Project Number: CAB-1023

DESIGN OF A SNOWBOARD BINDING SUSPENSION SYSTEM

A Major Qualifying Project Report

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Abstract

The objective of this work is to design, build, and test a snowboard binding suspension system that decreases the risk of ankle injuries. Axiomatic design was used to create functional requirements and design parameters based on the goals of the project to ensure that each design aspect was addressed. The system was comprised of four springs that were preloaded to transfer control loads through the device, but absorb potentially injurious loads. This allows the device to act as a normal binding while mediating loads that could cause harm to the rider. Static testing of the device was conducted to examine the extent of work absorbed by the device.

1. Introduction

1.1 Objective

The objective of this work is to design, build, and test a snowboard binding suspension system that decreases the risk of ankle injuries.

1.2 Rationale

Snowboarding, like any other popular outdoor sport, has many risks and potential for serious injury. From 2004 - 2005, the CDC reported that snowboarding had the highest percentage of outdoor recreational injuries (25.5%) that needed treatment by an emergency department (Flores, 2008). In 2001, there were over 54 million visits to ski areas in the United States, 40% of which were snowboarders. These snowboarders were estimated to have an overall injury rate of 4 injuries per 1000 visits (Funk, 2003). From 1988 - 2005, over an average of 16% of all snowboarding injuries were ankle related (Sealy, 2006). One of the most common ankle injuries that occur among snowboarders is the fracture of the lateral process of the talus (LPT).

The talus is an important bone in the ankle that connects the leg to the foot and helps to transfer the loads across the ankle. It is responsible for the rotary and hinge movements of ankle (Boon, 2001). The talus bone is an integral part of maintaining control of a snowboard. Due to its location and the nature of the fracture, a LPT can be hard to diagnose on a normal x-ray scan, and a computed tomography (CT) scan may be needed to accurately locate the fracture. If the injury is left untreated, it can cause ongoing pain and long term disability. The main cause of LPT injury is violent trauma such as high impact landings (Funk, 2003). High velocity landing from ramps or jumps can cause large impact forces to the ankle that could result in a fracture of the LPT.

By decreasing the forces transferred to the ankle, the chances of an LPT injury due to trauma will decrease. Our device acts as a suspension system that is used to mitigate impact forces that could potentially cause injury.

1.3 State – of – the – Art

There are many different patents for a snowboard suspension device, but none have been found on the market. Table 1 compares four different types of patents and this project's design. In the table, the patents are broken down into their design concepts as well as the absorption method used in the device.

The patents that were found fall under two types of absorptions methods; foam layers, and metal springs. The patient designed by Higgins uses a system of four springs that are oriented perpendicular to the top of the board. The springs are sandwiched between the snowboard and a top plate, which attaches to the binding. This design restrains the movement in the vertical direction as the springs compress to absorb loads.

The patient design by Cumby uses a set of plates located between the binding and board that act as a cantilever beam spring. The plates are offset from one another to allow for one of them to bend when there is a load applied. The amount that the plates bend and absorb is determined by the material of the plates.

Sanders' design uses multiple foam layers that are located between the binding and the snowboard, which absorb all loads through it. Gyro also uses a foam layer, but they are sandwiched between two plates with four hinges that are used to connect the two plates together. The top plate is attached to the binding and the bottom plate is attached to the snowboard. The hinges allow for the binding to move in the horizontal direction, parallel with the snowboard, while compressing to absorb loads.

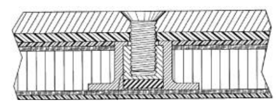
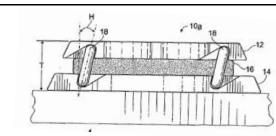
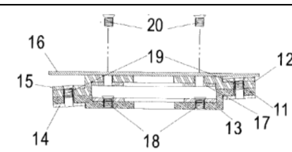
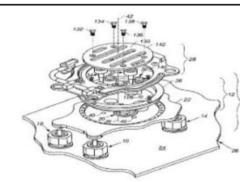
Patent Number	Design Concept	Absorption Type	Diagram
US 2004/0227311 A1 (Sanders, 2004)	• Shock-absorbing apparatus	• Multiple foam layers	
US2004/0232656 A1 (Gyr, 2004)	• Snowboard suspension device	• Foam layer insert • Use of a hinge	
US 2004/0100069 A1 (Cumby, 2004)	• Snowboard suspension device	• Cantilever beam • Four polyurethane plates	
US 6296258 B2 (Higgins, 2001)	• Shock-absorbing apparatus	• Allows a movement along an axis perpendicular to the surface of the board	
MQP Design	• Snowboard suspension device	• Suspension springs are adjacent to binding • Contains a preload	

Table 1: Patent Breakdown

1.4 Approach

Based on the State-of-the-Art, the foam layer and spring systems each have their advantages and disadvantages. The foam layers keep the overall height of the binding low, but absorb all loads that are applied to them, including the loads that are exerted to control the snowboard. This creates a different riding feel and can possibly hinder the user's control of the snowboard. The spring systems are dependent on the compressive properties of the spring, and increase the overall height of the binding. This design will improve the state-of-the-art by decreasing the height of the device, providing a means of adjusting the suspension and by including a preload that only allows the device to compress under potentially injurious loads.

Our device will transfer any control loads to the snowboard without interference from the device to provide the rider with full control of the snowboard, but will compress to absorb potentially injurious loads. This device is capable of adjusting the preload to accommodate different users since each user might need a slightly different setting for different weights and skill level. The unique design of this device allows the device to fully compress without any interference from the springs, so that the maximum height of the device can be reduced without sacrificing the amount of compression.

This project used Axiomatic Design as a framework for the design process. The goal of Axiomatic Design is to provide "the designer with a theoretical foundation based on logical and rational thought process and tools." (Suh 2001, p. 5) In Axiomatic design, the main objectives of the project are identified as the highest level Functional Requirements (FRs). These FRs are then broken down into each aspect and components to ensure that the FRs are collectively exhaustive. The FRs should also be mutually exclusive so that any changes made to one FR will not affect the others. For every FR, there is a corresponding design parameter (DP). The design parameters are the devices that accomplish the FRs.

2. Functional Requirements

Axiomatic design discomposes the different objectives of a project into functional requirements (FR) and design parameters (DP). This breakdown allows the designers to assure that everything in the project gets accomplished. The FRs should be decomposed and decoupled until a solution is apparent. The objective of this project is to create a snowboard binding that will decrease the risk of ankle injuries. The FRs and DPs were developed together, but in order to avoid redundancy in this report, the FRs and DPs are broken up into different sections. For ease of terminology, we have assigned the x direction to be parallel to the snowboard, and the z direction to be perpendicular to the snowboard, and the y direction to be out of the board.

We have broken down the major FRs into three main branches. Each of these branches is further broken down to incorporate the different components of each branch. The first main branch is the transfer of control loads from the foot through the device and into the snowboard, the second main branch is to mediate the potentially injurious loads that are transferred between the foot and the snowboard, and the last branch is to prevent possible snow build up in the device.

2.1 FR 1: Transmit Control Loads

The first main branch in the decomposition of this project is to transmit control loads from the foot to the board in all directions except for the y direction. The control loads are loads that the rider exerts in order to maneuver the snowboard. The control loads are first transmitted from the foot to the binding of the snowboard. They are then transmitted from the binding to the device and then transmitted through the device and into the snowboard. Since the control loads are a crucial part of snowboarding, our device should not hinder the transfer of these loads. To decouple this FR from the second FR, we distinguished the loads transferred to be those in the x direction and the z direction.

2.2 FR 2: Control Vertical Loads

The second branch of the functional requirements is to control the loads in the vertical direction. This branch is decoupled from the first one in that it is only specific to the y direction. Forces can be transmitted in the positive y direction, out of the snowboard, or in the negative direction, into the snowboard. The device should be able to transmit any loads in the positive y direction, such as trying to lift the snowboard. The potentially injurious loads, that we are concerned about, act in the negative y direction. As stated in the previous branch, the device should be able to transmit control loads in the negative y-direction, but in the event that a potentially injurious load is encountered, the device should absorb some of the load to prevent possible injury. Another part of this branch is to be able to adjust this absorption system so that it can be adjusted for variable loads.

2.3 FR 3: Prevent Possible Snow Buildup

The third main branch is to prevent potential snow buildup. This FR was added to maintain the functionality of the snowboard in the environment that would be common to snowboard use. The inner springs and displaced space of the plate needs to be free of snow in order for the device to operate.

3.0 Design Parameters

Using Axiomatic design, concept ideas began to take shape. Each design was taken into consideration of how well it would fulfil all the axioms and how easily it could be manufactured. The first concept ideas for the device can be seen in Appendix C. An exploded view of the final design, which was considered the best fit for fulfilling the objectve, can be seen in Figure 1.

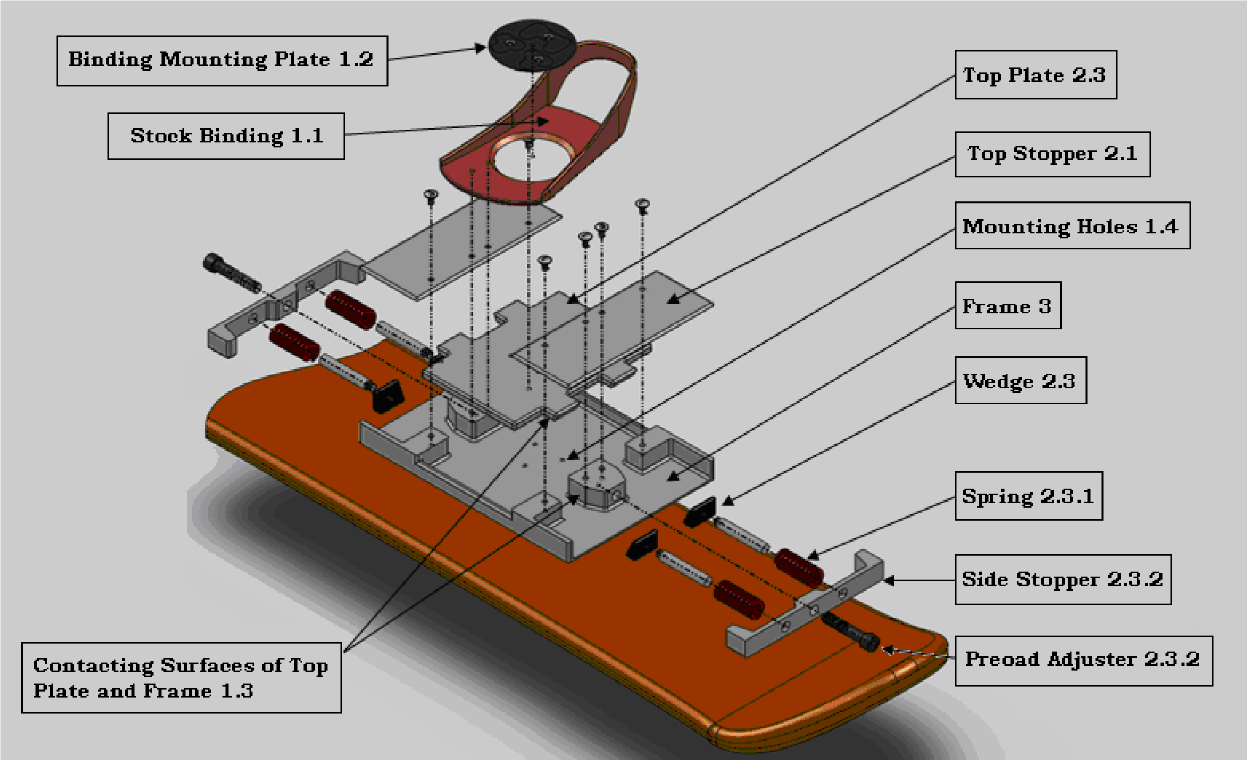


Figure 1: Exploded Assembly View of the Device

3.1 DP 1: Transmit Control Loads

To control the horizontal loads, no movement in the x and y direction will be allowed. This was done using tight tolerances for the plate and frame interface. The area described can be seen in Figure 2, the interfacing areas are shown in green. The space where the top plate fits against the frame was toleranced for a sliding fit. This fit is close enough for the top plate not to shift back and forth along the width of the snowboard. The width of the top plate was also toleranced to slide between the inner walls of the frame. This allowed for the top plate to not shift back and forth along the length of the snowboard. By tolerancing this plate to have a sliding fit with the frame around all edges, the device itself would not move in any horizontal direction.

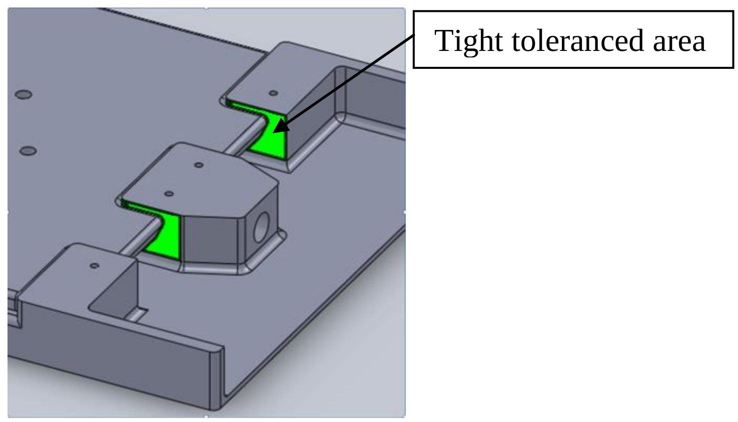


Figure 2: Top Plate–Frame Interface

3.2 DP 2: Control Vertical Loads

The mitigation of loads in the vertical direction is the prominent requirement for this project. The directions of the loads were broken up into the positive y-direction and the negative y-direction, this was to determine what loads would be absorbed.

3.2.1 FR 2.1: Transmit Any Magnitude of Loads in the Positive Direction

It is necessary to transmit all of the vertical loads to allow for normal control of the board during tricks such as jumping. All loads must be transferred to ensure that the device stays secure to the board, which is done through the existing hardware on the board. The top stoppers are screwed into the frame and control the distance that the top plate can travel upwards. This ensures that the top plate does not shoot out of the device and allows for the snowboard to be lifted.

3.2.2 FR 2.2: Control Edging Loads in the Negative Direction

In order to maintain safety, the snowboarder must to be able to transmit control loads to the snowboard. These control loads are transmitted through the snowboard by bringing the snowboard on its edge to carve into the snow and make a turn. The device has to be able to transmit these control loads, but absorb loads that could cause injury. A preloaded system was implemented since it would this requirement. The maximum loads that a rider exerts on a snowboard to edge were calculated and was used to determine the preload of our device.

3.2.2.1 The Preload System

The preload system is comprised of four wedge assemblies, two side stoppers, the top plate and two preload adjusters. Each wedge assembly is made up of one spring, one wedge and one shoulder bolt. The shoulder bolt screws into the drilled and threaded hole in the wedge. The spring fits snug around the shoulder bolt. The assembly is placed in the frame and is sandwiched between the top plate and the side stopper. The top stopper also ensures that the preload system does not move vertically. One of the preload systems can be seen in Figure 3.

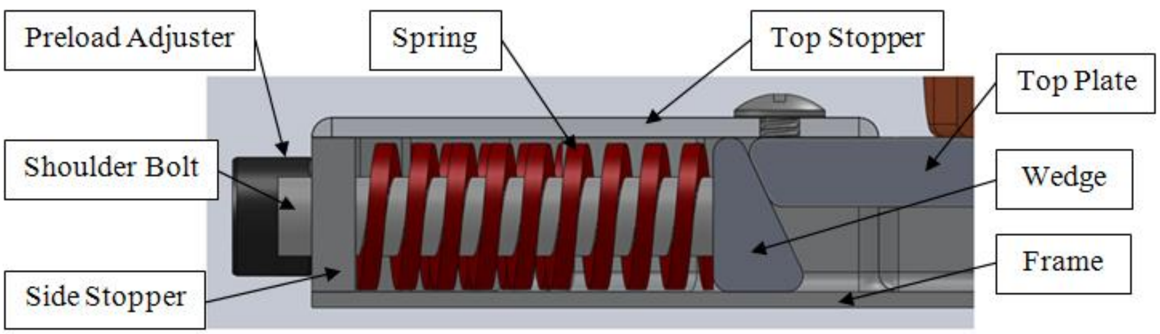


Figure 3: Preload System

The spring used for the system is 2–1/2” in length and have a compression rate of 322 lbs/inch. The space between the side stopper and the back of the wedge is around 2”. The reason for the 1/2 inch discrepancy is so the springs can be pre-loaded. This side stopper can be moved in and out of the frame using the preload adjuster to change the loading on the spring. The springs, combined, were calculated to have a total preload of 400 pounds. This preload was determined based on the calculated edging loads. In theory, the system should not move until loads greater than those needed for control are reached.

3.2.3 FR 2.3: Absorb Potentially Injurious Loads in the Negative Direction

Once the control loads are passed, the device will active. The top plate will begin to descend, pushing the wedge assemblies outwards. The spring compresses against the side stopper. This series of events transfers vertical loads to horizontal loads, preventing the potentially injurious loads from traveling to the rider's ankle. Once the impact has passed the springs push the top plate back up so the rider can continue without harm. Unfortunately, the device is not bottomless. Once the top plate bottoms out (when it completes its full descent of .375 inches and hits the frame), all loads will transfer directly from board to ankle as if the device was not in use. There is no preventing this action due to the trade off of size of the device.

3.3 DP 3: Prevent Snow Buildup

If snow enters the device, its effectiveness will decrease. A buildup of snow may cause the parts to slide incorrectly or prevent the top plate from completely descending. Also, the snow would cause corrosion. The frame was designed to prevent snow from getting under the top plate and to house all of the moving components. The side stoppers also have a tight fit on the frame so that no snow can enter from either side of the device. The top stoppers also prevent snow from entering the device from the top.

3.4: Finite Element Analysis

Finite Element Analysis (FEA) was done using SolidWorks 2009, Student Edition. The majority of the FEA done was for the wedges since they are necessary for most load transfer, and to the top plate, because it is the second largest and heaviest part in the device.

3.4.1 FEA of the Wedges

The wedges were analyzed for deformity under the sliding top plate. This was done to compare the deformation of Aluminum 6061 T6 and Delryn. The wedge was fixture at the bottom and on the back face. The slanted face was then selected to be a sliding fit and a load of 175 pounds which is around ¼ of the injury force specified earlier. The results for the aluminum and Delryn wedges FEA can be seen in Figures 4 and 5, respectively.

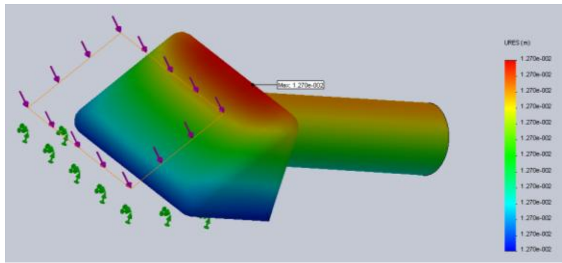


Figure 4: FEA of Wedge made of Aluminum 6061 T6

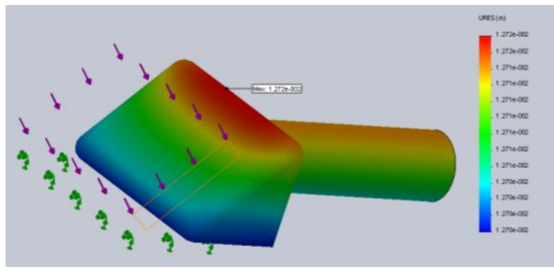


Figure 5: FEA of Wedge made of Delryn

Both materials under the same conditions performed similar in deformation. The aluminum had a surface deformation of 0.0461 inches. This is compared to the Delryn which deformed 0.0501 inches. Even though the Delryn would deform 5 hundredths more than aluminum, it was still chosen to be used for the wedges due to its low coefficient of friction when sliding against an aluminum plate.

3.4.2 FEA of the Top Plate

Multiple pocketing designs were made to decrease the weight of the part. The "Two Bar" design shown in Figure 6 was picked because it has the least deflection out all the pocketing profiles and it also removed the most unnecessary material. The other pocketing design can be seen in Appendix E. Also it was a relatively easy solution to the problem of the top plate hitting the hardware that connects the device to the snowboard.

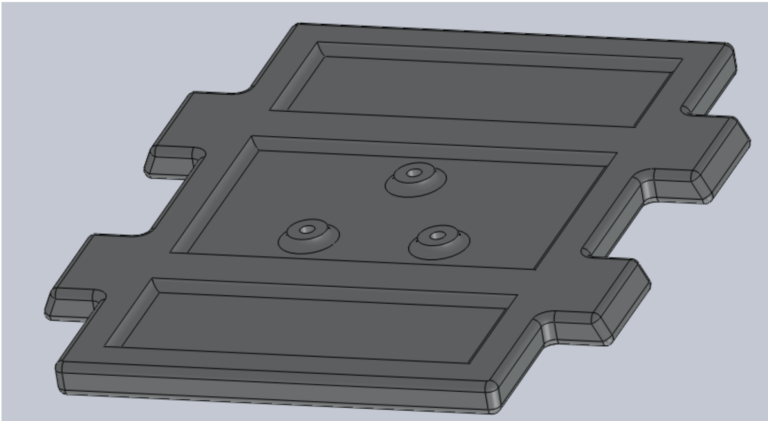


Figure 6: Bottom Side of Top Plate, “Two Bar” Design

When performing the analysis, the wedged faces of the top plate were set as fixed elements since they are where all the vertical loads flow through. All the other faces on the sides of the device were selected to be sliding fixtures. A theoretical maximum load of 750 pounds was applied to the top face of the top plate. The results of the test can be seen in Figure 7. The areas where the top plate most deflected are shown in dark red. It was calculated that the top plate would deflect 0.00265 inches. This was compared to the same test done on a non-pocketed top plate that resulted in a deflection of 0.00235 inches. Since the difference of deflection was in the ten-thousandths, the pocketing profile was deemed acceptable.

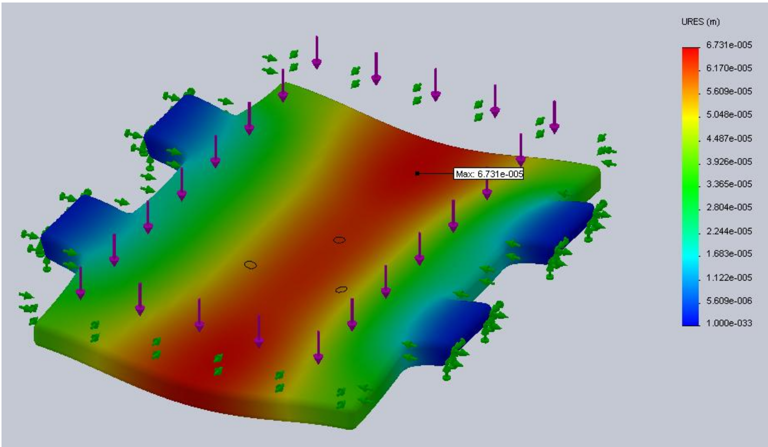


Figure 7: FEA of pocketed top plate

4.0 Production of the Prototype

The prototype was built using CNC machining mills. The parts designed in SolidWorks were imported into the Computer Aided Machining (CAM) Program Esprit, where the tool paths and cut profiles were programmed. The CAM programs were then loaded onto HAAS CNC mills. The prototype wedges were cut in HAAS Minimills, while the rest of the parts were cut in the HAAS VF4, which is larger and has a spindle capable of 12,000 RPMs.

6061 T6 Aluminum was chosen as the material out of which to make the prototype. Aluminum was chosen since it is a cheap material that is easy to machine. Aluminum is less dense than steel, which makes it easier to machine. Other lighter materials were also considered, but they are very expensive and due to cost constraints of the project, a cheap material was selected for the prototype. Every part except for the four wedge pieces were machined using 6061 T6 Aluminum.

4.1 Machining

The software ESPRIT was used for machining. ESPRIT allows for the planning of the tool paths that are going to be used when creating the desired part. The general process for creating tool paths is to export the solid model or assembly out of SolidWorks as a STEP file and import it into ESPRIT. When the part has finished loading, a stock material layer is added so the visual process for making the tool paths can be created and simulated. The origin then needs to be carefully thought out and placed on a feature of the part or on a corner of the stock material. The origin has to be accessible by the probe so it is oriented correctly with respect to the tool paths, and to make the machining process easier. The next step is to select all the tools that will be used for each of the tool paths and input all the required information for each tool, such as the tool length and width. Each face of the part may require different profiles and tool paths depending on the type of operation and the features that need to be machined. The different types of tool paths consist of pocketing, facing, drilling, and contouring. Each tool path has many different variables associated to creating the desired profile or features, these variables can be seen in Table 2.

Variables	Descriptions
Cut Depth	The total depth that the cutter has to travel to reach the desired face.
Starting Depth	The height that the tool path starts cutting at.
Incremental Depth	The increment at which the tool path lowers for each path.
Speed Rate	The rate at which the tool spins.
Feed Rate	The rate at which the part is fed or moved towards the spinning tool.
Pass Blending	This allows each pass to be spiraled into the next pass.
Entry Path	The path the tool uses to enter the stock material, the options are move over then down, or move down then over.
Exit Path	The path the tool uses to exit the stock material, the options are move over then up, or move up then over.

Table 2: Tool Path Cutting Variables

The tool paths were transferred to the machines where they were previewed using the current commands and then setting graph keys to preview the function of the desired tool path. The machining for the majority of our parts went smoothly with a few exceptions. The first set back that was encountered was that the frame walls were 0.25" to large. This discrepancy was the result of the profile selection tool that was selected to stop at the edge of the chamfer of the plate. This was undesirable and was corrected using an offset in the program by 0.25" which corrected the problem. Another problem that occurred was during the machining of the stopper plates, the tool started to chatter because there wasn't enough material to prevent the stock from moving. It was also fixtured length wise and this allowed the stock to act as a tuning fork and vibrate. However this wasn't a huge problem due to the fact that the finish of the surface had no function to the device.

4.2 Production of the Wedges

The wedges were manufactured out of the thermoplastic, Delryn. Delryn has a low coefficient of friction, which is ideal for our sliding interface. The sliding of aluminum on aluminum would result in great friction, a deciding factor in the application of Delryn wedges.

Additionally, aluminum sliding against aluminum has a corrosive effect, similar to that in a battery. By utilizing Delryn, any corrosive effects are avoided. Other plastics were also considered, but Delryn's strength under compression makes it ideal for the forces the wedges undergo. Delryn is one of the few machinable plastic polymers readily available, adding to its attractiveness for use in the suspension system. As an extremely lightweight polymer, Delryn would be an ideal material for other parts on the prototype, such as the frame and the top stoppers, but for the first prototype, it was cheaper to build and test an aluminum system. The prototype aluminum wedge pieces can be seen during production in Figure 8. From there, reductions in material, and the anticipated mechanical properties of a lighter weight material can be predicted after testing the aluminum prototype.

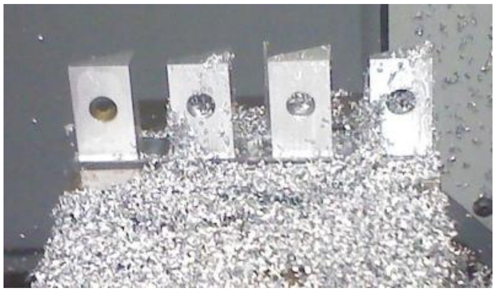


Figure 8: Trial Run for Machining Wedges

4.3 Purchasing of Materials

Commercially available parts were ordered from the company McMaster-Carr. The screws that hold down the top stoppers, the bolts that hold in the side stoppers and the Die Springs were all ordered through the McMaster-Carr online internet service (See Appendix F for details on ordered parts).

It was necessary to find a spring that has the properties needed to fulfill the proper forces and preload. The springs have to be very specific, as they are the most important part in determining what loads are transferred and what loads are absorbed. Die springs with the necessary properties were found on the McMaster Carr website. Each spring takes 155 pounds to compress at a rate of 322 pounds per inch. The springs fit a specified 2-1/2 inch length, and have a ½ inch to fit the guide rod (shoulder screw). The die springs were also selected for their red coat of paint. Aluminum and steel are far apart on the galvanic scale, so the coat of paint is necessary.

The top screws are capable of withstanding a tensile strength of 72,000 psi. Based on calculations of the force translated vertically by the top plate in an unloaded system, and the force exerted when the top plate springs back up after compression, the top screws are well over a safety factor of 500 pounds. The adjustment screws were selected based on the frame body thickness and screw combination that would provide the most tensile strength. The chosen combination uses a self-locking screw capable of withstanding 180,000 psi, well above the calculated force, and withheld all forces during testing. Shoulder bolts were ordered to fit inside the diameter of the die springs. The design parameter was to ensure that the die springs would not torque or slip out of alignment. The shoulder bolts screw into the wedge pieces, and during compression of the device, the ends slide out of the side stoppers. During assembly and testing, it was found that if the device is assembled properly, the pressure on the die springs holds them in place without the use of the shoulder bolts. Therefore, the shoulder bolts were removed in order to reduce weight, with no adverse effects to load bearing capability and reaction characteristics.

5.0 Testing of the Final Design

5.1 Tolerance Testing

The last operation to be done before assembly was tolerance testing. The parts need to fit within desired tolerances. The system design uses very tight cuts, to the ten-thousandth of an inch. During manufacturing, we were unable to meet some of these tight degrees. All parts were measured with a caliper set that measured distanced to the thousandth of an inch. When the parts were finished, and assembly was attempted, some of the parts were found to be outside the five-thousand tolerance range we wanted, and the top plate cuts were found to be up to a quarter of an inch off.

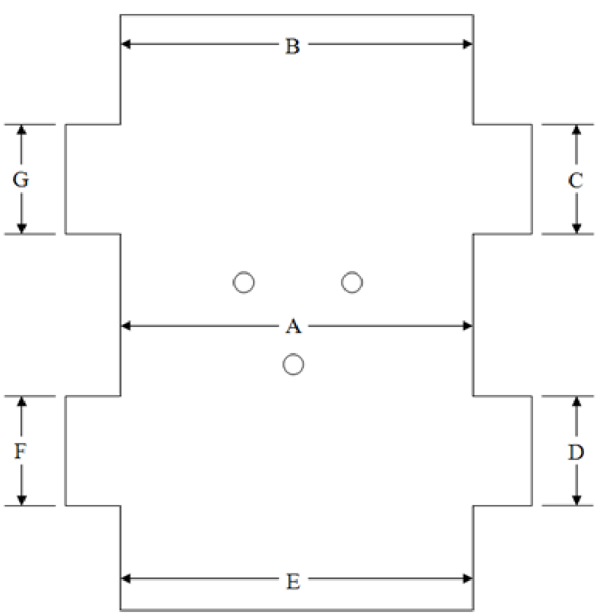
The frame was found to be the most accurate and symmetrical piece, within one ten-thousandth of all desired measurements. Therefore, it was selected as the reference from which to tolerance the other parts. This was particularly convenient, as all of the other parts either fit into or attach to the frame. The other parts were measured and their tolerance factor recorded.

Parts that were outside tolerance were ground to specification on the manual mill, and with CNC machining.

5.1.1 Tolerance Test Results

The side stoppers were measured and found to be one hundredth of an inch too long and did not fit properly inside the frame. They were ground down with a half inch end mill in a HAAS mini-mill to meet a five thousandth of an inch tolerance for sliding. Three out of the four wedges were found to be too wide for the frame. Each wedge was manually ground down separately to ensure a proper fit with the same five thousandth of an inch tolerance as the side stoppers.

The top plate was the most difficult part to fix. The initial manufacture of the part in the CNC machine was not programmed properly, and the entire part was a quarter inch too long in width. An eighth of an inch was taken off each side, following the established contour. This operation was performed on the manual mill, with a half-inch end mill. In order to meet the tight radius needed at the wedge points, a quarter-inch end mill was used afterwards. The same eighth-inch was taken off the wedge portions, and the 65 degree angle re-cut, using a sine table.



	Frame Length [in]	Top Plate Length [in]	Off By [in]	Amount to Remove [in]
A	5.743	5.863	0.120	0.130
B	5.736	5.856	0.120	0.130
C	1.502	1.498	-0.004	0.006
D	1.490	1.499	0.009	0.019
E	5.746	5.865	0.119	0.129
F	1.491	1.497	0.006	0.016
G	1.503	1.498	-0.005	0.005

Figure 9: Top Plate Tolerance Test

Tolerance testing provided clear insight of how the intended design and tolerance were able to be met, and how they were not able to be met during production.

5.2 Static Load Testing

Static load testing was done to observe how the top plate descends and if the preload works properly. The test was completed using a weight rig that was constructed out of a 2X4 piece of wood, stainless steel hooks, stainless steel chains tested for 750 pounds each, cast iron nails, and 25 pounds and 45 pounds weighted plates that are used for weight lifting. The static loading test can be seen in Figure 10.

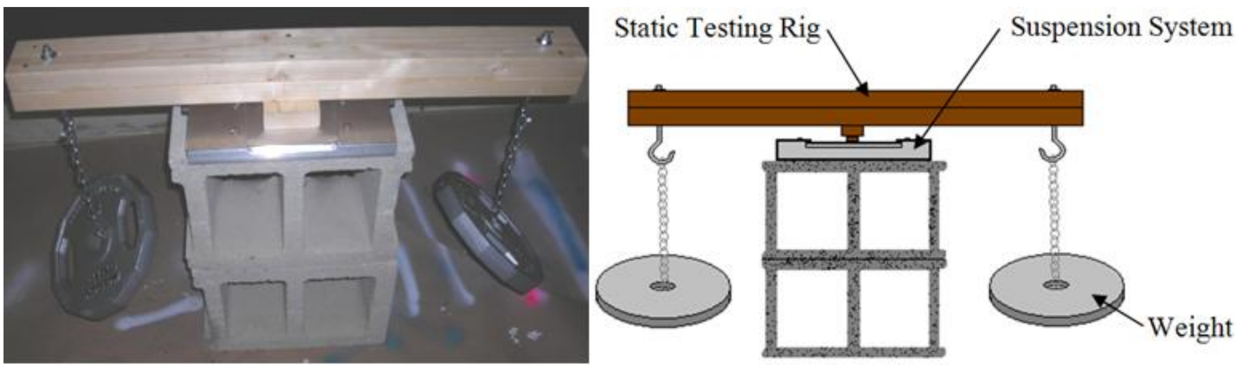


Figure 10: Static Testing Device

The testing device weighed 7 pounds before adding the weighted plates. To conduct the test, two cinderblocks were stacked one above the other. This was done to ensure no personal benches, tables or chairs were damaged from applying over 700 pounds to the system. The suspension device was placed on top of the cinderblocks, then a tiny square of 2X4, and then the testing device was placed on top of the wood square. The square is necessary to observe if the device will work if the loads are concentrated in the front, middle, and back side of the device. Either a 25 pounds or 45 pounds plate was hung on each chain and was held in place by the cast iron nail. After adding a weight to each side, the displacement of the top plate was measured with a caliper set. The decent was recorded at each 40 and 50 pound increments until maximum loading of around 750 pounds is reached.

5.2.1 Static Loading Test Results

The results of the static loading test can be seen in Figure 11. The graph shows that the preload was successful**.** The top plate stayed relatively stationary before the control load level of 300 pounds was applied. Studying the graph, it becomes apparent that the preload system would have to be tightened slightly. This is because the top plate began to move before the control loads when the loading was focused on the back of the plate and in the corner. This can be easily fixed for future testing by tightening the side stoppers to apply a higher preload. The device also bottomed out before the injury threshold was reached. This was expected and also acceptable because the device was not over engineered and absorbs loads between the control loads and the injury threshold.

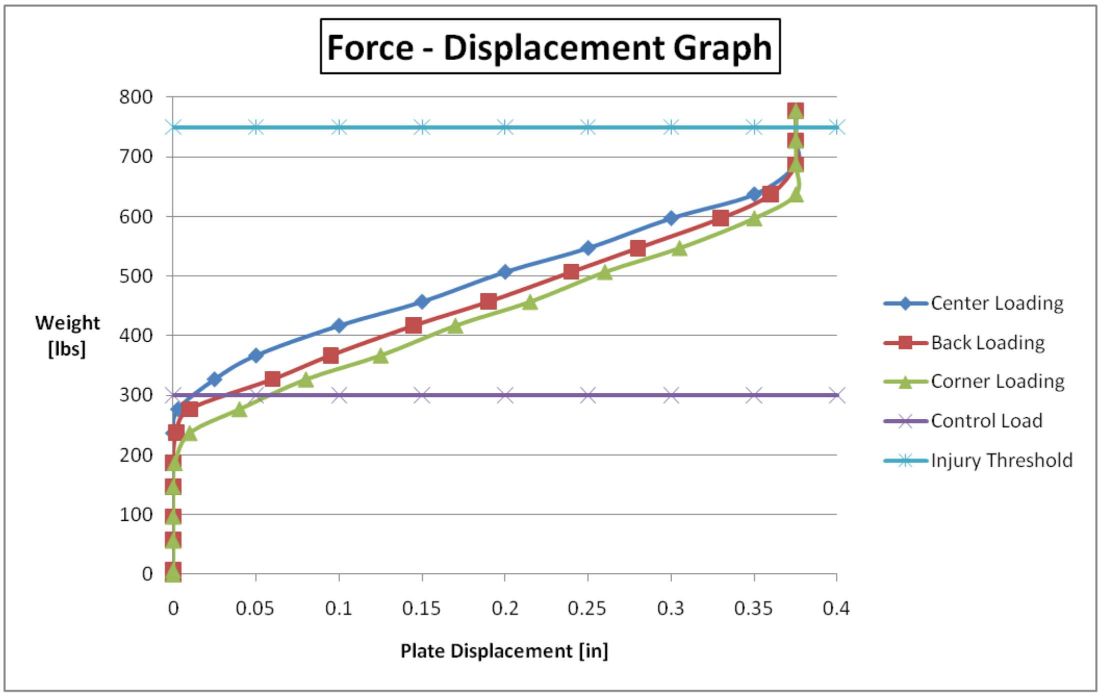


Figure 11: Force Displacement Graph

5.3 Dynamic Testing

Dynamic testing was to be performed on snow; unfortunately this was not possible due to the warm weather conditions at the time manufacturing was completed. The test consisted of the rider doing a sharp turn, a bunny hop which is a stationary jump, and going off the jump. The rider would then determine if the ride felt unchanged during a turn, and if the device appears to absorb some of the forces from the jump.

Since this testing methodology was unable to be fulfilled, the device was simply placed on the ground. A “rider” then stepped onto the device to see if the device would compress. The device did not compress, agreeing with the static load testing. Next, the “rider” applied some load by shifting their weight up and down, and side to side, simulating a mogul or turning, to observe if the top plate compressed. The top plate descended only slightly, meaning the device only had to absorb a small amount of the load. The “rider” then jumped on the device to try to fully compress the top plate. It is unsure if the device fully compressed, but it was observed that the top plate did descend more than in the previous test. The “rider” commented that jumping on the device did not hurt as much as anticipated. Using the comments made by the “rider” it is assumed the device performed successfully.

6.0 Discussion

Axiomatic design was a useful method for designing that helped to organize the objectives. It helped to show how things interacted with each other and how we could decouple things to make the design process easier. At first, the concept of axiomatic design seemed to hinder the development of ideas, but after taking a critical look at the process, it helped to analyze our concept ideas. The most effective way that we used axiomatic design was to narrow down our ideas in the conceptual designs so that we addressed all the FRs. By having the list of FRs, we were able to take each concept design and match each component with their corresponding DP. The software that we used for the axiomatic design was Acclero DFSS ™ Version 5.0. The software created an outline for our FRs and DPs, and we were able to organize them to see if they were coupled.

7.0 Conclusion

In order to decrease the amount of potentially injurious loads traveling into the Talus bone of the ankle during big-air, flat-landing snowboard riding, a snowboard binding suspension system was created. Using Axiomatic Design, the control loads were decoupled from the loads that would be absorbed, allowing for the creation of a system that would only absorb injurious loads. It also allowed for a requirement to make the device adjustable to a rider's weight. This was done using a horizontal spring preload system with a floating back that can loosen or tighten the spring system. The preload system was adjusted to prevent the top plate from descending until roughly 300lbs of force was applied, at which point, it would descend linearly with any additional amount of weight applied thereafter. All the parts for the device were modeled in SolidWorks. The parts that were not ordered were machined using Esprit software and HAAS machining mills. All machined parts were made out of Aluminum 6061 T6 except for the wedges which were made out of Delryn. Delryn was chosen because of its low coefficient of friction against the sliding aluminum parts.

After the device was manufactured and assembled static testing took place. The test consisted of a weight hanging rig that was placed on the top plate where the binding would be fastened. The rig was loaded gradually with 25 and 45 pound weights. The descent of the top plate was recorded at each weight increment. An abridged form of dynamic testing was performed, where a rider stood on the device and jumped on it to see how the top plate would recoil. The top plate performed as expected, allowing a descent after a large load is applied and to spring back up to the original position. Upon reviewing the data collected from the static testing the prototype was declared successful; the preload did not activate until the weight applied was equal to around the calculated control loads and it also theoretically absorbed loads that would be potentially injurious to a snowboarder's ankle.

8.0 References

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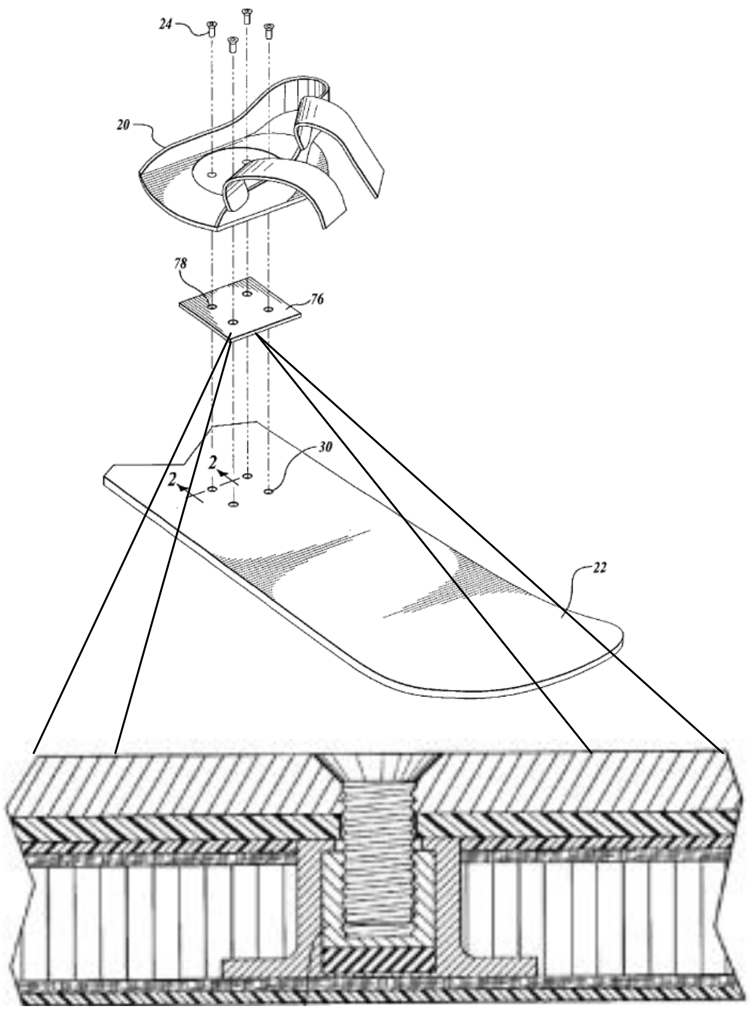
Appendix

Appendix A: Patent Research, Continued

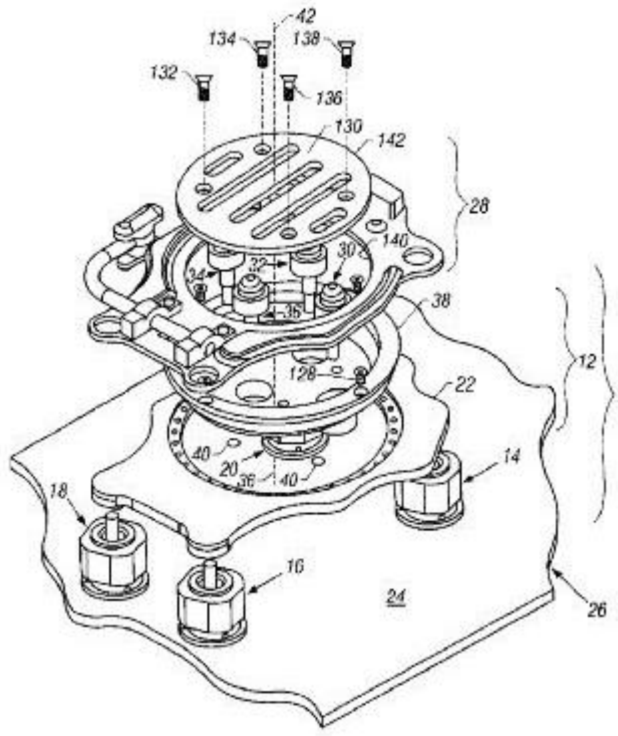
Binding Insert Suspension System, Sanders. 2004. Patent US 6296258 B2.

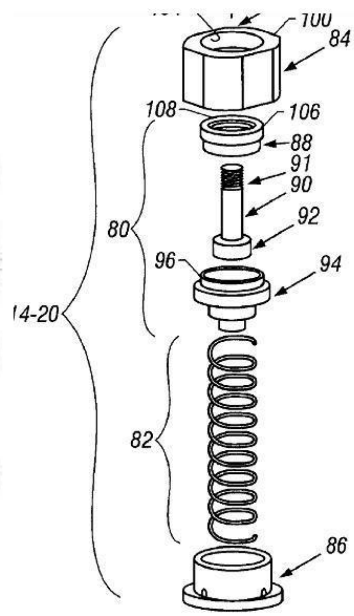


This patent is for a foam layer that is placed between the snowboard, and the standard binding. The holes in the insert are for the fastening hardware from binding to board. The hardware allows for the rider to control the board normally. The insert is comprised of multiple foam layers to absorb the loads when the rider lands after having big air. The foam layer is very thin and can be compressed only to a certain limit. The insert will absorb loads, but the amount of absorption depends on the type of foam used. The foam layer must be stiff enough to allow for an adequate absorption.

Shock-Absorbing Apparatus. Higgins, 2001. US2001/0001520 A1.

The snowboard shock-absorbing apparatus operates between the snowboard binding and the snowboard. The top plate of the binding is screwed into the top of the apparatus, which is a wider plate. The corners of the apparatus are fastened to the board with a bearing system. Each bearing systems allows a swivel from, or movement along an axis perpendicular to the surface of the board.





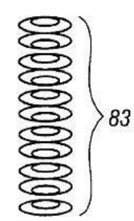
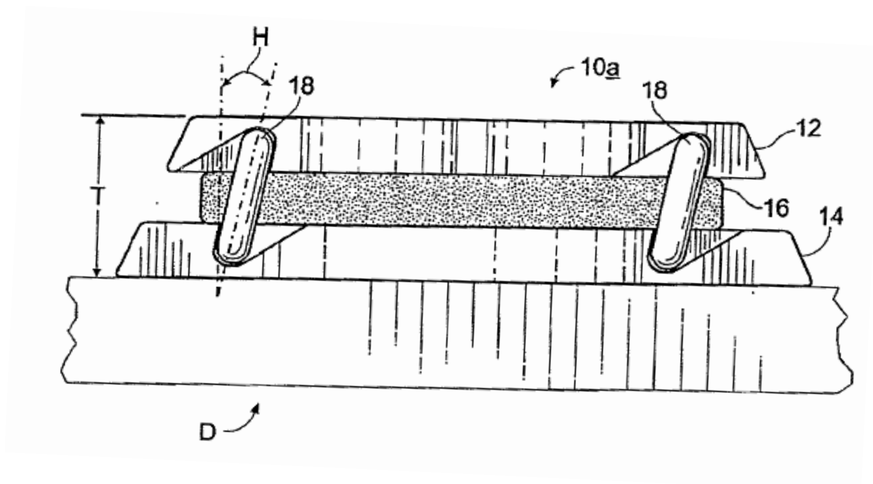


FIG. 5B

Each bearing has a spring inside of a cylindrical housing. A sliding pin is inserted into top of the spring housing, and screwed to the apparatus plate (to which the top plate is fastened). The pin has a large head and sits on the spring. The pin is able to push down on the spring but, not to exit the hole in the top of the cylinder, as it is the diameter of the pin. The bearing system is to the board at the bottom.

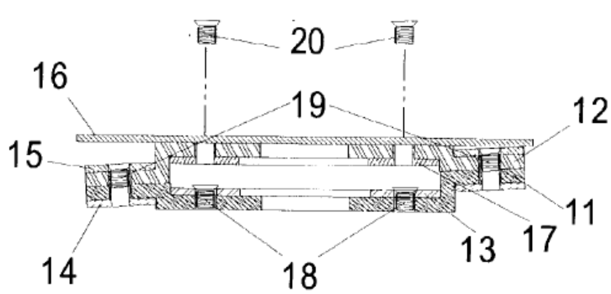
Snowboard Suspension Device. Gyr, 2004. US2001/0232656 A1.

This patent depicts a snowboard suspension device. This device is designed to absorb forces when the snowboard rider is navigating mogules on the mountain. This device absorbs forces in a two part system, the first is through the use of a hinge (part 18) on the drawing. This hinge allows the top plate (part 12) move down to the bottom plate (part 14), the second part is the foam insert (part 16) which does the absorption of the forces.



Snowboard Suspension Device. Cumby, 2004. US 2004/0100069 A1.

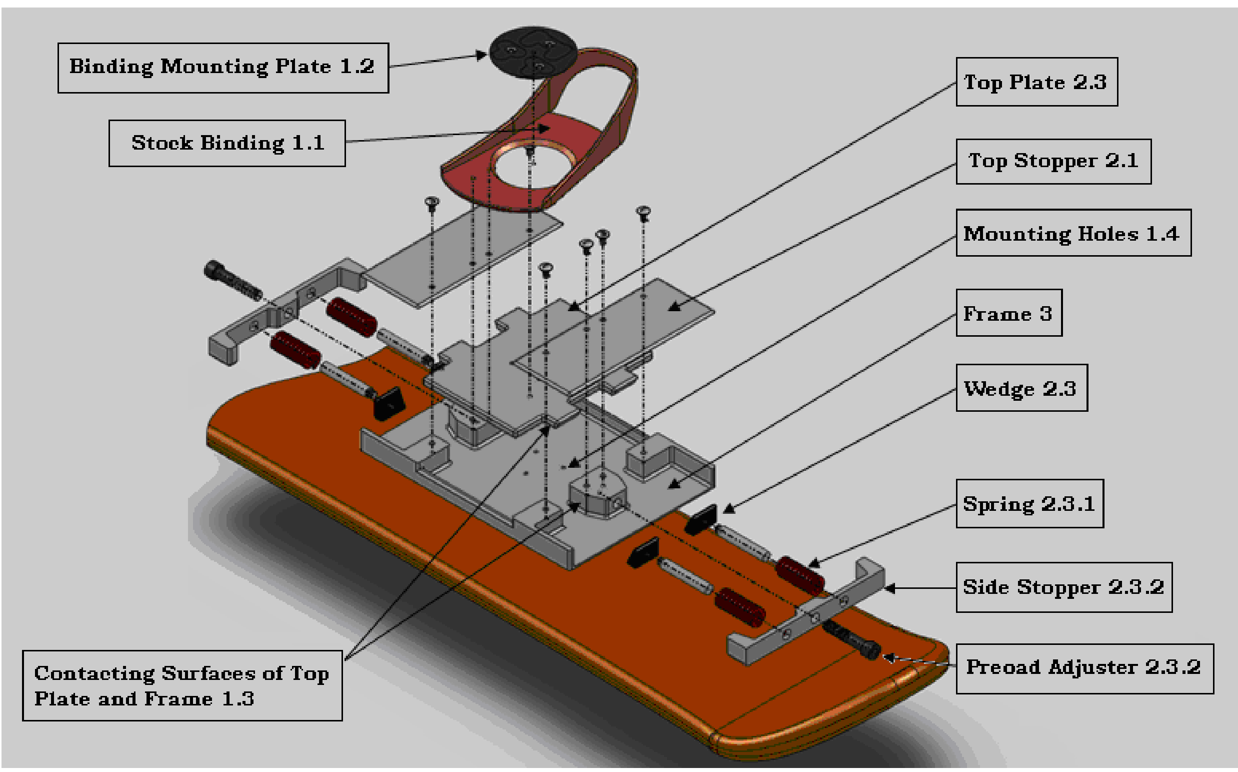
This patent shows the design of a snowboard suspension device that dampens the forces produced by a snowboard. This is done through two different means. The energy from the snowboard is transferred through the device via a set of four plates that are shaped and arranged to create a pocket. These plates would be made of a polyurethane material that is capable to bend and absorb energy. The pocket created by the plate allows the top plate to deflect in a cantilever motion to absorb and store energy. Various holes in the top and bottom plate provide an interface to attach the device to the snowboard.



SECTION B-B

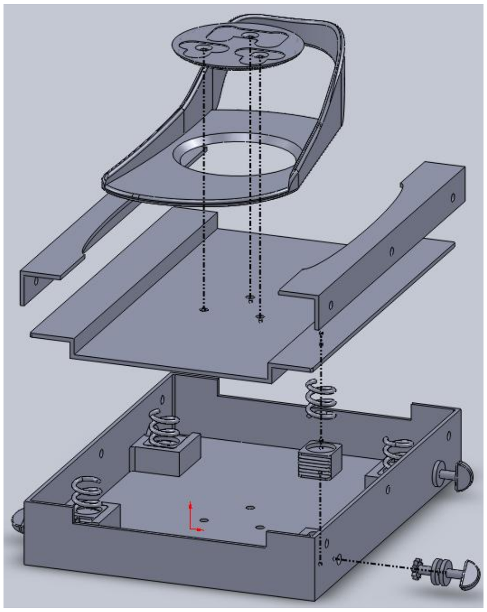
Appendix B: Acclaro Decomposition

#	[FR] Functional Requirements	[DP] Design Parameters
0	FR Decrease vertical, potentially injurious loads from board to ankle	DP Snowboard binding suspension system
1	FR Transmit control loads from the foot to the board in all directions, except in the vertical	DP System for transmitting control loads between the rider and the snowboard
1.1	FR Transmit loads from foot to binding	DP Existing binding
1.2	FR Transmit loads from binding to device	DP Binding attached to device
1.2.1	FR Transmit loads in the x-direction	DP Fastening hardware
1.2.2	FR Transmit loads in the z-direction	DP Fastening hardware
1.3	FR Transmit loads through the device	DP Interacting parts of device
1.3.1	FR Transmit loads in the x-direction	DP Close running fits for interacting part profiles
1.3.2	FR Transmit loads in the z-direction	DP Tight tolerance framework
1.4	FR Transmit loads from device to board	DP Bottom of device frame flush with the top of the board
1.4.1	FR Transmit loads in the x-direction	DP Fastening hardware
1.4.2	FR Transmit loads in the z-direction	DP Fastening hardware
2	FR Control loads in the vertical direction	DP Horizontal preloaded springs
2.1	FR Transmit any magnitude of loads in the positive direction	DP Top stoppers
2.2	FR Transmit control loads in the negative y-direction to maximum edging load	DP Preloaded spring system
2.3	FR Absorb potentially injurious loads in the negative y-direction	DP Plate descending .375 inches
2.3.1	FR Absorb through a certain means	DP Horizontal springs
2.3.2	FR Adjust to variable load	DP Preload system
2.3.2.1	FR Adjust to body weight	DP Spring adjustment screw
2.3.2.2	FR Adjust to activity i.e. taxiing, flat landing etc.	DP Spring adjustment screw
3	FR Prevent potential snow build-up in the device	DP Snow blocking shell around device



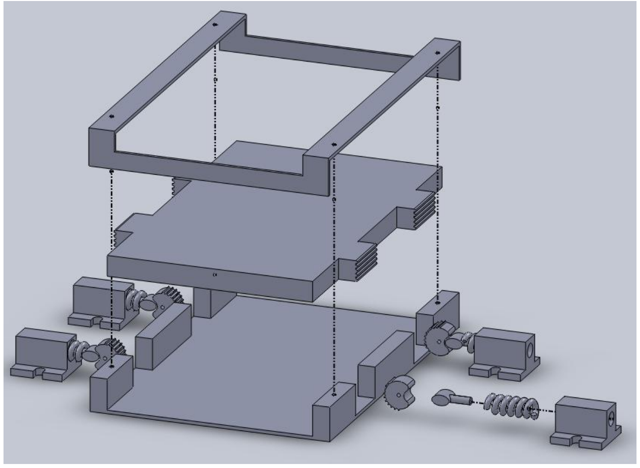
Appendix C: Concept Designs

Concept Design 1: Vertical Spring Box Design



This design concept was inspired by one of the existing designs that we found in the patient searches. This design implements four vertical springs resting in between a top plate and worm gear mechanism. The worm gears mechanisms are used to change the preload of the spring. This is done by turning the gears to raise and lower a platform that the springs sit on, thus, compressing or extending the springs. The binding is attached to the top plate of the device and the device is attached to the snowboard with the existing screws.

Concept Design 2: Horizontal Spring Geared Cam Design



This conceipt design is our first iteration of the final design we chose to build. The springs are moved off to the side of the device. The top plate has gear teeth that inface with the cam profile. Uses a cam profile to keep the plate from moving. The springs keep the cam profile form moving.

Appendix D: Force Calculations

Max force an ankle can withstand is 2200N – 4000N (Boon et al. 2001) an average of 3600N

Turning force: $F = \frac{Mv^2}{r}$

Average Mass (M) = 85kg

Average Velocity (v) = 15 m/s

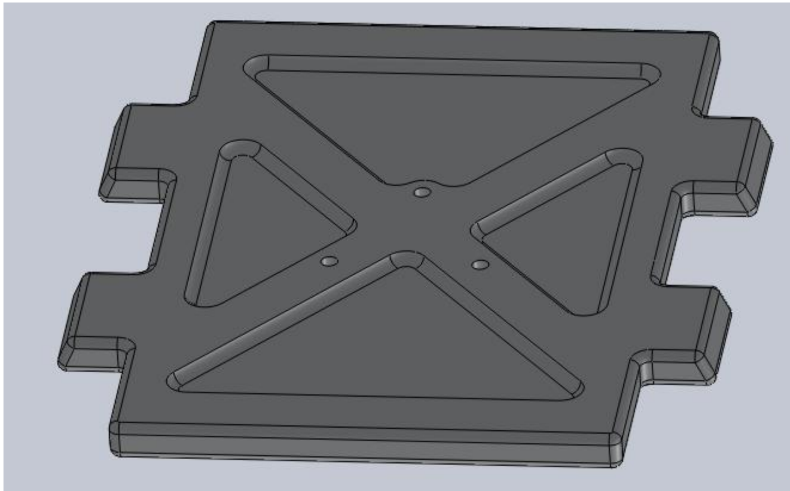
Calculating for different radius turns

Radius of Turn (m) r=	30	25	20	15	10	5	4	3	2
Total Force (N) F=	637.5	765	956.25	1275	1912.5	3825	4781.25	6375	9562.5
Force Per Binding (N) =	318.75	382.5	478.125	637.5	956.25	1912.5	2390.625	3187.5	4781.25

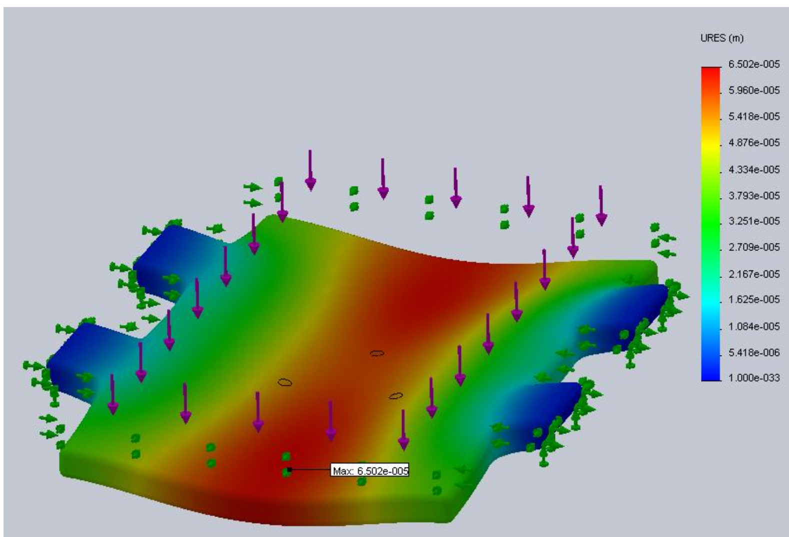
The spring was established based on the injury load of 3600 distributed between 4 springs for a total of 900N per spring, or 202 pounds.

Appendix E: FEA Iterations

X - Style



Bottom View of X – Style



FEA of X – Style

6.802×10^{-5} m = 0.00268 inches deformation

Appendix F: Ordered Parts Specifications

Springs:

- Product number 9584K53
  - 2–1/2” length
  - 1/2” rod fit size
  - Load needed to compress: 155lbs
  - Rate 322 lbs/inch

Shoulder Screw:

- Product number 91259A724
  - 3" Length
  - Inch Thread Size 3/8”–16
  - 1/2” Shoulder Diameter
  - Shear Stress 84,000 psi

Top Screws:

- Product number 91785A537
  - 1/2” length
  - Inch Thread Size 1/2”–20
  - Maximum Tinsel Yield Strength: 72,000 psi

Adjustment Screw:

- Product Number 91205A722
  - 2–1/2” length
  - Inch Thread Size 1/2” – 13
  - Maximum Tinsel Yield Strength: 180,000 psi
  - Self Locking Nylon Patch

Top Stopper Stock Material:

- Product number 89015K18
  - Aluminum Allow 6061
  - 12” x 12” x 1/8”

Top Plate Stock Material:

- Product number 8975K341
  - Aluminum Alloy 6061
  - 12” x 8” x 1/2"