it to be mounted to the blade. If the hole locations lined up, the locations were finalized, but if not, additional adjustments could be easily made. This prototype introduced the complication of securing the toe of the blade. While the problem was unable to be solved at this time, numerous methods were tested using this prototype.

First Order Prototype

The first order prototypes were constructed from acrylic sheets. Using a laser cutter from Universal Laser Systems, the 2-dimensional profiles of each part could be quickly and precisely cut out. In addition, holes could be added to check their locations and could be used for mounting. The advantage to using acrylic was that it allowed for components to be produced with precision. One of the major drawbacks of the cardboard components was the lack of precision and rigidity. These prototypes assisted in determining the final locations of each feature on the components. Before a design was determined to be complete, it was cut out in plastic and assembled to ensure that everything functioned smoothly. The largest drawback to these prototypes was that the laser cutter is incapable of producing 3d features. In addition, the acrylic cannot be easily machined which meant that a worm could not be mounted for testing. While this was an inconvenience, the advantages to using the laser cutter were far more significant.

Final Prototype

The final prototype was machined out of metal using a Haas CNC mill. After several consultations with machine shop personnel, the design was deemed ready for machining. Machining in metal proved to be more difficult than originally anticipated. The gear teeth on the adjustable plate required a ⅛ in. mill bit which meant the spindle speed needed to be reduced to avoid breaking the tool. The most significant challenge that needed to be overcome was the machining process. Because the plates were so small, they needed to be attached to other pieces of stock before they could be machined. The original plan was to drill out the mounting holes for each component, then use bolts to secure each component to a piece of “sacrificial stock” below. While this method would have worked, it would have significantly increased the time required to machine. In addition, the facing operations required for some components would have to be done in two operations to avoid collisions between the bolt heads and the tool. In order to avoid these issues, it was decided that the stock used for each component would be attached to a larger stock piece using adhesive. The adhesive sheets were placed between the two pieces of stock and was activated using a hot plate. Once cooled, the adhesive was, in theory, strong enough to hold the components in place during the machining process. Since the method of adhering the two plates had been decided on, Esprit was used to generate the tool paths. At this point, the parts were ready to be machined. It was expected that the adhesive would not be strong enough to hold the stock down during machining, but the operations were successful and the parts were made successfully as shown in Figure 7.

Figure 7: Final Assembly

Some of the features from the design were not included in the final prototype. The holes used to secure the adjustable plate to the static plate were not tapped as there we no more taps available for use in the machine shop. On the front plate, the area around the slots used for the hold down clamps was not counterbored. This feature was not included due to time constraints and the availability of machine shop personnel.

DESIGN REVIEW

After the final prototype had been manufactured, the device was assembled. Because of the mission features mentioned at the end of the prototyping section, the design could not be assembled in the ideal configuration. Bolts needed to be placed through the holes in the static plate that were intended to be tapped. These holes were not counterbored and so the bolt heads extruded up from the surface of the plate. This prevented the static plate from being mounted flush to the bottom of the boot. In addition, the counterbore holes for the static plate mounting holes and the blade mounting holes on the adjustable plate were not made larger enough. This meant that the static plate and the adjustable plate did not sit flush against each other. The pin used to mount the worm would not fit through the mounting hole in the static plate due to a design oversight. To accommodate this, the pin was cut in half and the first half was placed inside the worm before being pushed into position. The second half needed to have the extrusion for the key cut down so that it would fit through the hole on the static plate. While this solution worked, it was not ideal. Additionally, the plastic was weaker than expected and failed after extended use of the worm. Finally, hold down clamps of the proper size were not available at the time of assembly. They were instead replaced by metal toggle bolt anchors.

Aside from the changes listed above, the prototype functions as it was intended. The worm interacted well with the teeth of the static plate and required minimal force to adjust the placement angle of the blade. There was interference between the bolt heads between the static and adjustable plates which made some adjustments difficult, but the full range of motion was possible on the design.

FUTURE WORK

Before the device can be considered complete, additional work must be done on the design and analysis. The device as it is currently configured works, but improvements could and should be made to improve the design.

Toe Design

The main aspect of the design that needs to be improved is the locking mechanism at the toe. The current solution using toggle bolt anchors seems to work well, but it still relies on friction. Ideally a more secure mechanism can be developed that will lock the device in place without the need for clamps.

Worm

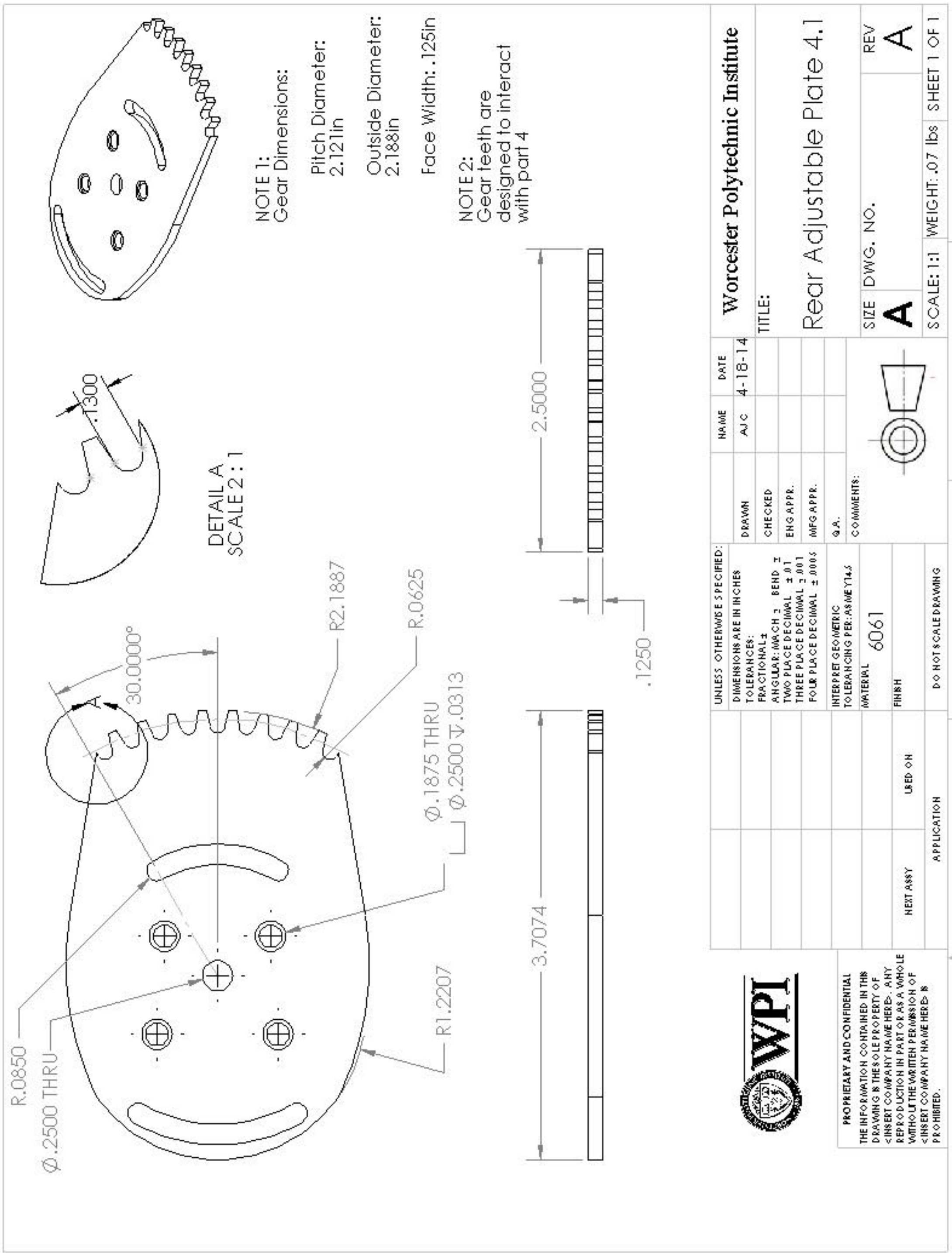
The next aspect of the design that needs to be improved is focused on the worm. If it is possible in the future to manufacture the gear teeth using a 1/16 in. milling bit, then a metal worm can be purchase for a reasonable price. The current solution using a plastic worm works, but the gear teeth are slowly shaving off the face of the teeth which will eventually result in its failure. If the limitation remains at 1/8 in. then a metal worm must be manufactured. If this is the case, it may be necessary to order a large quantity of worms to lower the price/unit to a suitable level.

Testing

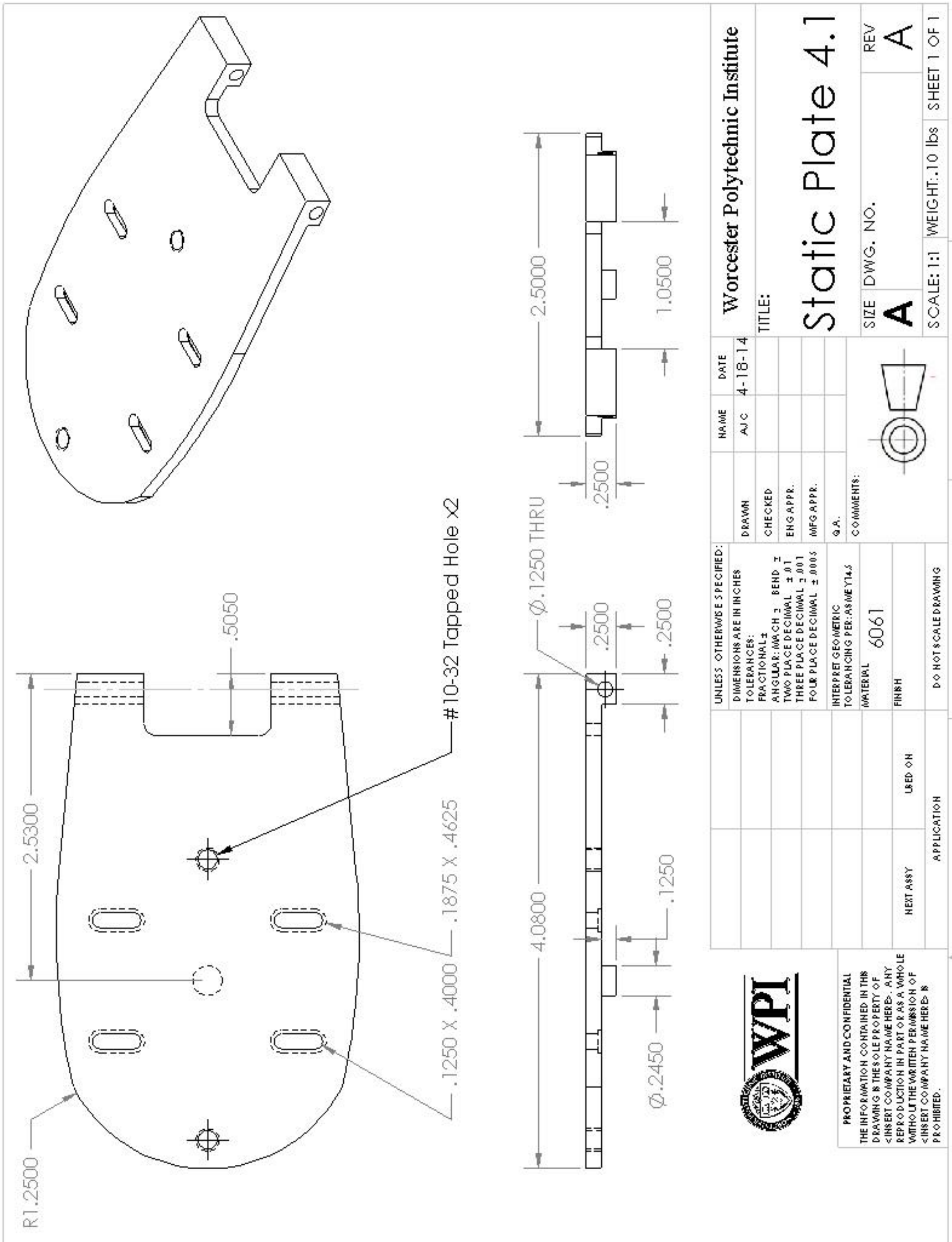
Since the project was focused on design and manufacturing, there was no testing done on the device. Before the device can marketed, it must be thoroughly tested to determine its functionality, limitations, and safety, as well as any unforeseen problems. It should be tested in a lab first with forces equivalent to stopping and jumping applied to heel, middle, and toe. The blade should first be positioned as it would normally be without the device, then the angle should be incremented slowly to ensure that it functions well at all positions. Once any issues have been resolved, the device should be tested on ice following the same methodology as the lab tests.

APPENDIX A: FINAL PART DRAWINGS

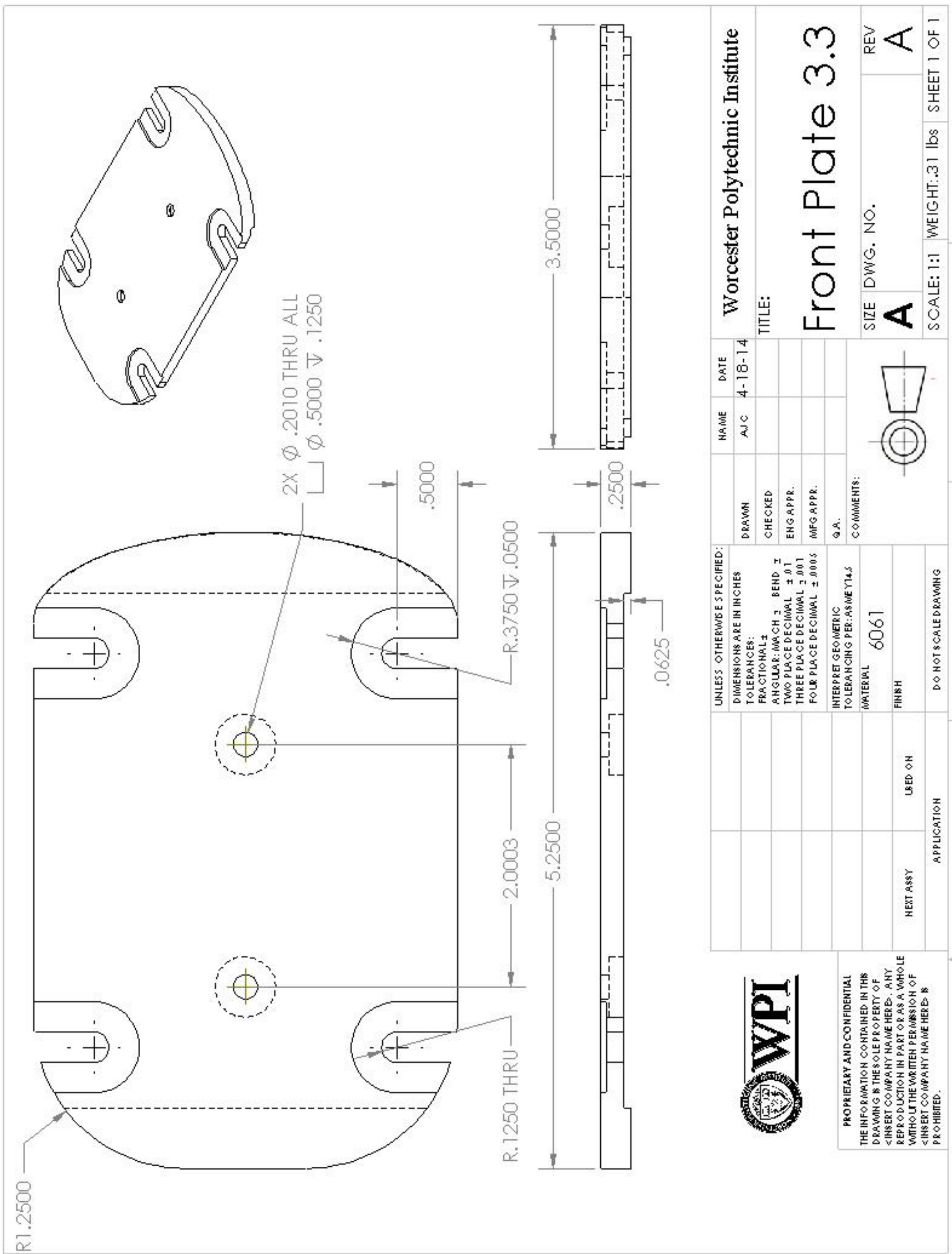
Adjustable Plate



Static Plate

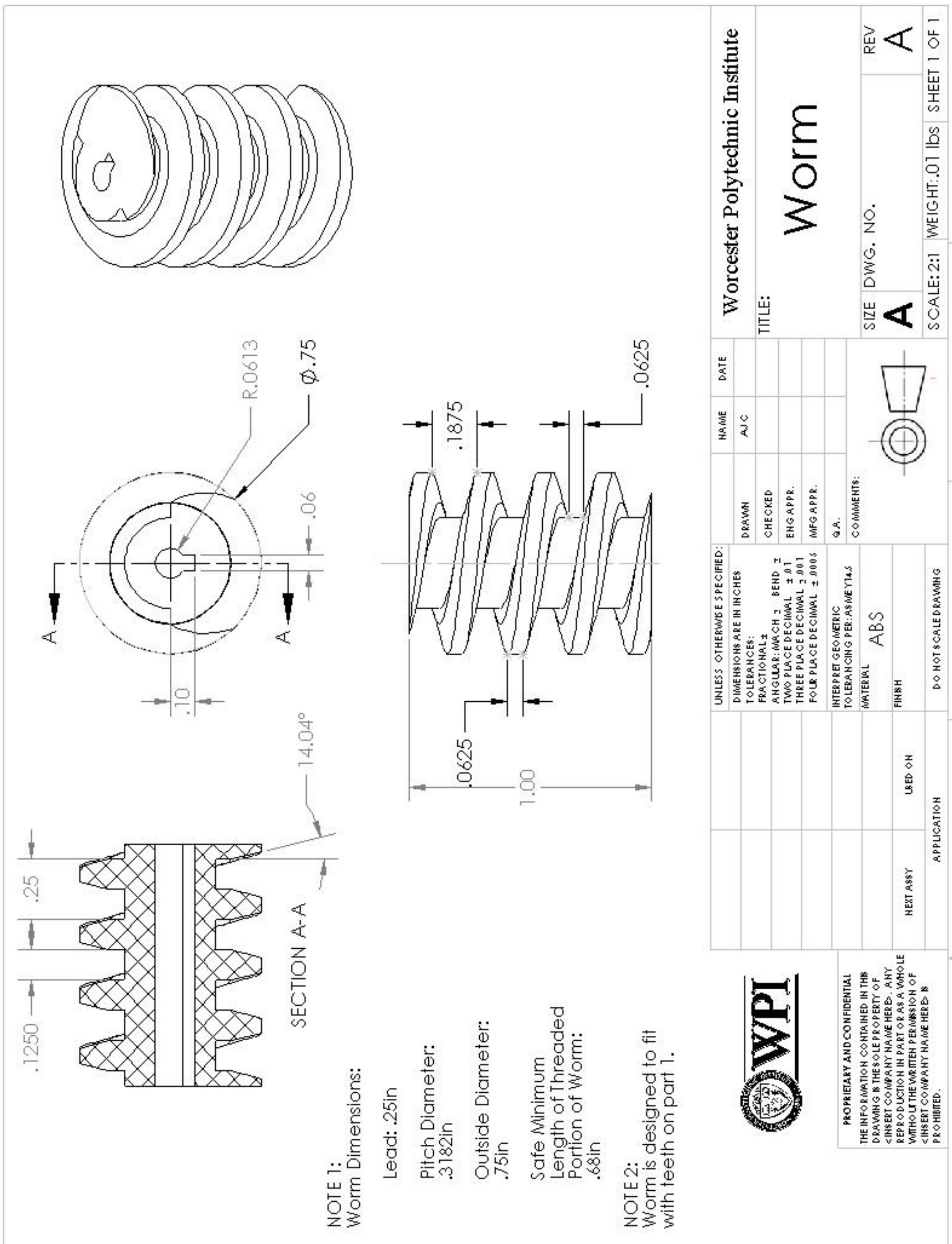


Front Plate



Worcester Polytechnic Institute
TITLE:
Front Plate 3.3
SIZE A
DWG. NO.
REV A
SCALE: 1:1
WEIGHT: .31 lbs
SHEET 1 OF 1
NAME
DATE
DRAWN
AJC
4-18-14
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
MATERIAL
6061
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
PROPRIETARY AND CONFIDENTIAL
2X ⌀ .2010 THRU ALL
⌀ .5000 ↧ .1250
R.3750 ↧ .0500
R.1250 THRU
R1.2500
3.5000
5.2500
2.0003
.5000
.2500
.0625

Worm



Worcester Polytechnic Institute
TITLE:
Worm
SIZE
A
DWG. NO.
REV
A
SCALE: 2:1
WEIGHT: .01 lbs
SHEET 1 OF 1
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ± .01
THREE PLACE DECIMAL ± .001
FOUR PLACE DECIMAL ± .0005
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5
MATERIAL
ABS
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
AJC
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
NEXT ASSY
USED ON
APPLICATION
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.
WPI
SECTION A-A
A
A
.1250
.25
14.04°
.10
.06
R.0613
Ø.75
.1875
.0625
.0625
1.00
NOTE 1:
Worm Dimensions:
Lead: .25in
Pitch Diameter: .3182in
Outside Diameter: .75in
Safe Minimum Length of Threaded Portion of Worm: .68in
NOTE 2:
Worm is designed to fit with teeth on part 1.
1
2
3
4
5

Bill of Materials

Table 2: Bill of Materials

BILL OF MATERIALS			
Part Number	**Description**	**Material**	**QTY**
1	Front Plate 3.3	6061	1
2	Rear Adjustable Plate 4.1	6061	1
3	Rear Stat Plate 4.1	6061	1
4	Worm	VeroWhitePlus	1

APPENDIX B: TEAROUT CALCULATIONS

Table 3: Tearout Calculation

TEAROUT CALCULATION						
Section	Force Type	Tearout Stress				
		d (m)	T (m)	$A_{tearout}$ (m^2)	Force (N)	Actual Stress (Pa)
Worm Pin	Jumping	0.00076	0.01585	2.415E-05	5336	220908561.5
	Stopping	0.00076	0.01585	2.415E-05	688.5	28503662.78
Adjustable Plate	Jumping	0.00178	0.00318	1.129E-05	4448	393966502.2
	Stopping	0.00178	0.00318	1.129E-05	688.5	60981550.53

Table 4: Allowable Stress Calculation

ALLOWABLE STRESS CALCULATION			
Material	Yield Strength (Pa)	Factor of Safety	Allowable Stress (Pa)
6061 Aluminum	241000000	2	120500000
6061 Aluminum	241000000	2	120500000
6061 Aluminum	241000000	2	120500000
6061 Aluminum	241000000	2	120500000

Table 5: Safe/Failure Calculation

SAFE/FAILURE CALCULATION				
Section	Force Type	Actual Stress (Pa)	Allowable Stress (Pa)	Safe/Fail
Worm Pin	Jumping	220908561.5	120500000	FAIL
	Stopping	28503662.78	120500000	SAFE
Adjustable Plate	Jumping	393966502.2	120500000	FAIL
	Stopping	60981550.53	120500000	SAFE

Table 6: Force From Stopping Calculation

FORCE FROM STOPPING CALCULATION		
Mass	68	kg
Velocity	4.5	m/s
Distance	1	m
Acceleration	10.125	m/s^2
Force	688.5	N

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