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Design of a Spring Loaded, Tilting Binding Plate

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DESIGN OF A SPRING LOADED TILTING BINDING PLATE

A Major Qualifying Project Report

Submitted to the Faculty

of the

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Table of Contents

Table of Figures

Abstract

The objective of this work is to design and build a device to reduce the incidence of inadvertent release and ACL injuries for skiers. The device is a spring-loaded, tilting binding plate. As with current binding plates, it provides a connection between the binding and the ski. Inadvertent release occurs when sufficient work is done on a binding to separate the boot and the binding. Inadvertent release often results in loss of control, which has been known to result in serious injuries and death. Axiomatic design was used to link functional and physical decompositions through the hierarchy and avoid unwanted coupling. In particular, it was important to decouple pitch, roll, and yaw so the spring system only influences pitch (fore and aft) and vertical displacement. Both roll and yaw loads are transferred through an interlocking "half moon" coupling mechanism. The approach is to increase the "work to release" without impairing the transfer of control loads from binding to ski. The binding plate may be displaced under the heel and toe to absorb injurious loads.

1. Introduction

1.1 Objective

The objective of this work is to mitigate two injury-causing phenomena that occur during normal skiing. The first such phenomenon to be avoided is inadvertent release. Likelihood of inadvertent release will be decreased by a function of the device that increases the “work to release” at the binding’s heelpiece. The device is also intended to mitigate the rate of ACL injuries caused by boot induced anterior drawer (BIAD) (Webster and Brown 1996). It is intended that the device will mitigate ACL injuries by absorbing sudden force applications (impulses) and releasing them over a longer period of time.

1.2 Rationale

This device is extremely important to the sport of skiing. According to an epidemiological study conducted using data from Norwegian ski resorts, knee injuries represented about 25% of all ski injuries that occurred between 2002 and 2004 (Ekeland and Rodven 2006). Of all knee injuries, “Anterior cruciate ligament (ACL) disruption has become the most common severe injury” (Johnson et al. 2003). Two specific mechanisms are known to cause ACL injuries: the “phantom foot profile” and “boot induced anterior draw (BIAD)” (Webster and Brown 1996) (Johnson et al. 2003). The “phantom foot profile” often begins with a backwards fall; the tail of the downhill ski and ski boot work to create a lever arm or “phantom foot”, placing an injurious load (bending and twisting) on the skier’s knee (Knee Injuries). This particular mechanism neither requires the skier to be travelling quickly nor does it require steep terrain. BIAD is similar to the “phantom foot profile” when considering the motion involved. BIAD occurs when the tail of the ski and the ski boot form a lever arm pushing the tibia forward, in relation to the femur, thus placing an injurious load on the ACL

(Webster and Brown 1996). Two typical incidents are known to cause this sort of injury: a skier landing off balance to the rear after a jump and a stationary skier being hit from the rear by another person (or object) (Knee Injuries).

Millions of people around the world participate in the sport of skiing both for recreation and competition. Injuries as a result of this sport can be extremely costly and disruptive; not only to the skier himself but also to society at large. "ACL injuries have been estimated to cost the United States hundreds of millions of dollars annually" (Webster and Brown 1996). While this estimate may seem like a small sum today, the cost has undoubtedly grown with inflation and increasing incidences of ACL injury in the current era. All economics aside, ACL injuries represent a potentially life changing event for the skier. After undergoing surgery and rehabilitation most athletes will eventually return to their sport however, with reduced ability (Radford).

1.3 State – of – the – Art

Currently there are many different binding plates on the market. Almost every binding manufacturer has developed a plate to work specifically with their binding. No design has been found however, which claims to mitigate inadvertent release or ACL injury. Most designs reviewed have two basic functions, according to their patent documents: elevation of the binding and damping of ski vibration (Maggiolo). The objective of elevation is most often satisfied in designing a support structure upon which the binding is mounted, the structure being affixed to the ski's top surface. Damping of vibration is satisfied by a suitable choice of material for the device. An elastomeric material may be incorporated into the support structure as a means of vibration damping, as in a patent assigned to Rossignol SA (Noviant).

1.4 Approach

This design will advance the state-of-the-art by utilization of a binding platform that can move independently, in the vertical direction with respect to the ski (about the pitch axis). The design will incorporate functionality demonstrated by the prior-art in order to maintain ease of use: fixation of bindings to the ski and elevation of bindings. Emphasis will be placed however upon the mechanism for movement of the binding platform. Vertical movement will be regulated by an adjustable mechanism; the device may be calibrated for a variety of skiers. Control of binding platform movement about the yaw and roll axes will be maintained through the use of another mechanism. The author has determined that movement of the binding about these axes should not be independent of the ski.

The design was realized through the use of axiomatic design. "Axiomatic design is a systems design methodology using matrix methods to systematically analyze the transformation of customer needs into functional requirements, design parameters, and process variables" (Suh 1990). In Suh's method, all of the designer's wants become functional requirements

(FR's) while the design features necessary to fulfill the wants become design parameters (DP's). The FR's must be collectively exhaustive; together they must fully describe the desired functionality of the device, while also being mutually exclusive. Mutual exclusivity of the FR's ensures that each of the customer's needs is met, and may be altered independently. By using this method the designer can be sure of two things. First, the design incorporates all of the customer needs that are physically possible and second, that the design is sufficiently "lean". If the FR's are truly collectively exhaustive and mutually exclusive, the customer's needs are met and unnecessary design elements have not been included.

It should be noted that the design decomposition focuses upon mitigating inadvertent release. The same design functions intended to mitigate inadvertent release may also be used to mitigate ACL injuries. Two main differences must be taken into account. First, the forward pitch suspension system used to increase "work to release" may also be used to dissipate injurious loads originating from a backwards – falling motion. Second, adjustability of the suspension system may be used to account for differences in the loads that need to be absorbed for ACL injury mitigation.

2. Design Decompositions and Constraints

The goal of this work, as reflected in FR0, is to add safety to the ski-binding interface. Specifically, the goal is to mitigate inadvertent release and ACL injury caused by BIAD. Multiple constraints apply to the design of a device. The device must retain the use of industry standard alpine ski bindings. Release characteristics of said bindings should not be affected so as to change their intended operation; binding release should still occur at the loads suggested by DIN settings. The device shall be designed for use by recreational and competitive skiers. In light of this constraint, the device shall raise the binding (with respect to the ski) only to a level required by other design characteristics; the device shall comply with FIS equipment rule A2.1.2 (Specifications for Competition Equipment and Commercial Markings). To maintain ski-ability, the device shall be no wider than a typical ski to which it may be affixed; the device shall comply with FIS equipment rule A2.1.1 (Specifications for Competition Equipment and Commercial Markings).

Further constraints may be placed upon the design. Because safety is the primary goal of this device, it must not introduce new hazards to the sport of skiing. The device must also function so as to significantly mitigate inadvertent release and ACL injuries; justification for the device can only be realized through demonstrated results. Manufacturing costs must also be considered while designing the device; it should be mass – produced to reduce cost and increase availability to the customer.

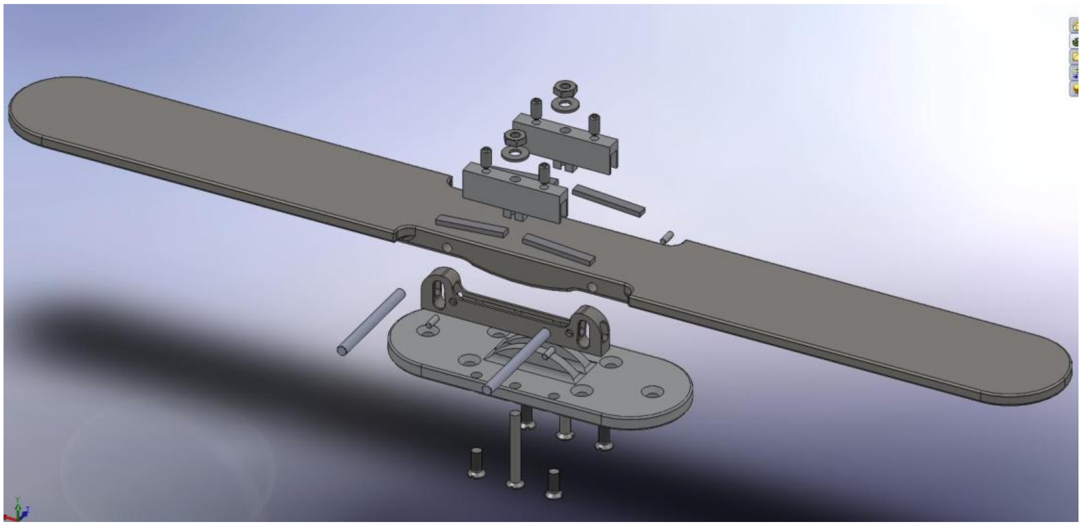

Figure 1

2.1 Level one

2.1.1 Functional Requirements (FRs)

Functional requirements, by axiom one, must be collectively exhaustive and mutually exclusive or CEME at each level in the decomposition (Suh 1990). To be collectively exhaustive the FRs must completely satisfy the customer needs, accounting for each required function of the device. To be mutually exclusive the FRs must not become redundant; each FR should be distinct from others at its level.

The level one FRs (FR1 and FR2) are CE because they satisfy the customer needs based upon functionality identified in the prior art (FR1) and adding safety to the interface (FR2). The FRs are mutually exclusive because they are distinct from one another, no functionality is shared by the FRs.

2.1.1.1 FR0 – Add Safety to the Binding – Ski Interface

The main functional requirement of this design is to add safety to the ski – binding interface. Specifically, the requirement is to add safety by mitigating inadvertent release and ACL injuries due to BIAD.

2.1.1.2 FR1 – Transmit Torque to Ski

The first level FR's begin with the most fundamental function of any binding plate. The plate must successfully transmit torque applied by the skier to the ski and vice versa. It may seem that an FR of binding restraint or binding support would be necessary before FR1. It was decided that binding restraint and torque transmission might be coupled at this high level in the decomposition; in this way binding restraint becomes a design parameter (Section 2.1.2).

2.1.1.3 FR2 – Increase "Work to Release"

Through background research it was decided that increasing the work to release, seen at a binding's heelpiece might mitigate inadvertent release. Figure 2 shows the approximate relationship between heelpiece displacement and applied load.

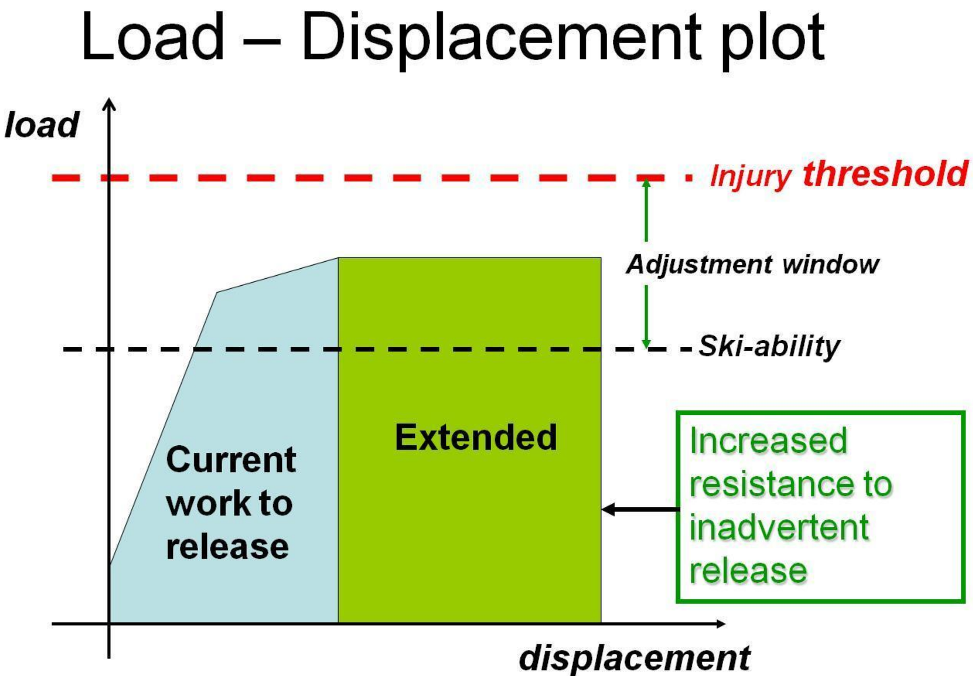

Figure 2

2.1.2 Design Parameters

2.1.2.1 DP0 – Binding – Ski Force Transmission System

This is the highest – level design parameter. As such it describes the system as a whole and does not mention specific features. DP0 is best reflected in the complete assembly of the device (Figure 3).

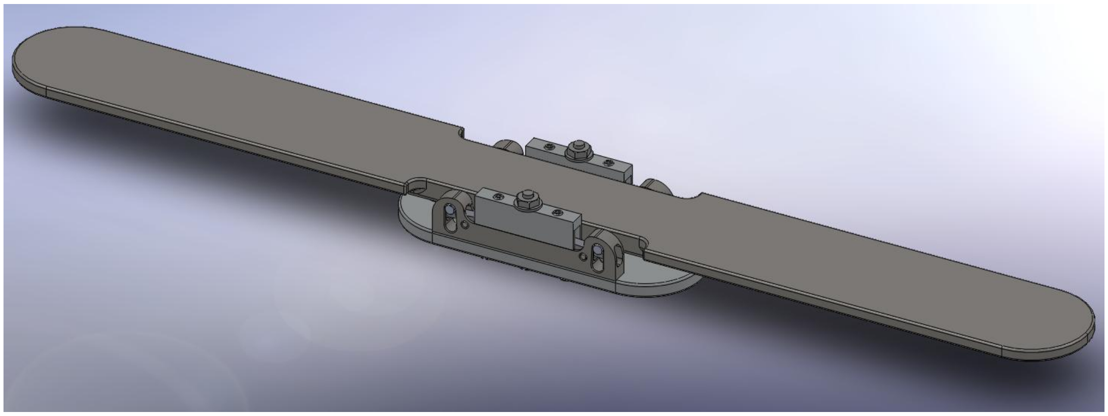

Figure 3

2.1.2.2 DP1 – Binding Restraint System

At this level in the decomposition the binding restraint system includes all structures, surfaces, and components directly utilized to maintain the binding position relative to the ski. FR1 is satisfied by this DP as a rigid connection to the device and subsequently, to the ski, will transmit torques from skier to ski.

2.1.2.3 DP2 – Force Control System

At this level in the decomposition the DP2 structures, surfaces, and components directly utilized to control force transmission and ultimately increase work to release. FR2 is satisfied by DP2 as the force control system increases heel displacement for a given force thus, increasing the work done.

2.2 Level Two

As progressive levels are added to the decomposition, parts and their functions become obvious. At this level components are generally conceived yet specific features are still uncertain.

2.2.1 Level Two Functional Requirements

Level one FRs are decomposed further to determine the functions that comprise the upper level system functionality.

2.2.1.1 FR1.1 – Transmit Torque from Binding to Top Plate

FR1.1 requires that torque be transmitted from the binding to the Top Plate. It is obvious from this FR that the binding must be rigidly attached to the top plate however; features defining the attachment require further decomposition. To maintain complete control over the ski, torque must be transmitted about three axes: vertical, transverse, and longitudinal.

2.2.1.2 FR1.2 – Transmit Torque from Top Plate to Bottom Plate

FR1.2 requires that torque be transmitted from the Top Plate to the Bottom plate. Because the Top Plate is required to move vertically with respect to the ski, it must move vertically with respect to the Bottom Plate. This requires separate treatment of torque transmission about three axes: vertical, transverse, and longitudinal (with respect to the ski).

2.2.1.3 FR2.1 – Allow only Vertical Movement (Kinetics)

Working under FR2, FR2.1 identifies that the top plate need only move vertically to increase the "work to release". Further decomposition is required to determine necessary components and constraints of the vertical movement. FR2.1 addresses the purely kinetic portion of increasing work to release.

2.2.1.4 FR2.2 – Dissipate Injurious Loads (Kinematics)

FR2.2 identifies the second function needed to increase the “work to release”. Further decomposition is required to determine what components are necessary to dissipate injurious loads. FR2.2 addresses the purely kinematic portion of increasing work to release.

2.2.2 Level Two Design Parameters

Level one DPs are decomposed further to determine components and subsystems that comprise the level one “systems”.

2.2.2.1 DP1.1 – Binding – Top Plate Interface

DP1.1 represents a sort of subsystem; it is the connection between the binding and the Top Plate. Though it is not very complex (see sections 2.2.1.1 and 2.2.2.1), multiple design parameters must be considered to verify that FR1.1 is satisfied.

2.2.2.2 DP1.2 – Plate – Ski Interface

DP1.2 is somewhat misleading. While it is called the plate – ski interface, it is actually the Top Plate – Bottom Plate interface. The Bottom Plate is rigidly mounted to the ski, essentially creating a single unit thus they are treated as one. As in DP1.1, a subsystem is identified by DP1.2. To satisfy FR1.2, this subsystem must include components that transmit torque about all three axes.

2.2.2.3 DP2.1 – Hinge System

To satisfy FR2.1, a unique Hinge System must be decomposed. While allowing the Top Plate to move, it must also ensure that the movement is essentially vertical. Further Decomposition is needed to realize necessary components.

2.2.2.4 DP2.2 – Mechanical Energy Dissipation System

To satisfy FR2.2, a unique Mechanical Energy Dissipation System must be decomposed. This system works to dissipate mechanical forces along the path of the Hinge system described by DP2.1.

2.3 Level Three

2.3.1 Level Three Functional Requirements

2.3.1.1 FR1.1.1 – Transmit Torque about Vertical Axis

FR1.1.1 is self – explanatory. It falls under FR1.1 (section 2.2.1.1) and requires that torque about the vertical axis be transmitted from the binding to the Top Plate.

2.3.1.2 FR1.1.2 – Transmit Torque about Transverse Axis

FR1.1.2 is self – explanatory. It falls under FR1.1 (section 2.2.1.1) and requires that torque about the transverse axis be transmitted from the binding to the Top Plate.

2.3.1.3 FR1.1.3 – Transmit Torque about Longitudinal Axis

FR1.1.1 is self – explanatory. It falls under FR1.1 (section 2.2.1.1) and requires that torque about the longitudinal axis be transmitted from the binding to the Top Plate.

2.3.1.4 FR1.2.1 – Transmit Torque about Vertical Axis

FR1.2.1 is self – explanatory. It falls under FR1.2 (section 2.2.1.2) and requires that torque about the vertical axis be transmitted from the Top Plate to the ski (through the Bottom Plate).

2.3.1.5 FR1.2.2 – Transmit Torque about Transverse Axis

FR1.2.2 is self – explanatory. It falls under FR1.2 (section 2.2.1.2) and requires that torque about the transverse axis be transmitted from the Top Plate to the ski (through the Bottom Plate).

2.3.1.6 FR1.2.3 – Transmit Torque about Longitudinal Axis

FR1.2.3 is self – explanatory. It falls under FR1.2 (section 2.2.1.2) and requires that torque about the longitudinal axis be transmitted from the Top Plate to the ski (through the Bottom Plate).

2.3.1.7 FR2.1.1 – Movement under Toe Piece

FR2.1.1 is a partial requirement of FR2.1 (section 2.2.1.3). It requires that the top plate is able to move vertically under the binding's toe piece. This requirement satisfies the kinetic component of increasing the "work to release" and thus mitigating inadvertent release.

2.3.1.8 FR2.1.2 – Movement under Heel Piece

FR2.1.1 is a partial requirement of FR2.1 (section 2.2.1.3). It requires that the top plate is able to move vertically under the binding's heel piece. This requirement provides the path along which injurious loads, originating from a backward fall, are dissipated. This FR satisfies the kinetic component of mitigating ACL injuries.

2.3.1.9 FR2.2.1 – Dissipate Injurious Loads under Toe

FR2.2.1 is a partial requirement of FR2.2 (section 2.2.1.4). It requires that excessive loads be dissipated under the binding's toe piece. This requirement provides the force dissipation, or kinematic component of increasing "work to release" and thus mitigating inadvertent release.

2.3.1.10 FR2.2.2 – Dissipate Injurious Loads under Heel

FR2.2.1 is a partial requirement of FR2.2 (section 2.2.1.4). It requires that excessive loads be dissipated under the binding's heel piece. This requirement provides the force dissipation, or kinematic component of mitigating ACL injuries.

2.3.1.11 FR2.2.3 – Adjust for Different Skiers

FR2.2.3 allows for adjustment of the Mechanical Force Dissipation System's preload. Much like a binding's DIN setting, the adjustment is intended to adapt the device's force dissipation characteristics to different skiers' height, weight, and skiing abilities.

2.3.2 Level Three Design Parameters

2.3.2.1 DP1.1.1 through 1.1.3 – Mounting Screws

DP1.1.1 consists of machine screws used to mount a typical binding to the Top Plate. The mounting screw pattern of typical bindings both rigidly mounts the binding and transmits torque about the vertical axis. DP1.1.2 and DP1.1.3 are simply proof (torque equations) that the same set of mounting screws, in conjunction with the Top Plate, will also transmit torque about the transverse and longitudinal axes.

2.3.2.2 DP1.2.1 and DP1.2.3 – Half Moon – Shaped Coupling Mechanism

DP1.2.1 suggests a mechanism that transmits torque about the vertical axis. The half moon-shaped coupling mechanism, with its closely engaged vertical surfaces, transmits said torque. DP1.2.3 suggests a mechanism that transmits torque about the longitudinal axis. The half moon – shaped coupling mechanism also transmits said torque.

2.3.2.3 DP1.2.2 – Torque Transmitted to Ski through Mechanical Force Dispersion System

Torque about the transverse axis represents a force along the vertical axis applied at a distance along the longitudinal axis. Because the force component is vertical, the torque should be transmitted to the ski through the mechanical force dispersion system in DP2.2 (section 2.2.2.4) by way of the hinge system in DP2.1 (section 2.2.2.3).

2.3.2.4 DP2.1.1 and DP2.1.2 – Front and Rear Hinge

DP2.1.1 and DP2.1.2 each suggest a hinge connection between the Top Plate and the Bottom Plate/ski. Front and rear hinges are required so that the Top Plate may move under the heel and toe piece independently, satisfying FR2.1.1 and FR2.1.2 (sections 2.3.1.7-8).

2.3.2.5 DP2.2.1 and DP2.2.2 – Forward and Rearward Pitch Suspension System

DP2.2.1 and DP2.2.2 suggest independent suspension systems for the toe and heel sections of the Top Plate. The embodiment of each suspension system is a spring and a spring support structure. The suspension systems are independent, and thus satisfy FR2.2.1 and FR2.2.2 (sections 2.3.1.9-10).

2.3.2.6 DP2.2.3 – Preloading System

DP2.2.3 suggests a system for preloading the suspension systems suggested by DP2.2.1 and DP2.2.2. Such a system would satisfy FR2.2.3 (section 2.3.1.11) by providing a means to adapt the suspension system characteristics to an individual skier's needs.

3. Physical Integration

3.1 Top Plate

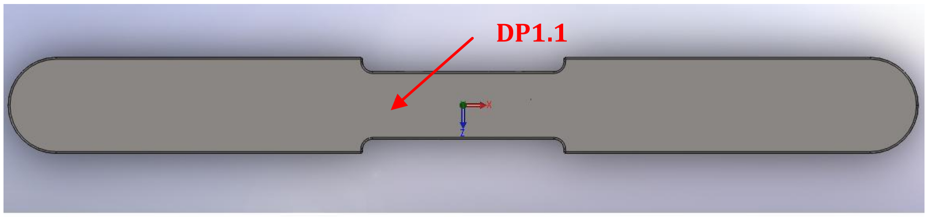

Figure 4

The top plate provides an interface and mounting surface for the binding. Here, loads are transferred from the binding to the rest of the device. FR1.1 is satisfied entirely by the top plate's top surface; figure 4 identifies the top surface as DP1.1. The top plate also partially satisfies FR1.2 and its children (FR1.2.1-3); FR1.2 is only partially satisfied because other elements of DP1.2 are identified elsewhere. Figure 5 shows a portion of the half moon – shaped coupling mechanism comprised by the top plate; this portion of the coupling can be identified as DP1.2.3 and DP1.2.1.

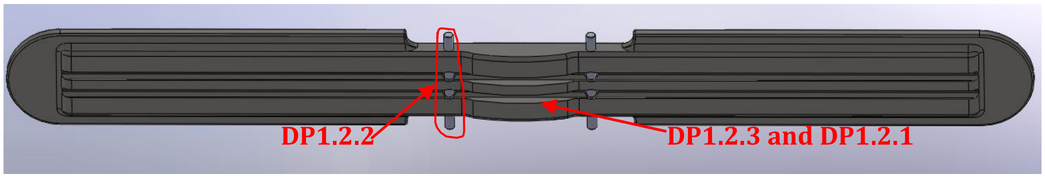

Figure 5

3.1.1 Finite Element Analysis of the Top Plate

While designing the top plate, it was noted that this component would be placed under significant loads. The top plate would be transmitting all loads from the binding, to the device, and subsequently the ski. Typical loads transmitted through a binding may exceed twice the skier's own body weight. Because this component is placed under significant loads and is supported at only two points near its center, the component must be as rigid as possible. The component must also be as light as possible. Finite element analysis was used in order to strike a balance between weight and stiffness. The design geometry was optimized as much as possible so that the component could be manufactured from aluminum stock. While designing the FEA simulation, loads were calculated assuming a skier weight of 185lbs and a maximum applied load (by the skier) of 300lbs. The loads were defined as distributed loads, placed approximately where the bindings are mounted to the plate. The component was constrained as though it was supported by its hinge pins. A graphic representation of the FEA result, using 6061-T6 aluminum is shown in figure 6; the graphic displays factor of safety in every region of the component. It can be seen that the factor of safety (FOS) for most of the component is less than 1; this means that the component will fail under the given loading conditions.

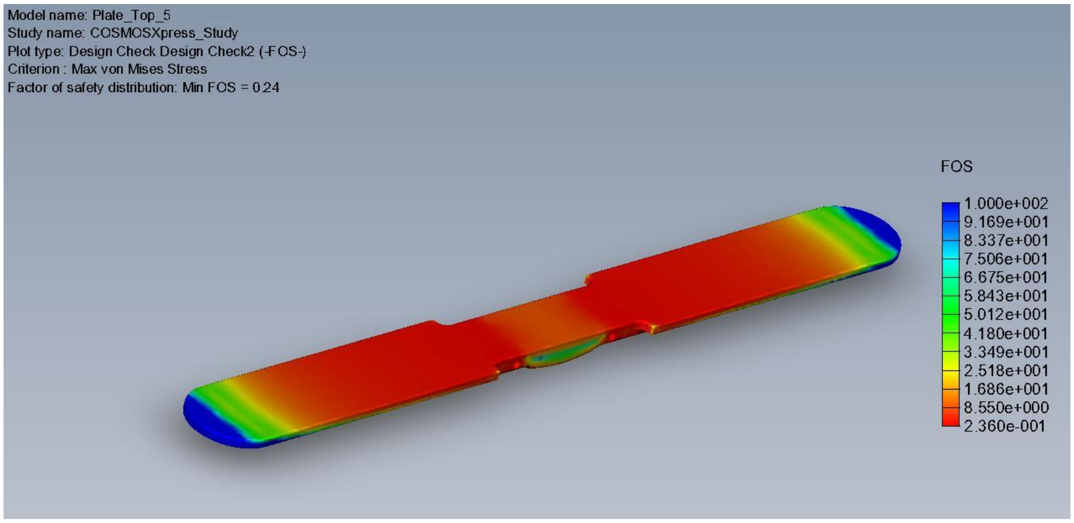

Figure 6

The same FEA simulation was completed using AISI 1018 steel; the result of this simulation can be seen in figure 7. When using steel for the component, the FOS was lowest at approximately 1.5; this means that the component can withstand approximately 1.5 times the given load.

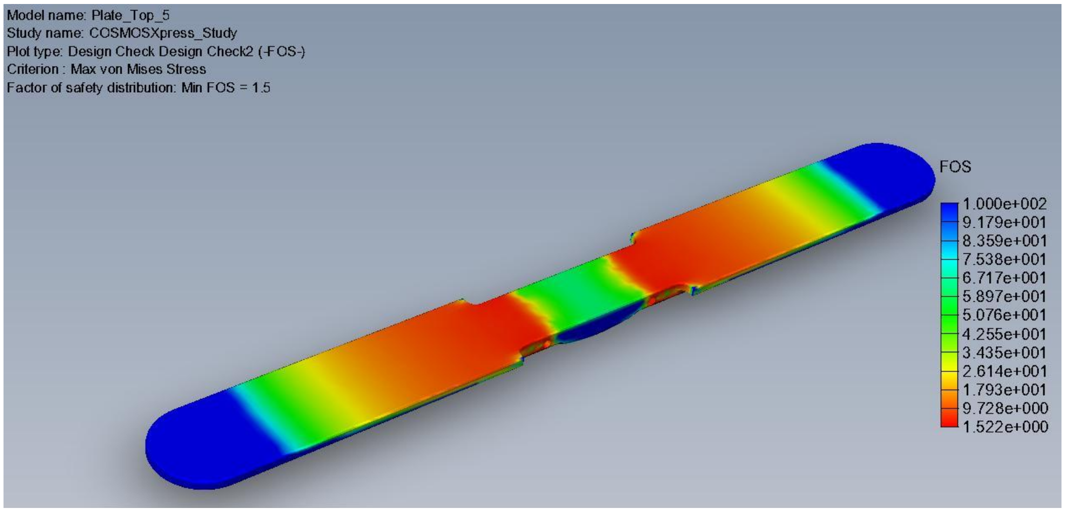

Figure 7

Although not pictured, FEA simulations were also done to investigate end deflection of the component. Loading conditions for the deflection simulation were identical to those in the FOS simulation. The simulation results once again proved that aluminum was not a suitable material choice for this component. When made from aluminum, the top plate deflected sufficiently to render the design features increasing “work to release” useless. The front portion of the top plate would touch the ski before the front hinge was able to move.

3.2 Bottom Plate

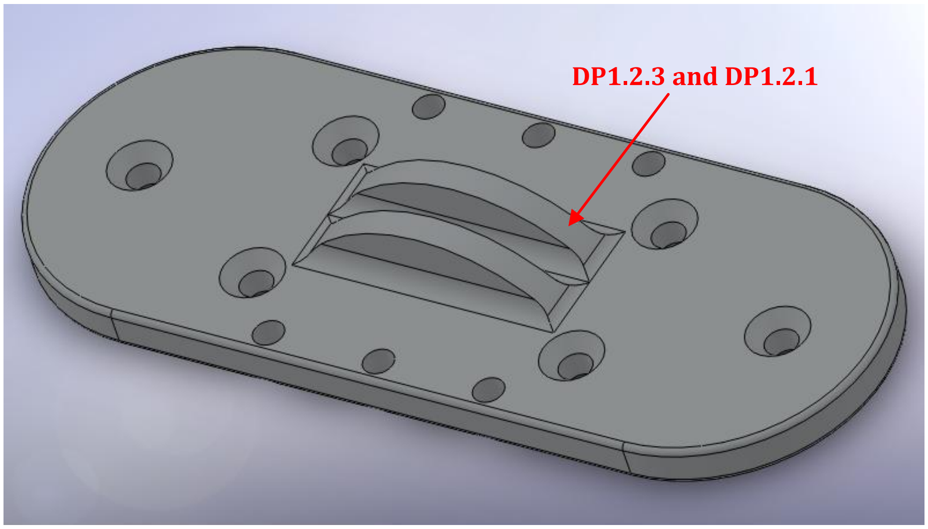

Figure 8

The bottom plate provides an interface between the ski and the device itself. At the same time, the bottom plate comprises a portion of the half moon-shaped coupling mechanism; in this way it satisfies FR1.2.1 and FR1.2.3. Figure 8 identifies the bottom plate portion of the half moon-shaped coupling mechanism as DP1.2.1 and DP1.2.3.

3.3 Base Side

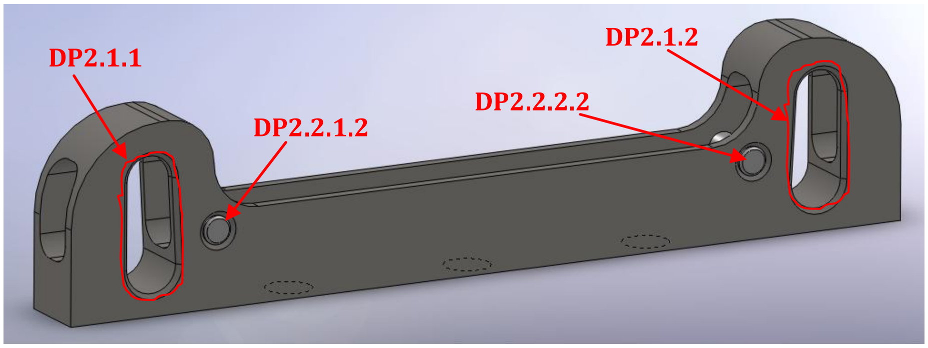

Figure 9

The base sides, shown in figure 9 (two are used, per assembly), act as a support structure for most of the device. The base side components are mounted to the bottom plate while all other components are mounted to the base sides. Multiple FRs are satisfied by this component. FR2.1 and its children are satisfied by this component; the journals, labeled DP2.1.1 and DP2.1.2 in figure 9, work with a set of support pins to comprise the front and rear hinges. The base sides, in conjunction with spring support pins, comprise support structures for the cantilevered beam springs; in this way FR2.2.1.2 and FR2.2.2.2 are satisfied. The previously mentioned support structures are labeled DP2.2.1.2 and DP2.2.2.2 in figure 9.

3.4 Cantilevered Beam Spring

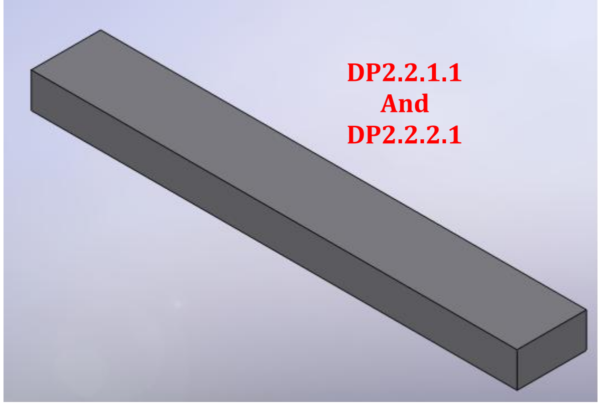

Figure 10

The cantilevered beam spring is used as a part of the suspension system; it absorbs the vertical force component of torque entering the device. In this way, the cantilevered beam spring satisfies FR2.2.1.1 and FR2.2.2.1. The beam itself is marked DP2.2.1.1 and DP2.2.2.1 in figure 10.

3.4.1 Alternatives Spring Designs Considered

Considering FR2.2.1.1 and FR2.2.2.1 (section 2.3.1.9-10) it can be determined that a spring is necessary for satisfaction. The type of spring is not however, dictated by the FRs. Coil springs were first considered because they are readily available and frequently used in machine designs. Coil springs were ruled out however, due to size restrictions; a coil spring of sufficient stiffness would be wider and taller than the base sides (where the springs are mounted).

At this point it was decided that a cantilevered beam might provide sufficient stiffness in the given size restriction. A set of standard beam equations was used to determine the maximum stiffness value that could be obtained. FEA was used to verify that a cantilevered beam spring was indeed, the correct design choice.

3.5 Preloading System

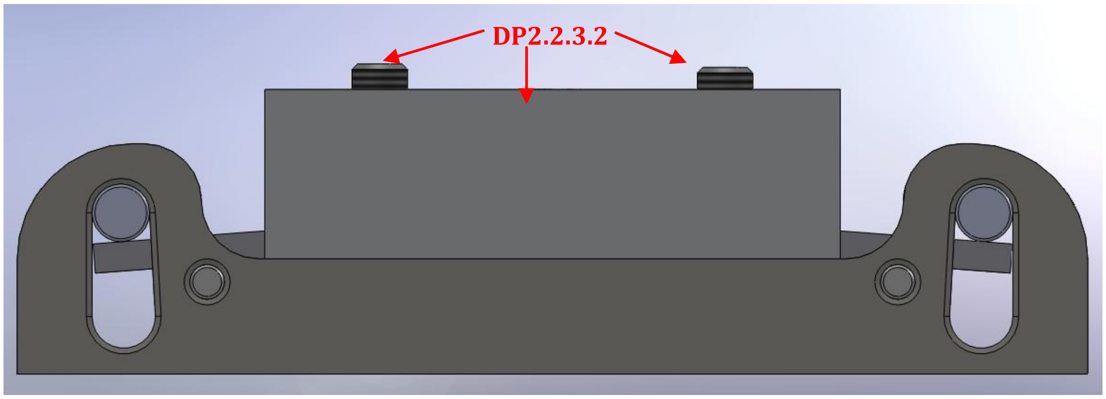

Figure 11

The preloading system satisfies FR2.2.3.2 which requires that the suspension system is adjustable for different skiers. The preloading system operates on the same principle as a binding's DIN adjustment. The spring is preloaded with a certain amount of force so that the suspension system does not move until an equal or greater amount of opposite force is applied. It should be noted that the entire assembly shown in figure 11 is not included in the preloading system; appropriate components in figure 11 are labeled DP2.2.3.2.

4. Prototype Production

4.1 Production of the Bottom Plate

It should be noted that the design decomposition focuses upon mitigating inadvertent release. The same design functions intended to mitigate inadvertent release may also be used to mitigate ACL injuries. Two main differences must be taken into account. First, the forward pitch suspension system used to increase "work to release" may also be used to dissipate injurious loads originating from a backwards – falling motion. Second, adjustability of the suspension system may be used to account for differences in the loads that need to be absorbed for ACL injury mitigation.

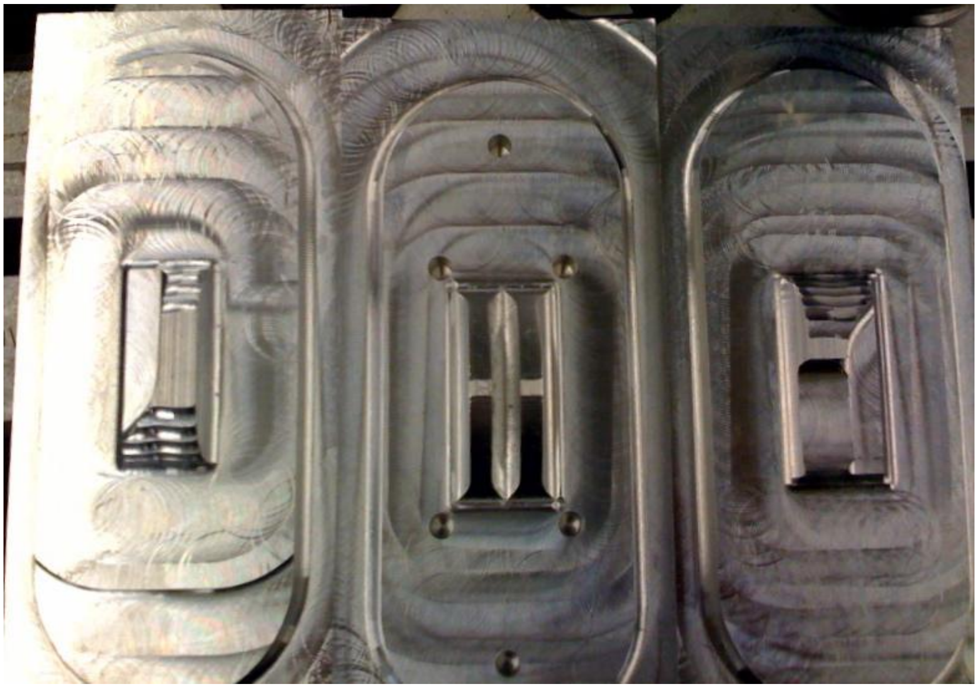

Figure 12

This part required multiple machining processes to arrive at the finished part. The first process shapes the part from the top down and drills six holes. figure 12 shows the bottom plate after a successful first process (center of picture). The part is then placed upside down into a vise so the remaining stock material can be removed; the part's final height dimension is reached after this operation. Further operations were required to countersink the six holes shown in figure 12 (center of picture) and subsequently drill and countersink six holes on the underside. Despite the difficulties encountered while prototyping this part, its manufacture (in a CNC mill) should only take about 45 minutes.

4.2 Production of the Top Plate

The top plate presented an array of manufacturing challenges. Due to the part's large size (approximately 21 inches in length, cut from 24 inch work piece) a larger machine tool had to be used; a Haas MiniMill was suitable for the bottom plate while a Haas VM3 was used for the top plate. Again, size came into play when attempting to fixture the work piece; two vises were used and placed so as to reduce part deflection while machining. When creating tool paths for the top plate, it was decided that the most complicated (geometrically) side should be cut first. This meant that the underside of the top plate would represent its first process. The first process worked well, accurately creating the complex underside of the top plate. A problem was noticed however, after removing the part from its fixture. AISI 1018 steel, a cold-formed material was used as the raw stock. Because the stock material retains latent stresses from cold-forming, a part will tend to warp when machined from only one direction (top-down or bottom up). The problem was solved using multiple steps. First, instead of removing all the stock material (from the part's backside) at once, the part was pocketed in an effort to relax the bowing (See figure 13).

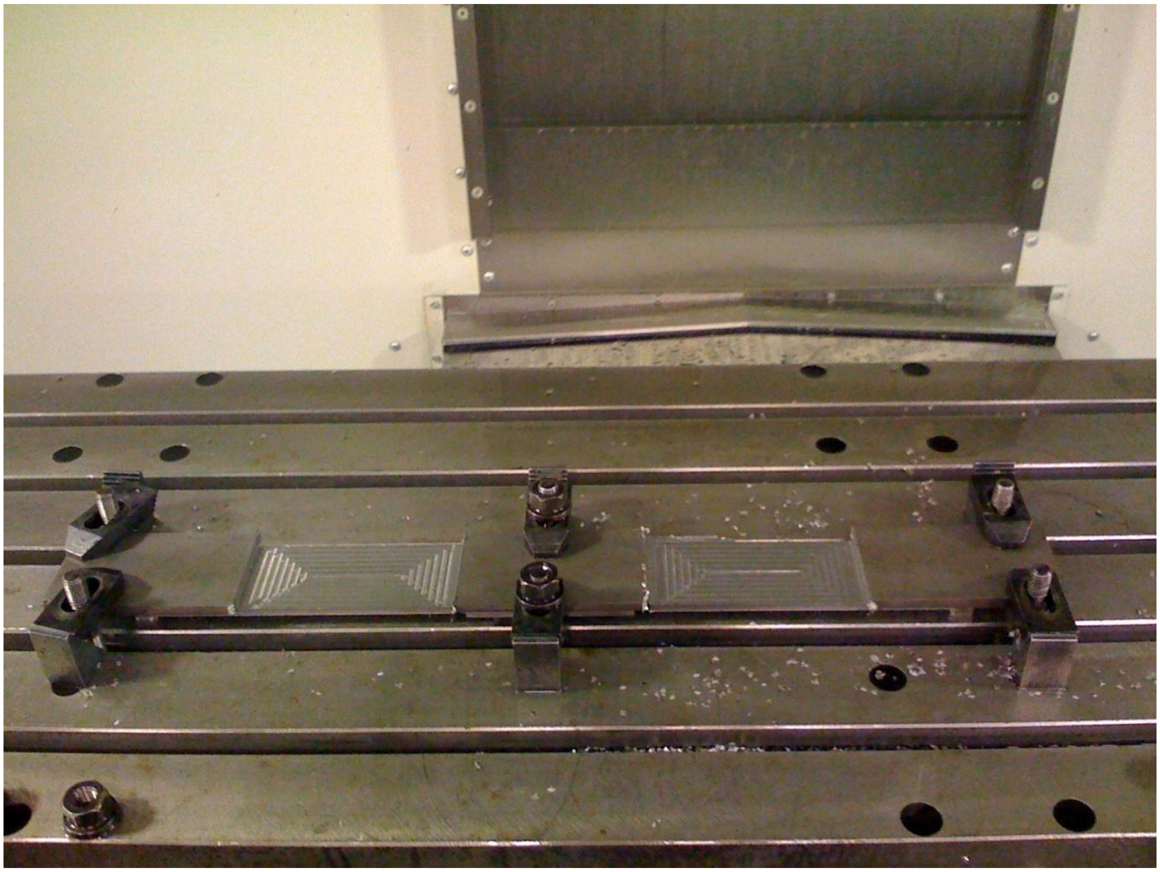

Figure 13

Once the part was again flat, it was placed in two vises so the remaining stock material could be removed. After this operation however, the part bowed in the opposite direction. No photographs were taken of this stage. The part was straightened using a two-step process however. The part was first stress relieved through a heat-treating process. After the latent stresses were removed, the part was straightened using a straightening press.

5. Testing of the Final Design

The final design has not currently been fully tested. Time restrictions did not allow for a proper field test before writing this report. A bench scale evaluation of the suspension system was attempted however no results were obtained. The bench scale test was not effective due to the testing equipment and procedures being used. Normally during a test of this sort, the ski is clamped to a table or bench while torque about the transverse axis is applied through a boot. Because the device allows for such natural flexing of the ski, deflection of the ski was difficult to isolate. The ski deflected to absorb all work being done to the device, rather than the suspension system deflecting to increase the "work to release".

6. Iteration

The device was not iterated. No testing was completed and thus, no design changes were introduced through test results. Once again, time constraints did not allow for the prototype to be iterated.

7. Discussion

7.1 Design Methodology

Axiomatic design was used over the course of this work. The axiomatic design method dictates that the designer should list all functional requirements and subsequently list all design parameters necessary to fulfill them. This of course, is an oversimplification of the process. The designer must make sure that the FRs are collectively exhaustive and mutually exclusive; that the design is complete and all its features are necessary.

7.1.1 Role of Axiomatic Design in Accomplishing Objectives

Axiomatic design is a method built around accomplishing objectives. Each of the design's objectives can essentially be embodied as an FR. The main objective of this work was to mitigate inadvertent release by designing a device that increases "work to release" at the binding's heel piece. This objective is imposed upon the design as an upper level functional requirement (FR2). Every subsequent step in the decomposition aims to fulfill this FR and thus accomplish the objective. The second objective of this work was to mitigate ACL injuries through another function of the device. Mitigation of ACL injuries, as stated in earlier sections of the report, can be achieved utilizing design parameters similar to those for inadvertent release. For this reason, ACL injury mitigation was designed under FR2.

While decomposing FR1, it was realized that torque transmission, from binding to ski, should be dealt with about three axes. The three axes to be considered were the vertical, transverse, and longitudinal with respect to the ski. Torque had to be transmitted across two critical junctions: from binding to Top Plate and from Top Plate to Bottom Plate. Through decomposition, it was clear mounting a binding to the Top Plate with machine screws would provide sufficient torque transmission (see section 2.3.2.1). Transmission of torque from the Top to Bottom plates however, was not so simple. Torque about the transverse axis had to be transmitted through the force control system, to increase "work to release". A simple pin connection was used and became part of the hinge system. It was determined that direct transmission of torque about the transverse and longitudinal axes was favorable. The rigid mechanical coupling also needed to maintain effectiveness throughout the device's range of motion. The preceding two requirements became FR1.2.3.1 and FR1.2.3.2. The resulting DPs determined that the mechanism should have a series of contacting vertical surfaces, shaped in such a way to maintain surface engagement despite movement. These DPs led to the conception and integration of a half moon-shaped coupling mechanism for transmission of torque about the longitudinal and vertical axes. While not directly related to the design objectives, this development was critical to the device's overall performance.

Because the device has not been tested, it is impossible to judge whether or not the overall objectives have been met. In theory however, all objectives have been met. The design approach led to the development and prototyping of a device that should mitigate inadvertent release and ACL injuries. The design and implementation process were, overall, successful in accomplishing the objectives.

7.2 Design Constraints

Through the design and realization of the device, all design constraints were implemented. From the beginning, the physical design of the assembly was dimensionally based upon a typical binding, plate, and ski setup. This allowed the device to comply with the size constraints mentioned earlier.

The small amount of testing that was completed demonstrated the device's compatibility with a standard ski binding; the binding released normally when proper torque was applied. The design constraints were useful as a guideline for the initial (physical) design phase.

7.3 Improvements to the Prior Art

7.3.1 Work to Release Independent of Binding

As mentioned in the introduction, "work to release" is currently limited by the binding. Even the best-designed bindings can only offer a limited amount of "work to release", contributing to the likelihood of inadvertent release. In theory, the device is able to provide an increased "work to release". This claim is still theoretical due to a lack of testing. This increased "work to release however, is completely independent of the binding; giving the skier an extended range of control and mitigating the likelihood of inadvertent release.

7.3.2 Adjustability for Many Skiers

By implementation of the preloading adjustment system, the device is adjustable for different skiers. This system places an adjustable static load on the suspension system springs, ensuring that the system does not deflect under any lesser loads. This functionality allows the skier to define the shape of the ski/binding setup's "work to release" plot. This system should be refined and improved. Currently, all four springs are preloaded independently; this would create difficulty in maintaining similar settings within each pair of springs (front and rear). For this reason, it is suggested that the preload adjustment should be designed so each pair of springs (front and rear) may be adjusted together. This would ensure similar preloading of each spring in its respective pair. A system should also be developed which correlates preload settings to the internationally accepted DIN settings used for bindings. Such correlation would make adjustment of the device easier from skier to skier.

7.4 Potential Consumer Use

There is a high potential for consumer use of this device. Provided that testing verifies the device's intended functionality, many consumers could benefit from its improvements over the prior art. Regardless of testing however, the prototype should be developed further. Different material choices, for instance, could be made to remove a significant amount of weight from the design. Further refinements should also be made to the cantilevered beam springs; material choice, geometry, and heat treatments could all be optimized. With these improvements to the current design, the device has potential to become a standard piece of equipment among competitive and recreational skiers alike.

8. Conclusions

In this section, a bulleted list of conclusions will be drawn.

- The design and implementation process has, in theory accomplished the objectives.

- The resulting device should, in theory, mitigate the likelihood of inadvertent release and the occurrence of ACL injury from BIAD.
- The device does require further testing and development. Improvements should be made in the following areas.
    - Material choice concerning stiffness, fatigue life, yield strength, and suitability to cold environments.
    - Weight of the device; the prototype is too heavy for consumer use.
    - Preloading system. The system should correlate to the DIN settings of a binding and be easily adjusted.
- The device has serious potential in the consumer market. Inadvertent release and ACL injuries current issues that need attention in the sport of skiing.

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