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Eliminating Moisture in Military Footwear: An Air Flow Solution for Soldiers Perspiring Feet When Training in Extremely Cold Weather

By

Mingshuo Li

A Thesis submitted
in Partial Fulfillment of the Requirements
for the Degree of
Master of Fine Arts in Industrial Design

School of Design
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Rochester Institute of Technology
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Thesis Committee

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Keywords: airflow in footwear, military boots, cold weather, air valve, ergonomics for military footwear

Abstract:

Ground soldiers in extremely cold environments could easily suffer terrible foot conditions because of the wet environment inside their boots produced by generated perspiration. The current winter military boot products on the market focus more on warmth and weather protection, eliminating moist air and functional design is lacking in winter boot products.

A military boot system is proposed that will absorb and eliminate foot perspiration and provide a warm and comfortable environment for feet. This proposed design is to add an airflow system to the midsole of the shoe, pushing the air inside the shoe by naturally squeezing the airbag located at the heel when the foot moves.

After footwear prototype experiments, this system allows the temperature of the foot, which has been heating up due to exercise, to drop significantly within the closed shoe compartment environment, significantly improving comfort and reducing sweat production. With this tested airflow system, soldiers can constantly allow airflow to the foot during dynamic training, keeping the inside of the foot dry without expending external capacity. Even when the soldier is at rest, airflow can be generated by a removable external fan and disposable heating pads can be used to generate thermal airflow to the foot when it is cold.

Introduction:

The sweat glands of the foot are well developed, with a total of about 250,000, averaging about 600 sweat glands per square centimeter. Sweating of the feet is known to be quite easy and common (LaFee, 2017).

Globally there are large numbers of armies serving in extremely cold regions. Most of these armies are concentrated in the northern regions of the northern hemisphere, covering northern Europe, Siberia, northern North America, etc. Being trained, and operating, in these places is a considerable challenge for Army units.

Military footwear becomes problematic when the army trains in extremely cold weather. Soldiers need to wear thick insulated military boots to keep their feet warm, but these military boots have poor breathability. When soldiers train or move to make their feet generate heat, the heat cannot be radiated, thus leading to severely perspiring feet. This poor foot environment has caused soldiers a lot of distress. Hypothermia, trench foot and frostbite are prevalent, and what is easily overlooked is that the wet foot environment can easily reduce the friction of the socks and cause the foot to slide easily in the shoe.

In response to this problem, an airflow system for perspiring feet is proposed. This system does not require additional energy, considering the difficulty of having a steady source of energy for military personnel to train and conduct operations in the cold zone, as the foot movement of the heel on the airbag forms a pressure difference to the hot and humid air that is sucked out of the shoe. This proposed design needed is one that will reduce the humidity and heat inside the shoe.

The design of military boots is a comprehensive design. The functionality and structural complexity of the foot and the overall coordination of the human body are all factors that need to be considered. Therefore, diverse needs and functions are taken into consideration throughout the design.

Problem statement:

Ground soldiers in extremely cold environments could easily suffer terrible foot conditions because the wet environment inside the boots produced by foot perspiration. The perspiration could cause foot discomfort and even ulceration, if not eliminated. It is proposed that a winter military boot be designed that can relieve the moisture and perspiration to protect the soldiers' feet.

Project overview:

Background research and insights

A study showed that foot injuries incurred during military training are common. Thirty two percent of the 356 Marines studied had foot injuries after 18 days of winter training. The incidence of cutaneous foot injuries (blisters, abrasions, and hot spots) was 64.3%, and the incidence of traumatic injuries (acute ligament sprains and fractures) was 27.0% (White, 1998).

Under controlled experimental conditions, an increase in skin surface hydration increases the rate of temperature change of the skin in response to loading applications, thereby increasing the risk of blister production (Kirkham,2014.） Hiking in wet socks was associated with a 1.94 times greater risk of experiencing foot blisters （Escher，2022).

Soldiers often include four basic subjects during extreme cold weather training: (Vergun, 2017) (Decker, 2017) skiing, shooting, camping and hiking. In training, the Canadian Army, often has winter training gear that provides only limited continuous thermal protection. (White, 2019) At the meantime, the comprehensive approach to training has diversified the needs of military boots, and the combination of movement and peace in cold areas can easily leave the feet in a cold or hot and humid environment.

To help distinguish and identify the different geographical features faced by the extreme cold, four featured geographical types of extreme cold weather was studied:

1. Polar environment. A harsh environment covered in snow and ice. Snowstorms and cold winds for most of the year. Most of the land is covered with ice. Where there is no ice, the soil is very poor and vegetation is limited. Mostly mosses and lichens grow there.
2. Glacial environment. Cold climate, at high latitudes or high altitudes. High precipitation provides input to glacial systems. The distribution of vegetation and fauna is more differentiated and usually depends on the location of the glacier.
3. Periglacial environment. Vegetation increases here where meltwater is available and soil depth is sufficient to support growth. Much of the land is permafrost which limits plant

growth to mosses, lichens and small shrubs of birch and willow.

4. Alpine. Cool climate with some snow cover, but not necessarily all year round. Seasonal variations are evident in high mountain areas. The windward side of the mountains receives a lot of precipitation. The leeward side is drier and is protected by strong winds. Due to steep slopes, the terrain is difficult for animals, plants and people.

In general, the cold environment has complex terrain and the most important concerns are camouflage, weather protection and anti-slip.

Competitive analysis

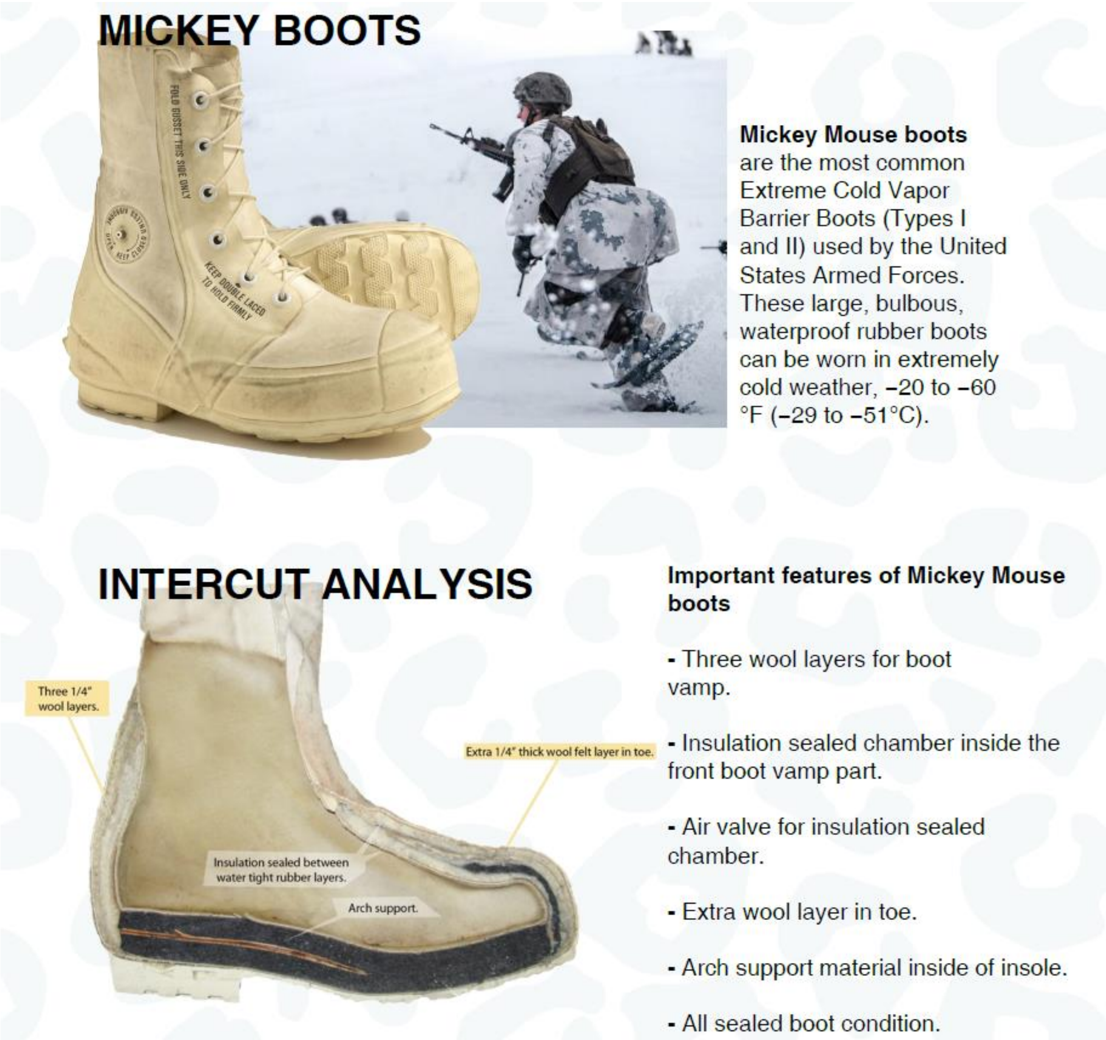

Fig. 1 Competitive analysis

Mickey Mouse boots are the most common Extreme Cold Vapor Barrier Boots (Types I and II) used by the United States Armed Forces. These large, bulbous, waterproof rubber boots can be worn in extremely cold weather, −20 to −60 °F (−29 to −51°C).

But this product has certain flaws. Airtightness: the airtightness does not let feet breathe. (South, 2018) Heaviness: It is thick and heavy, especially often need to add snowboard, soldiers are easily fatigued. Inflexibility: putting it on and taking it off is not an easy task. Low support: its ankle and calf support are poor; soldiers are more likely to break their feet and fall.

User research

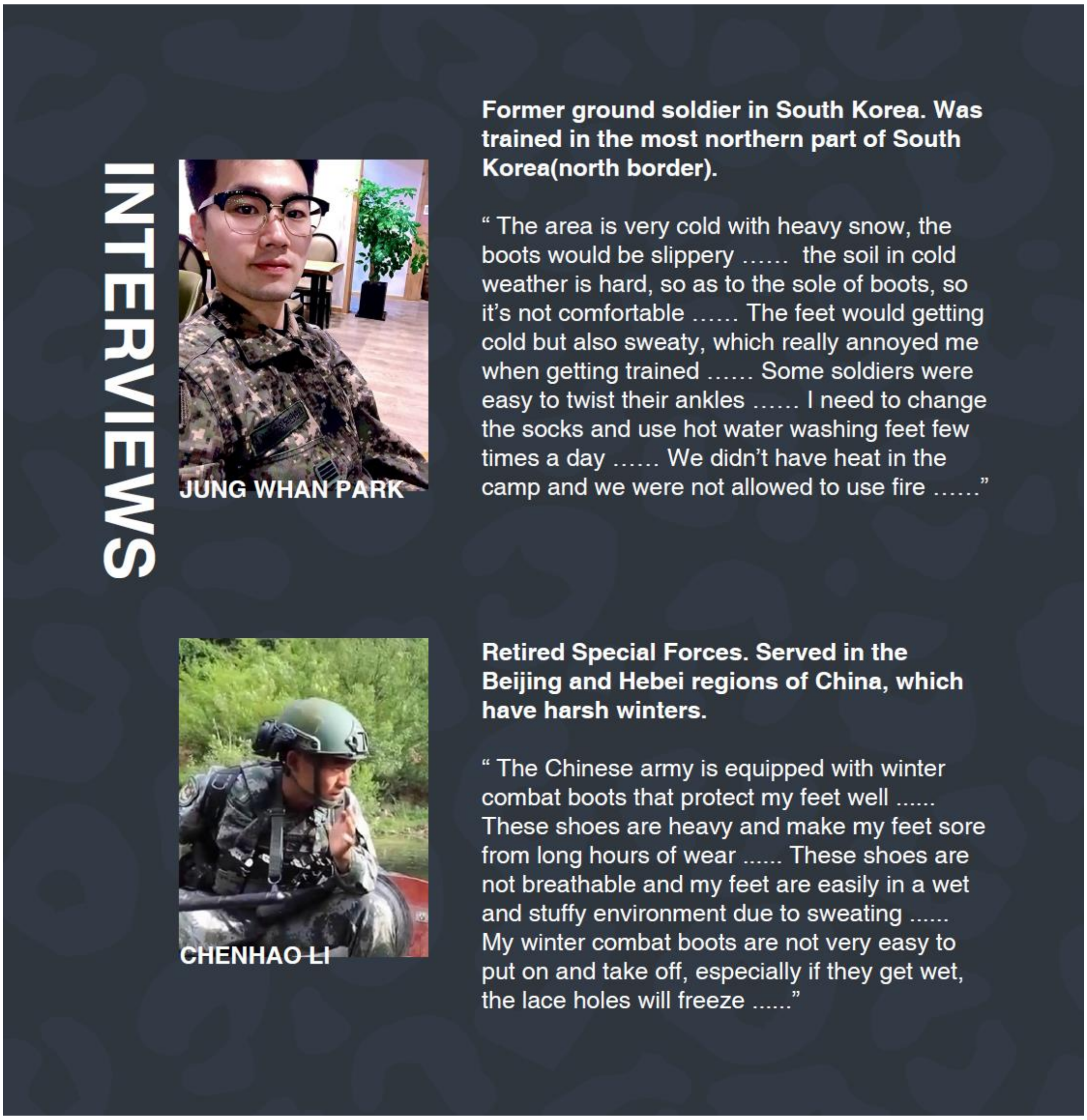

Fig. 2 Interviews

Observations from interviews: 1. The ground condition could be very slippery and hard. 2. The feet are easy to get sweaty when training. 3. The foot condition really bothers the soldiers. 4. The sole of boots is thick, easy to twist ankle. 5. The sweat generated from bottom to top. 6. The campfire are not allowed to use in battlefields to prevent exposure. 7. The power supply is not stable in battlefields so heating system is limited.

Sweating testing

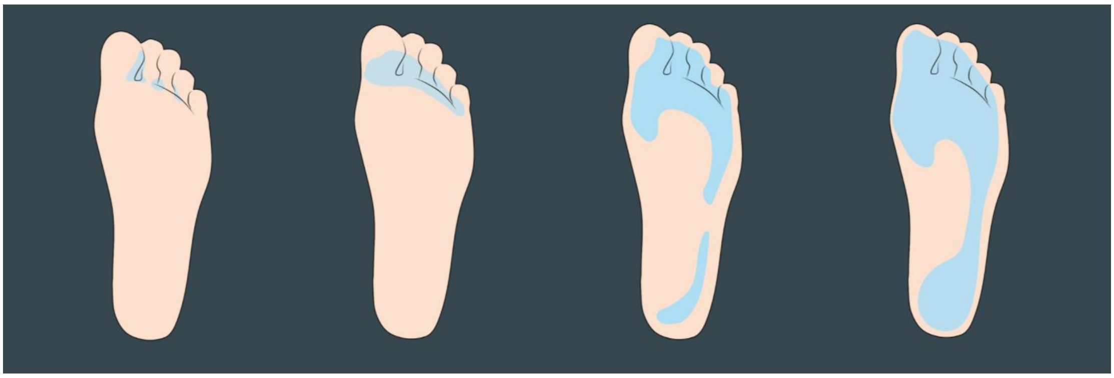

Fig. 3 Foot sweating simulation

The experiment was conducted on a treadmill for 40 minutes, and at 15, 25, 35 and 45 minutes the experimenter took off his shoes to leave sweat marks on the kraft paper. The final results showed that the sweating was most noticeable on the toes and gradually spread to the entire foot.

Prototypes

The idea of an airflow system is built up with an inflatable airbag. Based on this structure, the soldiers could press this airbag with their heels to push the air inside without consuming extra energy. To explore and develop the shape and structure of this airflow system, a few prototypes were built.

Fig. 4 Different prototypes

User comfort testing

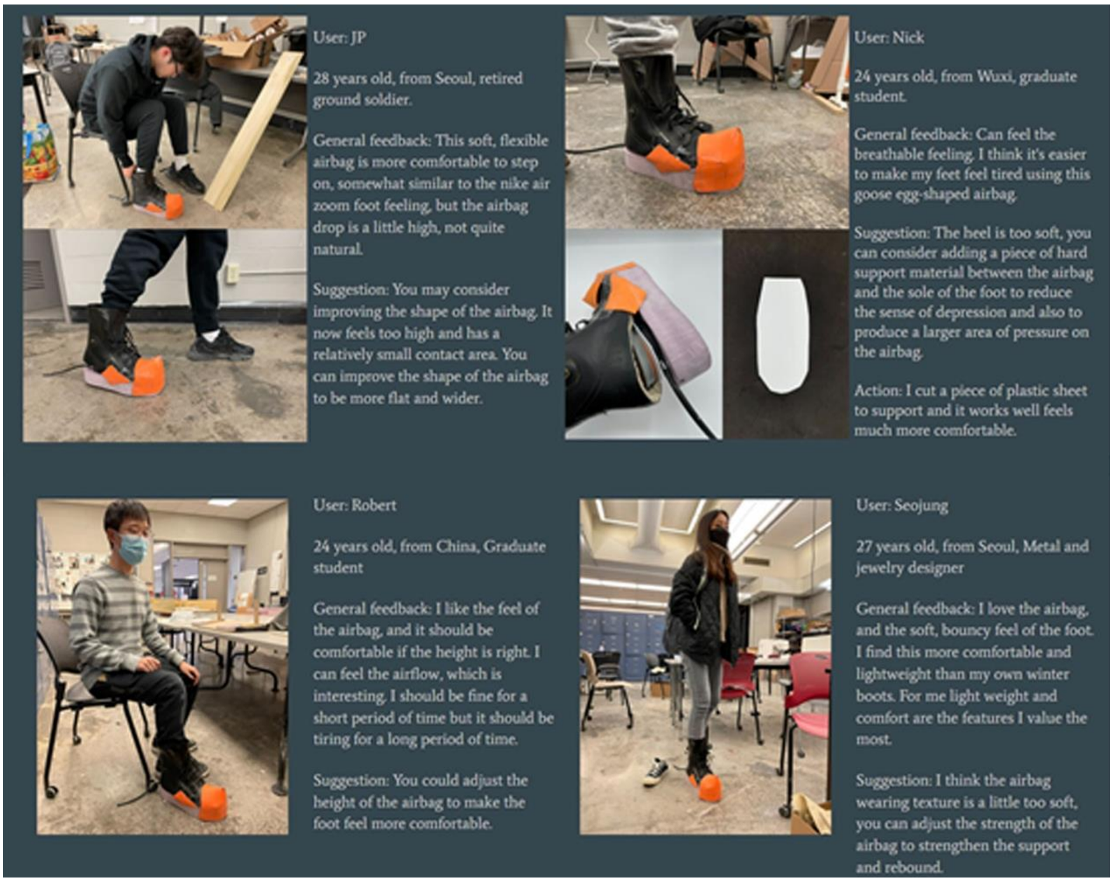

Fig. 5 User comfort test

Insights from the comfort test: the rear palm airbag should not be too soft or too hard, to ensure a certain degree of support under the premise of flexibility; consider placing support pieces in the midsole to stabilize the midsole structure.

Outsole friction testing

Six different sole patterns were chosen to test slip resistance in the snow.

Outsole pattern	**Slip resistance level**
Shallow square spike outsole	Medium
Deep square groove outsole	Good
Organic shape spike outsole	Good
Shallow wave pattern outsole	Bad
Deep spike outsole	Good
Deep wave pattern outsole	Bad

The results show that the shape of the outsole that provides good grip in the snow is characterized by a deep grain spike pattern.

Airflow efficiency testing

To test it, a control group and a blank group were set up. The premise of each experimental group was to run for 15 minutes to allow the foot to generate heat, then place the foot into the prototype for 3 minutes to allow the temperature inside the model to rise and measure the temperature no.1. Under this premise, the control group used an airbag pump to allow the airflow in the sole, and the blank group did not use an airbag pump, and then measured the temperature no.2 after 5 minutes. Finally, the results were compared.

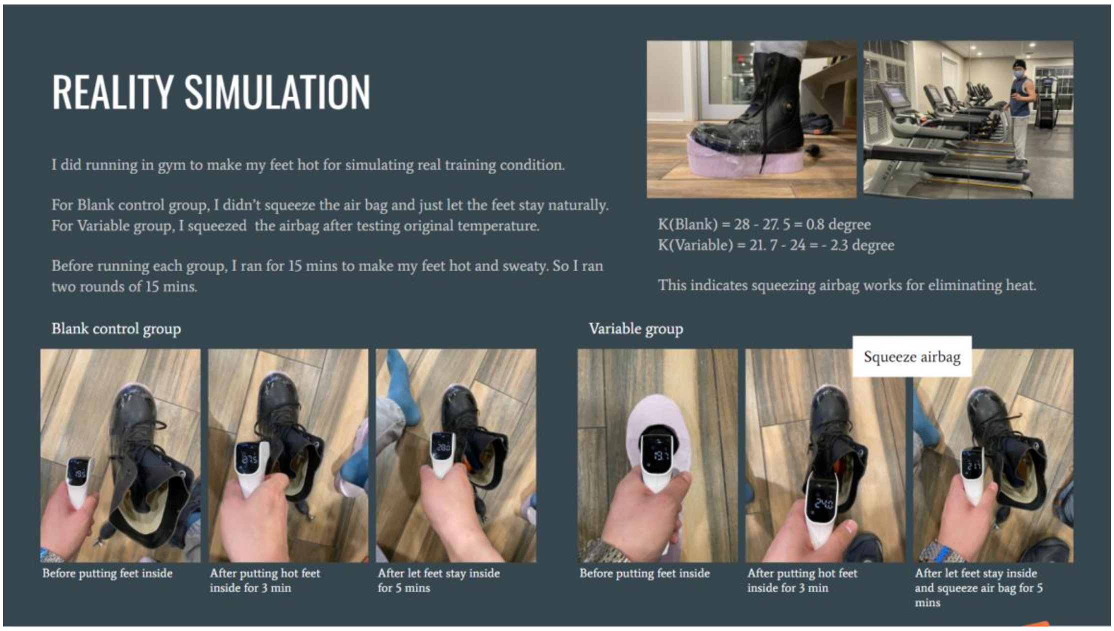

Fig. 6 Airflow efficiency test

	control group 1	blank group 1	control group 2	blank group 2
before putting feet inside	19.7 ℃	19.5 ℃	21.6 ℃	20.8 ℃
After putting warm feet inside for 3 mins	24 ℃	27.5 ℃	27.0 ℃	26.5 ℃

After letting feet stay inside for 5 mins (with & without airflow)	21.7 ℃	28.0 ℃	25.7 ℃	28.2 ℃
Temperature change	-2.3 ℃	0.5 ℃	-1.3 ℃	1.7 ℃
Result	cooler	warmer	cooler	warmer

Fig. 7 Airflow efficiency test result

It can be found that the temperature inside the shoe gets dropped with the help of airflow system, and the drop of temperature can reduce the production of sweat on the foot and keep the foot dry.

Final design

Fig. 8 Aesthetic design

Fig. 9 The final rendered model

Fig. 10 Explosive view

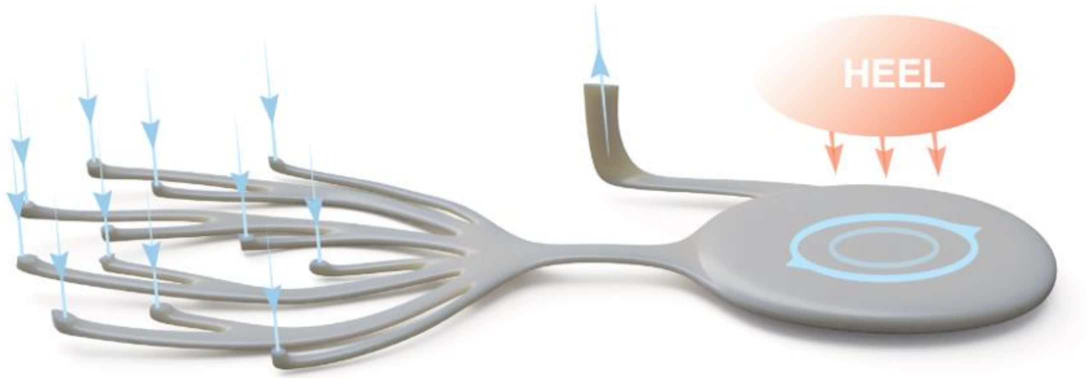

Fig. 11 Air flow system

Fig. 12 Attachments

Fig. 13 Final prototype

The final design is a light cool gray tone overall, designed to blend in with the snowy environment. It breaks away from the conventional military boot look and has a certain sense of fashion while retaining a sense of ruggedness. The sole uses a combination of large grain and small grain shades to ensure good slip resistance. The inner outsole of the toe part is turned up to provide some protection for the toes. To make it easy for users to put on and take off, the new design features two reliable buckles and a Velcro strap, and these also give the overall look a more rhythmic feel. The tongue-less design also ensures ease of donning and doffing and the simplicity of the shoe's upper structure.

Considering the possibility of reduced visibility due to snow and fog, a detachable and rechargeable light fixture is introduced, which can be adjusted for brightness and angle. The proposed design includes the features of supporting the foot at several strong points of stress, such as the outer forefoot, arch, and heel. The upper is designed with a double layer, with an air layer in the middle to slow down heat loss and enhance warmth. The upper is distributed with waterproof and breathable areas, which can ensure the balance of internal and external air pressure when the airflow circulates in the boot. The sole contains an airflow system, a Kevlar puncture-resistant layer, a carbon fiber stabilizer, and a Vibram slip-resistant outsole, which can meet the special needs of winter military boots.

The heart of the design is the airflow system in the midsole. A thin duct in the form of a tree branch connects the air vents in the forefoot of the insole to the elastic air bladder in the rearfoot. From the flexible airbag, another thick tube extends along the inside of the upper to an air valve at the neck of the foot. This creates a pathway for the air inside the shoe and the air outside the shoe. The elastic airbag at the heel has a built-in fiber, and when the user performs dynamic movements, the heel will continuously squeeze the airbag to produce deformation, and the deformation of the airbag will generate negative air pressure and promote airflow in the airflow system. At this time through the adjustment of the air valve to change the airflow inward or outward flow direction. (The air valve is a one-way valve, that is, the airflow can only be one-way flow) Thus, the airflow system has two working states:

1. Exhaust mode. Adjust the valve direction to outward, that is, by squeezing the air bag in the rear palm to pull the air out of the shoe, so as to achieve the purpose of dehumidification and perspiration. In addition, a removable rechargeable exhaust fan is introduced, which can be attached to the upper and connected to the air valve opening to increase the efficiency of exhaust and dehumidification when needed. This mode is suitable for use during or after training to help keep the foot dry.

2. Suction heating mode. Adjust the direction of the air valve inward, that is, squeeze the air bag to introduce air into the shoe. This is done in conjunction with the air heating module on the inside of the upper to introduce hot air into the shoe. The air heating module consists of a heat barrier bag on the inside of the upper and a disposable heating pad, which directly contacts the air duct to heat the air. This mode is suitable for the morning when you just put on the cold military boots or before training to help quickly create a warm environment inside the shoes.

Conclusion

In the design process of this project, it is of interest that it is important to use innovative thinking and to solve and see problems through different approaches. This experience has been very valuable in helping me to take an integrated view of the problem while coordinating different aspects.

In the next adjustment phase, I hope to test the upper parts of the boot, but right now my model focuses on the functional sole part of the shoe, and the upper part of the shoe needs assessment. I will test the upper for warmth, partial breathability, and the feasibility of a multifunctional modular upper. In addition, I hope to be able to contact active-duty military personnel to help me test a fully functional model to conduct basic military training simulations, so that the closest real-world testing will reflect the most pragmatic conclusions.

For others working in this area or would like to design military boots you must first conduct background information research. Based on the identified design problem, conduct extensive research on the context of the problem, the target population, and the technology that may be applied to it. This research is important to clarify the design and to prevent extraneous attempts to make the work more efficient. Conduct interviews and research with potential users so that you can learn a lot of detailed information. Differentiate your designed products from those on the market and clarify the design philosophy and design style.

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