ROTATIONAL SNOWBOARD BINDING

A Major Qualifying Project Report:

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Abstract

The objective of this project was to design, manufacture and test a system that allows a conventional snowboard binding to rotate. This system would help reduce the likelihood of applying injurious loads on the lower limbs during skating and ski lift loading/unloading. Currently there are no products on the market that offer hands free rotation of the binding. This design functions by using an interior cam-follower system that fits within the mounting disc area of a conventional snowboard binding. This spring-loaded cam-follower system allows the rider to select one of two different position options: one for skating and one for riding. The system prototype was manufactured using CNC machining and was tested using a torque wrench to document its performance. The prototype was field-tested at a local ski resort and the results were analyzed to ensure the functional requirements were met.

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1. Introduction

1.1 Objective

The objective of this project was to design, manufacture and test a system that allows a conventional snowboard binding to rotate. This system would help reduce the likelihood of applying injurious loads on the lower limbs during skating and chairlift loading/unloading.

1.2 Rationale

Statistics show that snowboarding is increasing in popularity at a rate of twenty percent per year (Chalat, 2001). This growth increases the number of injuries caused by snowboarding. Hospital surveys show that between seven and twenty percent of snowboard injuries are lift related, and the majority of these injuries occur during loading and unloading the lift (Douka et al, 2008). In addition to hospital surveys, video analysis has shown that eighty-five percent of all people who fall while exiting ski lifts were snowboarders (Coats and Whelan, 2008). The awkward position that riders must use to exit the lift could be the reason for this high percentage.

One way to decrease the percentage of lift related injuries is a rotational binding system. This system would allow the rider to skate, load, ride and exit lifts with a foot position parallel with the board. The position of the leg in current skating practices is awkward and puts undesired loads on the knee (Refer to Appendix 1 for current practices). While riding the lift snowboarders must support the back end of the board with their foot, putting undesired loads on the ankle. A rotating snowboard binding would not only be more comfortable for the rider but also decrease knee and ankle injuries.

1.3 State-of-the-Art

There are four commercial snowboard-binding interfaces and several patents that incorporate a rotational mechanism. The products currently on the market include: The Swiveler, the Xturn, the Flip-U and Fronts. There are three important characteristics of each design to compare; compatibility with contemporary snowboard specifications, operation of the rotational mechanism, and the materials used to manufacture the device.

For a new device to be appealing to the majority of snowboarders it needs to easily integrate with an existing snowboard by using conventional mounting hole patterns. There are currently two conventional hole patterns for binding attachment; a four-hole pattern and a three-hole pattern used exclusively by Burton. Of the four products found, the only rotational system that is not universally compatible is the Flip-U. This system is only used with hole patterns found in adult-sized plastic bindings.

The mechanism that each binding system uses for rotation is particularly important to compare because this is the main function this project aims to improve. The first two systems, Fronts and the Flip-U, both have rear-foot initiated rotation. In order for the Fronts system to rotate, the rider must kick a switch on the front of the binding with their back foot. The Flip-U system operates in a similar way but uses a sliding lock mechanism operated by the rear foot. The remaining two binding systems, the Swiveler and the Xturn, both use a hand operated rotational release. The Swiveler uses a strap that is fastened to the base of the binding and the rider’s leg. In order to begin rotation the rider must bend over and pull the strap. To use the Xturn, the rider must pull a handle attached to the heel back-plate. All of these designs require an extra appendage to operate.

Since this new design incorporates rotating parts, it is important to pay attention to each material's coefficient of friction. Material selection can also affect the dimensional specifications of the device. The Swiveler and the Flip-U each make use of polymers. The Swiveler is a combination of a polymer composite and a high-strength aluminum, while the Flip-U is made strictly of a high-strength polycarbonate. The material used in the Fronts binding system is stainless steel. The X-Turn is only a conceptual design and does not have a specified material. Table-1 shows the material properties and dimensional specifications of the four binding systems discussed in this section.

Table 1: Current products on the market

Product	Rotational Mechanism	Compatibility	Materials	Height	Weight
Swiveler	Strap on binding side	Universal	Polymer composite, high strength aluminum	Unavailable at this time	15.8 ounces
Xturn	Handle on binding rear	Universal	None defined	dimensions unavailable	dimensions unavailable
Flip-U	Foot Switch	Adult plastic Bindings	High Strength Polycarbonate.	Unavailable at this time	"Negligible"
Fronts	Foot Switch	Universal	Stainless Steel	0.25"	Unavailable at this time

A comparison of the current binding systems shows that there is no system that conveniently allows the rider to rotate.

1.4 Approach

Using axiomatic design, this project sought to improve upon previous MQP designs and the four products mentioned in the State-of-the-Art. By considering the interior disc of the snowboard binding to be a common design characteristic of almost all snowboard bindings, the system could be contained within the binding rather than underneath it like other designs. Given that the majority of the components could be concealed inside the binding, the system would have less mass and a much lower ride height than its predecessors.

This device was designed to weigh less than 4.75 lbs and not increase the height of the binding more than 1.25 inches. It is composed of materials that will improve ease of use and overall aesthetics as well as prevent snow buildup in the components. A cam-follower system was designed to allow the rider to rotate the front foot so that it can be parallel with the board without compromising foot position adjustability.

Each component of the design was modeled in Pro-Engineer and a finite element analysis was performed using SolidWorks Simulation. With the CAD and FEA work complete, tool paths for the manufacturing process were generated in Esprit. The components were machined using the HAAS CNC machine center in the Washburn Shops at Worcester Polytechnic Institute. The binding was tested in the Washburn Lab against its functional requirements using a torque wrench to read and administer various torques along the three major axes of the binding. Lastly, the system was field tested at two ski resorts: Mt. Wachusett and Sugarloaf USA.

2. Design Process

Through the use of axiomatic design (Suh, 2002) and several constraints, a decomposition of the required components was developed. The functional requirements and their corresponding design parameters were developed in a hierarchical fashion beginning with the main objective as Functional Requirement 0, which acts as a parent to the subsequent requirements also known as children. This process aims to organize and reduce the number of functional requirements of the system such that any set of "children" are mutually exclusive from one another and collectively exhaustive with respects to their corresponding "parent".

2.1 Design Constraints

The following constraints were considered before the design process could begin to ensure success in satisfying the objectives:

- The binding attachment system must not allow the transmission of injurious loads via rotation to the lower limbs of the rider.
- The binding attachment system must be compatible with the existing four-hole interface of commercially available snowboards.
- The binding attachment system must be compatible with the existing mounting disc area of commercially available bindings
- The binding attachment system must be lighter than 4.75 pounds
- The binding attachment system must raise the height of the binding no more than 1.25 inches.
- The binding attachment system must allow its user to perform normally accepted snowboarding maneuvers

2.2 Design Decomposition

The design decomposition highlights each functional requirement developed in the design process and explains the reasoning behind the selection of a design parameter to satisfy it. Detailed drawings of every component described can be found in Appendix 2. Figure 1 shows the first three levels of the functional requirements and their corresponding design parameters.

0 FR	Provide the ability rotation of binding during taxiing/snowboarding	DP	Selectivly rotatable snowboard binding attachment system
1 FR	Transmit rding-control loads between foot and board	DP	Binding mounting system
1.1 FR	Transmit forces in the xy plane	DP	Cylindrical surfaces alligned with Z-axis (inner and outer ring system)
1.2 FR	Transmit moments about the x and y axes	DP	Surfaces parallel to X-Y plane
2 FR	Control binding rotation	DP	Spring loaded cam system
2.1 FR	Transmit Mz binding	DP	Surfaces that are not tangent to rotation between binding and board
2.2 FR	Provide angular locations for different ride positions	DP	Angular locations of notches in external cam
2.3 FR	Reduce friction between moving surfaces	DP	Selected materials
3 FR	Maintain functionality of rotation over time	DP	Preservation system
3.1 FR	Protect against enviornmental hazards	DP	Features protecting from enviornmental elements
3.2 FR	Protect against wear	DP	Optimization of material properties
4 FR	Allow for stance adjustment	DP	Current commercial attachment system
4.1 FR	Provide longatudinal placement adjustability	DP	mounting holes on board and inner ring
4.2 FR	Provide binding angle adjustability	DP	V-shaped notches on binding and outer ring

Figure 1: Paired functional requirements and design parameters

Functional Requirement 0 – Allow snowboard binding to rotate

The objective of this project is to enable a snowboarder to rotate their foot for the purposes of skating in a more comfortable position. In addition to this, the solution should also reduce the likelihood of skating related injuries and increase the success rate of loading and unloading lifts properly. In order to accomplish this, a design parameter called “DP 0: Selectively rotatable binding attachment system” was derived. A complete three dimensional model of the final product can be seen in figure 2.

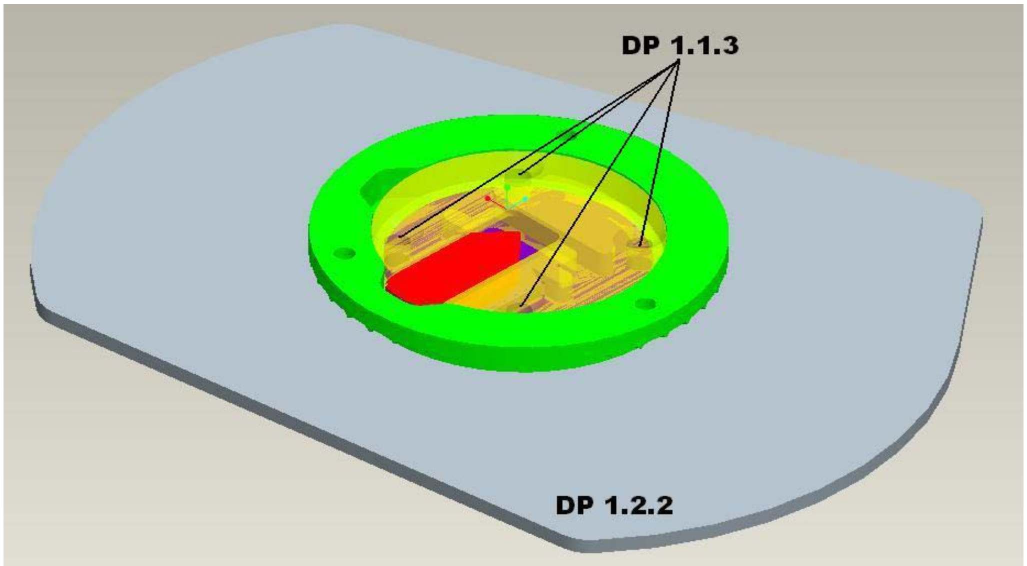


Figure 2: Selectively rotatable binding attachment system

FR 1 – Transmit riding control loads between foot and board

In order for this design to satisfy the constraints it must allow the binding to function in all the ways a snowboarder needs it to. The most important of these functions is the proper transmission of control loads between the rider's foot (binding) and the surface of the board. The efficient transmission of these loads allows a snowboarder to control their direction of motion, speed, and their ability to stop. This FR can lead to only one design parameter: DP 1: Binding mounting system. This DP introduces the attachment of the binding to the board using an intermediate component. The user's safety and satisfaction is inherently dependant on their control of the board; therefore this design parameter is paramount to the design.

FR 1.1 – Transmit forces in the XY-plane

FR 1.1 expresses the need to restrain the binding from any horizontal motion with respect to the board. The existing system normally experiences these forces during riding and skating. The design must transmit these forces in the same way without allowing any significant movement along this plane. The solution for this FR is: DP 1.1: concentric vertical cylindrical services between the components. Surfaces of this nature will only restrain planar translation and rotation about the axes along the horizontal plane, not the vertical z axis.

FR 1.1.1 – Transmit Fx and Fy between binding and outer ring

This FR describes the need to restrain the planar motion between the binding and the new mounting system. The binding has an existing cylindrical surface on the interior of the mounting disc hole. The design of the new binding mounting system will feature a matching exterior cylinder (DP 1.1.1 in Figure 3) which will contact the binding and transmit the forces.

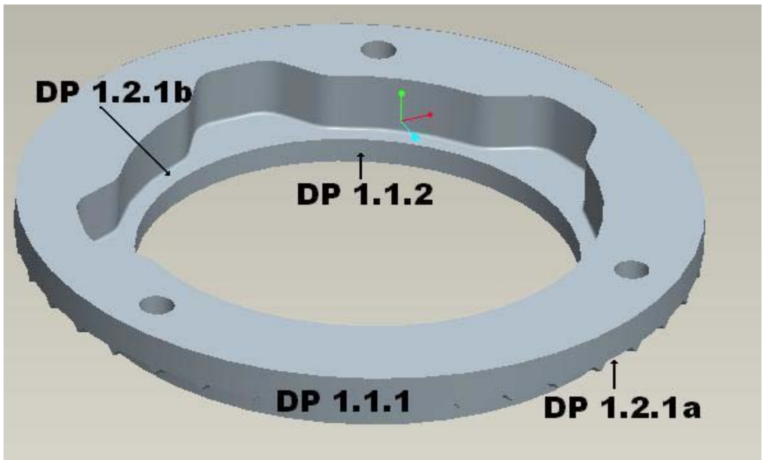


Figure 3: Outer ring

FR 1.1.2 – Transmit Fx and Fy between outer ring and inner ring

The mounting system will be separated into two major components to satisfy the rotating requirement as mentioned earlier. FR 1.1.2 requires that these two components be separated by a smaller vertical cylindrical interface (DP 1.1.2 in figure 3) concentric to the one mentioned in DP 1.1.1. This interface will allow the two components to rotate about one another.

FR 1.1.3 – Transmit Fx and Fy between inner ring and board

FR 1.1.3 suggests the need to transfer the horizontal forces between the mounting system and the board. This is accomplished by having compatible board fasteners which effectively join the inner ring to the surface of the board. The placement of these fasteners is standardized due to the nature of the original binding design and therefore the locations seen in figure 2 were the only option.

FR1.2 – Transmit moments about the X and Y axes

FR 1.2 requires that the moments about the axes located on the horizontal plane be transmitted from the binding to the board through the mounting system. In the traditional setup these moments are transmitted through two locations. The load in the negative Z-direction is transmitted through a contact point on the outside edge of the binding and the load in the positive Z is always transmitted through the mounting screw on the opposing side. These two loads create a moment across the base plate of the binding. Within the mounting system this moment will be transferred through the board via DP 1.2: Surfaces parallel to the XY plane.

FR 1.2.1 – Transmit positive Fz loads

This FR describes the need for the transmission of the positive vertical forces between the binding and the board. This force must be transmitted through the mounting system; to achieve this DP 1.2.1 was created. The design parameter 'DP 1.2.1 a', seen in figure 3, describes a surface that matches the bindings mounting disc hole. This feature has a horizontal component that will transmit the vertical forces to the binding. Within the mounting system the forces will be transmitted between a horizontal "step" feature as part of the interface between the two components (outer ring and inner ring). This step feature, labeled 'DP 1.2.1 b' in figures 3, 4 and 5, consists of an overlapping area between the outer ring and the inner ring. The overlap created by the inner ring keeps the outer ring from moving upward.

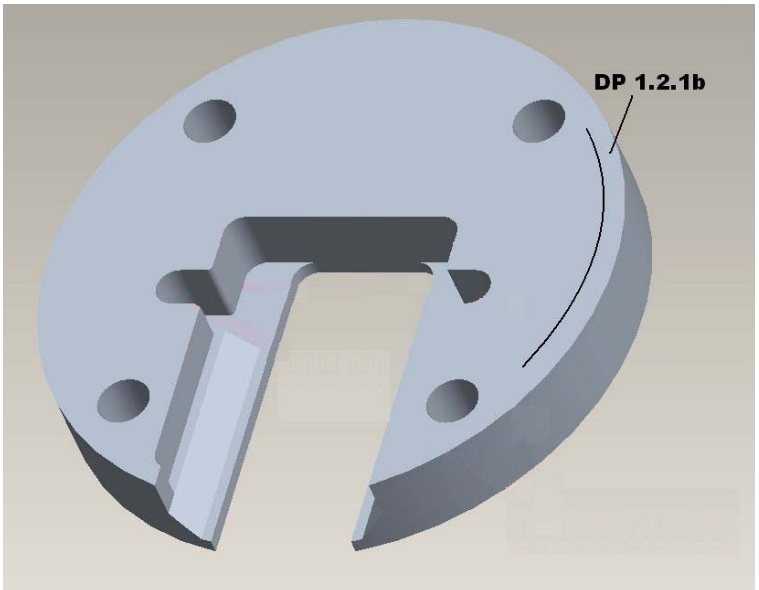


Figure 4: Bottom side of inner ring (top half)

FR 1.2.2 – Transmit negative Fz loads

This FR describes the need for the transmission of the negative vertical forces from the board to the binding. This is accomplished through DP 1.2.2: a component with contacting horizontal surfaces between the binding and the board. This component is referred to as the intermediate plate and is labeled 'DP 1.2.2' in figure 2 and figure 5.

FR 1.2.3 – Provide lever arm for transmission of moments

The functional requirement 1.2.3 suggests that the moments between the binding and board along the x and y axes can be broken down into two vertical components. The lever arm between these components is DP 1.2.3, the length of material between each of the contact points is the measure of this lever arm as seen in Figure 5. This collection of components acts to achieve the desired transmission of the vertical forces across this arm. Similarly, the individual components act as lever arms in between one another to transmit the load vicariously across the assembly.

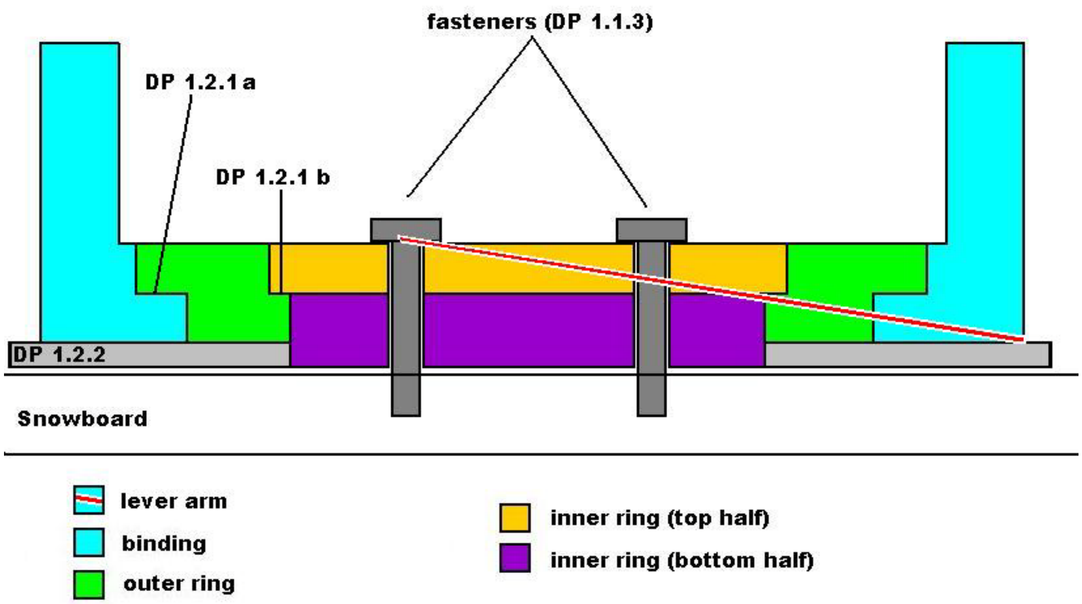


Figure 5: Cross section of assembly

FR 2.0 Control binding rotation

This design allows the rider to rotate their binding when desired, but prevents the binding from inadvertently rotating during typical riding conditions. DP 2.0 controls this motion through the use of a spring loaded exterior cam setup. The internal spring-backed follower presses against the external cam ring to provide pressure against inadvertent rotation.

FR 2.1 – Transmit moment in the Z direction for the binding

When the rider applies a moment of about 15 Nm about the z-axis, the binding will rotate. Anything under this value will cause the binding to remain in a fixed positing with relation to the snowboard. This moment goes through the binding, the outer ring and the inner ring. DP 2.1; 'Surfaces that are not tangent to rotation between binding and board' was created to satisfy this FR.

FR 2.1.1 – Transmit moment in the Z direction between the binding and the outer ring

When the binding is rotated the moment is transferred to the outer ring of the mounting disc via the ridged surface interface on the outside of the alignment ring component (DP 2.1.1 which is on the surface described by DP 1.2.1a). The teeth with a height of 0.075 inches and an angle of 45 degrees lock together with the matching teeth on the existing binding to transmit moments about the z-axis.

FR 2.1.2 – Selectively transmit moment in the Z direction between the outer and inner ring

FR 2.1.2 can only be satisfied by a DP which is active in a certain range of force. DP 2.1.2, 'cam-follower system,' will allow a follower to slide in and out of notches when the desired loads are applied.

The moment about the z-axis from the outer ring is transferred through the spring loaded follower to the inner ring when the moment is less than 15 Nm. When the moment becomes greater than that, the follower is pushed in and the binding is allowed to rotate. A block of rubber is used as the spring force behind the follower. When the binding is rotated out of the cam notch, the follower's back side presses against the rubber which is held in place by the interior walls of the inner ring top. The rubber deforms elastically and expands perpendicular to the axis of compression. Figure 6 demonstrates this action and shows its position in the system. Due to the nature of rubber the spring constant K will change with displacement, but the maximum spring constant will be reached when the follower exits a cam notch.

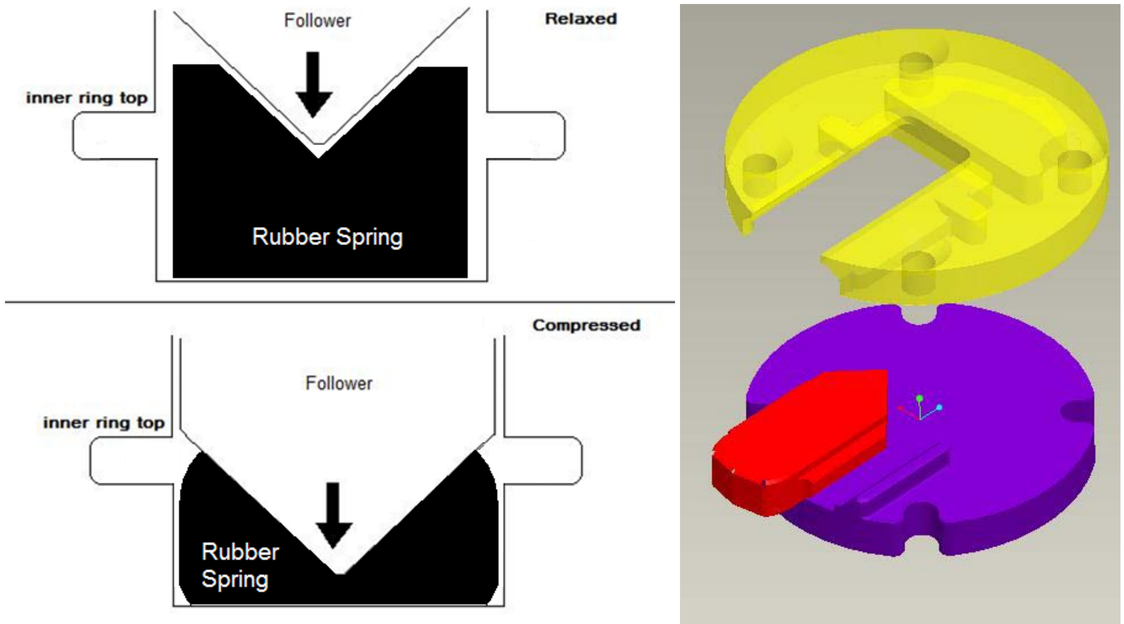


Figure 6: Rubber block acting as a spring (contained in the inner ring top half) on left and inner ring assembly on right

The front side of the follower has two flat surfaces that come together at a rounded edge. This edge is the only area of contact as the follower travels through the region between notches.

The external cam profile is designed to have two contact points with the follower when it is fully in a notch. The shape of the notch is similar to a "bell curve" with the deepest part extending beyond the end of the follower's reach. The cam-notch surface is angled at 55 degrees from tangent to provide resistance against rotation. The transitions between various sections of the cam surface have a minimum radius of .02 inches instead of a sharp edge to reduce friction.

The follower can only move along the x-axis (across the width of the board) with no translation in the ZY plane and no rotation about any axis. The cam itself will rotate around this interior assembly to create the desired motion. The follower is held in place by parallel 45-degree angled tracks. The contact area on these tracks is minimized to reduce friction between the brass follower and the aluminum.

FR 2.1.3 – Provide lever arm for transmission of moments (about Z)

A lever arm is required for the transmission of the Z moment through the various parts. The lever arm is provided by each circular component aligning concentrically, with the center of the inner ring being the common center. The lever arm through the outer ring is measured by the difference between the radius of the outside edge and the radius of the follower contact point on the cam surface. The lever arm through the follower is measured by the distance from the radius of the follower contact point with the cam surface and the outside radius of the inner ring. Lastly, the lever arm for the moment through the inner ring is measured by the difference between the radius of the outside edge of the inner ring and the radius of the mounting-screw hole pattern. These design parameters are listed as DP's under 2.1.3.

FR 2.2 – Provide angular locations for different ride positions

DP 2.2 states that the external cam profile will feature different notches at different angles for the binding to lock into. This will provide a location for the binding in normal riding location where the binding is oriented at 15 degrees from 0, as well as in skating position (90 degrees from 0). For the binding to be universal it will provide notches for both goofy and regular riding stances. The three notches are seen on the inside of the outer ring in figure 3.

FR 2.2.1 – Provide primary angular location for riding

The primary angular location for the front foot, while riding, is located 15 degrees from the positive x-axis. This location is where the binding will be setup like any ordinary binding, and used for typical riding conditions (this doubles as the goofy riding location).

FR 2.2.2 – Provide angular location for skating

The notch for skating will be located at 75 degrees about the Z axis from the riding location. This notch will provide a location for skating and loading /unloading ski lifts. The notch is offset a full 90 degrees to account for the fact that most binding setups have the front foot angled forward approximately 15 degrees. The goofy skating location is also included in this which adds a third notch to the design located 90 degrees from 0, or just 75 degrees on the other side of the notch for the normal riding location.

FR 2.3 – Reduce friction between moving surfaces

For the rotation to be smooth and to minimize the torque required to rotate the binding, the friction needs to be kept as low as possible between surfaces of the moving parts. By reducing the friction the majority of the rotational resistance is provided by the spring-loaded cam follower and reduces the required rotational force during the intermediate zones between the notches.

FR 2.3.1 – Reduce friction between cam and follower surfaces

To reduce the friction between the cam and follower surfaces brass and Lexan were used. Brass was used for the follower and Lexan was used for the cam. The interaction of these two materials provides a relatively low coefficient of friction. Also, the design of the edge on the follower reduces the contact area between the two surfaces decreasing the friction during movement.

FR 2.3.2 – Reduce friction between board and intermediate plate

To reduce friction between the board and the intermediate plate, Teflon was used as the material for the intermediate plate. This Teflon will have a low coefficient of friction with the board surface as it rotates with the binding.

FR 3 – Maintain functionality of rotation over time

The third functional requirement demands that the functionality of the device is preserved over time. The cam and the snowboard itself are both subject to environmental hazards as well as wear from general use and thus must be protected from said elements.

FR 3.1 – Protect against environmental hazards

Environmental hazards that could potentially impede the rotation function include snow, dirt, salt, and dust from storage. Preventing these and other foreign contaminants from entering the cam and the space between the board and base plate are essential to preserving the rotational function of the binding. The DP's for the 'cover plate' and 'intermediate plate material' were created.

The cam is composed of several components with tolerances that allow for minimal space between each other. Contaminants finding their way between the inner and outer ring will impede rotation, while contaminants that get into the spaces between the inner top ring, inner bottom ring, and follower will reduce the follower's ability to move along its track. In order to protect the cam, a thin cover of aluminum was designed to fit over the top of the entire mechanism. Screws are used to secure it so that the rider's boot may rest on top of it as if it were a normal binding.

The section of the board upon which the binding rotates is also at risk of damage from friction and foreign contaminants. To prevent wear on the surface of the snowboard the intermediate plate is made of Teflon. This layer will reduce friction and provide a disposable medium which can be replaced at low cost. As the Teflon becomes full of scratches and grooves (which hold dirt, ice, snow and dust) it can easily be replaced.

FR 3.2 – Protect against wear

The rotational function requires moving parts and the surfaces of these parts to slide along each other, ultimately causing wear over time. Since there is little that can be done about reducing the load on the components, the best way to resist wear is by using materials that will reduce friction for the given load.

The cam-follower is composed of several components with different materials chosen for low friction and long life. The follower slides along a track made by the upper and lower inner rings. The tip of the follower also slides along the inside of the outer ring and in and out of the v-shaped notches of the cam itself. To protect the follower against wear the material selected is brass because the coefficient of friction between aluminum and brass is much lower than that of aluminum on aluminum. Similarly, the outer ring slides around the inner ring and the material selected for the outer ring should also be different. Brass would not suit this application because it is relatively pliable, therefore Lexan, a machinable plastic, was chosen for its light weight and low coefficient of friction with aluminum. Since the cam surface is part of the outer ring, the interface between the follower and cam surface has already been chosen: brass on Lexan. This surface also has a much lower coefficient of friction than the other interfaces and is ideal for this application.

The board to binding interface experiences wear from the rotation of the intermediate plate along the surface of the snowboard. The material of the snowboard is fixed. The intermediate plate will only work in compression during snowboarding so it can be made from a variety of materials. The best way to reduce friction and ultimately reduce wear on the board to binding interface is with a Teflon intermediate plate.

FR 4 – Allow for stance adjustment

The fourth functional requirement is for the allowance of stance adjustment. As riders come in varying sizes, a single set stance could make riding awkward for any person that doesn't fit that stance profile. Ensuring this adjustability is important to make the binding accessible to as many riders as possible. To satisfy this requirement the DP 4: 'current commercial attachment system' was created.

FR 4.1 – Provide longitudinal placement adjustability

To account for different sized legs, longitudinal placement adjustability allows a snowboard binding to be moved along the length of the board to alter the space between the rider's feet. On a typical snowboard, mounting holes are provided. Snowboard bindings typically have a mounting hole pattern that matches most boards so that the rider can fasten the two together with a simple Philips head screw driver. The rotational snowboard binding attachment system is made with a similar four mounting hole pattern to fit a conventional snowboard.

FR 4.2 – Provide stance angle adjustability

The angle relative to the board edges at which the rider's feet rest is crucial to riding and rider comfort. Most beginners are assumed to use 15 degrees downhill for their lead foot and zero degrees for their back foot. The angle profile for any given rider, however, is a personal preference. In order to allow for different angle profiles, the binding must be able to fasten to the board with multiple angular offsets. On the rotational snowboard binding, this is accomplished the same way as a conventional binding with the interior ring of V-shaped teeth inside the binding. The attachment system includes a ring of corresponding teeth which are along the outside edge of the outer ring, which enable the user to select their preferred angle.

3. Physical Integration

After specifying the design parameters, the next step is to integrate all of them together into components. Since the design was constrained to a small area and most of the features are location dependant, this process has few solutions.

3.1 Compatibility matrix

Figure 7 demonstrates the process used to determine if the functional requirements and design parameters are coupled. If any of these are fully coupled the design would not function properly. Partially coupled pairings are acceptable and do not necessarily affect the functionality of the design. However, it is preferable to limit the number of partially-coupled design parameters and functional requirements when possible.

	DP0: Selectivly rotatable snowboard binding attachment system	DP1: Binding mounting system	DP1.1: Cylindrical surfaces alligned with Z-axis (inner and outer ring system)	DP1.2: Surfaces parallel to X-Y plane	DP2: Spring loaded cam system	DP2.1: Surfaces that are not tangent to rotation between binding and board	DP2.2: Angular locations of notches in external cam	DP2.3: Selected materials	DP3: Preservation system	DP3.1: Features protecting from enviornmental elements	DP3.2: Optimization of material properties	DP4: Current commercial attachment system
FR0: Provide the ability rotation of binding during taxiing/snowboarding	X											
FR1: Transmit rding-control loads between foot and board		X			O	O	O	O	O	O	O	O
FR1.1: Transmit forces in the xy plane			X	O	O	O	O	O	O	O	O	O
FR1.2: Transmit moments about the x and y axes			O	X	O	O	O	O	O	O	O	O
FR2: Control binding rotation		X	O	O	X				O	O	O	O
FR2.1: Transmit Mz binding		O	O	O		X	O	O	O	O	O	O
FR2.2: Provide angular locations for different ride positions		O	O	O		O	X	O	O	O	O	O
FR2.3: Reduce friction between moving surfaces		O	O	O		O	O	X	O	O	O	O
FR3: Maintain functionality of rotation over time		O	O	O	O	O	O	O	X			O
FR3.1: Protect against enviornmental hazards		O	O	O	O	O	O	O		X	O	O
FR3.2: Protect against wear		O	O	O	O	O	O	O		O	X	O
FR4: Allow for stance adjustment		O	O	O	O	O	O	O	O	O	O	X

Figure 7: Compatibility matrix

After examining the matrix it is apparent that one partial coupling between DP1 and FR2 exists. However, this particular instance is unavoidable due to the nature of the design. The couple limits some of the design options, but still is usable since it is not fully coupled.

3.2 Fits

After the components were modeled in CAD, the appropriate tolerances were applied to each so they would fit together as desired. For all of the moving parts of this device a close running fit was applied. From *The Machinery's Handbook (27th Edition)*: “Close running fits are intended chiefly for running fits on accurate machinery with moderate surface speeds and journal pressures, where accurate location and minimum play are desired."

The fit chosen for the inner ring/outer ring interface is an H8f7 close running fit. For a nominal hole size of 2.5 inches for the bottom section of the outer ring and 2.72 inches for the top (50-80mm in both cases) this fit requires the hole to be 46 micrometers (0.001811inches) larger. The adjusted diameters for the outer ring are 2.502 inches for the bottom and 2.722 inches for the top. The top of the inner ring, has an outside diameter of 2.72 and in an H8f7 fit this size needs to be decreased by 60 micrometers (0.002362 inches). For the bottom half of the inner ring the nominal diameter was 2.5 inches and the handbook specified that it be decreased by 30 micrometers (0.001181 inches). The final diameters for these components are 2.498 inches for the bottom and 2.718 inches for the top.

The fit chosen for the follower/inner ring interface is an H8h7 sliding fit. For the nominal hole size of 0.7 inches (14-18mm) it must be increased by 27micrometers (0.001063 inches). The follower rails must be decreased by 18 micrometers (0.0007087 inches). These requirements resulted in having the follower tracks separated by 0.701inches and the follower's rails would be 6.99 inches apart.

Similarly, the fit between the outside of the tracks on the inner ring bottom and the inside of the slots they fit is an H8h8 fit. This fit is described as a locational fit which can be assembled by hand. The outside of the tracks on the inner ring bottom need to be reduced from 1.1 inches by 33 micrometers (0.001299 inches) and the inside of the slots on the inner ring top need to be wider by 33 micrometers. The outside of the tracks are 1.099 inches and in the distance between the slots where they fit is 1.101 inches.

4. Prototype Production

4.1 Machining

The main objective for the prototype construction process was ease of manufacturing. First, a model was created in Pro Engineer and imported into ESPRIT. Tool paths were then created in ESPRIT by defining the features of the follower and specifying the tools to be used. This process was used for all the parts in the assembly.

The fixturing used for each of the components was standard; the follower was held using a regular vice, the inner ring top and bottom were held in collets and the outer ring components were held in a three-jaw chuck. In addition to using the standard mills for these components the two parts of the inner ring also had to be turned down in a lathe. Figure 8 shows each of these finished components. Further details on the manufacturing process for each of the components can be found in Appendix 3.

Figure 8: Machined components

4.2 Machined Parts Assembly

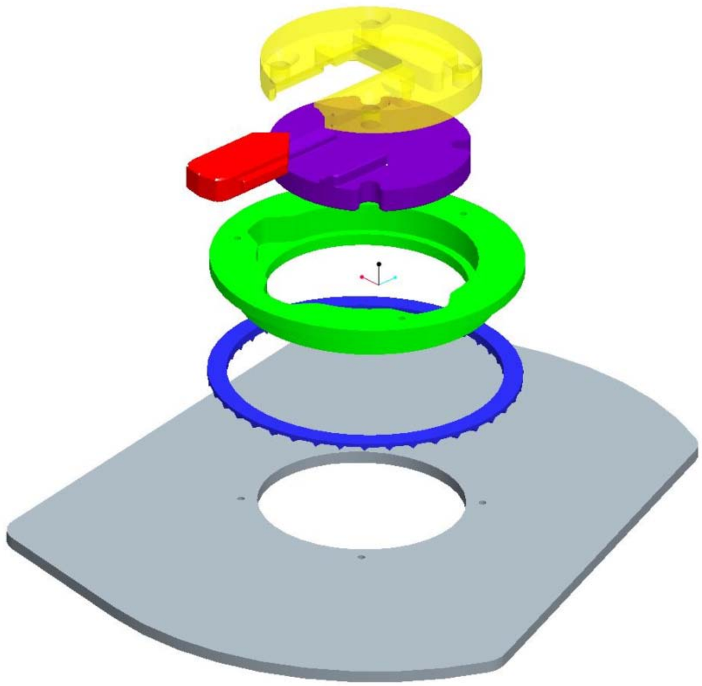


Figure 9: Exploded view of assembly

Once all of the parts were manufactured, they were measured and assembled in the manner suggested in Figure 9. The measurement was compared to the measurement defined on the CAD file to find the variation and error that occurred during machining. Table 2 shows a comparison of the measurements from the CAD file to the actual prototype.

Table 2: Comparison of dimensions between the CAD model and prototype

Part Thickness			
Part	CAD	Measured	% Difference
Outer Ring - Al	0.5 in (total), 0.15 in (ridge)	0.499 in (total), 0.15 in (ridge)	0.02 (total), 0 (ridge)
Outer Ring -Lexan	0.5 in (total), 0.15 in (ridge)	0.499 in (total), 0.15 in (ridge)	5 (total), 2 (ridge)
Alignment Ring	0.112 in (inner), 0.045 in (outer)	0.111 in (inner), 0.041 in (outer)	0.893 (inner), 8.889 (outer)
Inner Ring Top - Al	0.31 in	0.318 in	2.581
Inner Ring Top - Lexan	0.31 in	0.30 in	3.333
Inner Ring Bottom	0.3 in (plate), 0.463 in (ridge)	0.295 in (plate), 0.458 in (ridge)	1.667 (plate), 1.08 (ridge)
Follower	0.326 in	0.327 in	0.307
Part Diameter			
	CAD	Measured	% Difference
Outer Ring - Al	3.87 in (outer), 3.39 in (ledge), 2.729 in (inner)	3.867in (outer), 3.386 in (ledge), 2.725 in (inner)	0.0775 (outer), 0.118 (ledge), 0.147 (inner)
Outer Ring -Lexan	3.87 in (outer), 3.39 in (ledge), 2.729 in (inner)	3.869 in (outer), 3.389 in (ledge), 2.73 in (inner)	0.0258 (outer), 0.0295 (ledge), 0.0366 (inner)
Alignment Ring	3.40 in (inner), 3.87 in (outer)	3.398 in (inner), 3.822 in (outer)	0.0588 (inner), 1.240 (outer)
Inner Ring Top - Al	2.721 in	2.705 in	0.588
Inner Ring Top - Lexan	2.721 in	2.718 in	0.110
Inner Ring Bottom	2.5 in	2.489 in	0.440
Follower	0.842 in (width), 1.559 in (length)	0.843 in (width), 1.556 in (length)	0.119 (width), 0.192 (length)

All of the dimensions are close to those from the model with the largest percentage difference of 8.89%. This difference is on a small dimension and the actual difference is only 0.004 inches. Most of the dimensions are within a fraction of a percent of the CAD model, showing precision in the machining process.

5. Testing and Results

Testing the rotational binding was accomplished by evaluating the effectiveness of the binding to meet the functional requirements. Tests were performed in a laboratory setting as well as in the field at Wachusett Mountain and Sugarloaf USA. The combination of a Lexan outer ring and an aluminum inner ring produced the lowest amount of friction during rotation and was used as the subject for all testing.

To test the functional requirements of the mechanism in the lab, an apparatus was made by drilling a hole in the toe of a soft snowboard boot and placing a steel pipe through the boot. A 90° elbow was attached and fitted with a socket so that the Craftsman digital torque wrench could take measurements as close to the vertical (z-axis) location of the binding as possible. A limitation of the torque wrench was that its lowest effective measurement is 13.6 Nm. As this was in the middle of the design's range, a "torque divider" was created. The torque divider functioned on the similar principle of a torque multiplier, but was oriented such that the actual torque would be smaller than torque displayed by the torque wrench. A relation was developed to calculate the actual torque. The relation was:

$$\tau_{actual} = \frac{d_2}{d_1} \tau_{displayed}$$

Where d_1 was the distance from the drive of the wrench to the point where the force was applied and d_2 was the distance from the center of the binding to the point where force was applied. Both d_1 and d_2 are depicted in figure 10.

Figure 10: Torque divider apparatus

Functional Requirement 1, “Transmit riding-control loads between foot and board”, was tested by attaching a laser to the binding and measuring the angles of displacement between the board and binding at different torques. Unintended displacement more commonly referred to as “slop”, plays a critical role in the way the snowboard feels to the rider. Commercial bindings experience little slop and riders feel in control of the board.

Torque was applied about the x- and y-axes using the testing boot secured in the binding. The binding displaced during the application of the torque, demonstrating the transmission of the riding-control loads and satisfying Functional Requirement 1. For comparison, a commercially available Burton binding disc underwent the same tests. To ensure accurate data, all measurements were repeated eight times. The results of the tested torque versus deflection are displayed in figures 11 and 12.

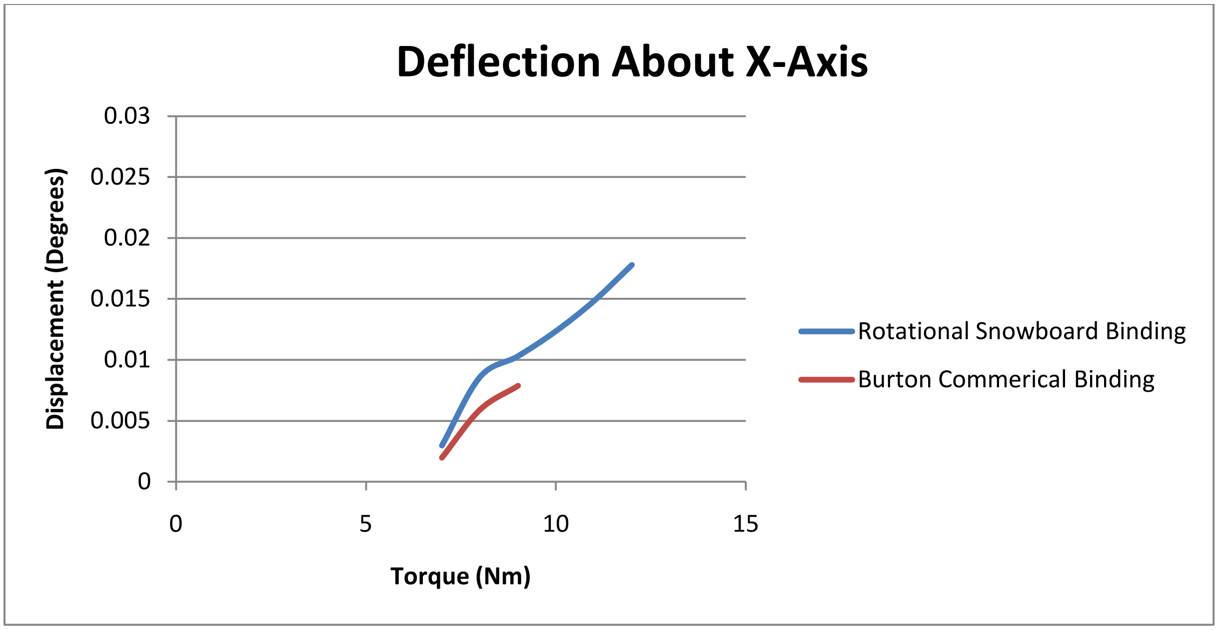


Figure 11: Deflection about x-axis

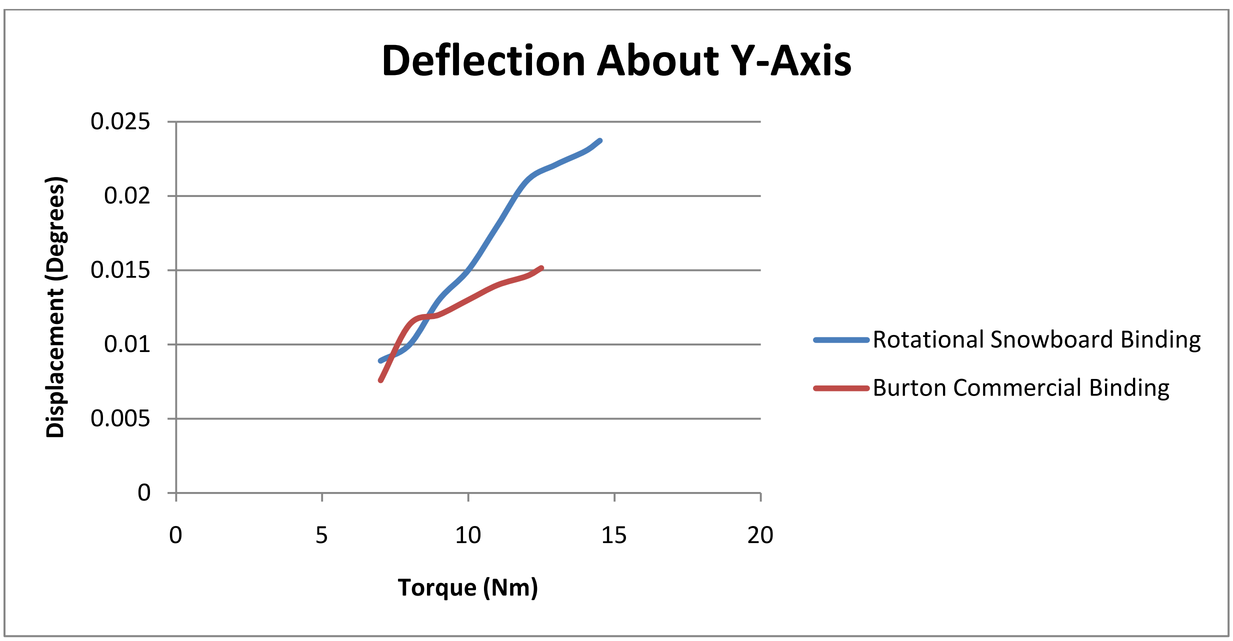


Figure 12: Deflection about y-axis

The Burton binding experienced less angular displacement than the rotational snowboard binding in both instances. Each configuration experienced a maximum torque value where the binding would not displace any farther. The maximum deflection for the rotational snowboard binding was 0.018° about the x-axis and 0.024° about the y-axis. The maximum deflection for the Burton commercial binding was 0.008° about the x-axis and 0.015° about the y-axis. With these values, it can be seen that the rotational snowboard binding experiences 2.25 times the amount of deflection about the x-axis as the Burton binding and about 1.5 times the amount of deflection about the y-axis. Because the y-axis runs through the sides of the boot, the torque is applied along the axis which runs from the toe to heel. This may account for the reduced deflection in that direction, as there is less room for the binding to rotate that way.

To test Functional Requirement 2, “Control binding rotation,” the boot apparatus was placed in the binding and a torque was applied about the z-axis. The application of torque had to be slow and steady to obtain accurate measurements. The measurements were repeated eight times to ensure accuracy. A graph of the torque versus angular position of the binding is depicted in figure 13.

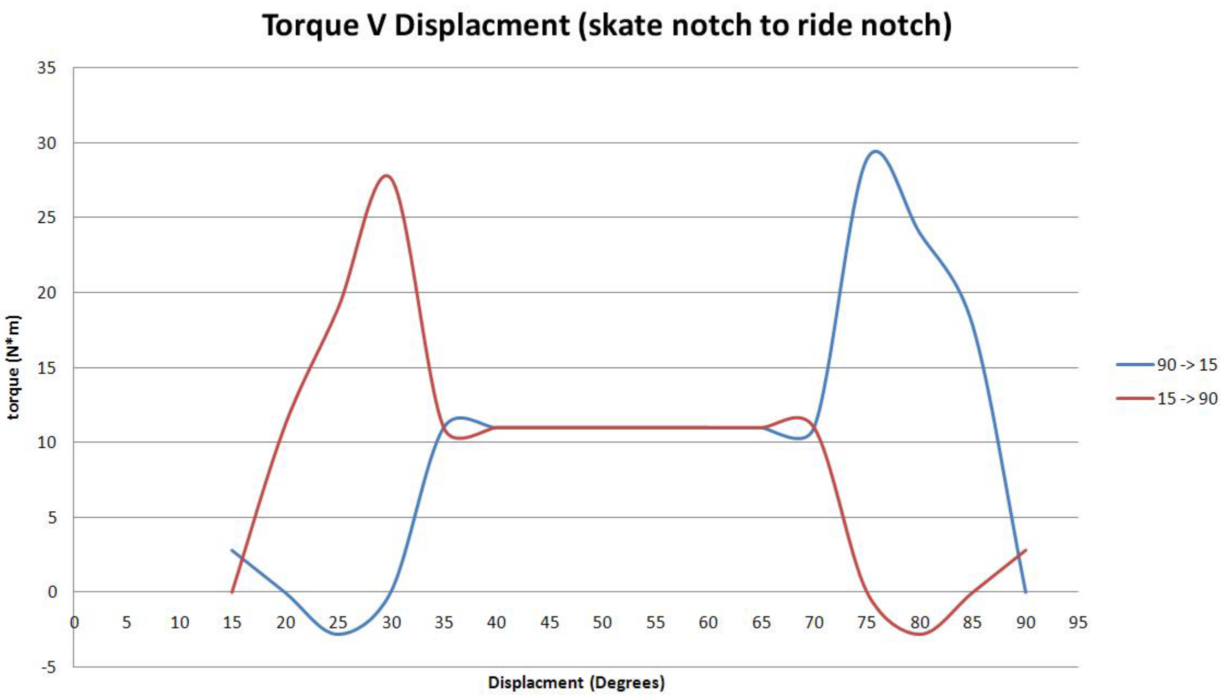


Figure 13: Torque versus angular position of binding

The upper peaks on the graph represent the torque as the follower exits the first notch at the beginning of the rotation and the lower peaks are where the follower enters the second notch at the end of rotation. The steady line between 40° and 65° represents the "traveling torque" that takes place while the follower travels between the cam notches. The "traveling torque" was about 11 Nm. The peak of 28 Nm is well above the 15 Nm safety limit, and is still within the range of torque that can be easily applied by the foot, therefore satisfying Functional Requirement 2.

After the snowboard was used on the mountain, it was taken back to the laboratory to test Functional Requirement 3, "Maintain functionality of rotation over time." This functional requirement addresses damage from wear as well as foreign contaminants in the binding. The binding underwent the same test as in the testing of Functional Requirement 2, and the results were compared to the results in the previous test. The binding was disassembled and inspected for wear or foreign contaminants. The graph of the test results is pictured in figure 14.

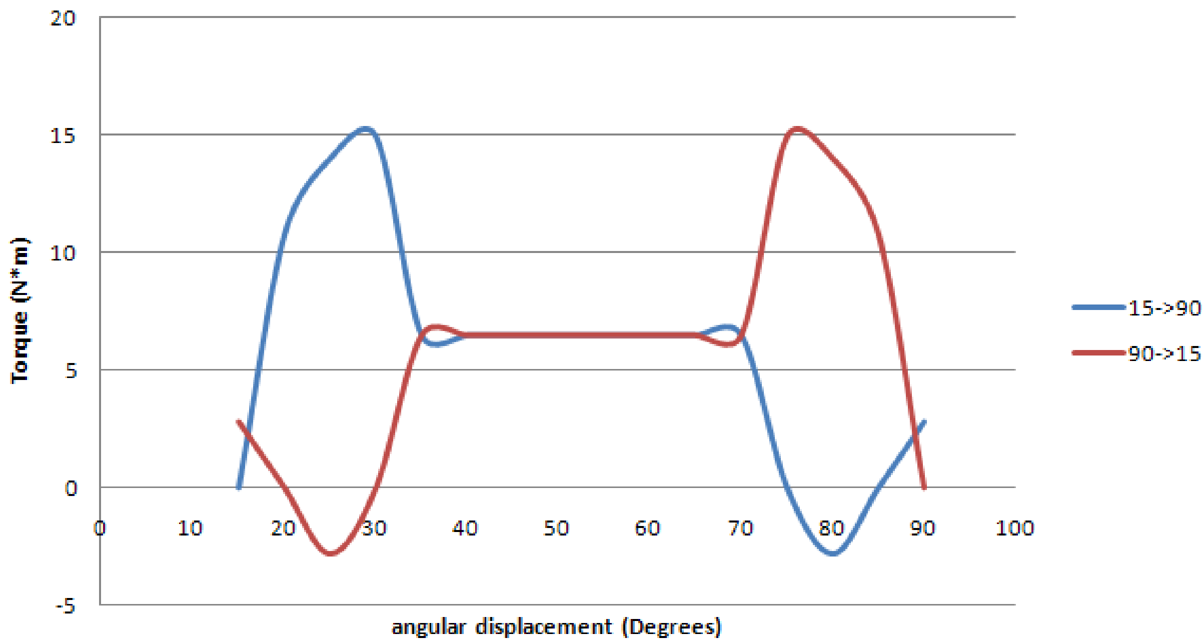


Figure 14: Torque versus angular position of binding post slope test

As show in figure 14, the torque required to activate rotation reduced to 15 Nm for both notches. This value is the target value the project aimed to meet, but is also a drastic decrease from the 28 Nm prior to slope testing. The torque require between notches was also reduced to about 6 Nm, slightly more than half of the previous 11 Nm.

All components were inspected after the slope test for noticeable wear. No wear or foreign contaminants were found, satisfying Functional Requirement 3. The mechanism should be put through more slope testing to study long term effects of riding on the components. Further examination of the surfaces of the Lexan and aluminum may need to be conducted for a better understanding of the reduction in minimum torques.

The final functional requirement, “Allow for stance adjustability”, was tested by aligning the disc teeth on the outer ring such that the binding could be placed in different default positions. The binding was able to be placed in any position it was manufactured to use.

6. Discussion and Recommendations

In order to improve the manufacturing and assembly processes, certain components could be manufactured using different techniques or with new design parameters. This section discusses the problems that arose throughout the project and proposes ways to improve the design.

6.1 Satisfaction of Constraints

The constraints were all met as shown in Table 3.

Table 3: Satisfied constraints

Constraint	Final Design	Success
The binding attachment system must not allow the transmission of injurious loads via rotation to the lower limbs of the rider.	The binding rotates at loads of 28 Nm or less	Yes
The binding attachment system must be compatible with the existing four-hole interface of commercially available snowboards.	The binding can be mounted to a snowboard	Yes
The binding attachment system must be compatible with the existing mounting disc area of commercially available bindings	The binding can be mounted to a snowboard	Yes
The binding attachment system must be lighter than 4.75 pounds	The system weighs less than 2 lbs	Yes
The binding attachment system must raise the height of the binding no more than 1.25 inches.	The system raises the height of the binding 1/8th of an inch	Yes
The binding attachment system must allow its user to perform normally accepted snowboarding maneuvers	The binding was successfully ridden in normal conditions	Yes

6.2 Overall Height

The design objective of this project was to create a system that could operate within the small disc space available inside a snowboard binding. This system met this requirement; however in order for it to fit there is a slight increase in the height of both the center disc and the overall ride height of the binding. The mechanism does extend above the foot-bed of the binding by approximately $1/8^{th}$ of an inch. The next iteration could improve upon this design by fitting it flush with the foot-bed, which would eliminate any intrusion of the system into the boot-binding interface. It is unlikely that the binding could get much closer to the board, considering that there is only a $1/8^{th}$ inch difference between them. However, anything closer would be a preferred improvement.

6.3 The Spring

Another difficult aspect of the design is the spring. The initial design intended to use a flat piece of steel acting as a simply supported beam or leaf spring. The follower was to apply a load at its center and either end would be restrained by features on the inner ring top. This solution was not effective because multiple spring thicknesses and combinations all plastically deformed and failed to maintain the required spring constant. The next option was rubber. A rubber spring solved this problem; however, the inner ring components and follower were still designed for a leaf spring. Also, due to a lack of pretension in the system, the binding appears to have some play within the notch when loads well under 5 Newton-meters are applied.

The problems with the spring can be solved by redesigning the inner ring, follower or spring. A flat backside to the follower would be optimal for contact with the rubber spring. Also, the cavity in which the rubber is contained could be longer as to allow a longer piece of rubber to fit inside. This rubber piece could be made to be slightly longer than the cavity such that when assembled the follower would have a higher pretention than in the current setup. This design would allow a higher pretension while minimizing the change in the rubber’s spring constant vs. displacement. The bigger the ratio of rubber length to displacement, the closer the spring comes to having a linear spring constant. Also other options could be researched to replace the rubber as the spring.

6.4 The Inner Ring

Fixing the inner ring top and bottom components together using simple fasteners would make assembly much easier. When the spring and follower are assembled between the two halves of the inner ring one must hold the four parts very carefully from both sides while placing it inside the outer ring. This process is clumsy and inefficient.

If there were holes drilled and tapped going through the components, small screws could be used to attach them to one another once the spring was inserted. Then, the follower could be loaded from the front and the whole subassembly could be placed into the outer ring without the need to hold the two halves together.

6.5 The Outer Ring

The outer ring in this project was manufactured using HAAS CNC machines. However, plastic molding may be a better option. This method might allow the outer ring and alignment ring to be one part as was the original design intent. The time it takes to produce one alignment ring is relatively long due to the nature of the machining process required. If a negative of the outer ring with the V-shaped teeth on it was created, then it could easily be molded out of one material. This would not only reduce production time but it would also eliminate the need for the extra fasteners that are required to attach the alignment ring to the outer ring.

6.6 The Intermediate Plate

The point at which the intermediate plate is attached to the outer ring consists of four small 4-40 machine screws which go through holes with countersinks in the Teflon plate and into the threads which were tapped into the bottom side of the outer ring. This attachment prevents the screws from making contact with the snowboard surface and ensures a firm connection between the binding and the outer ring. Over time and extended use the Teflon appears to become compressed at this site and the components become lose. To reduce the slop between these components the best solution would be to reinforce the intermediate plate so that it will not deform in this manner. If the Teflon intermediate plate contained a steel or aluminum ring on the top side around where the holes are drilled through it, it might be sturdier under these conditions.

6.7 Testing

After the prototype was finished the 2010 winter season had ended and there were minimal opportunities to test the binding attachment system on the slope. It would have been beneficial to get feedback from users of varying snowboard ability given a fully open ski resort with lift access and a full day of riding. A long term test could also be performed to look into the amount of wear the system might experience over the course of an entire season.

6.8 Design method

The original concept of utilizing two concentric, circular components was set as a constraint at the beginning of the design process. Given that all snowboard bindings have this one common disc cavity, the best way to reduce the height of the binding would be to contain as much of the mechanism within this cavity as possible. Unfortunately, this constraint limited the possible solutions to the functional requirements. As the details of the design developed, axiomatic design was utilized to ensure the decoupling of design features and provide solutions to various integration issues. In the end the design process did benefit greatly from using axiomatic design in that, each design parameter is realized in the prototype and there is only one partial coupling in the design.

7. Conclusion

The previous WPI MQP done in 2009; "Design of a Snowboard Binding" created a functional yet bulky rotational system. One of the main objectives of the "Rotational Snowboard Binding" project was to create a hands free rotational system that was much smaller in both size and weight compared to the 2009 MQP. This was accomplished by choosing a different area of the binding system to alter. The final outcome of this project produced a much smaller, lighter and easily adaptable rotational snowboard binding system. The final prototype rotates as intended with only minor slop when in a notch. The size of this design and ability for it to be integrated into a standard binding makes it very appealing for the snowboarding market. Future iterations could improve this design by changing the spring, materials or tolerances. These changes could reduce the friction as well as the small amount of slop in the system.

8. Appendices

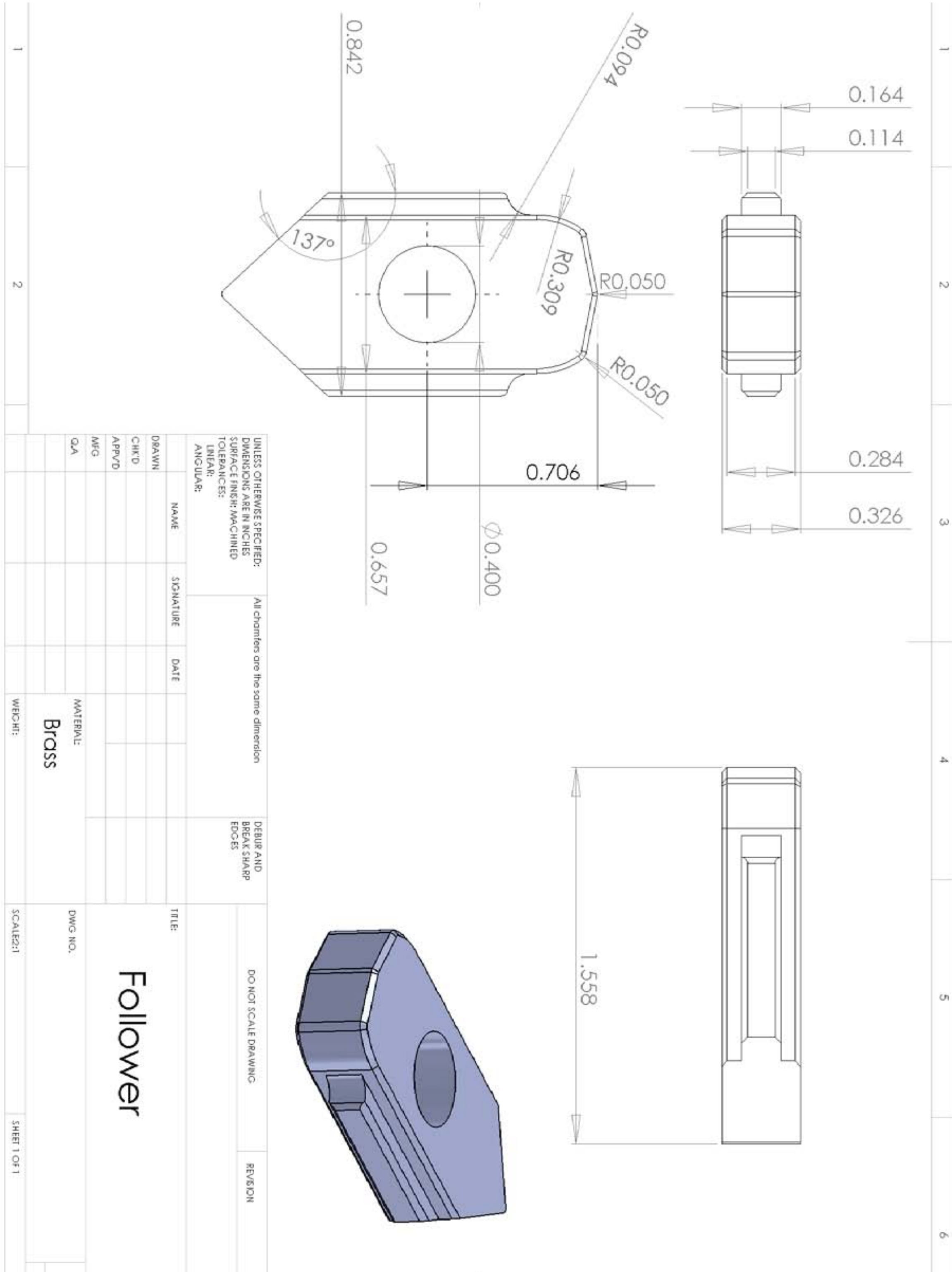
Appendix 1: Snowboarding Mechanics.

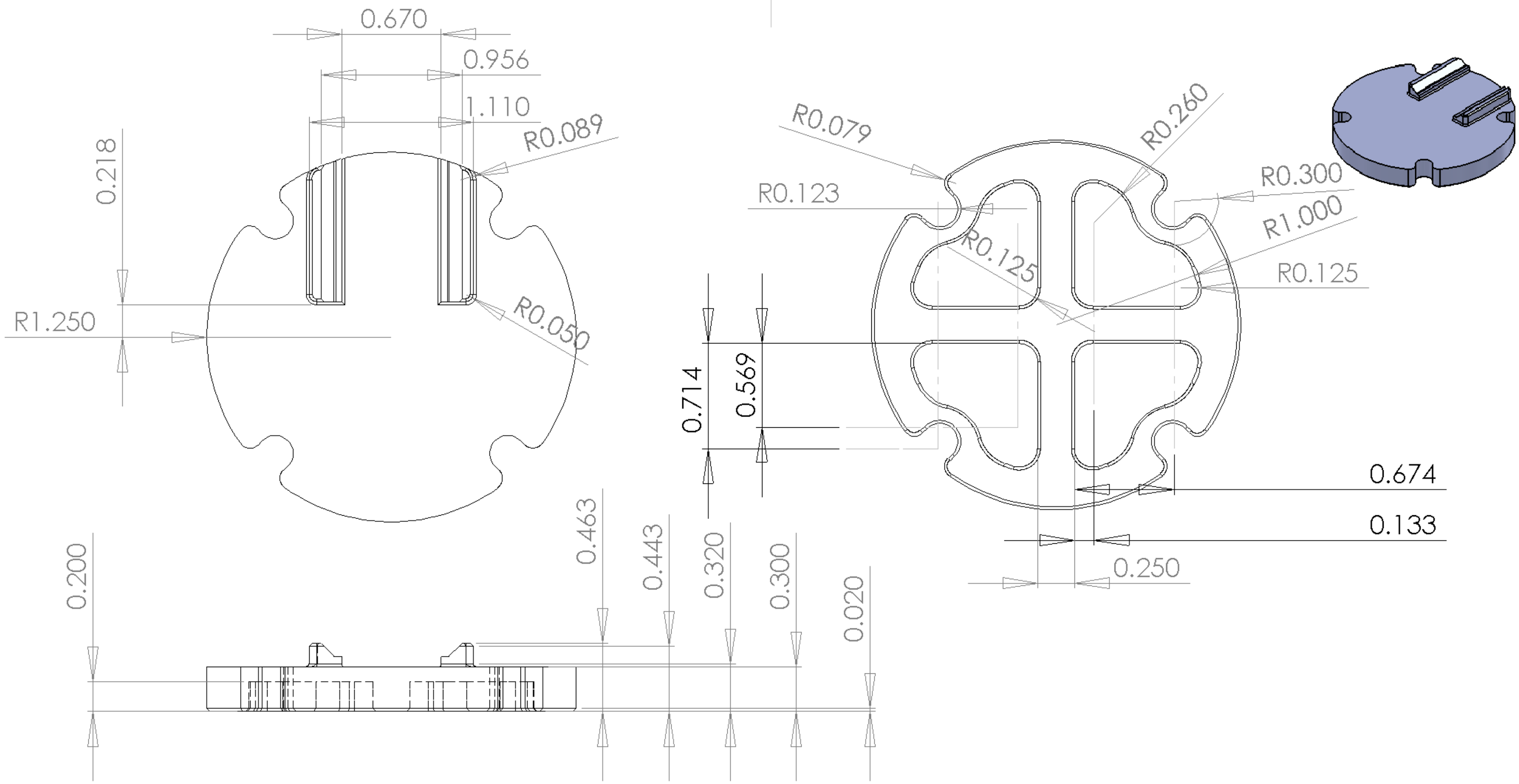
When riding a snowboard downhill, the rider has both feet strapped into bindings on the board with the feet close to perpendicular (usually within 15 degrees depending on rider preference) of the board's longitudinal axis. A snowboard rider has the option of which foot to place downhill. These options are referred to as regular for left foot downhill and goofy for right foot downhill. The rider controls the direction and speed of the ride by carving, or riding on an edge of the board. The sharper the carve is, the sharper the turn and greater the speed check. To alternate directions the rider alternates which edge, toe or heel, he is riding on.

When the rider reaches a flat area of terrain, such as an area to get in line to get on a lift, the rider un-straps their rear foot from the binding. This foot is used to "skate" along the flat area or through the lift line. The term skate refers to pushing along with the free foot, while the front foot rides on the board still in the binding. Currently, there are two main methods of skating: with the push foot on the front, toe, side of the board, or with the push foot on the back, heel, side of the board.

Loading and unloading from the lift is another operation that happens on a snowboard with one foot unstrapped. The loading process involves skating up to the area where the chair swings around to pick the rider up. While waiting for the chair the rider stands with their foot at an angle to allow their body to be close to parallel with the approaching chair and the board to be close to perpendicular with the chair. Once on the chair the board hangs off of the front foot more or less in line with the chair. When approaching the unloading area of the lift, the rider prepares by rotation their foot so that the board again approaches perpendicular with the chair. Sometimes to facilitate this, the rider will shift in the seat so their body is more in line with the board. As the rider exits the chair they place their back foot on the board and glide down the exit ramp. The rider then skates across any flat at the top of the lift to where the slope begins, stops, and straps their back foot in to ride down the hill.

Appendix 2: Detailed CAD drawings





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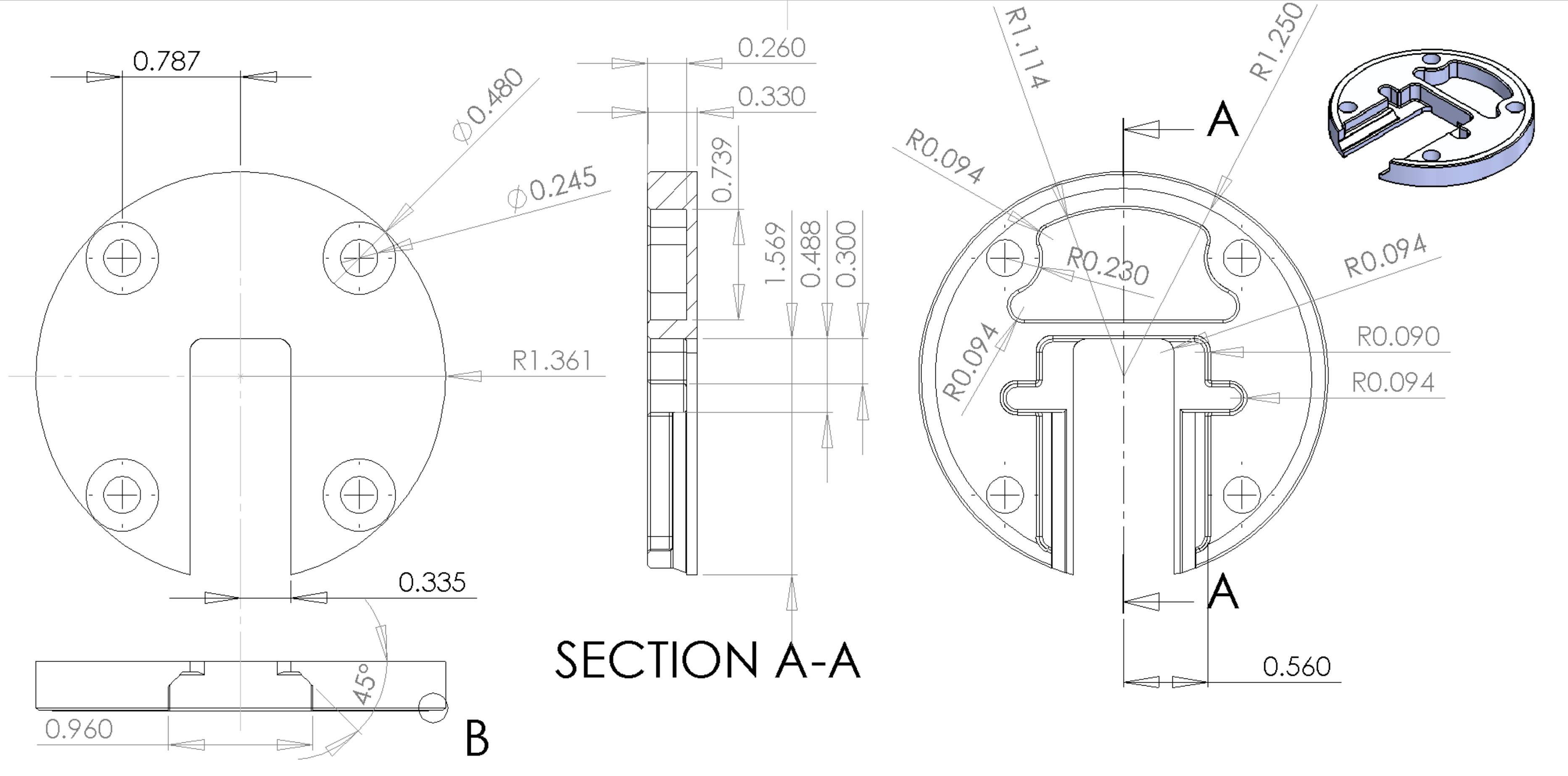
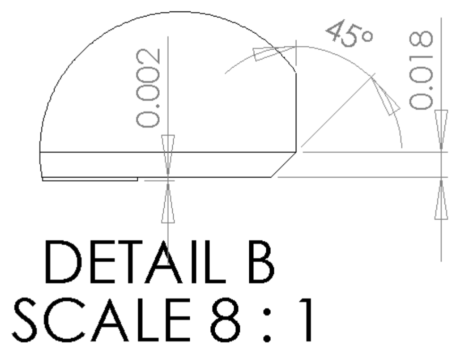
	NAME	SIGNATURE	DATE		TITLE:	
DRAWN					Inner-ring Bottom	
CHK'D						
APPV'D						
MFG						
Q.A				MATERIAL: Aluminum T6061	DWG NO.	
				WEIGHT:	SCALE:1:1	SHEET 1 OF 1





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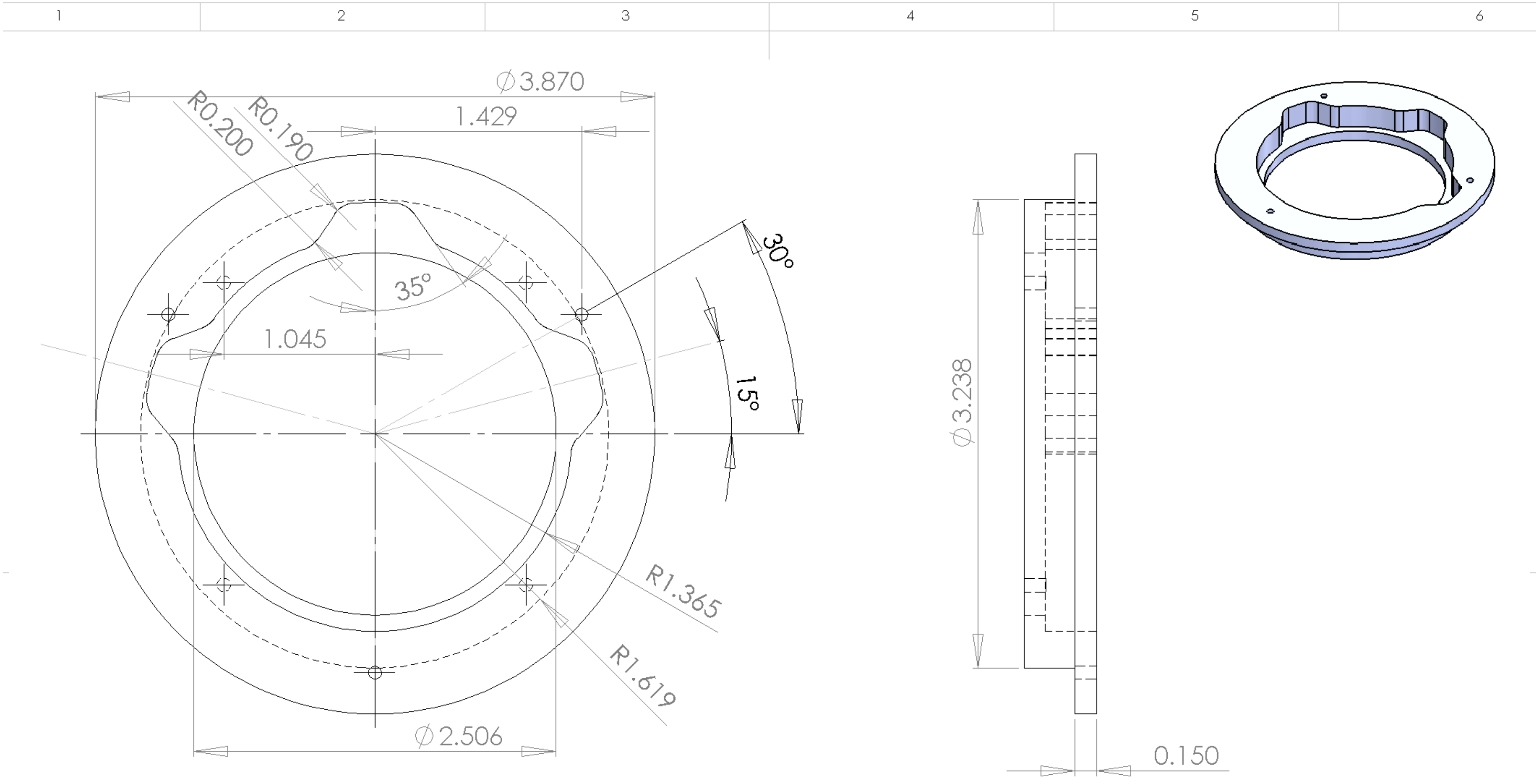
CHK'D					
APPV'D					
MFG					
Q.A			MATERIAL: Aluminum T6061	DWG NO.	
			WEIGHT:	SCALE:1:1	SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES SURFACE FINISH: MACHINED TOLERANCES: LINEAR: ANGULAR:	All holes are made and threaded to fit 4-40 machine screws at a depth of 0.2 inches	DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION

	NAME	SIGNATURE	DATE
DRAWN			
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE: **Outer-ring**

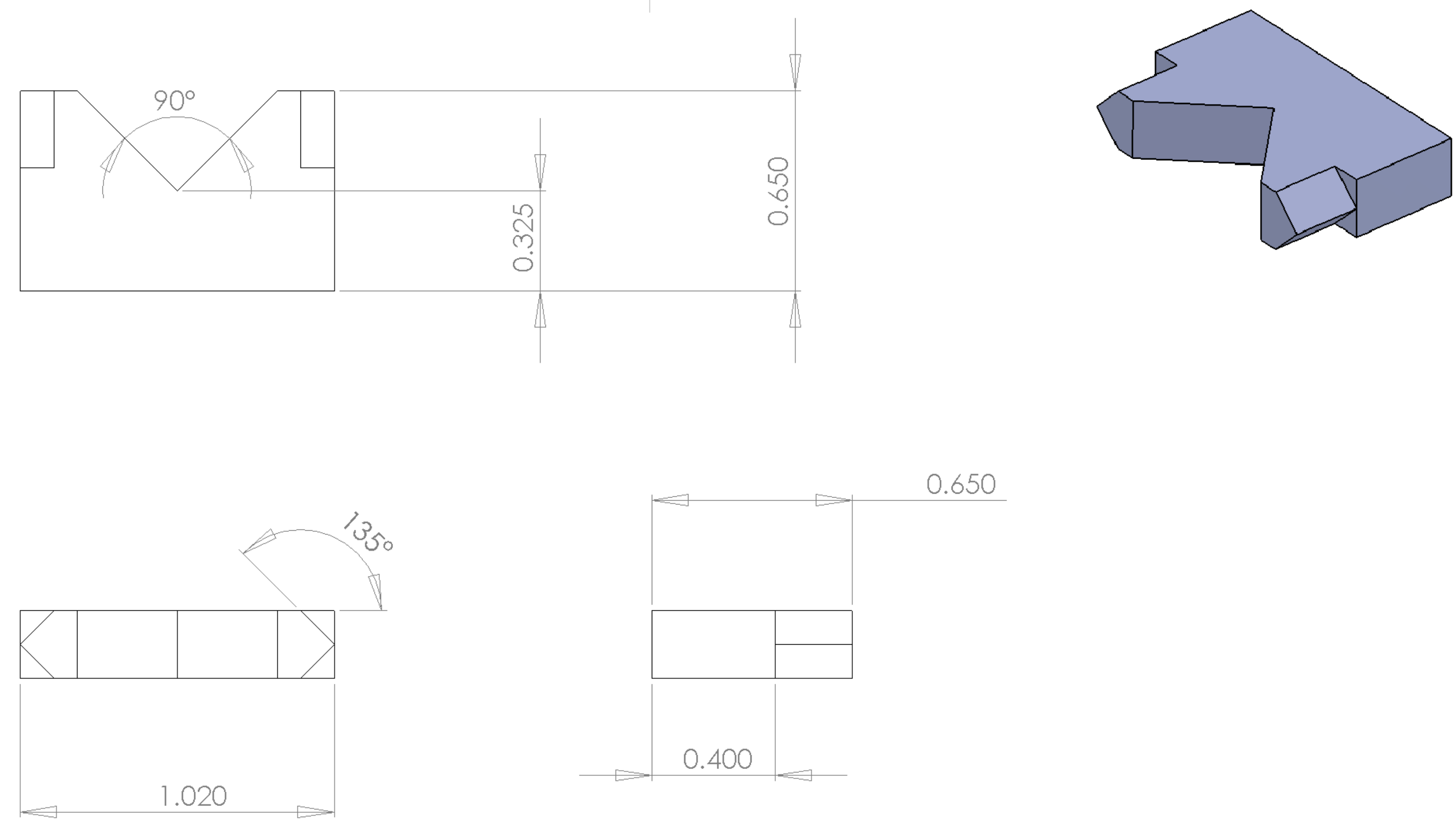
MATERIAL: Lexan (Polycarb.)

DWG NO.

WEIGHT:

SCALE:1:1

SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES SURFACE FINISH: MACHINED TOLERANCES: LINEAR: ANGULAR:	FINISH:	DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION

	NAME	SIGNATURE	DATE
DRAWN			
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

Rubber Spring

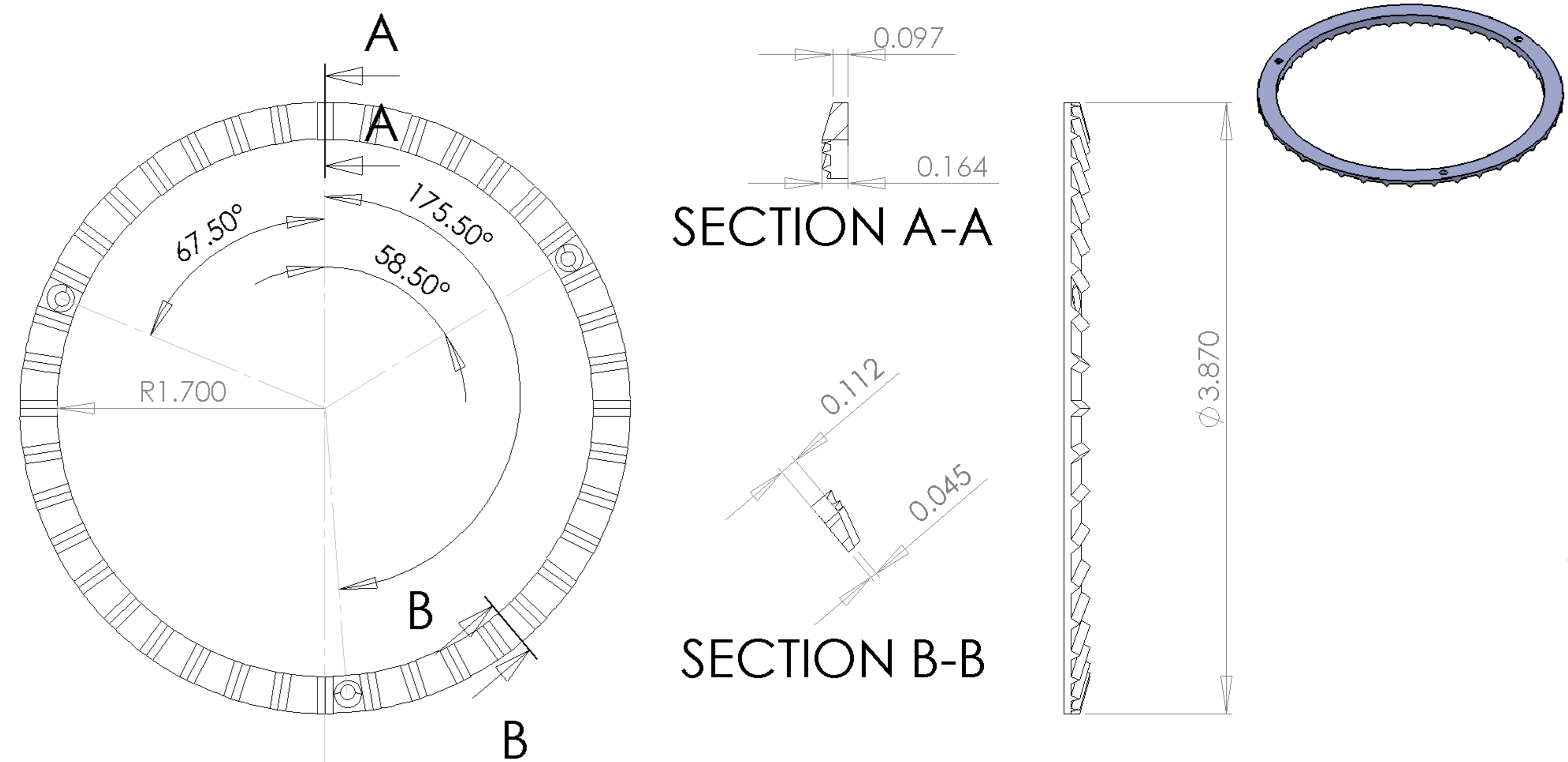
MATERIAL: Rubber

DWG NO.

WEIGHT:

SCALE:2:1

SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES SURFACE FINISH: MACHINED TOLERANCES: LINEAR: ANGULAR:		The holes are made to fit 4-40 machine screws with a countersink for the head of the screw. The sides of the protruding teeth are oriented at 45 degrees		DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION
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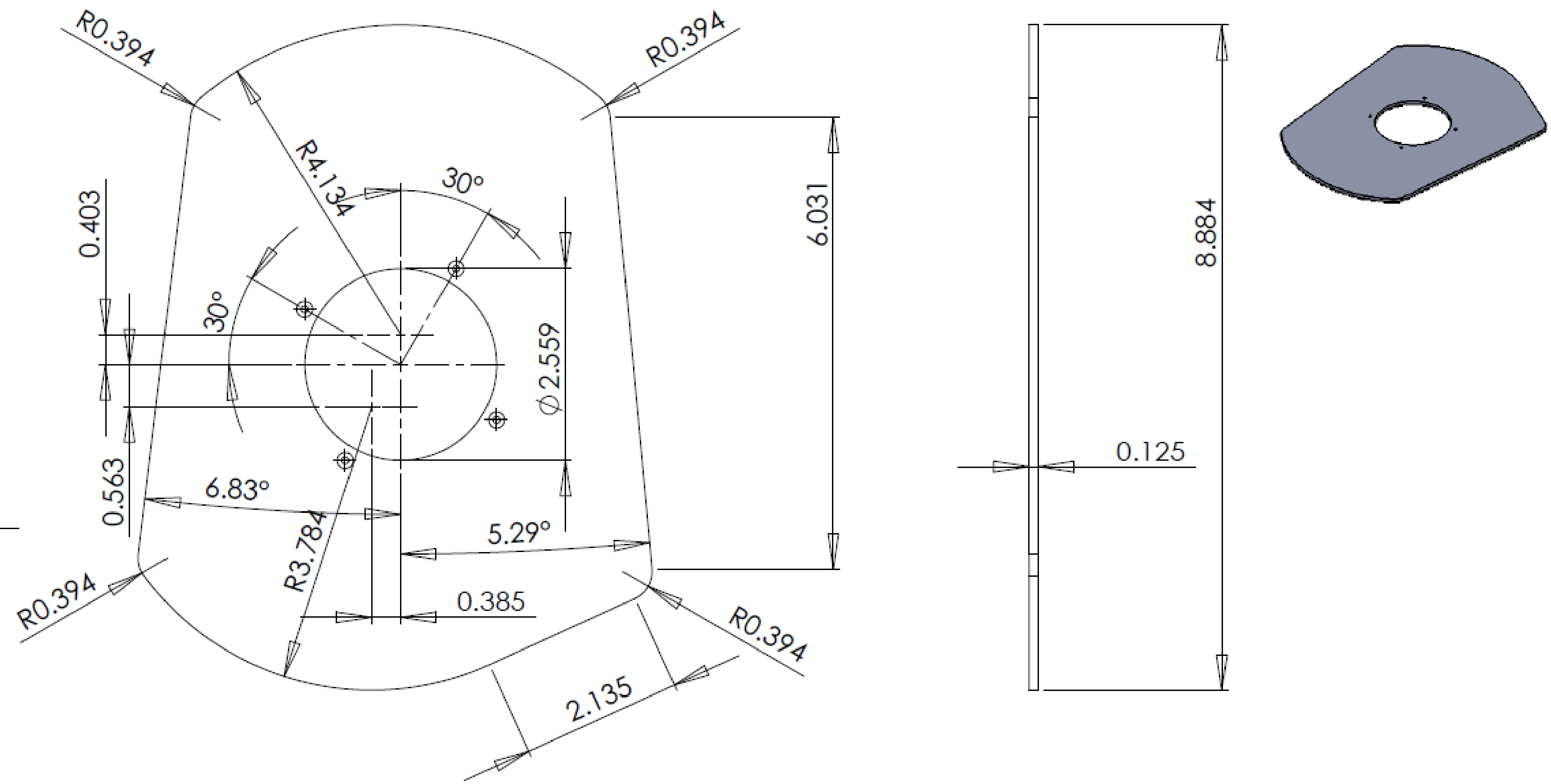
DRAWN					Alignment Ring	
CHK'D						
APPV'D						
MFG						
Q.A				MATERIAL: Aluminum T6061	DWG NO.	
				WEIGHT:	SCALE:1:1	SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
SURFACE FINISH: MACHINED
TOLERANCES:
LINEAR:
ANGULAR:

the four holes are made to fit 4-40 machine screws and are have countersinks

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN			
CHK'D			
APPV'D			
MFG			
Q.A			

MATERIAL: Teflon (PTFE)

WEIGHT:

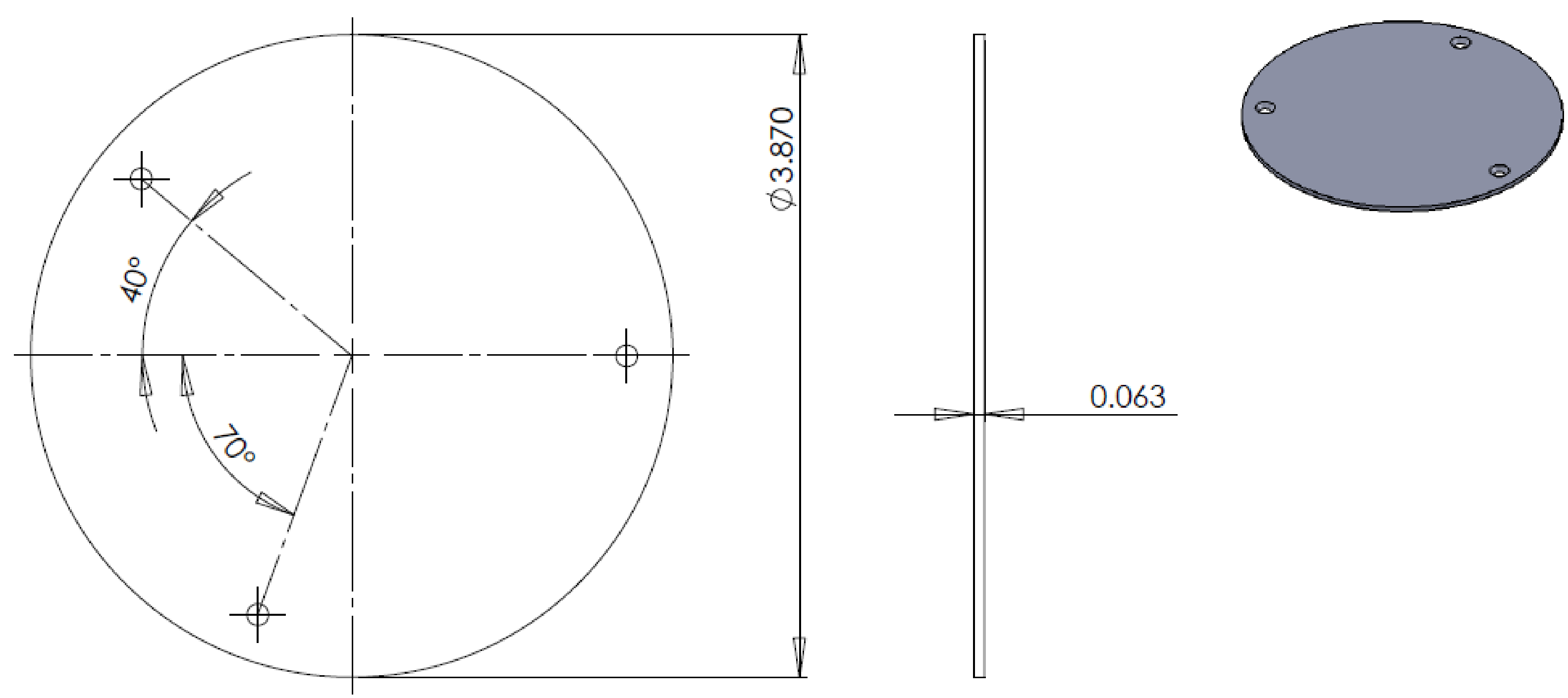
TITLE: Intermediate Plate

DWG NO.

A4

SCALE:1:1

SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES SURFACE FINISH: MACHINED TOLERANCES: LINEAR: ANGULAR:	The three holes are made to fit the head of a 4-40 machine screw	DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING / REVISION

	NAME	SIGNATURE	DATE
DRAWN			
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE: **Cover Plate**

MATERIAL: Aluminum T6061 or Acrylic

DWG NO. A4

WEIGHT:

SCALE:1:2

SHEET 1 OF 1

Appendix 3: Manufacturing

The initial prototype was made out of aluminum with a brass follower. The reason aluminum was chosen was because it is cost effective and easy to machine. Brass was chosen for the follower because of the low coefficient of friction when in contact with aluminum. The follower interacts with other aluminum parts and an aluminum-on-aluminum interaction creates undesired amounts friction.

The first part that was manufactured was the brass follower. First, a model was created in Pro Engineer and imported into ESPRIT. Tool paths were then created in ESPRIT by defining the features of the follower and specifying the tools to be used. This process was used for all the parts in the assembly. The stock used to cut the follower was approximately 1 inch thick and 2 inches wide. Figure 15 shows a representation of the stock used for the brass follower.

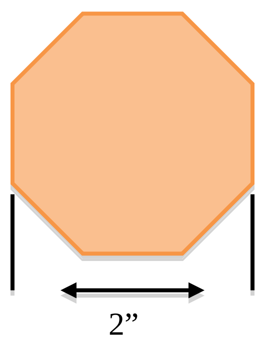


Figure 15: Representation of stock used for copper follower

The brass stock was fixtured in a standard vice on top of parallel bars. For the first tool path, a pocketing operation was used with the follower itself defined as an island in ESPRIT. This operation used a ½” end mill while cutting around the profile of the part at a depth of -.35” from the origin. Once the pocketing operation finished, two contouring operations were made with a ¼” end mill. This operation machined the top of the rails located on each side of the follower. The ¼" end mill was used because it was the largest tool that could be used for this particular operation. Because there were small radii in certain locations of the part, the next operation utilized a 1/8" end mill. This operation contoured around the part and milled the remainder of stock that the ½" and ¼" end mills couldn't. The next step was creating a chamfer along the outside of the part and along the rails. This was intended to lower the amount of friction created between the follower and the pocket to which it slides. This operation was done with a 45° chamfered end mill contouring along these features.

The last operation was done strictly for fixturing purposes. A hole of .266" diameter was drilled through the center of the part in order to locate it when flipped over. Since the part is symmetric, the simplest way to machine it was to flip, align by probing off the hole, and run the same operations again. Figure 8 shows the final follower used in the prototype.

Figure 16: Follower after machining

The next part that was manufactured was the inner ring bottom. In order to machine this part a 2.5 inch diameter collet was used to fixture the aluminum stock material. For these collets, each was machined to a diameter specific for each part.

Figure 17: Finished inner bottom ring

Much like the follower, the best way to machine this part was to do it in two sections; one side at a time. The first operation used a 3” face mill to face off the top of the stock to ensure flatness and a nice surface finish. The next operation utilized a ¼” end mill to pocket the four heart shaped pockets located symmetrically about the part. These pockets were intended to reduce the overall mass of the part. Low spindle speeds and feed rates were used to ensure that the ¼” end mill would not break during the operation.

The next operation was the most delicate. Using a 1/8” end mill, the tool contoured along the outermost edge. The 1/8” end mill was the largest size that could be used to machine the radii of the four holes located around the part. Again, slow spindle speeds and feed rates were used to ensure the small end mill would not break.

The next operation put a chamfer along all the edges of the first side. Like the follower, a 45° chamfer end mill was used. The last operation drilled two 1/8” holes centered about two of the holes on the outside of the part. This operation was strictly for fixturing purposes. It was essential for the rails created on the following side to be perfectly between a set of holes. Because of this, the 1/8” holes were drilled in order to locate the part when machining the other side.

The part was then flipped, fixtured, and faced until the two 1/8" holes were completely through the part. Once this was complete, dowel pins, a straightedge, and a gauge were used to ensure the part was fixtured correctly. The next operation on this side used a ½" end mill and a pocketing operation to face off the remaining stock and contour around the two rails. Then, a 45° chamfer end mill was used to create a chamfer for the follower to sit. Figure 17 shows the finished inner ring bottom.

The third part machined was the inner ring top. This part was machined much like the inner ring bottom; in two sides with aluminum stock held in a round collet. The first operation cut the pockets and the rails for the follower, while the second drilled the mounting holes. Once these four holes were drilled, the part was flipped and aligned using dowel pins much the same as before. Again, using a straight-edge and a gauge the part was aligned correctly. After this, a facing operation cut to the proper depth and a ½" drill created counter sinks in the holes. Figure 18 shows the finished top inner ring.

Figure 18: Inner top ring

Originally the outer ring was designed as one single piece; however, it was split into two separate parts for ease of machinability. The first part machined of this subassembly was the outer ring. This was the easiest of all the parts to import into ESPRIT as well as machine. This part was made from 4 inch round piece of aluminum stock and was held in a large chuck by standard size jaws for the first operation. Figure 19 shows the top side of the finished outer ring.

Figure 19: Top side of the finished outer ring

The second operation performed on the outer ring involved turning down the bottom side to remove excess stock material and to adjust its shape such that it would fit into the v-shaped notches in the standard binding. Special jaws had to be created for the lathe to hold as much of the part as possible without crashing the tool into the jaws. The jaws were made to hold the piece from the top side and would align it while holding only 0.15 inches of its thickness. The entire part was ½ inch thick and the section with a smaller diameter was turned down 0.35 inches leaving a 0.15 inch "lip" on which the alignment ring would be mounted. This smaller diameter was created to match the inner diameter of the alignment ring. Finally, 4 holes were drilled on the bottom of the part by which the inter-plate would later be attached.

The second part of the subassembly was the alignment ring. This was the most difficult to import into ESPRIT and create cut paths for, as well as machine. The difficulty associated with this part can be attributed to the conical shape of the ring and the v-shaped teeth oriented radially around the part. The first problem that arose was creating the tool paths. Using ESPRIT 2009, it was not possible to create a tool path that would make the grooves that align this ring with the snowboard binding. Using ESPRIT 2010 however, tool paths were created going around the stock in a circular motion. While making small cuts along the radius, the tool also made incremental steps down in the z-direction. Next, the part was put into a lathe and the extra stock at the end of the part as well as in the middle was removed. Figure 20 shows the finished alignment ring, which is exceptionally small as well as thin.

Figure 20: Alignment ring

The alignment ring was then fixed to the outer ring using 4- 40 screws. Three holes were drilled into both the alignment ring and outer ring normal to the surface of the alignment ring with the teeth. This diagonal placement would ensure that the alignment ring would stay attached under torque as well as prevent any part of the screw from interfering with other components negatively. Countersinks were then added in order to make the screw heads flush with the alignment ring. Finally, the holes were threaded using a 4-40 tap. The subassembly is shown in figure 21.

Figure 21: Subassembly of the outer ring and alignment ring

The inter-plate and the cover-plate were manufactured a bit differently because of their specific materials. Using a laser plotter, the inter-plate was cut from 0.125 inch thick PTFE (Teflon) and the cover-plate was cut from acrylic 0.04 inches thick. Using the solid models of these components, the drawings were generated in Pro Engineer and transferred into AutoCAD. The drawing was then changed to have 0.5 mm thick red lines and the laser printer was set to recognize only these lines in the drawing. Finally, the correct material and cutting power were selected on the printer software and the pieces were cut.

Lastly, all of the holes in the various components of this assembly which receive 4-40 flat –top Philips head screws were drilled using the drill press and a 3/32 inch drill bit. They were then threaded using a 4-40 tap.

Appendix 4: Finite Element Analysis

The following images were generated using the program SolidWorks to generate a finite element analysis of the load bearing components. First a model of the existing mounting disc was created (see figure 22) in the CAD program and loaded until it had a factor of safety just below 1. The disc reached this point at a load of 2400 Newtons. Then the same load was applied to the outer ring and the inner ring.

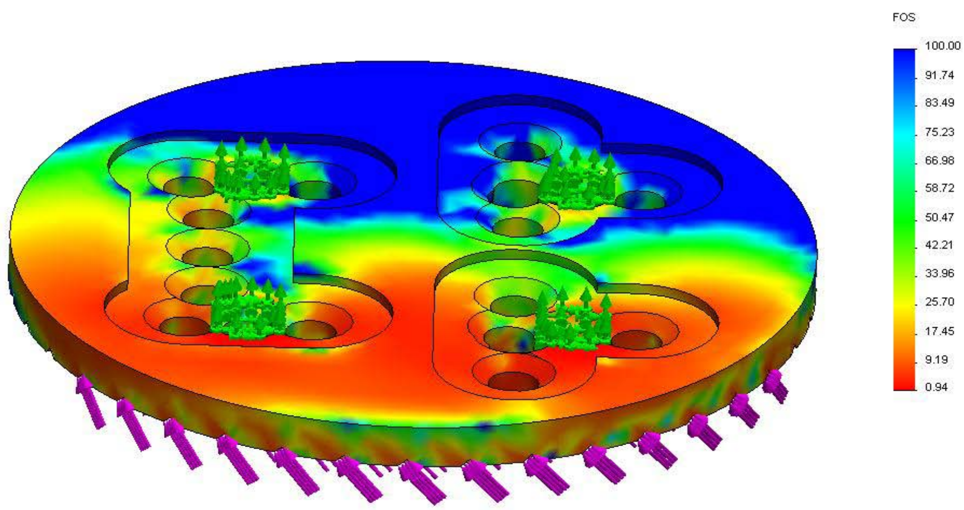


Figure 22: Burton Disc Loaded for failure (factor of safety = 1)

The results are shown in figure 23 and figure 24. The factor of safety for the Lexan outer ring is approximately 1 and the factor of safety for the inner ring top is approximately 2. The factor of safety of 1 means that the outer ring would fail only under loads greater than or equal to that required to make the polycarbonate Burton disc fail. The factor safety of two in the inner ring top means it would require twice this load for this component to fail.

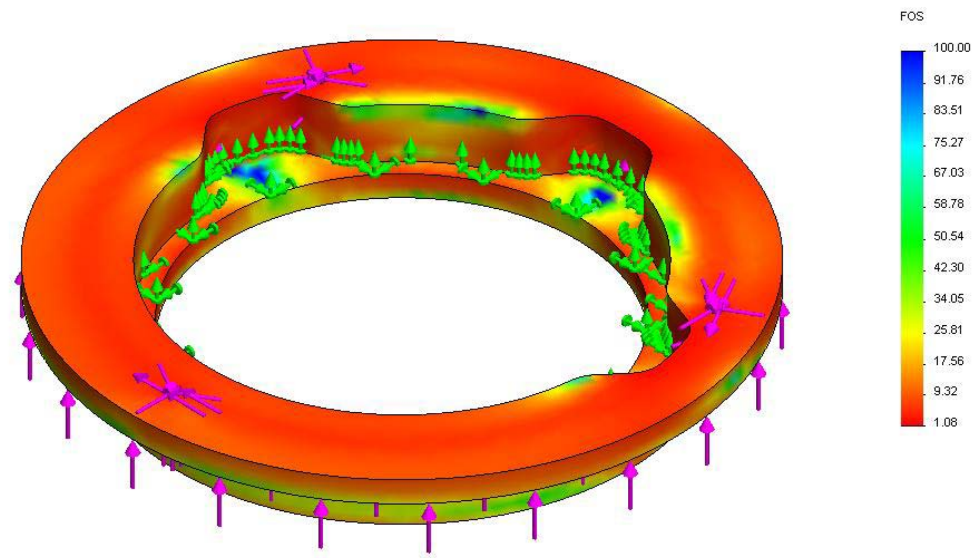


Figure 23: Outer ring (made from Lexan) loaded to the same 2400 Newtons as the Burton disc

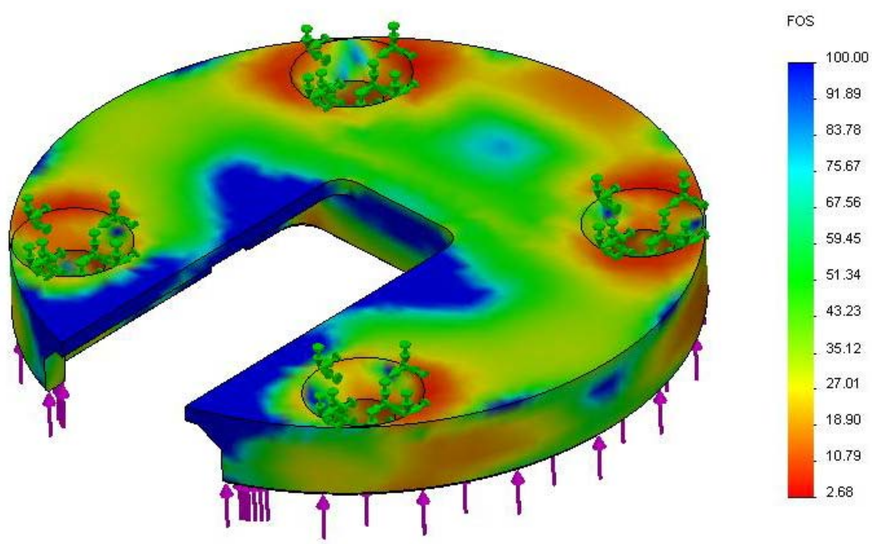


Figure 24:The inner ring loaded with 2400 Newtons

Appendix 5: Testing Photos

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