

Design of a Hands-Free Rotational Snowboard Binding

A Major Qualifying Project Report

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Abstract

Moving around while in non-riding situations while on a snowboard is both uncomfortable and potentially dangerous. The possibility of designing a rotational snowboard binding is a relatively new however promising idea. This binding would allow for parallel positioning of the binding, which would allow the rider to move along in a manner similar to a skateboard. This would allow for better mobility on flat ground as well as getting on and off the lift. The following paper describes the process of attempting to design a durable, safe, and efficient rotational snowboard binding. Research on existing bindings on both snowboards and skis was conducted. Information was also used from previous attempts at designing this mechanism. A cam and follower rotational mechanism was, with help from past years' designs, designed, iterated, and manufactured in order to achieve this goal. The design was tested to ensure its safety, and we believe we met our goal of creating a mechanism that would allow for rotation of bindings on any snowboard.

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1. Introduction

1.1 Objective

The objective of this project is to design a rotational interface between a traditional snowboard binding and the snowboard. This mechanism allows for rotation of the front foot from a normal riding position to a position parallel to the length of the board. This allows for easier mobility when in non-riding situations, such as getting on and off a lift, as well as movement on flat ground. Many lower leg injuries can be avoided due to this increased mobility.

1.2 Rationale

One reason behind the creation of a rotational binding system is to prevent injuries. Injuries happen all the time on the mountain for many reasons. Within the 16th edition of Skiing Trauma and Safety a study was done by Arne Ekeland and Andreas Rodven on injuries in the Norwegian Ski Resorts. These studies were done over the years of 2002 to 2004. The injury totals found were 7252 injuries per 4.884 million boarder days. This can be simplified down to 1.5 injuries per 1000 days. Of course this is all participants on the slopes, not just snowboarders. This is broken down more into type of injury and site of injury and can be seen below in Figures 1 and 2.

Type of Injury	Alpine Skiers	Telemarkers	snowboarders
Fracture	22	24	35
Dislocation	4	6	4
Sprain	29	22	20
Contusion	36	33	36
Cut	9	14	5

Figure 1 : Type of Injury Table (Skiing Trauma and Safety: Sixteenth Volume, ASTM STP 1474, ed. R.J. Johnson, J.E. Shealy, T. Yamagishi. American Society for Testing and Materials, Philadelphia, 2006.)

Site of Injury	Alpine Skiers	Telemarkers	Snowboarders
Head	17	20	15
Neck	3	4	3
Shoulder	10	17	12
Arm	4	4	9
Wrist	5	5	28
Hand	7	8	4
Thorax/Abdomen	3	4	4
Back	7	11	10
Thigh	4	2	1
Knee	25	12	7
Lower Leg	11	5	2
Ankle	5	9	5

Figure 2: Site of Injury Table (Skiing Trauma and Safety: Sixteenth Volume, ASTM STP 1474, ed. R.J. Johnson, J.E. Shealy, T. Yamagishi. American Society for Testing and Materials, Philadelphia, 2006.)

The injuries that are most important for the rationale behind the rotational binding system are the injuries of the knee, lower leg and ankle. These injuries account for 14 percent of the snowboarder injuries within Figure 2. Many of these injuries are twist related and usually result in injuries of ligaments which are usually serious. This can be seen in the Colorado Snowboarding Injury Study done by Peter C. Janes and Paul Abbott Jr. within the twelfth edition of Skiing Trauma and Safety “Knee injuries numbered 644 (15 %; 11 % ligament, 4% non-ligament). Of the 11 % knee ligament injuries 275(6.4%) were to the MCL and 144(3.4%) to the ACL (N=4266)”. These injuries can occur on the slopes but also upon entering

and exiting the lift areas. The breakdown of accident sites was also done by the study of Injuries in Norwegian Ski Resorts 2002-2004. This can be seen below in Figure 3.

Accident Points	Alpine Skiers	Telemarkers	Snowboarders
Groomed Slope	75	59	58
Off pist	10	20	7
Snowboard Park	9	19	32
Lift	5	2	3

Figure 3: Accident Site Table (Skiing Trauma and Safety: Twelfth Volume, ASTM STP 1345, ed. R.J. Johnson. American Society for Testing and Materials, Philadelphia, 1999.)

Lift injuries only account for 3 percent of injuries within this study. However, in The American Journal of Sports Medicine a study was done by Jan R. Idzikowski, PA-C which was the Ten-Year Results from the Colorado Snowboard Injury Study in which “Eighty-one percent of all snowboarding injuries (N=6018) were the result of a fall, with about 9 % from a collision with a tree or skier and the remainder from a twist or lift mishap”. This shows that 10 percent of injuries with in this study were due to a twist of lift mishap.

With out a rotational binding the snowboarder is forced to push off his back foot while his front foot is stuck perpendicular to the board. This creates an awkward position for the rider which can end up in an injury. If the rider falls getting on or off the lift it could cause his leg to twist while his foot is stuck in the binding. This can lead to serious injuries of the knee and lower leg which is seen in the previous data. This same kind of twist injuries also occur on

the slopes. The rotational binding system will give some protection to these injuries as well because the binding will not be completely stiff. It will give in both directions that might disperse the force just enough to protect against injury.

The rationale for this project can also be seen in the comfort the rider will have with a rotational snowboard binding. When moving from the bottom of the slopes to the lift as well as on the lift and off the lift there can be extreme discomfort for the snowboarder. The rider will come to the bottom of the hill and un-strap the back foot. With the front binding locked in at a position which is perpendicular to the board it is difficult to push yourself forward. This can be seen below:



Figure 4: Snowboarder riding on flats ("How to Get on a Ski Lift with a Snowboard."

Ehow.Com. 21 Apr. 2008 <http://www.ehow.com/how_6937_ski-lift-with.html>.)

This is because the rider will be pushing in a direction that is perpendicular to the direction of his front foot. This causes difficulty, especially when moving up or down small hills. With a rotational binding the rider will be able to move much easier. This is because the front foot will have the ability to rotate parallel to the snowboard. This will result in the snowboarder being able to push in the same direction that his front foot is facing. This leads to more comfort when moving from the bottom of the slope to the lift.

When the rider reaches the lift the comfort issue rises again. With a traditional snowboard binding the rider has to stand with his back perpendicular to where the ski lift will pick up. The rider has to rotate the torso while keeping the knee and lower leg in the same position. This can lead to difficulty getting on the lift and can be seen below:



**Figure 5: Snowboarder getting on lift. ("How to Get on a Ski Lift with a Snowboard."
Ehow.Com. 21 Apr. 2008 <http://www.ehow.com/how_6937_ski-lift-with.html>.)**

With a rotational snowboard binding the rider will be able to stand with the back to the ski lift. This will increase comfort when getting on the lift because the rider will simply have to sit down similar to a skier. The torso will not have to be rotated just prior to pick up.

When riding the ski lift there is still discomfort. This is because the snowboard hangs off the front foot pulling the knee sideways. This can lead to soreness in the knee because of the direction in which the knee is being pulled. This can be seen below:



Figure 6: Snowboarder riding lift (" Snowboarder Ridingn Lift." [Corbis](#). 21 Apr. 2008

<<http://pro.corbis.com/search/Enlargement.aspx?CID=isg&mediauid=1A489EED-D7DA-4006-956D-96CD3C425BF2>>.)

A rotational snowboard binding will reduce this soreness within the knee. Instead of pulling the knee sideways the snowboard will be pulling the knee down in a natural parallel position.

Finally, getting off the lift proves to be difficult when using a traditional snowboard binding. With the back foot unstrapped the rider has to put the back foot in the middle of the board and once again rotate his torso to now be perpendicular to the board in a traditional riding position. This can be seen below:



Figure 7: Snowboarder getting off lift ("Beddys Blog." 21 Apr. 2008

<<http://www.beddysblog.com/images/P2050681.JPG>>.)

A rotational binding will eliminate this problem because the rider will not have to rotate off but instead can ride off forward and push with his back foot if needed.

1.3 State-of-the-Art

The idea of this project is being continued from the MQP last year done by Patricia Adamson, Marina Gurbanov, and Whitney Rock. Their rotational binding set the ground work for a rotational binding to be created by allowing a binding to rotate hands free. Their design did have some issues of height and also they only allowed for rotation in ninety degree increments not to parallel to the board. The design used a cam and follower system shown below in Figure 8.

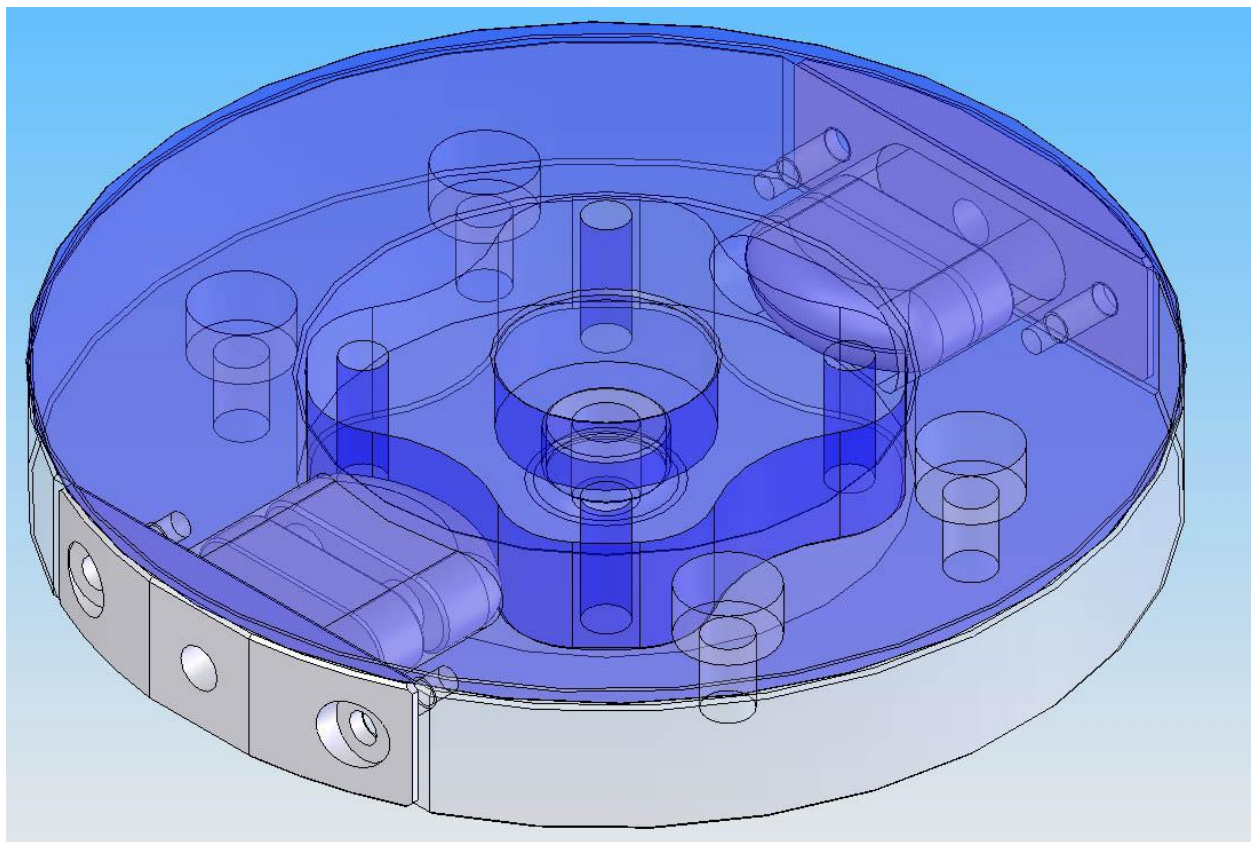


Figure 8: 2007 Rotational Binding.

There are numerous designs for bindings which use the idea of rotational bindings as well as designs with safety release mechanisms. Many patents have been issued for these two

concepts. U.S patent 6923454 is a snowboard binding rotational mechanism. “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.” (Drako 2002).

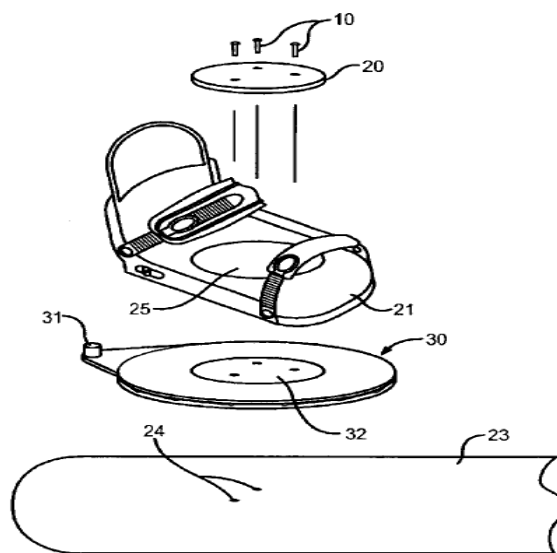


Figure 9: Snowboard Binding Assembly.(Darko, D. (2002). U.S. Patent No. 6,923,454.

Washington, DC: U.S. Patent and Trademark Office.)

US patent 6575489 is a snowboard rotatable binding conversion apparatus which provides the same basic idea as the previously stated patent. However the designs differ as stated in this designs description:

“A snowboard rotatable binding conversion apparatus that is inserted between and attaches to a snowboard and a boot binding to render the boot binding rotatable in relation to the snowboard. The snowboard rotatable binding conversion apparatus includes a base, an engaging plate which sandwiches the

base between the engaging plate and a snowboard, a top plate which sandwiches the engaging plate between the top plate and the base, an engaging element which engages an engaging slot in an engaging plate, an engaging bar which movably secures the engaging element to the base, a tension bar that provides tension to the engaging element, a tether attachable to the engaging element, and a plurality of screws and screw-receiving holes to attach the engaging bar to the base, the engaging plate to the snowboard, and the top plate to the base.” (US patent 6575489 abstract).

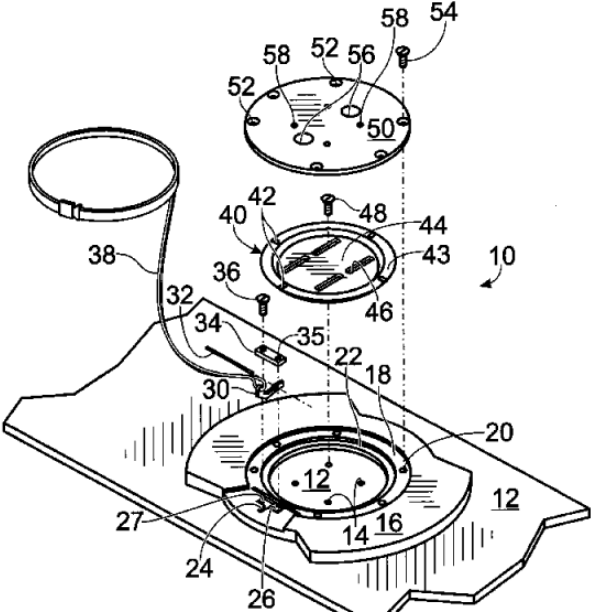


Figure 10: Detailed Snowboard Binding Design. (White, R. (2002). U.S. Patent No. 6,575,489.

Washington, DC: U.S. Patent and Trademark Office.)

1.4 Approach

The process of axiomatic design was used in the design process. The first part of axiomatic design is creating a list of customer needs. These customer needs can then be converted into functional requirements which fill those needs. Functional requirements are broken down until they are extremely specific and the solution is obvious. This also decouples each functional requirement from each other so that instead of solving a complicated design problem each simple function is designed for individually. Once all functional requirements are set those functional requirements can be turned into design parameters that will fulfill those needs. The next step in the process is to check to make sure that none of the functional requirements or design parameters do not interfere with each other. Once this is complete the design process should be extremely easy due to the simplification of the problem.

2. Method

2.1 Design Decomposition and Restraints

The axiomatic design process was done in the program Acclero. Seen below in Figure 7 is the design decomposition for the rotational binding.

#	[FR] Functional Requirements	[DP] Design Parameters
0	FR Provide rotational attachment between snowboard binding and board with snap in parallel and transverse positions	DP Rotating interface cam mechanism
1	FR Transmit control loads from foot to board	DP Load transmission elements
1.1	FR Transmit moments about the horizontal axes	DP Center screw--cam rim
1.2	FR Transmit shear perpendicular to board axis	DP Center post
1.3	FR Fasten the mechanism to the binding	DP Binding screws
1.4	FR Fasten the mechanism to the board	DP Board screws
2	FR Allow for adjustable snap-in rotation about Z axis	DP Rotatable adjustable spring loaded cam system
2.1	FR Provide rotational support on the board	DP Lower disk
2.2	FR Provide rotational support on the binding	DP Upper rotatable disk
2.3	FR Provide force for snap	DP Cantilever spring follower
2.3.1	FR Provide spring force	DP Cantilever geometry
2.3.2	FR Provide adjustment	DP Sliding cantilever adjustment
2.3.3	FR Provide for a snug fit	DP Cantilever support spring
2.4	FR Provide snap position at 90 degrees	DP 90 degree flat
2.5	FR Provide snap position at 17 degrees	DP 17 degree flat
3	FR Protect the mechanism from contamination	DP Oring--Overhang

Figure 11: Design Decomposition in Acclero.

This breakdown shows every function of the rotational binding and the part of the design that is accomplishing the task. All of these functional requirements are labeled below on the pictures of the parts.

2.1.1 FR 1 Transmit Control Loads from Boot to Board

The first functional requirement of the rotational binding is to transmit the control loads from the foot to the board. The first control load to be transmitted is the moments about the horizontal axis (FR1.1) created when the rider uses the edges of the board to turn. These moments are transmitted by the center screw and the rim of the cam that comes in contact with the base (DP1.1). These design parameters can be seen in Figure 12 and Figure 13.

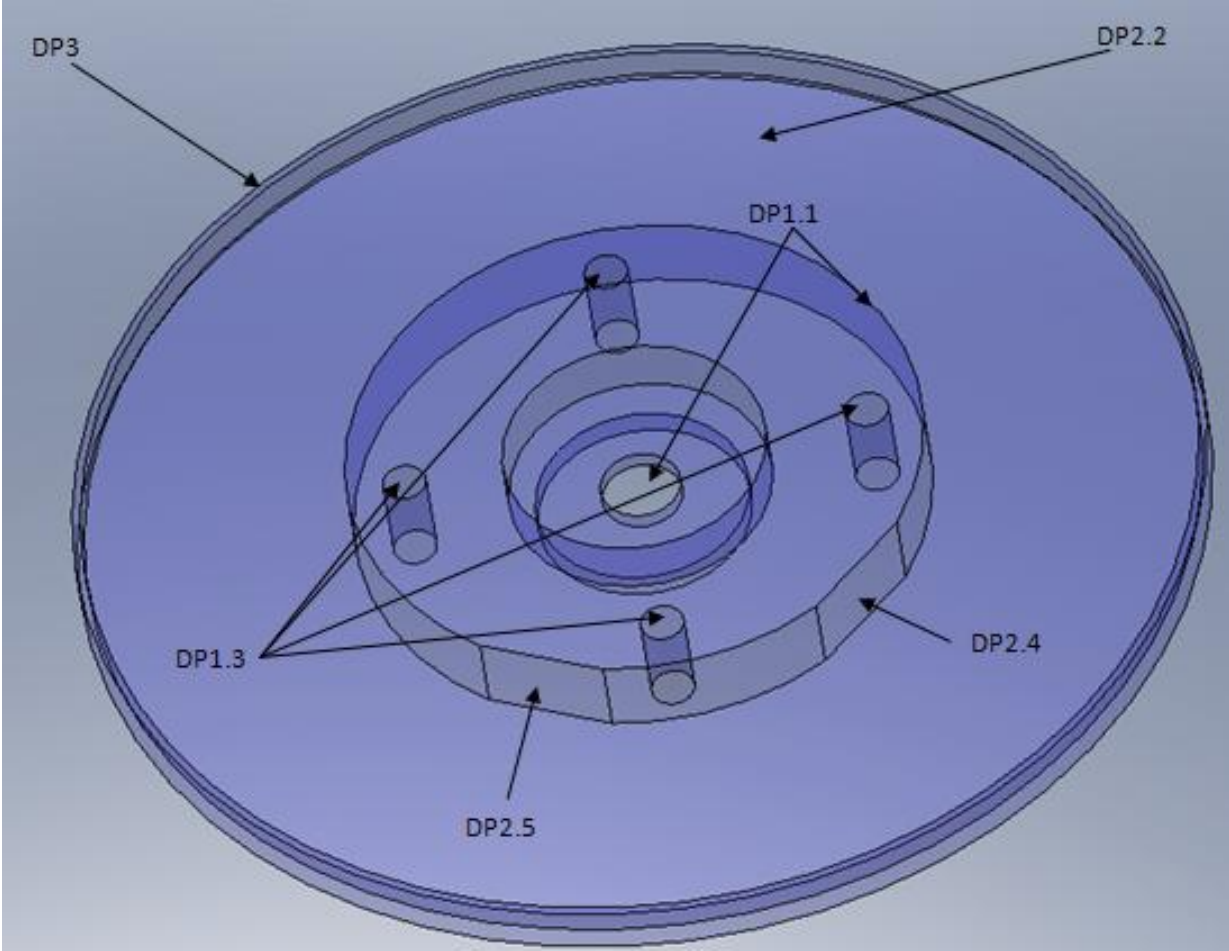


Figure 12: Cam with Design Parameters Labeled.

The next control load to be transmitted is the shear force perpendicular to the board axis (FR1.2). These forces are all transmitted by the center post of the base which can be seen below (DP1.2).

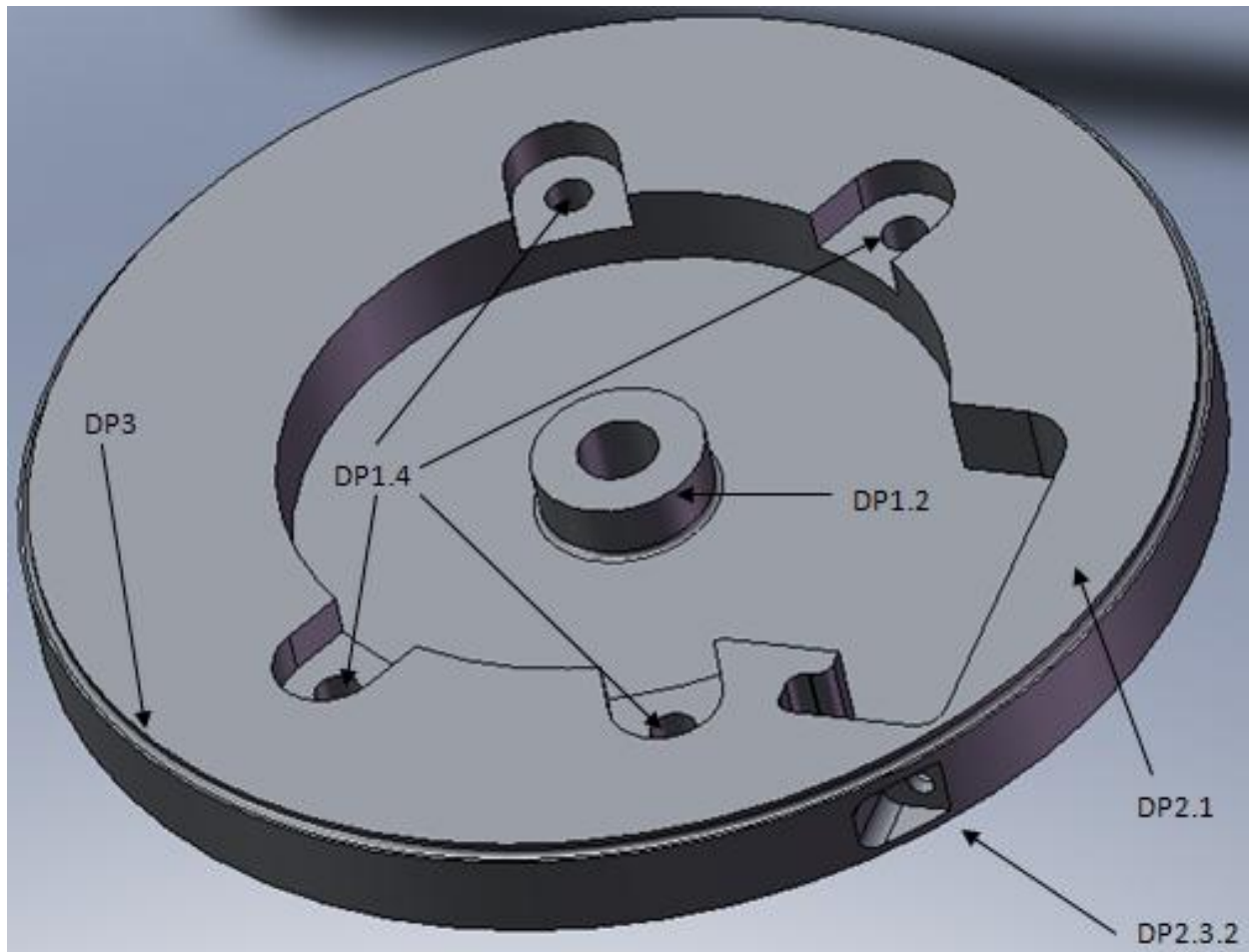


Figure 13: Base with Design Parameters Labeled.

The first two functional requirements transmitted the loads from on half of the design to the other but did not yet transmit the load through to the foot to the board to do this FR1.3 and FR1.4 are needed to transmit the loads through from the boot to the board. This is accomplished by machine screws through four holes on the base (DP1.4) and machines screws through four holes on the cam (DP1.3). These holes can all be seen above in Figures 12 and 13.

The first functional requirement basically confines the design to perform like a normal snowboard binding so that there is no difference in the experience on this design to a standard snowboard binding.

2.1.2 FR 2 Allow for Adjustable Snap in Rotation about Z Axis

The second functional requirement is where the actual performance of the system is dictated. This first child of this functional requirement is to provide for rotational support on the board. This means creating a rotatable part of some sort that would allow for rotation this was accomplished with the lower disk (DP2.1). This is shown above in Figure 9. The next functional requirement was to provide rotational support on the binding. This created the rotatable upper disk (DP2.2) seen above in Figure 8. Both DP2.1 and DP2.2 had to interface to be able to accomplish this design and attach the two elements together accomplishing FR1.

Now that there are two half of the design supporting rotation the rotation is the next focus. The functional requirement of providing force for snap in was created (FR2.3). This was simplified into sub categories of FR2.3.1 provide spring force, FR2.3.2 provide adjustment, FR2.3.3 provide for snug fit. The spring force was provided by a cantilever follower (DP2.3.1) shown below in Figure 14.

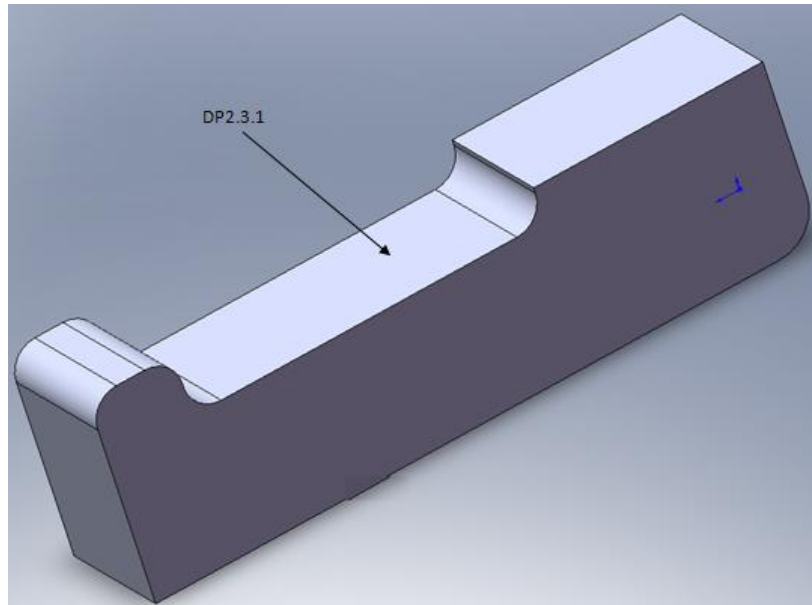


Figure 14: Cantilever Follower with Design Parameters Labeled.

The geometry of this cantilever dictated the force against the cam in bending which intern created the torque needed to rotate the mechanism. The next functional requirement of providing adjustment was accomplished by DP2.3.2 a sliding cantilever adjustment. This adjustment can be seen in Figure 15 and the location of the adjustment screw is seen in Figure 13.

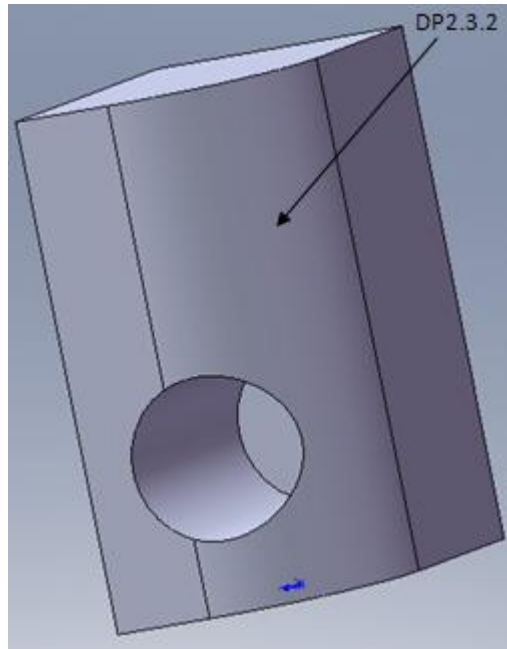


Figure 15: Cantilever Adjustment with Design Parameter Labeled.

The final functional requirement was to provide a snug fit which would not allow for slop between the cam and follower. This was accomplished with DP2.3.3 which was a spring to support the cantilever pushing it up against the cam. Our design used a piece of hard rubber behind the cantilever.

The next functional requirement was to provide our snap-in positions at both a riding angle of 17 degrees (FR2.5) and a non-riding angle of 90 degrees (FR2.4). These were both accomplished by a cam flat located at these two angles. This can be seen above on the cam in Figure 8.

All of these functional requirements contribute to the ability of the mechanism to rotate and perform the needs of the design.

2.1.3 FR 3 Protect Mechanism from Contamination

The final functional requirement FR3 is to protect the mechanism from contamination which is mostly dirty water and snow getting into the mechanism. This could cause the mechanism to not operate as expected to it needs to be eliminated. This is accomplished by an o-ring sitting on the base being held in place by the overhang of the cam (DP3). The overhang of the cam can be seen in Figure 8 and the slot for the o-ring can be seen above in Figure 9.

3. Description of Parts

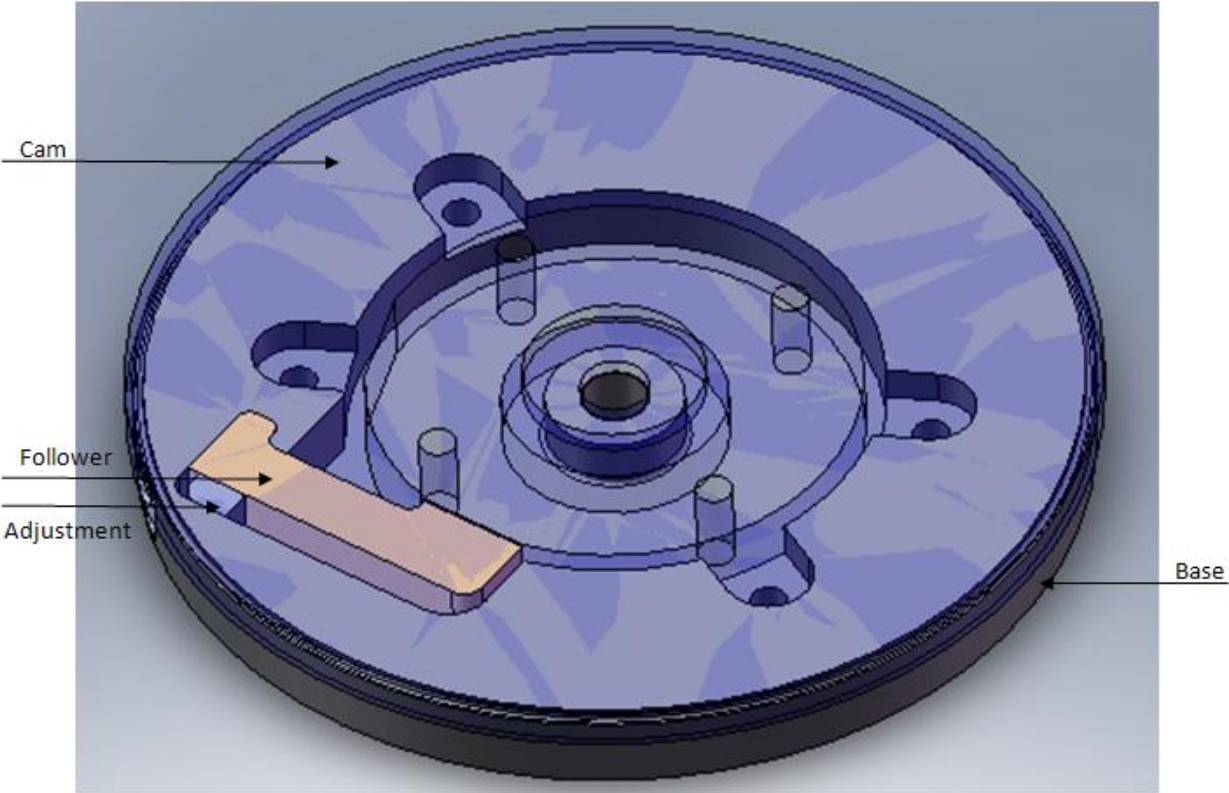


Figure 16: Assembled Rotational Binding in Solidworks.

3.1 Base Plate

The base of the design is where all the parts fit to create the function of the design. The base has a keyway for the key on the follower to lock into and just enough room for the adjustment piece to squeeze in behind it. The overall diameter of the base is 5.3 inches its height is .47244 inches. This decreased in size from last year's design by thirty one percent. The base has countersinks for screws to hold it to the board. The pocket in the center of the base for the cam to sit in is .3937 inches deep or 1 cm. The center post has a diameter of .47 inches and the hole in the center of the post was drilled and threaded for a 5/8 inch screw. Also there is a recess and hole on the side of the base to allow for the adjustment screw to enter there and sit on a flat surface. There is also an o-ring slot visible on the top edge of the base. The cam is machined from 2000 series aluminum.



Figure 17: Picture of Base of Binding.

3.2 Top Plate – Cam

The Cam is shown above in Figure 16 of the full assembly. It sits in the pocket of the base around the center post. The cam is the same height of the follower .47244 inches and has a diameter of 5.4 inches. The cam has a recess for the bearing to fit into and another recess on the other side to contain the head of the screw holding it to the base. The cam has four threaded holes to attach it to the board which are 7M hex head bolts. The cam also has an overhang around its edge which is 1.5 mm thick to create the seal with the o-ring. The cam has two flats on it at both 17 and 90 degrees. These two flats allow for a riding snap-in position and a parallel non-riding position. The cam is made from 2000 series aluminum.



Figure 18: Picture of Cam section of Binding

3.3 Adjustment

The adjustment piece is a small piece of stainless steel. It has a rounded edge so that it can fit flush against the base at the binding's loosest adjustment setting. The hole was drilled and tapped for a 6/32 screw. The adjustment is one cm tall to fit exactly within the pocket in the base.

3.4 Follower

The follower was machined from bronze 954. This was chosen because of its material properties which yielded the correct torque we needed for our displacement. The follower is also one cm tall to fit into the pocket of the base. The key on the follower fits exactly into the keyway on the base to allow for no movement out of its appropriate position, but due to the support for the cantilever being small, a piece of rubber was added to the back of the follower. The Rubber piece was used to make sure the follower was always held against the cam. The rubber was acting as a spring to ensure contact and ensure that the rotational force was at the level needed. The length of the cantilever in the design is 38 cm but the total length of the follower is 48 cm because 10 cm of the follower is not extended past the adjustment piece where the reaction force acts. The actual surface following the cam is flat. All rounds on the key are present to allow it to fit into the rounds on the base.



Figure 19: Picture of follower.

3.5 Hardware

Most of the hardware involved in this rotational snowboard binding is commercially available from most hardware stores. There are many machine screws and a bearing that are integrated into this device to make it function. The bolts that connect the rotational binding to the board and the rotational binding to the traditional binding are metric 6 machine screws. These screws come with the board, but can be bought at any store if they need to be replaced. To keep the screws consistent, the rotation binding was made to accept these 6 mm screws, by using a metric 6 tap to create threads. This makes these screws a standard part instead of having many different sizes of screws. There was another machine screw in the mechanism, which was a 5/16 screw. The final screw in the design is the screw that moved the adjustment piece. The screw is a regular 6/32 screw able to be found at any hardware store. This screw was the center post, which attached the two halves of the rotational binding together. It was essential that this screw was sturdy enough to hold the device together, but not too big, so it didn't take up too much room. The final piece of hardware in the system was a bearing that contacts between the center post on the base and the cam piece. This was added to take some of the forces, so the center post didn't have to take all of the force. It also decreased the friction between the two pieces of aluminum.

4. Testing and Analysis

4.1 Center Post Analysis

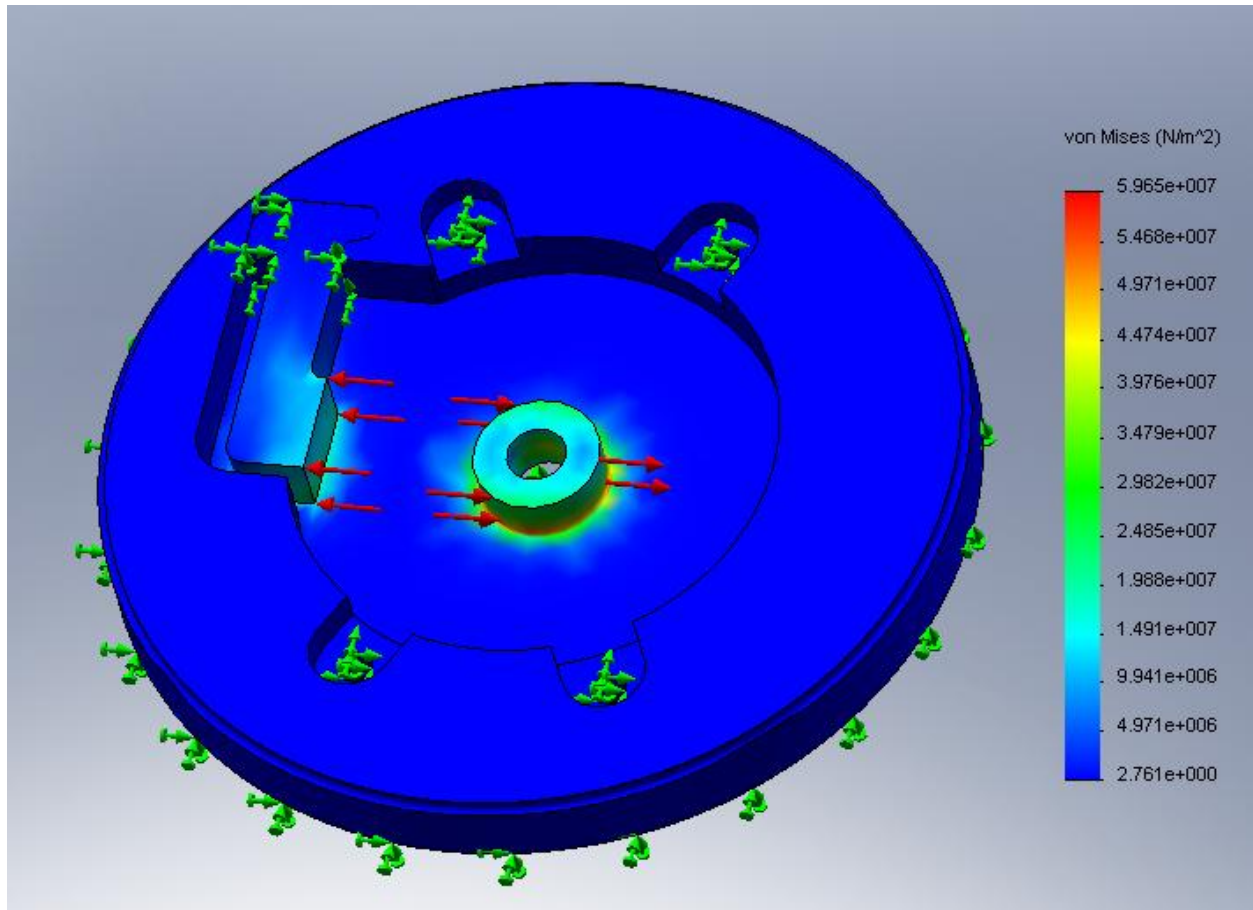


Figure 20: Finite Element Analysis Using Cosmos.

After using software to complete finite element analysis on the base of the device, as shown in Figure 24, it was determined that the stresses that would be applied to the critical sections would not be of any concern. The amount of force that the pin and follower would be subjected to would never reach a magnitude that would cause failure. How the device would behave if it was subjected to a crashing situation was never determined, and would be an important test to run if this mechanism were put into production.

4.2 Follower Analysis

From mathematical analysis of the cantilever follower, it was found that the best material for the part would be bronze. Bronze has a Young's Modulus of 1.24×10^{11} . To get the desired 21 Newton*meters of torque needed to rotate the binding, a displacement of .0009mm was needed from the follower. From the torque of 21 Newton*meters, the force on the cam is 5290.6667 Newton's. This force on the flat of the cam will hold the rotational binding in place when the rider is going down the mountain.

4.4 Prototype Assembly

Assembling the prototype of this device should have been an easy task, but after machining of the parts, we found that it wasn't in some cases. It was realized that some parts cannot be made to be a perfect fit, because they need some leeway to fit together. This caused the group to go through several iterations of each part before the final design was complete. Each part was made at least three times, until it was correct. The first version of the cam that was machined did not work. The reason it did not work is because the overhang on the outside of the piece was not big enough and was unable to hang over the base. The base also had to be re-made after the first piece. This is so because the center post was made too small. This was found out when the center hole was being threaded, and the post broke off from the rest of the base. It was fortunate that the post broke during this part of machining, and did not break when it was in use, possibly causing injuries. The first iteration of the follower had a different way of connecting to the base towards the end of the cantilever. The second iteration was easier to machine and easier to implement, so it was chosen for the final design. The adjustment piece also had to be remade, because the radius on the part was made the wrong size at first.

4.5 Laboratory Tests of Torque

Before any parts had been machined the required torque to rotate the binding was calculated mathematically. As shown in Figure 25 the maximum theoretical torque that we calculated was 21 Newton meters, which are far greater than any torque experienced during slope riding, determined from background research. Once the final assembly of our design had been completed the actual maximum torque required to rotate the binding was calculated with a Vermont Release Calibrator torque wrench. This was accomplished by strapping a boot into the rotational binding and putting a prosthetic foot into that boot. After this the torque wrench was used to measure torque with respect to the angle the foot was at, as shown in Figure 26 the maximum actual torque required to rotate the binding is 24 Newton meters. The difference in actual torque and theoretical torque is due to late design modifications that were not taken into account in the theoretical torque calculations.

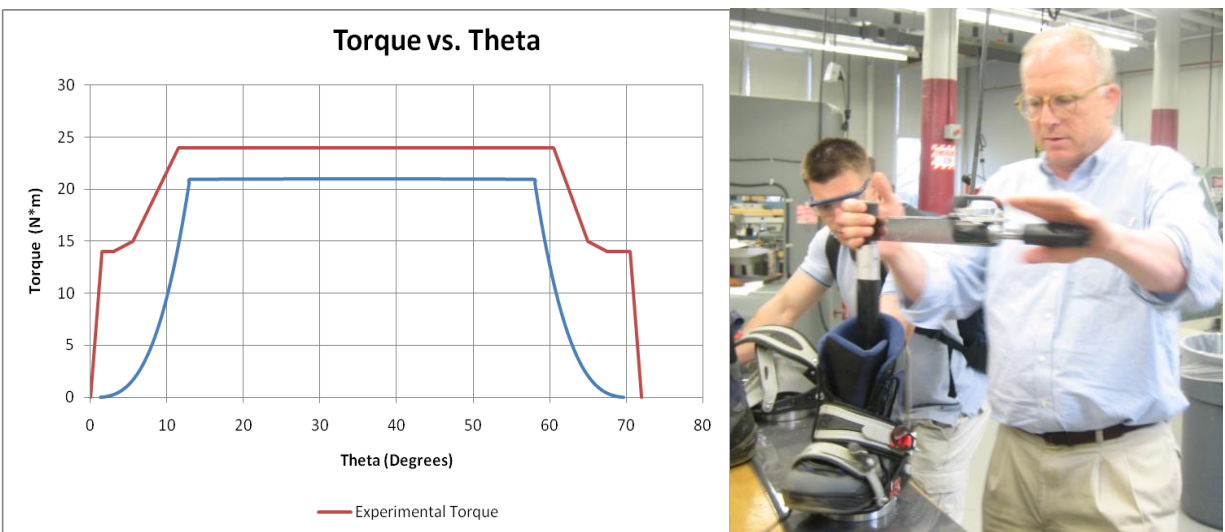


Figure 21: Theoretical and Actual Torque vs. Theta and Torque Test.

4.6 Realistic Situation Testing

The on slope testing of the rotational snowboard binding system was done at Wachusett Mountain. The on slope testing was done by an experienced snowboarder within the group, George Chyoghly, as well as a random participant at the mountain, Barry Dempsey. The testing done consisted of actual riding situations as well as moving from the bottom of the hill to the lifts. Due to it being so late in the skiing season the lifts were not open and testing with the lifts could not be done.

Actual riding testing consisted of the rider snowboarding down the hill. The tester made sure to perform many situations of riding. These included the initial start, riding down the hill, backside carving, front side carving, and stopping. Air tricks as well as rail tricks could not be done because of the inability to access the freestyle park. During the on slope riding the tester made sure to test two main attributes of the binding. First, that the binding being raised 1.2 cm off the board did not affect the feel of the snowboard. It was discovered that the feel of the snowboard was not altered due to the raise created by the rotational mechanism. It felt the same as a normal snowboard which is important because snowboarders do not want to sacrifice comfort on the snowboard for this rotational mechanism. The second attribute tested was the feel of the actual binding. Making sure that the binding did not rotate at all during riding situations is extremely important. If the snowboarder felt any rotation at all it would be uncomfortable as well as extremely dangerous. During the test it was discovered that the binding did not rotate at all. It remained locked in the first toggle position with no rotation. This showed that while in riding situations the rotational mechanism felt the same as a traditional binding mechanism.

Testing done at the bottom of the mountain consisted of actually performing the action of rotating the mechanism as well as moving from the bottom of the hill to the lift. Upon reaching the bottom of the hill the tester first unstrapped the back foot. With the back foot unstrapped the tester continued into the rotational portion of the test. Rotation of the front foot proved to be successful. The torque needed to rotate the mechanism was not too high and actually turned out to be rather easy. The tester proceeded to move from the bottom of the hill towards the lift. During this portion the tester made sure that while in the second toggle position there was no rotation. This turned out to be true. The comfort of riding in this position proved to be far superior to a traditional position.

The on slope testing of the rotational mechanism proved to be a success. The rotational mechanism was designed to make sure that the comfort of the snowboard was not affected by the raise created by the mechanism. The rotational mechanism also did not rotate during riding situations and was easy enough to rotate at the bottom of the hill. The comfort of going from the bottom of the hill to the lift with the rotational mechanism proved to be far superior to traditional bindings. The random participant, Barry Dempsey, was quoted as saying, "I like the rotational binding because it does not rotate while riding and is easy to rotate at the bottom of the hill. If I were to buy a new snowboard I would definitely try to buy one with this mechanism".

5. Iteration

5.1 Follower

Since this project is a continuation of a previous group's design, many changes had to be made in order to improve upon the efficiency of the mechanism. When evaluating the previous design, our group needed to look for ways to make the design simpler and therefore cheaper. Many other aspects needed to be included in the thought process. Things like manufacturability, safety in use, functionality, efficiency, as well as cost needed to be considered when attempting to revamp this design. Making the design smaller created a lower cost as well as a lower weight, which were both very desirable. Although the concepts of a rotating mechanism as well as the cam and follower system were deemed necessary in our new design, a myriad of things were changed.

The design that was used last year included a cam with 4 dwells in it. In each of these dwells sat the follower which designated the "snap in" positions. The design consisted of two followers on each side of the cam, and these followers were forced into contact with the cam through adjustable spring systems. These force in the spring was made adjustable through the means of using a plate which could be screwed in or out which would essentially preload the spring and make the required force to move it larger. The dwells were evenly spaced so that the rider could turn the binding in increments of ninety degrees. There were several problems with this idea that were addressed when going through the redesigning process.

In respect to the followers, there were several reasons why the group believed it to be inefficient and unnecessary to have two separate followers on each side of the cam. The concept of an adjustable system was very important to this design and in no way was regarded as unnecessary. We believed that a system with two separate adjustable parts allowed for a situation where the strength of the springs could differ from one side to another. This situation would create unequal forces on different parts of the cam and would contribute to wear as well as the surpassing of fatigue and strength limits. Another reason of limiting the number of spring to one allowed for a reduction of the number of parts, specifically the number of moving parts. The more moving parts that exist in a mechanism, the more work has to be completed as to their strengths and fatigue limits. This obviously led to a simpler design. Limiting the number of parts in general simply allows for less manufacturing and assembly, as well as a lowered overall cost. Therefore, the group decided that it would be far more efficient to use only a single spring system, although what system that would be had yet to be decided.

The first decision that was made in the designing process was that we were indeed going to use a spring system in order to keep the follower in contact with the side of the cam. The use of mechanical systems would simply create far too many moving parts and is not applicable in this situation. The group, when attempting to decide what spring system would be best for the follower, discussed many different ideas. The common coil spring system that was used in last year's design was considered heavily, however we wanted to improve upon the efficiency and simplicity of the follower in some way. The idea of using a leaf spring, a mechanism commonly used in car suspensions, was considered. A leaf spring consists of a slender arc shaped lengths of steel. This length of steel allows for horizontal movement under

some predetermined force. This force is determined by the mechanical properties of the steel being used. The leaf spring concept was discarded, however, mostly due to a rather difficult process of providing adjustability to the spring. If this idea was used, adjusting the strength of the spring would almost prove redundant in comparison to using the simpler and less breakable coil spring.

The next idea that was considered was the use of a simpler cantilever concept. A cantilever is a simple beam that is fixed at only one end, allowing for some sort of deflection based on the force applied at the other. The beam displaces the load applied to the support, which is where this load is resisted by the moment and shear stress. This system seemed to be a very usable design, mostly due to its simplicity. The follower could be kept in contact with the cam through a simple beam, which would only be deflected based upon what material it was to be constructed of. The use of this concept in our design would also allow for the group to put into effect skills we had learned while conducted our college learning experience. The concepts of evaluating the deflection as well as the fatigue analysis of a simple cantilever were familiar to us and therefore we would be able to do an effective job of designing. This design would also be simpler in that there would be only one moving part to the entire spring system. Both of these ideas are what convinced our group to use the cantilever idea as our spring system. The adjustability of this design was actually very simple as well; however it will be discussed later on in the examination of iterations.

Now that the group had decided on a cantilever spring to hold the follower in place, we needed to examine the follower itself and if any improvements on its design could be

made. The follower that had been used previously fitted into four dwells that existed on the cam. The group ran into several problems with continuing this idea after decided to use a cantilever system. Because of the range of materials that could be used, the deflection that the cantilever was to go through would most probably be very small. With a dwell cam system, the force that is enacted on it can be directly related to the depth of the dwell. Combining the dwell concept with the high forces we were going to see with this design would create the necessity for dwells that were either far too steep for be manufactured precisely enough with the machines we had available. This would either rule out our cantilever system, or eliminate the ability to use a dwell system. This brought to mind the use of a flat cam and follower system. This system would consist of a flat follower which comes into contact with another flat on the cam. These would consist of our required “snap in positions”. These flats would be cut into the original radius of the cam. Therefore, there would be an increase of the radius whenever the cam was rotated as it came out of the flat positions. A certain torque provided to the rotation of this cam would thus force the follower to deflect a certain amount.

After solidifying what type of spring system as well as what kind of cam and follower system would be used, the process of material selection needed to be completed. The torque required for the design used last year was relatively low compared to what the group desired. This would not be a point that was lost while going through our design process. We wanted to ensure a torque of somewhere between 30-70 N*m. Based on the limitations given by our torque range and the radius of our cam, there were only some materials that could be used for the cantilever. Two materials that were relatively easy to obtain and fit in this range were bronze and steel. Because of the easy of manufacturability of the small cantilever, it was

decided that the cantilever could easily be created out of both of these materials. This would allow for testing with both materials and therefore difficulties in workability could be evaluated. After this evaluation, a material would be chosen based on its functionality as well as its manufacturability.

Another iteration that was completed with the cantilever was how it was to be supported at the end opposite to the follower. Since the cantilever was meant to be interchangeable for this design, it would not be directly integrated into the base, although in future designs this may be more desirable. Since the cantilever would be a separate piece, a simple key, or notch could be manufactured at the end opposite to the load. This key would resist the load placed at the other end. When this concept was first used, the key was designed a certain distance from the non-load end of the cantilever. This extra distance was deemed completely unnecessary, and in another iteration of the design was eliminated. This allowed for a smaller amount of material in the design and thus a lower weight and cost.

5.2 Cam

The next aspect of the design that was to be iterated was the actual cam. There were several problems that were noticed. Firstly, riders tend to prefer to ride at a certain angle to the board, as it is relatively uncomfortable to ride exactly perpendicular to the board. This was an idea we wanted to address, because this new design was expected to be a working prototype somewhat ready for mass-production. The design last year accomplished the goal that it set out for, however there were problems with introducing the design into real world environments. It only allowed for ninety degree rotations relatively to its starting point. This limited the design in that even if the starting angle was adjusted to seventeen degrees (which is a generally accepted angle), the boot would be seventeen degrees off parallel. This would create an uncomfortable situation similar to the original non-rotational binding. With the dual spring system, this concept seemed unsolvable. However, with only one spring, the dwells, or in our case, the flats could be created at any angle deemed acceptable. The location of these flats on the cam now became one of our most important decisions. In the end, we created only two flats. One would be seventeen degrees from perpendicular to the board. This would allow for a comfortable riding position, which could also be adjusted through the screws that attach the boot to the board. The other flat would be positioned seventy-three degrees from this first flat, which would allow for near parallel position of the boot to the board. Now, even if the starting angle was adjusted to fifteen or nineteen degrees, the non-riding position would only be off parallel by a few degrees. This vastly improved on the design in regard to its functionality.

Another iteration that was completed on the cam was creating a recess for the introduction of a bearing. A bearing was necessary in order to facilitate the rotational movement about the center pin. Since a bearing was not included in any previous designs, a small circular section was removed from the design of the cam. This was a simple, yet necessary iteration in the creation of the cam.

Another concept which needs to be addressed in the design process is protection from contamination. This design includes very small tolerances in relation to the displacement of the follower, and therefore even a single particle of dirt could disrupt how effective the mechanism is. Another reason why protection from the elements during use is important is wear and rust. At this point, at least one of the materials being used is metal, and since the binding will obviously be used in wet situations, rust of the components cannot be allowed. Because of the importance of protection, an overhang was included, which is to be placed on the outer radius of the cam piece. This small piece would hang over the edge of the base and, along with an O-ring, would provide for adequate protection from any contamination.

The last process entailed with evaluation of the cam design was material selection. Since the loads that were being brought upon the cam would not prove damaging with almost any material, it was decided that the cam was to be constructed of steel. This was one situation where the ability to mass-produce was somewhat overlooked in order to create a working prototype. Based on manufacturability, the group decided to create the cam out of aluminum. Future iterations of this design may look for the possibility of plastics for the construction of this piece.

5.3 Base and Adjustment

The third portion of the design that was changed from past designs was the base of the binding. Although the rest of the design differs in many ways, for the most part this does not affect the design of the base. There were however, some small changes that were made. As mentioned previously, adjustability of the strength of the spring system was an asset to our design. Our group came up with the idea of somehow limiting the length of the cantilever, which would in effect regulate the amount it was deflected under a given load. The solution to this problem came through an adjustment piece, which could be screwed in and out of the open space behind the cantilever piece. This forced the cantilever to bend over a smaller length, and thus increased the strength of the spring system. The cantilever spring system was now fully adjustable. The creation of the adjustment piece forced a small screw hole to be manufacturing into the base design. This screw hole was originally very small, however it was changed to a much larger hole in order to better support the loads being placed upon it.

Another change made in the base design was the location of the key hole for fitting of the cantilever/follower piece. Since the position of this keyhole changed from our first design, the group needed to reposition the key hole as well. Another improvement in the field of protection was the inclusion of an O-ring, or a small rubber ring surrounding the base in order to seal the mechanism. Because of the problems caused by contamination, a slot was created into the base in order to allow for placement of this O-ring. At first, this slot was placed into actual section of the base. This position was quickly changed by placing this slot at the top of the base rim, and having an overhang to ensure this seal.

The last significant iteration made to the original design was the size of the center post. When evaluating the loads and moments concerned with rotating the mechanism, the group realized there were going to be problems with keeping the post the way it was. This fear was seen clearly in the fact that our original post broke nearly minutes after its use. The group came to the realization that the only thing that was limiting the radius of this center post was the four screws that attached the cam to the boot. After this, the radius of the post was increased significantly so that there would be its ultimate tensile strength as well as its fatigue strength limits would never be reached during use.

6. Discussion

During this project a successful design was created. The goals that were set were achieved by the end of the project. A rotational binding system which had the ability to rotate between two positions, but still be comfortable for the snowboarder was produced. There were many peaks and valleys associated with this project and the group did a good job overcoming these obstacles. The final prototype proved to work through testing phases, but many changes could be made to make the design and actual manufactured part better.

When thinking of the design it is important to think outside the box. Make sure to give every thought consideration no matter how radical it may seem. A big suggestion would be to have the axiomatic design done very early in the project. Moving away from metals would also be a good idea. The use of plastics, specifically Delrin, should be a consideration in future projects. Integrating the rotational mechanism into the board may be a good direction to take. Also, during the design process we probably should have had the cam on the outside to avoid problems with attaching the prototype to the binding and board. Reducing the amount of moving parts is always important and this could have been done by making the follower part of the base. The final consideration with in the design process may be to make the inside parts of the mechanism inaccessible to the customer. This would make sure that the customer is not making unintended adjustments to the mechanism. This could prove to be dangerous to the customer.

While coming up with a design it is very important to make sure you use the same units in which the CNC machines operate. Learning how to use the CNC machines very early into the

project and getting experience in using those machines is imperative, or else you will be pressed for time to test the final design on the mountain. Another task that must be completed almost right after the project is started is ordering required parts, such as drill bits, screws, Teflon, and different metals or plastics decided upon. Completing the machining at an earlier date will allow for more extensive on slope testing, such as rail tricks, lift tests, and crash testing.

In this year's design the O-ring and overhang did not work properly, this interaction is very important as it protects the internal portion of the mechanism from the elements and prevent rusting. Another aspect that must be completed before any further progress can be made in the project is properly coating and lubricating all parts, one major possibility that was looked at this year was Teflon anodized coating. Once these steps have been taken in this project this concept should be patented and marketed.

7. Conclusion

In conclusion the project not only produced a successful design and prototype, but also proved to be a high-quality learning experience. The project was a continuation of previous projects which also attempted to create a rotational binding mechanism. Through a creative thinking process the basis of the design was formed. This design was simpler and had fewer moving parts than previous designs which were initial goals. The rotational mechanism created actually has the fewest moving parts of any rotational binding created. Through a well thought out design process as well as the use of axiomatic design the mechanism was continually altered until an acceptable design was created. With the design modeled in the Solid Works the project moved onto the manufacturing phase. In years past, groups did not manufacture the parts themselves, but this was a large part of our project. The group learned how to create tool paths with the use of Esprit and also learned how to operate the HAAS mini mills within the Washburn machine shop. Many iterations were made during this stage in order to create a working rotational mechanism. With a prototype created the project moved on to the testing phase where the torques were tested using a torque wrench. On slope testing was also done at Wachusett Mountain. The group set out to design and create a rotational binding mechanism which would have the ability to meet customer needs. Through creative thinking, a design process, manufacturing, and testing this was successfully achieved.

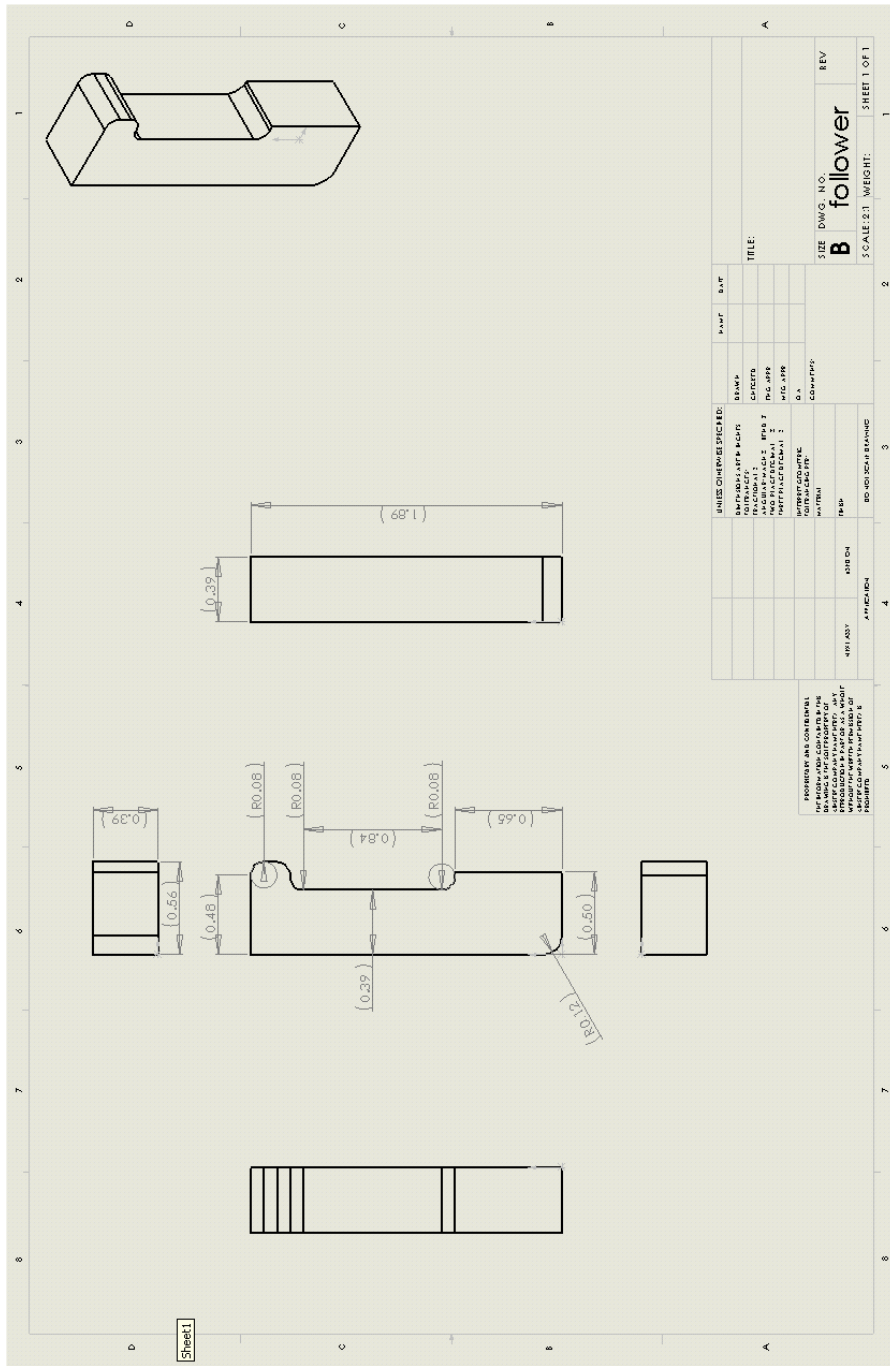
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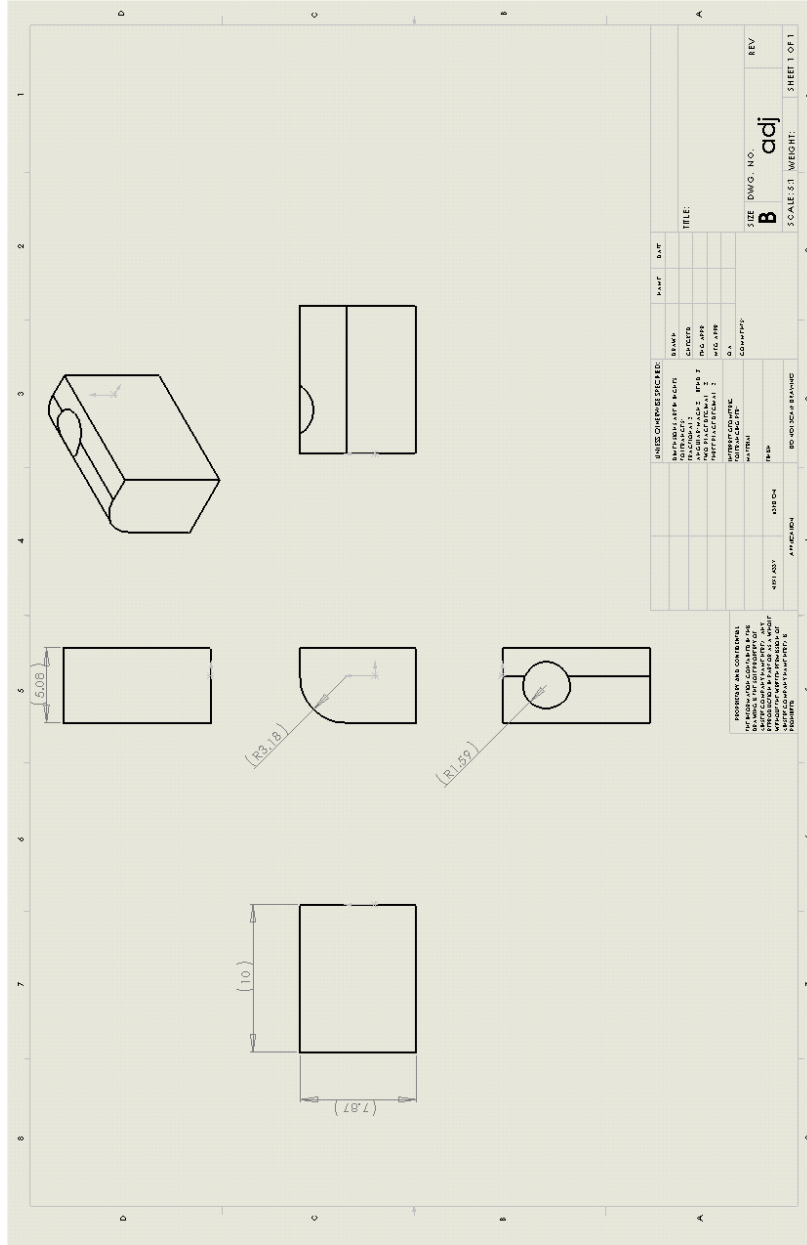
Acknowledgments

We would like to thank Christopher Brown for all of his guidance and advice on our project. We would also like to thank Torbjorn “Toby” Bergstrom, Brendan Powers, and Neil Whitehouse for their assistance in the manufacturing process. A special thanks to Barry Dempsey for being an assistant in the testing phase. We would also like to thank WPI and the ME department for the opportunity to complete this project.

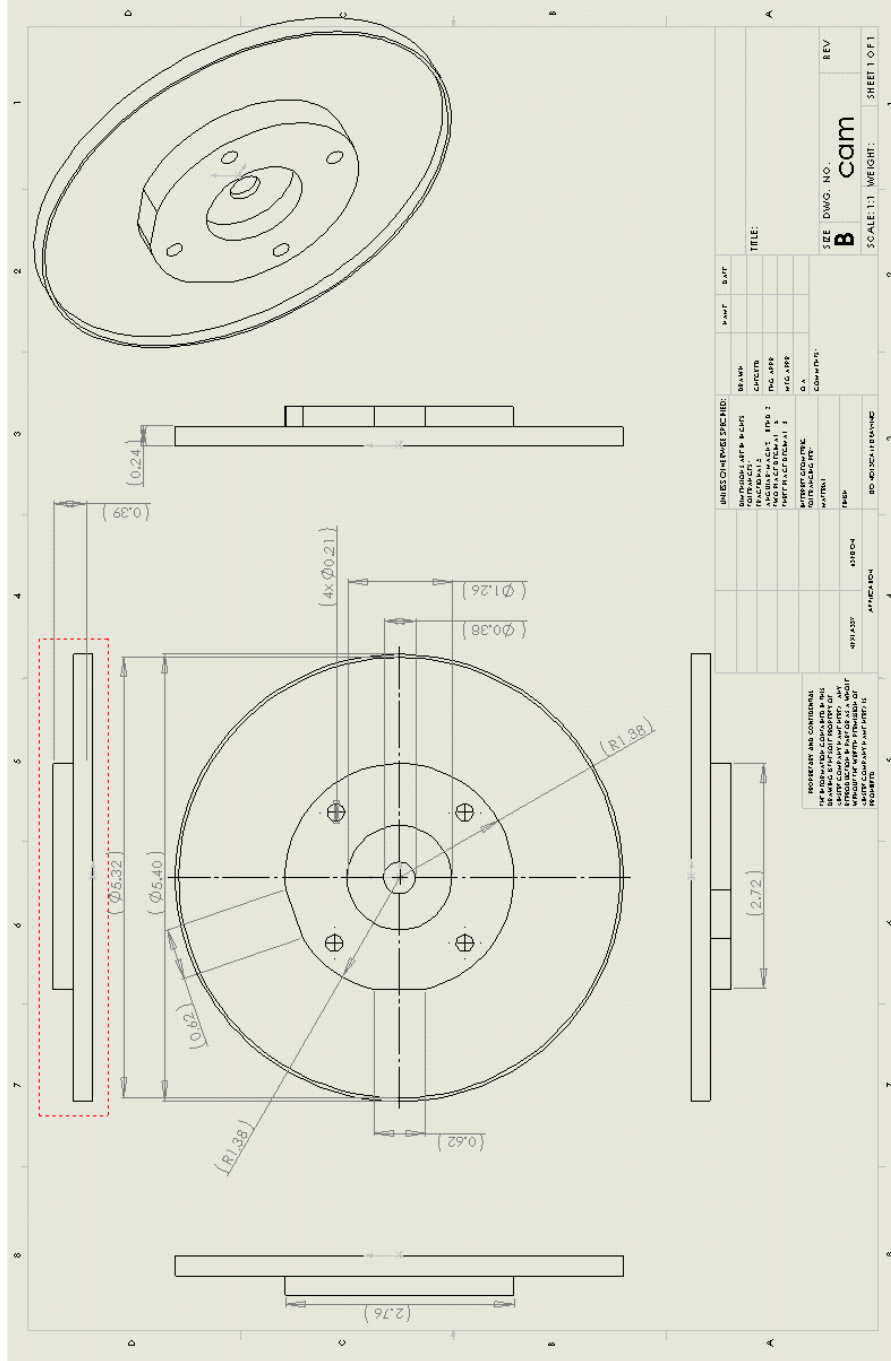
Appendix A



Appendix B



Appendix C





Rotational Snowboard Binding

George Chynghty, Eric DeLuca, Charles Fradella, Christopher Norton, Keegan Richey
 Advisor: Christopher A. Brown
 Mechanical Engineering Department

Abstract

A group of five WPI seniors worked on a project concerning a rotational snowboard binding. The design is used in both getting off a lift as well as in non-riding situations. The design is a modification of the existing design in both the mechanism of its rotation as well as its materials. The program Esprit along with HAAS MiniMills were used in order to machine this new design. The design was tested and evaluated according to its safety and efficiency.

Objective

The objective of this project was to design a rotational interface between a traditional snowboard binding and the snowboard. This mechanism would allow for rotation of the front foot from a normal riding position to a position parallel to the length of the board. This would allow for easier mobility when in non-riding situations such as getting on and off a lift as well as movement on flat ground. Many lowering injuries can be avoided due to this increased mobility.

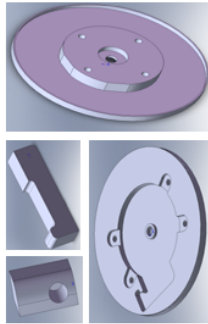
Axiomatic Design

Axiomatic design is the process of converting customer needs into functional requirements. These functional requirements relate to design parameters which fulfill the customer needs. Shown below is our axiomatic design decomposition.

Functional Requirements	Design Parameters
FR1: Mount snowboard onto binding	DP1: Mount snowboard onto binding
FR2: Mount snowboard onto binding	DP2: Mount snowboard onto binding
FR3: Mount snowboard onto binding	DP3: Mount snowboard onto binding
FR4: Mount snowboard onto binding	DP4: Mount snowboard onto binding
FR5: Mount snowboard onto binding	DP5: Mount snowboard onto binding
FR6: Mount snowboard onto binding	DP6: Mount snowboard onto binding
FR7: Mount snowboard onto binding	DP7: Mount snowboard onto binding
FR8: Mount snowboard onto binding	DP8: Mount snowboard onto binding
FR9: Mount snowboard onto binding	DP9: Mount snowboard onto binding
FR10: Mount snowboard onto binding	DP10: Mount snowboard onto binding
FR11: Mount snowboard onto binding	DP11: Mount snowboard onto binding
FR12: Mount snowboard onto binding	DP12: Mount snowboard onto binding
FR13: Mount snowboard onto binding	DP13: Mount snowboard onto binding
FR14: Mount snowboard onto binding	DP14: Mount snowboard onto binding
FR15: Mount snowboard onto binding	DP15: Mount snowboard onto binding
FR16: Mount snowboard onto binding	DP16: Mount snowboard onto binding
FR17: Mount snowboard onto binding	DP17: Mount snowboard onto binding
FR18: Mount snowboard onto binding	DP18: Mount snowboard onto binding
FR19: Mount snowboard onto binding	DP19: Mount snowboard onto binding
FR20: Mount snowboard onto binding	DP20: Mount snowboard onto binding

Final Design

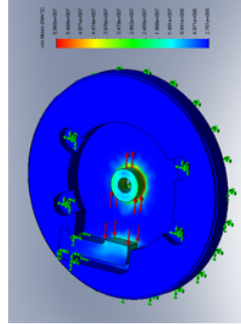
Our final design has the least moving parts of any existing rotational snowboard binding system. This design consisted of a cam and follower system. The cam is attached to the base of the snowboard and the follower is attached to the binding. The length of the cantilever beams is variable by means of the steel adjustment piece being moved in or out using a machine screw. The aluminum cam allows for two snap in positions at a traditional riding angle specific to the rider and an angle parallel to the length of the snowboard. The cam rotates around a post and bearing located at the center of the base. This post also transmits the control loads from the rider to the board. To alleviate stress between the cam and follower hard rubber was inserted behind the follower to act as a second spring. The base is attached to the board by four screws whose positions are delegated by the board. The cam is attached to the traditional snowboard binding with another four screws. To protect the mechanism from contamination a system was integrated into the design. This system consisted of an o-ring around the base which was covered by the overwing of the cam.



Parts of Device (clockwise from top left): Adjustment Piece, Cantilever Follower, Cam, Base



Assembly of Rotational Device Without Cam



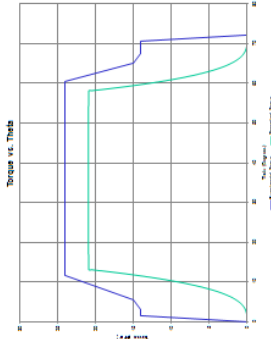
Finite Element Analysis of Base Under Rotational Loads

Manufacturing

The manufacturing of the prototype was done completely by the group members. The solid models were used in Esprit to create tool paths for the HAAS MiniMills. The program Esprit was used to machine the adjustment piece and the cantilever beams of the device. At least three iterations of each part were done during the machining process.

Testing

Both laboratory and on slope testing was performed on our design. The laboratory test was done with a torque wrench. Higher torque values than expected were obtained due to the additional spring behind the follower. The tolerance of the measuring device caused our experimental data to be skewed.



Results

Our design was highly successful in meeting customer needs. The experimental torque needed to rotate the interface was very close to our desired torque. Our on slope testing showed that the rotational interface did not interfere with normal riding. The design also performed well when the snowboard was rotated parallel to the board. It provided increased mobility in non-riding situations.

Acknowledgments

We would like to thank Christopher Brown for all of his guidance and advice on our project. We would also like to thank Torbjorn Tobo Bergstrom, Brendan Powers, and Neil Whitehouse for their assistance in the manufacturing process. A special thanks to Barry Dempsey for being an assistant in the testing phase. We would also like to thank WPI and the ME department for the opportunity to complete this project.

Appendix E

	Riding Position	Rotated Positon			Riding Position	Rotated Position		
Traditional Riding Angle	Cam Slot 1	Cam Slot 2	Cam Slot 3	Cam Slot 4	Cam Slot 5	Cam Slot 6	Cam Slot 7	Cam Slot 8
15	0	73	90	107	180	71	90	109
16	0	73	90	107	180	71	90	109
17	0	73	90	107	180	71	90	109
18	0	73	90	107	180	71	90	109
19	0	73	90	107	180	71	90	109
20	0	73	90	107	180	71	90	109
21	0	73	90	107	180	71	90	109
	Cam Slot 1	Cam Slot 2	Cam Slot 3	Cam Slot 4	Cam Slot 5	Cam Slot 6	Cam Slot 7	Cam Slot 8
Traditional Riding Angle	Lift Riding Positon w/o Rotatio	Lift Riding Positon with Rotation			Not Used	Lift Riding Positon with Rotation		
15	15	88	105	122	195	86	105	124
16	16	89	106	123	196	87	106	125
17	17	90	107	124	197	88	107	126
18	18	91	108	125	198	89	108	127
19	19	92	109	126	199	90	109	128
20	20	93	110	127	200	91	110	129
21	21	94	111	128	201	92	111	130
		Nintey Degrees is Perfered Lift Riding Positon						

Appendix F

	mm ³	g/mm ³		
	Volume	Density	Weight	
cam	62346	0.0027	168.3342	0.168334
base	115689	0.0027	312.3602	0.31236
follower	5178.558	0.00785	40.65168	0.040652
adjustment	329.1357	0.0027	0.888666	0.000889
o ring	x	x	x	x
bearing	x	x	0.05	0.02268
Total Weight			kg	0.545
			lbs	1.201

Appendix G

Pin Analysis

Front Boot

$$\begin{aligned} F_{xfmin} &:= -45\text{ l} & F_{xfmax} &:= 39\text{ l} \\ F_{yfmin} &:= -74\text{ l} & F_{yfmax} &:= 89\text{ l} \\ F_{zfmin} &:= 75\text{ l} & F_{zfmax} &:= 275\text{ l} \\ M_{xfmin} &:= -41\text{ l} & M_{xfmax} &:= 17\text{ l} \\ M_{yfmin} &:= -14\text{ l} & M_{yfmax} &:= 15\text{ l} \\ M_{zfmin} &:= -4\text{ l} & M_{zfmax} &:= 14\text{ l} \end{aligned}$$

Back Boot

$$\begin{aligned} F_{xbmin} &:= -46\text{ l} & F_{xbmax} &:= 37\text{ l} \\ F_{ybmin} &:= -50\text{ l} & F_{ybmax} &:= 36\text{ l} \\ F_{zbmin} &:= -84\text{ l} & F_{zbmax} &:= 270\text{ l} \\ M_{xbmin} &:= -38\text{ l} & M_{xbmax} &:= 34\text{ l} \\ M_{ybmin} &:= -14\text{ l} & M_{ybmax} &:= 12\text{ l} \\ M_{zbmin} &:= -4\text{ l} & M_{zbmax} &:= 14\text{ l} \end{aligned}$$

$$\begin{aligned} R_x &:= F_{zfmax} & M_{ry} &:= M_{xfmi} & a &:= 0.00 \\ C_1 &:= F_{zfmax} & C_2 &:= M_{xfmi} & C_3 &:= M_{xfmin} \cdot a - \frac{F_{zfmax} \cdot a^2}{2} \\ C_4 &:= \frac{-M_{xfmin} \cdot a^2}{2} - \frac{F_{zfmax} \cdot (-a^3)}{6} \end{aligned}$$

Selected Material: SAE 4027 Steel(unknown material)

$$E := 206.8 \cdot 10^9$$

$$M := .002$$

$$D := .00$$

$$r := \frac{D}{2}$$

$$L_x := .01$$

$$I := \frac{1}{4}(M \cdot r^2) + \frac{1}{3}(ML^2)$$

Plot Functions

Define the Step Function

$$\delta(x, z) := \text{if}(x \geq z, 1, 0)$$

Define the x range

$$x := 0, 0.00 \dots L$$

Define the Singularity Functions

Loading Function

$$q(x) := -M_{xfmin} \cdot S(x,0) \cdot (x-a)^{-2} + R_x \cdot S(x,0) \cdot (x-0)^{-1} - F_{zfmax} \cdot S(x,0) \cdot (x-a)^{-1} + M_{ry} \cdot S(x,0) \cdot (x-0)^{-2}$$

Shear Function

$$V(x) := R_x \cdot S(x,0) \cdot (x-0)^0 - F_{zfmax} \cdot S(x,0) \cdot (x-a)^0 + C_1$$

Moment Function

$$M(x) := -M_{xfmin} \cdot S(x,0) \cdot (x-a)^0 + R_x \cdot S(x,0) \cdot (x-0)^1 - F_{zfmax} \cdot S(x,0) \cdot (x-a)^1 + M_{ry} \cdot S(x,0) \cdot (x-0)^0 + C_1 \cdot x + C_2$$

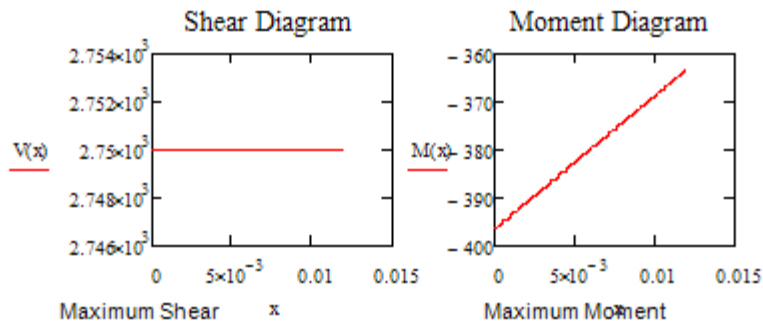
Slope Function

$$\theta(x) := \frac{1}{E \cdot I} \left[-M_{xfmin} \cdot S(x,0) \cdot (x-a)^1 + \frac{R_x}{2} \cdot S(x,0) \cdot (x-0)^2 - \frac{F_{zfmax}}{2} \cdot S(x,0) \cdot (x-a)^2 + M_{ry} \cdot S(x,0) \cdot (x-0)^1 + \frac{C_1}{2} \cdot x^2 + C_2 \cdot x + C_3 \right]$$

Deflection Function

$$y(x) := \frac{1}{E \cdot I} \left[\frac{-M_{xfmin}}{2} \cdot S(x,0) \cdot (x-a)^2 + \frac{R_x}{6} \cdot S(x,0) \cdot (x-0)^3 - \frac{F_{zfmax}}{6} \cdot S(x,0) \cdot (x-a)^3 + \frac{M_{ry}}{2} \cdot S(x,0) \cdot (x-0)^2 + \frac{C_1}{6} \cdot x^3 + \frac{C_2}{2} \cdot x^2 + C_3 \cdot x + C_4 \right]$$

Plots of Singularity Functions

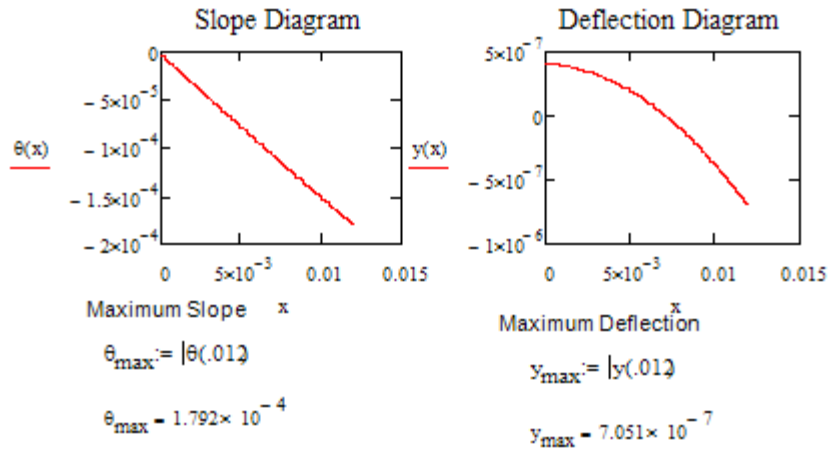


$$V_{\max} := |V(0)|$$

$$V_{\max} = 2.75 \times 10^3$$

$$M_{\max} := |M(0)|$$

$$M_{\max} = 396.25$$



$$\epsilon_{\max} := \frac{D}{2}$$

$$\sigma_{\text{anom}} := \frac{M_{\max} c}{I}$$

$$\sigma_{\text{anom}} = 1.27 \times 10^7$$

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$$S_{\text{ut}} := 51$$

$$S_m := .98 S_{\text{ut}}$$

$$S_{\text{eprime}} := .98 S_{\text{ut}}$$

$$C_{\text{load}} := 1$$

$$C_{\text{size}} := 1$$

$$A_s := 57 \quad b := -.71$$

$$C_{\text{surf}} := A \cdot S_{\text{ut}}^b$$

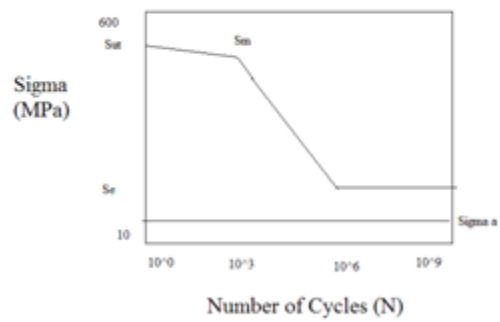
$$C_{\text{surf}} = 0.65$$

$$C_{\text{temp}} := 1$$

$$C_{\text{reliab}} := .75$$

$$S_e := S_{\text{eprime}} \cdot C_{\text{load}} \cdot C_{\text{size}} \cdot C_{\text{surf}} \cdot C_{\text{temp}} \cdot C_{\text{reliab}}$$

$$S_e = 126.516$$



The line of Sigma a never intersects with the failure line in this S-N diagram. Therefore with this material selected and the given stresses failure will not occur. This is worst case scenario given the forces and moments provided.

Appendix H

Section properties for the shaft are as follows:

$$\begin{aligned} \text{OD} &= 12.0 \text{ mm} \\ \text{ID} &= 7.0 \text{ mm} \\ t &= (12.0 \text{ mm} - 7.0 \text{ mm}) / 2 \\ &= 2.5 \text{ mm} \\ c &= 12.0 \text{ mm} / 2 \\ &= 6.0 \text{ mm} \\ \text{Area} &= \pi[(12.0 \text{ mm})^2 - (7.0 \text{ mm})^2] / 4 \\ &= 74.6 \text{ mm}^2 \\ J &= \pi[(12.0 \text{ mm})^4 - (7.0 \text{ mm})^4] / 32 \\ &= 1,800.0 \text{ mm}^4 \\ I &= \pi[(12.0 \text{ mm})^4 - (7.0 \text{ mm})^4] / 64 \\ &= 900.0 \text{ mm}^4 \\ S &= 900.0 \text{ mm}^4 / 6.0 \text{ mm} \\ &= 150.0 \text{ mm}^3 \\ Q &= [(12.0 \text{ mm})^3 - (7.0 \text{ mm})^3] / 12 \\ &= 115.4 \text{ mm}^3 \end{aligned}$$

For stress element A (on the top of the shaft):

The force $P_z = 5,000.0 \text{ N}$ creates the following stresses:

a) *Although P_z creates a moment about the y axis, it produces zero flexural stress on stress element A because $z = 0$ at this location. In other words, element A is on the neutral axis for moments about the y axis.*

b) *A transverse shear stress due to the 5,000.0 N shear force. The magnitude of the shear stress is given by:*

$$\begin{aligned} |\tau_v| &= |V_z|Q / I t \\ &= (5,000.0 \text{ N})(115.4 \text{ mm}^3) / [(900.0 \text{ mm}^4) (2 \times 2.5 \text{ mm})] \\ &= 18,599.4 \text{ psi} \end{aligned}$$

Sign convention: Generally, the proper shear stress direction is determined by inspection. The direction of the stress is shown on the stress element.

Summary for stress element A (on the top of the shaft): The normal stresses for the combined loading can be determined by superimposing the individual cases. For stress element A (on the top of the shaft), the total normal stress acting on the element is a stress of 0.0 psi. The shear stresses for the combined loading act in the positive z direction on the positive x face of the element. The magnitude of the shear stress is 18,599.4 psi.

The principal stresses for the element are

$$\sigma_1 = 18,599.4 \text{ psi}$$

and

$$\sigma_2 = -18,599.4 \text{ psi}$$

The maximum in-plane shear stress is

$$\tau = 18,599.4 \text{ psi}$$

and the absolute maximum shear stress equals the in-plane shear stress. This condition occurs when σ_1 and σ_2 have opposite signs.

For stress element D (on the +z side of the shaft):

The force $P_z = 5,000.0 \text{ N}$ creates the following stresses:

a) *A linearly distributed compression normal stress due to a bending moment about the y axis.* The magnitude of the normal stress is given by:

$$\begin{aligned} |\sigma_x| &= |M_y z| / I \\ &= (2.5 \text{ mm})(5,000.0 \text{ N})(6.0 \text{ mm}) / 900.0 \text{ mm}^4 \\ &= 12,086.3 \text{ psi} \end{aligned}$$

The direction of the stress is shown on the stress element.

b) *Although P_z creates shear stress in the shaft, the transverse shear stress on element D in the z direction is zero at this location. When subjected to a shear force in the z direction, the outermost surfaces of the shaft in the z direction are free of shear stress.*

Summary for stress element D (on the +z side of the shaft): The normal stresses for the combined loading can be determined by superimposing the individual cases. For stress element D (on the +z side of the shaft), the

total normal stress acting on the element is a compression stress of 12,086.3 psi. The shear stresses for the combined loading are zero.

The principal stresses for the element are

$$\sigma_1 = 0.0 \text{ psi}$$

and

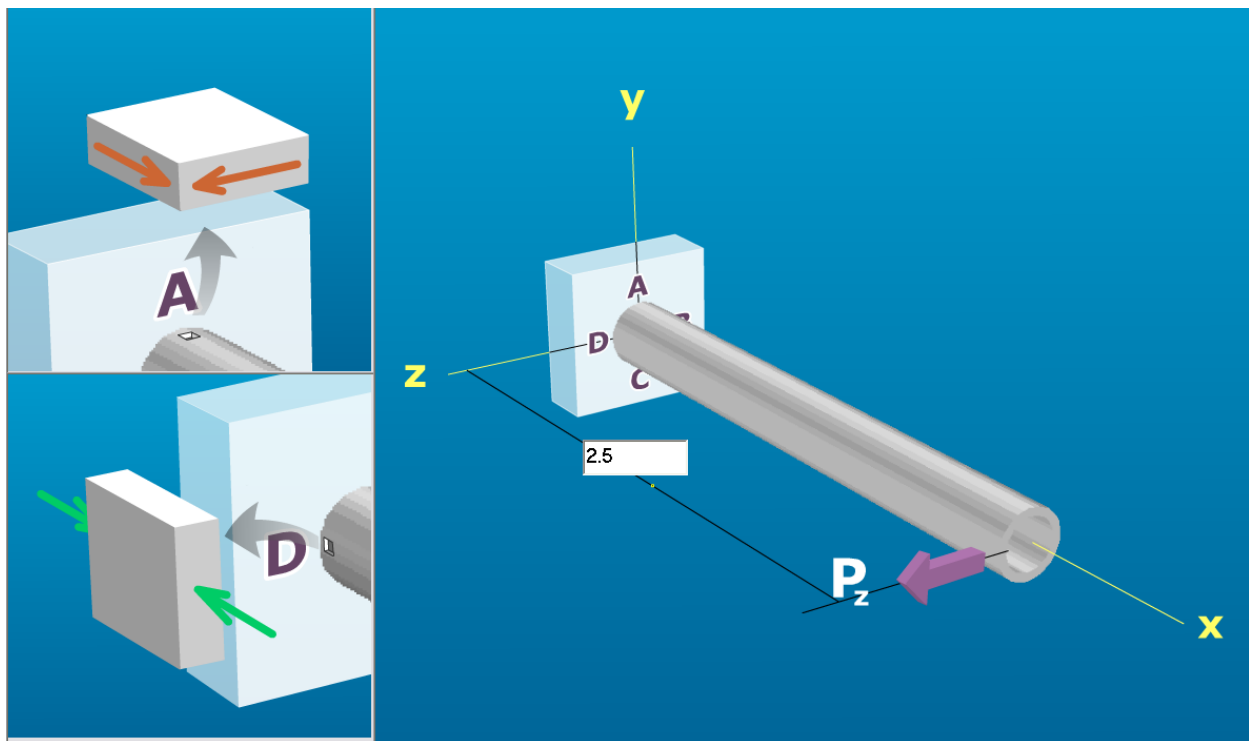
$$\sigma_2 = -12,086.3 \text{ psi}$$

The maximum in-plane shear stress is

$$\tau = 6,043.1 \text{ psi}$$

and the absolute maximum shear stress equals the in-plane shear stress.

This condition occurs when σ_1 and σ_2 have opposite signs.



Appendix I

Manufacturing

All Manufacturing for this project was done by the group. The first step in the manufacturing process was to find the materials. The aluminum parts were cut out of sheet aluminum stock readily available in the machine shop. The other metals had to be bought at onlinemetals.com. There we found the appropriate size stock for the stainless steel and bronze piece. The next step was to cut the stock with the horizontal band saw to the appropriate size. Now we had stock about the size needed to machine our final parts.

All the machining from this point on was done on the HAAS Minimill and the tool paths and NC code was written in Esprit. The first machining operations were facing operations on every part to get them down to the exact rectangle size to perform the final contouring and pocketing operations to cut the part. The facing operations on the aluminum were done with a 3 inch face mill designed for aluminum and the bronze and steel piece were faced with a 2 inch face mill designed to cut steel. These face mills were used in combination with a 5/8th end mill to cut stock which had two opposite faces that were not parallel.

The next step in the process was to perform various contouring and pocketing operations to create the features of the parts. The first part machined was the follower. To create the geometry of the follower two contouring operations were performed. The first contouring operation brought the height of the actual follower surface down to the right size. The next contouring operation created the key that will fit into the base. The tool paths for these contouring operations can be seen below in Figure I-1. The tool used in the first operation

was a 5/8th inch end mill. The tools used in the second operation were the 5/8th inch end mill to perform the roughing cut and a 9/64 inch end mill to perform the finishing cut.

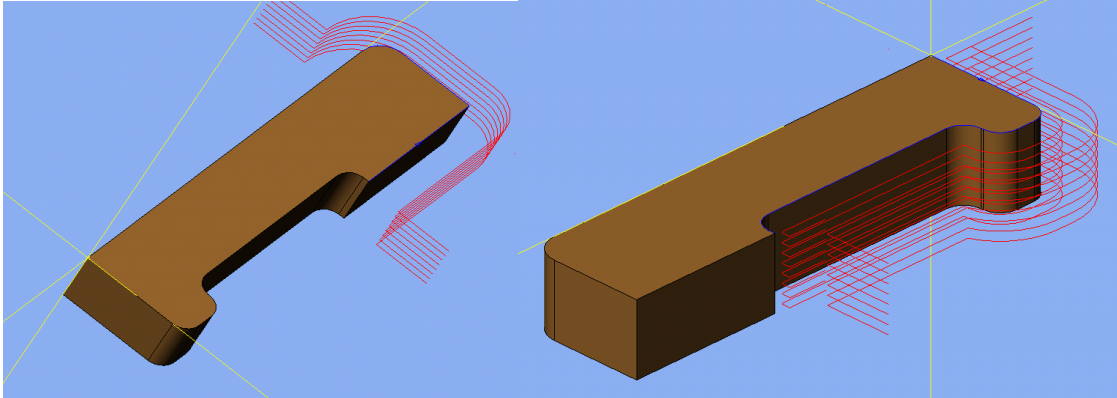


Figure I-1: Follower Tool Paths.

The next part manufactured was the adjustment piece. This piece also had two operations to create it. The first was a drilling operation to create the hole to be tapped for the adjustment screw. This was done with a number 25 drill. The next step was to rotate the piece and create the round using a 9/64th inch end mill. The adjustment piece tool paths can be seen below in Figure I-2.

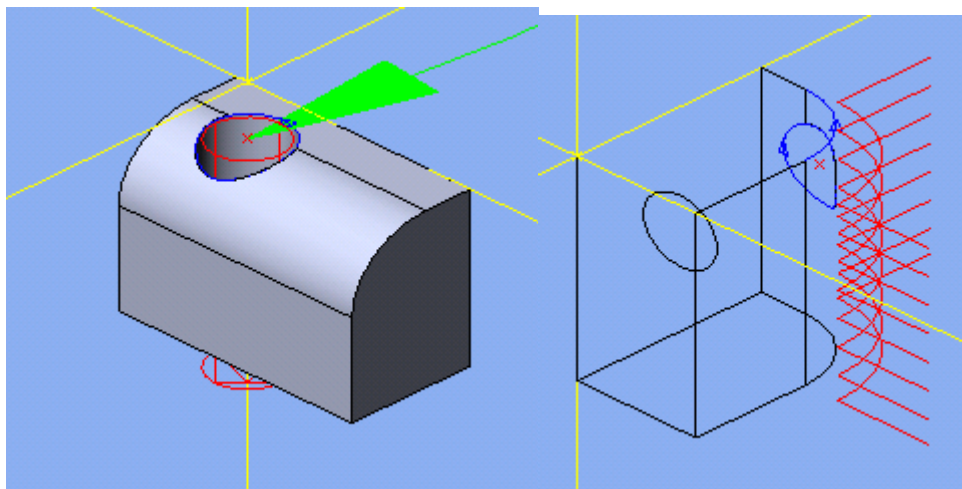


Figure I-2: Adjustment Tool Paths.

The third part manufactured was the cam. The cam had three operations to create it. The first was drilling the four holes to be tapped so that the stock could be fixture without holding its edges so that the circle could be milled. These holes were drilled with a letter B drill. The next step was to tap the holes on the cam and then fixture it to our fixture plate with the same drilled and tapped holes on it. This allowed for the next operation to cut the circle without hitting the vice. The next operation used removed a lot of material using a 5/8th inch end mill and a 5/32nd inch end mill. This operation created the circle, the cam profile, and the recess for the bearing. The final operation created the recess for the center screw to sit in this was also done with a 5/8th inch end mill. The tool paths can be seen below in Figure I-3.

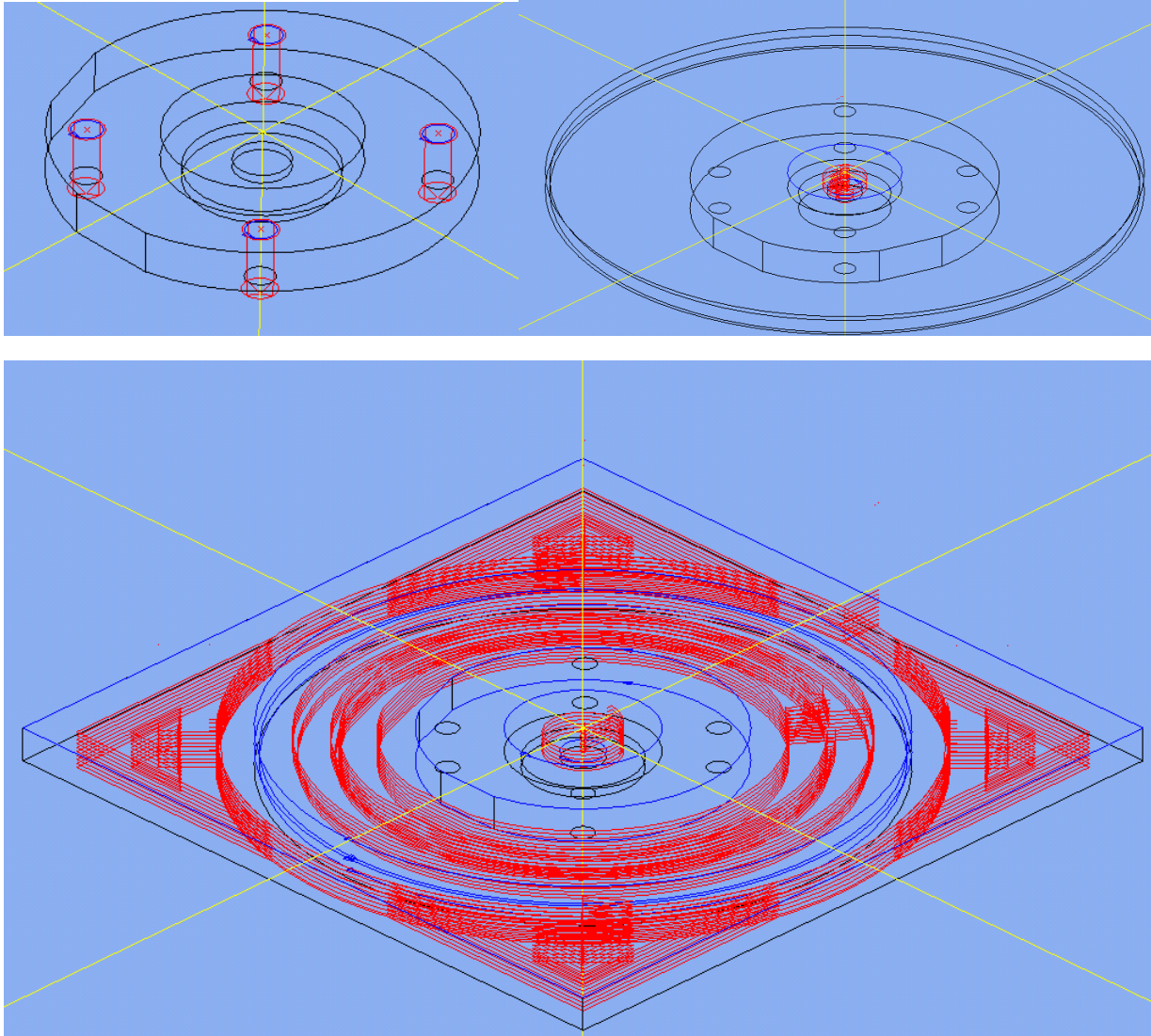


Figure I-3: Cam Tool Paths.

The final part manufactured was the base. This part required three operations the first created the recessed for the base screws using a $5/8^{\text{th}}$ inch end mill and drilled the holes for the attachment to the board with a letter I drill. The next step removed most of the pocket with the same $5/8^{\text{th}}$ inch end mill and then used a series of progressively smaller end mills to create the keyway ($5/16^{\text{th}}$ inch end mill, $5/32$ inch end mill, and $9/64^{\text{th}}$ inch end mill). The hold in the

middle of the post was also drilled with a letter G drill. A round was also added at the bottom of the center post using a 1/8th inch ball mill.

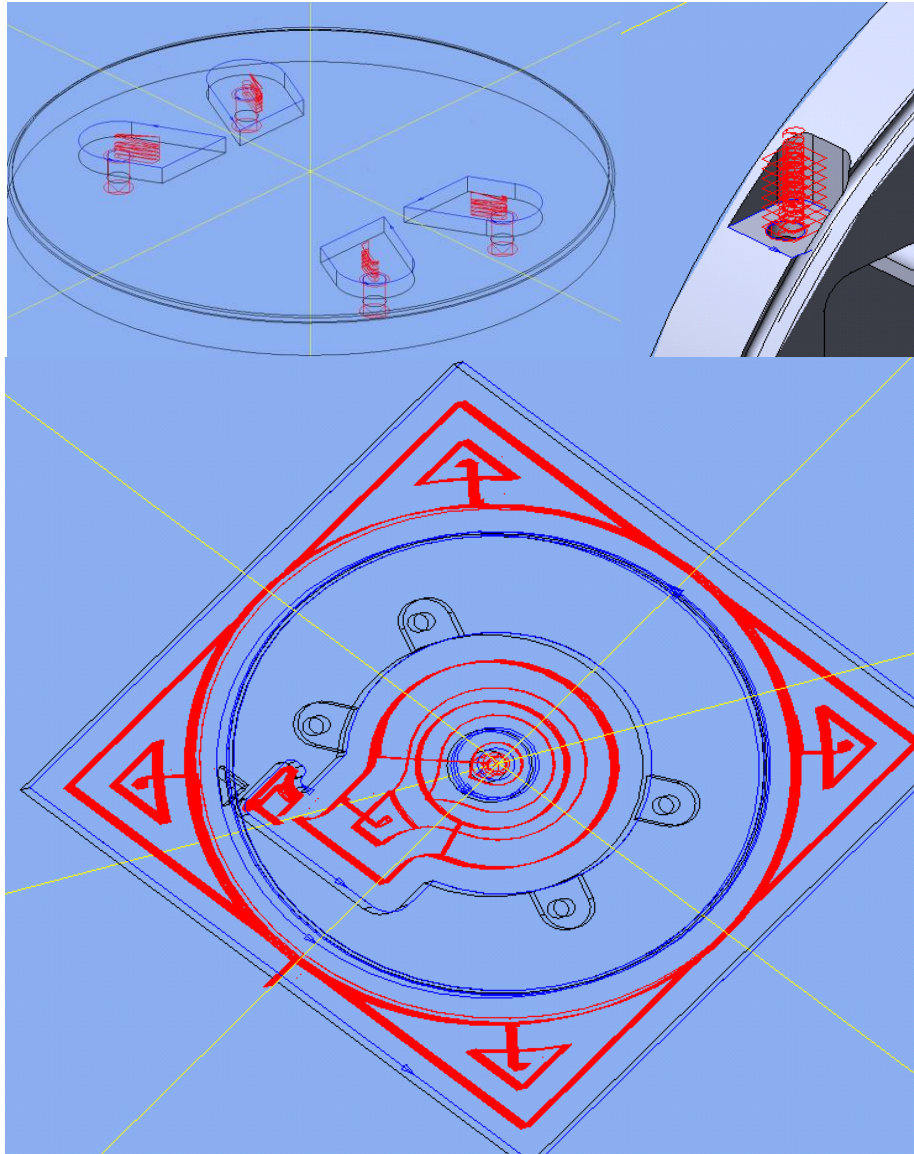


Figure I-4: Base Tool Paths.