Innovative Anti-Slipping Mechanisms for Shoe Soles

A Major Qualifying Report

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Table of Contents

Table of Figures

Table of Tables

Abstract

Winter running can cause slipping, which can lead to injury. To prevent this, runners need multi-surface shoes that provide traction on winter surfaces. Two solutions were chosen and analyzed. One system utilized thermoelectric cooling technology to freeze the thin water layer on top of ice, while the other utilized a spiked conveyor belt mechanism that will rotate when slipping occurs. After analyzing both solutions, recommendations were made for future development of anti-slip mechanisms.

Acknowledgements

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- **Kyle Fortin** for assistance in the manufacturing of our prototype and the machining of parts

1. Introduction

1.1 Objective

The objective of this project is to analyze current anti-slipping shoe sole mechanisms and use axiomatic design to introduce new and innovative anti-slipping mechanisms that have traction on ice and pavement.

1.2 Rationale

Winter running leads to an increased risk of fall or fall related injuries due to ice and snow. Fractures in the forearm and wrist are 3.7 times and 7.3 times more likely, respectively, during the winter months due to falling on ice (Br Med J, 1981). Slipping can occur when the foot pushes off the ground, as well as when the heel lands on the ground. Many slip and falls are due to wearing the wrong footwear on a slippery surface (Becker, 2001).

1.3 State of the Art

1.3.1 Current Products

Currently, there are no products on the market that have the ability to hold traction on ice and pavement. Many shoes designed for traction on ice use metal spikes, which will decrease traction on pavement. Table 1 shows a comparison chart of the best winter running shoes from 2015 (Bowe, 2015). Another version of this chart comparing features and downsides of each shoe can be seen in Appendix A.

Shoe	Ice?	Snow?	Pavement?
Skechers GoRun Ultra Extreme	No	Yes	Yes
Salomon S-Lab Fellcross 3	No	Yes	No
Icebug Aurora BUGrip	Yes	Yes	No
La Sportiva Crossover 2.0 GTX	No	Yes	No
Saucony Ride 7 GTX	No	No	Yes
The North Face Ultra Equity Gore-Tex	No	Yes	Yes
Inov 8 Mudclaw 300	Yes	Yes	No
New Balance Minimus Zero Trail v2	No	Yes	Yes
Newton Boco AT	No	Yes	Yes

Table 1: Current Winter Running Shoes Comparison Chart

1.3.2 Prior Art

Prior art was researched to see what anti-slipping shoe sole mechanisms have been patented and if they were similar to our ideas. We had two design solutions, a thermal solution utilizing thermoelectric cooling technology and a mechanical solution utilizing a spiked wheel that rotated when slipping occurred. We did not find any patents that were similar to our two design solutions, although there were some patents that used the same concept to prevent slipping on ice. A footwear traction device, US 5943792 A, uses the same idea that our thermal solution is based on. This idea involves freezing to prevent slipping. Instead of freezing the thin water layer on top of ice like our thermal solution does, the shoe sole is fibrous and hygroscopic. The shoe sole is wet, and when it comes in contact with the cold ice, it freezes to the ice and prevents the user from slipping. Footwear with manually extendable spikes, US 7490418 B2, uses the same concept as our mechanical solution, retractable spikes. The difference is that the mechanism in US 7490418 B2 needs to be manually extended and retracted, while our mechanism will automatically engage when slipping occurs and disengage when the slipping motion has been stopped. There are various patents for retractable spike systems to prevent slipping, but all involve the user to react in order for the spike system to engage with the ice. Our mechanism reacts to the slipping motion, engaging when slipping occurs. This prevents accidental spike system engagement and eliminates the need for the user to react when they slip on ice to prevent a fall. A detailed chart of patents researched can be seen in Appendix B.

1.3.3 Archival Literature

Research was found about testing 49 different shoe materials on dry ice and wet ice and assessing the shoe's ability to hold traction on these surfaces. The article concluded that of the materials tested, 90% were slippery on wet ice while 60% were slippery on dry ice. It was also concluded that 5 materials were slip-resistant on dry ice, while only 1 material was slip-resistant on wet ice. No materials tested were slip-resistant on both dry ice and wet ice. For dry ice, the authors recommend a shoe sole made of thermoplastic rubber with a large cleated area. This material is soft in comparison to other shoe materials. For wet ice, the authors state that a new material needs to be developed. They recommend a material that is hard with a soft base in combination with sharp cleats to provide traction on wet ice (Grönqvist, 1995).

1.3.4 Axiomatic Design

Axiomatic design was used when creating our design solutions. Axiomatic Design is a system of thinking when designing based on two principles that utilize a matrix to analyze the customer's needs. The two principles are Axiom one and Axiom two. Axiom one is also known as the independence axiom, which allows the functional requirements to maintain independence from each other. Axiom two is also known as the information axiom, which minimizes the informational content of the design. When using axiomatic design, functional requirements (FRs) are created with corresponding design parameters (DPs). The functional requirements are prioritized, with FR0 being the main goal of the design. The software program Acclaro was used to develop our design decompositions for our two solutions (Suh, 2001).

1.4 Approach

As seen through current market research and prior art research, designing a shoe that has traction on all three winter surfaces has not been done yet. We are using axiomatic design to innovate anti-slipping mechanisms to give winter runners a shoe that will provide traction on ice, snow, and pavement. Although the decompositions for the two design solutions are for an entire shoe sole, as the year progressed we decided to focus on the most challenging aspect of our project, traction on ice in combination with track on pavement. These two surfaces are quite different, so finding design solutions to satisfy both conditions was difficult.

2. Thermal Solution

Our thermal solution utilized a thermoelectric cooling device powered by a piezoelectric disc or battery. Thermoelectric cooling devices work by using P-type and N-type semiconductors, which are oppositely charged, to cause heat to flow in one direction. These semiconductors are mounted in rectangular arrays between two ceramic plates. When power is supplied to the thermoelectric cooling device, one ceramic plate on the device becomes cold and the other side becomes hot. This is due to the fact that heat flows in one direction. One side becomes cold as the heat is absorbed, and the other side becomes hot as the heat is released.

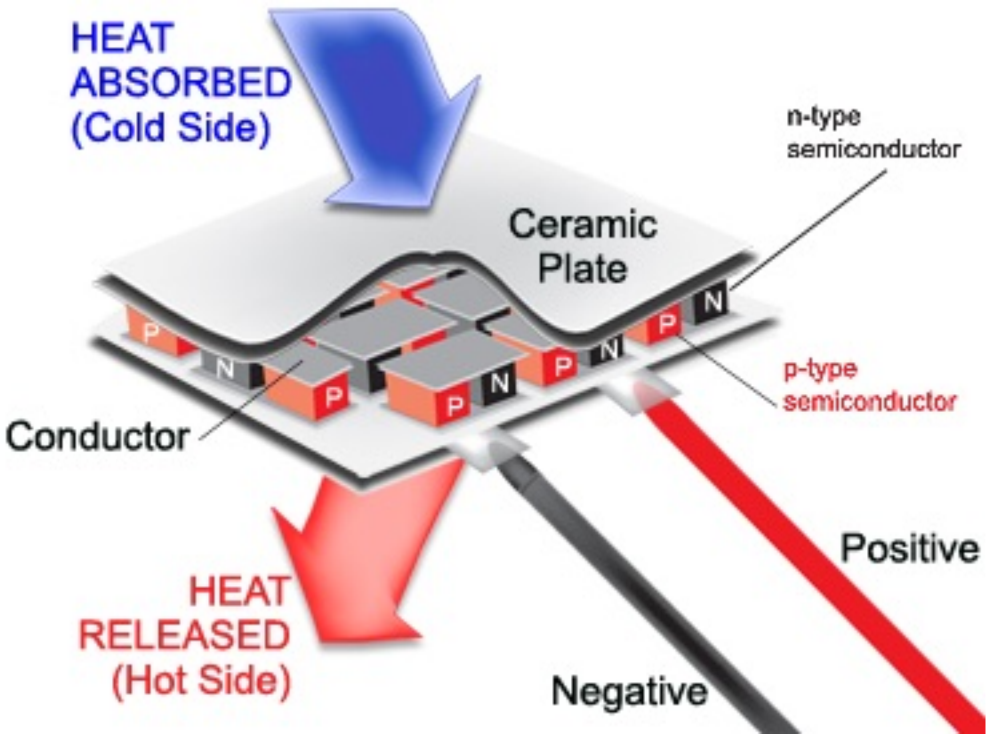


Figure 1. Diagram of Thermoelectric Cooling Device (FrozenTEC, 2016)

2.1 Design Decomposition

FR0 is the main goal of our design, which is to provide traction on snow, ice, and pavement during winter running. The DP that will satisfy this FR is to have a multi-surface winter running shoe that has the ability to provide traction on these three surfaces. A main constraint in the design is that the mechanism that provides traction on ice cannot compromise the shoe's ability to hold traction on pavement. Figure 2 shows the decomposition for our thermal solution.

FR0. Provide traction on ice, snow and pavement	**DP0.** Multi-surface winter running shoe
FR1. Limit tangential slipping on Ice	**DP1.** Buttons/Spikes that freeze water layer on ice
FR1.1. Remove heat from button/spike	*DP1.1.* Thermoelectric cooler
FR1.2. Concentrate cold temperature in a smaller area for freezing	*DP1.2.* Semiconductors arranged in ring formation
FR1.3. Provide power source to thermoelectric cooler	*DP1.3.* Piezoelectric discs or batteries
FR2. Provide Traction on Snow	**DP2.** Tread that grips snow
FR2.1. Maintain sole flexibility in the snow	*DP2.1.* Material for sole that maintains flex and direction when cold
FR2.2. Increase amount of edges on sole surface	*DP2.2.* Pattern of tread blocks with siped-surfaces
FR3. Provide Traction on Pavement	**DP3.** Material Specifications for sole
FR3.1. Prevent slipping on pavement due to material hardness	*DP3.1.* Material for shoe sole suited for pavement
FR3.2. Prevent slipping on pavement due to limited static friction	*DP3.2.* Surface modifications to provide optimal static friction
FR4. Provide Traction on Surfaces with Water Layer	**DP4.** Tread that allows water removal from interface
FR4.1. Force water out of shoe sole interface	*DP4.1.* Deep grooves in sole that act as channels
FR4.2. Separate majority of sole surface from water layer	*DP4.2.* Convex bump texture to raise sole off the ground

Figure 2. Thermal Solution Decomposition

2.1.1 FR1 and DP1

Tangential slipping on ice needs to be limited (FR1). To accomplish this, the design needs to freeze the thin water layer on top of ice (DP1). This functional requirement was divided into three children. FR1.1 says that heat needs to be removed from the buttons or spikes. To accomplish this, a thermoelectric cooling device was used (DP1.1). FR1.2 states that the cold temperature from the thermoelectric cooler needs to be concentrated into a small area where the spike or button is. This FR was added due to testing results. Due to our testing results, the thermoelectric cooling device needs to be redesigned to form a ring rather than a square (DP1.2). FR1.3 states that there needs to be a power source for the thermoelectric cooling device. In order to supply power to the thermoelectric cooling device, piezoelectric disks or batteries will be used (DP1.3).

2.1.2 FR2 and DP2

The shoe sole needs to have traction on snow (FR2). To accomplish this, the shoe sole needs a tread that could grip snow (DP2). Research on tires was used when designing a shoe sole that has traction on snow. Information about tires can be found in Appendix C. After researching snow tires, this functional requirement was divided into two children. FR2.1 states that shoe sole flexibility needs to be maintained in the snow. Some materials lose flexibility when they become cold, so a material that has the ability to maintain flex and direction when cold needs to be used for the shoe sole (DP2.1). While researching snow tires, we found that they differ from all season tires due to the number of edges they have. When there are a greater number of edges, the tire had better traction in snow. For this reason, the sole needs and increased number of edges (FR2.2). To accomplish this, the shoe sole needs a pattern of tread blocks with siped surfaces (DP2.2). The decomposition of FR2 needs revising as the children may not be entirely independent from one another.

2.1.3 FR3 and DP3

The shoe sole needs to have traction on pavement (FR3). To accomplish this, the materials used for the shoe sole needed to be specified (DP3). This functional requirement was divided into two children. FR 3.1 states that material hardness cannot cause slipping on pavement. To satisfy this functional requirement, the material chosen for the shoe sole needs to be suitable for pavement (DP3.1). The shoe sole also needs to prevent slipping on pavement due to limited static friction (FR3.2). For this reason, surface modifications to provide optimal static friction need to be done (DP3.2). The decomposition of FR3 needs revising as the children may not be entirely independent from one another.

2.1.4 FR4 and DP4

The shoe sole needs to be able to provide traction on surfaces with a water layer (FR4). To accomplish this, the tread needs to be designed to allow water removal from the interface (DP4). This functional requirement was divided into two children. FR4.1 states that water needs to be forced out of the shoe sole interface. To satisfy this functional requirement, there need to be deep grooves in the shoe sole to act as channels for the water (DP4.1). The majority of the shoe sole surface should also be separated from the water layer (FR4.2), so the bottom of the shoe should have a convex bump texture in order to the shoe sole off the ground (DP4.2). The decomposition of FR4 needs revising as the children may not be entirely independent from one another.

2.2 Testing Methods

2.2.1 Thermoelectric Cooling Device Temperature Testing

Thermoelectric cooling (TEC) devices were purchased and tested in the Electrical and Computer Engineering lab using the DC Power Supply. Initially, we tried testing the TEC devices without a heat sink. We found that the side that was supposed to remain cold became hot quickly. For this reason, further testing was done with heat sinks. Two heat sinks were used, the difference between them being the fan placement (Figure 3). One heat sink was equipped with a fan underneath it, while the other was equipped with a fan on the side. Both heat sinks and the TEC had the same max voltage of ±12 V. Originally we were using one voltage source to power both devices, but we realized that two 12V power sources needed to be used because the heat sinks required a much larger current.

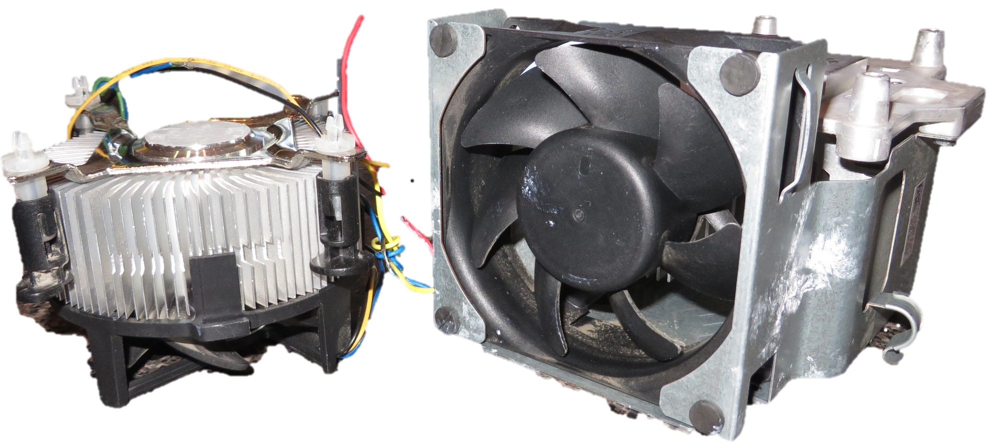


Figure 3. Heat Sink 1 (Left) and Heat Sink 2 (Right)

Once we had made these changes, we tested the TEC and heat sink using an infrared thermometer to monitor the temperature in 30-second intervals for 5 minutes. Due to the drastic temperature changes that occur within the first 30 seconds, we decided to monitor the temperature in 5-second intervals during the first 30 seconds. We did multiple trials using each heat sink. We did the first trial at the lowest voltage the heat sink would operate, and then increased the voltage by approximately 2V until 12V was reached. Heat sink 1, equipped with a fan underneath, was tested at 4.6 V, 6.7 V, 8.6V and 10V. Heat sink 2, equipped with a fan on the side, was tested at 6 V and 8.6 V. The maximum voltage of 12V was never reached with either heat sink due to the limitations of the Electrical and Computer Engineering laboratory. The graphs of these tests can be seen below in Figure 4 and Figure 5.

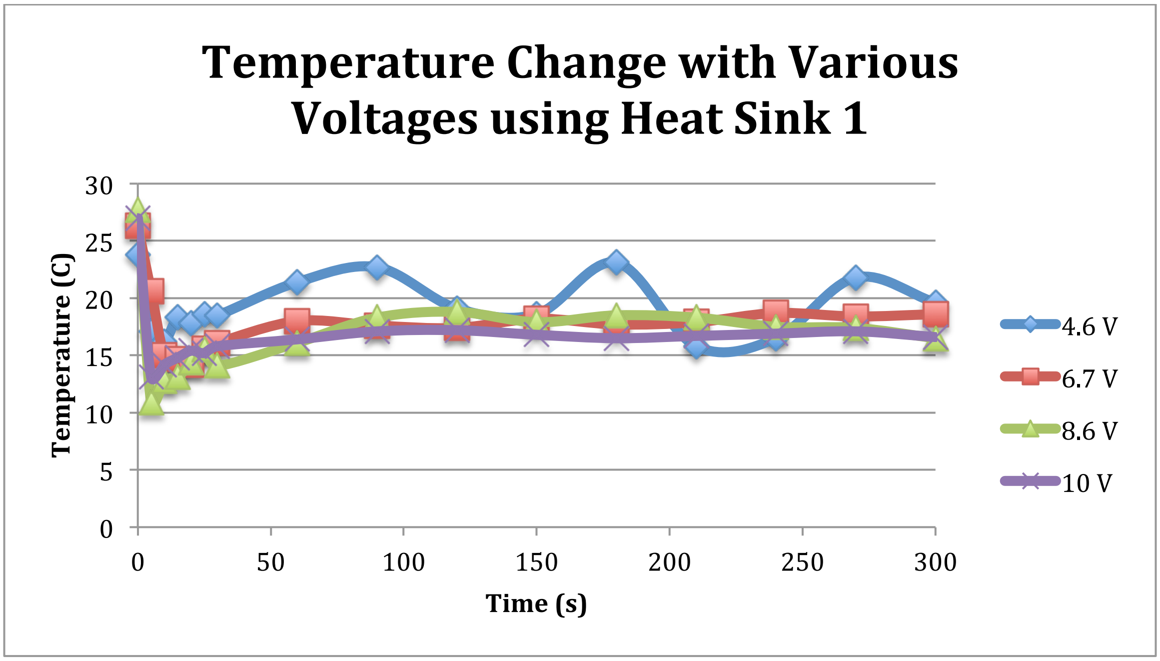


Figure 4. Heat Sink 1 Testing

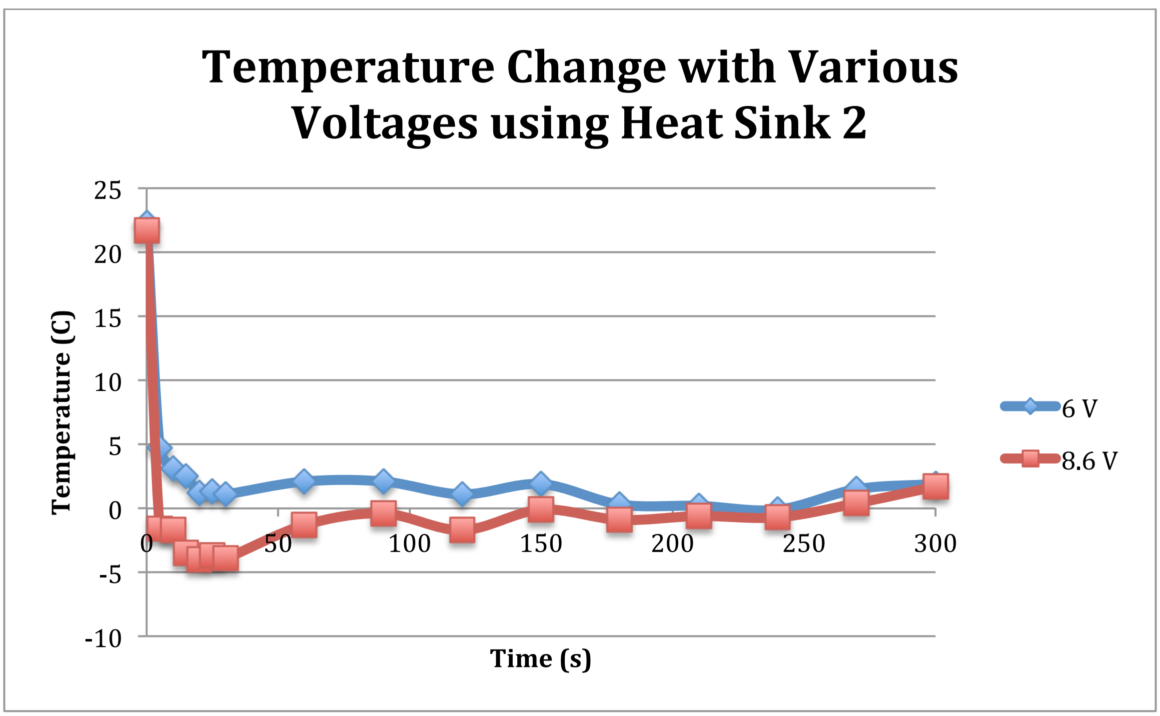


Figure 5. Heat Sink 2 Testing

As seen in the graphs in Figure 4 and Figure 5, even with the use of a heat sink the TEC did not reach or maintain cold enough temperature to freeze the thin water layer on top of the ice. A heat sink is too large to fit inside a shoe sole, so with current technology this thermal mechanism would not be possible.

2.2.2 Cold Metal and Wet Ice Test

To prove this idea is possible, a simple test was done to show that metal will stick to wet ice if it is cold enough. A metal screw was left in the freezer for approximately 2 hours. Once the screw had been in the freezer for 2 hours, it was removed. A small ice cube was taken out of the freezer and was allowed time to melt slightly in order to mimic the concept of the thin water layer on top of ice. Once the cold nail touched the slightly melted ice, the ice stuck to the nail. According to Colbeck, the water layer thickness on top of ice is 1.5 μm (Colbeck, 1992). A picture showing this test can be seen below in Figure 6.

Figure 6. Cold Metal and Wet Ice Test

2.3 Results and Design Recommendations

Since our testing results show that using TECs to freeze the thin water layer on top of ice would not be possible with the current technology, the TEC was redesigned to have a new configuration.

Theoretically, if the P-type and N-type semiconductors were arranged in a ring formation instead of a rectangular array, the center of the ring would be cold enough to freeze the thin water layer on top of ice where the spike or button is. In this configuration seen in Figure 7, the center of the ring is the cold side while the outside of the ring is the hot side.

FR1.2

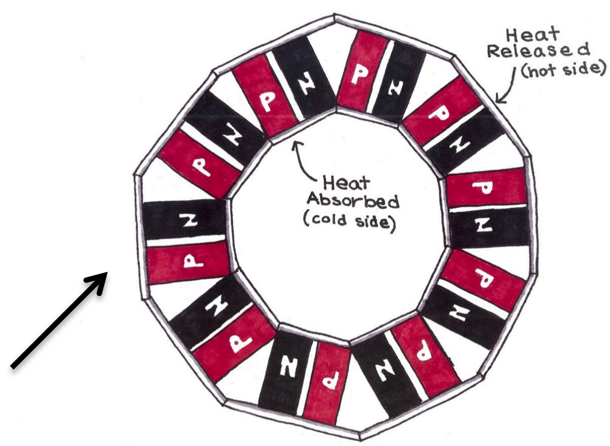


Figure 7. TEC Ring Configuration Design

The cold temperature would be concentrated into a small area where the spike or button is located, while the heat would be dispersed to a much larger area. A piezoelectric disc or a battery would power the TEC. A cross section of a shoe equipped with the redesigned TEC and a power supply can be seen in Figure 8 below. The zoomed in view in Figure 8 shows that the metal would be flat and be flush with the bottom of the shoe sole. The TEC would not be touching the ground and would be inside the shoe sole.

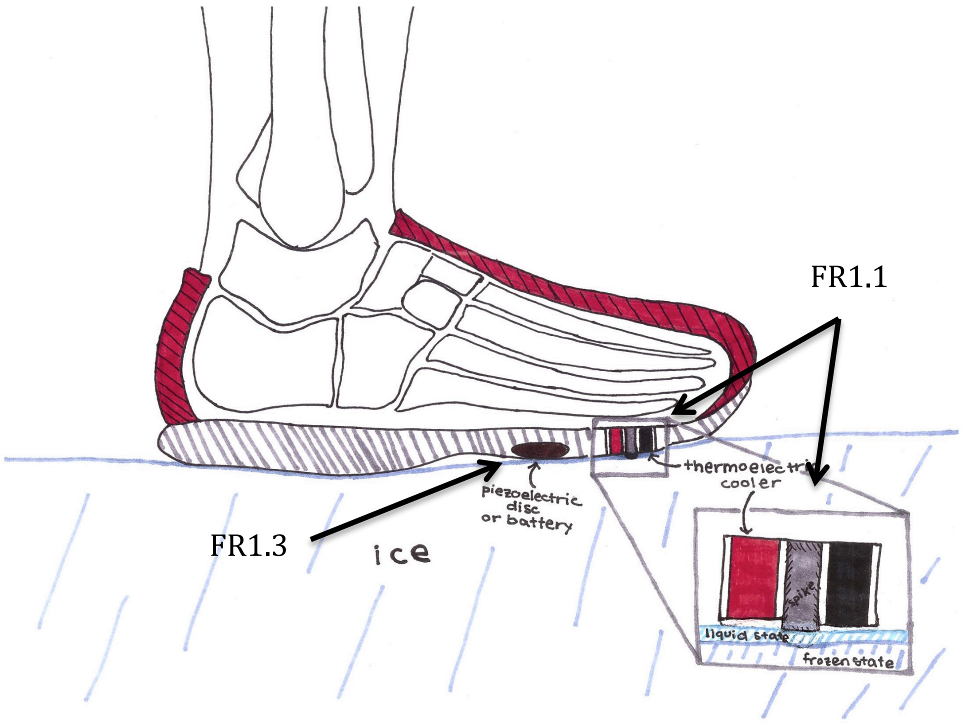


Figure 8. Cross Section of Shoe Equipped with TEC and Power Supply

Future design recommendations for our thermal solution would be to use heat transfer to calculate how much heat needs to be removed. The time it takes for the heat to be removed would also be useful so it can be compared to the duration that a foot is in contact with ice while running. If enough heat can be removed fast enough, then this solution has the potential to work with the redesigned TEC.

3. Mechanical Solution

Our mechanical solution utilizes a spike system that engages when slipping occurs. There are many shoes for winter running that currently use spikes to gain traction on ice, but these shoes can not be used on pavement or indoors because of this.

3.1 Design Decomposition

FR0 for the mechanical solution is the same as the thermal solution; provide traction on ice, snow, and pavement. The DP that will satisfy this FR is also the same; a multi-surface winter running shoe that has traction on these three surfaces. A major constraint for our mechanical solution was that the mechanism used for traction on ice could not interfere with the shoes traction on pavement. This was more challenging when designing a mechanical solution since spikes were to be used for traction on ice. In order to decouple traction on ice from traction on pavement, axiomatic design was used to find a solution that would satisfy both conditions. Figure 9 shows the decomposition for the mechanical design solution. Since the mechanical decomposition for FR2, FR3, and FR4 is the same as the thermal solution decomposition, only FR1 and DP1 are discussed below.

FR0. Provide traction on ice, snow and pavement

- **FR1.** Limit tangential slipping on Ice
  - *FR1.1.* Provide traction at starting position to engage spike system
  - *FR1.2.* Stop slipping motion
  - *FR1.3.* Return to initial position automatically
- **FR2.** Provide Traction on Snow
  - *FR2.1.* Maintain sole flexibility in the snow
  - *FR2.2.* Increase amount of edges on sole surface
- **FR3.** Provide Traction on Pavement
  - *FR3.1.* Prevent slipping on pavement due to material hardness
  - *FR3.2.* Prevent slipping on pavement due to limited static friction
- **FR4.** Provide Traction on Surfaces with Water Layer
  - *FR4.1.* Force water out of shoe sole interface
  - *FR4.2.* Separate majority of sole surface from water layer

DP0. Multi-surface winter running shoe

- **DP1.** Spike system that engages when slipping occurs
  - *DP1.1.* Smaller spikes or textured buttons on start position treads
  - *DP1.2.* Larger spikes on treads mechanism turns
  - *DP1.3.* Spring/Elastic system to resume initial position
- **DP2.** Tread that grips snow
  - *DP2.1.* Material for sole that maintains flex and direction when cold
  - *DP2.2.* Pattern of tread blocks with siped-surfaces
- **DP3.** Material Specifications for sole
  - *DP3.1.* Material for shoe sole suited for pavement
  - *DP3.2.* Surface modifications to provide optimal static friction
- **DP4.** Tread that allows water removal from interface
  - *DP4.1.* Deep grooves in sole that act as channels
  - *DP4.2.* Convex bump texture to raise sole off the ground

Figure 9. Mechanical Solution Decomposition

3.1.1 FR1 and DP1

Tangential slipping on ice needs to be limited (FR1). To accomplish this, a spike system that engages when slipping occurs must be used (DP1). This functional requirement was divided into three children. FR1.1 states that traction must be provided on the start position treads to engage the spike system. To satisfy this functional requirement, smaller spikes or textured buttons need to be on the start position treads (DP1.1). Once slipping on ice occurs, it needs to be stopped (FR1.2). To do this, treads will be equipped with larger spikes that become visible when the mechanism turns (DP1.2). The mechanism needs to return to its position automatically once the foot leaves the ground (FR1.3), so the mechanism is equipped with a spring or elastic system to help the tread links return to their initial positions.

3.2 Design Methods

Solidworks was used to model our design. Once the CAD was finished, the parts were saved as STL files and sent to the 3D printer. The spikes were made in the machine shop and the pins to hold the tread links together were ordered online.

3.2.1 CAD Modeling

Parts were modeled and assembled using Solidworks. A wheel was made to act as a track for the tread links to move on. Three types of tread links were created: a tread link with holes for spikes, a tread link with no holes that was symmetric, and a tread link that was also symmetric but had the same holes as the tread links with holes. Pins and spikes were also made in Solidworks for assembly purposes. Two sub-assemblies were made. These sub-assemblies are the tread link with the smaller spikes (Figure10) and the tread link with larger spikes (Figure 11).

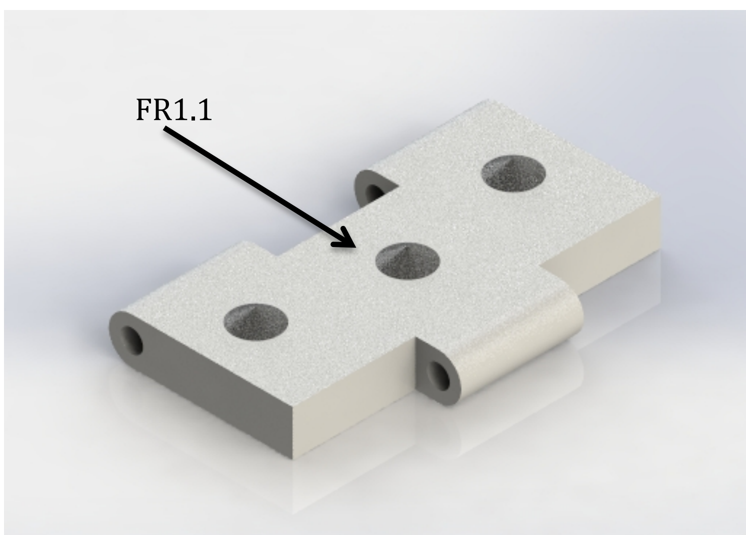


Figure 10. Tread Link Small Spike Sub-Assembly

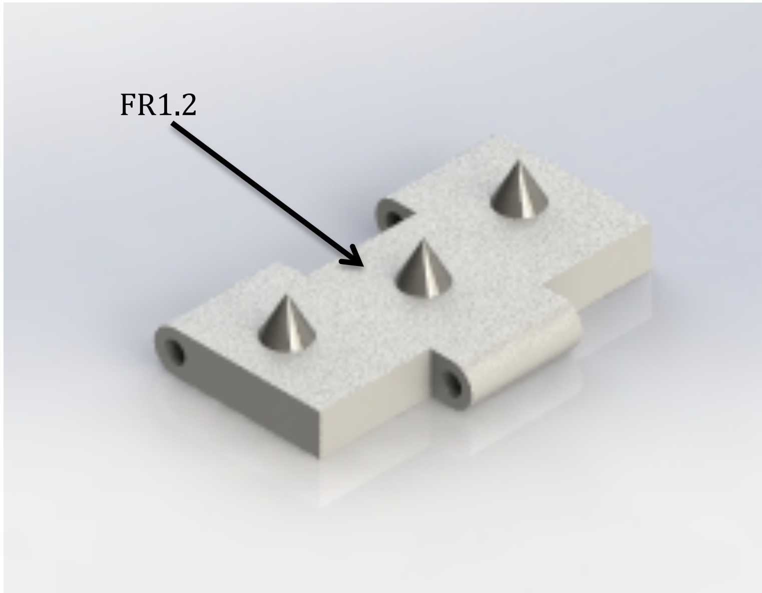


Figure 11. Tread Link Large Spike Sub-Assembly

These parts were assembled using concentric mates, coincident mates, and path mates. The path mate allowed the tread links to rotate around the wheel in Solidworks like they would in the real prototype. The symmetric tread link is stationary at the top of the wheel. The purpose of this tread link is to act as an anchor for the spring or elastic system so the tread links can resume their initial positions. The full assembly in isometric view can be seen in Figure 12. In this assembly, the elastic system used for resuming initial position is not depicted. A full list of CAD drawings can be seen in Appendix D.

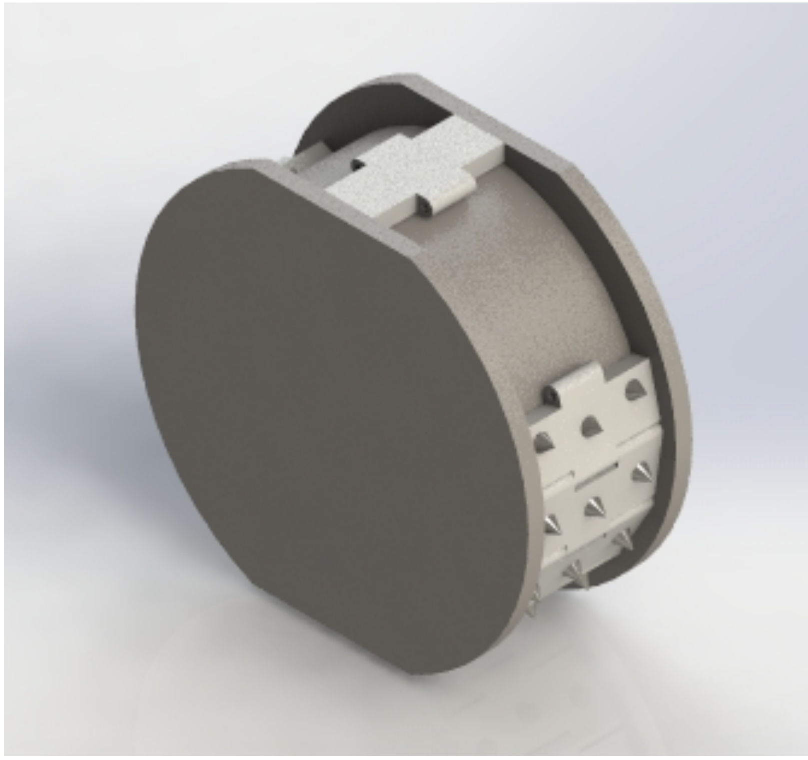


Figure 12. Isometric View Full Assembly

The idea behind this mechanism is that the small spikes would provide enough traction on ice to cause the mechanism to turn when slipping on ice. When the mechanism turns, the large spikes become visible and make contact with the ice, stopping the slipping motion. The mechanism then returns to its initial position using elastic thread once the slipping motion has been stopped and the foot has left the ground. Side views of the mechanism when the spike system is engaged and not engaged can be seen below in Figure 13 and Figure 14.

Figure 13. Spike system not engaged (no slipping)

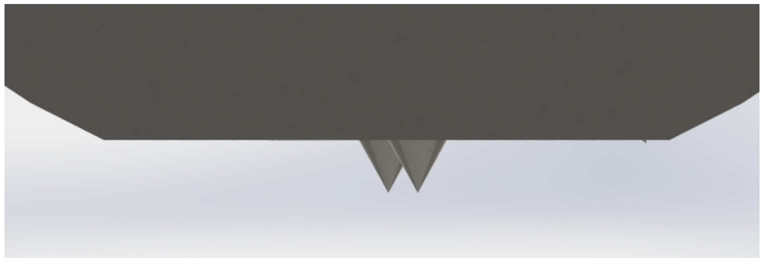


Figure 14. Spike system engaged (slipping)

3.2.2 Prototype

The CAD model was 3D printed in Higgins Laboratories. Parts that were 3D printed include the wheel, 10 tread links with holes, 1 symmetrical tread link, and one symmetrical tread link with holes. Once parts were 3D printed, they were assembled. After testing out different numbers of tread links, we decided on using 6 tread links, one being the symmetrical tread link with holes. These tread links were assembled to one another using 1/8" diameter 18-8 Stainless Steel dowel pins that were 1" long. These dimensions were chosen to match the hole size of the tread link as well as the tread link length. The CAD files used when designing the spike were made into CAM files so that the spikes could be manufactured in the Machine Shop. The lathe was used to make these spikes. The spikes were pressed into the spike holes on top of the tread links. Of the 6 tread links, 2 have small spikes and 4 have large spikes. The middle 2 have small spikes, while the outer 2 on each side have large spikes to counteract slipping in either direction. The symmetrical tread link was glued into place at the top of the wheel and elastic thread was tied to the end tread links and the link glued into place, as seen in Figure 15. The elastic thread was tied so that it was already tight in order to keep slack from building up. When slack built up, the tread links would lift off from the wheel, so this needed to be prevented. Figure 16 shows the spike and tread link assemblies on our prototype.

Figure 15. Top of Prototype

Figure 16. Bottom of Prototype

3.3 Results and Design Recommendations

Once the prototype was assembled, a basic test on ice was done to analyze the device's movement. A large block of ice was used to test our mechanism. We tried to mimic the slipping motion by pressing the mechanism into the ice and pulling in either direction. Once the large spikes made contact with the ice, we could no longer pull the mechanism, showing that the slipping motion would be stopped.

Other configurations using similar concepts were also designed. The first design iteration was based on a gear (Figure 17). This mechanism uses a similar concept as our prototype, but instead of having spiked tread links rotating on a stationary wheel, the wheel itself rotates and is equipped with spikes.

Figure 17. Shoe Equipped with Gear Mechanism

This mechanism uses springs to restore its initial position, but it could also use magnets. Drawings depicting the movement of the mechanism can be seen below in Figure 18. The first drawing shows the mechanism just as the foot begins to slip backwards on the icy hill. The next drawing shows the foot slipping on ice, and the mechanism rotating the opposite direction of the slipping motion. The last drawing shows the mechanism once the large spikes have made contact with the ice and have stopped the slipping motion. The gear mechanism and the design used for our prototype would both need to be small, and there would need to be multiple mechanisms at the toe and heel of the shoe sole in order to supply enough traction.

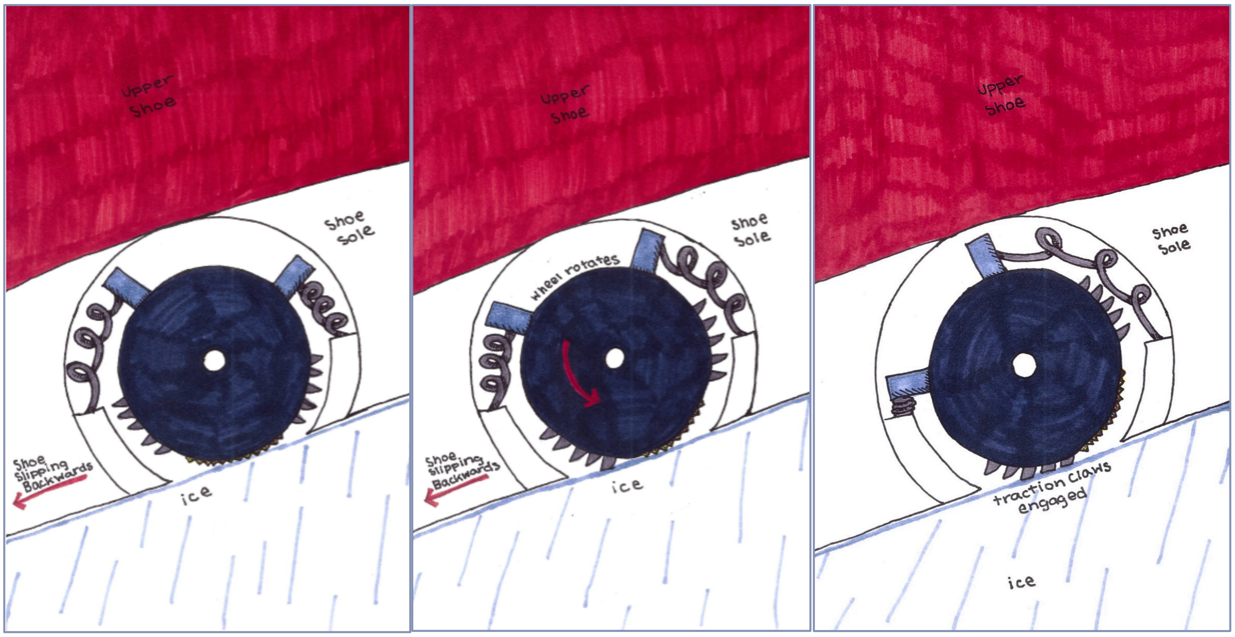


Figure 18. Gear Mechanism Movement

The second design iteration was based on a tank tread. This design has the same rotating tread link concept as our prototype, but utilizes a different configuration (Figure 19). With this configuration, there only needs to be one mechanism at the toe and one at the heel since it has the ability to cover a larger surface area.

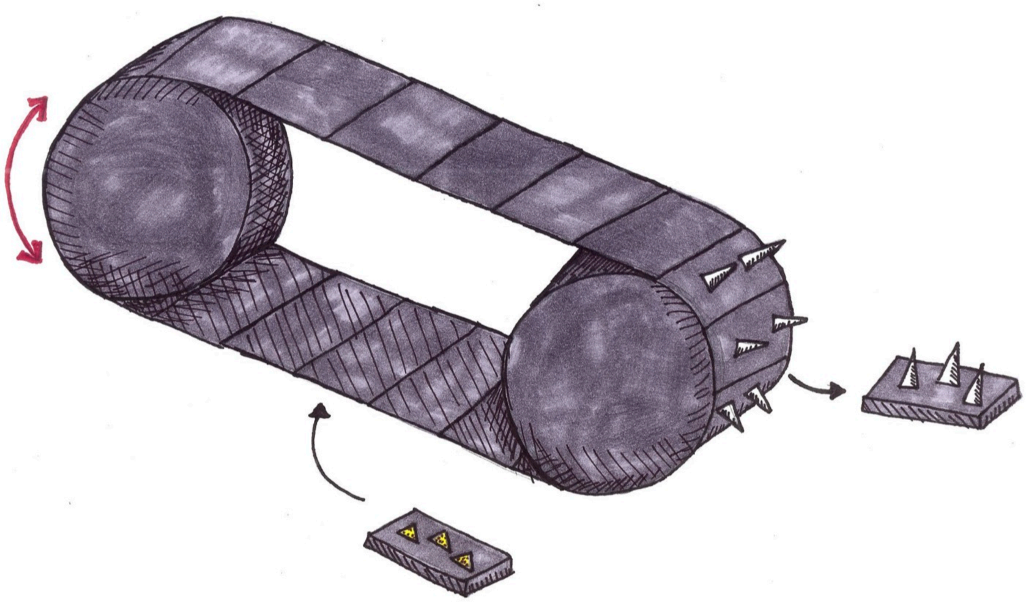


Figure 19. Tank Tread Mechanism

Future recommendations for our mechanical solution would be to calculate the time it takes for the device to restore its initial position. It is important that the device returns to its initial position before the foot hits the ground again, so the timing must be right. We would also recommend changing certain aspects of the design used for our prototype. We found it would be useful if the wheel had a raised edge to keep the tread links on the wheel. The tread links had the tendency to lift off the wheel when the mechanism moved. We believe our gear mechanism idea is the most promising, and should be investigated further.

4. Discussion

4.1 Accomplishments

We researched two different types of design solutions for an anti-slipping mechanism for shoe soles. Our mechanisms are unique in the way that the thermal solution freezes the water layer on top of the ice to prevent slipping and in the way our mechanical solution is self-activating and retractable. Both solutions operate without the user needing to manually engage the system. Our thermal solution uses a thermoelectric cooling (TEC) device that is on whenever the user is moving. The TEC was redesigned to remove heat faster and release heat to a larger area. The spike or button will always be cold and will be able to freeze the water layer on top of ice. Our mechanical solution uses a self-activating spike system, which only engages when slipping occurs. The mechanism will automatically return to its initial position once the slipping motion is stopped.

4.2 Critical Assessment

Axiomatic design was not useful to us when coming up with design solutions. We did find it useful for refining design solutions to satisfy all functional requirements. Axiom one was used to prevent coupling, which was especially useful for our mechanical solution. A spike system was designed that will effectively stop slipping on ice while not hindering traction on pavement using axiom one. We recommend future design MQP groups study axiomatic design before beginning their MQP and learn how to properly use this design method.

4.3 Constraints

4.3.1 Ice and Pavement Decoupling

The main constraint when designing an anti-slipping shoe sole mechanism for ice was choosing a design solution that did not adversely affect the shoe's traction on pavement. This caused us to get creative and utilize axiom one to design solutions that were affective on ice as well as pavement.

4.3.2 Demographics

When designing an anti-slipping mechanism for a running shoe, it is important to consider the demographics of the target population. The mechanism needed to be easy to use and not require runners to have to change their natural motion to activate the device. If the runner is required to do this, it could lead to injury and activation inaccuracy.

4.3.3 Patent Infringement

Each design solution had to be unique and not infringe on any patents. This is important since we applied for two provisional patents, one for our thermal solution and one for our mechanical solution. Similar patents are mentioned in section 1.3.2, but more extensive patent research can be found in Appendix B. Our thermal solution has been filed as a provisional and we have submitted our provisional application for our mechanical solution. The applications for these provisional patents can be found in Appendix E.

4.4 Impact of Solutions in Global, Economic, Environmental, and Societal Context

Our anti-slipping mechanisms will be beneficial to runners all over the world since there is currently no running shoes available that have traction on ice and pavement. Economically, our design will enhance the winter running shoe market, offering runners a safe and effective shoe for winterized surfaces. Large shoe companies could utilize our anti-slipping mechanisms in their products, which would revolutionize the running shoe market.

4.5 Deficiency in Prior Art

As previously stated, no winter running shoes currently on the market have the ability to provide traction on ice and pavement. Prior art researched resulted in many manually activated anti-slipping mechanisms that were retractable. The issue with these patented designs is that they require the user to activate the anti-slipping mechanism. This means that the user either has to stop running to activate the mechanism or change their foot positioning to activate the mechanism. Both options are burdensome and could be dangerous to the runner.

4.6 Potential Commercial Use of Invention

Our designs are useful for running, but could also be used to in walking shoes, work boots, and other athletic shoes. Our designs are beneficial since they give users a safe shoe option to use on ice as well as pavement. This would decrease the chance of slipping and falling and the injuries resulting from this. Although the mechanisms we designed are more complicated than current winter running shoes, they are more effective when providing traction, and therefore much safer. The implementation of this mechanism into shoes would increase the cost of the shoe, but the benefits provided by these mechanisms outweigh the cost differential.

4.7 Critical Assessment of Design Method

Axiomatic design was a new design method for us and was hard to use when we began our project. This resulted in several design solutions that were not acceptable and had not been fully thought through (Appendix F). We found it difficult to use axiomatic design to come up with a solution, and found ourselves choosing a solution first instead and then modifying the axiomatic design to match this design solution. This issue was never overcome, but axiomatic design was useful in modifying our chosen design solutions. It forced us to think about the purpose and function of different components, as well as provided clear visuals of the functional requirements and design parameters that were chosen for each solution.

4.8 Issues Remaining

Some issues remaining include the fact that both solutions need calculations done to prove they are possible. For our thermal solution, heat transfer must be used to calculate the amount of heat the cold spike needs to remove from the thin water layer on top of ice, as well as how long it would take to remove this amount of heat. For our mechanical solution, timing needs to be evaluated so that the mechanism returns to its initial position between when the foot leaves the ground and the foot lands back on the ground.

5. Concluding Remarks

1. Designed two types of anti-slipping shoe sole mechanisms, a thermal mechanism and mechanical mechanism. A prototype of the mechanical mechanism was created using 3D printing technology. Two provisional patents were filed on the intellectual property.
2. Axiomatic design was used to decouple our design solutions, allowing the mechanism to meet all functional requirements independently.
3. Issues remaining include heat transfer calculations for the thermal solution and timing calculations for the mechanical solution.

6. References

Balgin, L. (1996). U.S. Patent No. 5,497,565. Washington, DC: U.S. Patent and Trademark Office.

Becker, William J. et al. (2001). Preventing Injuries from Slips, Trips, and Falls. University of Northern Florida IFAS Extension. pag. 1-7.

Bowe, Tucker. (2015). 10 Best Winter Running Shoes of 2015. Gear Patrol. n.pag. Print.

Br Med J (Clin Res Ed). (1981). Epidemic of fractures during period of snow and ice.

Colbeck, S. C., & U.S. Army Cold Regions Research and Engineering Laboratory. (1992). A review of the processes that control snow friction. Springfield, Va;Hanover, N.H.;: U.S. Army Corps of Engineers, Cold Regions Research & Engineering Laboratory.

Escobar, Joe. (2001). Understanding the basics of aircraft tire construction and maintenance. Aircraft Maintenance Technology.

FrozenTEC, (n.d.). Internal TEC structure. Retrieved February 11, 2016, from http://www.frozentec.com/technoogy-principal.html

Grönqvist, R et al. *International Journal of Industrial Ergonomics* **16** (1995) 191-200

Henry, W., & Hilt, C. (1967). U.S. Patent No. 3,343,283. Washington, DC: U.S. Patent and Trademark Office.

Jennings, H. and Thomas, J. (2008). Materials of Cement Science Primer. Retrieved from http://www.iti.northwestern.edu/publications/utc/tea-21/FR-5-Jennings-Thomas.pdf

Jones, Riley. (2013). KNOW YOUR TECH: Saucony PowerGrid Cushioning Keeps Classic Tech Fresh. Complex.com. n.pag. Print.

Jordan, J.C. (1998). U.S. Patent No. 6,256,907. Washington, DC: U.S. Patent and Trademark Office.

La Sportiva Crossover GTX Mountain Running Shoes. SectionHiker.com. n.pag. Print.

Maxwell, Paul Bryan & Van Der Meer, Alex. Winter automobile or light truck tire. US 5647926. (1997) n.pag. Print.

Mercer, D. (1994). U.S. Patent No. 5,289,647. Washington, DC: U.S. Patent and Trademark Office.

Metzler, Brian. (2014). Shoe of the Week: Skechers GoRun Ultra Extreme. Competitor.com. n.pag. Print.

Obeydani, M. (2009). U.S. Patent No. 7,490,418. Washington, DC: U.S. Patent and Trademark Office.

Omar, Y. (2013, January 27). ALL ABOUT TRACK & FIELD SPIKES & HOW TO PURCHASE THEM. Retrieved February 3, 2016, from http://eliteathleticperformance.com/blog/2013/01/27/145/

Ostrowski, E. (1979). U.S. Patent No. 4,159,582. Washington, DC: U.S. Patent and Trademark Office.

Remington, M., Hodge,D., and Schafer, R. (1998). U.S. Patent No. 5,732,482. Washington, DC: U.S. Patent and Trademark Office.

Rosenberg, R. (2005). Why is ice slippery? Physics Today,58(12), 50. doi:10.1063/1.2169444

Scheibe, Robert R., et al. An Overview of Studded and Studless Tire Traction and Safety. Washington State Transportation Center (TRAC). (2002) pp. 1-4.

Shanks: Meta-Shank. Inov-8.com. n.pag. Print.

Smith, Russell J. Tires for airplane wheels. US 2403309 A. (1946). n.pag. Print.

Suh, N. P. (2001). *Axiomatic design: Advances and applications*. New York: Oxford University Press.

WiseGEEK. (n.d.). What is a Piezoelectric Transducer? Retrieved February 4, 2016, from http://www.wisegeek.org/what-is-a-piezoelectric-transducer.htm

Zosel, Kristen. (2015). Salomon S-Lab Fellcross 3 Review. iRunFar.com. n.pag. Print.

7. Appendices

Appendix A – Shoe Comparison Chart Showing Other Traction Surfaces, Features, and Downsides

Shoe	Other	Features	Downsides
Skechers GoRun Ultra Extreme	Wet, sloppy conditions (Metzler, 2014).	- Waterproof; breathable - Cushioned for impact	Will not have traction on ice
Salomon S-Lab Fellcross 3	Trail (fell) running; slippery rocks and mud (Zosel, 2015).	- Salomon's patented Mud & Snow Non-Marking Contagrip (¼ inch lugs on the sole, sharp chevron pattern) (Zosel, 2015).	No traction on ice; lugs too stiff to have traction on pavement
Icebug Aurora BUGrip		- Patented carbide-tipped studs	Studs prevent traction on pavement
La Sportiva Crossover 2.0 GTX	Ice & rock mixture; mud and trails	- AT Grip Zone sole makes it slip proof - Attachable Tungsten-alloy hobnails	- No traction on flat ice; heavy shoe (La Sportiva). - Hobnails not practical since the shoe can't be used on other terrain such as bare pavement with the hobnails attached (La Sportiva).
Saucony Ride 7 GTX	Wet conditions	- Waterproof - iBR+ rubber outer sole and PowerGrid cushioning (iBR+ rubber is a lightweight rubber; PowerGrid uses PowerFoam, which is an injected mold compound that is lighter and more durable than other materials) (Jones, 2013).	- No traction on ice and not a good tread for snow; shoe is better for rainy weather

The North Face Ultra Equity Gore-Tex	No deep snow	- Lug sole similar to that of a work boot which leads to sturdier foot placement and better traction	No traction on ice
Inov 8 Mudclaw 300	Mud	- Patented first generation Meta-Shank technology (3 finger polymer aligned behind metatarsals, provides greater forefoot flexibility and control when contouring, while retaining underfoot impact protection) (Shanks: Meta Shanks). - Quick release cleats	Better for trail running, not street running; no traction on bare pavement
New Balance Minimus Zero Trail v2	Turf fields; softball fields	- Large lugs on sole designed to prevent slipping when trail running - REVlite cushioning	Although suitable for pavement, not comfortable for running on pavement due to large lugs on sole; no ice traction
Newton Boco AT	Trail terrain	- Biomechanical metatarsal sensor plate - Multiple direction lugs	Not suitable for icy pavement; better for trail running

Appendix B – Prior Art Research Charts

Thermoelectric Design

Cited Patent	Title	Notes
US 5943792 A	Footwear traction device	A hygroscopic fibrous shoe sole that freezes when in contact with ice
US 20130019503 A1	Method and apparatus for cooling footwear	Use thermoelectric heat exchangers to cool/heat the foot in a shoe
US 6499306 B2	Compact thermoelectric cooling system	A way to compactly encase a thermoelectric cooling system with a power supply
US 6807869 B2	Shoe based force sensor and equipment for use with the same	A force sensor for the bottom of shoe - placement of our buttons
US 1568064 A	Anti-slipping device for shoe soles and heels	Placement of spikes on shoe sole = placement of our buttons
US 20110231977 A1	Helmet cooling device	Helmet air cooling system with a fan
US 7296304 B2	Crash helmet with thermoelectric cooling	Use a thermoelectric to cool air and a fan to push it into the helmet
US 6510696 B2	Thermoelectric air-condition apparatus	Thermoelectric used in an air conditioner

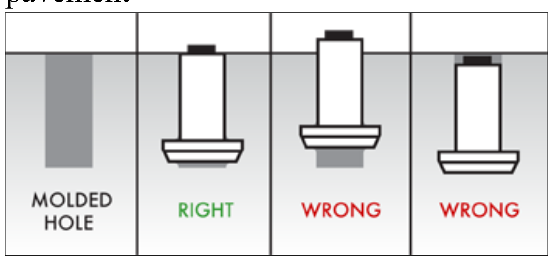
Mechanical Design

Cited Patent	Title	Description
US 3343283 A	Retractible Anti-slip device for shoe heels	Retractable spikes mounted on a horizontally-pivoted bifurcated lever.
US 5732482 A	Retractable spike system for shoes	Selectively extendable spring-biased spikes mounted to the sole.
US 4159582 A	Gripper element for sports shoes	A gripper element for sports shoes extended when the wearer's weight is impressed upon the shoe.
US 5289647 A	Shoe with retractable spikes	A golf shoe with a spike biased to an extended position with a helical spring.
US 7490418 B2	Footwear with manually extendable spikes	A shoe equipped with spikes that manually retract and extend when an actuator gear is rotated.
US 5497565 A	Spike assembly for footwear	A spike assembly encased in a rotatable shaft and lock subassembly with a motion translation device.
US 5815951 A	Athletic shoe with retractable spikes	An athletic shoe with spikes attached to a plate that extends when an inflatable bladder is filled with fluid.

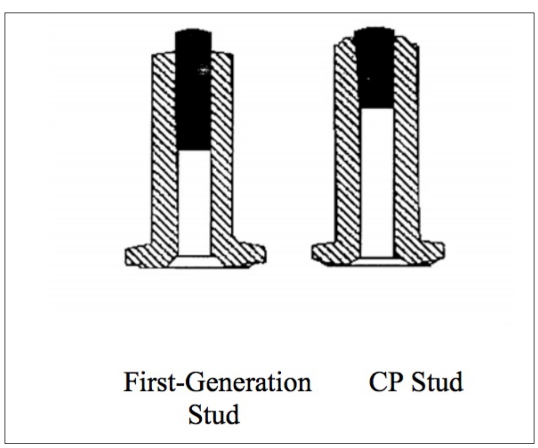
Appendix C – Tire Research

How Studded Tires Work:

- Easy to install alternative to tire chains
- Many states have rules and regulations on studded tire use, allowing use during certain time frames in the year, or not permitting use at all.
- Typically a tire's tread design will contain 80 to 100 studs made of a tungsten carbide pin encased in metal.
- Use the vehicle's weight and centrifugal forces to provide ice traction by chipping into the driving surface.
- The stud is designed with two basic parts that have varied in size, weight, and composition over the years
    - Stud Jacket (sleeve) - flange at base hold it in place on the tired
    - Stud Core - situated within the jacket; protrudes from tire to make contact with the pavement



- The stud is secured in place over time by the rubber
- Protrusion length has changed greatly over the years due to the negative effects tire studs have on roads. They now have tapered edges and can slide into the sleeve farther when the rubber starts to wear down around the stud. The first stud had a protrusion length of 0.087 inches, while current studs have a protrusion length of 0.039 inches - 0.059 inches (1 mm - 1.5 mm).



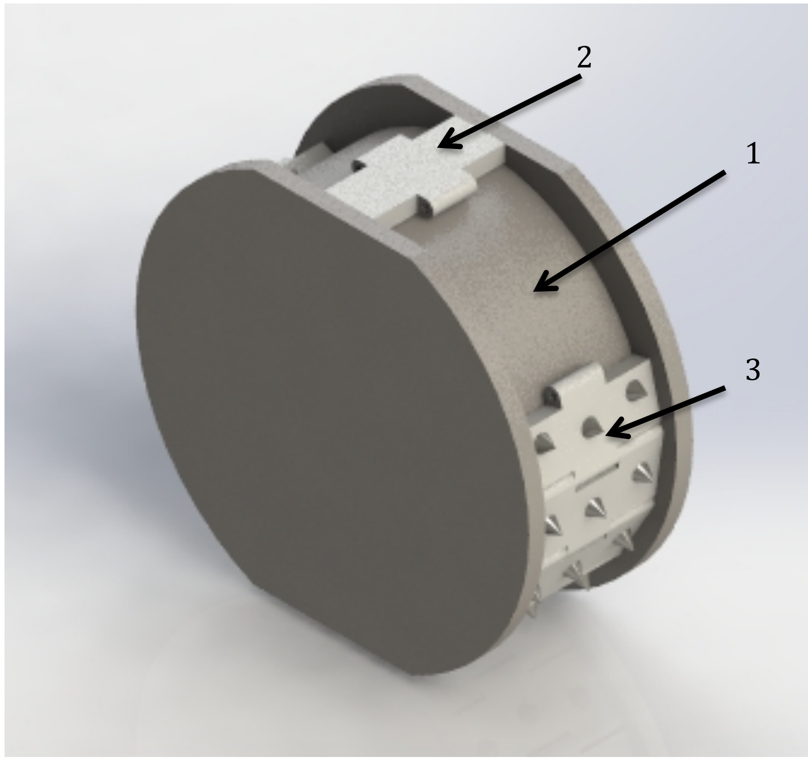
Snow Tires for Cars:

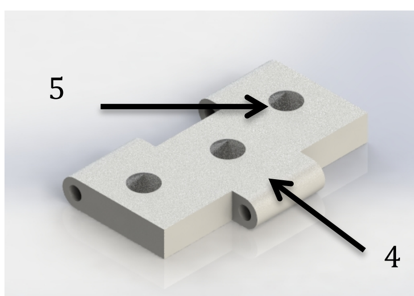
- Snow tire treads typically have large traction lugs that are widely spread, leading to a low contacting surface; suited for deep snow but are noisy on clear roads (Maxwell, 1997).
- All season tire treads have wide transverse grooves and circumferential grooves; grooves are less wide than snow tires, but wide enough to provide traction in snow. They do not provide good traction in extreme winter conditions (Maxwell, 1997).
- For icy and muddy conditions, metal studs or cleats are preferred for best traction, but are often prohibited due to the damage they cause on roads (Maxwell, 1997).
- Patent for new tire tread suggests using a high density of sipes within the traction element to provide better traction for snow and ice due to increased number of tread edge that will provide forward traction (Maxwell, 1997).
    - Sipes are grooves or channels in the tread of the tire that improves its grip.

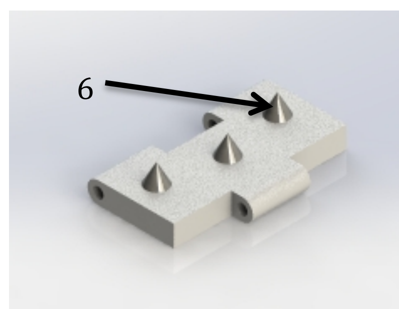
Tires for Airplanes:

- Designed to provide braking traction, not driving traction (Smith, 1946).
- Two types of airplane tires: Bias-Ply and Radial-Ply
- Bias-Ply is a popular choice because they are durable and re-treadable (Escobar, 2001).
    - Ribbed tread design made out of rubber mixed with other additives to provide durability, wear resistance, and toughness; has good traction under various runway conditions
    - Has a sidewall that extends from tread edge to bead area
    - Tread reinforcing ply (fabric) is used to strengthen and stabilize tread area for high speed
    - Other features: buff line cushion, breakers, casing plies, wire beads, apex strip, flippers, ply turnups, chafer, and liner
- Radial-Ply has reduced rolling resistance and less construction components, so they are much lighter than Bias-Ply (Escobar, 2001).
    - Has an overlay (reinforcing rubber coated fabric) placed on top of belts to aid high speed operation
    - Has belt plies, which stiffen the tread area for increased landing; also increases tire strength
    - Has casing plies which differ from the Bias-Ply tire since they run radially from bead to bead (Bias-Ply run opposite angles to one another)
    - Has chippers which are rubber coated fabric layers applied at diagonal angles to improve the durability of the tire in the bead area

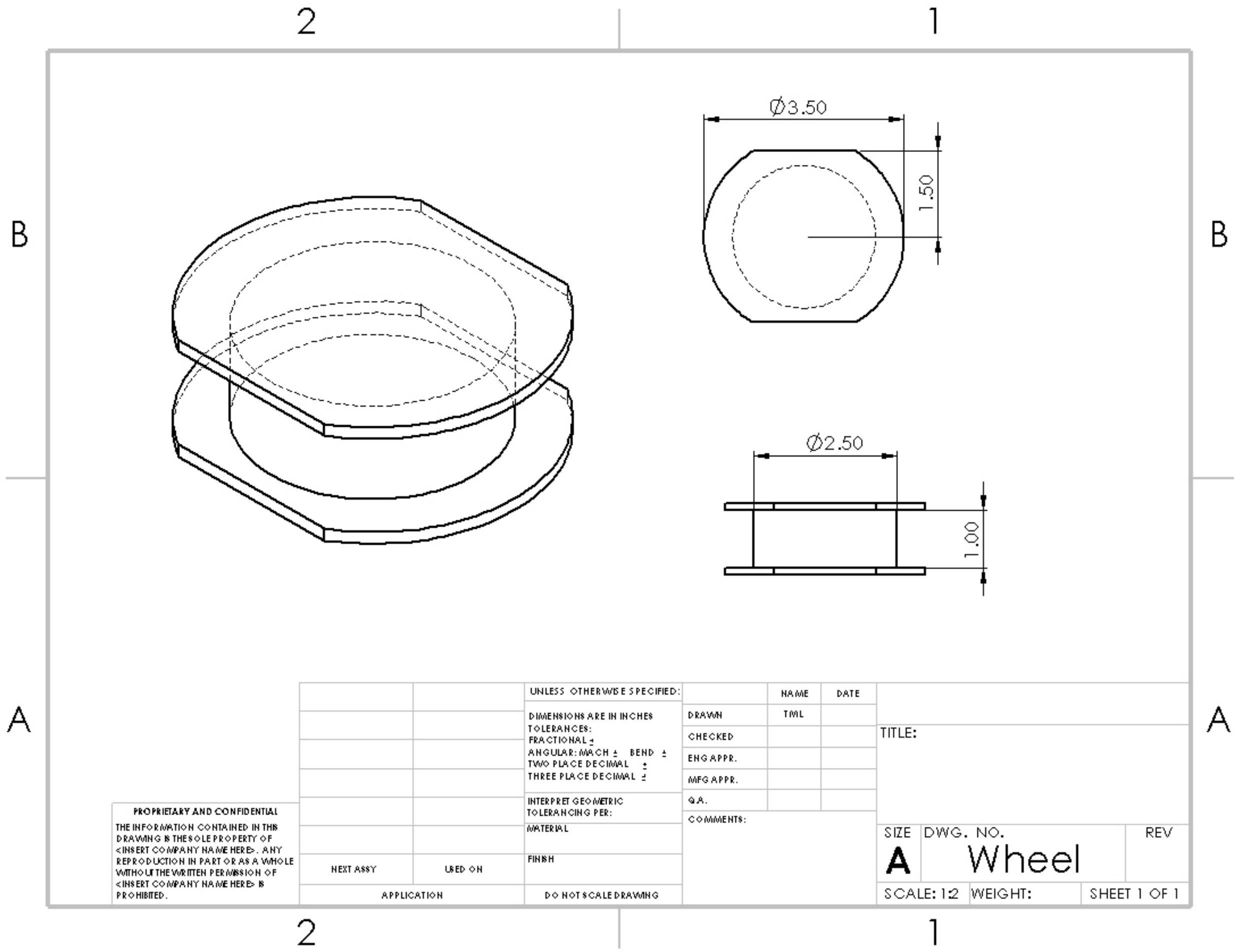
Appendix D – CAD Drawings



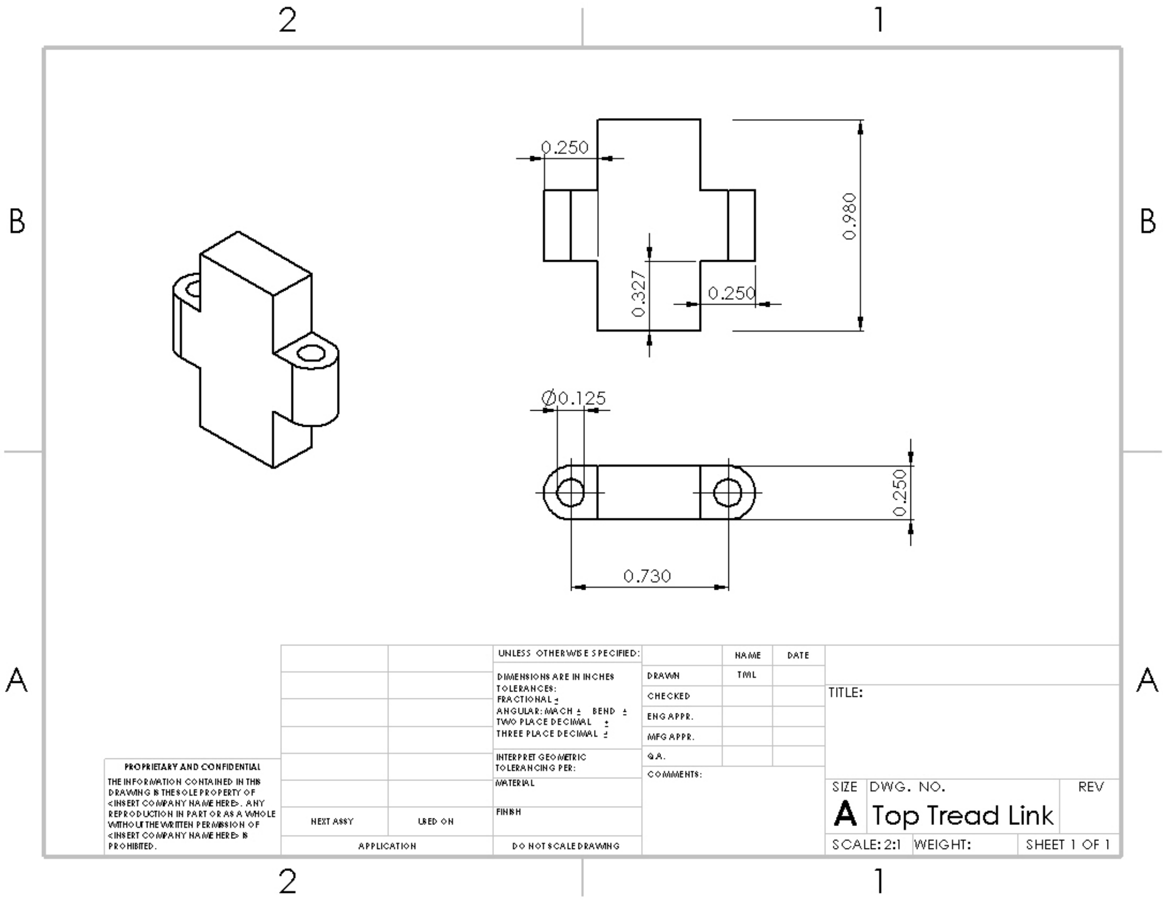




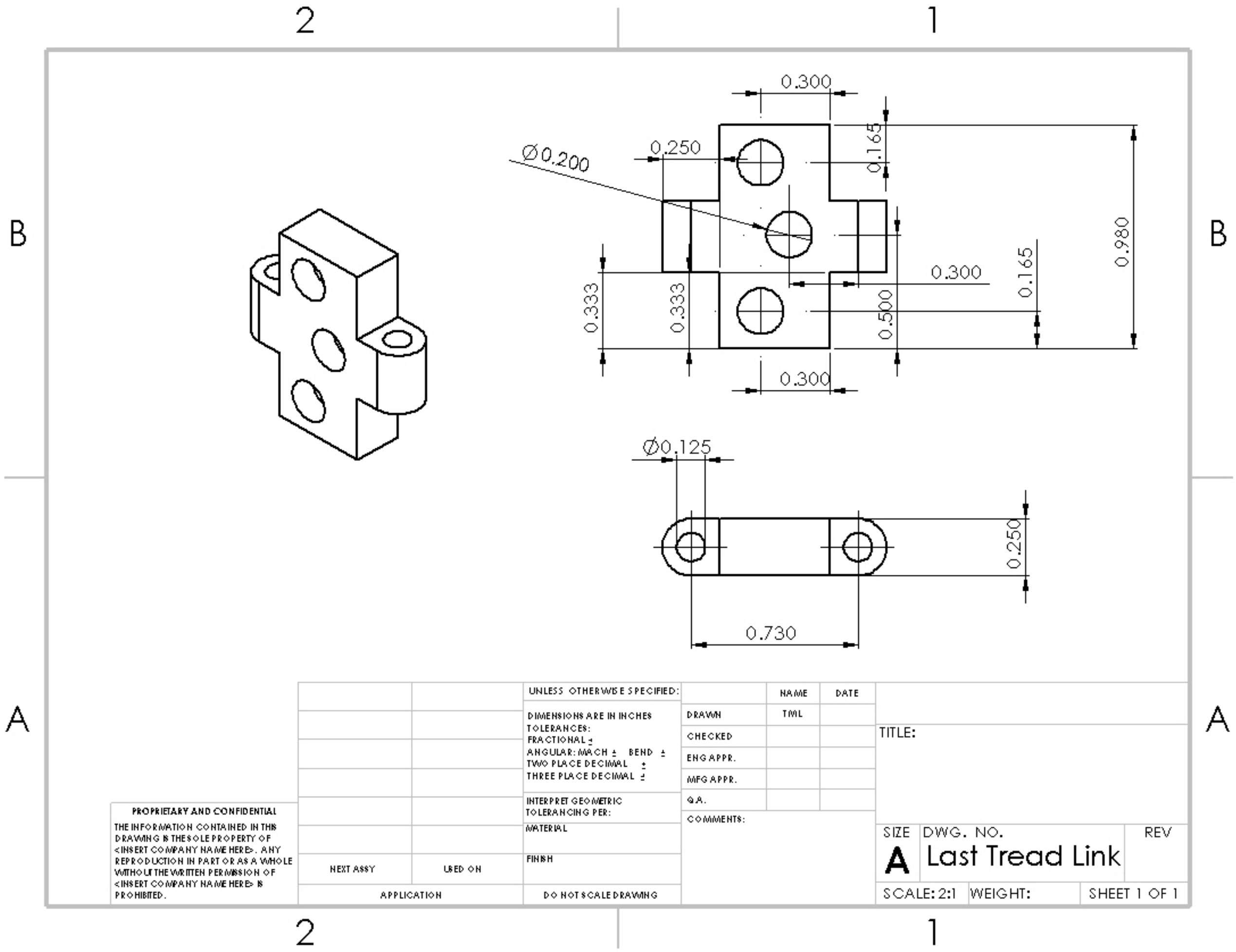
Wheel Drawing – 1



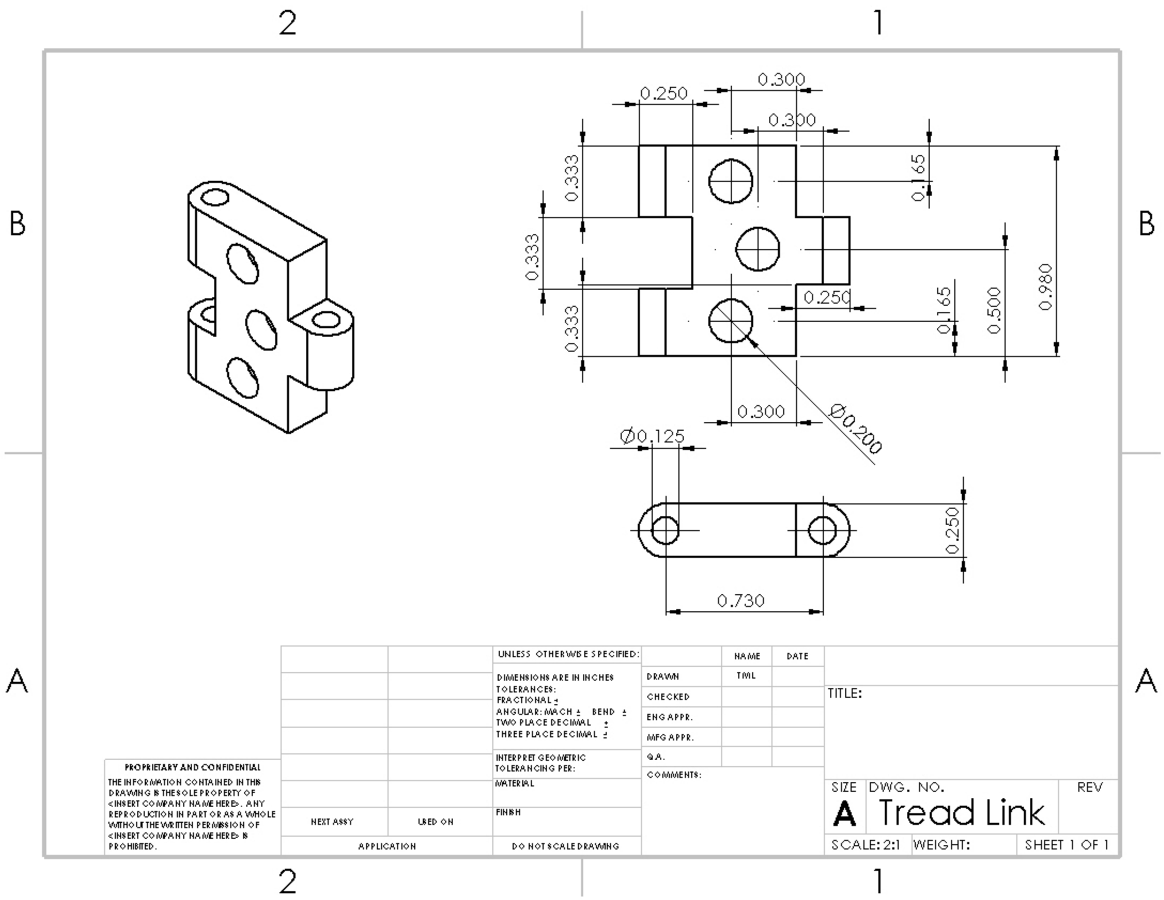
Top Tread Link – 2



Last Tread Link – 3



Tread Link - 4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UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
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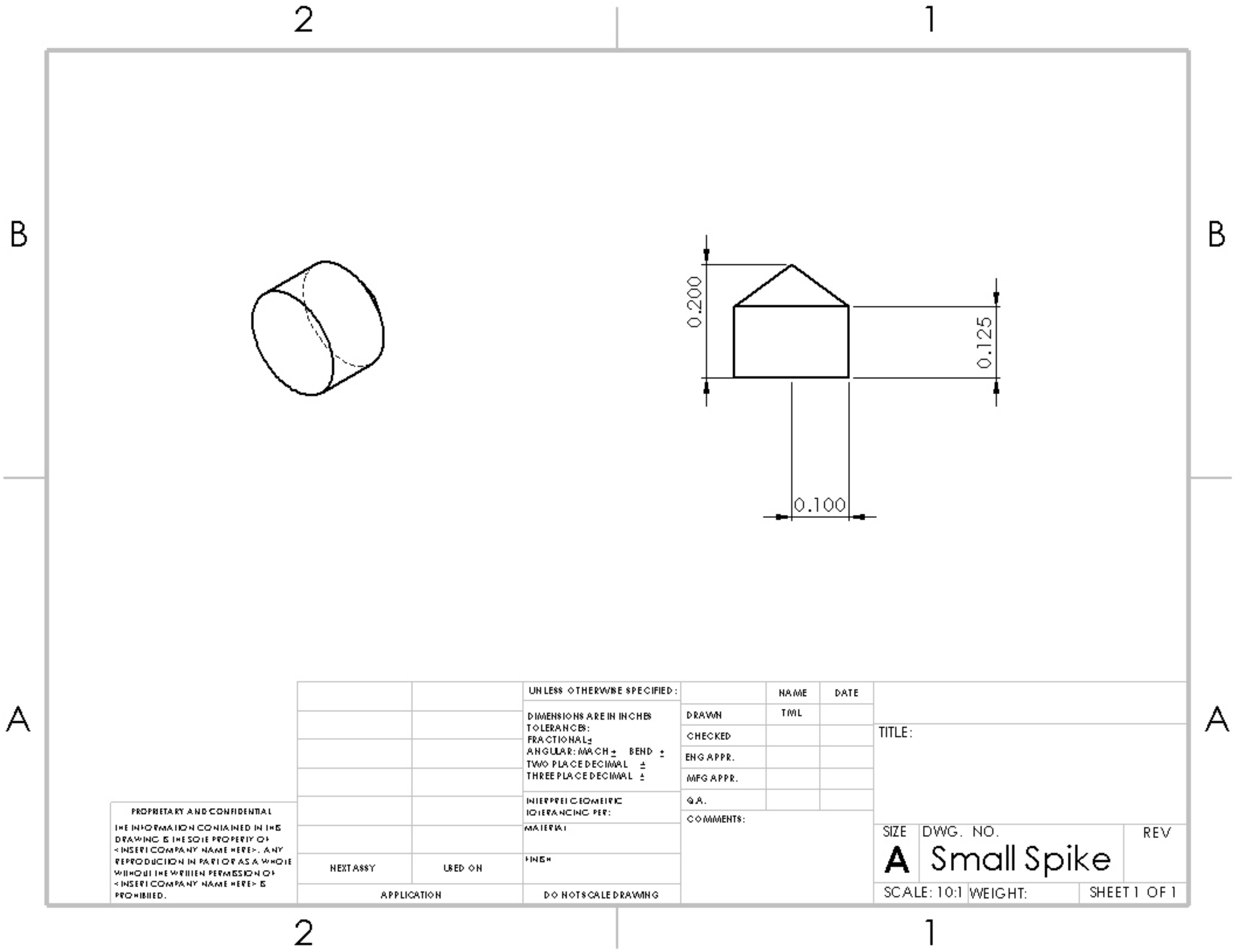
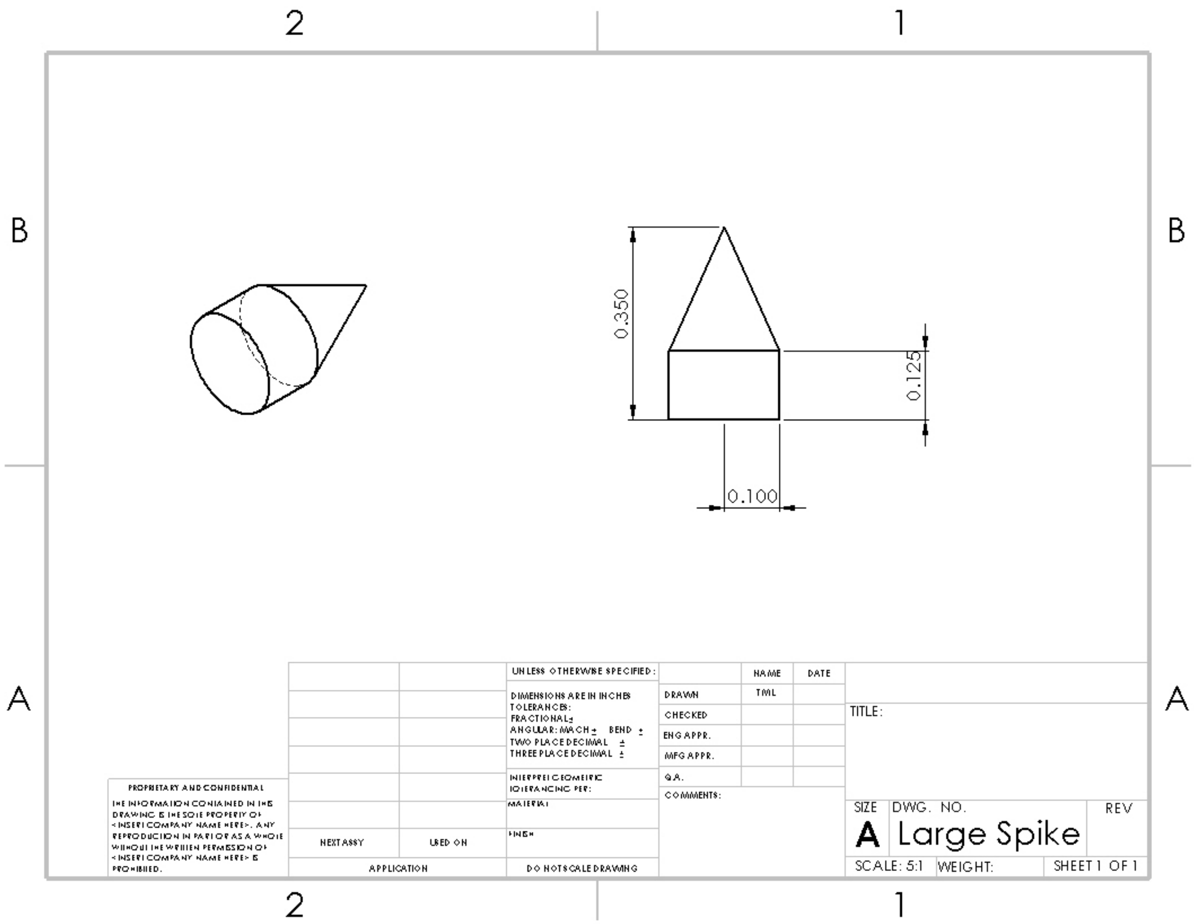
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.

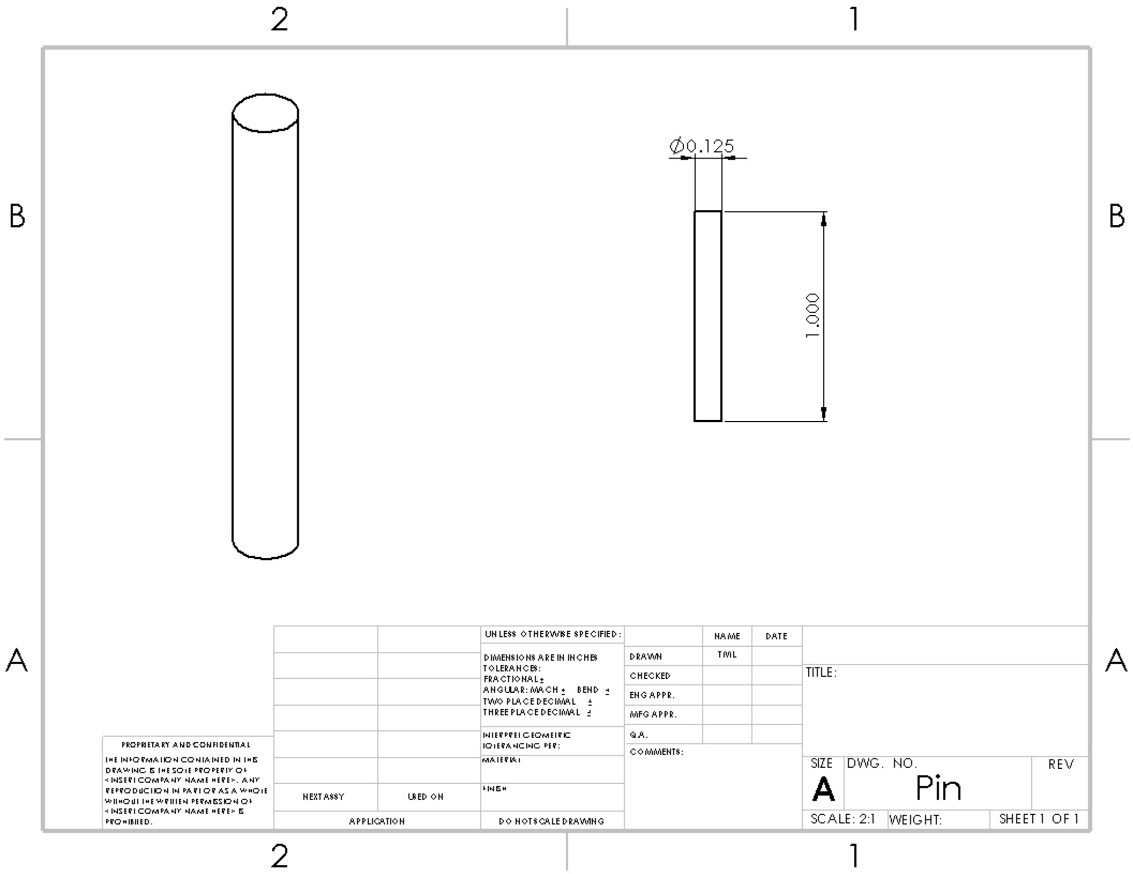
Small Spike - 5



Large Spike - 6



Pin – Not Visible in CAD Assembly



Appendix E – Provisional Patent Applications

Invention Disclosure Form: Thermal Solution

1. Brief Descriptive Title of the Invention
Winter sports shoe sole providing improved traction

2. Inventor(s) - Name, position, department, phone. (Identify all individuals who have made significant intellectual contributions to this invention's advance over prior technology, but do not include anyone merely because s/he has carried out some of the experimental work.)
Christina Bottom, Student, Mechanical Engineering, (774) 262-7565
Taylor Llodra, Student, Mechanical Engineering, (413) 313-4921
Christopher Brown, Professor, Mechanical Engineering, (508) 560-6986

3. Specify any other inventor(s) who is/are an employee or an organization other than WPI and the institutional affiliation.
N/A

4. Background (To successfully determine the patentability of this invention, it will be necessary to compare it to existing technology, referred to as "prior art." Provide any references to assist in this evaluation.)
A. If possible, identify any references to the prior art by patent number or journal article identification.
[Table]: Available in Appendix Patent Prior Art

B. Specify any deficiency in the prior art improved upon by this invention or any limitation which it extends.
The invention relates to footwear traction design. The prior art consists of two different categories. Anti-slip shoe sole design and thermoelectric cooling applications. The prior art contains many applications of the fundamental parts of our design. There was only one prior art source that was significantly similar to our current design. An add-on device intended to improve traction for the user on slippery surfaces as referenced by U.S. Pat. No: 4,702,021. While this device provides effective traction on an icy surface, it requires the user to maintain an attachment for their shoe. This could lead to failure during usage due to it not being incorporated into the shoe itself. We are taking these two idea categories and putting them together in a way that other designs have not. By utilizing piezo-electricity for energy and using that to power the thermocooling application, we are using these two applications to cool "buttons" on the bottom of a shoe sole causing them to freeze to any ice on the ground and providing the shoe with an anti-slip technique. The rest of the patents utilize the fundamental parts of our design they don't include them all together.

5. Briefly describe the invention (use additional sheets, as necessary). Indicate specifically what is considered to be the invention, as distinct from the prior art. The description may be by reference to another document, which should be attached to

this disclosure (e.g., copy of a report, preprint, excerpt from a proposal, etc.). Also attach any sketches, flow charts, structural formulas, circuit diagrams, etc. that are appropriate to and necessary for full disclosure. Please identify any such attachment(s) positively by having each page signed, dated, and witnessed.

The invention designed is a shoe sole with “buttons” that will freeze to the ground when in contact with a water layer on top of ice. Thermo-cooling modules powered by a piezoelectric sensor will cool our “buttons” down and allow them to freeze rapidly when in contact with water. The placement of these buttons will be focused around the toes, ball of foot, and heel. Approximately eight buttons will be used. This will allow the shoe to gain traction on ice for both heel striking and toe striking, as well as traction throughout the entire natural footstep while running or walking.

6. Conception is the recognition that a novel arrangement of structural elements, composition of matter, manner of implementing a process, etc. will produce a useful result. Does there exist an earlier, dated record of the invention's conception (e.g., a sketch, report, laboratory notebook entry, etc.) that describes this invention and can be independently corroborated? Please indicate what it is and where it is.
N/A

7. Indicate the first successful reduction to practice of this invention (date, place, record, witnesses).
N/A

8. Has this invention been disclosed to others, either verbally or in written form (date, place, to whom, method of disclosure)?
N/A

9. Indicate any pending disclosures (date, place, to whom, method of disclosure).
N/A

10. List patents, publications, and/or commercial products or processes known to you showing a.) technology closest to this invention, and b.) closest known use of those elements or steps of this invention that differ from a.).
As previously described in question 4, the invention relates to footwear traction design. The prior art consists of two different categories. Anti-slip shoe sole design and thermoelectric cooling applications. The prior art contains many applications of the fundamental parts of our design. There was only one prior art source that was significantly similar to our current design. An add-on device intended to improve traction for the user on slippery surfaces as referenced by U.S. Pat. No: 4,702,021. While this device provides effective traction on an icy surface, it requires the user to maintain an attachment for their shoe. This could lead to failure during usage due to it not being incorporated into the shoe itself. We are taking these two idea categories and putting them together in a way that other designs have not. By utilizing piezo-electricity for energy and using that to power the thermocooling application, we are using these two applications to cool “buttons” on the bottom of a shoe sole causing them to freeze to any

ice on the ground and providing the shoe with an (stickiness, magnetic attraction?) anti-slip technique. The rest of the patents utilize the fundamental parts of our design they don't include them all together.

11. Indicate the potential commercial use of this invention (e.g., fields of use, advantages, estimate of value)

This design could be utilized by shoe companies in order to provide consumers with a running shoe option suitable for winter conditions. Its advantages are that it combines different technology in order to provide simultaneous traction on three winter surfaces that you would encounter outside, such as snow, ice, and pavement. An average running shoe not suited for multiple winterized surfaces is typically priced between $80-120. Since this design combines the technology of the classic running shoe with our innovation for winterized traction, we believe our shoe should be priced closer to $200. According to IBISWorld Industry Report OD4605, Athletic Shoe Stores in the US create a revenue of $11.0 billion each year. We can see an upward trend in the price of shoes as well as the increase of consumers participating in athletic activities. This shoe design would be marketable to this growing demand.

12. Indicate any potential commercial licensees that may be interested in this invention.
N/A

13. Identify any sponsors and projects (provide fund number) under which either conception or first reduction to practice occurred, including partial funding and Federal "formula" funding. Also list any related projects and/or inventions and any other potential claimants to rights in this invention.
N/A

14. Were any University funds or other resources used in making this invention (if yes, please explain).

MQP funds were used in purchasing the piezoelectric disks, and the thermoelectric cooler mini module. A heat sink was also acquired without cost to us from the ECE department for testing the thermoelectric module. We used the equipment provided in the lab facilities of Atwater Kent Laboratories to test these components.

15. If funded by an external sponsor, has the sponsor been notified of this invention, either directly, in a progress or other report, or in an application for additional funds (date, sponsor, method of disclosure)?
N/A

Invention Disclosure Form: Mechanical Solution

WPI Disclosure Number (IPI will assign) ___________________
WORCESTER POLYTECHNIC INSTITUTE
INTELLECTUAL PROPERTY DISCLOSURE FORM
Forward this completed and signed form to the Office Intellectual Property and Innovation
Title of invention: Self-Activating, Rotating, Anti-Slip, Shoe Sole Mechanism
Department: Mechanical Engineering **Dean:** David Cyganski, PhD

1. Big Picture: What is the ultimate "one sentence" possible product?

This product is a self-activating shoe sole mechanism that rotates and prevents slipping on ice.

2. Inventor(s) - Name, position, phone, email. (Identify all individuals who have made significant intellectual contributions to this invention's advance over prior technology, but do not include anyone merely because s/he has carried out some of the experimental work.)

Christina Bottom, Student, (774) 262-7565, cjbottom@wpi.edu
Taylor Llodra, Student, (413) 313-4921, tmllodra@wpi.edu
Christopher Brown, Professor, (508) 560-6986, brown@wpi.edu

3. Specify any other inventor(s) who is/are an employee of an organization other than WPI and the institutional affiliation.

N/A.

4. Background (To successfully determine the patentability of this invention, it will be necessary to compare it to existing technology, referred to as "prior art." Provide any references to assist in this evaluation.) You should go to www.patentsrealfast.com/wpi **and use your WPI email for a quick and efficient way to search for prior art. A quick tutorial can be found at:** patentsrealfast.com/faculty

A. If possible, identify any references to the prior art by patent number or journal article identification.

- US Patent 3343283A - Retractible Anti-slip device for shoe heels
- US Patent 5732482A - Retractable spike system for shoes
- US Patent 4159582A - Gripper element for sports shoes
- US Patent 5289647A - Shoe with retractable spikes
- US Patent 7490418 B2 - Footwear with manually extendable spikes
- US Patent 5497565A - Spike assembly for footwear
- US Patent 5815951A - Athletic shoe with retractable spikes

B. Specify any deficiency in the prior art improved upon by this invention or any limitation which it extends.

The retractible anti-slip device for shoe heels by Henry and Hilt is extremely similar to the design we are proposing. This design features a hollow shoe heel with spikes mounted with a horizontally pivoted bifurcated lever. An operating rod rotated with a key provides projection or retraction. Our design also features projecting and retracting spikes however the mechanics of how these work are slightly different. In our design, the shear stresses that occur when slipping provide the projection of the spikes and an elastic around the device aids in retraction of the spikes. This difference allows the spikes to only project when in use and otherwise would be retracted and minimizes wear on the spike.

The retractable spike system for shoes by Remington, Hodge, and Schafer was designed primarily for golf shoes to protect the greens by allowing the user the ability to project the spikes only when needed on wet slopes or hills. They utilize a slider motion to allow the user to retract and project the spikes individually. Contrasting from our design, the user would be required to adjust the spikes every time they changed terrain. By creating a system that extends the spikes only when they are needed, we save the user this effort.

Ostrowski's gripper element for sports shoes utilizes a spring-loaded conical cover serving as a stop and concealing a spike which is exposed under the weight of the wearer. A restraining spring housed within the cover conceals the pin when weight is removed from the shoe. This is similar to our design in that when weight is removed the spikes become concealed however this design relies on a spring-loaded mechanism while our design has a conveyor belt motion depending upon the retraction of an elastic band.

The shoe with retractable spikes is designed by Mercer as a golf shoe with a spike enclosed in a housing near the sole or heel. The spike is dominantly extended with a helical spring. When the user comes in contact with a hard surface the spring retracts into the housing. This design is the opposite of ours in which we prefer to have the spikes retracted dominantly. In addition to serving an opposite purpose, this design uses springs to retract the spike while we rely on an elastic.

Footwear with manually extendable spikes is basically a gear assembly mounted within the heel. Obeydani uses an actuator gear to communicate with four drive gears. Couplings engage with the sole while spikes are threaded with the couplings. Drive shafts transfer the rotation from the drive gears to the spikes when the actuator gear is manually rotated. This manual rotation both extends and retracts the spikes. This design incorporates many mechanical pieces that all work together. In comparison, our design has fewer components and is automatic opposed to manual. Also the mechanisms in which the spikes extend and retract do not relate.

The spike assembly for footwear design by Balgin encases a rotatable shaft and lock subassembly in the heel and sole. A conversion device drives the network of shafts, levers, and rotatable roller bars. Spikes are dependent on the roller bars and roll out from inside the shoe. This device can be encased in the shoe or strapped onto the sole. Rotation of a knob is necessary to extend and retract the spikes. This varies from our design because it is mechanical while we have established an automatic system to expose and retract the spikes. The spikes are affixed to roller balls while we approached the solution to incorporate a conveyor belt mechanism.

Jordan's athletic shoe with retractable spikes contains a plate between the upper shoe and the outsole with spikes attached. The plate moves when lifted to extend the spikes and then can retract them when the force is removed. The plate is lifted by an inflatable bladder between the plate and outsole. Fluid is used to inflate and exhaust the bladder moving the spiked plate from extension to retraction. While achieving the same overall function, this mechanism relies on fluid to inflate a pocket. For our design, the spikes with extend when the user begins to lose traction and the conveyor belt mechanism pulls the spikes out from inside the sole. They retract when the user picks their foot up due to the elastic band.

There are also many other patents where spikes are used with shoe soles to increase traction on slippery surfaces. However those shoes can only be worn on the surface they were designed for with our design with a conveyer belt mechanism can be transitioned from slippery surface to pavement without wearing down the spikes unnecessarily.

5. Briefly describe the invention (use additional sheets, as necessary). Indicate specifically what is considered to be the invention, as distinct from the prior art. The description may be by reference to another document, which should be attached to this disclosure (e.g., copy of a report, preprint, excerpt from a proposal, etc.).

Also attach any sketches, flow charts, structural formulas, circuit diagrams, etc. that are appropriate to and necessary for full disclosure. Please identify any such attachment(s) positively by having each page signed, dated, and witnessed. Please list 4-5 key words to start.

Keywords: anti-slip, retractable, self-activating, rotating, ice

Our invention utilizes a conveyor belt mechanism in order to stop slipping on ice. The conveyor belt is composed of tread links with various sized spikes. Tread links that are visible when the mechanism is not being used are equipped with small spikes, while the tread links that are visible when the mechanism is in action are equipped with large spikes. The mechanism is designed to rotate when slipping occurs. The small spikes grip the ice enough to cause the conveyor belt to rotate, causing the tread links with the large spikes to become visible and make contact with the ice. When these large spikes make contact with the ice, they stop the slipping motion. Once slipping stops, the device returns to its original position by the use of elastic thread. The small spikes are made of a material that will not cause slipping on pavement but will provide enough traction on ice to cause the conveyor belt to rotate when slipping occurs. The large spikes are made of strong metal in order to dig into the ice and stop the slipping motion. There is one tread link locked in place at the top of the conveyor belt. This link will be used to anchor the elastic thread in order for the mechanism to be able to return to its original position. An assembled CAD model of the mechanism without the depiction of elastic thread is attached, as well as CAD models of important parts of the assembly that are not as visible in the assembly. Axiomatic design was also used for this invention. A complete decomposition will also be attached.

6. What level of proof do you have for the invention? Working prototype, proof of concept experiments, etc.?

For this invention, we have a proof of concept experiment. We have a basic 3D printed prototype that is assembled with spikes and when the mechanism is tested against a block of ice we find that it functions the way we expect it to.

7. Has this invention been disclosed to others, either verbally or in written form (date, place, to whom, method of disclosure)?

No.

8. Indicate any pending disclosures (date, place, to whom, method of disclosure).

N/A

9. What does the market look like for this invention? Indicate the potential commercial use of this invention (e.g., fields of use, advantages, estimate of value)

This invention will be used in the shoe industry. There is currently no shoe that utilizes a conveyor belt mechanism to stop slipping on ice. Current shoes designed for ice have metal spikes that are always visible. This prevents them from being used on pavement, as the spikes may cause slipping or get damaged from impact. The spikes on our mechanism that come into contact with pavement are made of a material that will not cause slipping, while the spikes that come into contact with the ground when slipping occurs on ice are larger and made of metal to gain traction and stop the slipping motion. This gives the shoe equipped with our conveyor belt mechanism the ability to be used on both ice and pavement, which is an advantage over other shoes currently available on the market.

10. Indicate any potential commercial licensees that may be interested in this invention.

Unknown.

FOR SOFTWARE DISCLOSURES ONLY – if not software proceed to 14.

11. Was any proprietary code or proprietary or trade secret information from outside of WPI used in the development of this software or are there any other limitations on WPI's use or disposition of this software that you know of?

Yes ____ No _____

If yes, send a copy of the agreement to ipi@wpi.edu **or describe below how the third party code may impose limitations on this invention.**

12. Documentation: Has documentation been prepared in conjunction with software? Yes ____ No ____

If yes, please describe if it is ready for public release, if no, please describe what efforts it will take to release.

13. Software maintenance and updates. If you answered yes to commercial release, are you or your department prepared to maintain and support the software and are resources available to do so? Yes ____ No ____

Do you and/or your department require further use of the software and/or are the inventors/authors intend to continue and enhance the software? Yes ___ No ___

End of Software section

14. Identify any grants, sponsors or projects (provide grant/contract number) under which either conception or first reduction to practice occurred, including partial funding and Federal "formula" funding. Also list any related projects and/or inventions and any other potential claimants to rights in this invention.

NOTE: This is very important to have the correct grant number in the proper format as WPI needs to report any inventions developed under federal grant money.

Grant:

Sponsor	Grant #	Principal Investigator

Federal formula funds (Hatch or McIntyre-Stennis). Specify:

Other Sources of Funds (Describe, ie. EPSCOR, Industry). Specify:

15. Were any University funds or other resources used in making this invention (if yes, please explain).

MQP funds were used in purchasing the elastic thread to retract the device, purchasing the pins used to connect tread links, and to cover 3D printing costs. The design prototype was 3D-printed using available machinery on campus. The machine shop was also utilized to manufacture the spikes needed for the tread links. Solidworks modeling software provided on WPI computers was used to create parts and assemblies, as well as creating stl files that were used by the 3D printer in order to make the prototype.

16. If funded by an external sponsor, has the sponsor been notified of this invention, either directly, in a progress or other report, or in an application for additional funds (date, sponsor, method of disclosure)?

N/A

This disclosure will become the first official University record of this invention. Before signing, please ensure, to the best of your knowledge, that all information provided herein is complete and accurate.
Signed and submitted by:

Inventor's Signature (1)	**Date**	**Citizenship**
______________________________	__________	___________

Print name: ______________________________

Home Address, Including City, State and Zip

Non WPI email

Inventor's Signature (2)	**Date**	**Citizenship**
______________________________	__________	___________

Print name: ______________________________

Home Address, Including City, State and Zip

Non WPI email

Inventor's Signature (3)	**Date**	**Citizenship**
______________________________	__________	___________

Print name:______________________________

Home Address, Including City, State and Zip

Non WPI email

NOTE: WPI will assume that any eventual revenue from this invention will be split equally, unless there is a different split as acknowledged below:

Inventor 1: Name Percent of Inventor share: __________

Acknowledged: ______________________________

Inventor 2: Name Percent of Inventor share: __________

Acknowledged: ______________________________

Inventor 3: Name Percent of Inventor share: __________

Acknowledged: ______________________________

Inventor 4: Name Percent of Inventor share: __________

Acknowledged: ______________________________

Departmental Endorsement: To the best of my knowledge, the above information is correct.

Department Head Signature Date

______________________________________ __________

Advisor Endorsement for Inventions by WPI Students: To the best of my knowledge, the above information is correct.

Student Advisor Signature Date

______________________________________ __________

For Office of Intellectual Property and Innovation use:
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Sponsorship Rights Verified: Yes No
Copies Attached: Yes No

Appendix F – First Design Solution Ideas

Small Spikes in Pavement

Decomposition:

FR1 – Provide Traction on Ice
- FR1.1 – Resist tangential loads from running
- FR1.2 – Remain strong and sharp throughout use
- FR1.3 – Maintain shoe flexibility when running
- FR1.4 – Enhance or maintain traction on pavement

DP1 – Spike system on shoe sole
- DP1.1 – Material selection based on tangential load calculations
- DP1.2 – Material with good wear resistance
- DP1.3 – Pattern for spike distribution that allows for flexibility
- DP1.4 – Spike diameter small enough to fit in pavement micro texture

Stress Doll

- This idea would require the user to run on toes whenever running on ice
- An air pocket would be located in the forefoot of the shoe
- When enough pressure/force is applied to the air pocket, the "cat claws" will extend out of the front of the shoe, providing traction on the ice
- Downsides to this idea are that a natural stride requires heel-toe strike
  - running on toes could lead to injury over time (not really our problem)
  - natural heel-toe strike could cause claws to extend slightly during normal stride, which could lead to issues on pavement
    - this could be fixed by requiring a certain amount of force (body weight) in order for the claws to extend
- Positives about this idea are that it is easy for the user
  - user only needs to change foot strike; running on toes isn't a motion that is out of the ordinary
  - since the claws only extend when running on toes and are retracted when not running on toes, there will be little error
- Idea came from the stress squeeze doll pictured below

Spring Loaded

- This idea would require the user to step on side of foot briefly before and after encountering ice
- There will be a button like feature on the outer edge of the sole, which can be clicked and unclicked when force is applied to it by stepping on side of foot briefly
- The button can be clicked when approaching ice and will release a spring, which releases the cat claws
- The button can then be clicked again when there is no longer any ice, which will recoil the spring and retract the cat claws

- Downsides are that the motion is unnatural and errors can occur
    - stepping on the outer side of the foot is unnatural and could lead to injury (again, not really our problem)
    - having a button to extend and retract claws could lead to accidental extension or retraction
        - this could be fixed by making sure button cannot be unintentionally pushed (location and force required)
- Positives are that it doesn't require change of foot strike for extended periods of time, only requires two small motions to extend and retract cat claws
- Idea came from a retractable pen, examples pictured below