

Design of a Snowboard Binding

A Major Qualifying Project Report

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By:

Ashkan Nowtash

Anthony Nuñez

Patrick Hill

Maxwell Welker

Date:

Approved:

Prof. Christopher A. Brown, Advisor

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Abstract

The objective of the MQP was to design a rotatable and releasable snowboard binding to provide riders with increased safety and comfort. Currently most snowboard bindings are constrained in one fixed position with the exception of two bindings that allow for rotation or release but none offer the ability to do both. An axiomatic design approach was used to establish a list of functional requirements and corresponding design parameters. The system uses a preloaded follower and a circular cam to allow the rider to rotate their leg on demand while still maintaining the ability to ride with no inadvertent rotation or release. The design was successfully tested at Wachusett Mountain on March 12, 2009.

1 Introduction

1.1 Objective:

The objective is to design, test, and build a rotatable, releasable snowboard binding. This binding would be designed so that it would conform to current snowboard specifications, and will be marketable to all snowboard users, regardless of size or experience. Once complete, the modified binding will allow the user to enter and exit the lifts with a greater degree of comfort and safety.

1.2 Rationale:

A rotational and releasable snowboard binding would be a step forward in the design of safe and comfortable snowboarding equipment out in the market. When on flat ground there is no way for the user to move comfortably. This causes a rider to remove the straps on his rear foot and push himself forward. Although it is unclear which mechanism is the cause for the majority of lower body injuries in snowboarding, this binding will help prevent rotation about the ankle and other injuries that occur when one foot is strapped in. In an analysis of multiple epidemiological studies, it was observed that between the years 1960 and 1990 about seventeen percent of all injuries to snowboarders were to the knees and about forty percent of all injuries were to the ankles. This percentage has since fallen to about five percent for both the ankle and knees. This decline was due to the evolution of bindings which are now more flexible than their predecessors (Shealy, et al., 2008). While injuries to the knee and ankle have reduced in recent years, any further reduction in injuries would still be a valuable improvement.

Another problem snowboarders face is difficulty entering and exiting a chair lift due to the awkward position of the front foot. In one study, a camera recorded riders exiting a chairlift for two consecutive days. The numbers of falls were recorded and statistical data was observed. Twelve percent of the total riders exiting the lift fell. Of the twelve percent who fell, eighty five percent were snowboarders. The

result of the observations concluded that equipment had the greatest effect on falling while unloading from a chair lift (Whelan and Coates, 2008).

1.3 State-of-the-Art:

Through a literature search conducted with the use of search engines, a lack of results for rotatable and releasable bindings was observed. The search results showed that there are multiple bindings out in the market that could rotate or release but not both. Current research shows that there are several manufacturers of a rotatable snowboard binding attachment on the market. The most notable product is from Sports180, Inc., named the “Flip-U”(www.sports180.com). It achieves the basic function of rotating the angle of the binding from a fixed perpendicular position to a fixed forward position. Achieving such motion comes with the need to lock and unlock the binding through the use of the rider’s hand or feet. US Patent Number 6923454 describes the Flip-U device.

The Flip-U is a simple device made of a lightweight polymer. While it provides rotation to increase comfort for the rider, the method of achieving rotation is not convenient. The rotation is limited to when the rider has the opportunity to adjust the locking lever with their hands or feet. Such a device benefits riders with added convenience in the lift lines and the ability to adjust their boot angles to better suit terrain. Sports180, Inc claims the device has a simple user interface and can be adjusted in the 3 steps seen below. The rotation is only permissible when the device is unlocked, thus having no benefit to injurious loads, and limiting convenience.



Figure 1 - The Steps for Operation of the Flip-U Device
www.sports180.com

A comparable product to the Flip-U binding is being sold commercially by JumpUSA. The Swiveler functions in a similar manner to the Flip-U binding requiring the rider to pull on a strap connected to the binding to allow for rotation. Similarly this device fails to rotate on demand thus having no benefit to injurious loads and convenience. A binding that allows for rotation on demand without the need to physically lock or unlock would be more comfortable and convenient. Such a binding could also have the ability to rotate 360° in the event of an accident. Large applied torques would allow the device to rotate while smaller torques would have no effect on rotation. Such a device was achieved by students attending Worcester Polytechnic Institute in 2007 (Adamson, et al., 2007).

Although there are a few rotatable bindings out in the market there is still a need for a hands-free rotatable and releasable snowboard binding. With the added convenience of a releasable binding and a rotatable binding a larger acceptance to these new forms of bindings, from the public, could be possible.

1.4 Approach:

Through the use of axiomatic design an efficient and effective design was achieved. The developed design would be an improvement on what is currently out in the snowboarding market by making it the only binding that is hands free. The most notable application of a hands-free release mechanism in sports is the clip-less pedals used in competitive bicycle racing which provides an excellent theory for release. Release through the clip-less pedal occurs only when an unnatural action is performed, which is rotation of the foot on the pedal. An unnatural motion ensures that the rider will only release on demand, reducing the likelihood of inadvertent release. Through the use of a rotating and then a lifting motion we could have a release mechanism incorporated into our design. This would allow the binding to be more convenient and safe. The binding would also allow for full stance adjustability by incorporating standard snowboard specifications.

This design was modeled through the help of Solidworks computer aided design software. Once the Solidworks models of the binding assembly were completed, computer aided machining software, Esprit, was used to design cut paths to properly machine the prototype. With the use of mini mills the parts were machined and then the prototype was tested. Also each individual part was analyzed with FEA software to check for possible failure during use.

2 Design Decomposition

Through the use of axiomatic design (Suh 1990), a final decomposition for a rotatable releasable snowboard binding was established. This decomposition, as seen in Figure 2 below, contains seven major functional requirements, some further decomposed with children and grandchildren. The decomposition describes every feature of the binding adapter.

0	FR	Provide foot to board interface to allow for rotation and release on demand	DP	Rotational and releasable binding
1	FR	Transmit loads from foot to board	DP	Compatible two plate adapter design
1.1	FR	Transmit loads from Foot to Binding	DP	Binding Straps
1.2	FR	Transmit loads from Binding to Top Plate.	DP	Four mounting points spaced in a square pattern 4cm apart and matching flat surfaces.
1.3	FR	Transmit loads from Top Plate to cam piece	DP	3 mounting points spaced equally from center of cam
1.4	FR	Transmit loads from cam piece to center peice	DP	Compatible Flush Surfaces
1.5	FR	Transmit loads from Bottom Plate Assembly to Board	DP	Four mounting points spaced in a square pattern 4cm apart
1.6	FR	Maximize moment transfer	DP	Wide I Shaped Base
2	FR	Control Rotation	DP	Circular CAM and follower system
2.1	FR	Provide Stabalization	DP	V shaped notches with filleted edges
2.2	FR	Resist Rotation at low torques	DP	Dual spring preloader with adjusting screw
2.3	FR	Allow rotation for higher torques	DP	Flat Outer CAM profile
3	FR	Provide Release for foot	DP	Four tabs and four slots that when properly aligned will allow for release or attachment.
4	FR	Reduce Wobble	DP	Close Running Fit for Inner/Cutter CAM Profile and dual spring follower system.
5	FR	Allow for ease of machining	DP	Maximized Tolerances
5.1	FR	Allow for ease of machining of bottom plate	DP	Filleted edges
5.1.1	FR	Allow for ease of machining for outer profile	DP	Fillets of $r=.75in$
5.1.2	FR	Allow for ease of machining of inner profile	DP	Fillets of $r=.25in$
5.2	FR	Allow for ease of machining for top plate	DP	Filleted edges of $r=.25in$
5.3	FR	Allow for ease of maching of cam-plate assembly	DP	Attachable cam
5.4	FR	Allow for ease of machining of follower	DP	Filleted edge of $r=.25in$
6	FR	Prevent Possible Snow Buildup	DP	Snow Resistant features
6.1	FR	Prevent snow from sticking	DP	Silicone lubricant coating
6.2	FR	Prevent snow buildup in follower system	DP	A sealed covering plate
7	FR	Provide Stance Adjustability	DP	Currently practiced methods for adjustability
7.1	FR	Provide Placement Adjustability	DP	Four mounting hole configurations such that binding could be adjusted in all possible configurations
7.2	FR	Provide Binding Angle Adjustability	DP	Top plate of device acts as snowboard surface in order for binding angle to be adjusted.

Figure 2 - Final Decomposition

2.1 Design Constraints

The constraints of this design are:

- The binding must mount to current snowboards using predrilled holes
- The binding must have the capability to attach to a standard strap-in binding
- The binding must not be longer than the width of a snowboard, nine inches.
- The binding must retain the ability to perform standard snowboard maneuvers
- The binding must not apply injurious loads to the rider.

2.2 Functional Requirement 0

In a proper decomposition the first functional requirement, FR0 should state the purpose of the design. The purpose of this design is to provide a foot to board interface to allow for rotation and release on demand. In order to achieve this functional requirement, DPO, a rotational and releasable binding adapter was created. The completed three dimensional model of the binding adapter can be seen below.

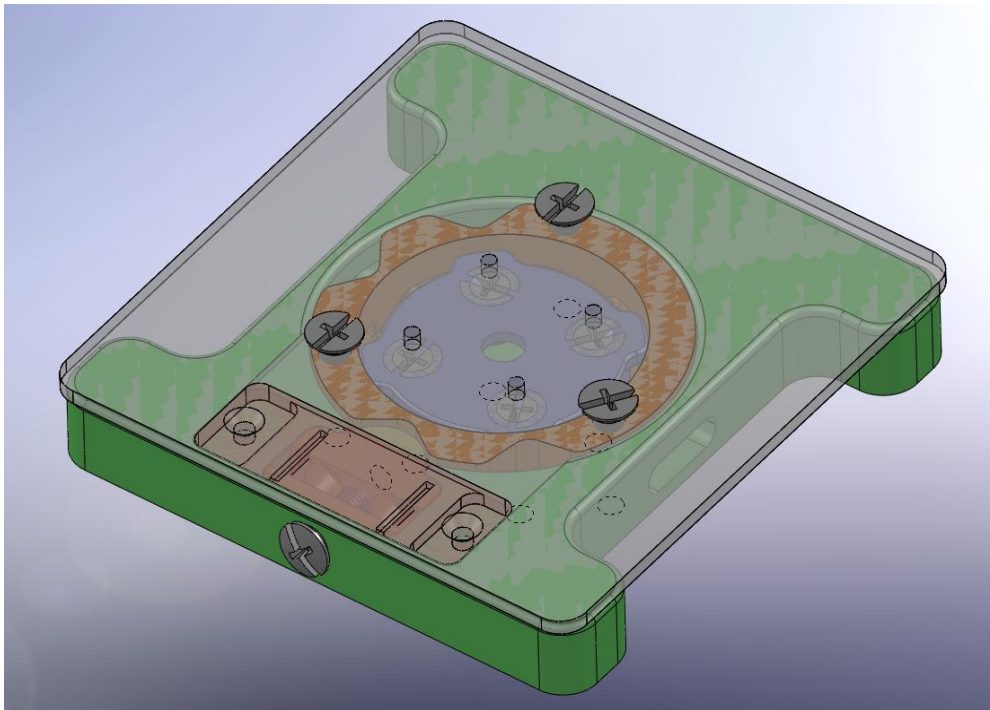


Figure 3 - Three Dimensional Model of Prototype

2.3 Functional Requirement 1

The first functional requirement calls for the need to transfer loads applied by the rider to the snowboard. A load applied by the rider must be successfully transferred to the snowboard in order to edge, jump, or stop. Since the binding adapter, pictured above, is a two-piece design loads must be transferred between the surfaces of the components to the surface of the board. Compatible surfaces must be maintained to ensure proper load transfer. Dissimilar surfaces will produce transmission inefficiencies when a given load is applied to the system. Since the entire system includes both the rider and the actual snowboard, the requirement of proper load transfer can be divided for each component in the system.

2.3.1 Functional Requirement 1.1

The first two components over which the loads must be transferred are the rider's foot and the standard commercial binding. While they are not part of the designed prototype, the bindings are a necessary component to the system and must be considered in analysis.

Traditional "strap-in" bindings utilize two straps to hold the rider's foot in the system. One strap is placed around the ankle of the rider to prevent excess motion. The second strap is placed over the rider's toes to prevent excess vertical motion. These two straps, as seen in Figure 4 below, are tightened and adjusted by the rider to a desired level. Loads applied by the rider's foot will be transferred to the edging surfaces of the snowboard when the foot is properly fastened using the binding straps.



Figure 4 - Commercial Binding Strap Configuration

2.3.2 Functional Requirement 1.2

Loads must be transferred from the bindings to the top plate of the prototype. The prototype must be able to support applied moments and torques. Therefore, the binding must be secured to the prototype in such a way as to allow for yaw, pitch and roll. The simplest way to provide such requirements is to maintain the current binding mounting setup. A traditional board and binding combination is mounted using four holes spaced four centimeters apart in a square pattern. Four screws are driven from the binding through the holes into the board. The machine screws provide proper loading in all directions while preventing the binding from separating from the board. In order to keep with the current configuration, four holes were drilled into the top plate as shown in Figure 5, below.

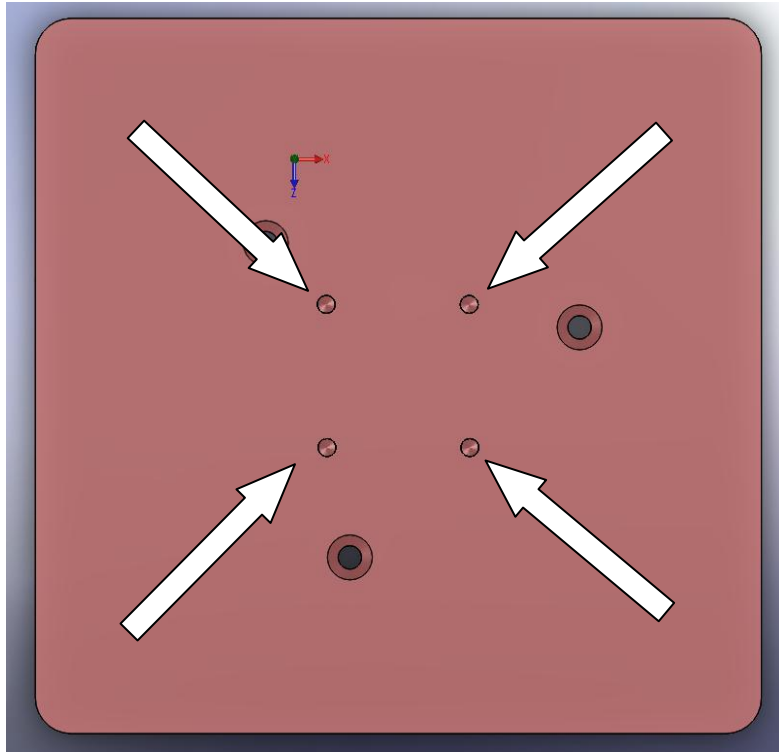


Figure 5 - Functional Requirement 1.2

2.3.3 Functional Requirement 1.3

In order to provide rotation loads applied to the top plate must be transferred to the device which allows rotation. In the prototype a cam was designed to allow for rotation. In order for the loads to properly be transferred to the cam, it must be mounted securely to the top plate. Three mounting holes spaced 120° apart allow for the cam to be secured to the top plate. The machine screws allow for proper transfer of loads from the top piece to the cam itself. Analysis of the forces exerted on the machine screws during operation can be seen in the Physical Integration section below. Figure 6 shows the top plate mounted to the cam piece through the use of three machine screws.

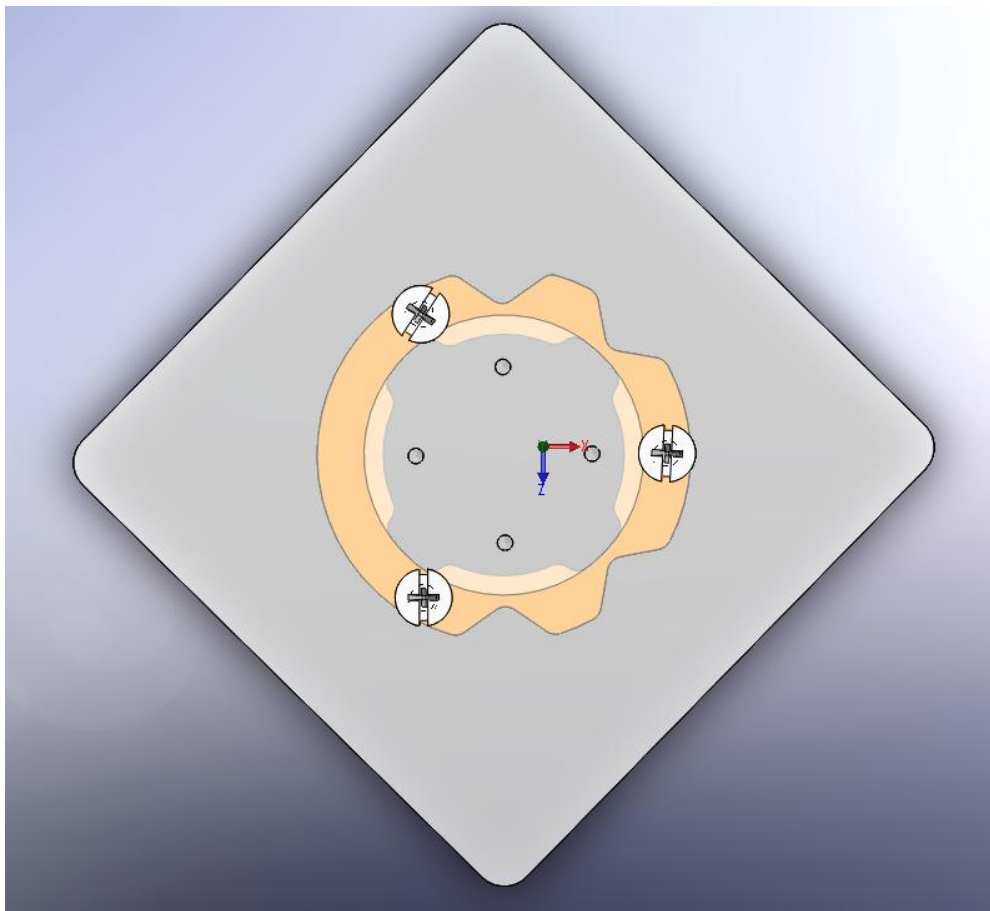


Figure 6 - Functional Requirement 1.3

2.3.4 Functional Requirement 1.4

The loads applied to the cam piece of the prototype must be successfully transferred to the bottom piece of the component. The rotation of the prototype is based on the interaction of the surfaces of the cam and bottom portion of the prototype. These surfaces must be compatible without severe surface roughness so an accurate coefficient of friction can be calculated. The coefficient of friction between the cam surfaces and the follower is crucial in determining the proper spring rates in order to allow for the desired compression at a predetermined load. The interaction of the follower and the cam must dictate the major component of friction. Therefore, the surfaces highlighted in Figure 7, below, must be designed in such a way to avoid contributing to the frictional force of rotation. With these surfaces designed in order to reduce friction, a more accurate theoretical analysis of the prototype can be performed.

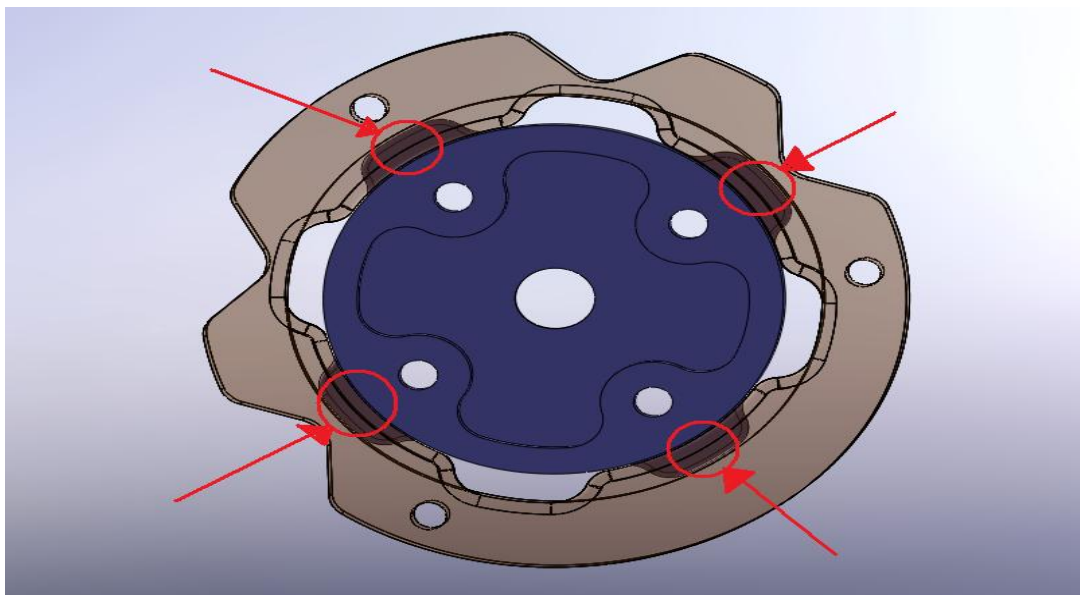


Figure 7 - Flush load Transferring Surfaces

2.3.5 Functional Requirement 1.5

Loads applied to the bottom plate of the rotational prototype must be successfully transferred to the board itself in order to provide stable and predictable edging. A typical commercial snowboard has a total of sixteen mounting holes, eight for each foot. Only four holes are required to mount a traditional binding to the board. By providing eight holes, manufacturers grant consumers with the ability to custom fit the snowboard to a specific riding position. The holes are spaced four centimeters apart from one another arranged in the pattern shown below.

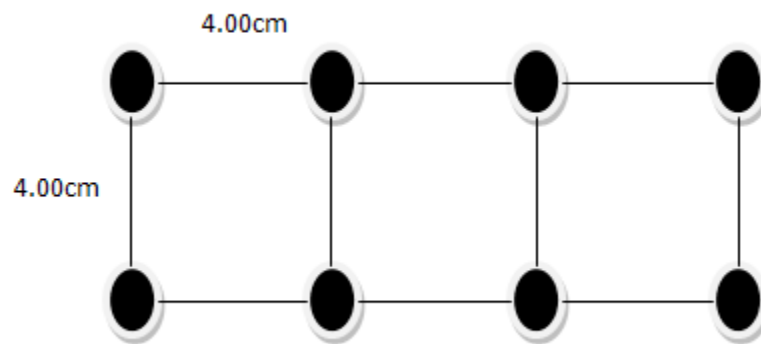


Figure 8 - Configuration of Snowboard Mounting Holes

The prototype binding must follow the same configuration. In order to achieve maximum adjustability, four mounting holes were chosen, allowing the rider to space his feet up to sixteen centimeters apart. Furthermore, commercially produced snowboards are predrilled and threaded using a M6 x 1.0 thread specification. Therefore, the prototype must be designed with a clearance hole for an

M6 machine screw. The clearance holes were dictated to be 0.281 inches in diameter. Functional Requirement 1.5 can be seen in the image below.

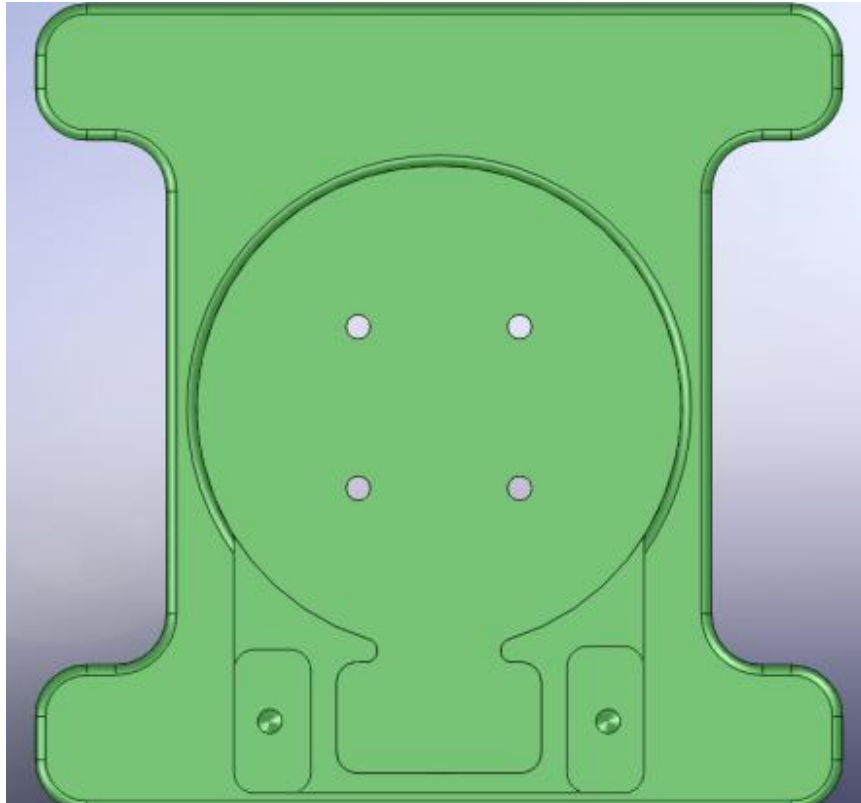


Figure 9 - Bottom Plate with four hole configuration

2.3.6 Functional Requirement 1.6

In order to maximize edging efficiency, the edging loads must be maximized. From an analysis perspective, the edging moments, therefore, must be maximized. Intuitively, a moment is simply a force multiplied by the distance about which the force is rotated. Since the forces exerted during snowboarding are based off the mass of the rider, they are difficult to change. Therefore the simplest way in which the moments can be maximized is to extend the distance where the forces are applied. In a traditional setup, the forces applied from the rider are transferred through the center of the board, 4 inches from the desired edge. By minimizing the distance between the edge and the farthest point of binding loading, the moment can be maximized. Conversely, weight is of concern so a design which

both minimizes the distance from the edge to the binding and minimizes weight was chosen. The design, as seen below in Figure 10 is an I-shaped design with the top and bottom portions of the “I” being the edging sides of the prototype.

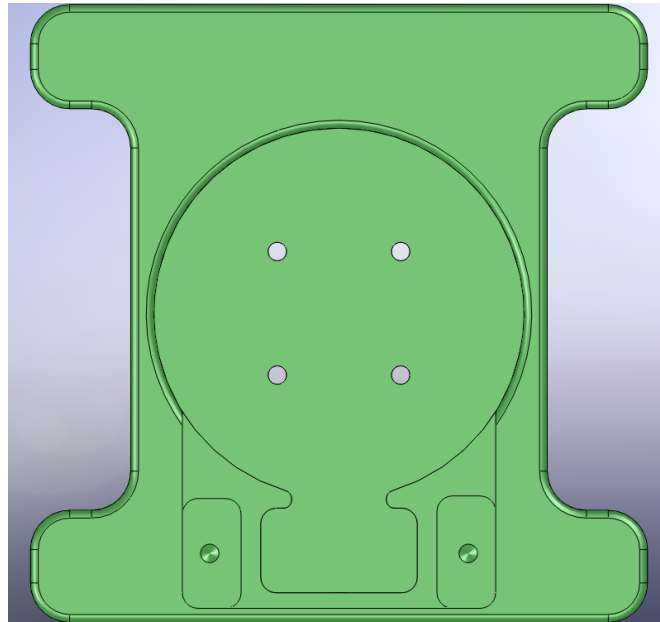


Figure 10 – Bottom plate showing “I” shape design

2.4 Functional Requirement 2

One of the objectives of this design was to allow the snowboard rider to rotate their feet in a controlled manner. The solution to this objective was the creation of a circular CAM and a follower system, which can be seen in Figure 11 below.

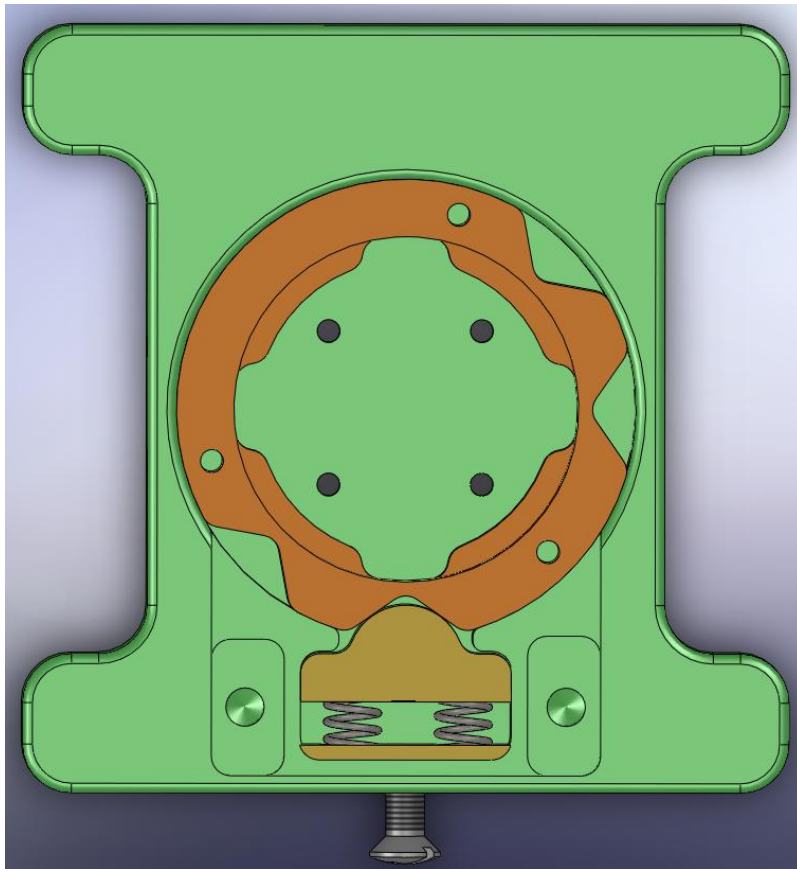


Figure 11 – Circular cam and follower system inside bottom plate

2.4.1 Functional Requirement 2.1

Functional Requirement 2.1 is to provide stabilization and resist rotation at low torques. While the rider is traveling down the slope there will be some rotational forces acting upon the binding system (Whelan and Coates, 2008). In a past MQP, these forces would result in some wobble for the rider and cause an unpleasant and unsafe snowboarding experience (Adamson, et al., 2007). This problem is overcome by machining V-shaped notches in the circular cam, shown below in Figure 12.

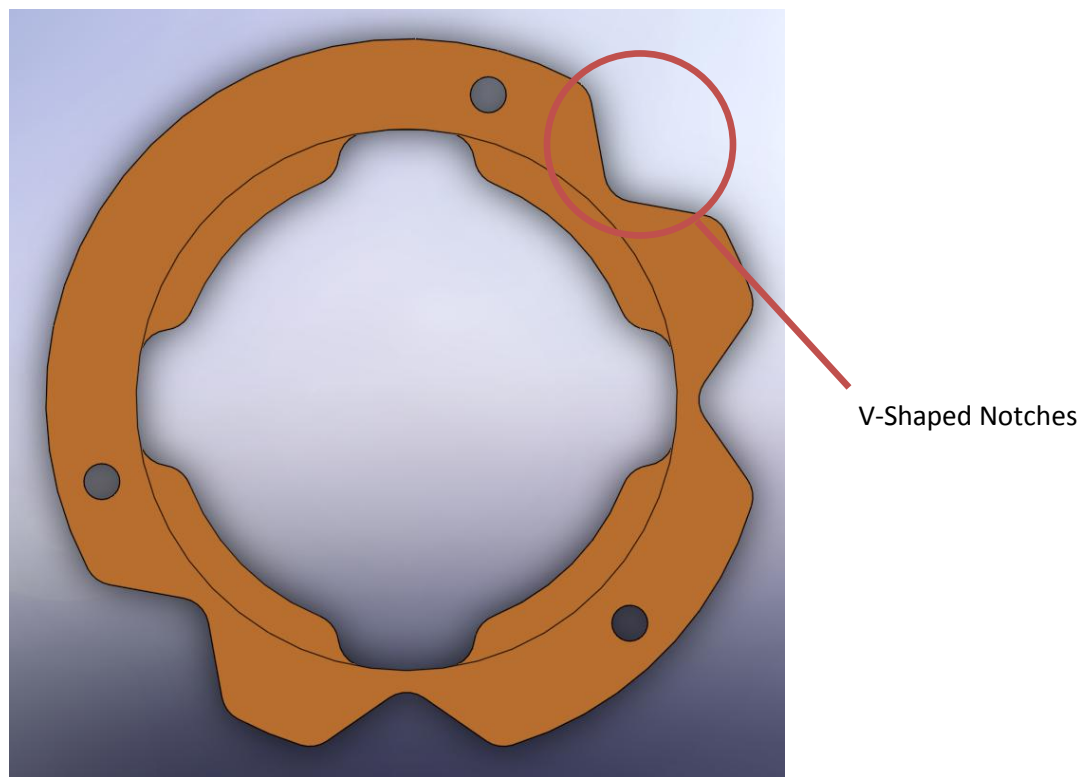


Figure 12 – Circular cam showing V-Shaped notches

Additionally the team implemented a dual spring preloader system, shown in Figure 13, to help reduce any wobble in the assembly.

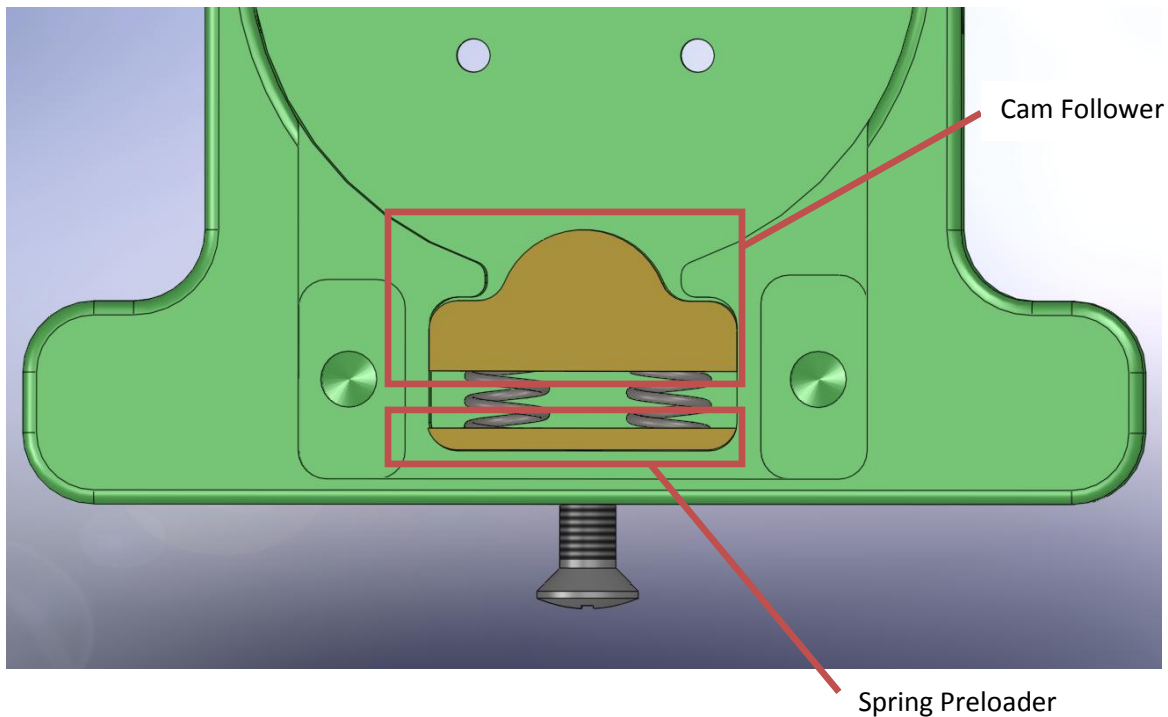


Figure 13 – Preloader and follower system

By machining the notches in the cam it allows the follower to have two solid points of resistance to any rotational forces. Additionally, the dual spring preloader system serves to help force the follower into the notches. With a larger force between the follower and the notches in the CAM profile, there is less room for the binding assembly to wobble at any point while it is in use. The selection of a proper spring constant is crucial to reducing wobble and allowing for rotation at a given applied force. The section below illustrates how the springs were chosen.

Spring Constant Calculations

Since the rotation of the device incorporates four stable riding positions a cam and follower system was chosen. The follower should compress when a torque of 15N is applied to the system. While there are numerous ways to allow for compression of the follower, a typical compression spring was chosen for simplicity and accessibility. Further research showed that springs can be chosen in nearly any diameter, spring length and spring constant. The design was intended to be as this as

possible while still performing the basic functions. Therefore, a spring should be chosen such that the spring constant allows for maximum compression with an applied load of 15N while being of the smallest possible diameter. The spring constant was determined analytically through the use of the basic equation shown below:

$$F = kx$$

Where F is the applied load, k is the spring constant and x is the deflection of the spring. Summation of the forces in the y-direction can be seen through the equation below:

$$F_y = kx = -N_f \sin(\theta) + N_f \mu \cos(\theta)$$

Where N_f is the normal force and θ is the angle between the normal force and the x-component of the applied force. This can be seen through the diagram below:

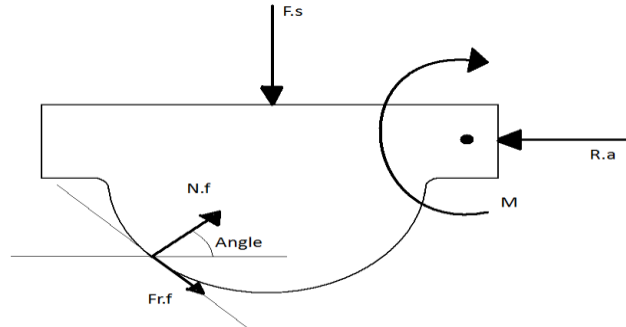


Figure 14 - Free Body Diagram of Follower

Solving the equation shown above for the normal force yields:

$$N_f = \left(\frac{kx}{\mu \cos(\theta) - \sin(\theta)} \right) (\mu \sin(\theta) + \cos(\theta))$$

Since the normal force is directly equal to the negative value of the torque applied over the radius of rotation, the equation above can be rewritten as:

$$\frac{-T}{r} = \left(\frac{kx}{\mu \cos(\theta) - \sin(\theta)} \right) (\mu \sin(\theta) + \cos(\theta))$$

Solving the equation above for k, the spring constant, yields:

$$k = \frac{-T(\mu \cos(\theta) - \sin(\theta))}{rx(\mu \sin(\theta) + \cos(\theta))}$$

The values in TABLE 2 Below are the given values needed to solve for the spring constant.

Parameter	Value
T	15Nm
r	6cm
x	1.2cm
θ	55.29°
μ	0.36

Table 1 – Values to solve spring constant

Substituting these values into the equation shown above yields a spring constant equal to 14856.98N/m which in English units is 84.835lbf/in. Further research showed that this spring constant is achievable with commercially produced compression springs; however, the diameter of such a spring increases size dramatically. Therefore, the decision was made to use two springs each requiring 42.418lbf/in spring constants to achieve a similar result.

2.4.2 Functional Requirement 2.2

To make the binding assembly functional, the cam must be able to rotate at high torques. When a torque greater than 15Nm is applied by the rider, the binding will rotate to the next resting position. For the binding to rotate smoothly, a uniform outer CAM profile was necessary. This outer profile is shown below in Figure 15.

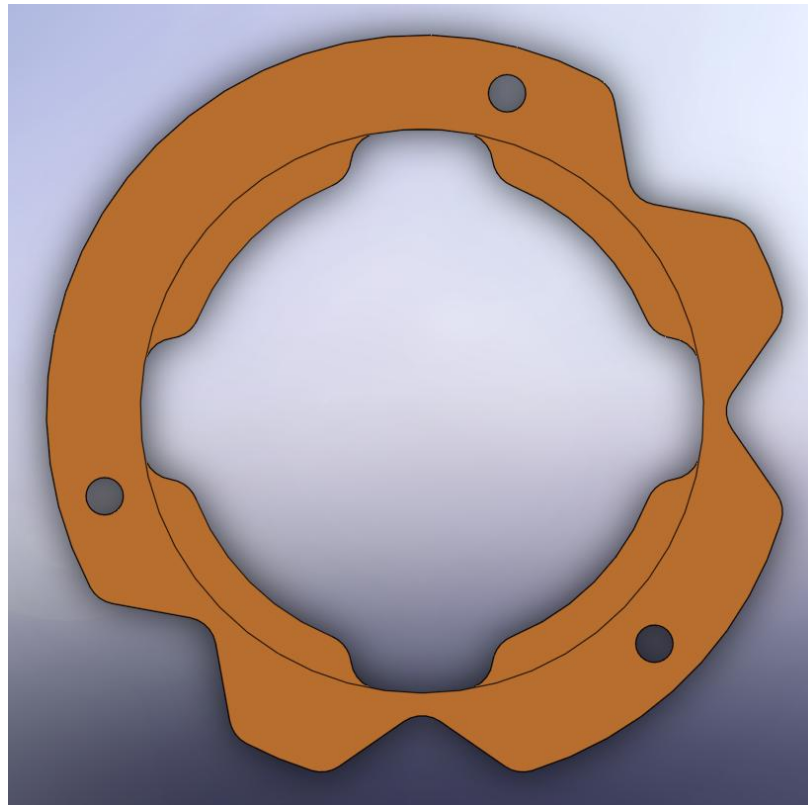


Figure 15 – Circular cam

2.5 Function Requirement 3

The third major objective of the binding is to provide a method to release. The rider should be able to release his foot when arriving at the bottom of a trail or when needed to propel himself to a given destination. In order to achieve this without the need to stop or use one's hand, the upper and lower binding pieces were designed such that they could lock or unlock through rotation. The center piece in the image below is mounted directly to the bottom plate and the snowboard. The four tabs of the center piece rest on the corresponding extrusions on the cam. In Figure 16, below, the binding is in a locked riding position. Should the rider attempt to lift his foot out of the binding, the tabs will prevent the cam from releasing.

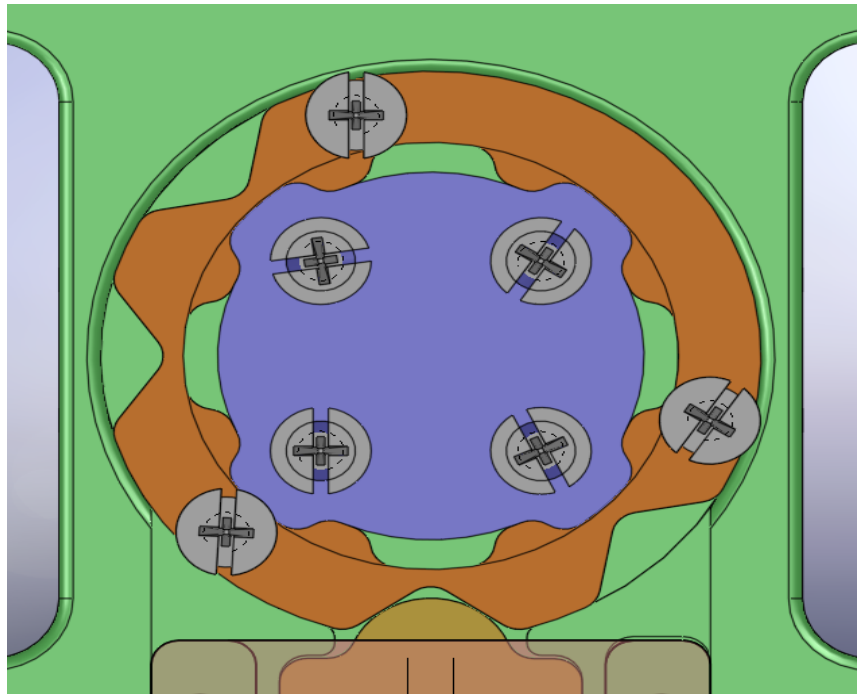


Figure 16 - Riding position

In order to properly release his rear foot, the rider must rotate his foot 45° clockwise to a release position. In this position, the tabs on the center piece and the slots on the cam will allow for the cam to release from the assembly, freeing the rider's foot. This can be seen in Figure 17, below.

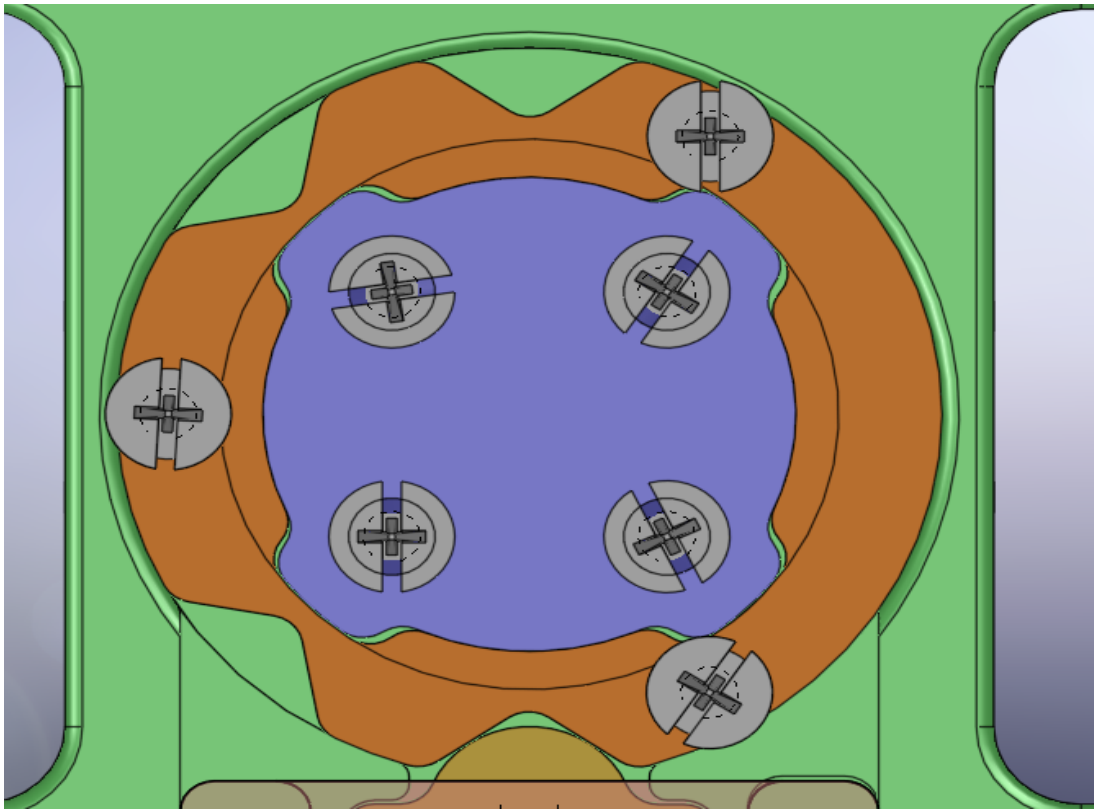


Figure 17 – Tabs and slots aligned

Since a universal binding to be used on both feet was created, a second release position was incorporated to allow for release of the front foot. This position is located 135° counterclockwise from the normal riding position or 45° counterclockwise from the parallel riding position. The second release position allows the rider to release his front foot without the need to rotate back to the rear foot release position.

2.6 Functional Requirement 4

As observed in a previous snowboard binding MQP their designed used one contact point for their riding positions which contributed to a noticeable amount of wobble. To help improve upon the design, the binding's wobble should be minimized to provide the maximum load transferability and feel of security. Functional Requirement 4 calls for the reduction of wobble. It is achieved by providing close running fit tolerances on the rotating components. A close running fit machined cam profile and corresponding bottom plate will help reduce wobble felt by the rider.

Wobble felt by the rider causes several concerns for the rider. The riding locations are based on positions machined into the cam and these positions are primarily located by feel. The design calls for the ability to rotate the device to a normal riding position (0 degrees), a parallel position (90 degrees), two release positions (-45 and 135 degrees), and excessive wobble would add difficulty in locating these positions. Also normal riding situations slight adjustments in rider position and edging forces can result in changes in speed or direction. If the device has severe wobble, the rider would need to apply a force to overcome the wobble prior to edging or rotating. This creates a situation in which the rider is not achieving efficient energy transfer as a portion of the work applied to the system is wasted on overcoming the wobble of the device.

2.7 Functional Requirement 5

Another important function we wanted to have for our parts was for them to be easily machineable. To accomplish this function we need to maximize tolerances, which would allow for easy milling and assembly. Our primary approach to this was to use filleted edges. Fillets help machine parts with ease since sharp edges inside a corner are very difficult to machine with a mill and create unwanted stress concentrations. The fillets all vary in size due to drill bits specs that accommodate our material and depth needs. We also broke our components into sub divisions which were easier to machine alone than together as one piece.

2.7.1 Functional Requirement 5.1

The bottom plate had two main sections which dictated the radii which we would use for the fillets. These sections were the inner and outer profile of our product.

Functional Requirement 5.1.1

The outer profile isn't as critical in constraints in regards to fillet radius and surface quality so we chose a radius that would allow us machining features on the outer profile with very little stress on the mill and our product. Therefore we choose a radius that was larger than the radius of our end mill that was chosen to be 5/8" in diameter, and that radius was .75in.

Functional Requirement 5.1.2

The inner radius was more critical in regards to fillet radius and surface quality so we choose radius that would minimize changes to the inner profile of our design. To do this we determined the best radius to minimize changes to the inner profile was roughly 1/4". Therefore we wanted a radius that was smaller than that. We found a bit that fit these constraints that had a diameter of 3/8" and then based our profile cut paths off that.

2.7.2 Functional Requirement 5.2

The upper plate was a part that didn't have many critical radii so to reduce machine time and cost we opted to use an end mill that was already in use for the previous FR. Therefore we decided to use the 3/8" end mill to create 1/4" radius cuts to the upper plate outer profile.

2.7.3 Functional Requirement 5.3

The cam-plate assembly was one of the most difficult parts to consider during machining. Our cam was a complicated shape with two different profiles embedded within it and therefore to machine it would require either casting or another approach. We decided casting would not be an easy process to do since it requires time and it would be more costly to do so. Therefore the decision to split our cam-plate assembly would allow us to create the inner and outer profile of the cam with ease.

2.7.4 Functional Requirement 5.4

The follower is another important part of our design that had to fit in some tight tolerance so we based our decision to fillet the edges relative to the inner cam profile of our other parts and inner profile depth. The end mill for the inner profile had a radius of 3/8" so we could have fillets in the inner profile with radius of 1/4".

2.8 Functional Requirement 6

In order to keep the binding system functioning correctly while snowboarding, the team determined that part of the design needed to prevent snow build up in the assembly. If there was a buildup of snow in the assembly then it would cause the CAM to jam and not perform correctly. To prevent snow buildup in it the team decided to add features to help protect against snow interference.

2.8.1 Functional Requirement 6.1

The first step to ensure that the assembly would perform correctly is to prevent any snow from sticking inside the assembly. This would be accomplished by using an anti moisture coating on the aluminum surfaces to help prevent snow from sticking to the metal. To help prevent snow sticking to the metal we used a silicone based lubricant.

2.8.2 Functional Requirement 6.2

Another section of the binding assembly that needs to be protected from any snow buildup is the dual spring follower system. If snow was to get this section it would prevent the compression of the follower and render the binding useless. A decision was made to use a cover plate to prevent snow from getting into this section. This designed covering plate is shown below in Figure 18.

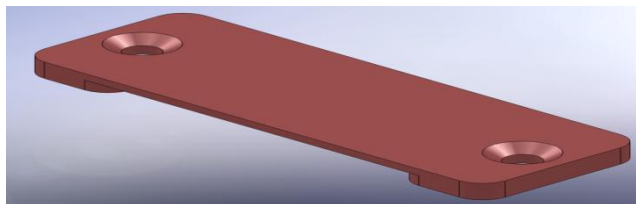


Figure 18 – Follower assembly cover plate

2.9 Functional Requirement 7

The final functional requirement, Functional Requirement 7, calls for the ability to adjust the snowboard configuration to further customize rider positions. In order to achieve such a goal the design parameter is to use the currently practiced methods for stance and riding adjustability.

2.9.1 Functional Requirement 7.1

Current commercially produced snowboards, with the exception of Burton boards, use an eight hole configuration as seen in Figure 19 below.

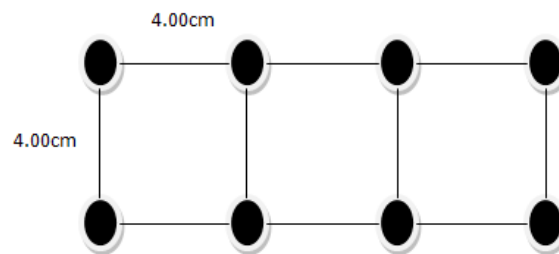


Figure 19 – Standard binding attachment configuration

Since the binding only requires a total of four holes to be properly secured, the stance can vary over a total distance of 12cm. This ensures that the rider has the ability to adjust either foot from the most outward position to the most inward position. In order to keep this adjustability possible, the base of the designed component must keep the same mounting configuration as commercial bindings. Therefore, the bottom plate was designed in such a manner. This configuration can be seen in Figure 20 below.

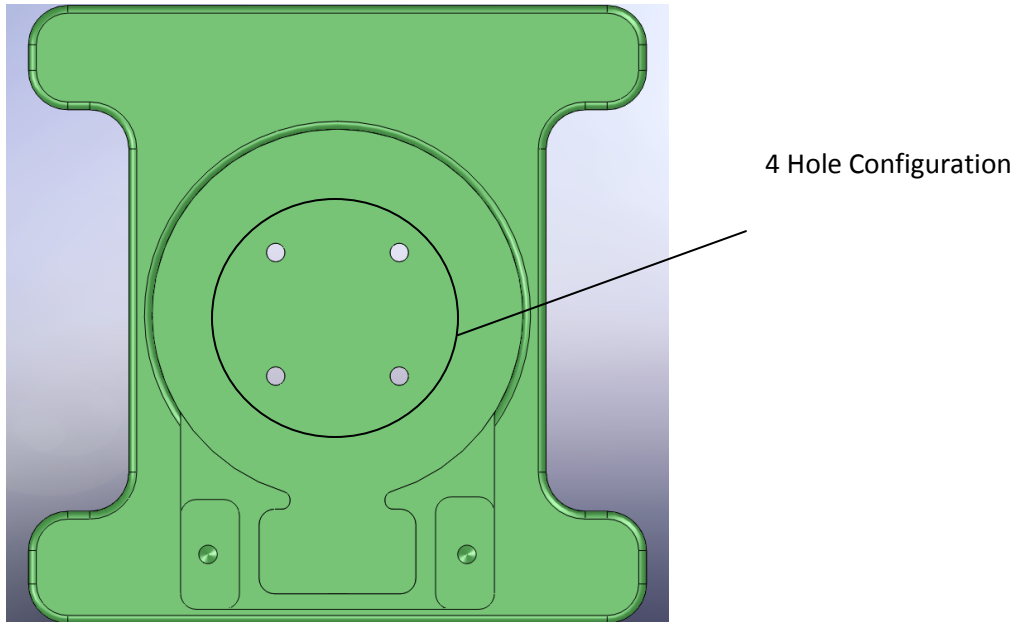


Figure 20 – Bottom plate showing holes for attachment to board

2.9.2 Functional Requirement 7.2

Binding adjustability is most commonly achieved through the use of two interlocking plates with grooves on them. Usually the front foot of the rider is set to an angle of fifteen degrees counter clockwise while the rear foot can be set to five degrees clockwise. These angles can be changed by the rider to fit their personal riding style. In order to keep this adjustability, the top surface of the binding adapter must act as the surface of the snowboard and it must be wide enough so that the binding can be placed flush on the surface to allow for adjustment.

3. Physical Integration

3.1 Description of Components

3.1.1 Bottom Plate

The main purpose of the bottom plate is to mount the device to the snowboard while allowing for methods of rotation and release. It has an I-beam type shape to allow for maximum moment transfer for edging while minimizing weight. The design of this component uses four holes to mount to the snowboard. The circular pocket cut into the bottom plate houses not only the cam but a center piece used for release and stabilization. Figure 22 shows where it houses the follower, compression springs, and preloader.

Since the binding adapter will be subject to snow, ice, and cold temperatures, the impact of such environmental conditions must be taken into consideration. A cover plate, described below, protects the springs from possible snow contamination. Machined from 6061 T4 aluminum, the bottom plate weighs 2.44lbs, and measures 7.87in x 7.87in x 0.98in.

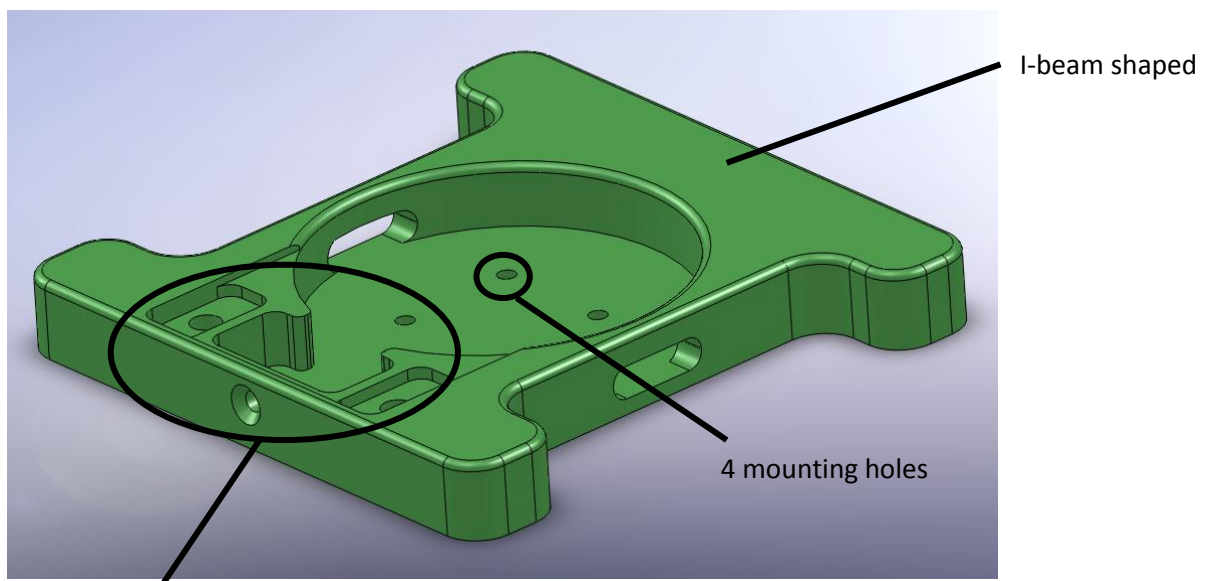


Figure 21 – Bottom Plate

Housing for Dual Spring
Follower system

3.1.2 Inner Piece

The inner piece was designed to keep the user secured to the board when in the riding position. The tabs on the outside of the inner piece, as seen in Figure 27, are designed so that when the user is in their riding position the inner rim of the cam would be positioned below the tabs. This would prevent any vertical movement in the binding assembly when in the riding position. When the user rotates the binding to a release position the slots in the inner rim of the cam would be aligned with the tabs on the inner piece. This would allow the user to pull their foot free by lifting upwards.

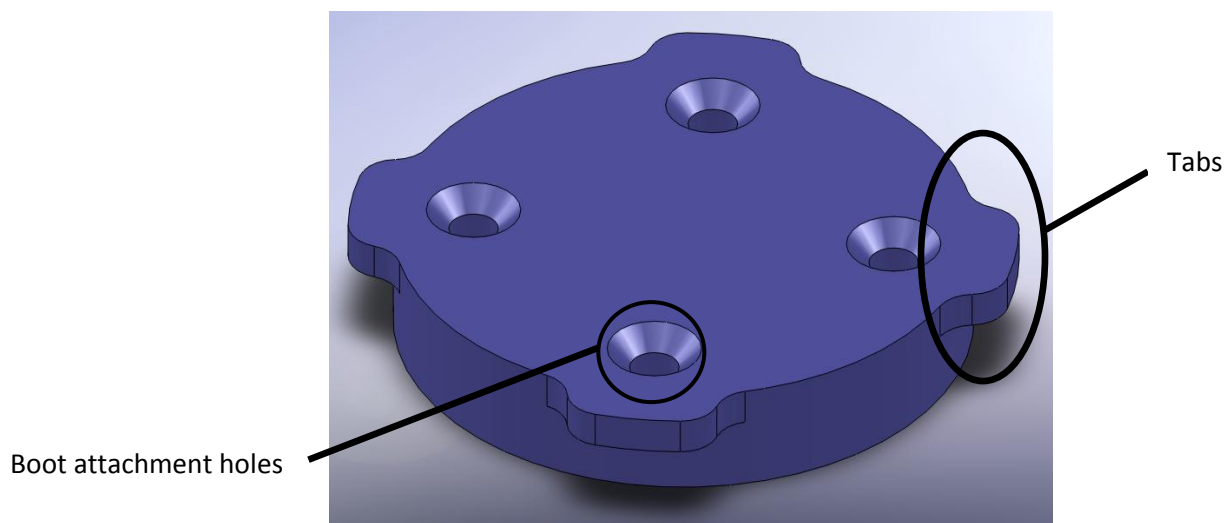


Figure 22 – Inner piece

The holes positioned in the center of the part, shown in Figure 27, would be used to attach the inner piece to the snowboard. The holes would line up through the bottom plate and with the pre-made holes on the snowboard. Machined from 6061 T4 aluminum, it weighs .25lb, has an outside diameter of 3.52 in, and a height of 0.59in.

3.1.3 Very Top Piece

The top of the snowboard binding assembly has several functions. First, this is where the user would attach their boots. The boots would be securely attached to the top plate by being screwed into the four clearance holes in the center of the piece, as shown in the figure below. These four holes would be machined so that they would line up with standard strap-in binding mounting points.

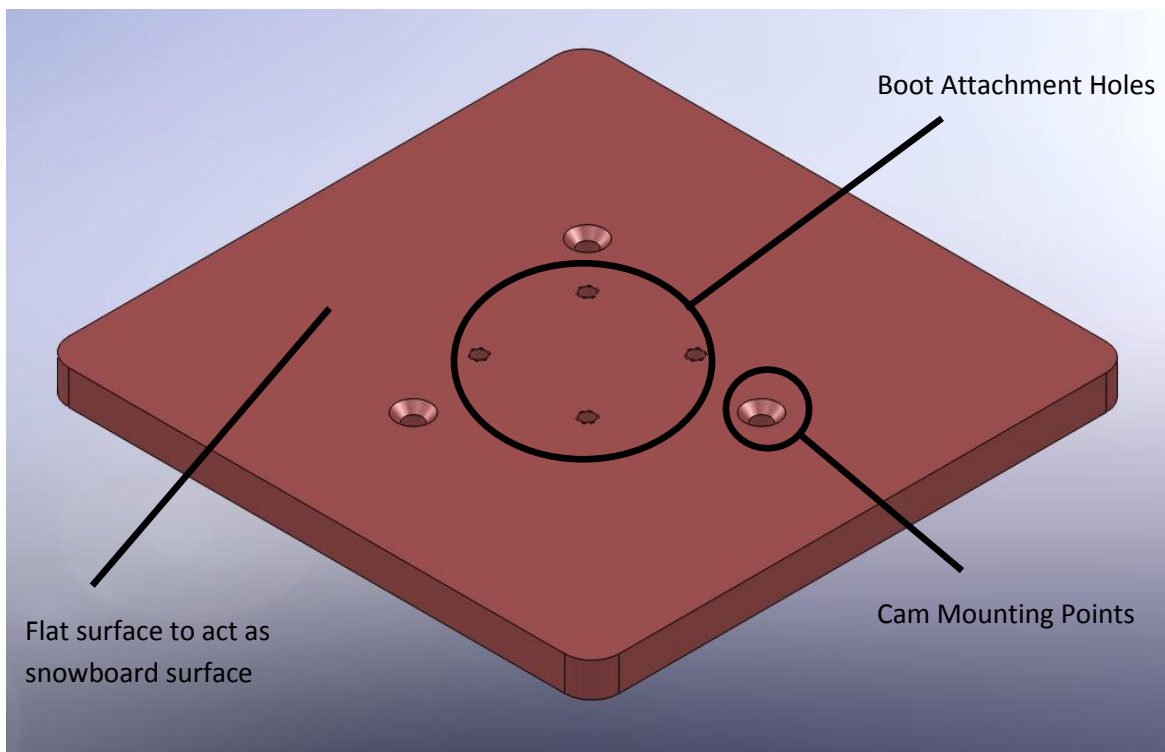


Figure 23 – Top piece showing boot attachment holes and cam attachment points

The three countersunk holes on the very top plate are used for attachment to the CAM profile. They would be clearance holes for M6 size screws and would ensure that the CAM profile is securely affixed. The very top piece was also designed in a square fashion in order to help ensure that no snow, water or debris will get into the binding assembly. With the current design the CAM would be completely covered regardless of the rider's foot position and also during any rotational motion. Machined out of 6061 T4 aluminum, it weighs 1.14lbs, and measures 8in x 7.87in x .19in.

3.1.4 Cam

The cam was designed to act as an interface with the top plate and bottom plate assembly. It has three mounting points to help transfer loads from the top plate to the bottom plate assembly. The cam has 4 positions designated by the v shaped notches which are for the release and riding stances. It has a general round shape to allow for easy rotation once the follower is outside of the v shaped grooves. The cam has an inner lip with 4 slots in it to help retain the inner piece when locked or allow for release when aligned properly. Machined out of 6061 T4 aluminum, it weighs 0.52lb, and has an outer diameter of 4.69in and a height of 0.79in.

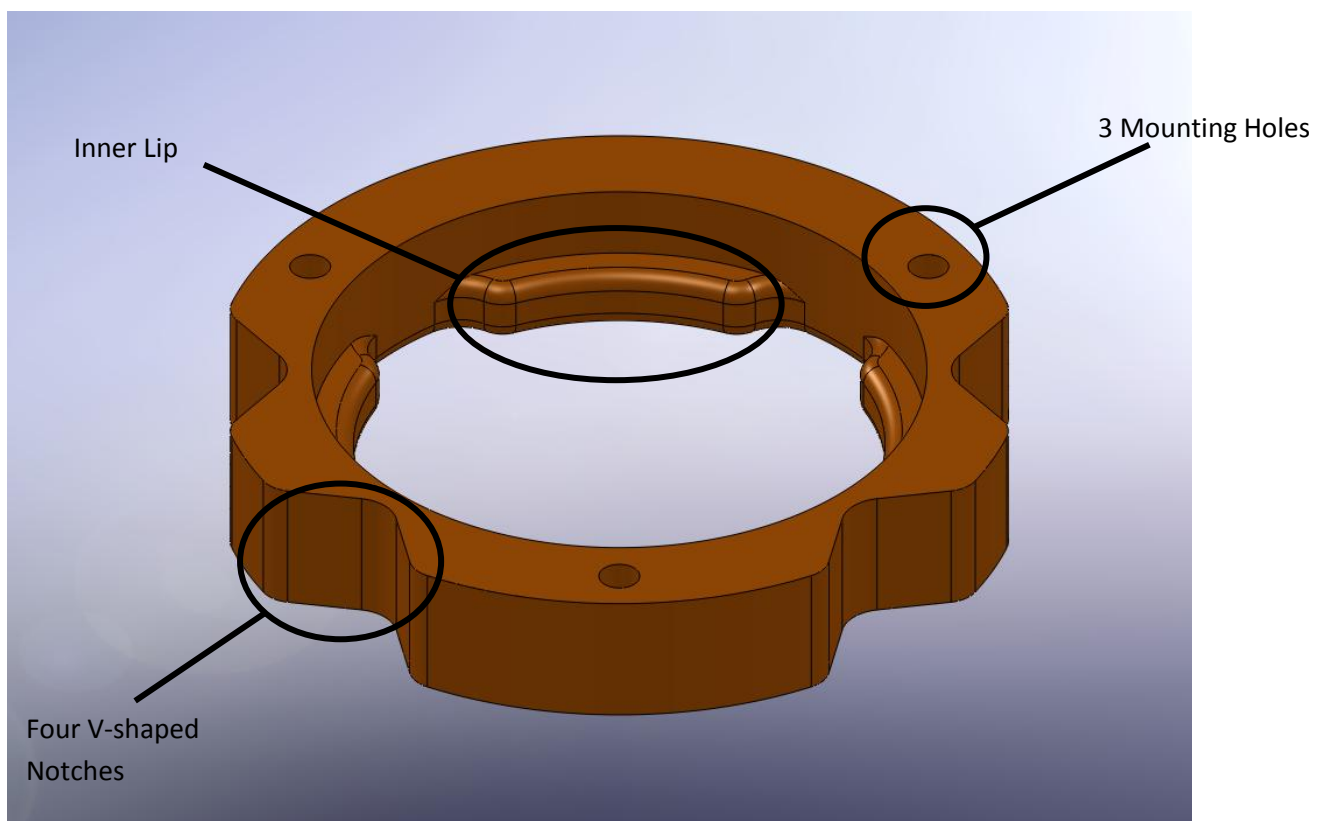


Figure 24 - Cam Piece

3.1.5 Follower

The follower is a component which would be used as a resistor to rotation for the top plate assembly. The follower was designed to have a rounded wall interface that would make contact on two points of our v shaped cam design. Machined out of brass, it weighs 0.23lb, and measures 2in x 1in x 0.69 in.

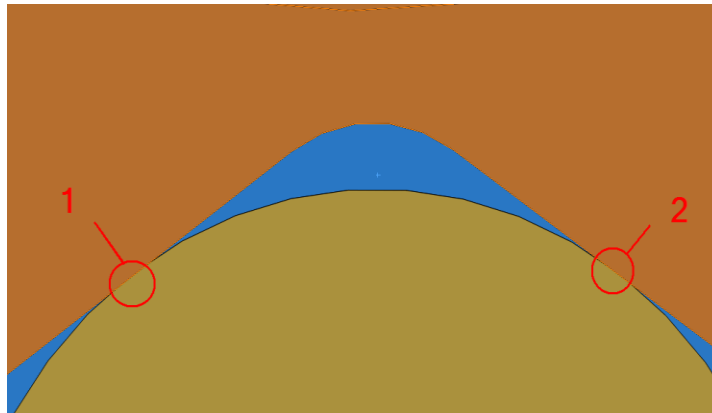


Figure 25 – Contact points between cam and follower

To allow for an even supply of force the follower was designed with two recessed regions to allow for our springs to sit inside of. The point of the dual spring system instead of a single spring system is to help reduce binding and locking up of the follower on the side wall as seen as in Figure 24.

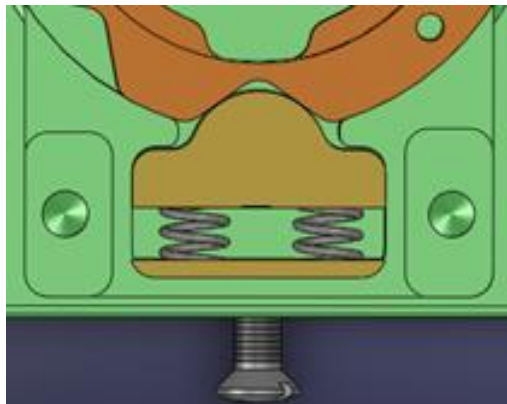
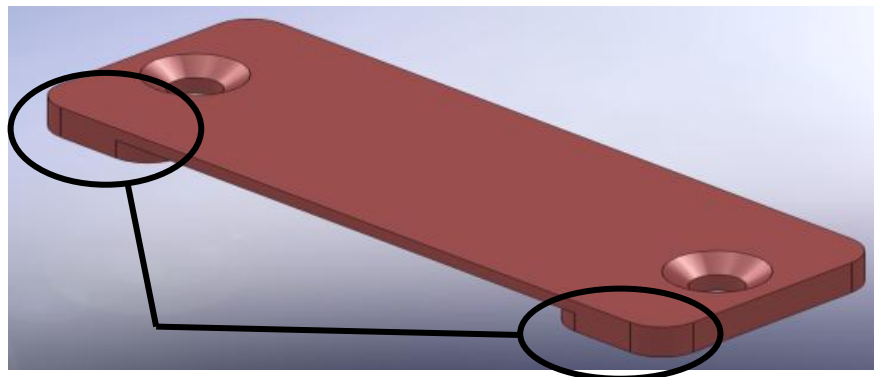


Figure 26 – Dual spring preloading system

3.1.6 Cover Plate

The purpose of the cover plate was to protect the dual spring loaded follower system from contamination. Its other purpose is to act as a guide for the follower and preloader to minimize rotation or binding of the system. It was made to fit tightly and securely to above the system. With the use of two extrusions we can ensure it will fall into place and not shift around as it fits in the identical size recession on the bottom plate. Machined out of 6061 T4 aluminum, it weighs 0.08lb, and has an overall dimension of 3.98in x 1.38in x 0.25in.



Mating Extrusions

Figure 27 - Cover Plate

3.1.7 Preloader

The purpose of the preloader is to allow for an increase of torque needed to rotate the top plate assembly. When a set screw is screwed in it will compress the springs, preloading the system. This is done by having an identical two recessions to contain the other end of the springs within itself. The other side of the preloader also has a recession to allow for a screw to sit in allowing even application of force. Machined out of brass, it weighs 0.06lb, and measures 2in x 0.7in x 0.25in.

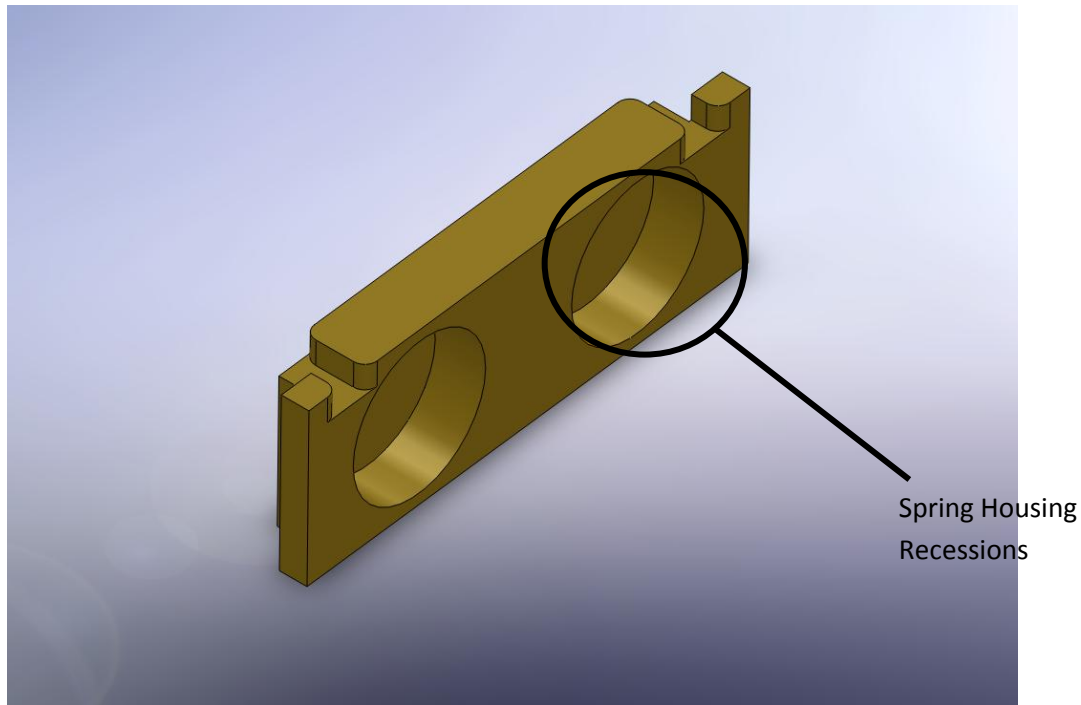


Figure 28 – Preloader

3.2 Finite Element Analysis

Finite element analysis was constructed prior to machining on the major load bearing components of the system. These components are the bottom plate, the inner piece, and the cam and follower system. Components were constrained according to the mounting conditions and stresses were verified to ensure that no component exceeded the yield stress of the material. Deflections were observed to ensure the component did not deflect to an extent as to inhibit proper functionality.

3.2.1 Bottom plate:

The figure below shows the bottom plate of the binding. A snowboard is constructed such that it can flex and bend to overcome terrain and loads applied by the rider. Therefore, the binding mounted to the top of the snowboard must be constrained in such a way to illustrate this flex. The bottom plate of the binding was constrained accordingly and stresses and deflections were observed through the use of finite element analysis. The table below illustrates the number of nodes and elements as well as the degrees of freedom and maximum stress.

Element Type	Seed Size	# nodes	# Elements	DOF	Max Stress (MPa)
C3D10	0.16	94304	61050	287592	1.240E+06

Table 2 - Summary of Data

In this problem the part was created in Solidworks and then imported to Abaqus using STEP File. The C3D10 element type was used. The entire holes for screws were selected and degrees of freedom were fixed. Material properties of 6061-T4 Aluminum were assigned. The part was meshed and the smallest allowable seed size was used to get the maximum number of nodes available. An increase in nodes results in an improved representation of actual stresses. The finite element models for the stress and deflection are shown in figures 21 and 22.

Deflection of 0.2mm from an experimental data was used to deflect the bottom plate and find the maximum stresses on the plate. The part was found to be over designed which caused the areas near the screws to exceed the allowable stress. To improve this design and to reduce weight, the bottom plate was pocketed in three sections. Another finite element analysis of the pocketed bottom plate illustrates that the stresses were reduced by 50% as seen in Figure 23. A plot of the deflections of the pocketed plate can be seen in Figure 24.

Bottom Plate deflection:

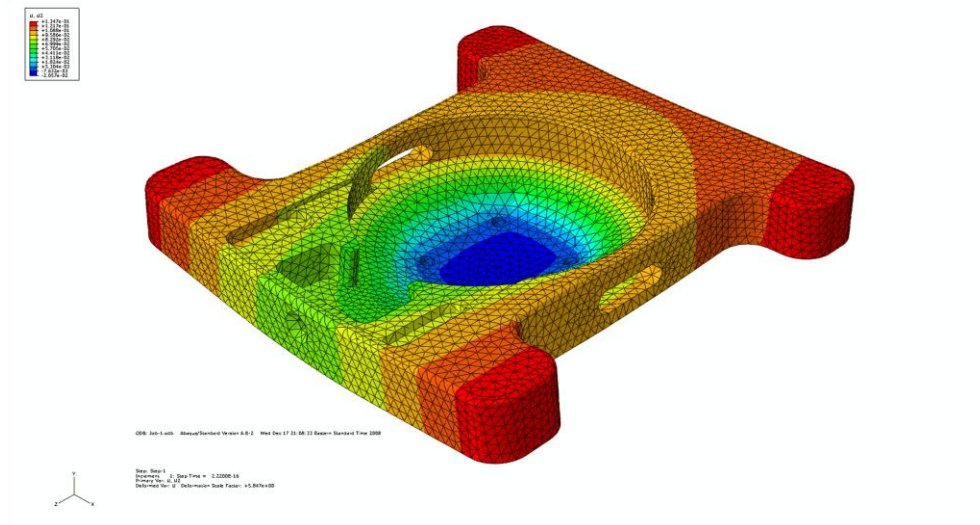


Figure 29 - Deflection on the Bottom Plate

Stress On the Bottom Plate

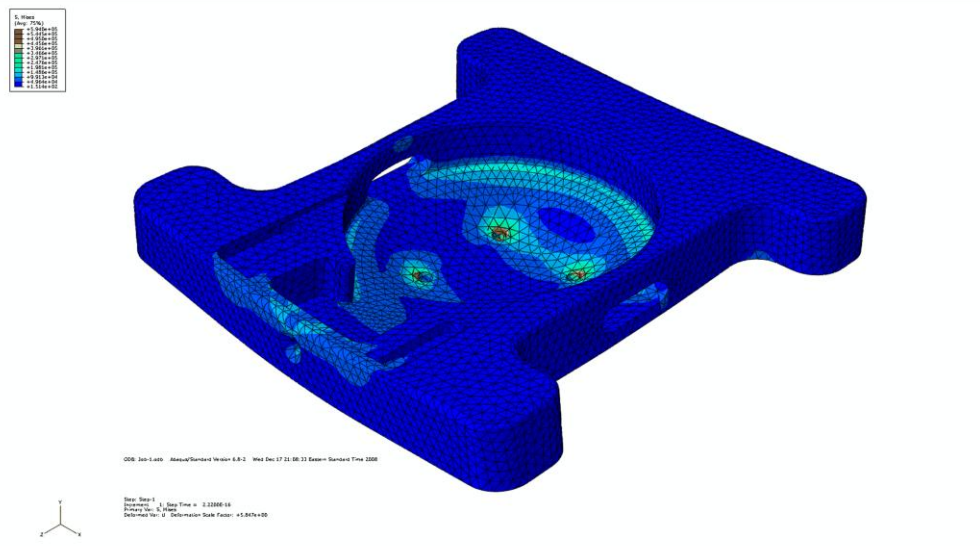


Figure 30 - Stress on the Bottom Plate

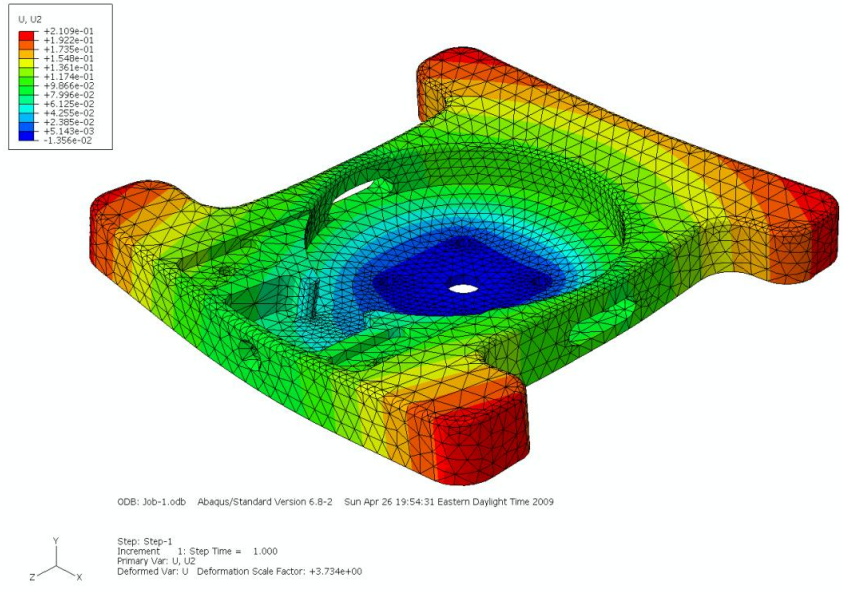


Figure 31 - Deflection on the Bottom Plate with Pocketing

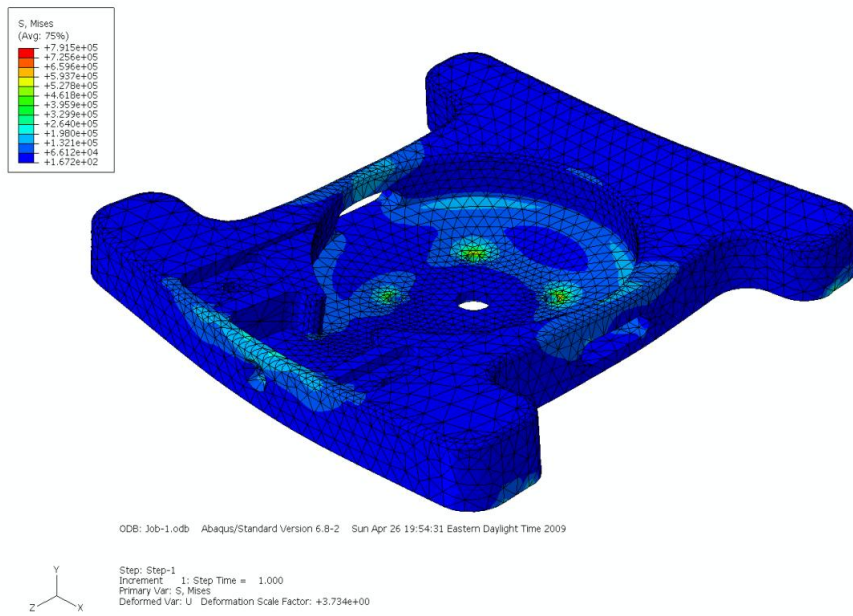


Figure 32 - Stress on the Bottom Plate with Pocketing

3.2.2 Inner Piece:

The figure below shows the inner piece of the binding. There are four force applied to this part on the four edges occurring when a rider attempts to release his foot while in a locked position. The

purpose of this finite element analysis was to determine if the deflection and stresses occurring on the four tabs resulted in part failure. Table 3 below shows the number of nodes and elements as well as the maximum deflection and stress.

Element Type	Seed Size	# nodes	# Elements	DOF	Max Stress (MPa)	Max Deflection (mm)
C3D10	.075	97627	66799	292881	2.687×10^3	1.089E-04

Table 3 - Summary of Data

The part was constrained such that the applied forces affected only the four tabs as the rest of the part was constrained in all degrees of freedom. A lifting force was applied to each of the tabs and the stresses and deflections were observed. The figures below show the stress distribution and deflections of the inner piece of the binding.

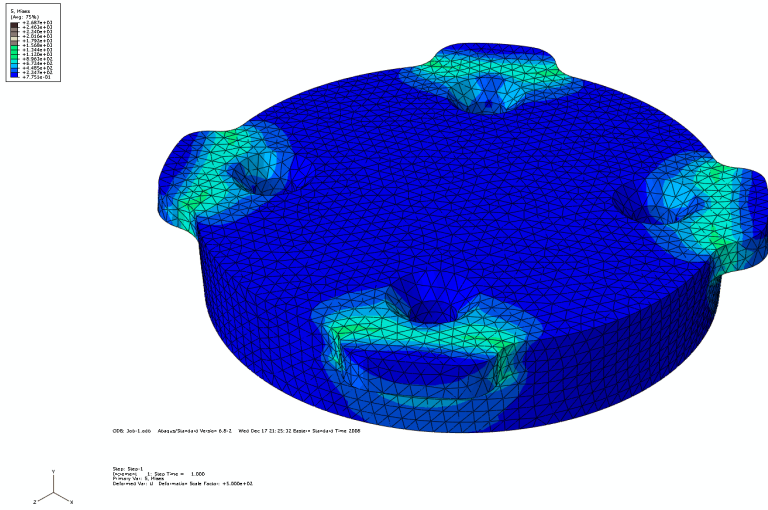


Figure 33 - Stress on the Inner Piece

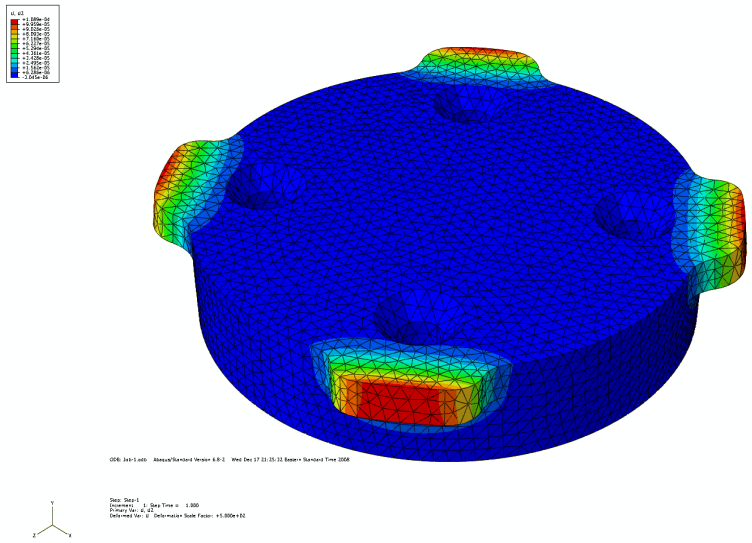


Figure 34 - Deflection on the Inner Piece

3.2.3 Cam System:

An additional finite element model was created to observe the lifting force on the cam. Since the cam is mounted to the top plate of the binding through the use of three machine screws, this model observes the force applied at the mounting locations. Table 4 below shows the maximum stress and maximum reaction force on the cam.

Element Type	Seed Size	# nodes	# Elements	DOF	Max Stress (MPA)	Max reaction Force (lb)
C3D10	0.1	69297	45323	219033	9.612E+02	2.364E+00

Table 4 - Summary of Data

The purpose of this finite element model was to ensure that the use of three mounting holes allowed for proper mounting of the top plate and cam without excessive stresses or deflections. The images below show the stress distribution and deflection observed by the cam in this finite element model.

CAM System:

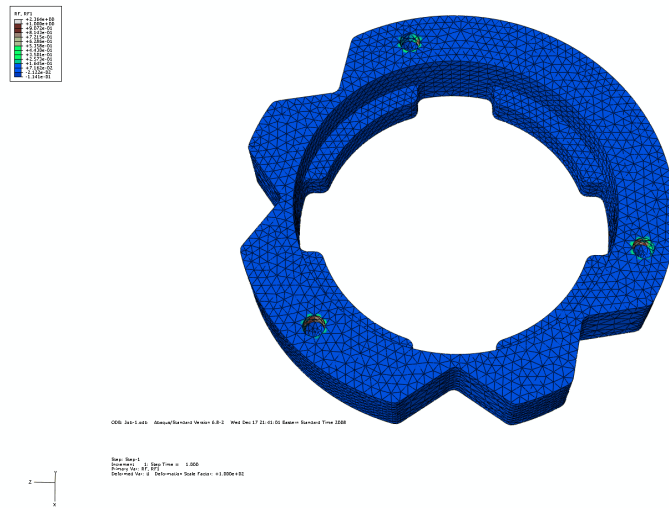


Figure 35 - Reaction Force on the Cam

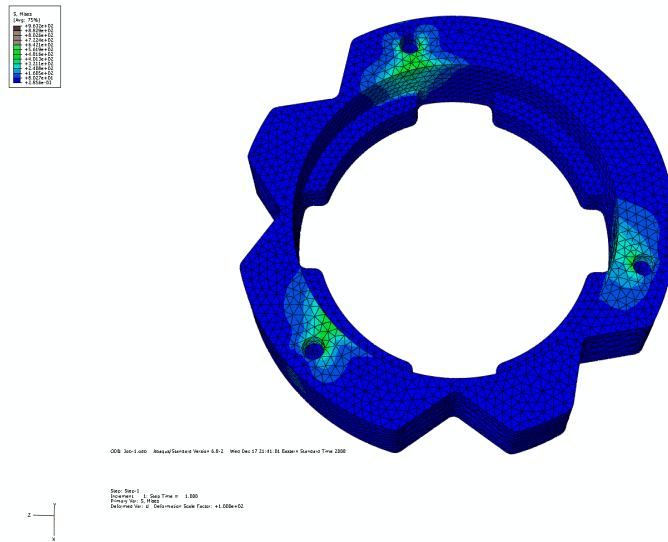


Figure 36 - Stress on the Cam

3.2.4 Contact Problem:

Since the cam and follower must have reliable and predictable interaction for proper rotation, a finite element analysis was created to determine the contact pressure during such rotation. Table 5 below shows the maximum reaction force, the maximum stress and the maximum contact pressure as observed by this model.

Method of Contact	Element Type	# nodes	# Elements	DOF	Max reaction Force (lb)	Max Stress (MPa)	Max contact Pressure (N/mm ²)
Surface to surface	C3D10M	12988	7578	67347	80	2.748E+02	4.670E+02

Table 5 - Summary of Data

In this contact analysis, the rotation of the cam causes a displacement of the follower resulting in contact pressure and a corresponding reaction force. The maximum reaction force of this system is 80lb which is verified through Hooke’s Law since the system contains two springs with stiffness of 45 lbf/in each, and less than an inch of displacement. Figures 29 and 30 illustrate the constraints applied to the cam and follower assembly. Figure 31 and 32 show the contact pressure and stress distribution. Finally, Figure 33 shows the reaction force as a function of rotational time.

CAM and Follower Assembly

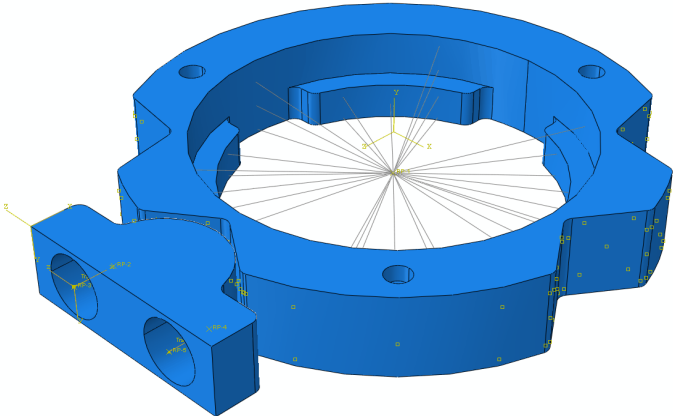


Figure 37 - Boundary conditions and interaction on the Cam

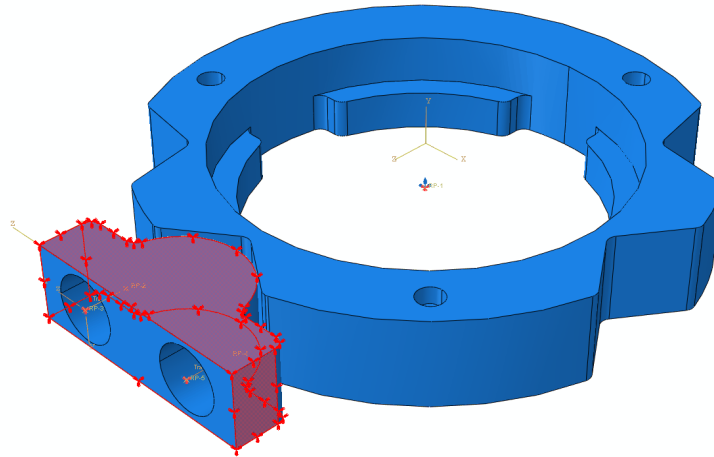


Figure 38 -The boundary conditions on the Follower

Contact Pressure And Stress for Cam Follower System

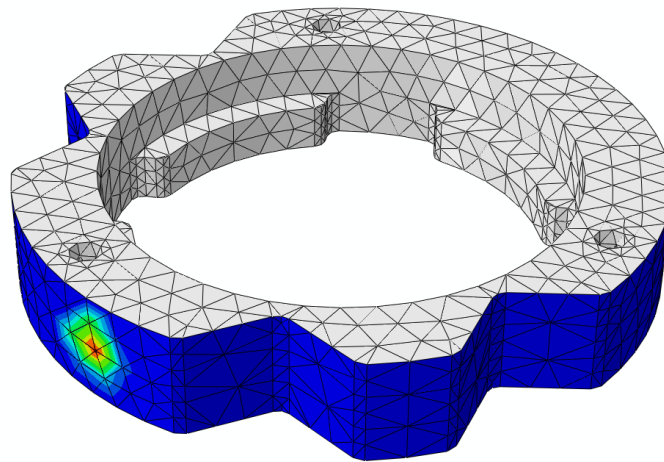
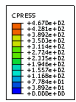


Figure 39 - Contact Pressure on the Cam

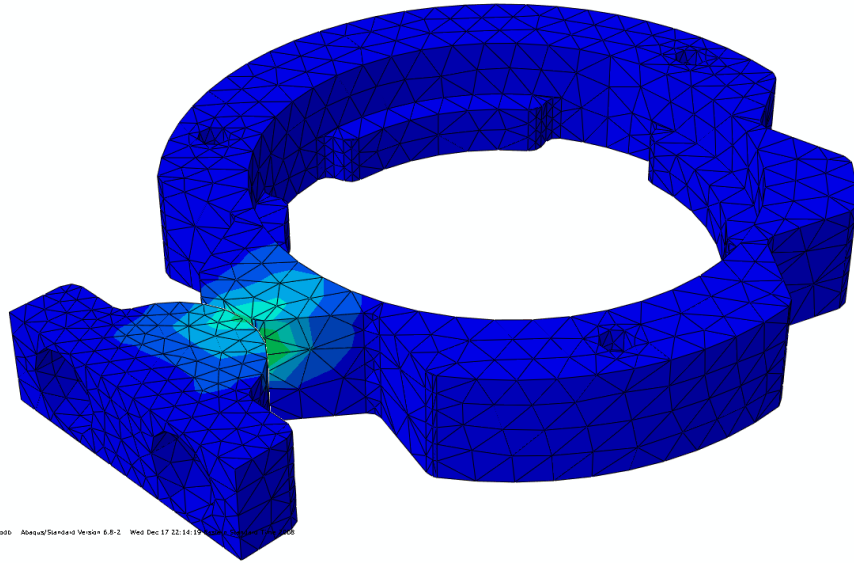
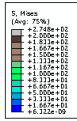


Figure 40 -Stress for the Cam Follower system

Reaction Force on the Follower for Cam Follower System

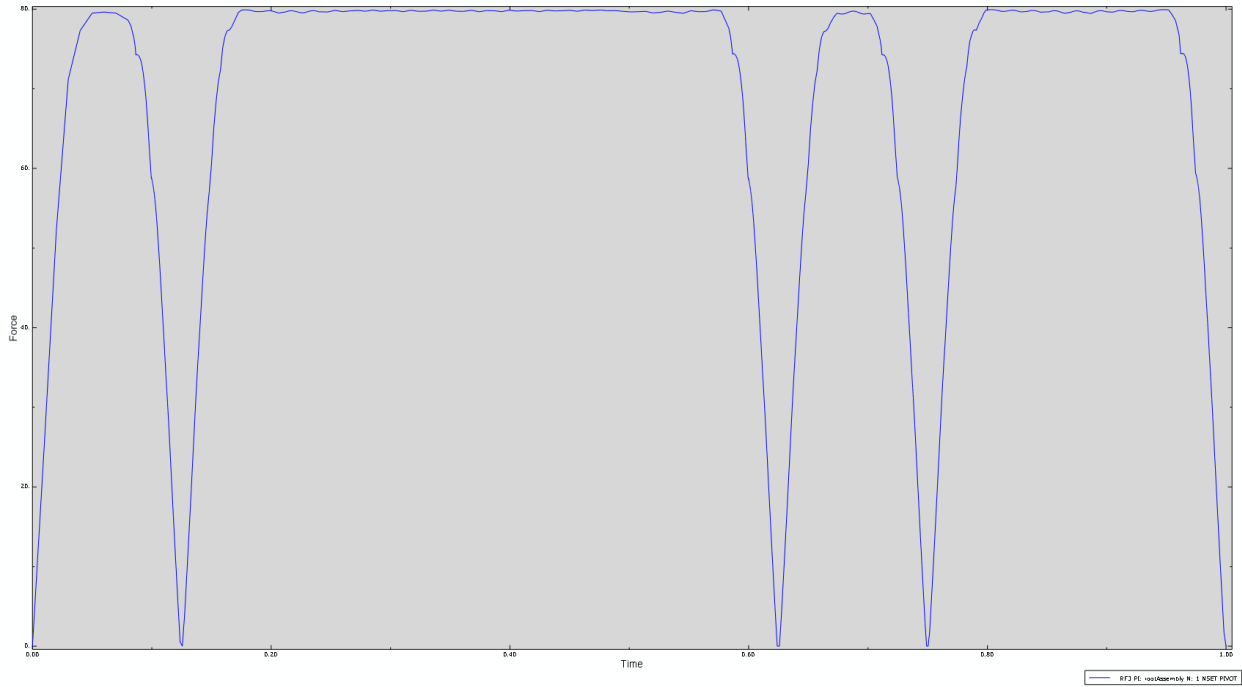


Figure 41 - Reaction Force of the Cam Follower system

4. Prototype Construction

4.1 Machining

The machining process was based off ease of manufacturing. Initial thoughts were to use aluminum for its ease of machining and its relatively low price value compared to other metals. Also considered were other metals that could be used on our cam profile/follower assembly. Considering the product was to be used in water based sports galvanization was a big factor on material choice. Since aluminum was chosen for the base material the follower was to be of another material, since galvanization between aluminum and aluminum contact was not desirable. Also the coefficient of friction was very high as well between aluminum and aluminum contact. Therefore brass was chosen due to it being a metal that doesn't galvanize as much as aluminum.

First part produced was the initial design of the follower with no slots. First a Solidworks assembly file was created with a 3D model of the all our components assembled. The follower cad file was then imported into esprit where cut paths were created to get the desired shape. This was machined by cutting out a 6inx2inx1.25in piece of brass stock. The stock piece was clamped into a vice and was cut out of carbide end mills of various sizes. The follower was then repositioned for various other cut paths until the final desired shape was achieved as seen below.



Figure 42 - First Follower No Slots

The next part produced was the bottom plate. The Solidworks cad file was imported into esprit and cut paths were created to get the desired shape. Attempts to use glue as the only form of containment were attempted. First attempt was a failure with the bottom plate being thrown from fixture plate after it was successfully faced down to correct height. Second attempt was a failure with the bottom plate being thrown again even after cut depths were reduced to small increments. Final attempt was to fixture the stock with glue and bolts. The bolts would hold down the bottom plate while the inner cut profile was created to desired shape. After the inner profile was complete the bottom plate had a clearance hole which was drill through the part and fixture plate. The outer cut paths were done while a bolt held down the bottom plate from within its inner profile. The final part came out as shown below.

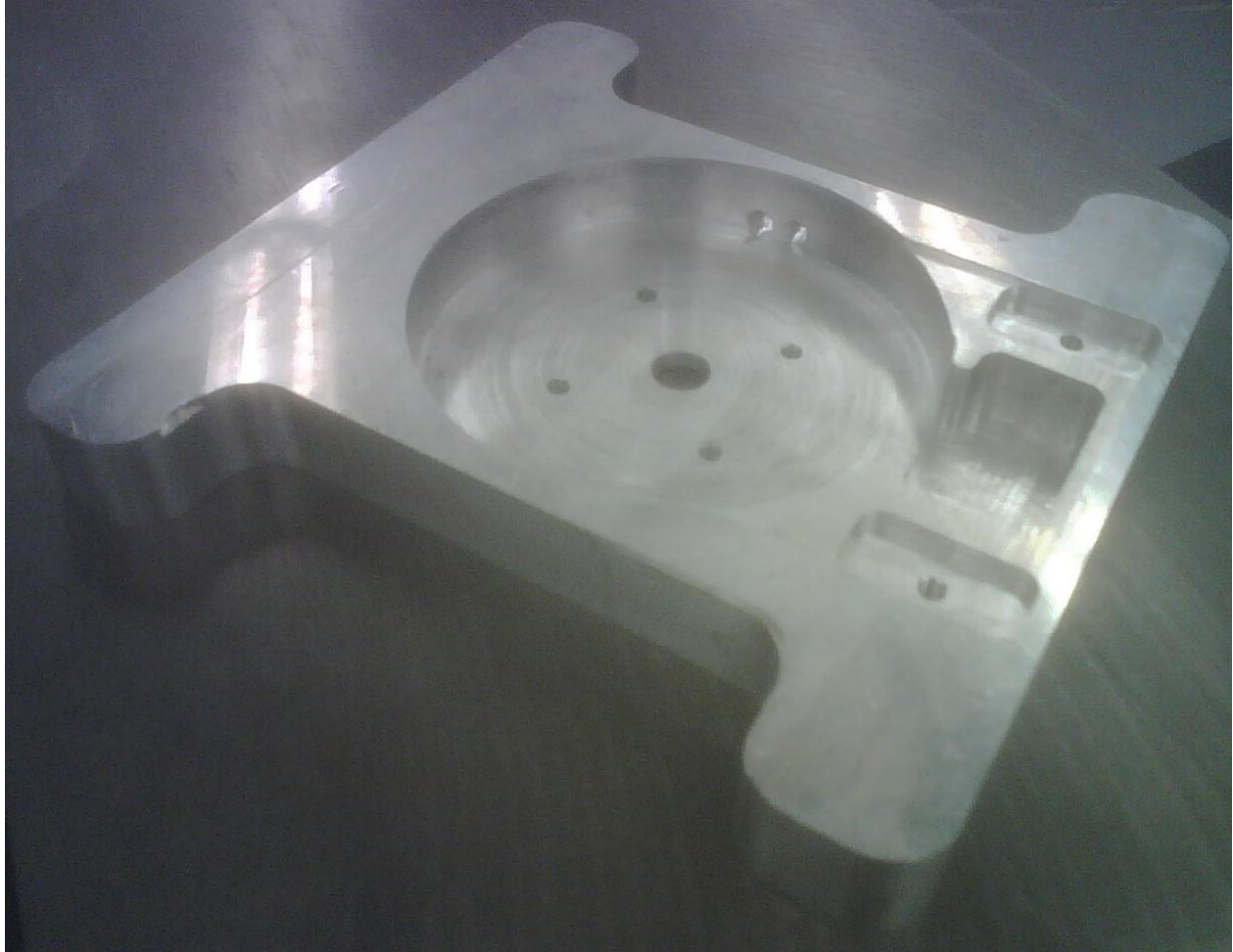


Figure 43 - First Bottom Plate

All the other following parts were created in a similar fashion. Either they were created with solely the use of a vice and/or they were created with the use of glue and fixture plate combination. The order of the all the parts produced for our first prototype were as follows: Follower without slots, Bottom Plate, Cam, Bottom Tabbed Piece, and Very Top Plate. After this a discovery was made which led to alterations of the design in regards to the type of fit that was to be used for our cam and bottom interface. After researching the different types of fits that could be used it was decided to change the cam size to allow for a “Close Running Fit” to get less binding when sliding along each other.

With these changes made the machining of the second iteration of the prototype cad assembly began. First part produced was the follower, then the bottom plate, and cam. The bottom tabbed piece and very top plate was reused due to no changes made to its final design. Afterwards a problem was noticed in regards to the dual spring follower system. It was discovered that the follower was rotating instead of compressing due to changes done to the type of fit in the system. Therefore slots were added to the dual spring follower system with the use of the cover plate.

After the changes were made the final versions of all of the parts were ready to be produced. Slots were added to our existing follower and preloader. Guides were added on the cover plate to constrain the motion of the follower to only one degree of motion. The cover plate was machine out and tested with success. Next duplicate parts were produced of all the parts which were already machined out. Those would be the bottom plate, cam, bottom tabbed piece, follower, cover plate, and very top plate. The only final piece required to be machined was the preloader which was to be made of brass. This was produced in a pair since it was the last part required for the two assemblies. After these two preloaders were completed the parts were assembled and tested. The following pictures are of the final prototypes attached to the snowboard.



Figure 44 - Final Assembly

4.2 General Assembly

The assembly of the snowboard binding was completed in two iterations; one was used on each binding. In the first iteration the parts were machined with no clearance, similar to a press fit. This proved difficult to assemble because several of the parts needed to be sanded down to fit together. This was remedied in the second iteration by researching ASME standards for part clearances. The team decided to remedy the tight tolerances in the first iteration by machining the second binding using ASME standards for a close running fit. The second iteration worked as planned and another round of machining was not necessary.

The first part of the binding that needs to be assembled is the dual spring cam follower system. The two springs should be inserted into the follower and then into the spring preloader. Next, the preloader system needs to be manually compressed and inserted into the designated recess in the bottom plate. After inserting the preloader the cover plate will be attached and screwed down with two M6x10 screws.

To attach the binding assembly to the snowboard the first step is to attach the bottom plate and inner piece to the board using four M6x14 screws. These screws are threaded through the inner piece and the bottom plate and tightened into the existing binding holes found on all snowboards. The next step is to attach the circular cam to the top plate. This is done by arranging the cam so that the notches are correctly aligned in a clockwise fashion. The three countersunk holes on the top plate are then used to attach the circular cam and top plate, using M6x25 screws. The remaining four holes are used to attach the binding strap to the top plate. Four M6x14 screws are inserted through the typical binding holes and then screwed into the top plate, securing the binding strap at the desired angle.

Once these steps are completed the last thing to do is insert the top plate and circular cam into the pocket on the bottom plate. After aligning the tabs on the inner piece with the spaces on the circular cam the top plate can be dropped into the bottom plate. At this point the user must simply turn his or her foot 45 degrees counter clockwise to be in the riding position.

5. Testing and Analysis

5.1 In-Lab Torque Testing

The first test that was done was torque testing to ensure that the design performed according to our design specifications. This was done with the use of a ski binding torque tester. The test was done at various angles along the whole range of motion. The torque test was also done using both the 38lb/in compression springs and the 45lb/in compression springs. For the 38lb/in compression spring a maximum torque of 21Nm was achieved without lubrication or preload. For the 45lb/in compression springs a maximum torque of 27Nm was achieved without lubrication or preload. To test preload the first step that was performed was to increase the compression of the dual spring system. With the system compressed the preload resulted in a maximum torque of 35Nm which is about 10Nm more than the non preloaded system. Then the preloader screw was turned back 1.5 turns and tested again. This

resulted in a 5Nm drop in torque with a maximum torque of 30Nm. After these tests were done lubricant was added to the system to test differences in torque. The lubricant yielded little effects in ideal situation but as explained later is a major factor in repeatability when used on the mountains.

The next step was to determine the torques at different angle ranges in order to create a torque versus angle plot to have a better understanding as to what torques the leg will undergo as it rotates about our cam-follower system. The following charts shows the results gathered from our tests with the two different compression springs.

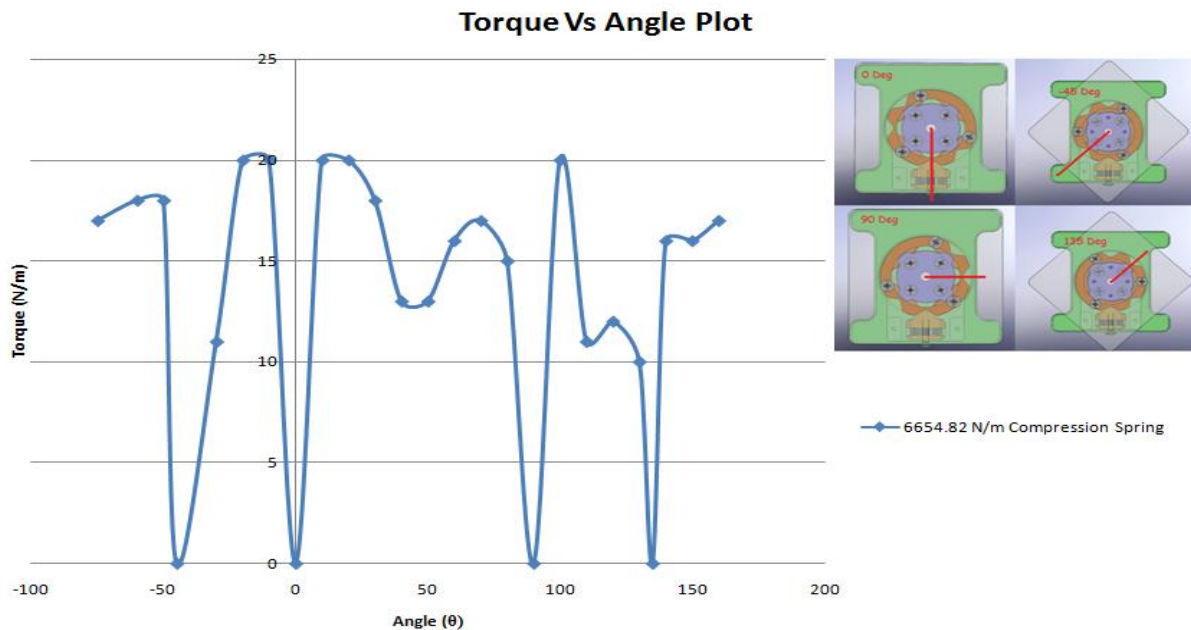


Figure 45 - Torque Vs Angle Plot with 6654.82N/m Compression Spring

The chart above clearly shows that to overcome the locked positions a torque of 20Nm is required to continue rotation. This is higher than the expected 15Nm but this could be as a result of excess friction between brass and aluminum components. As seen in the chart below the higher force compression springs yielded a larger torque requiring about 27Nm of torque when rotating from the normal riding position.

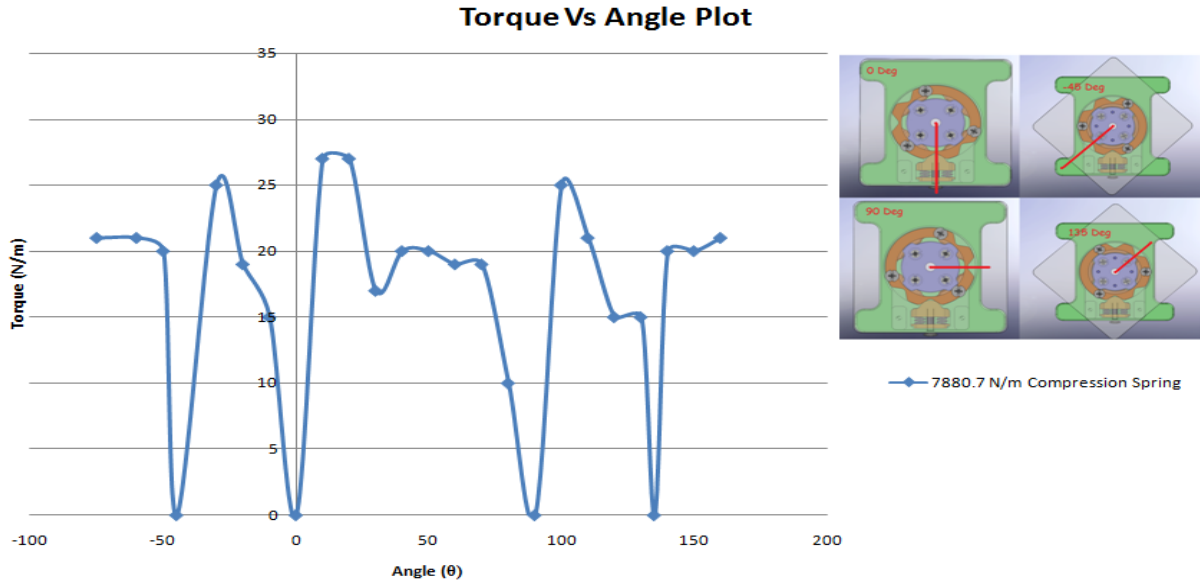


Figure 46 - Torque Vs Angle Plot for 7880.7N/m Compression Spring

Seen below is the chart with both graphs superimposed on each other. It seems in general there is about a 20% increase when using the higher compression springs. This data is particularly valuable as it illustrates adjustability for different riders.

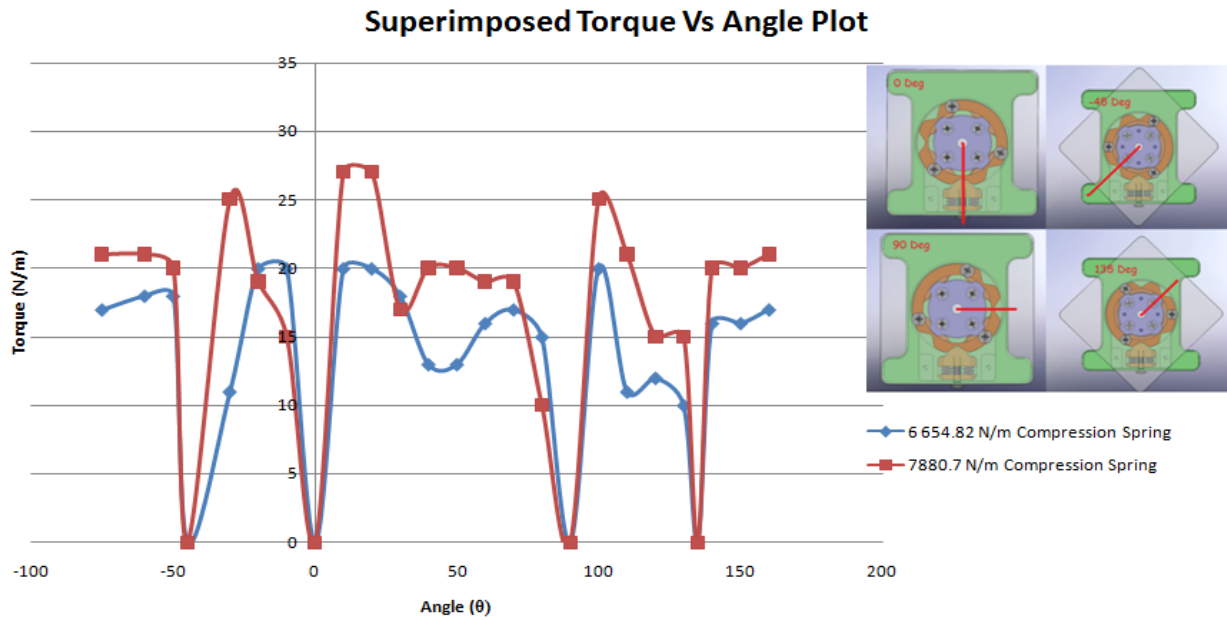


Figure 47 - Super Imposed Torque Vs Angle Plot

5.2 On Slope Testing

On March 12, 2009, the team tested the design at Wachusett Mountain in Princeton, MA.

Several runs were made on a moderate trail with two different riders and different configurations. The design was first tested on flat ground at the base of the mountain to ensure proper function. Riders noted ease of rotation and were able to readily practice releasing and reengaging the binding. Once the basic rotational and releasable functions were established, the snowboard was used to traverse on flat ground. Ease of travel was greatly increased over the current method in which the lead foot is perpendicular to the direction of motion. Stress in the lead leg felt greatly reduced as the rider could travel with comfort and ease. After experimentation on flat ground, the design was tested on a 2,400ft trail. The results of the on slope testing were as follows:

Test 1:

Patrick Hill did his initial run down the easy slopes. He reported that initially felt awkward because he knew the bindings could rotate. After about a minute of using them and not putting mind to the rotation he was able to ride down the slopes slowly with no problems.

Test 2:

Prof. Christopher A. Brown did his initial run down the easy slopes. He reported to have fallen twice while attempting to go down the slopes. Upon descending from the ski lift, Professor Brown fell while only having one foot secured to the board. As designed, the binding rotated and, upon impact, released to free the knee from any twist injury that may have occurred. He reported no problems with inadvertent release while riding down the slopes. Professor Brown reported some snow build up in binding.

Test 3:

Patrick Hill did his second run down the easy slopes. This time he was trying to snowboard more aggressive to test for any kind of inadvertent release. He reported that there were no problems or rotation occurring while riding. He also reported snow build up in binding.

Test 4:

Prof. Christopher A. Brown did his second run down the easy slopes. He reported again that no noticeable rotation could be felt while riding down the mountain.

Test 5:

Patrick Hill did his third run down the easy slopes. For third run the higher force springs were used to allow for increase in aggressive maneuvers and to reduce the little amount of noticeable free play while in the locked position. He was successfully able to ride down aggressively.

Test 6:

Patrick Hill's did his final run down the easy slopes. For the last run even more aggressive maneuvers were attempted such as jumping. Patrick Hill reported that his front leg was able to rotate out of locked position when he landed awkwardly but was able to recover while riding. Besides this incident there were no reports of inadvertent rotation or release.

On-slope testing was performed to verify that all snowboarding maneuvers could occur without inadvertent rotation or release. Both riders noted that the snowboard was able to edge effectively

without inadvertent rotation when both feet are properly secured to the board. Typical snowboard edging felt comfortable and stable. The image below illustrates performed snowboard maneuvers.



Figure 48 - Snowboard Testing (Photo take by Christopher A. Brown)

During the course of the day there were problems with torque for rotation becoming very high. A couple of ideas that are believed to cause this is snow build up in the binding or debris getting in the binding, such as dirt or metal filings. Torque testing was performed on site to compare the torque of the binding while in its dirty state versus its clean and lubricated state. The images below shows one on-site torque test being performed as well as the contamination of snow and debris within the pockets of the adapter.



Figure 49 - Torque Testing (Photo taken by Anthony Nunez)



Figure 50 - Binding Debris Contamination

The bindings were tested immediately following the third run down the trail. Four tests were performed prior to disassembly. The results of tests one through four can be seen in the table below.

Test	Measured Torque (Nm)	Result
1	66Nm	Movement clockwise
2	79Nm	Movement Clockwise
3	90Nm	Minor Movement Clockwise
4	118Nm	No movement

Table 5 – Contaminated Torque Testing

Following the first four torque tests, the bindings were completely disassembled and cleaned. They were washed and dried with water only. The bindings were then lubricated with Fabulous B'laster™ Silicone Aerosol Lubricant. A liberal coat was applied to all surfaces of the bindings and the testing continued with a total of 6 more tests. Tests five and six were using 45lb/in springs and a system that was cleaned with water only. Tests seven through ten were using 45lb/in springs and a cleaned and lubricated system.

Test	Measured Torque (Nm)	Result
5	24Nm	Movement Clockwise
6	22Nm	Movement Counterclockwise
7	30Nm	Movement Clockwise
8	22Nm	Movement Clockwise
9	25Nm	Movement Counterclockwise
10	22Nm	Movement Clockwise

Table 6 – Clean Binding Torque Testing

As it can be seen there is a great reduction in torque when the system is cleaned, dry and lubricated. It was also noted that snow build up was greatly reduced after the lubrication was applied to the binding. Testing results suggest that lubrication is a necessity in a product like this to reduce the amount of snow buildup in binding while moving along flat grounds.

When riding a chair lift to the top of the trail, skiers now have the ability to sit normally, facing the direction of motion comfortably. Currently, snowboarders have to position the lead leg in an awkward manner to allow for their lead foot to rest on the chairlift’s rail. This often forces the rider to keep one leg positioned uncomfortably or position one’s entire body away from the direction of travel. The use of the designed binding allows the rider to rotate the lead foot to the parallel position, thus able to utilize the rail as a skier would. This creates a ride that is remarkably comfortable. At the top of the lift, the rider must simply stand up; rotate the front foot to the riding position, and coast down the small incline. The rear foot can then be quickly snapped into place, eliminating the need for the rider to come to a stop, sit down, strap the rear foot into the binding, and attempt to stand when both feet are in a fixed position. The use of the binding reduces the time a snowboarder needs to spend at the top of the mountain prior to starting the descent.

Over several tests, riders were able to increase the level of riding from gradual edging and coasting, to aggressive turning, jumping and stopping. The binding maintained edging function while providing the rider with increased convenience. The day ended with success as the design team was satisfied with the overall performance of the rotational releasable binding.

6. Iterations

The initial mountain test on March 12 brought about several design changes that future iterations of this prototype should include. While the prototype test was a success, several improvements could still be made. Future iterations of the design could fine tune certain aspects that were overlooked during preliminary testing. Such iterations include the need to reduce mass, improve snow removal and reduce overall height.

The most apparent change that a future iteration should include was the alteration of material selection. Aluminum and brass were chosen for an initial prototype for their ease of machining, relatively low cost, and ease of obtaining. This caused a single binding to weigh 4.75lbs. While this sufficed for initial testing and design concept, the snowboard was significantly heavier to carry. Should an additional iteration be made, a lightweight polymer is suggested. The use of such a polymer could reduce the overall weight to approximately 1lb. It should be noted, however, that spring constants were chosen based off the frictional force and normal force between aluminum and brass. The alteration of material will change such a value and could result in the need for different springs to be used. Nonetheless, a lightweight alternative should be sought after to improve mass characteristics.

Throughout the day of testing another design consideration became apparent, the need to prevent snow from sticking to the device. This could be achieved in several ways. The design could be reworked such that it contains no internal pockets for snow to build. This route may be the most difficult option as it calls for a redesign of the current prototype. The design could provide a means to remove snow. This could be accomplished through forcing the snow from interior pockets to the exterior. A design could incorporate a pad with which the rider could step on to remove snow from the top components of the design. Finally, the design could be coated in such a manner that the likelihood of snow build-up is decreased. Different coatings can be used to reduce friction, however, the

interaction with water, snow and ice needs to be tested. Iterations could use one or several of these techniques to ensure that snow does not contaminate the operation of the prototype.

Snowboarding is as much about style as it is about function. This can be seen in board, binding and boot designs and artwork as well as snowboarding apparel. In order to appeal to the estimated five million snowboarders in the United States, designs must be slim, sleek and fashionable. Future iterations of the prototype should reflect this need. Currently the prototype sits at an overall height of 1.25in. While this does not hinder performance, a risen height does not aesthetically appeal to consumers. A future iteration could attempt at reducing the overall height of the prototype. Currently, the height of the prototype is driven primarily by the diameter of the springs required for sufficient preloading and compression. In order to achieve the required spring constants, while minimizing size, two springs of 0.60in diameter were used. This dimension drove the remainder of the design ultimately leading to the overall height. A future iteration could provide a different method for preloading and compression or simply use more springs in series, thus reducing the overall height of the prototype.

7. Discussion

The design completed by an MQP team at WPI during the spring of 2007 has the ability to rotate a full 360° on demand. A cam and follower system is used with two sets of compression spring driven followers. As torque is applied to the system the springs compress, allowing the system to rotate about the cam profile. In order to provide the rider with comfort and convenience, the cam profile has four semicircular portions spaced 90° apart. Such a design allows for a noticeable riding position when the rider is positioning his foot to travel downhill. An additional stable position is located 90° away from the first, and rotation to this position provides the rider with the option of adjusting his foot to the direction of travel. By allowing the foot to face the direction of travel less stress is placed on the rider when maneuvering to and from chair lifts. This rotation of the foot not only provides the rider with comfort and ease in movement on flat terrain but could also reduce injuries.

While the MQP team provided an excellent proof of concept, the design leaves much to be desired. The riding positions are designated by semicircular profiles on the cam of the device. This allows for recognizable location, however, does not provide a stable feel in the designated positions. When the rider's foot is placed in one of the semicircular positions there is noticeable wobble allowing the foot to move a few degrees in each direction. This is far from ideal for downhill edging situations. In another MQP of 2007, it was stated through their literature research that although the majority of the forces applied to the board are in the form of edging moments there are still low torques applied about the bindings (Rohit, et al., 2007). These small torques can cause the rider's foot to rotate perceptually in each direction on the rotatable binding, which could create an unstable feel while edging. While the MQP team's design provides an excellent concept and base for a rotational binding, it lacks the ability to release on demand. In order to remove one's foot from the system, the conventional binding straps must be disengaged. The ability to quickly remove the rider's rear foot would provide significant convenience for all riders.

With the objective of creating a rotatable and releasable binding, axiomatic design was used. Through the use of axiomatic design a final design for a rotatable and releasable binding was quickly reached. Originally a cam and cantilever beam system was considered for a final design. Flaws were noted in our design and with the help of the axiomatic design process these flaws were eliminated. This final revision resulted in the cam and spring loaded follower system, which has proven to be successful based on the team's testing.

When tested in the laboratory the binding torque measurements were within 10% of the objective of 15Nm, when lubricated. Without lubrication, torques were larger due to increased friction but were within reason for the objective. When tested on the slopes it was evident that the binding was an overall success. The bindings resisted the low torques that occur when carving in turns yet were rotatable on demand. Although we noted a slight wobble when using the weaker springs, a change to the stronger springs reduced this wobble.

A problem noted in the design was snow and debris build up in the bindings. When this buildup occurred it became difficult to rotate the bindings. The bindings were tested to find that torques increased by up to 500%, but simply cleaning and re-lubricating of the bindings the torques were back within intended range. Towards the end of testing, aggressive maneuvers were done successfully proving the stability of the binding.

With the realization of overlooked objectives, several recommendations could be made in regards to weight reduction, snow removal, and height reduction. Weight was a major concern once assembled and could be reduced with the use of lighter materials. For snow and debris prevention, the change in the pocketed cam could prevent snow buildup, as could water repelling lubricant, or a stomp

pad. To help reduce height, smaller diameter springs could be used or another form of spring such as a leaf spring could be used.

Overall, the designed binding performed as intended. Rotation and release actions were performed with ease. Riders noted an increase in comfort, especially when riding on a chair lift. Rotation of the front foot resulted in a natural travelling motion and a reduction in stress on the front knee. The ability to effectively release one's foot allowed for a reduction in the time a snowboarder spends strapping in and out of his bindings. Addressing the issues of snow buildup, weight, and height, would improve an already successful design. Such improvements would allow for increased marketability to the approximately five million snowboarders in the United States (Voje Julian, 2008).

Appendix

A Brief History of Snowboarding:

The first snowboard appeared in 1965 and was designed by Sherman Poppen. The design was basically a skateboard with the wheels removed, utilizing a rope attached to the front to steer. It was called a Snurf Board and was marketed mainly to children. It was very different from the designs of snowboards seen today. Over the following decades snowboarding became more popular and more advanced models were created. In 1979 Jake Burton Carpenter entered a Snurfing competition with a board design of his own. The revolutionary part of his board was that it contained bindings for the rider's feet. The bindings made it much easier to control the board and gave the rider an advantage over the models that used a rope steering system. The binding design caught on, and now all snowboards incorporate some kind of binding system. In 2008 it was estimated that there were 5.1 million snowboarders in the United States. To meet the demand of the growing sport a multitude of companies have arisen, marketing snowboards and snowboard gear. (Voje Julian, 2008)

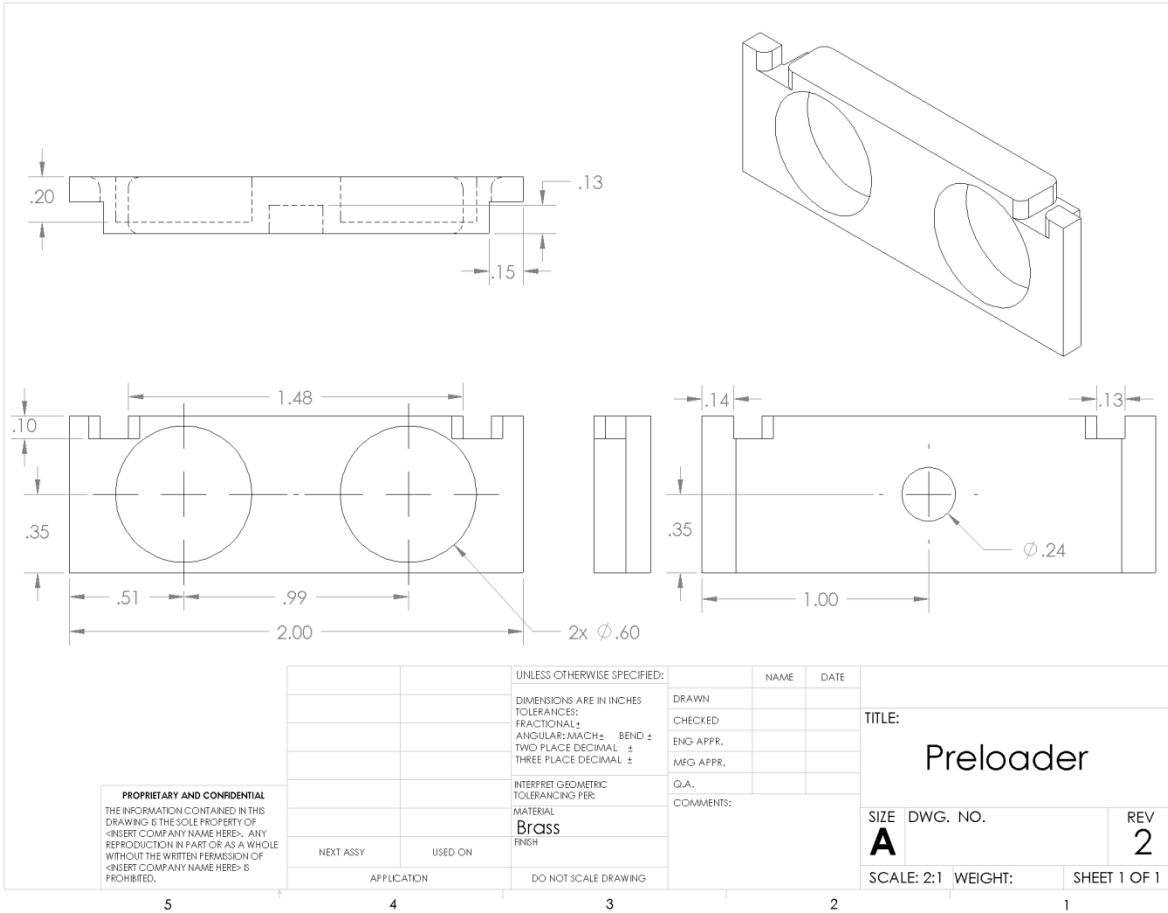
Hardware

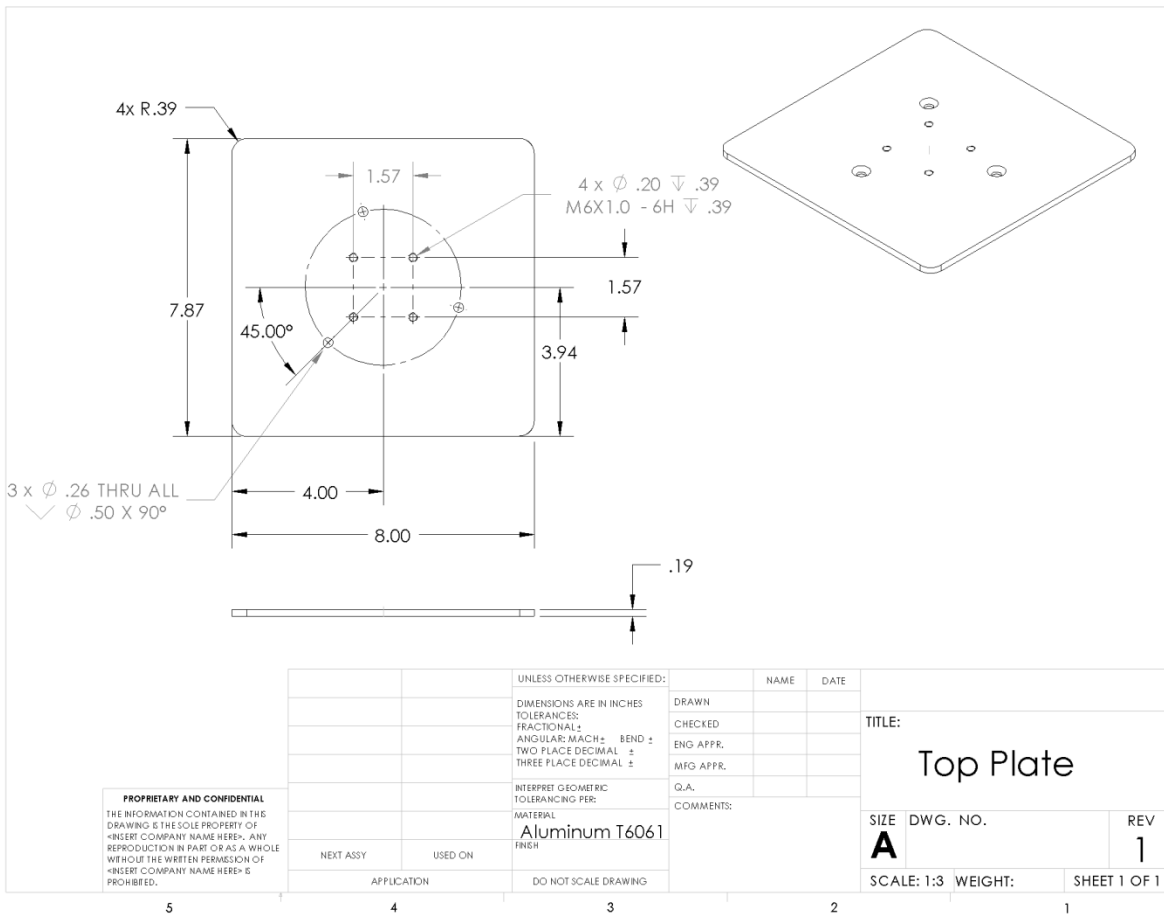
A single rotational releasable binding adapter requires a total of fourteen screws. Four screws mount the center piece and bottom plate to the snowboard. Four screws mount the top plate to the commercial binding. Three screws mount the top plate to the cam. Two screws mount the cover plate to the bottom plate, and finally, one screw is used for the preloading of the compression springs. Each of the five uses for machine screws has a required length. While each of the mounting requirements can call for its own thread and length choices, the decision was made to use a single thread type. This decision was made for two distinct reasons. Using a single thread type with only varying lengths allows for ease of machining, requiring less time and tools. Second, for the consumer, using the same thread type prevents the possibility of using the wrong screw in the wrong location. Should the consumer have

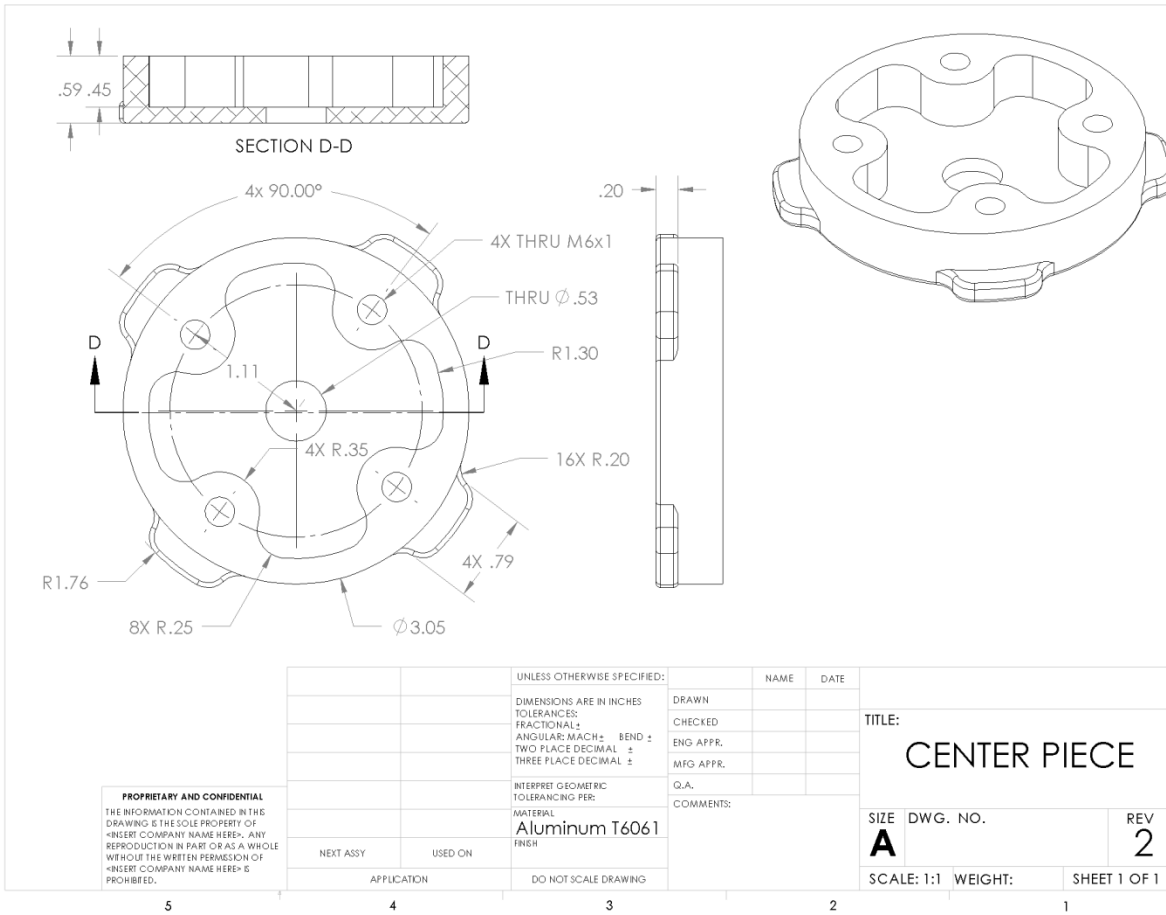
to take the device apart for installation or removal, using the same thread type provides easier assembly.

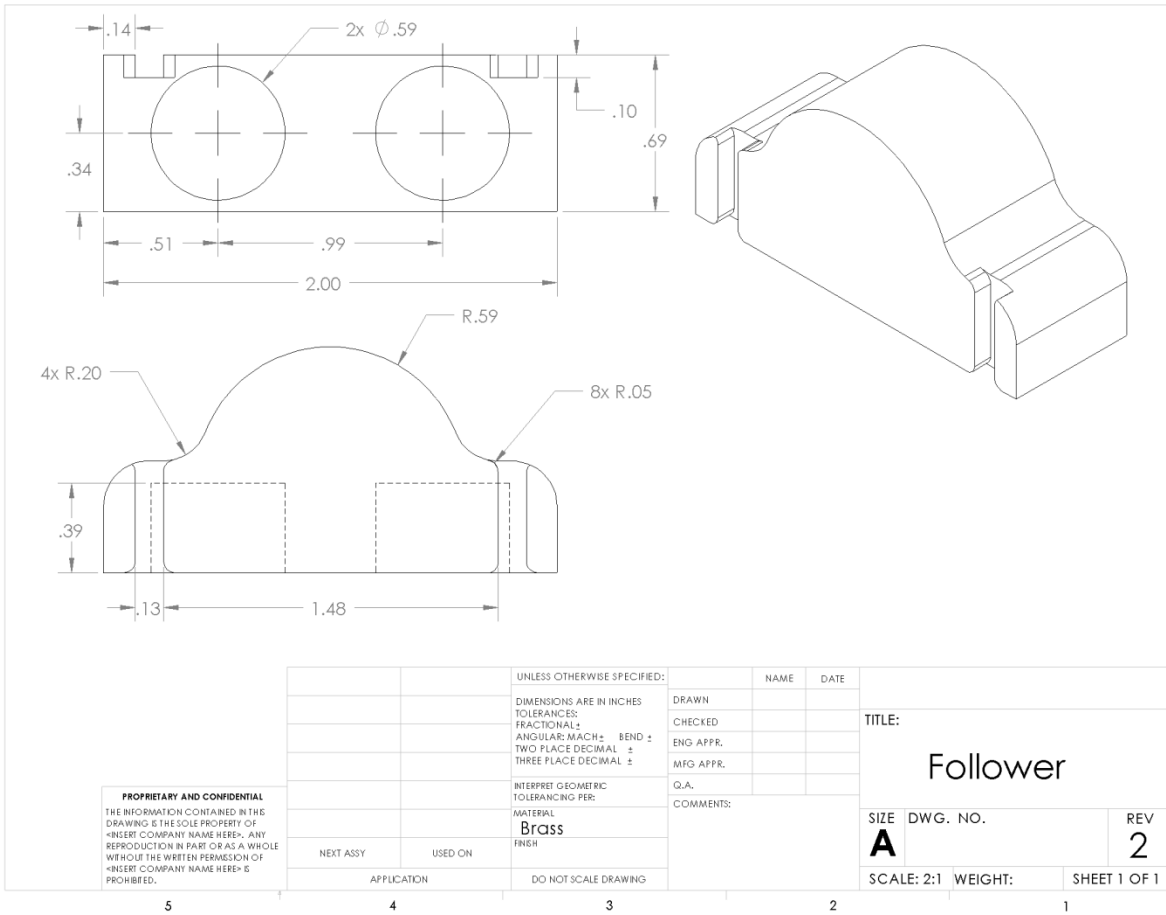
Once the decision was made to use a single thread type, the specific thread must be chosen. Again, with convenience in mind, an M6 x 1.0 specification was selected. Currently manufactured snowboards and bindings use such a thread. All of the mounting requirements call for a countersunk screw as the interaction between rotating surfaces is crucial. A table of the required machine screws can be seen below.

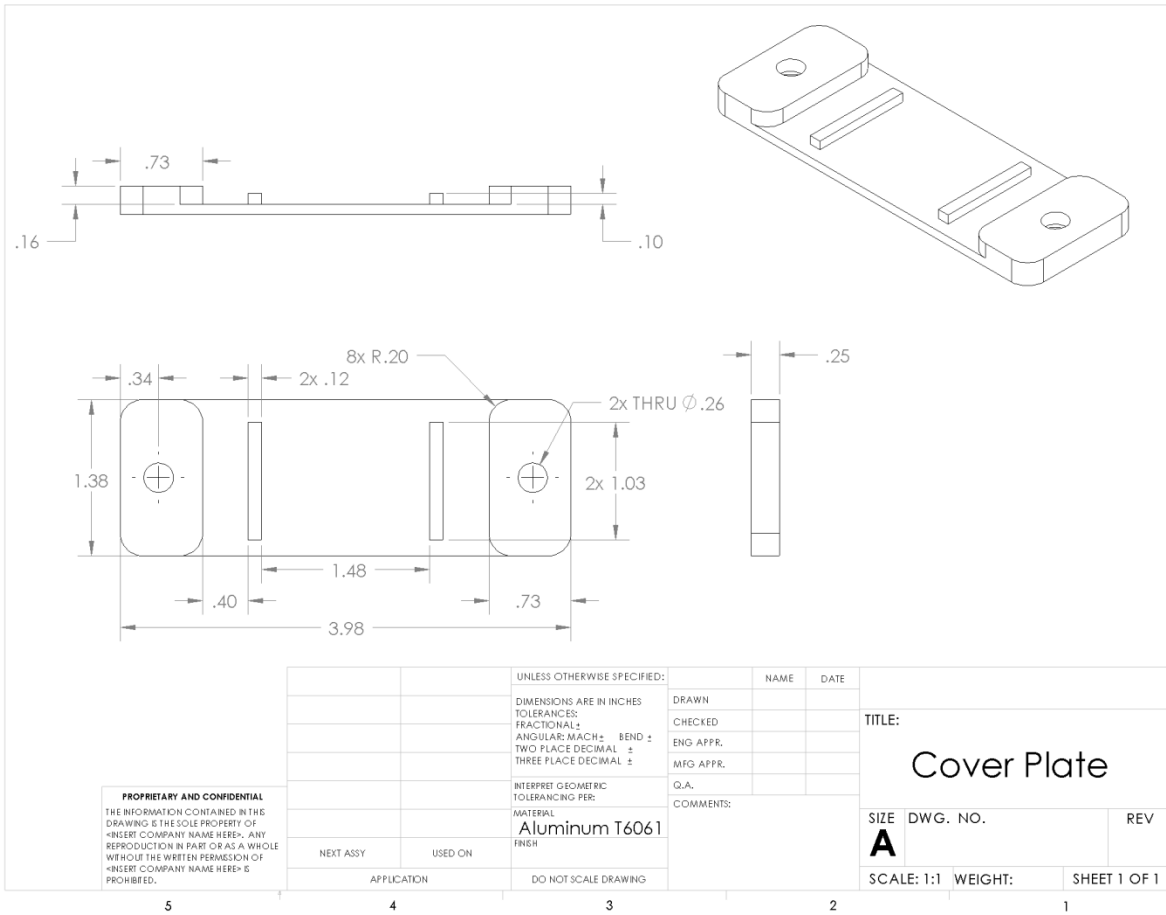
Machine Screw Thread (Metric)	Machine Screw Length (mm)
M6 x 1.0	10mm
M6 x 1.0	16mm
M6 x 1.0	25mm

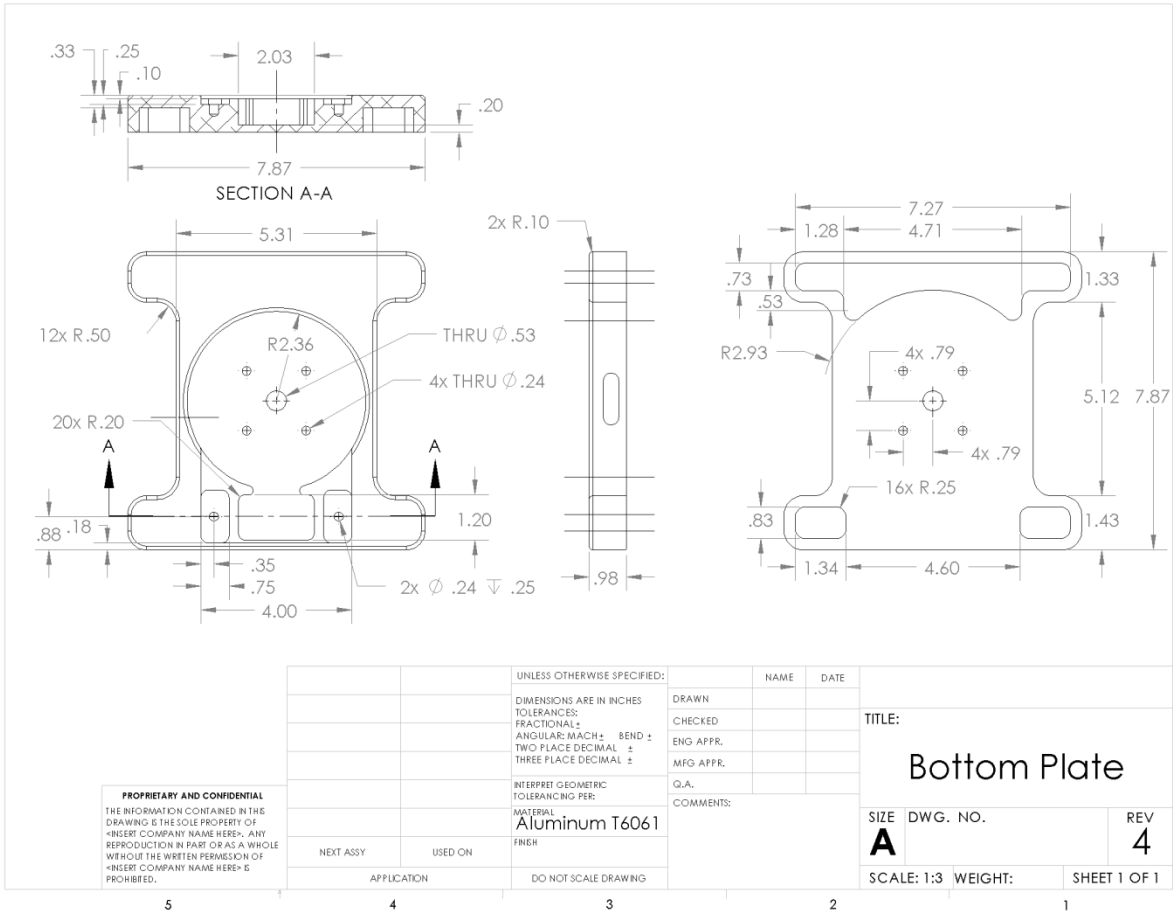












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Bryne, Richard M. "Clipless Bicycle Pedal." US Patent 5606894.

4 Mar. 1997.

Abstract

The improved clipless pedal comprises an assembly of a generally rounded body having a top surface, a bottom surface, and circumferential edge with a metal insert. A recessed area is formed extending diametrically across each of the top and bottom surfaces. The metal insert fits within the recessed area with its top surface generally flush with the surface in which it is placed. An inset is cut into the circumferential edge to form a chord across each end of the recessed areas. The diametric distance between the insets corresponds to the spacing between the spring-biased tongues of the locking mechanism of the cleat in their relaxed condition. The pedal body is formed from a lightweight plastic or polymer. In an alternate embodiment, means are provided for varying float range of the pedal with respect to the cleat by narrowing the angle within the recessed area.

Drako, Dean M. "Snowboard Binding Rotational Mechanism." US Patent 6923454.

2 Aug. 2005.

Abstract

A mounting assembly in accordance with the invention provides rotational adjustment of a board binding, such as a binding of a snowboard, wakeboard, or the like, without the use of external tools. A spacer plate which enables the mounting of the binding in a position above the board is combined with a mechanism which can change its thickness on demand, thereby locking or unlocking the binding from a freely rotatable position.

Druss, Barry L. " Boot Sole Structures." US Patent 4026045.

31 May 1977.

Abstract

Boot or footwear sole structures and assemblies adaptable to various conditions where components are fixed to the sole between the heel and the toe portions of the boot by the forced interaction of opposed bearing surfaces on the components, with supporting areas or bearing profiles formed in the sole on respective sides of an opening that is provided between the heel and toe portions. The components stiffen the sole when assembled, and in addition portions thereof can be specially adapted for particular uses, such as climbing spikes, ice crampons, skates or ski bindings, thereby giving the boot sole structures varied adaptability and interchangeability to various modes of activities.

Hull, Maury L.. "Ski Binding with Universal Release." US Patent 4361344.

30 Nov. 1982.

Abstract

A ski binding assembly includes a releasable binding for rigidly securing a ski boot to the ski with a release actuating element for releasing the ski boot from the binding upon occurrence of a release condition determined by a preprogrammed control. The releasable binding includes circular elements, nested one within the other, and a detent for selectively locking the elements together while being capable of unlatching the elements upon operation of the release actuating element.