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Load Absorption Device for Skate Blades

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Abstract

Growth in technical and physiologic demands for skaters has led to an increase in sport related injuries; studies have shown that over 44% of figure skaters experience overuse injuries during their career. Current skates are composed of stiff leather uppers, padding to ensure a tight fit and to help cushion landings, and a wooden and cork sole to which the blade attaches. Landing loads which reach forces up to ten times a skater's weight are repetitively applied to the skater's joints without a means of cushioning. Repetition of exposure to these high landing loads leads to overuse injuries that cannot be alleviated without rest. The objective of this project is to develop a mechanical absorption system for figure skates which will aid in the prevention of jump landing-related injuries without obstructing the skaters' motion or disregarding the rules and regulations for competition. The design, which was realized through the principles of axiomatic design, absorbs loads in the vertical direction, preventing injurious loads from reaching the foot and ankle. The design was created in SolidWorks and manufactured using ESPRIT and Haas CNC machines.

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1. Introduction

The incidence of injury in figure skating is common, especially among elite skaters who practice frequently and attempt to complete difficult skills. Some injuries occur due to errors, while others are caused by overuse of a joint, tendon, or bone. In a recent study of elite (competition level) figure skaters, 42.8% of female participants and 45.5% of male participants reported overuse injuries (Dubravcic-Simunjak, 2003). These injuries included jumper's knee (patellar tendonitis), stress fractures, and ankle sprains. The previously listed overuse injuries mostly stem from the exertion of large mechanical loads on various portions of the leg while landing jumps.

The current high-end figure skate boots popular with high-level skaters offer minimal shock absorption in the form of a cork heel on the skate as opposed to a wooden heel (Riedell Ice, 2010). There are no mechanical design components that are included to actively absorb landing loads.

Recently, in an attempt to remedy the previously listed shortcomings of the traditional figure skate boot, Bill Fauver, a former Olympic figure skater and current figure skating coach, patented a design for a boot that would more successfully absorb mechanical loads due to jump landings and would allow for full flexion of the ankle (Fauver, 2009). His new boot has triangle-shaped portions cut out of the upper part of the boot, allowing ankle flexion, and a series of pistons mounted along this cut-out to absorb the load as the ankle flexes (Figure 1). While this design works mechanically, it is not entirely successful because the pistons impede the skater's ability to closely cross their feet over or bring their feet close together during spins.

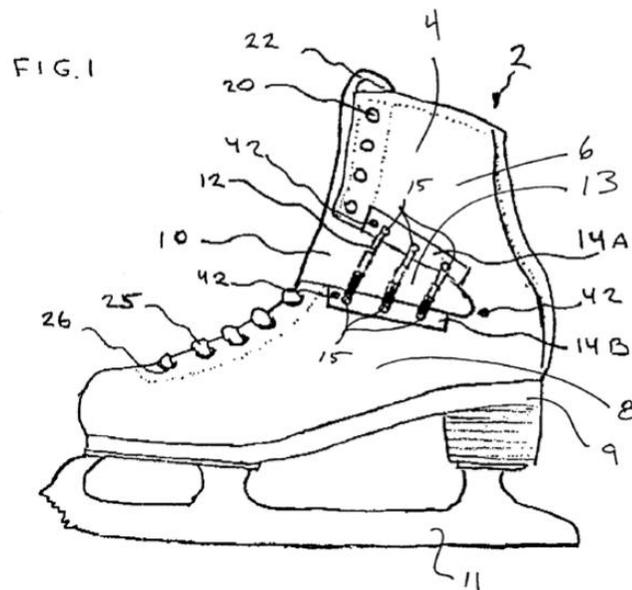


Figure 1: Sketch of Fauver's patented boot design

The purpose of this project was to improve upon Fauver's design by creating a novel absorption system for figure skates that will reduce injurious loads to help prevent both overuse

injuries and injuries due to jump landing error. If successful, the design could then be marketed and produced as a replacement to traditional skate blades for figure skaters looking to avoid overuse injuries.

1.1 Objective

The objective for this project is to develop a mechanical absorption system for a figure skate. This system should aid in the prevention of jump landing-related injuries.

1.2 Rationale

As previously discussed, the repeated application of large loads to a skater's joints can cause overuse injuries such as jumper's knee (patellar tendonitis), stress fractures, and ankle sprains (Dubravcic-Simunjak, 2003). The figure skates currently on the market offer little shock absorption to help reduce these loads. As a result, skaters have no way of protecting their joints during hours of practice. The other main problem with traditional skate boots is that they are stiff in their upper portion, which prevents necessary ankle flexion for reduced-impact landings. When landing jumps, it is natural for the ankle to bend downward toward the foot to move with the direction of the landing force. If the ankle is forced to remain rigid, that force concentrates at that one point, instead of being dispersed.

Considering the problems with traditional figure skate boots stated above, we began working to improve a patented design by Bill Fauver, a former Olympic figure skater. Because Fauver's design already allows for ankle flexion of the skater, we concluded that our design needed to absorb landing loads transferred from the ice to the skater using a mechanical absorption system that would not impede the skater in any way.

1.3 State of the Art



Figure 2: Hinged boot

The standard figure skate boot is composed of leather uppers with a wooden sole and a 1.5-2 inch heel made of cork to which the blade attaches. Within the boot are layers of padding to ensure a tight fit and help to cushion landings. Standard blades are generally made from either carbon steel or stainless steel and have varying rockers, or bends in the blade, depending on the type of skating the blade is intended to be used for. These blades mount directly to the bottom of the figure skate boot at the front and back of the boot.

In addition to Fauver's design, previously mentioned in section 1, researchers at the University of Delaware recently developed a hinged boot (Figure 2) which enabled skaters to flex their ankles while skating and jumping allowing for more cushioned landings.

Improving the cushioning of landings and allowing ankle flexion would help to prevent some of the common skating injuries (Manser, 2004). However, these boots lack durability and were much less stiff leaving skaters feeling that they did not provide enough ankle support (Waldman, 2006).

The most common absorption systems utilized in other athletic footwear such as sneakers are foams and air or liquid filled bladders within the midsole. The foam methods however become much less effective with wear as the foams are compressed and the fluid bladders can be troublesome as fluids can leak from the bladders (Healy, 2003). Other athletic shoes use springs to aid in the absorption of forces however this method cannot be utilized in a figure skate design because of the mechanical advantage provided.

1.4 Approach

To improve upon the current load absorption methods and devices currently on the market, we sought to design a device to be located in a non-obstructing area of the skate that would absorb injurious landing loads and would be adjustable for multiple skaters and for different levels of skill difficulty. We used Acclaro, an axiomatic design software program, to come up with functional requirements (FR's) of the device and design parameters (DP's) for the FR's. Due to time constraints and the somewhat steep learning curve associated with axiomatic design, we also began to draw iterations of our design in SolidWorks so we could visualize what we were working on. Initially, we thought we would design an improved absorption system located at the ankle that would not impede the skater's ability to cross over or spin, like the pistons did in Fauver's design. We later abandoned this idea, though, because we could not easily manufacture a device made out of a soft material nor could we easily incorporate such a device into the leather boot, as we have no leatherworking skills. We then considered where the loads were being applied to the skater during jump landings, and concluded that a device located between the blade and the boot could potentially absorb these loads.

Once we determined our basic FR's and DP's, we were able to start drawing in SolidWorks. After several iterations, we came up with a system that incorporates the actual figure skate blade into a piston that compresses a leaf spring to absorb vertical loads. This is the basis of our design. Working from this basic design we needed to consider the machinability of the design, potential assembly of the final product, materials, placement, adjustability, and overall geometry. We also considered that our device should not aid the skater in the initiation of any jumps, as this has been said to be illegal in competition (Fauver, 2012). Incorporating these considerations led us to our final design.

2. Design Decompositions and Constraints

As discussed in the introduction, there are a significant number of elite figure skaters that suffer from overuse injuries. These injuries could potentially prevent these skaters from practicing or competing. Furthermore, even though the injuries are not usually severe, there are still high medical costs associated with their diagnosis and treatment. For example, a single x-

ray can cost up to \$1200 (Ankle X-ray, New Choice Health, Inc.) and an MRI can cost up to \$12,000 per image (MRI, New Choice Health, Inc.). Additionally, physical therapy after an injury averages from \$80-\$175 per session (Physical Therapy Report, Corvel). This device will lessen the instance of injury by mitigating the loads associated with jump landings. Reducing the instance of injury benefits the consumer by decreasing the cost of doctors, physical therapy, and braces as well as the need to relinquish valuable ice time or withdraw from competition due to injury thus maintaining the integrity of the competitions.

Axiomatic design was used in conjunction with Acclaro software to develop a design with components that were mutually exclusive and collectively exhaustive. Functional requirements (FR) and design parameters (DP) were broken down into children who summarize the parent requirements. The highest level functional requirement, FR-0 is that the device will absorb loads in the vertical direction. To do this we will create a vertical load absorption device which is our initial design parameter, DP-0. This FR and DP were broken down into five children and those children were also broken down until the design became clear.

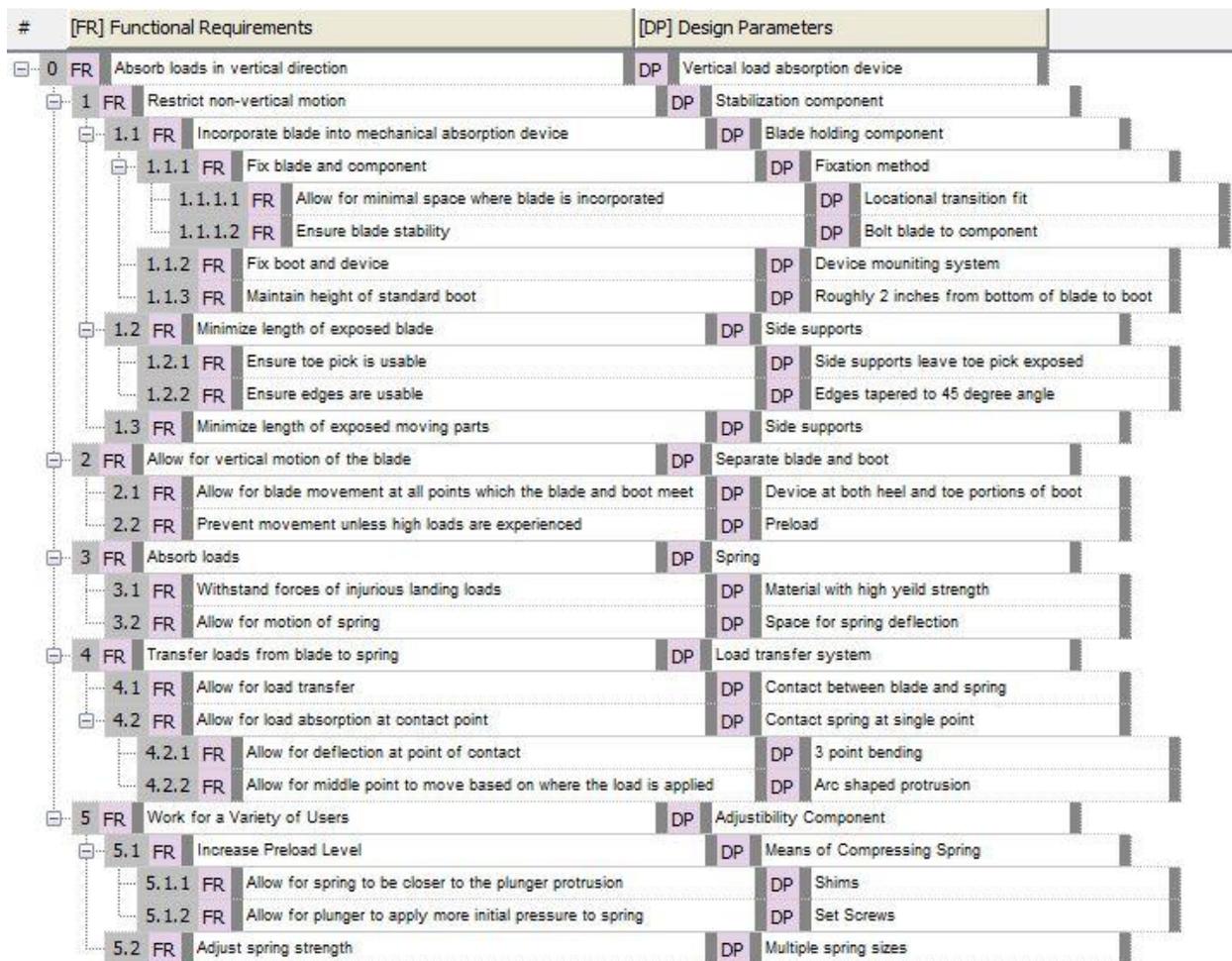


Figure 3: Acclaro decomposition

Constraints we considered include weight, resistance to corrosion, size, and the ability to be manufactured. Weight is an important consideration because the device should provide a

feel similar to the initial blade and any additional weight can slow the skater down or prevent them from jumping as high. Corrosion resistance is also of high importance because the skaters are constantly on the ice exposing the blades to water. Corrosion does not only affect the blade but the boot as well. Boot rot can be a cause of corrosion which increases the need for boots and blades. The size of the device is also important because the device cannot get in the way of the skater or interfere with traditional skating techniques. Ensuring that the device is roughly the same height as the stems of traditional blades is beneficial to help ease the transition from traditional blades to the use of this device. The final constraint is manufacturability. It is important that the device be easily manufactured and assembled to allow for a prototype to be developed. The final Acclaro can be seen in figure 3.

FR1 Restrict non-vertical motion

The first functional requirement focuses on the prevention of non-vertical motion. This restriction is important because this device should have a stiff feel similar to that of traditional blades.

DP1 Stabilization component

A component to stabilize the blade is imperative to the design because any play in the device could be detrimental to the skater. Non-vertical movement of the device could prevent skaters from comfortably using the device and might lead to increased instance of injury.

FR1.1 Incorporate blade into mechanical absorption device

Incorporation of the blade into this device is important because the device is located between the boot and the blade making it necessary for the blade to fit within the device. In addition, the use of modified traditional blades ensures that the desired size, shape, and properties of the blade are met.

DP1.1 Blade holding component

When incorporating the blade into the device, the blade needs to be held sturdily within the device.

FR1.1.1 Fix blade and component

The blade and device must be fixed, allowing for the high landing loads experienced by figure skaters to be applied to the device without any play or movement.

DP1.1.1 Fixation method

A variety of fixation methods were considered including welding, fastening, and press fits. After consideration of these methods we determined a transitional fit and fastening to be ideal fixation method for the application. Welding was removed as an option because it is a more permanent fixation method and blades need to be removed and replaced which would shorten the

life of the device. In addition to blade replacement, using a fastener-based fixation method allows skaters to use any blades that they want.

FR1.1.2 Fix boot and device

The device also must be able to mount to the bottom of the boot. Inability to do so would prevent the device from functioning properly.

DP1.1.2 Device mounting system

Current blades are mounted to the bottom of the boot using screws. We want to replicate this because it is a simple and low cost method that does not further complicate the design. One factor to consider for this method of mounting the device to the boot is that the screws need to be able to be accessed. This played a part in our design because the screws needed to go into the boot prior to the assembly of the device.

FR1.1.3 Maintain height of standard boot

The height of the device plays into our constraint of size. The device needs to fit under the boot and cannot interfere with skating technique.

DP1.1.3 Roughly two inches from bottom of blade to boot

Maintaining a height of roughly two inches will keep the device comparable to a traditional blade. This is an important consideration because many skaters will be used to skating with standard blades and it is important that the transition to this device be as seamless as possible.

FR1.2 Minimize length of exposed blade

Minimizing the length of blade that is exposed can help to lessen the amount of play within the design thus diminishing non-vertical movement.

DP1.2 Side supports along blade

Supporting the sides of the blade in conjunction with proper tolerancing and fastening will help to stabilize the blade and prevent motion.

FR1.2.1 Ensure toe-pick is usable

The side supports are important to ensure that play is minimal but it is imperative that the supports do not inhibit the function of the blades. To prevent loss of function, it is important that the toe pick is fully exposed.

DP1.2.1 Side supports leave toe-pick exposed

Allowing the toe pick to be exposed ensures full function of the blade.

FR1.2.2 Ensure edges are usable

Ensuring that the edges of the blade are usable is an important functional requirement because the edges of the blade are important to allow the skater to skate on the ice. Without access to blade edges the skaters would not be able to move or skate properly.

DP1.2.2 Edges tapered to 45 degree angle

To ensure that the edges of the blades are usable we tapered the sides of the device to create a 45 degree angle. This angle allows skaters to skate normally, land all jumps, and do other tricks. The ability to perform these tasks corresponds to the requirement that the device cannot interfere with the skater and satisfies the size constraint.

FR1.3 Minimize length of exposed moving parts

Minimizing the length of exposed moving parts helps to stabilize the device and prevent rotational play.

DP1.3 Side supports along moving parts

Having supports to guide moving parts helps to ensure stability and prevent unwanted motion that could be detrimental to the performance of the skater.

FR2 Allow for vertical motion of the blade

While we want to restrict non-vertical motion, we want to allow vertical motion within the device. This is key as it is how the loads will be mitigated.

DP2 Separate blade and boot

Separating the blade and the boot will allow for loads which are typically transferred directly to the boot and foot to be mitigated through a device placed between these two components.

FR2.1 Allow for blade movement at all points which the blade and boot meet

Movement of the device will help to transfer loads from the blade to a spring mitigating forces applied to the foot. The device must allow the blade to move at every point which it meets the boot to prevent the blade from bending.

DP2.1 Device at both heel and toe portions of boot

Mounting the device on both the heel and toe portions of the boot similar to a traditional skate blade will prevent any bending of the blade and allow for load absorption along the entirety of the blade.

FR2.2 Prevent movement unless high loads are applied

Preventing movement of the device unless high loads are applied mimics the feeling of stiffness provided by traditional blades. It also allows for the skater to skate normally, approach jumps, and perform skills with little risk of injury without engaging the device.

DP2.2 Preload

Applying a preload to the device allows for the skills with little to no risk of injury to be performed as if the device is not present. A preload will ensure that the device only acts when the skater is exposed to injurious loads such as the high impact loads of landing challenging jumps.

FR3 Absorb loads

The device will help to prevent injury by absorbing injurious loads experienced by skaters when landing challenging jumps.

DP3 Spring

A spring was chosen as the best method to absorb the loads. Other methods discussed for the absorption of loads include hydraulic and pneumatic devices, Bowden cables, and magnets. The spring stood out as the most feasible option because it could be quickly reset allowing for skaters to perform combination jumps, it was simple to implement, and it would require minimal space. This final reason was important as size is a constraint for the design.

FR3.1 Withstand forces of injurious landing loads

In order to assist the skater in preventing overuse injuries the spring must be capable of withstanding the loads applied during a typical competitive skating routine. These loads can be up to 102.24 MPa.

DP3.1 Material with high yield strength

The spring must be made of a material able to withstand forces up to 102.24 MPa without exhibiting plastic deformation. After looking into a number of metals it was determined that high fatigue resistant spring steel had the best properties for this application.

FR3.2 Allow for motion of spring

Transferring landing loads from the blade to the spring requires deflection of the spring.

DP3.2 Space for spring deflection

In order for the spring to deflect, it needs space to do so. This needs to be considered in the design of the device and when considering thickness of the spring.

FR4 Transfer loads from blade to spring

Transferring the loads from the blade to the spring is a necessary requirement for the mitigation of injurious loads.

DP4 Load transfer system

A system to transfer these loads must be implemented in this device. This system should be located between the boot and the blade and assist in transferring loads from the blade to the spring.

FR4.1 Allow for load transfer

The device should allow for load transfer between the blade and the spring.

DP4.1 Contact between blade and spring

To allow for load transfer the blade and spring need to be in contact with each other. This can be done with addition of a piston-like part to the design. The blade can be attached to the bottom of the piston so when the blade moves, the piston also moves. The top of the piston can interact with the spring allowing for load to be transferred from the blade and piston to the spring.

FR4.2 Allow for load absorption at contact point

The load will be absorbed by deflection of the spring. Ideally the majority of the load will be absorbed above the point at which the skater lands on the blade.

DP4.2 Contact spring at single point

To absorb the load at a single point of contact a protrusion will be added to the plunger so the spring and plunger will touch only at this point. This will help to control the location at which the spring deflects and prevent unwanted contact of the spring and plunger.

FR4.2.1 Allow for deflection at point of contact

To absorb loads, the spring must deflect. This deflection can occur in a variety of ways. The spring could begin in a concave shape and be flattened when forces are applied or it could start as a flat spring and bend in a convex shape when loads are applied.

DP4.2.1 Three-point bending

Applying three point bending loads to the spring was determined to be the ideal method of transferring loads from the blade to the spring.

FR4.2.2 Allow for middle point to move based on where load is applied

The middle point of the protrusion should be able to move so the loads are absorbed directly above the location of the landing loads rather than over the entirety of the device.

DP4.2.2 Arc-shaped protrusion

To allow for the movement and absorption described above a teardrop-shaped protrusion should be included atop the plunger rather than a cylindrical protrusion. This teardrop will allow for the plunger to rock thus absorbing the loads directly above the point at which they are applied.

FR5 Work for a variety of users

The device must work for a variety of users because skaters weigh different amounts and the difficulty of each routine is different.

DP5 Adjustability component

The variances listed above create the need for an adjustable device that can meet the needs of a broad spectrum of skaters.

FR5.1 Increase preload level

A heavier skater will require the preload on the device to be adjusted. The amount of preload must be increased to accommodate someone who will apply a greater force to the device.

DP5.1 Means of compressing spring

To increase the preload, the spring must be placed under a greater amount of compression. This can be done in a variety of ways; two methods that are easy to implement and adjust are outlined below.

FR5.1.1 Allow for spring to be closer to the plunger protrusion

Preload can be applied to the device by bringing the plunger protrusion closer to the spring.

DP5.1.1 Shims

One way of applying this preload is with shims above the spring. This lowers the spring allowing the plunger to apply a greater force to the spring. A thicker shim would provide a greater preload.

FR5.1.2 Allow for plunger to apply more initial pressure to spring

Preload can also be applied by bringing the plunger and protrusion closer to the spring.

DP5.1.2 Set screws

Set screws below the shoulders on the plunger can be turned to raise the plunger and protrusion closer to the spring and increase the amount of preload. This option is the ideal solution but if needed, both preload screws and shims can be applied.

FR5.2 Adjust spring strength

Another way to make the device adjustable is by changing the thickness of the spring. This is a slightly less adjustable solution.

DP5.2 Multiple spring sizes

A thicker spring will be more suitable for someone of greater weight. Varying spring sizes is a means of making the device adjustable however this a more permanent means of adjustability.

3. Physical Integration

Each component was designed with a particular functional requirement and design parameter in mind. These FRs and DPs are mutually exclusive and collectively exhaustive and when combined they create the working device (Figure 4).

The three portions of the base are connected with low head bolts and create the casing in which the spring and plunger sit. At the top of the base, there are screws which mount the device to the boot satisfying FR 1.1.2. On either side of the lower portion of the base, set screws are in place to assist in preloading the spring. These set screws satisfy FR 5.1.2. The tapered portion of the base and plunger fulfill FR 1.2.2 allowing the skater to use the edge of their blade. Also, the base was extended to have a larger area supporting the plunger and preventing rotational motion as described in FR 1.3. The slot at the bottom of the plunger holds and stabilizes the blade meeting FR 1.1. The plunger allows for contact between the blade and the

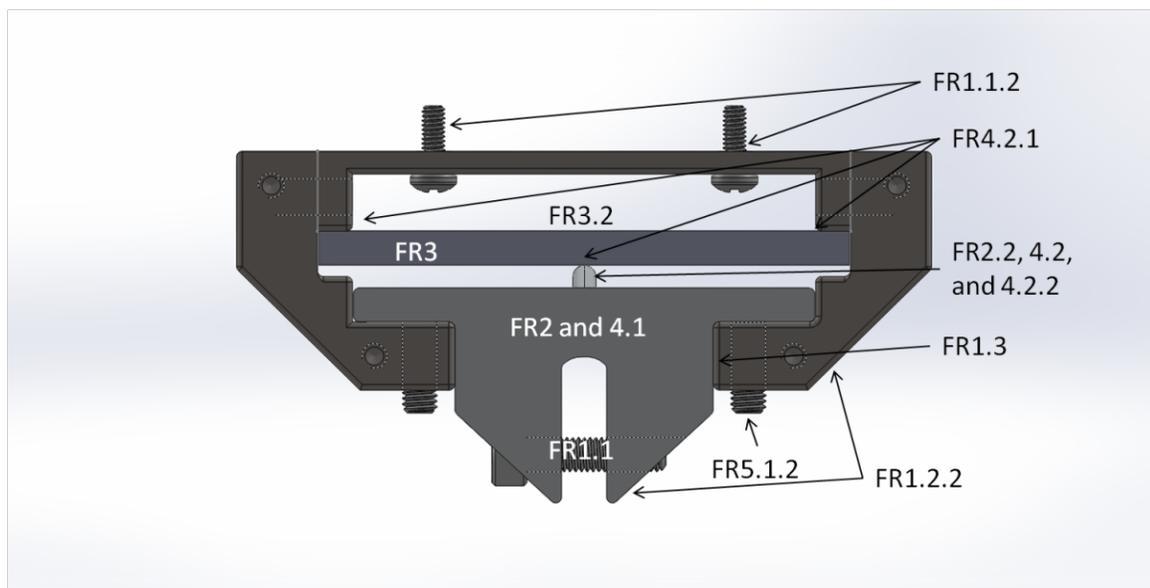


Figure 4: Front view of device with functional requirements



Figure 5: Integration of device with boot and blade

spring satisfying FR 4.1. The tear-drop shaped protrusion on the top of the plunger fulfills FRs 2.2, 4.2, and 4.2.2 by applying constant pressure to the spring at a single point directly above the applied load. The protrusion also works with the top portion of the base allowing the spring to deflect in three-point bending as specified by FR 4.2.1. The spring absorbs loads by deflecting into the gap created by the top part of the base meeting FRs 3 and 3.2. The device with the boot and blade can be seen in figure 5.

Tolerancing is an important consideration for the design because the device needs to move freely while providing a feeling of stability for the skater. Another consideration with tolerancing is that the blade

will be exposed to significant changes in temperatures. Proper tolerancing was determined by using the Machinery's Handbook and the chosen fits can be seen in figure 6. For the interface between the base and the spring, a medium running fit was chosen because the spring is exposed to high pressures and needs to remain in place but does not need to be tightly fit within the allotted space because the spring must be able to deflect. A close running fit was selected for the interfaces between the base and the plunger. This fit was selected because it is intended for uses where minimum play is desired. This is an important factor for these interfaces because they aid in stability of the blade and prevent rotational motion. The plunger also needs to have the

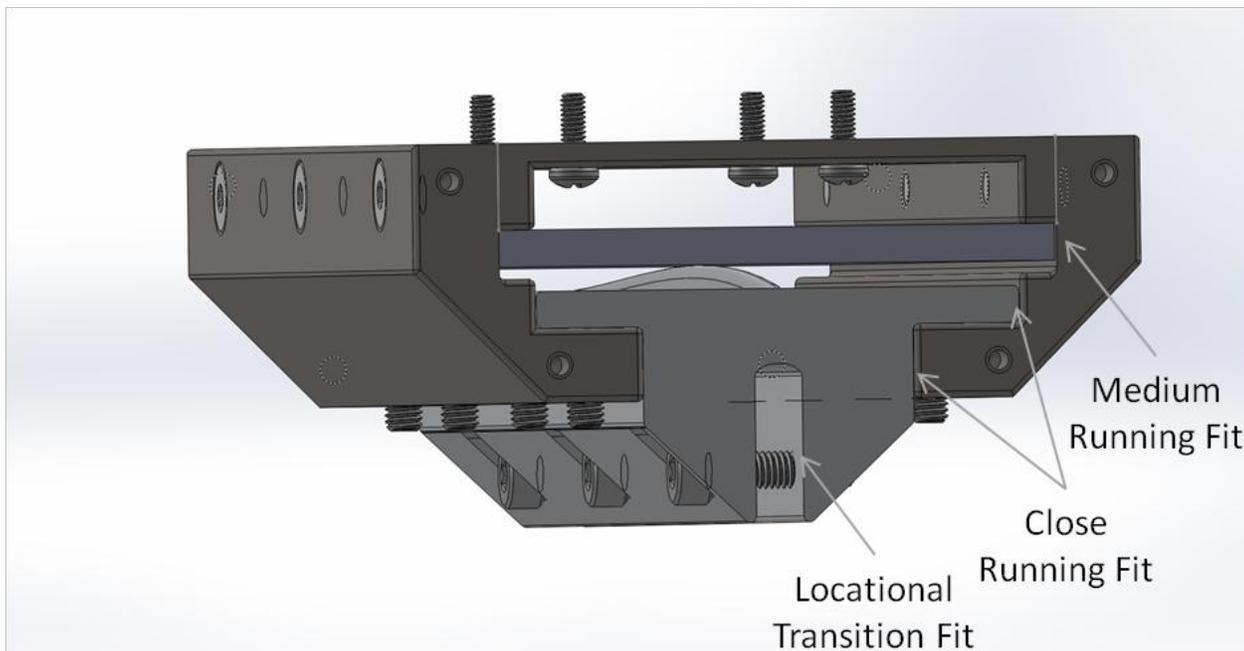


Figure 6: Tolerance choices within the design

ability to move within the base as this is how the vertical loads are absorbed. The other part of the design which required proper tolerancing was the slot in the plunger that the blade fits into. For this part, a locational transition fit was chosen. This is a desirable fit for the part because it is intended to provide accurate location and high interference without requiring the blade to be pressed into place which ensures blade stability.

4. Prototype Production

The prototype was developed using ESPRIT and Haas CNC Machines. The plunger portion of the prototype was the part was placed in a vice and machined with a ball end mill. The blade holding portion was machined first followed by the shoulders and teardrop-shaped protrusion. The base was machined in three parts. The top part of the base was put into a vice and machined into a block with the proper dimensions and then pocketed to create the correct shape. The other two parts of the base were machined using soft jaws. After squaring the block, and machining the steps, the part was rotated and the chamfer was machined. These three pieces were put together using low head bolts and set screws were added to the base for preloading the plunger. The leaf spring was machined using a magnetic table and ball end mill; a picture can be seen in figure 7. The spring was squared and machined down on both sides to the desired height. A larger piece of steel was used to brace the spring in place. This prevented the spring from sliding on the table due to the machining forces.

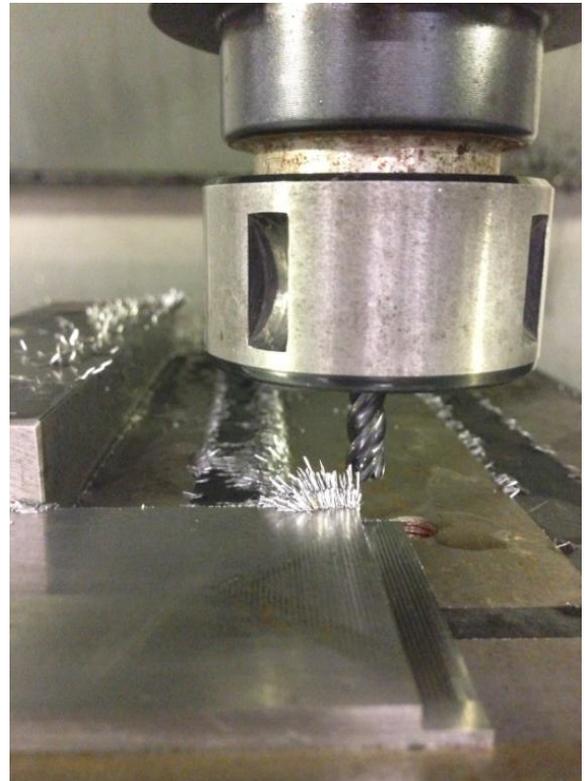


Figure 7: Machining of leaf spring on magnetic table

5. Testing of the Final Design

There are several tests that need to be completed to fully test the final design. Due to the limited time between the development of the first set of prototypes and the end deadline for this project, limited testing has been completed.

In order to test the machined leaf spring to determine if its thickness was appropriate for absorption of three to ten times the user's body weight. To test this, a three-point bending test was conducted in an Instron machine (Figure 8). The sample was loaded into the machine lengthwise on top of two supports located on each side of the sample. Then, a metal dowel was placed in the center of the sample. The three-point bending test was then run until the sample

demonstrated plastic deformation. This allowed us to quantify the yield strength of the material (Figure 9).

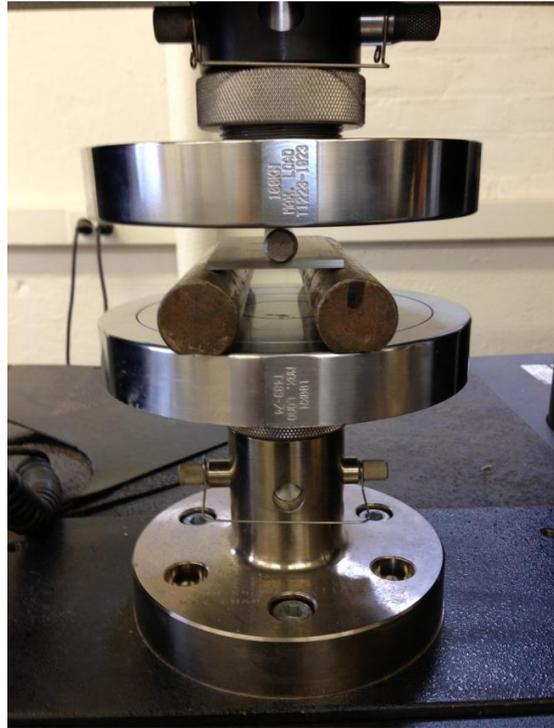


Figure 8: Three point bending test setup

Leaf Spring Stress vs. Strain - 3 Point Bending

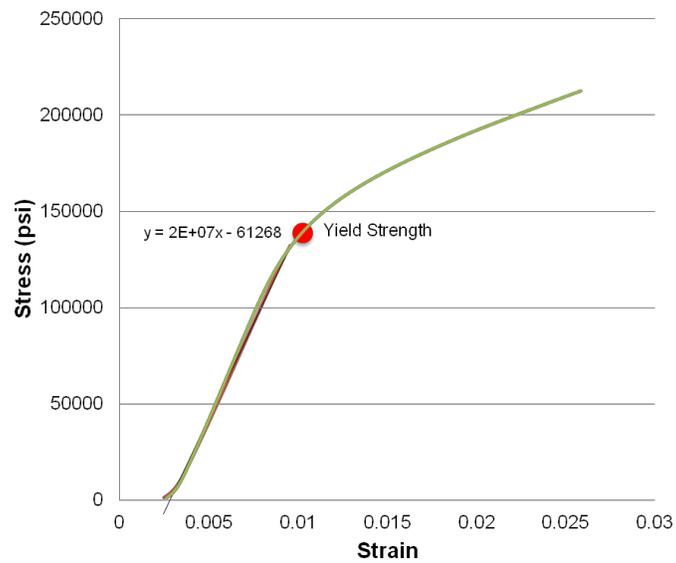


Figure 9: Stress vs. strain curve for leaf spring in three-point bending test

The value for the yield strength showed that the thickness of the spring was too high for our intended application so we needed to manufacture a spring that was slightly thinner. Instron testing for the thinner spring has not yet been conducted.

A table of FR's and associated tests that should be conducted can be seen below (Table 1):

Table 1: Functional requirements and tests

Functional Requirements (FR's)	Tests
Ensure blade stability (1.1.1.2)	Apply lateral load to blade and measure displacement
Ensure toe pick is usable (1.2.1)	Measurements/user testing
Ensure edges are usable (1.2.2)	Measurements/user testing
Prevent movement unless high loads are experienced (2.2)	Finite Element Analysis/Instron testing/user testing
Absorb loads (3)	Finite Element Analysis/Instron testing/measure displacement of spring
Withstand forces of injurious landing loads (3.1)	Instron testing
Allow for motion of spring (3.2)	Measure area in which spring can displace against overall spring displacement
Allow for deflection at point of contact (4.2.1)	Three-point bending Instron test
Allow for middle point to move based on where the load is applied (4.2.2)	Applying point loads at different locations along blade
Work for a variety of users (5)	Subject testing
Increase preload level (5.1)	Instron testing at differing preload levels
Adjust spring strength (5.2)	Instron testing with different sized springs

6. Iteration

Throughout the design process, several iterations of the axiomatic design and the SolidWorks drawings were created. Originally, a design incorporating an absorption system located at the ankle of the boot was considered. Different mechanisms that could accomplish the same goal of absorbing loads exerted on the ankle during jump landings were designed (Figure 10). Because the team had no access to leatherworking tools and it was decided that an absorption system that would mitigate load transfer from the ice to the foot would be more beneficial, the ankle load absorption design was abandoned.

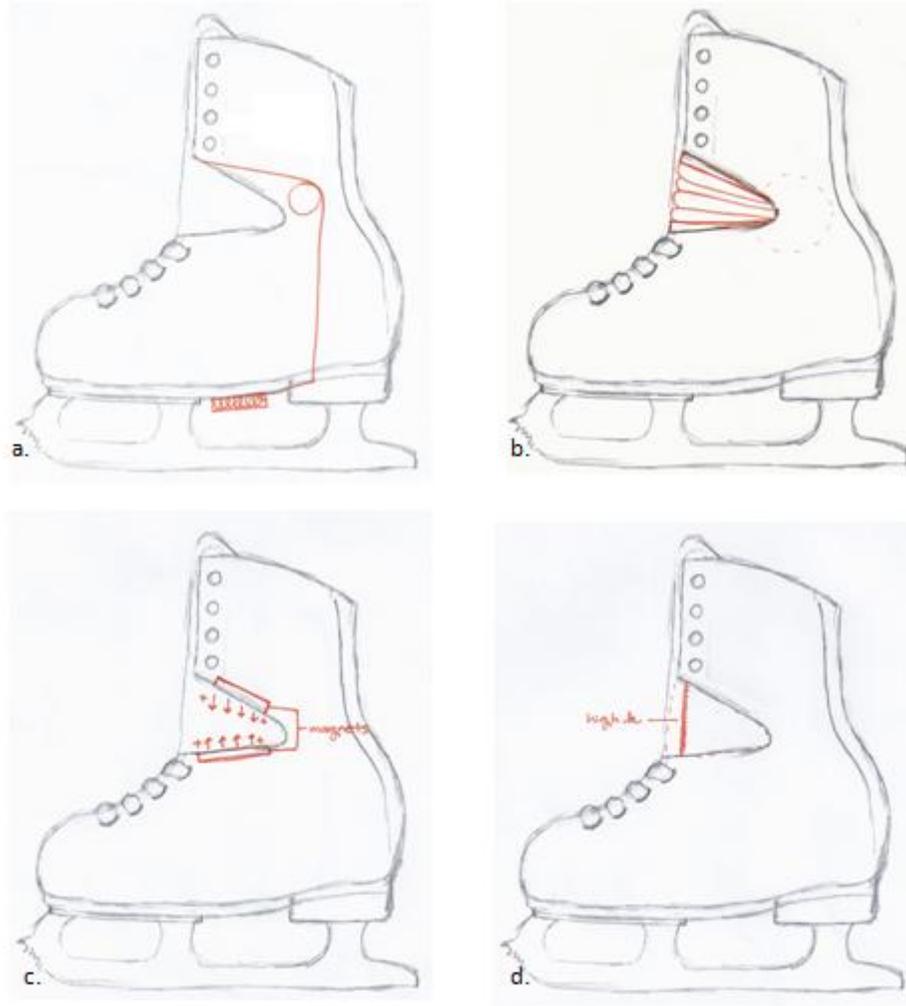


Figure 10: Ankle absorption initial design. a. Bowden cable b. Pneumatic Bellows c. Magnets d. Spring

When designing a load absorption device to be located between the skate blade and the bottom of the boot, Acclaro Axiomatic Design software and SolidWorks software were used. Initially, the design was decomposed solely in Acclaro. Then, drawings were created in SolidWorks to help visualize the concept. As the design evolved, new ideas were incorporated into the decomposition and then drawn in SolidWorks. The first iteration of the design incorporated a basic piston system that compressed a curved leaf spring (Figure 11). Working from this design, other iterations were drawn. The curved leaf spring was then replaced with a straight rectangular spring and the flat plunger was changed to include a protrusion in the middle to allow for three-point bending of the spring. The initial design was intended to be used with shims located beneath the plunger to adjust the preload. This iteration also incorporated splits in the base to allow for assembly of the final device as well as holes for fasteners (Figure 12).

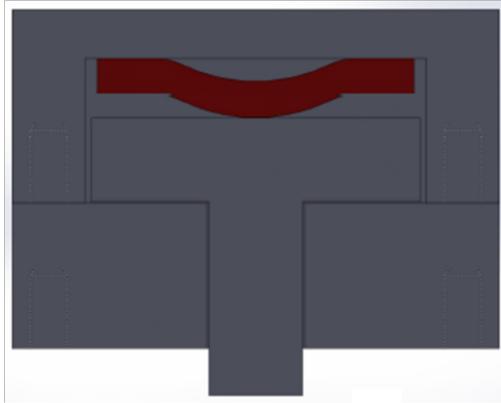


Figure 13: Initial blade design



Figure 12: Design iteration two

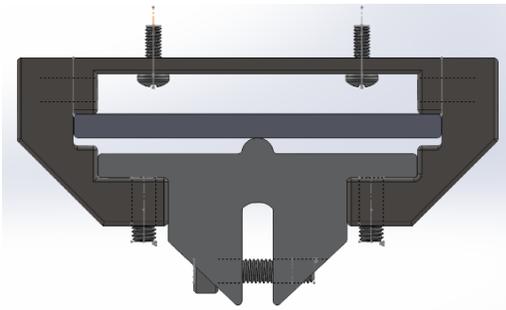


Figure 11: Final design

The design was drawn with the intention that set screws would be used to create a preload. Finally, a slit was added to the plunger so a blade could be inserted. In the last major iteration (Figure 13), the locations of the splits in the base were changed to improve the ability to successfully assemble the device. Forty-five degree angles were cut from the sides of the plunger and the base to prevent the device from interfering with sharp turns. The center protrusion was changed from a half-cylindrical shape to a half-teardrop shape to concentrate the load more toward the front of the device and to allow for the device located at the front of the skate and to allow for the entire blade to “rock” when the spring is compressed. Because the piston devices are located at the front and the back of the skate, it is important that they can move together so the blade will not deform in response to the compression on either end. Endplates were also added to ensure that nothing would slide out of the device during skating.

7. Concluding Remarks

Throughout this project we accomplished the following:

- Background research of figure skating and related injuries
- Axiomatic decomposition of design with Acclaro software
- SolidWorks of the design
- Production of prototype using ESPRIT and Haas CNC machines
- Provisional Patent
- Winners of the 2013 Strage Innovation Award

8. Discussion

8.1 Accomplishments Review

Throughout the scope of this project, the team was able to make several accomplishments, as listed in section 7. First, background research was conducted to help educate the team on the topic of figure skating, common injuries suffered by figure skaters, and about the products currently used by figure skaters. Then the team learned how to use axiomatic design, with no experience, through use of Acclaro software. The team also learned how to make drawings in SolidWorks for the purpose of this project. Neither team member had significant CAD experience prior to the start of the MQP. A prototype was produced using ESPRIT software and CNC machining. The team had to learn how to convert SolidWorks files into ESPRIT files and how to create machining paths for the machinist to work with.

Based on the design and the first prototype, the team was able to file a provisional patent through the WPI Technology Transfer Office. For the school to support the provisional, the intellectual property must be promising enough to potentially be successful in its intended market.

Finally, the team won first place in the WPI Strage Innovation Awards Competition. This competition provides a platform for students with innovative ideas to compete. The idea that the judges deem the winner must fulfill criteria such as: technical merit, viability, feasibility for implementation, and market demand.

8.2 Axiomatic Design Review

Based on the objective stated in section 1.1, the axiomatic design method worked to accomplish our goal. A basic design was created as a solid proof of concept to which improvements can be made. Though a perfect, production-ready prototype has not been created, further use of axiomatic design will help to define necessary additional components.

8.3 Constraint Fulfillment

As discussed in section 2, the constraints included: weight of the device, high resistance to corrosion, size, and ability to be manufactured. While the size and manufacturability constraints have been met, the low weight requirement and corrosion resistance requirements have yet to be fulfilled. As mentioned previously, the aluminum and steel prototype is too heavy to be usable in competitive skating. The device would add a detrimental amount of weight to the skate, making it difficult to execute skills. Additionally, the prototype was created out aluminum and a high fatigue resistant spring steel, neither of which resists corrosion due to water. A material such as titanium or a fiber-reinforced polymer would provide the necessary corrosion resistance of the device.

8.4 Improvements Over Prior Art

Our team's design provides several improvements over the prior art. First of all, it is located beneath the boot and has chamfered sides to prevent the device from ever coming into contact with the ice while the skater is on their inside or outside edges. Secondly, it is

adjustable. A preload feature was incorporated into the design so the initial amount of force exerted on the leaf spring can be changed based on weight of the skater or difficulty of a routine. This feature also ensures that the spring will only engage when landing loads are reached. This prevents the skater from experiencing any “bouncing” motion due to spring engagement while skating normally. Finally, our design can include a one-directional friction component that would prevent the spring from pushing the skater up when initiating jumps.

8.5 Potential Commercial Use

This design could be used to replace the traditionally used blades currently on the market. Because there are no similar products currently on the market, this design could be marketed as the only load absorbing skate blade available. For a detailed cost breakdown, see Appendix C.

9. Future Work

Though the final design has been completed for the purpose of this project, there are still many tests that need to be conducted and possibly several more design iterations to be made before the device is complete. As listed in Table 1 in section 5, there are several tests that should be conducted to help finish creating a final design. Finite Element Analysis and subject testing have yet to be conducted and additional mechanical testing should also be completed. These tests will help to define the final shape of the design and which materials would be best to use. They will also be important for collecting data that will help strengthen a patent application.

The current aluminum and steel prototype is very heavy in comparison to a traditional blade. As is, the device would add a significant amount of weight to the skate that could be detrimental to performance; therefore, alternative materials should be considered. Fiber reinforced polymers, such as carbon fiber, might be appropriate materials for the base and plunger of the device because it has good mechanical properties and is significantly lighter than metals. Alternative materials should also be considered for the spring. There might be a polymer that could replace the spring steel to further decrease the weight of the device while still absorbing the necessary loads. Furthermore, polymer-based materials would likely be much easier to manufacture because streamlined techniques could be utilized rather than CNC machining.

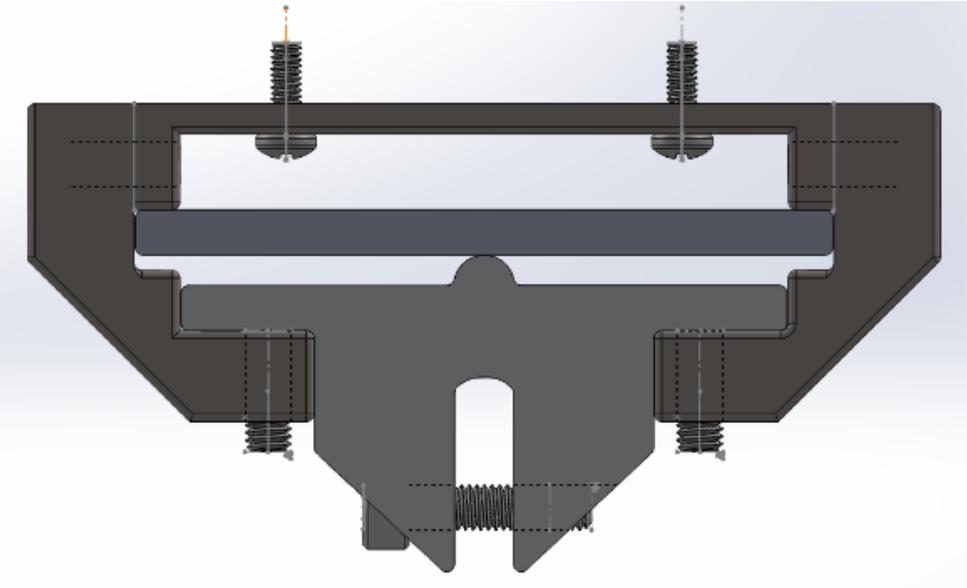
Biomechanical analysis, such as video analysis or force plate testing, could be conducted to help quantify the difference in load transfer, from the ice to the foot, between the team’s design and traditional skate blades. These numbers would prove whether or not the design reduces the loads that can lead to overuse injuries.

References

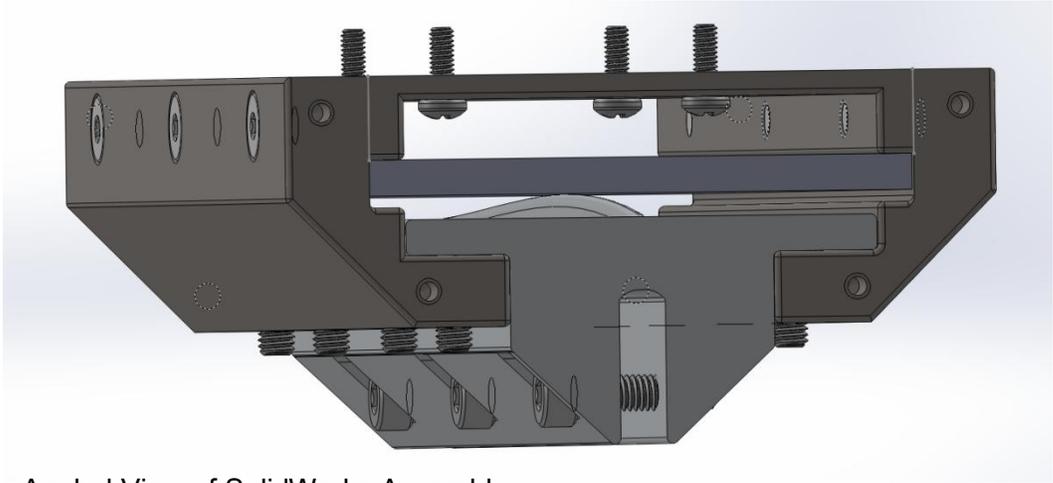
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Appendices

A. SolidWorks Drawings



Front View of SolidWorks Assembly



Angled View of SolidWorks Assembly



Angled View of SolidWorks Plunger and Teardrop-Shaped Protrusion

B. Spring Calculations

Stress:

$$\sigma = Mc/I$$

σ = stress

M = moment

c = distance from neutral axis = 1.5 mm = 0.0015 m

I = inertia | $I = (1/12) bh^3$

b = 100 mm = 0.1 m

h = 3 mm = 0.003 m

Applied force (F):

150 lbs = 68 kg

68 kg = 666.85 N

Applied force is equal to ten times the body weight accelerating downward. In this case, we used a weight of 150 lbs.

Moment (M):

$$M = r \cdot F$$

r = 23 mm = 0.023 m

$$M = 0.023 \text{ m} \cdot 666.83 \text{ N} = 15.33709 \text{ N}\cdot\text{m}$$

Inertia (I):

$$I = (1/12) bh^3$$

$$I = (1/12) \cdot (0.01 \text{ m}) \cdot (0.003 \text{ m})^3$$

$$2.25 \text{E}-10 \text{ m}^4$$

Stress (σ):

$$\sigma = Mc/I$$

$$\sigma = [(15.33709 \text{ N}\cdot\text{m}) \cdot (0.0015 \text{ m})] / 2.25 \text{E}-10$$

$$102247267 \text{ Pa}$$

$$102.247267$$

$$\sigma = 102.24 \text{ MPa}$$

This value for stress is about equal to the value of the yield strength for fatigue-resistant 5160 Spring Steel

Deflection

$$\delta = [(1/48)PL^3]/EI$$

δ = deflection

P = load = 102.24 MPa

L = 40 mm = 0.04 m

E = elastic modulus

For spring steel, E = 206,842 Mpa = 206,842,000,000 Pa

I = inertia = 2.25E-10 m⁴

Deflection (δ):

$$\delta = [(1/48) \cdot 102.24 \text{ Mpa} \cdot (0.04 \text{ m})^3] / (206,842,000,000 \text{ Pa} \cdot 2.25 \text{E}-10 \text{ m}^4)$$

$$0.0018307 \text{ m}$$

$$\delta = 1.8 \text{ mm}$$

C. Manufacturing Cost Analysis

Manufacturing Options:	
<p>Injection Molding and Drill/Tap Holes</p> <p>Assumptions: 2 molds (\$200,000/mold) Each mold produces 5 sets of blades 10 minutes per mold (35 sets/hour) 1 hour to Drill, Tap, and Assemble Cost of operator: \$25/hour Cost of Materials: \$268/set*</p>	<p>CNC Machining (ie Mill) and Tap Holes</p> <p>Assumptions: 8 hours to machine, tap, and assemble Cost of operator: \$25/hour Cost of Materials: \$268/set*</p>
<p>*This cost is likely significantly less because materials will be purchased in larger quantities than the single prototype costs</p>	

Blade Cost
(Standard 100-625/set of blades)
ReLeaf Blade-25% Premium for Function
Cost: 125-780/Set of Blades
Suggested Cost of ReLeaf Blades: \$750/set

If blades are sold for \$750, after selling 875 sets of blades, the injection molding costs will be covered and the cost to manufacture one set of blades reduces to \$293.71. This cost is less than that of machining each set of blades and allows for greater precision and less variability. If more than 2300 sets of blades are sold, the overall production cost of injection molding is less than the cost of CNC machining.

It might also be valuable to investigate the cost of expendable molds rather than permanent molds. When determining the best means of manufacturing.

Sets of Blades (x)	Cost to Produce "x" Blades (Injection Molding)	Production Cost/Set of Blades	Cost to Produce "x" Blades (CNC Machining)	Production Cost/Set of Blades
100	429371	4293.71	46800	468
200	458742	2293.71	93600	468
300	488113	1627.04	140400	468
400	517484	1293.71	187200	468
500	546855	1093.71	234000	468
600	576226	960.38	280800	468
700	605597	865.14	327600	468
800	634968	793.71	374400	468
875	656996.25	750.85	409500	468
900	664339	738.15	421200	468
1000	693710	693.71	468000	468
1100	723081	657.35	514800	468
1200	752452	627.04	561600	468
1300	781823	601.40	608400	468
1400	811194	579.42	655200	468
1500	840565	560.38	702000	468
1600	869936	543.71	748800	468
1700	899307	529.00	795600	468
1800	928678	515.93	842400	468
1900	958049	504.24	889200	468
2000	987420	493.71	936000	468
2100	1016791	484.19	982800	468
2200	1046162	475.53	1029600	468
2300	1075533	467.62	1076400	468
2400	1104904	460.38	1123200	468
2500	1134275	453.71	1170000	468

D. Provisional Patent

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eFiled Application Information

EFS ID	15399953
Application Number	61807066
Confirmation Number	3294
Title	SKATE BOOT FORCE ABSORBING APPLIANCE
First Named Inventor	Christopher A. Brown
Customer Number or Correspondence Address	58406
Filed By	Christopher J. Lutz/Pina L. Butler
Attorney Docket Number	WPI13-01p
Filing Date	
Receipt Date	01-APR-2013
Application Type	Provisional

Application Details

Submitted Files	Page Count	Document Description	File Size	Warnings
WPI13-01p-Patent-App.pdf	9	Specification	40553 bytes	◆ PASS
WPI13-01P-ProvisionalSB.pdf	3	Provisional Cover Sheet (SB16)	1476882 bytes	◆ PASS
WPI13-01P-DRAWINGS.pdf	11	Drawings-only black and white line drawings	1624741 bytes	◆ PASS
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If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.

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Provisional Application for Patent Cover Sheet					
This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53(c)					
Inventor(s)					
Inventor 1					<input type="button" value="Remove"/>
Given Name	Middle Name	Family Name	City	State	Country j
Christopher	A.	Brown	Worcester	MA	US
Inventor 2					<input type="button" value="Remove"/>
Given Name	Middle Name	Family Name	City	State	Country j
Karin	E.	Greene	Worcester	MA	US
Inventor 3					<input type="button" value="Remove"/>
Given Name	Middle Name	Family Name	City	State	Country j
Devon	L.	Rehm	Worcester	MA	US
All Inventors Must Be Listed – Additional Inventor Information blocks may be generated within this form by selecting the Add button.					<input type="button" value="Add"/>
Title of Invention	Skate Boot Force Absorbing Appliance				
Attorney Docket Number (if applicable)	WPI13-01p				
Correspondence Address					
Direct all correspondence to (select one):					
<input checked="" type="radio"/> The address corresponding to Customer Number			<input type="radio"/> Firm or Individual Name		
Customer Number	58406				

The invention was made by an agency of the United States Government or under a contract with an agency of the United States Government.	
<input checked="" type="radio"/> No.	
<input type="radio"/> Yes, the invention was made by an agency of the United States Government. The U.S. Government agency name is:	
<input type="radio"/> Yes, the invention was under a contract with an agency of the United States Government. The name of the U.S. Government agency and Government contract number are:	

Entity Status

Applicant asserts small entity status under 37 CFR 1.27 or applicant certifies micro entity status under 37 CFR 1.29

- Applicant asserts small entity status under 37 CFR 1.27
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Signature

Please see 37 CFR 1.4(d) for the form of the signature.

Signature	/Christopher J. Lutz/			Date (YYYY-MM-DD)	2013-04-01
First Name	Christopher J.	Last Name	Lutz	Registration Number (If appropriate)	44883

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Inventors: Christopher A Brown, Karin E Greene and
Devon L Rehm
Attorney Docket No.: WPI13-01p

SKATE BOOT FORCE ABSORBING APPLIANCE

BACKGROUND

- 5 The incidence of injury in figure skating is common, especially among elite skaters who practice frequently and attempt to complete difficult skills. Some injuries occur due to errors, while others are caused by overuse of a joint, tendon, or bone. In a recent study of elite (competition level) figure skaters, 42.8% of female participants and 45.5% of male participants reported overuse injuries (Dubravcic-Simunjak, 2003).
- 10 These injuries included jumper's knee (patellar tendonitis), stress fractures, and ankle sprains. The previously listed overuse injuries mostly stem from the exertion of large mechanical loads on various portions of the leg while landing jumps.

SUMMARY

- 15 A skate boot appliance attaches to the bottom of a skate boot and interfaces between a skate blade and the boot bottom for selectively absorbing impact forces above a displacement threshold that could result in injury to the skater. The appliance maintains the skate blade in a fixed arrangement during normal skating activities, so as not to interfere with normal skating activities. Upon an external force greater than the
- 20 displacement threshold, three to ten times the body weight, the appliance permits displacement of a plunger disposed between the skate blade and the bottom of the skate boot to move axially upward in response to a spring loaded counterforce mechanism designed to selectively respond to excessive force such as that resulting from jumps, and also to absorb a series of brief but intense forces transmitted from the ice surface.
- 25 The plunger displaces in a receptacle housing the counterforce mechanism, such as a

spring, and employs a friction limiter to prevent a spring response that violates competition rules by unnaturally assisting a skating maneuver.

The skate boot appliance attaches to the bottom of a skate boot to absorb loads associated with a figure skating landing. The system will be capable of absorbing loads several times the body weight of the skater. The system will be comprised of a small beam spring or leaf spring and a piston or plunger in which the blade will be fixed. The spring will be preloaded to prevent any unwanted vertical motion of the blade while experiencing normal loads during skating. The appliance will be adjustable allowing for the skater to determine the ideal preload set based on the individual's weight and the difficulty of the routine. The appliance will incorporate a one-directional friction function to prevent the spring from aiding in the initiation of jumps.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other objects, features and advantages of the invention will be apparent from the following description of particular embodiments of the invention, as illustrated in the accompanying drawings in which like reference characters refer to the same parts throughout the different views. The drawings are not necessarily to scale, emphasis instead being placed upon illustrating the principles of the invention.

Fig. 1 shows a front elevation of a plunger and leaf spring disposed in the appliance in a particular configuration;

Fig. 2 shows a perspective view of the appliance of Fig 1;

Fig. 3 shows a front elevation of a particular configuration including a plunger, leaf spring and receptacle looking lengthwise along a skate boot mounting position;

Fig. 4 is a solid rendering of the configuration of Fig. 3;

Fig. 5 is an exploded view of the configuration of Figs 3 and 4, showing the skate blade, plunger, protrusion, receptacle, leaf spring and housing adapted for mounting on the bottom of a skate boot;

Fig. 6 shows a perspective of the assembled appliance of Fig. 5;

Fig. 7 shows a solid rendering of the appliance of Fig. 6;

Fig. 8 shows a front elevation of an alternate configuration having set screws for fixing a tension of the plunger against the leaf spring and mounting screws for skate boot attachment;

5 Fig. 9 shows the plunger of Fig. 8 including the friction limiting portions and the protrusion;

Fig. 10 is a perspective view of the plunger as in Fig. 9 showing the half-teardrop (teardrop) protrusion shape; and

Fig. 11 shows a side view of the teardrop protrusion of Fig. 10.

10 DETAILED DESCRIPTION

The current high-end figure skate boots popular with high-level skaters offer minimal shock absorption in the form of a cork heel on the skate as opposed to a wooden heel (Riedell Ice, 2010). There are no mechanical design components that are included to actively absorb landing loads.

15 In an attempt to remedy the previously listed shortcomings of the traditional figure skate boot, Bill Fauver, a former Olympic figure skater and current figure skating coach, patented a design for a boot that would more successfully absorb mechanical loads due to jump landings and would allow for full flexion of the ankle (Fauver, 2009). His new boot has triangle-shaped portions cut out of the upper part of the boot, allowing
20 ankle flexion, and a series of pistons mounted along this cut-out to absorb the load as the ankle flexes (Figure 1). While this design works mechanically, it is not entirely successful because the pistons impede the skater's ability to closely cross their feet over or bring their feet close together during spins.

The purpose of the disclosed approach is to create a novel absorption system for
25 figure skates that will reduce injurious loads to help prevent both overuse injuries and injuries due to jump landing error. Such a design could be marketed and produced for figure skaters looking to avoid overuse injuries.

The objective of this project is to develop an appliance having a mechanical absorption system for a figure skate. This system should aid in the prevention of jump
30 landing-related injuries while regarding the rules and regulations for competition

As previously discussed, the repeated application of large loads to a skater's joints can cause overuse injuries such as jumper's knee (patellar tendonitis), stress fractures, and ankle sprains (Dubravcic-Simunjak, 2003). Conventional figure skates offer little shock absorption to help reduce these loads. As a result, skaters have no way of protecting their joints during hours of practice.

Upon considering the problems with traditional figure skate boots stated above, the disclosed approach improves upon a patented design by Bill Fauver, a former Olympic figure skater. Review of Fauver's design led us to conclude that our design needed to absorb landing loads exerted on the ankle using a system that would not impede the skater and would absorb loads between the ice and the bottom of the foot. Other skates, such as hockey and speed skates, may also benefit from such an appliance.

Accordingly, configurations disclosed herein teach a skate footwear appliance including a base adapted for attachment to the bottom of a skate boot, and a receptacle in the base adapted to receive a plunger. The plunger is responsive to external forces on the skate boot from skating movements, such as an upward force resulting from landing following a jump. The receptacle has a counterforce mechanism for opposing the external forces from the jump, such that the counterforce mechanism has a displacement threshold based on a computed external force injurious to a wearer of the skate boot. The plunger remains fixed in response to external forces below the threshold, permitting normal activities similar to a conventional fixed blade, and is responsive to external forces greater than the threshold by displacement within the receptacle. In an expected usage, the external forces are substantially upward force in response to jumping movements of a skater, and the plunger is displaceable axially in response to the external force and substantially fixed with respect to lateral forces. In other words, the plunger moves only axially along the axis orthogonal to the bottom of the skate, substantially aligned with an upright position of the skater.

The appliance secures to a blade attached to a distal end of the plunger (nearest the ice), such that the blade defines an interface between the skate boot and the ice surface and is adapted to transmit the external forces from the ice to the plunger responsive to movements of a wearer of the skate boot. The threshold force is then

based on measurements of a skater wearing the boot landing on a blade attached to the plunger following an airborne jump, such as height and weight of the skater, as well as an expected jump height and gravitational response that determine the landing force.

5 In the example arrangement, the plunger further includes a shaft extending downward from a bottom of the boot and attached to the blade at a distal end, and a widened portion at a proximate end, generally forming a “T” shape, such that the receptacle is adapted to receive the proximate end for accommodating vertical movement, and the distal portion of the shaft remains axially fixed in the receptacle for preventing lateral movement. The “T” shape is such that the wider portion occupies the proximate end disposed in the receptacle nearest the skate boot bottom and perpendicular to the narrower orthogonal portion which provides parallel engagement to the blade.

15 At the proximate end of the receptacle nearest the boot, the counterforce mechanism comprises a spring adapted to remain substantially fixed until the external force reaches the displacement threshold, and displaces further in response to forces less than the displacement threshold once the displacement threshold is reached. In the example arrangement, the spring is a leaf spring engages a convex arc and/or protrusion on the plunger, and the base further comprises a void on an opposed side of the leaf spring, such that the void is responsive to the leaf spring for receiving deflection. The leaf spring is engaged to the plunger and shelves or lips on opposed sides of the void in a 3 point manner for deflecting the external forces.

20 In an example arrangement, the plunger further comprises an asymmetrical teardrop shape for varying a response along a length of the plunger. The plunger may also include a protrusion for concentrating the external forces on a predetermined portion of the leaf spring, typically in the center of the plunger for engaging a central portion of the leaf spring.

25 A particular feature of the design addresses the notion that the appliance should not aid the skater in the initiation of any upward movement, such as jumping, to prevent the appliance from giving the skater any unfair advantage during competition. To satisfy this constraint, we implemented a one-directional friction component that disallows the

30

plunger in the piston system to transfer loads back to the skater in the upward direction after downward load absorption. Current designs on the market do not prevent this secondary load transfer, and could potentially be ruled illegal by USFSA (United States Figure Skating Association). Any absorption system used in competitive figure skating
5 can only work in one direction. This means that it may absorb downward landing forces, but it cannot aid in the initiation of upward movement, i.e. jumping, of the figure skater. The shock absorption systems in the prior art do not account for this rule and would therefore be illegal in figure skating competitions.

Accordingly, the widened portion has friction limiters at a circumference of the
10 widened portion, the friction limiters for frictionally engaging the sides of the receptacle in one direction and having a different friction response in the opposed direction.

Further, the shock absorption systems in the prior art are not designed to absorb the full impact load of a jump landing. Their main goal is to reduce impact loads, but not completely dissipate injurious downward landing forces; therefore, they cannot
15 adequately reduce the risk of injury.

Deployment of the appliance in a skating context could potentially be used to help reduce injurious landing loads. This device could be purchased instead of a traditional skate blade. Since figure skaters need to buy their boots and their blades separately, this product would simply give them another choice.

20 While the system and methods defined herein have been particularly shown and described with references to embodiments thereof, it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the scope of the invention encompassed by the appended claims.

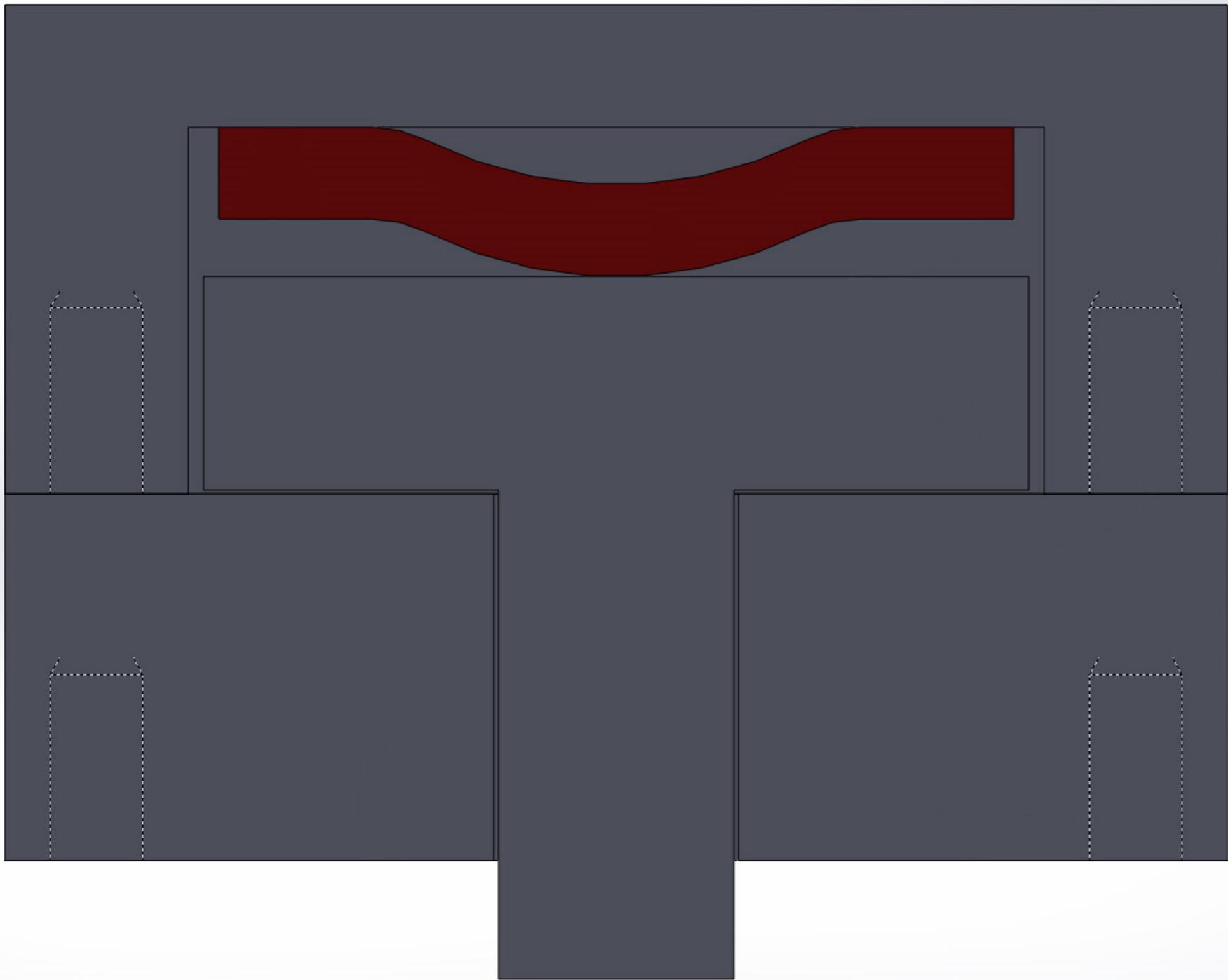
CLAIMS

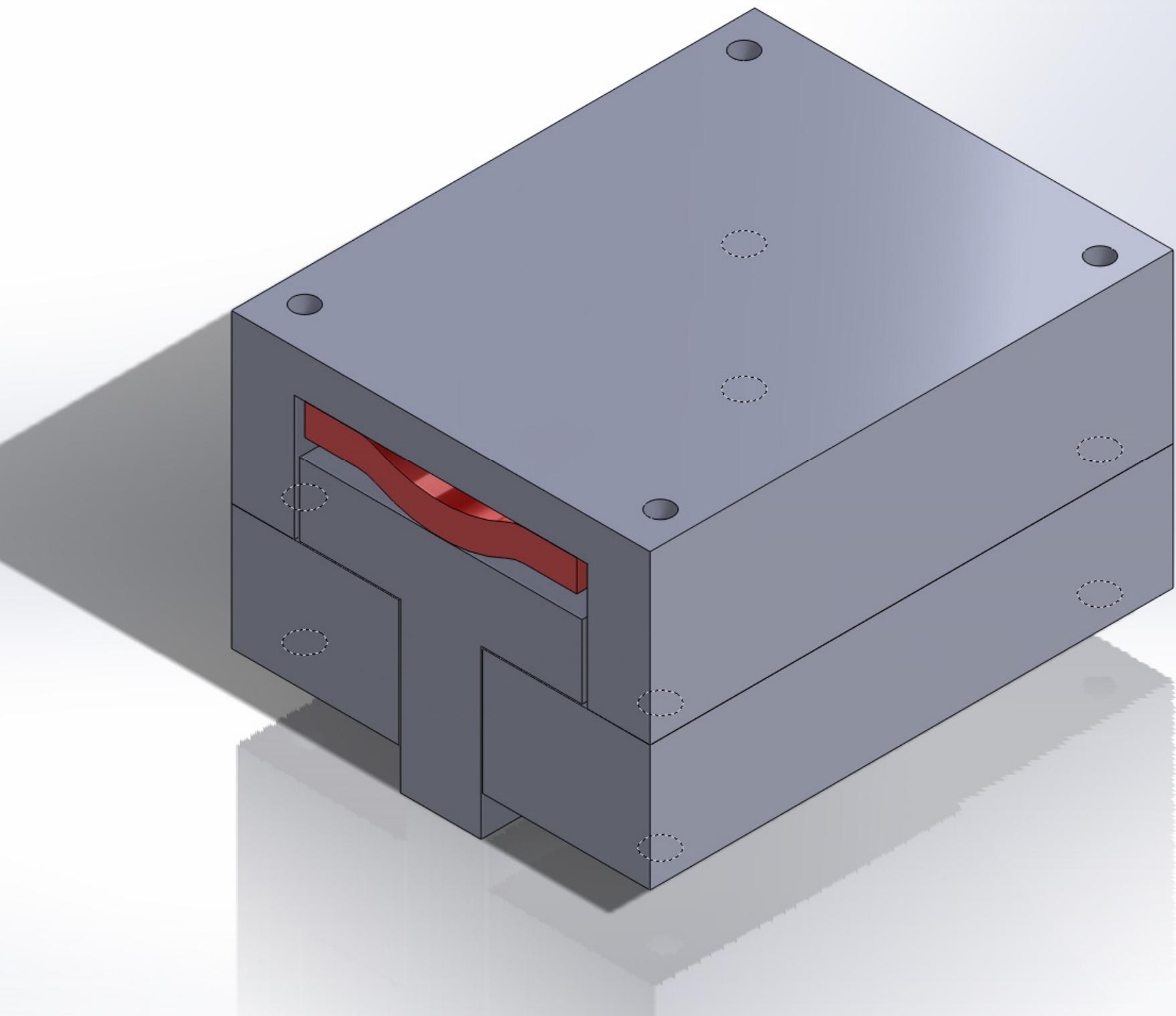
What is claimed is:

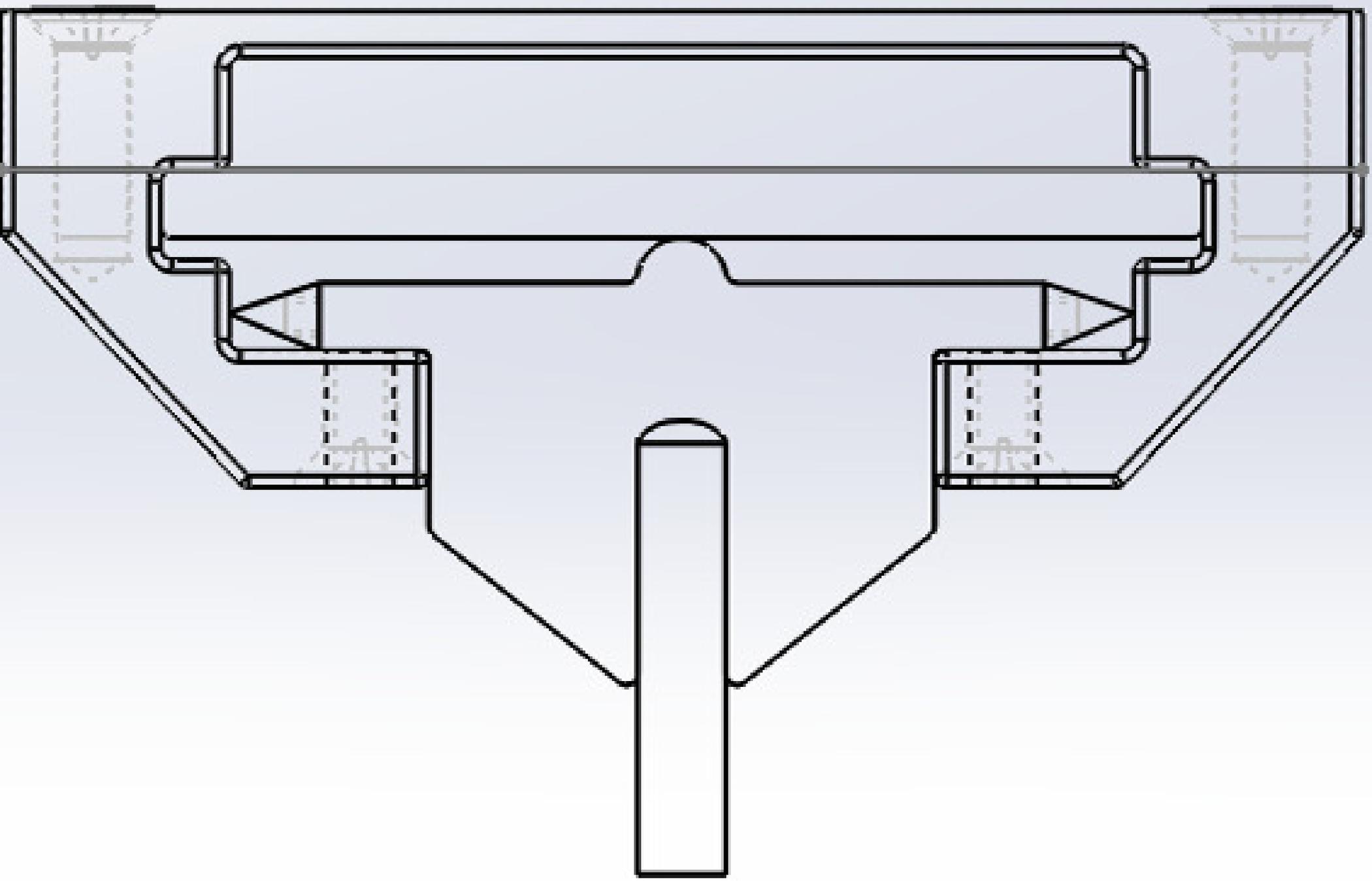
1. A skate footwear appliance comprising:
5 a base adapted for attachment to the bottom of a skate boot;
a receptacle in the base adapted to receive a plunger;
the plunger responsive to external forces on the skate boot from skating
movements;
the receptacle having a counterforce mechanism for opposing the external
10 forces, the counterforce mechanism having a displacement threshold based on an
external force injurious to a wearer of the skate boot; and
the plunger remaining fixed in response to external forces below the threshold,
and responsive to external forces greater than the threshold by displacement within the
receptacle.
15
2. The appliance of claim 1 wherein the external forces are substantially upward
force in response to jumping movements of a skater, and the plunger is displaceable
axially in response to the external force and substantially fixed with respect to lateral
forces.
20
3. The appliance of claim 2 further comprising a blade attached to a distal end of
the plunger, the blade defining an interface between the skate boot and an ice surface
and adapted to transmit the external forces from the ice to the plunger responsive to
movements of a wearer of the skate boot.
25
4. The appliance of claim 2 wherein the threshold force is based on measurements
of a skater wearing the boot landing on a blade attached to the plunger following a
airborne jump.

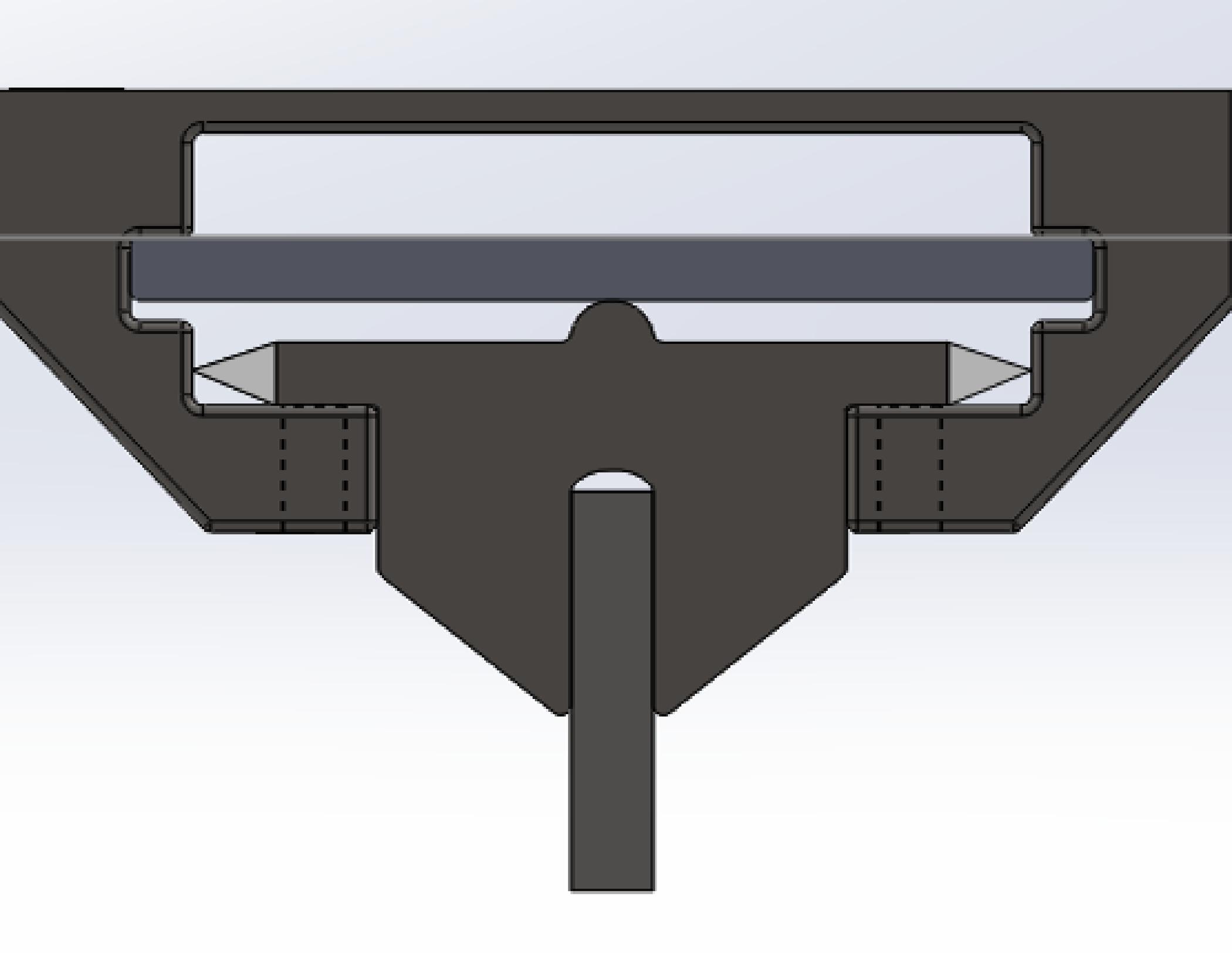
5. The appliance of claim 3 wherein the plunger further comprises:
a shaft extending downward from a bottom of the boot and attached to the blade
at a distal end; and
a widened portion at a proximate end, the receptacle adapted to receive the
5 proximate end for accommodating vertical movement, the distal portion of the shaft
remaining axially fixed in the receptacle for preventing lateral movement.
6. The appliance of claim 5 wherein the widened portion has friction limiters at a
circumference of the widened portion, the friction limiters for frictionally engaging the
10 sides of the receptacle in one direction and having a different friction response in the
opposed direction.
7. The appliance of claim 1 wherein the counterforce mechanism comprises a
spring adapted to remain substantially fixed until the external force reaches the
15 displacement threshold, and displaces further in response to forces less than the
displacement threshold once the displacement threshold is reached.
- 8 The appliance of claim 7 wherein the spring is a leaf spring for engaging the
plunger in a 3 point manner responsive to the external forces; and
20 the base further comprising a void on an opposed side of the leaf spring, the
void responsive to the leaf spring for receiving deflection.
9. The appliance of claim 8 wherein the plunger further comprises an asymmetrical
teardrop shape for varying a response along a length of the plunger.
25
10. The appliance of claim 8 wherein the plunger further comprises a protrusion
having a half tear-drop shape for concentrating the external forces on a predetermined
portion of the leaf spring.

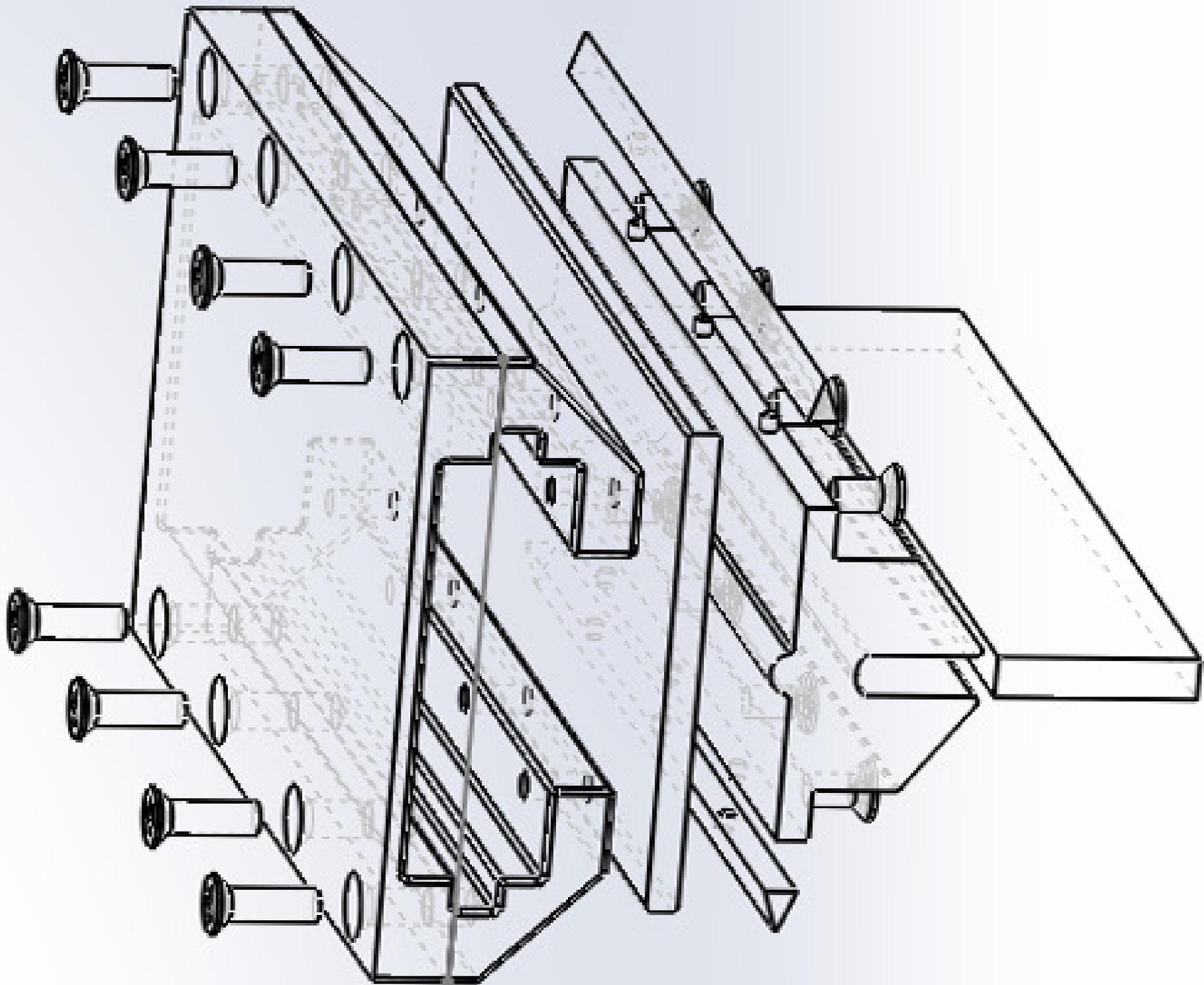
11. The appliance of claim 9 wherein the plunger comprises a “T” shape having a broad portion at the proximate end disposed in the receptacle and a narrower orthogonal portion engaging the blade.

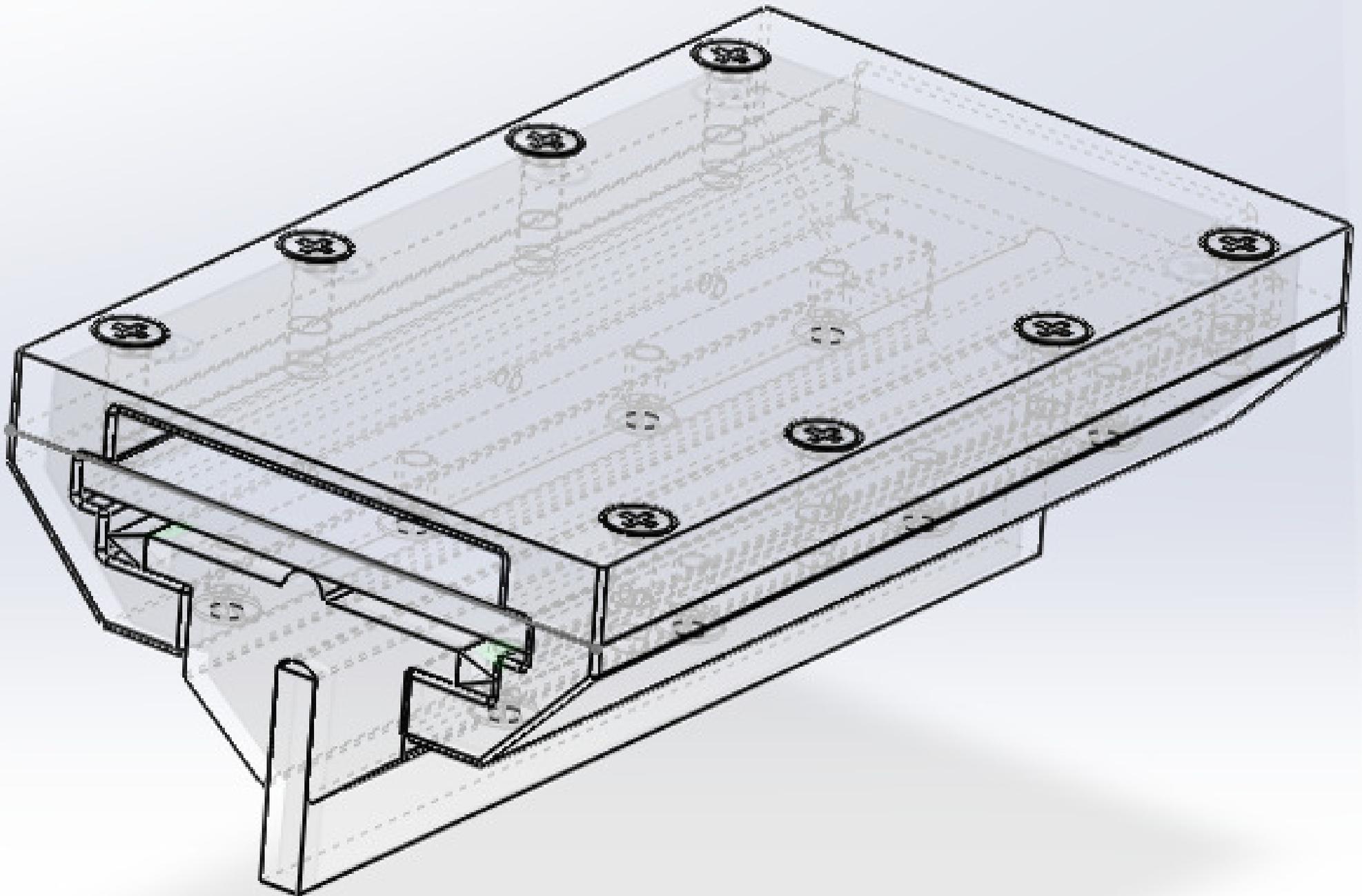


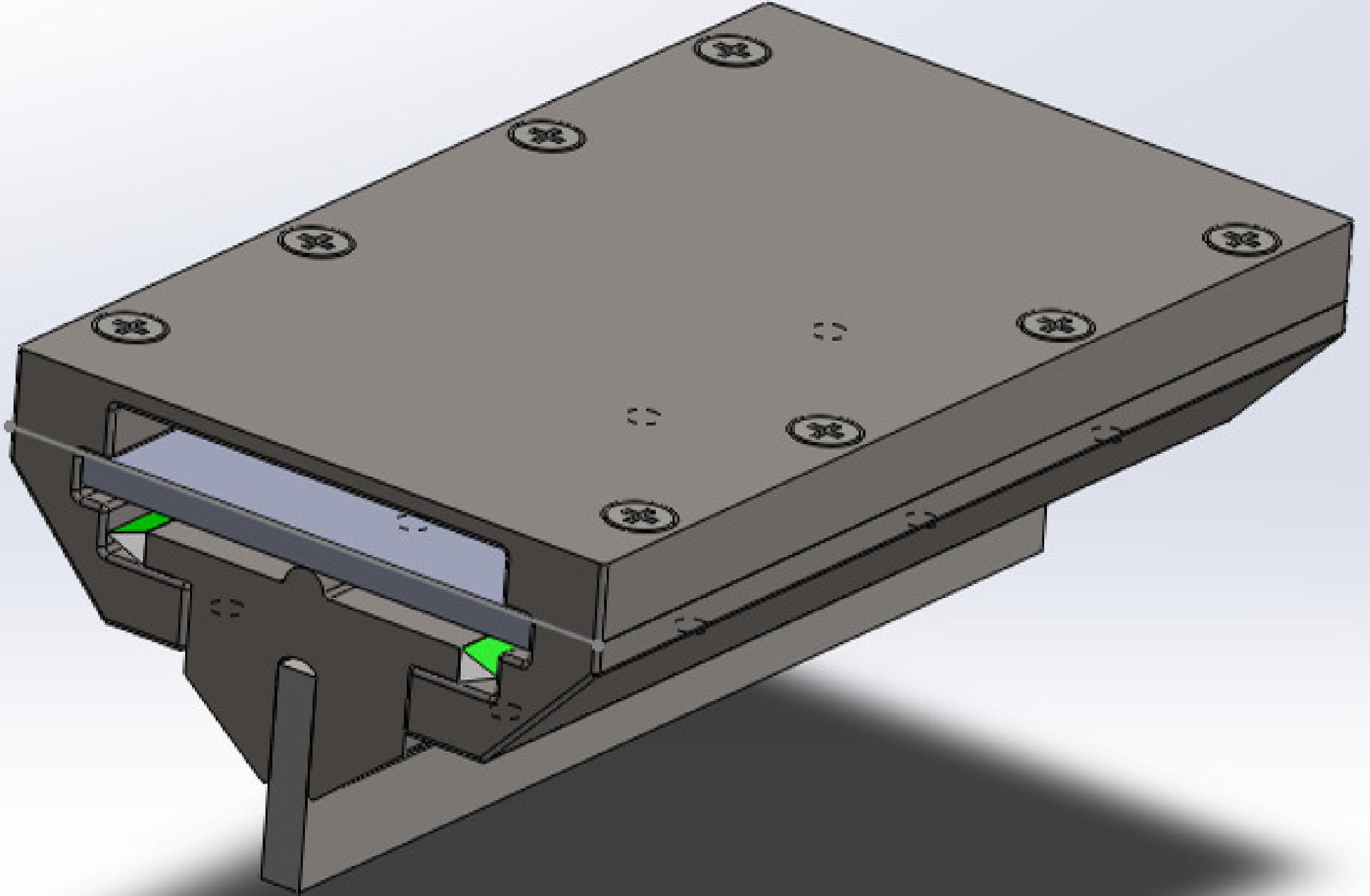


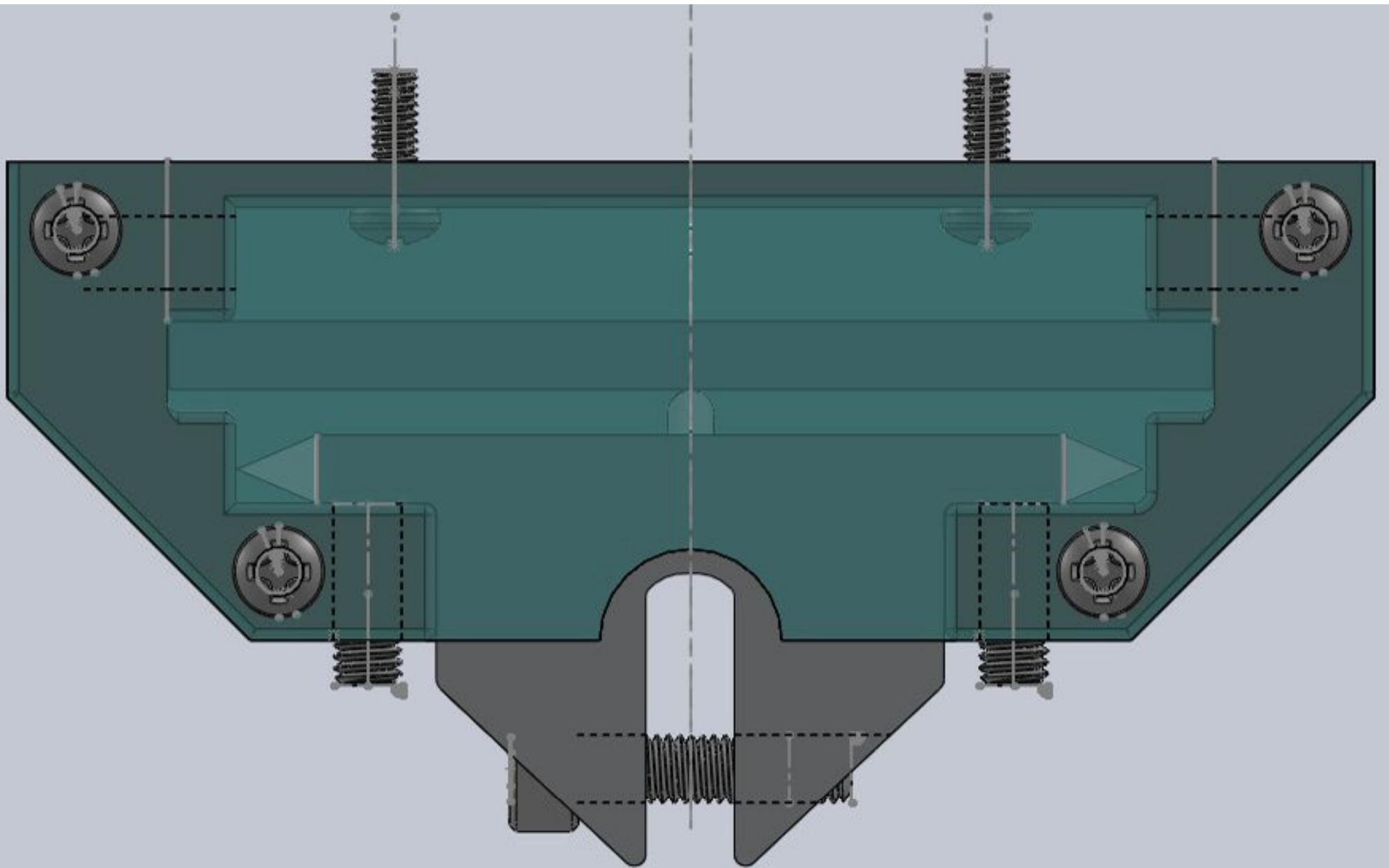












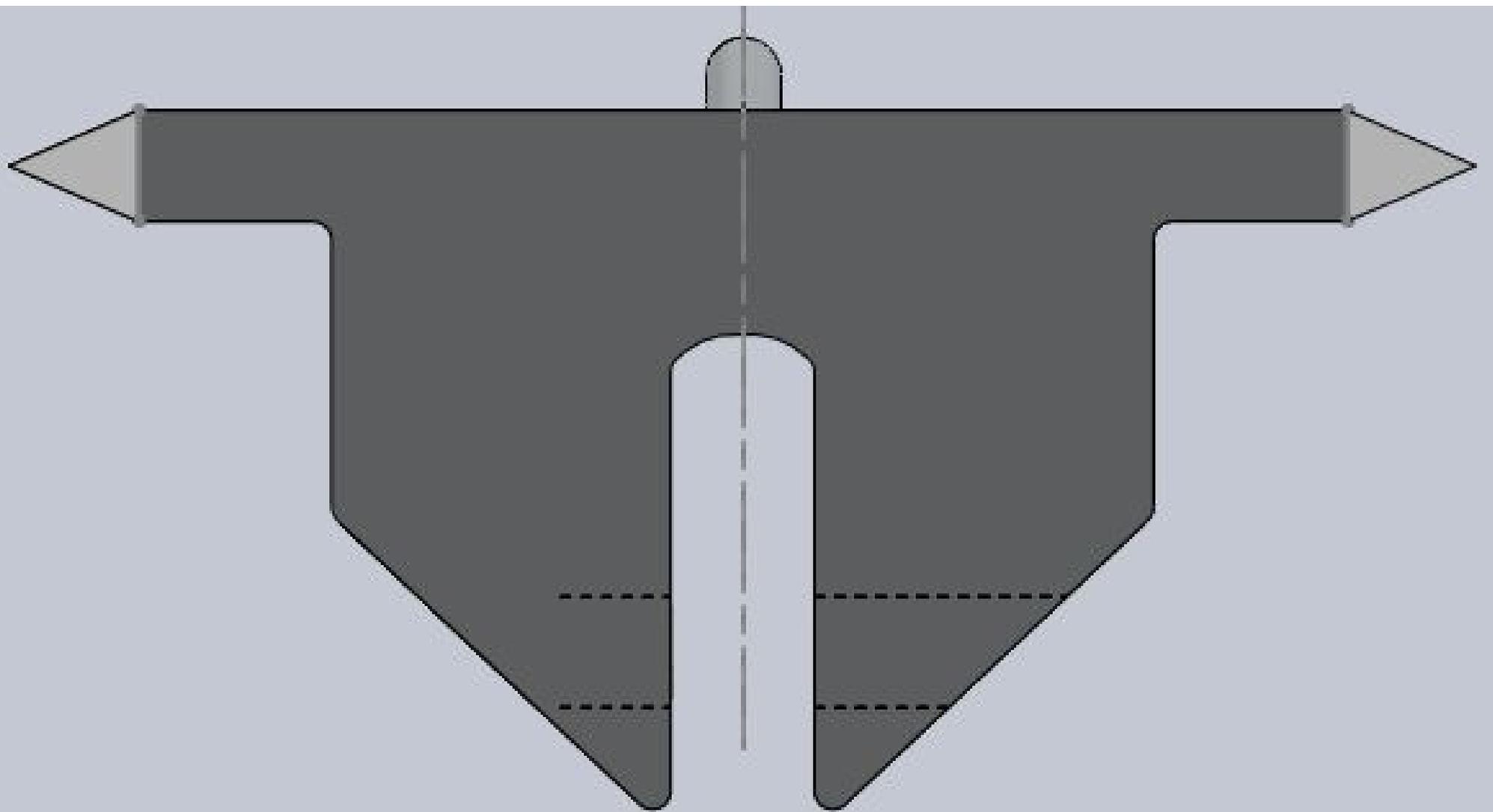


FIGURE 10-10

