

Steller's Ski Wear

Thermoregulation-Focused Ski Mountaineering Apparel Design

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Abstract

This paper examines the role that apparel plays in ski mountaineering performance. At this time, many top outdoor brands such as Patagonia, Black Diamond, and Arc'teryx design apparel specific to backcountry skiing, ski touring, and ski mountaineering. These products are designed to maximize athlete comfort, performance, and style.

This report incorporates analyses of these products, along with intellectual property research, athlete interviews, and academic research to better understand how ski mountaineering apparel can best help improve athlete performance, and where the current options can be improved. It argues that the area with the most room for improvement is in thermoregulation.

This leads to the ultimate goal of this project: how could ski mountaineering outerwear provide thermal comfort through a larger range of conditions?

Keywords: Ski mountaineering, outerwear, apparel, design, thermoregulation

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Introduction

“How Could We” Statement

Ski mountaineering is an intense sport that features rigorous high-output aerobic activity in high-elevation snowy environments. In these environments, “The weather can change very rapidly with little warning” (National Parks Service, 1970). The combination of high elevation and canyons that manipulate the wind direction cause the weather to change faster and be less predictable than the weather at lower elevations (The Catalyst, 2020).

However, while the outdoor weather can change rapidly, “the body’s climate can change even faster” (Ulriksen, n.d). As an athlete changes from high-aerobic-output to low-aerobic-output activity in cold areas, the body temperature can drop rapidly, especially if the athlete is sweaty. “Moisture next to your skin can suck heat away from your body four times as fast as air - thus it is highly important not to get excessively sweaty on the uphill” (Larsen, 2020).

The combination of high and low output periods during ski mountaineering leads to two general rules: “Staying warm while moving is directly linked to staying dry,” and “staying warm while stationary relies on your ability to insulate” (Larsen, 2020).

Therefore, the best solution to thermoregulation for ski mountaineering will facilitate air flow during high-output uphill travel in order to keep the user dry and can trap air for insulation to keep the user warm during periods of inactivity and in cold temperatures.

This leads to the ultimate goal of this project: How could ski mountaineering outerwear provide thermal comfort through a larger range of conditions?

What Is Ski Mountaineering?

The sport of ski mountaineering involves traveling across mountainous terrain using skis for both walking uphill and descending downhill. There are 3 primary modes of travel in ski mountaineering: skinning, boot packing, and downhill skiing. Skinning involves attaching skins to the bottom of the skis that provide traction, allowing the athlete to move uphill without sliding backward. Boot packing involves strapping the skis to the athlete's backpack, and hiking uphill using ski boots and crampons. This mode of travel is traditionally used in terrain that is too steep and/or technical for skins to be used. Downhill skiing is used for descending. For this mode of travel, the athlete removes the skins from their skis and skis downhill. This can be done using either Alpine Touring (AT) bindings which lock the heel down into alpine mode, or telemark bindings which leave the heel free. Figure 1 shows these three modes of travel.

Figure 1

Ski Mountaineering Modes of Travel



Note. This figure illustrates the three modes of travel in ski mountaineering. From left to right: Skinning, boot packing, and descending.

Ski Mountaineering History

Ski mountaineering originated in prehistoric times as a method for Norse peoples to travel across snowy, mountainous terrain for trading and hunting (Dawson, 2021). The earliest evidence of skiing is a petroglyph of a skier from 2,000 B.C. (Dahlmann, 2020). Figure 2 shows this petroglyph.

Figure 2

Rodoy Petroglyph, 2000 B.C. (Dahlmann, 2020)



Later, Viking peoples in Norway wrote sagas about skiing. The Viking peoples also worshiped pagan gods including Ullr, the Norse God of skiing. Figure 3 shows a depiction of Ullr on the Böksta Runestone, erected around 1050 A.D. (Koopmans, 2020). Ullr is seen on the bottom-right of this runestone.

Figure 3

Ullr, the Norse God of skiing depicted on the Böksta Runestone, 1050 A.D. (Koopmans, 2020)



There are many Norwegian legends that celebrate great ski mountaineering feats. During the Norwegian Civil War in 1206 A.D., the Norwegian military infant prince Haakon IV Haakonson over mountains and through a blizzard from Lillehammer to safety Østerdalen (Vea, n.d). Haakonson grew up to put an end to the civil war in 1240, and lead Norway to its “golden age.” The journey to save Haakonson is celebrated every year in the Birkebeinerrennet, an annual Norwegian ski mountaineering race, in which participants ski 54 km while carrying a 3.5kg backpack to symbolize the weight of the 1-year-old prince (*Birkebeinerrennet*, n.d).

In the 1800s, the Norwegians brought ski mountaineering to the Alps (Dawason, n.d). This spread the sport through the rest of Europe and later to North America. In the North American Pacific Northwest, many famous peaks were first climbed by ski mountaineers. For example, in 1854 A.G. Aiken made the first ascent of Mt. Adams using skis (Topinka, n.d).

Ski Mountaineering Today

Today, modern technology has made ski mountaineering equipment lighter, faster, and safer than ever before. These technological advancements have changed not only what feats are possible, but also have made the sport more accessible and popular. The 2020 Covid-19 Pandemic also drastically boosted participation in ski mountaineering, as ski resorts closed, forcing skiers to the backcountry. Even when resorts reopened, many skiers sought to avoid crowds at resorts and opted for the backcountry. This trend is reflected by a drastic increase in gear sales. In the 2020-21 season, year-to-year sales of ski touring and ski mountaineering equipment increased by 76% (Luhn, 2021). This trend in increased backcountry participation is expected to continue past the pandemic. As Snowsports Industries America noted, “if there’s one story worth discussing heading into Winter 2022-23, it’s the continued rise of backcountry/alpine touring interest” (Storm Mountain Media, 2022).

This rise in popularity has led to ski mountaineering competitions, where athletes compete for the fastest time in a course that goes from the base of a mountain up to a summit, and then back down to the base. These races will be added to the 2026 Winter Olympic Games in Milan and Cortina d’Ampezzo, Italy (Mather, 2022). The introduction of high-profile globally televised Olympic ski mountaineering races, increased gear sales, and increased participation all indicate that ski mountaineering will continue to see massive growth in popularity in the years to come.

Demographics

Despite advancements in ski mountaineering technologies, ski mountaineering equipment remains fairly expensive. An entry-level touring setup costs about \$2,000-\$2,500, and prices only go up from there (*How much should I pay for a ski-touring setup?* 2022). This high cost of

entry to the sport means that many athletes are high-income young professionals who have a decent amount of disposable income. Of athletes who go ski mountaineering 6 or more times per season, 40.1% fall in the 25-34 age range, and 68.2% make at least \$75,000 annually (*Snowsport Participation Study*, 2021).

Within ski mountaineering participants, there is a significant gender disparity: 66% of participants are male and 34% are female. While this disparity reflects the outdoors and snowsports industries as a whole, there are efforts being made within ski mountaineering to bring more women into the sport. Women's ski clubs like "Lady Shred," "Babes in the Backcountry," and "She Jumps" encourage women to enter the sport through community events and free first-time gear rental (Hansman, 2021) (*Women's mentorship program*, 2022). Educational groups like Altus Mountain Guides and Northwest Avalanche Center offer educational and sometimes subsidized backcountry courses specifically for women (*Women's mentorship program*, 2022) (*Women's Ski Mountaineering*, n.d). Many believe that initiatives such as these will help bring more women into ski mountaineering and balance out the gender disparity.

Target User & Market Size

Based on the demographics research, the target user for this line of products is high-earning young professionals who have extensive skiing experience. These skiers are the weekend warrior type, who try to make the most of their weekends and enjoy spending their disposable income on gear.

Therefore, the target user is a 24 to 36-year-old male who makes over \$75,000 annually and lives in the United States of America. Based on the SIA Participation data for backcountry skiing, this accounts for approximately 128,000 potential users (*Snowsport Participation Study*,

2021). This number of projected users will likely continue to grow as more people continue to enter this sport.

Athlete Skills

Ski mountaineering combines the technical skills of mountaineering and alpine skiing with the cardiovascular endurance of cross-country skiing and rock climbing. Therefore, some important skills for ski mountaineering athletes include avalanche safety knowledge, mountaineering knowledge, cardiovascular endurance, and alpine skiing ability. Ski mountaineering educational courses generally assume that beginner ski mountaineers have already developed athletic skills and stamina from alpine skiing, rock climbing, running, and other sports. Therefore, courses focus on knowledge-based skills such as route planning, avalanche rescue, navigating crevasses, building anchors, and belaying (Stock, n.d). Figure 4 shows an example of students in a course learning how to build an anchor and belay.

Figure 4

Ski Mountaineering Students Learn Safety Techniques (Stock, n.d)



Based on these skills, the athlete apparel needs are incredibly demanding. The athlete needs apparel that not only provides warmth and environmental protection, but also is waterproof, breathes well during high-aerobic-output activity, offers a maximum range of motion and mobility, is comfortable to wear all day, and is lightweight.

Ski Mountaineering Environment

Ski mountaineering is an intense sport that features rigorous high-output aerobic activity in high-elevation snowy environments. In these environments, “The weather can change very rapidly with little warning” (National Parks Service, 1970). The combination of high elevation and canyons that manipulate the wind direction cause the weather to change faster and be less predictable than the weather at lower elevations (The Catalyst, 2020).

This project will focus on Mt. Hood as an example of a popular ski mountaineering route in the Pacific Northwest. As the U.S. Forest Service warns potential climbers, “Mt. Hood is notorious for rapidly changing weather. Storms can arrive quickly, resulting in poor visibility and extreme temperature swings” (*Climbing Mt. Hood*, n.d). Mt. Hood is particularly prone to extreme weather and temperature swings because of the elevation and exposure. Figure 5 shows ski mountaineers approaching the summit of Mt Hood on a warm spring day. The most common route for climbers is the Hogsback route, on the south side of Mt. Hood. This route is the namesake for this collection.

Figure 5

Ski Mountaineers Approach the Summit of Mt. Hood (Bosworth, n.d).



Ski mountaineers typically begin their journey at 6000' of elevation at the Timberline Lodge, and take 4-5 hours to reach the summit at 11,240' (*Climbing Mt. Hood*, n.d). At the nearest National Weather Service weather station, located at Government Camp (3,914'), the 2021 season (January - March) high temperature was 60 °F, and the season low temperature was 5 °F (US Department of Commerce, n.d). It should be noted that this station is thousands of feet lower than the summit, and the summit temperatures can get much lower. Mt. Hood also has one of the deepest and most consistent snow bases in the country. Mt. Hood Meadows, a ski resort on Mt. Hood, receives an average of 444" of snowfall each season (Meadows Team, 2019).

Steller's Jay Physical Adaptations

Many animals reside on Mt. Hood, and have developed interesting adaptations to thermoregulate in this extreme environment. Among these is the Steller's Jay, a non-migratory bird native to the Pacific Northwest that resides on Mt. Hood year round. This bird has developed physical adaptations that allow it to use its feathers for insulation in the winter, and for ventilation in the summer. In the winter, the Steller's Jay "fluffs" its feathers, trapping warm air around its body. In the summer, when the Steller's Jay needs to cool down, it "flutters" its feathers, opening air channels that allow cool air to cool itself off. Figure 6 shows these physical changes in action.

Figure 6

Steller's Jay Physical Changes for Thermoregulation



"Fluffing"

Expanding feathers to trap air and keep the body warm.



"Fluttering"

Opening feathers to allow for ventilation and cooling.

Standard Layering System

Today, ski mountaineering athletes rely on a standard layering system consisting of base layers, mid layers, insulation layers, and outer layers. A well balanced layering system is essential for temperature control and for moisture management. Figure 7 shows this layering system.

Figure 7

Typical Ski Mountaineering Layering System



The outer layer is a hard shell or soft shell that blocks wind and snow. The insulation layer is a down or synthetic-fill puffy that provides extra warmth in cold conditions. The midlayer is a lightweight fleece made of wool or synthetic materials that breathes very well and provides some insulation. The base layer is a very thin tighter fitting wool or synthetic layer that is worn against the skin to wick sweat.

Product Focus

This project will focus on a ski mountaineering apparel. Specifically, this project will focus on developing two lines of apparel: one for winter and one for spring. Spring skiing is extremely popular in the Pacific Northwest, which makes a spring-specific collection important. Each collection will include a touring cap, a shell top, and shell pants. Figure 8 visualizes what this line plan will look like and how the various elements can be worn together.

There are many other components to a ski mountaineering apparel system beyond those created for this project. These include base layers, gloves, socks, eyewear, and packs, and helmets. The products designed for this project will integrate with these other components to create a coherent system.

Figure 8*Line Plan Visualization*

Ski Mountaineering Safety & Regulations

In order to safely ski in the backcountry, athletes must be trained in reading avalanche conditions and must carry avalanche rescue equipment and other safety equipment. Certain equipment should always be carried. This equipment includes a helmet, skins, an avalanche beacon, an avalanche probe, a shovel, and a touring backpack. Other safety equipment must be carried during certain routes, depending on the length of the journey and the conditions, but is not necessary for all circumstances. This equipment includes a repair kit, maps, a compass, an ice axe, a two-way radio, food, water, a first aid kit, an emergency heat source, emergency blankets, emergency shelters, an air mattress, extra layers, a headlamp, a GPS, and a satellite phone. Figure 9 shows an example of the items that may be carried for a ski mountaineering expedition.

Figure 9

Ski Mountaineering Safety Equipment Kit Example (Goodland, n.d)



Most events and races have a list of required safety equipment. For example, the Elk Mountain Grand Traverse, which is considered by many to be “North America's premier ski mountaineering race,” has a very extensive pack list (*Elk Mountain Grand Traverse: Insider's Gear Guide 2022*).

However, for the majority of athletes who are pursuing ski mountaineering ventures outside of organized competitions, they must determine their gear pack lists independently. Ski mountaineering apparel must be compatible with all of the safety equipment listed above. The most important pieces of equipment are the avalanche beacon, the helmet, and the backpack.

The avalanche beacon is worn on a harness underneath the outer and mid-layers. Therefore, the outer and mid layers must allow for easy access to the avalanche beacon in the event of an emergency.

The helmet should always be worn while descending but is sometimes removed during non-technical ascents. Therefore, the apparel should be compatible with helmets. Specifically, this means that all hoods, hats, and eyewear should be compatible with helmets. The pack may carry safety equipment and skis and can become heavy. Therefore, the apparel must allow a heavy backpack to be worn comfortably over all layers.

Product Anatomy & Jobs to be Done

Product Anatomy

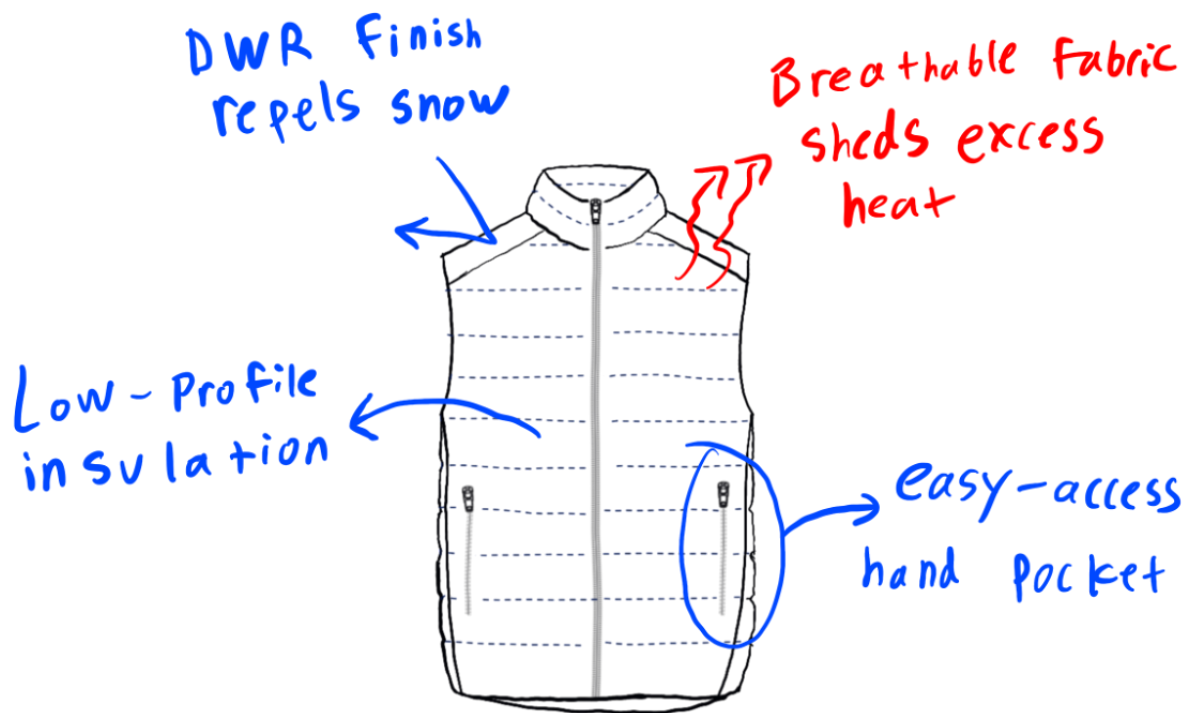
This section will dissect the product anatomy of each component.

Vest

The insulated vest can either be worn as an insulating mid-layer under a shell jacket or worn on its own over a base layer. This garment functions to provide insulation and block the wind when the skier stops moving, descends, or is exposed to sudden wind gusts, while also remaining highly breathable and shedding excess heat. The vest has several key components. The breathable, DWR-finished fabric repels snow while also allowing excess heat and water vapor to escape. The low-profile insulation provides warmth without obstructing outer layers from fitting correctly. The easy-access hand pockets are convenient for storing items without donning and doffing the backpack. Figure 11 shows an illustration of these key features.

Figure 11

Vest Product Dissection

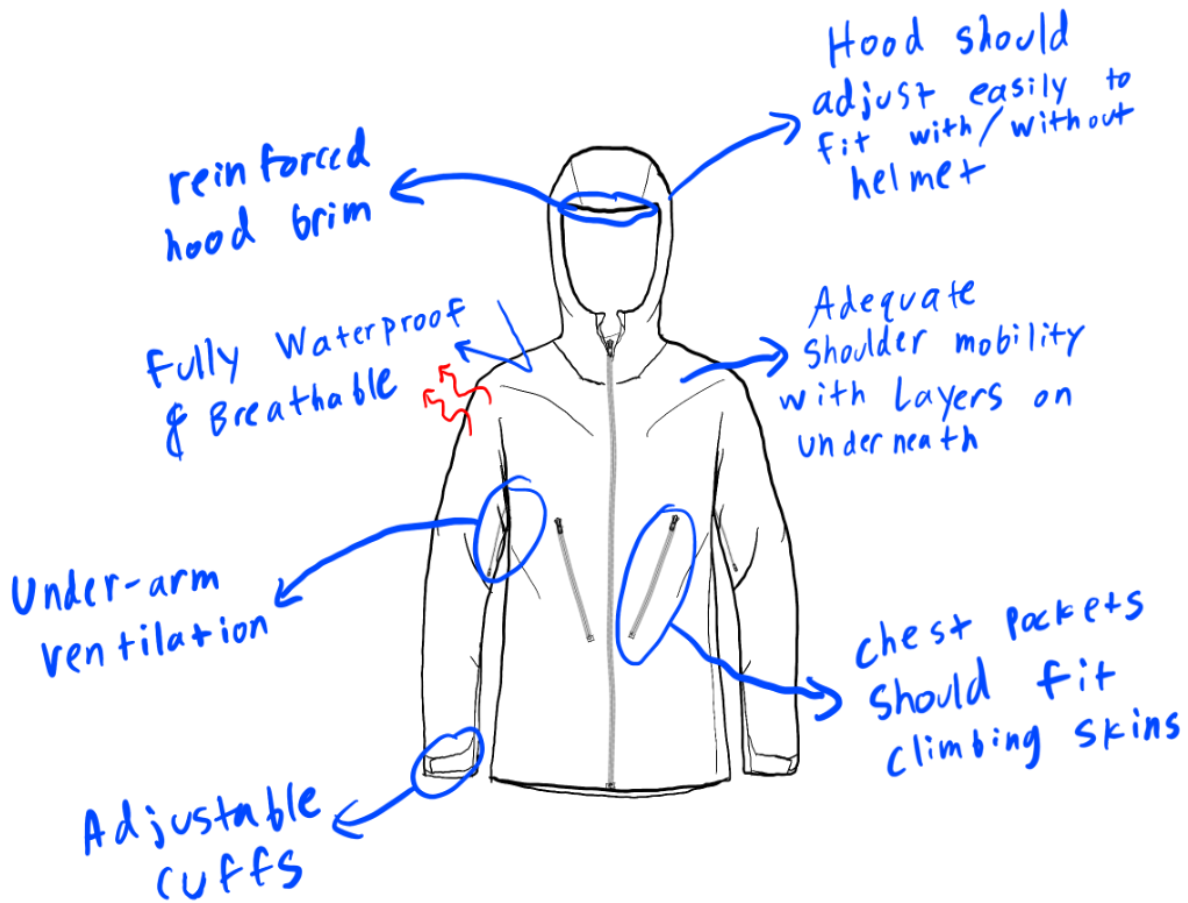


Shell Jacket

The shell jacket is typically worn all day during colder and windier days, and on warmer days the jacket is typically packed during the climb and worn during the descent. The shell jacket has several important features. The adjustable cuffs cinch down to prevent snow from entering the sleeves. The adjustable vents facilitate ventilation and cooling. The chest pockets allow for easy climbing skin storage. The reinforced hood brim prevents the hood brim from blocking vision. The hood adjustment points allow the helmet to fit well either over a helmet or without a helmet. The jacket is typically constructed of either a soft shell or a hard shell material. Figure 12 shows an illustration of these key features.

Figure 12

Shell Jacket Product Dissection

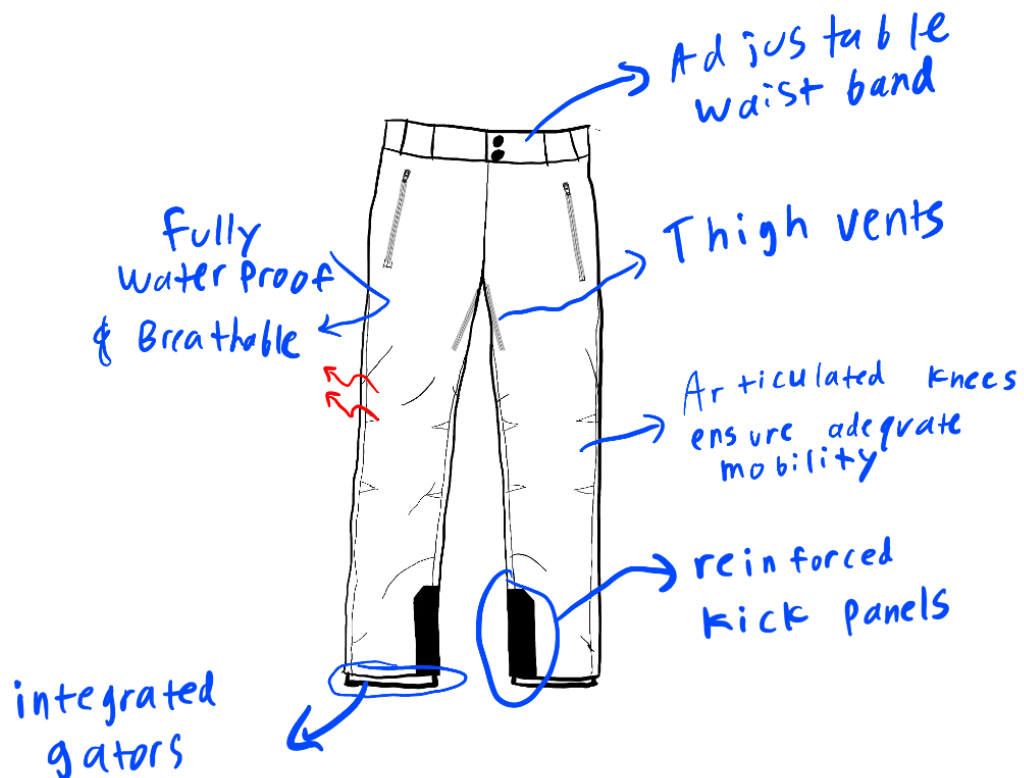


Shell Pants

The shell pants are typically worn all day every day. The pants have several important features. The adjustable waistband accommodates various waist sizes. The thigh vents facilitate ventilation and cooling. The articulated knees help improve mobility. The reinforced kick panels help improve durability in high-wear areas. The integrated gators help create a snug fit over boots. The pants are typically constructed of either a soft shell or a hard shell material. Figure 13 shows an illustration of these key features.

Figure 13

Shell Pants Product Dissection

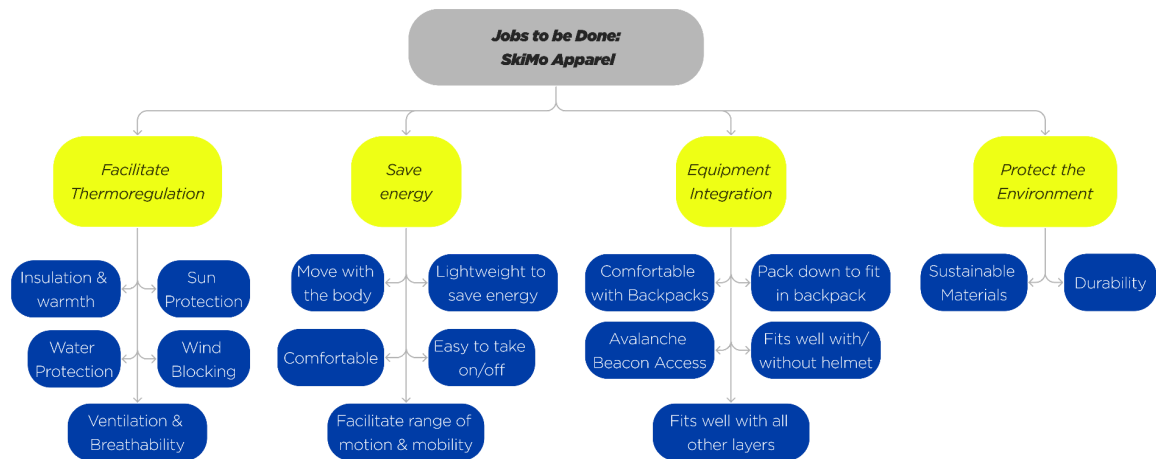


Jobs to be Done

All Ski Mountaineering apparel must perform well in many different conditions to meet the intensive needs of the athletes. The jobs to be done can be divided into four general categories: facilitating thermoregulation, conserving energy, integrating with equipment, and protecting the environment. Figure 14 shows a breakdown of these categories.

Figure 14

Ski Mountaineering Apparel Jobs to be Done



The first job category is the facilitation of thermoregulation. Both uphill modes of travel, skinning and boot packing, are energy-intensive aerobic activities. During these aerobic activities, the apparel must breathe well to avoid trapping sweat. However, the apparel must also provide adequate thermal and environmental protection during snowy winter days. Perhaps most importantly, the apparel must be adaptable, so that it can adapt to the changing environments and conditions that the user experiences.

The next job category is energy conservation. All garments must fit well, be comfortable, and provide an adequate range of motion for all movements. The garments should also be easy to take on and off. Garments also must be as light-weight as possible in order to reduce the weight that athletes carry uphill, and therefore reduce the work that the athlete exerts.

The next category is equipment integration. All garments must remain functional and comfortable in conjunction with all necessary safety equipment. This means hoods should fit well with a helmet. Jackets and vests should not inhibit beacon access, or pants should have a designated beacon pocket. All removable layers should pack down well to fit into a backpack. And all layers should be comfortable when worn together and when worn with a backpack.

The final job category is environmental protection. Environmental advocacy has become an increasingly important issue to outdoors enthusiasts such as ski mountaineers. Organizations such as Protect Our Winters (POW) have been working to connect professional athletes to legislators to help improve environmental policy. Pow executive director Mario Molina believes that POW has pushed “the entire industry into the realization that civic engagement is not a political activity” (Duncombe, 2022). For the purposes of this project, environmental responsibility will be approached through sourcing sustainable materials and through durability, both of which have been shown to be two of the most impactful ways outerwear brands can reduce their carbon footprint (Salfino, 2022).

Key Competitors and Baseline Products

The existing ski mountaineering apparel framework relies on a layering system. This layering system typically has 4 components: base layers, mid layers, outerwear, and accessories (*How to layer for backcountry skiing*, n.d). This section will analyze the components that will be redesigned for this project in depth. These products will be designed to be worn with other in-market products, such as base layers, gloves, eye wear, that would typically be worn with these garments.

The layering system starts a base layers. Base layers make direct contact with the skin and are typically made of knit polyester or wool that wicks sweat and moves with the body. The base layers may or may not provide insulation or compression, depending on the conditions and the wearer's preference. This collection will not include a base layer.

The next layers are midlayers and insulation layers. Midlayers are fleece jackets that provide insulation without inhibiting breathability. Insulation layers are puffy jackets with a down or synthetic fill that provide insulation in cold conditions. These layers can be worn on

their own or underneath a shell jacket. This collection will not include mid layers or insulation layers.

The next layer is outer layers. Ski mountaineering outer layers typically have an uninsulated shell construction. These shells come in two different forms: hard shells and soft shells. The materials section will analyze the differences between hard and soft shells in depth. Many outerwear companies release shell jackets and pants in the same line with the same name. For example, Patagonia's top-of-the-line touring softshell pants and jacket are the Patagonia Upstride, Black Diamond's top-of-the-line touring pants and jacket are both called the Dawn Patrol, and Arc'teryx's top-of-the-line touring hardshell pants and jacket are both called Rush. Figure 15 compares the Upstride, Dawn Patrol, and Rush shell jackets. The Upstride is a soft shell, the Rush is a non-hardshell, and the Dawn Patrol is a hybrid, meaning it has both hard shell and soft shell paneling.

Figure 15

Competitor Shell Jacket Comparison



Figure 16 compares the Upstride, Dawn Patrol, and Rush shell pants. The Upstride and Dawn patrol pants are both soft shells, and the Rush is a 4-way stretch hardshell. It should be noted that the shell pants generally use stretchier fabrics than the shell jackets, despite having the same product names.

Figure 16

Competitor Shell Pants Comparison



In warmer climates, skiers may opt to wear a vest instead of a full jacket. This collection will focus on a vest. Some key examples of touring vests are the Norrona Lyngen, the Patagonia Nano-Air, and the Dynafit TLT Light. All of these examples use synthetic insulation. The use of predominant synthetic insulation for ski touring vests is discussed in the materials section. Figure 17 shows what these products look like, along with prices, weights, and materials.

Figure 17

Competitor Vests Comparison



SWOT Analysis

A SWOT analysis examines the strengths, weaknesses, opportunities, and threats of any given product. As part of this project, a SWOT analysis was performed for an assortment of shell jackets, shell pants, insulated vests, and caps that are marketed to be used for ski mountaineering.

The jackets analyzed are the Arc'teryx Rush hardshell jacket and the Patagonia Upstride softshell jacket. The SWOT analyses for these products take into account not only the material differences between hardshell and softshells but also the design differences and the findings from customer reviews. The findings from these SWOT analyses are shown in tables 1-2.

The pants analyzed are the Arc'teryx Rush hardshell pants and the Patagonia Upstride softshell pants. These products are the sister products to the shell jackets that were analyzed. The findings from these SWOT analyses are shown in tables 3-4.

The Dynafit TLT Light Vest and was also analyzed using the SWOT method. This product was selected because it represents the designs of most ski mountaineering vests. The findings from this SWOT analysis is shown in table 5.

Table 1

SWOT Analysis for the Arc'teryx Rush Jacket (Rush Jacket Men's, n.d).


Arc'Teryx Rush Shell Jacket		Strengths	Weaknesses	Opportunities	Threats
	Materials	Hard-shell, Waterproof, Windproof, durable.	Less breathable, non-stretch, less packable, expensive.	Improved stretch. Better end-of-life plan (3L fabrics are hard to recycle)	Gore fabric, easy for other companies to use the same materials.
	Hood	Hood adjustment system allows for tightening/loosening	Adjustment hardware can be super annoying/hard to get it to fit right.	Hood that adjusts without hardware.	Most outerwear companies have similar hood adjustment systems.
	Chest	Fully waterproof shoulders, looser fit to accommodate more layers.	No stretch, can be a tight fit for certain body types.	Add more stretch, more breathability.	Jackets with more stretch in the chest.
	Sleeves	Articulated fit for superior mobility	Non-stretch, can be tight with additional layers. Articulation design has a lot of seams which increases weight.	Add stretch panels. Reduce seams.	Easy to add articulation to a sleeve. Companies could copy this design and add paneling for greater stretch.
	Pockets	Watertight zippers. Pockets are large enough for climbing skins.	Why is there a ski pass pocket on a backcountry jacket?? Could have a sandwich pocket. Could have a beacon pocket. More internal pockets.	Add additional pockets. Remove unnecessary ski pass pocket.	Competitors with more pockets.
	Vents	Vents are adjustable with zippers. Vents are quite large.	Vents are not mapped to sweat maps. Vents don't have a mesh lining.	Provide better ventilation to high-sweat areas (under backpack)	Most companies use the exact same vents. No differentiation.

Table 2

SWOT Analysis for Patagonia Upstride Jacket (Patagonia Upstride Backcountry Ski Jacket, n.d)


Patagonia Upstride Shell Jacket		Strengths	Weaknesses	Opportunities	Threats
	Materials	Soft-shell, breathable, comfortable, some stretch, DWR Finish.	Not waterproof, less durable.	Stretch could be improved even further.	Soft-shell fabric is similar to that of a lot of other companies, lack of differentiation.
	Hood	Hood adjustment system allows for tightening/loosening	Adjustment hardware can be super annoying/hard to get it to fit right.	Hood that adjusts without hardware.	Most outerwear companies have similar hood adjustment systems.
	Chest	Breathable, some stretch "comfort stretch"	Could have more stretch, does not fit well with additional layers.	Add more stretch, more breathability, fully waterproof paneling.	Jackets with more room in the chest.
	Sleeves	Articulated fit for superior mobility	Non-stretch, can be tight with additional layers. Articulation design has a lot of seams which increases weight.	Add stretch panels. Reduce seams.	Easy add articulation to a sleeve. Companies could copy this design and add paneling for greater stretch.
	Pockets	Pockets are large enough for (most) climbing skins.	Pocket zippers are not durable. Zippers are not waterproof. Pockets don't fit all climbing skins. Not enough internal pockets. Can't use pockets and vents at the same time.	Add additional pockets. Remove unnecessary ski pass pocket.	Competitors with better pockets.
	Vents	Pockets and vents are the same, reduced weight.	Vents are not mapped to sweat zones. Vents are through the pockets, so you cannot use the vents and the pockets at the same time.	Provide better ventilation to high-sweat areas (under backpack)	People seem to prefer the underarm vents.

Table 3

SWOT Analysis for Arc'teryx Rush Bib Pants (Rush Bib Pant Men's, n.d)


Arc'Teryx Rush Shell bibs		Strengths	Weaknesses	Opportunities	Threats
	Materials	Hard-shell, Waterproof, Windproof, durable.	Less breathable, non-stretch, less packable, expensive.	Improved stretch. Better end-of-life plan (3L fabrics are hard to recycle)	Gore fabric, easy for other companies to use the same materials.
	Waistband	Bib style accommodates more sizes.	Heavier than a traditional waistband. Harder to remove pants with bibs.	Removable bibs.	Lighter pants that fit well without bib.
	Fit around thighs	Looser fit, accommodates larger thighs	No stretch, can be tight/limit mobility for larger thighs.	Reduce material. Add stretch.	No distinguishing features.
	Boot fit	Excellent fit, boot strap goes over top of gator to keep snow out. Reinforced kick panel.	Excess material around smaller ultra-light boots.	Reduce weight. Is pant covering and gator excessive?	Non-patented closure mechanism, has been copied by other brands (outdoor research and others)
	Pockets	Watertight zippers.	No beacon pocket.	Add beacon clip to pockets.	Competitors with more pockets.
	Vents	Vents are adjustable with zipper. Vents are quite large.	Vents are not mapped to sweat maps (outer thigh). Vents don't have a mesh lining. Way for air to enter but no clear exit point.	Provide better ventilation to high-sweat areas (butt/crotch)	Many companies use the exact same vents. No differentiation.

Table 4

SWOT Analysis for Patagonia Upstride Pants (Patagonia Upstride Backcountry Ski Pants, n.d)



Patagonia Upstride Shell Pants		Strengths	Weaknesses	Opportunities	Threats
	Materials	Soft-shell, breathable, comfortable, some stretch, DWR Finish.	Not waterproof, less durable.	Stretch could be improved even further.	Soft-shell fabric is similar to that of a lot of other companies, lack of differentiation.
	Waistband	Waistband is lighter than bib style	User feedback reports it doesn't fit well for all users. Often too tight. Inadequate adjustability.	Better adjustability.	Pants with more adjustable waistband. Bibs that don't rely as heavily on waistband for fit.
	Fit around thighs	Tighter fit, less excess material. **Some** stretch (not enough)	"My crotch blew out" - review. Can reduce mobility. Too tight. So tight that you can't put anything in your pockets.	Add better articulation. Make the thighs looser.	Pants with more mobility in thighs.
	Boot fit	Reinforced kick panel.	Reported to be too tight for certain boots.	Adjustable system to fit more boots.	Pants with wider boot cut.
	Pockets	Has pockets...	No beacon pocket. Thighs are too tight to put anything in the pockets. Pockets are inset so whatever is in the pockets pokes your groin.	Add beacon clip to pockets. Move pockets outwards.	Competitors with better pockets.
	Vents	Vents are adjustable with zipper. Vents are quite large.	Vents are not mapped to sweat maps (outer thigh). Vents don't have a mesh lining. Way for air to enter but no clear exit point.	Provide better ventilation to high-sweat areas (butt/crotch)	Many companies use the exact same vents. No differentiation.

Table 5

SWOT Analysis for Dynafit TLT Light Ves(TLT light insulation M VST, n.d)

Dynafit TLT Light Vest		Strengths	Weaknesses	Opportunities	Threats
	Materials	Insulated front, windproof. Uninsulated back & sides, excellent stretch and mobility. Very packable design.	Back could be cold if there's no pack on.	More breathable insulation could be preferred by some users.	Soft-shell fabric is similar to that of a lot of other companies, lacking differentiation.
	Collar	Low-profile collar (no hood) reduces weight while providing some warmth for the neck.	Zipper in the mouth	Asymmetric zip could make the collar more comfortable.	Some users may prefer different collar systems (hoods, asymmetric zippers, no collar, etc...)
	Chest/Shoulders	Insulated chest and shoulders keep users warm.	Stretch panels do not go over the chest/shoulders, less play with different body types.	Stretch in chest/shoulders	Waterproof shoulders would be better.
	Back	Stretch back panel for ultimate mobility and better fit. Uninsulated for more breathability under a backpack	Uninsulated, not windproof, user's back could get cold in windy conditions.	Modular insulation for the back.	Vests with insulated back may be preferred by some users.
	Pockets	Chest pocket is out of the way. Single pocket design is lighter	Hand pockets could be nice.	Add hand pockets	Vests with more pockets.

Intellectual Property Landscape

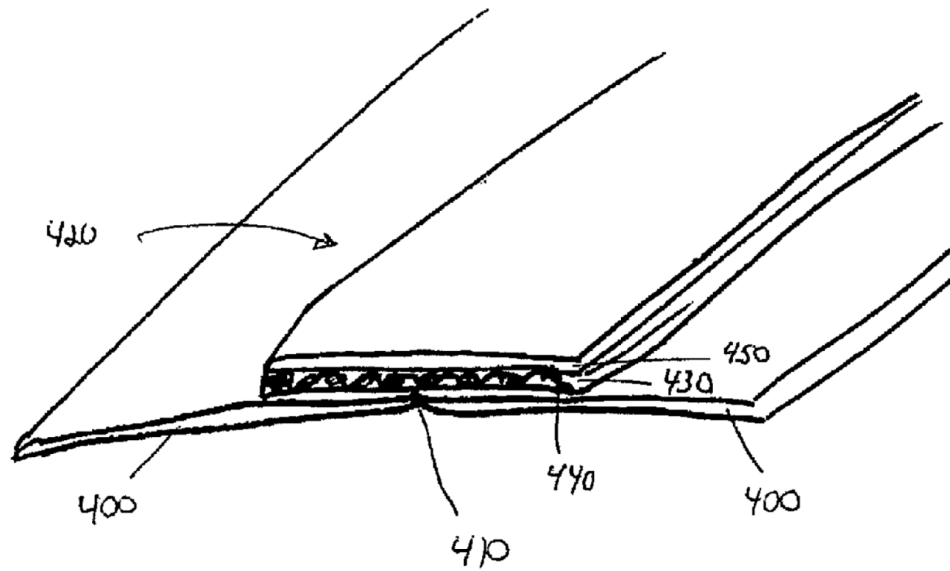
Many companies currently compete in the ski mountaineering apparel space, and these companies use patents to protect their original ideas and inventions. These patents protect

inventions in spaces such as garment construction, new materials, and innovative garment features. This section of the paper will cover some of the most interesting and relevant patents in the ski mountaineering patent space.

First, Patagonia has a patent on reinforced seams. This patent protects “a composite seam system including a narrow weld bead joining two panels of fabric and a seam tape applied thereon” (Harward, n.d). Figure 19 shows a diagram of this patent. Initially, this seems to cover all seams manufactured using a USLB machine and SRT. However, closer inspection reveals that this patent protects a very specific type of seam tape. This tape is a straightforward 2-layer TPU system that then has a tricot-type “reinforcing” layer added under the adhesive with the intention that the melted adhesive will flow into and through the tricot layer to meet the substrate. As such, this interesting patent from Patogiona protects an innovative new seam tape construction.

Figure 19

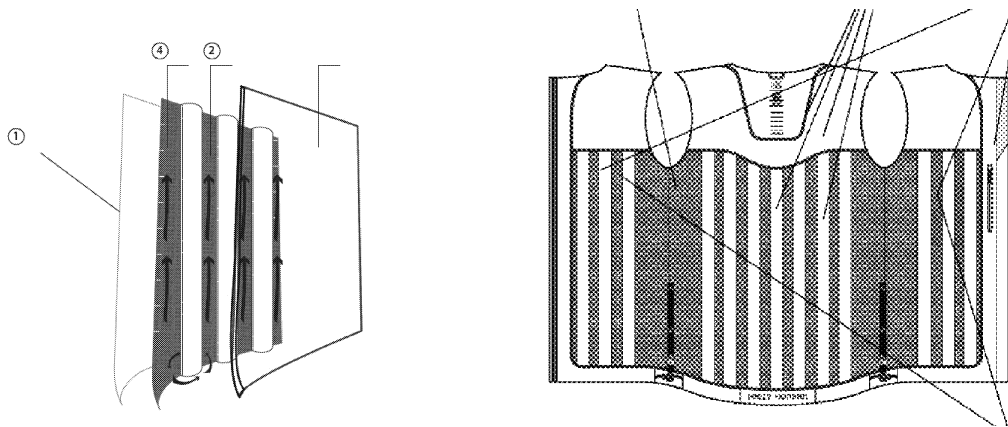
Patagonia's patent on reinforced fabric seams (Harward).



Helly Hansen has a patent protecting their micro-climate system, a series of air tubes that run the length of a jacket to improve airflow. Figure 20 shows an illustration of this patent. Since this patent, Helly Hansen has branded this innovation as their H2FLOW™ temperature regulation system. This system creates air pockets that retain body heat when needed but also have an innovative ventilation system that allows this trapped warm air to easily be released and replaced by cool air from outside of the body. Many of Helly Hansen's current top-of-the-line ski jackets utilize this technology.

Figure 20

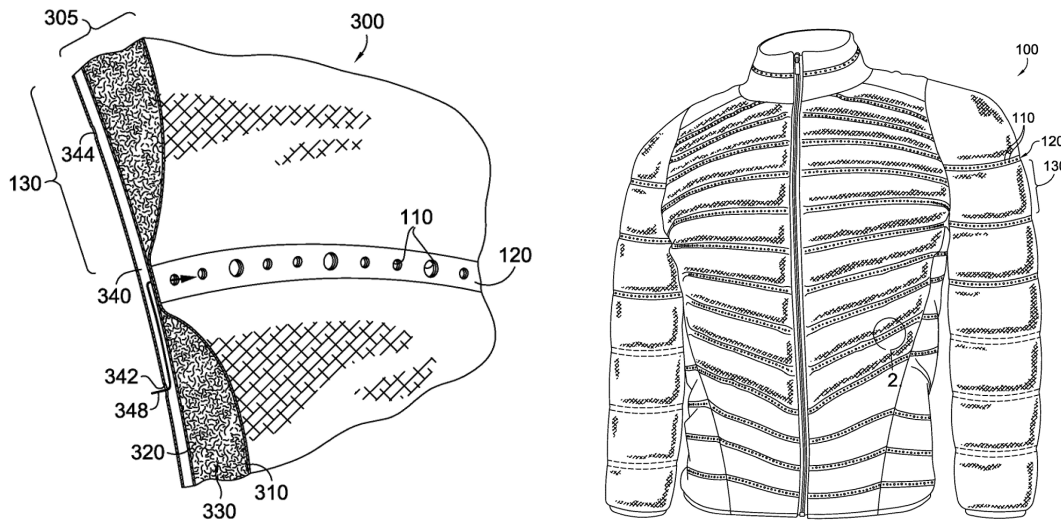
Helly Hansen's Patent on their Micro Climate System (Ulriksen, n.d)



Nike has a similar patent surrounding ventilated insulation. They have a patent protecting an insulated polyfill/down jacket with wider bonded baffles. These bonded baffles have laser-cut perforations that are designed to improve airflow and breathability in an insulating layer (Ingram et al., 2022). Figure 21 shows illustrations of this design.

Figure 21

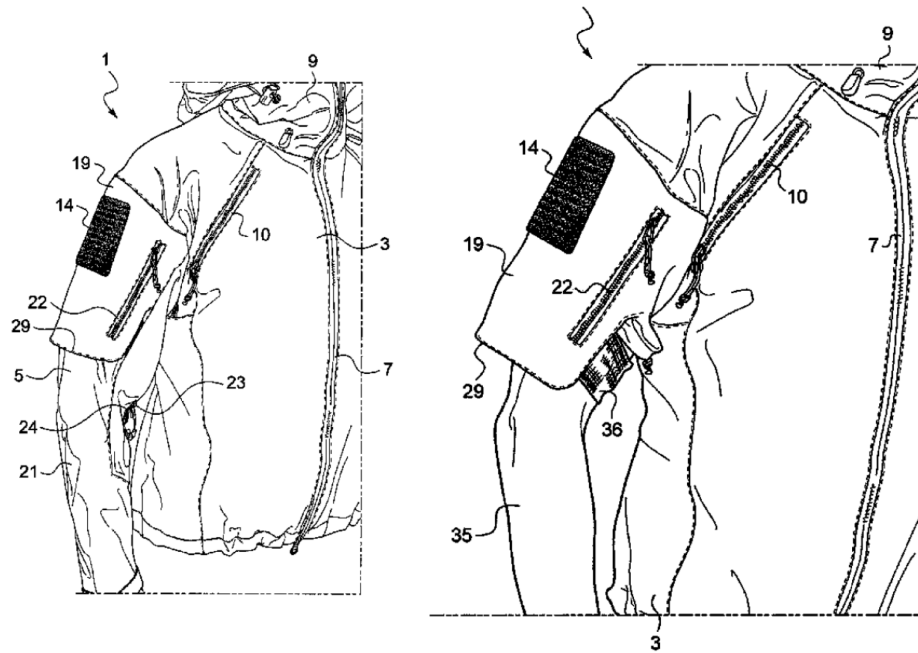
Nike Patent for Ventilated Garments (Ingram et al., 2022)



Another relevant patent concerning ski mountaineering is the roll-up sleeve system from Arc'teryx (Fayle et al., 2013). This system allows the jacket's sleeves to transition from long-sleeve to sleeveless, with the excess fabric being stored in a shoulder pocket. This invention helps facilitate breathability and thermoregulation and is implemented in the Arc'teryx Leaf Gryphon Jacket. Figure 22 shows an illustration of this invention.

Figure 22

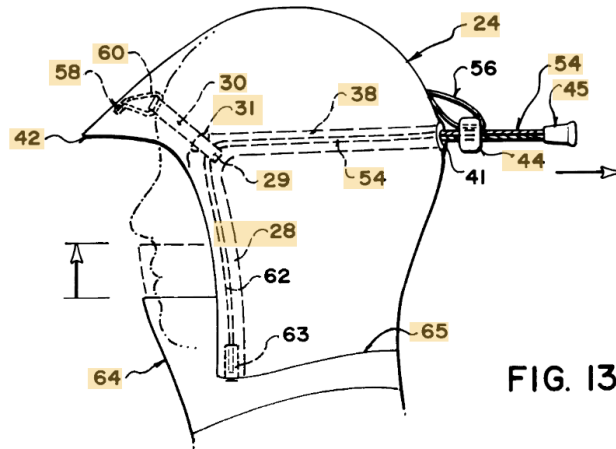
Arc'teryx Roll Sleeve System (Fayle et al., 2013)



There also are many inventions and patents surrounding hoods, particularly ways to easily adjust the volume of the hood. Arc'teryx is among the companies holding patents in this space, with the hood design shown in Figure 23. However, there are many other companies who own IP in this space, including the 7 other hood adjustment patents referenced by Arc'teryx's patent (Fayle & Routh, 2003). The Arc'teryx storm hood patent protects their mechanism of adjusting the volume both vertically and horizontally with a single adjustment.

Figure 23

Arc'teryx Adjustable Storm Hood Patent (Fayle & Routh, 2003)



Materials and Manufacturing

Materials

Material selection is an integral component of apparel design. In outerwear, such as shell jackets and pants, the typical materials are hardshell or softshell fabrics. Hardshell and softshell fabrics each have their own unique advantages and disadvantages. The hard shell typically has a 2L, 2.5L, or 3L construction, with a woven face. These hard shells are fully waterproof and windproof and can be designed to offer superior packability, durability, and weight compared to soft shells. Hard shells typically have a woven face fabric that is either non-stretch and made of nylon or has stretch and is made of a nylon/elastane blend. Due to limitations with the waterproof membrane, stretch hard shells typically have more of a “comfort stretch” than a functional stretch. Adding stretch to hardshell fabrics can reduce the durability, breathability, and waterproofness, or can increase weight. Stretch fabrics are more common in pants than in jackets, because leg mobility is more important to skiers than arm mobility.

Soft shells typically have a single-layer knit construction with a soft brushed inside, a DWR finish, and no waterproof membrane. Soft shells offer superior stretch, comfort, and breathability at a cheaper price than hard shells but lack the waterproof and windproof properties of their hardshell counterparts (*Hardshell vs. Softshell Jackets: How to choose*, n.d).

Insulation is another key material category in this space. Insulated vests and jackets typically fall into two categories: down, and synthetic insulation. Both of these types of insulation have their own unique advantages and disadvantages. Down is made from waterfowl plumage, and is known for being “light, easy to compress, long-lasting and breathable” (Pasteris, 2022). Because down has a better warmth-to-weight ratio than synthetic insulation, it is superior insulation for garments where warmth is crucial.

However, down has one critical flaw: it does not perform well when it gets wet. Because of this, the US Army developed Primaloft in the 1980s as a “synthetic down” that can provide reliable insulation even in wet environments (Shulley, 2017). Synthetic insulators like Primaloft are cheaper and more water-resistant than down (Pasteris, 2022). These insulators also can be used with a wider variety of fabrics than down, because it does not require down-proof linings. Therefore, synthetic insulation is superior for applications that will get wet or snowy. As a result, the vast majority of ski mountaineering vests on the market use synthetic or Primaloft insulation, including all of those analyzed in this paper.

This is because vests are not designed to provide maximum insulation. If a user is looking for maximum insulation, they will choose a down puffy jacket. Vests are typically designed to insulate the wearer's chest and core while allowing for breathability and for dissipation of excess heat and sweat. Additionally, vests will often get wet, either from exposure to snow or from the sweat of the wearer.

Synthetic insulation is a particularly logical choice in the Pacific Northwest, which is the target environment for this project. This is because the conditions in the “Pacific Northwest are a lot warmer and wetter, giving synthetics the upper hand” (Shulley, 2017). Therefore, the vest designed for this project will be compared to vests that use synthetic insulation. This is more appropriate than comparing with down vests that are unlikely to be used in this environment.

Manufacturing

The manufacturing methods of apparel can drastically affect the ultimate performance of the manufactured garments. Some of the key construction methods are cut and sewn seams, sewn and taped seams, and reinforced ultrasonic line-bonded (USLB) seams. All of these

manufacturing methods optimize for different factors and play a critical role based on garment type and material selection.

Cut and sewn seams are the cheapest and most common type of construction. This construction method involves cutting garment pieces out of fabric and sewing them together. The sewing can be done by any stitch type, including a lock stitch, overlock stitch, flatlock stitch, and active seamer to name a few. The type of stitch used affects performance, durability, and cost.

Figure 25 shows an example of a hat made using cut-and-sew manufacturing.

Figure 25

5-panel hat made using cut-and-sew manufacturing (Red 5-panel)



Another type of seam is sewn seams that are covered by seam tape. This follows the same first step as cut-and-sew seams, but then seam tape is used to cover the sewn seam. Seam tapes can provide waterproofing, durability, and abrasion resistance. The type of seam tape used depends on the fabric being used. For example, a 2L waterproof hardshell fabric will use a 2L seam tape, and the same goes for 2.5L and 3L waterproof hardshell fabrics (Bemis Associates, n.d). Seam taping is most common for waterproof garments, but can also be used to improve the

performance and durability of non-waterproof garments. Seam tapes are usually applied using an industrial laydown machine such as the Macpi 336.59T seam sealing machine (Macpi Group, 2021). Figure 26 shows an example of a seam that is sewn and then sealed with seam tape.

Figure 26

Seam that is sewn and then sealed with seam tape (Seam-sealed, n.d)

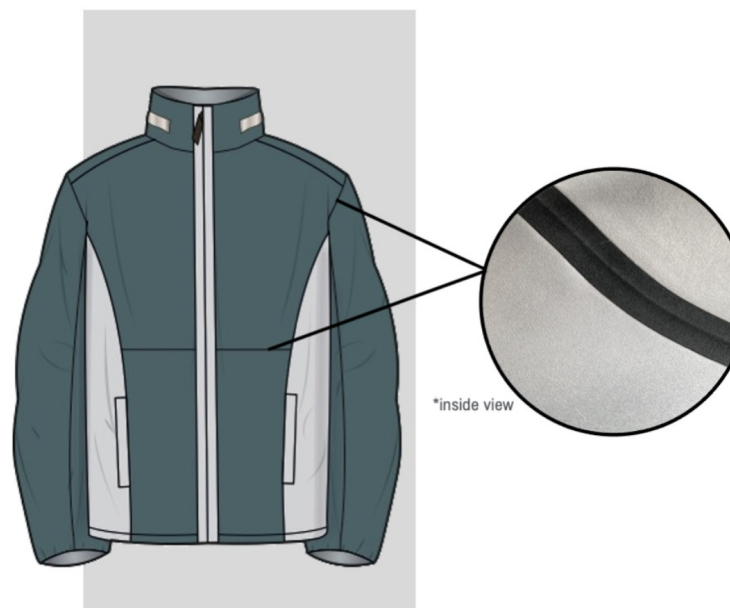


Another type of seam is a USLB seam that is reinforced with seam reinforcement tape (SRT). This type of seam uses a USLB machine to create a weak bond between two pieces of fabric. This weak bond is then reinforced using SRT. The SRT can add not only durability but also waterproofing. SRT-reinforced USLB seams weigh less than traditional seams, hold less water, are lower profile, more comfortable, and more durable, but they also are more expensive to make. This type of seam is typically seen in the highest pricepoint garments. Because the

advantages of this type of seam are not limited to waterproofing, this type of seam is seen not only in waterproof outerwear but also in sportswear and intimates. Figure 27 shows an example of this type of construction used for a 3L waterproof jacket (Bemis Associates, n.d).

Figure 27

Waterproof 3L Jacket with a USLB seam reinforced with SRT (Bemis Associates)



Branding Language

Branding in the outdoors industry is incredibly important to the success of a product and company. Three of the most important elements of branding are color, graphics, and logos. This section will examine each of these sections individually, and then examine how one company combines all of these elements to create intuitive and cohesive branding across their entire product line.

Color

Color and color blocking are huge aspects of outerwear design. Many companies with popular and well-known products release similar product lines year after year with few changes besides the colorways. Two colors that are particularly common in the outerwear industry today are blue and yellow. These colors will be the focus of this project based on their popularity today and expectations to remain popular in the coming seasons. This section will examine how those colors will evolve over the next few seasons.

Two of the blue tones for A/W 22/23 are Arctic Blue and Atlantic Blue, both of which confirm the importance of green-infused blues. Black Diamond's 2022/2023 Mission Shell Jacket perfectly exemplifies an application of Atlantic Blue, as shown in Figure 28. The third blue this season, Lazuli Blue, signals "the return of deep, saturated tones" (Smith, 2022). Looking forward to the next few seasons, blue is expected to remain popular but will shift away from the green-infused colors and towards lighter colors and pastels.

Yellow outerwear will also remain robust in A/W 22/23 and beyond (Smith, 2022). This season, warmer golden yellow-browns are especially popular, such as the Satin Brass. Black Diamond's 2022/2023 Mission Shell Jacket is also sold in this Satin Brass color. Looking to future seasons, yellow outerwear will remain popular but will shift to more mineral and earth-inspired tones (Smith, 2022).

Figure 28

A/W Color Trends 2022-2025. The 2022/2023 Black Diamond Mission Shell jacket exemplifies the A/W 22/23 Color Trends (Smith, 2022)



Graphics

Graphics are another important element of ski outerwear. Three key trends for this season are color blocking, eye-catching prints, and asymmetric trims. The goal of the prints and color blocking is to introduce interesting shapes and colors. This helps apparel feel fun and dynamic, and creates a “main character energy.” The asymmetric trims help draw attention to the functional components of the garments, making products feel more technical and performance-driven. Figure 29 shows some examples of these trends. These trends are popular

this season and are expected to carry through to the following seasons as well. The products developed for this project will incorporate these key graphics trends.

Figure 29

Ski Mountaineering Graphics Trends



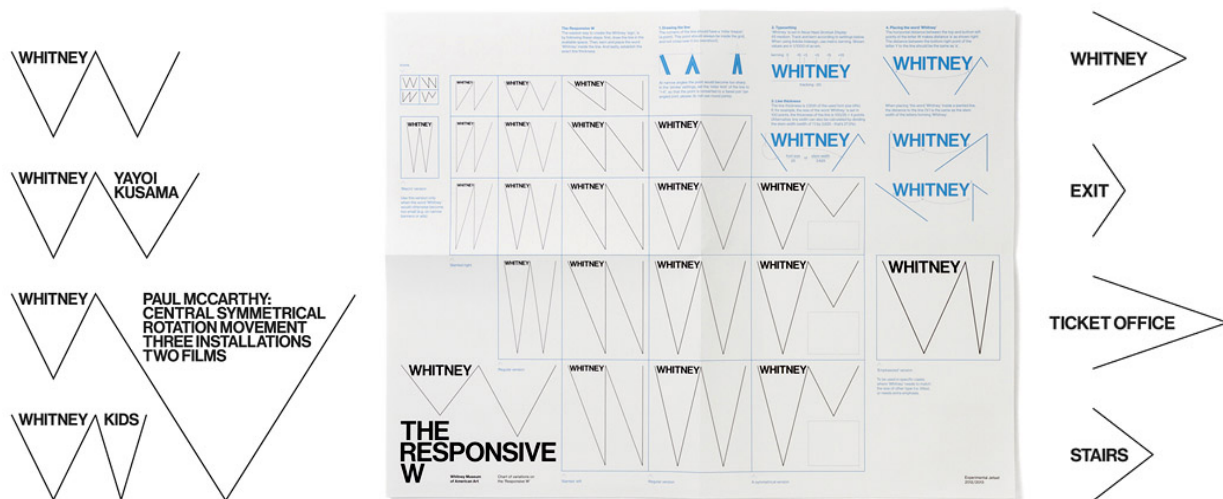
Logos

Logos and branding are another important aspect of the apparel space. One growing trend in this area is the concept of a dynamic logo and a dynamic brand identity. This is perhaps best exemplified by The Whitney Museum's logo, a "W" that can be graphically changed and manipulated to fit whatever marketing it is used for. Figure 30 shows some ways in which the "W" can be changed to fit different surrounding text and marketing media (*Whitney*

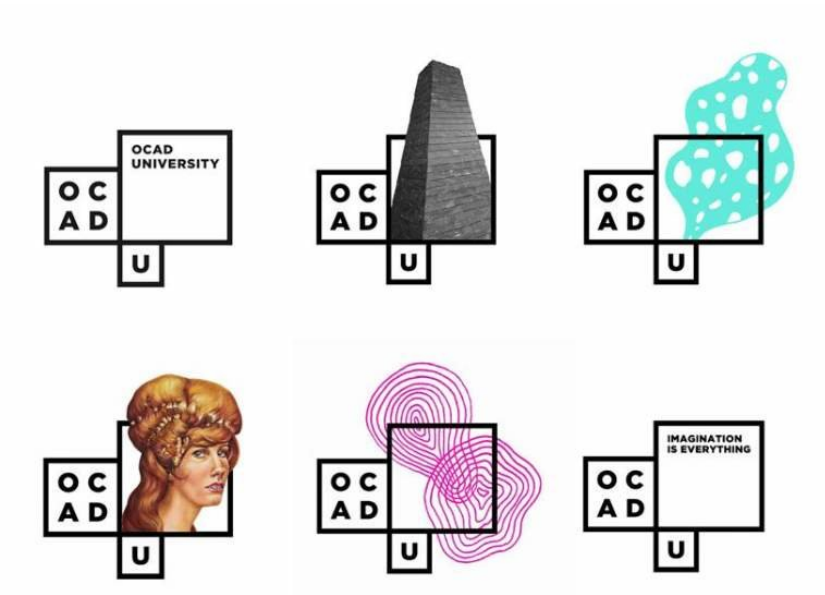
Graphic Identity 2013). Creating this dynamic logo and brand identity means that the Whitney's logo is versatile, adaptable, and fits perfectly wherever and however it is used.

Figure 30

The Responsive "W". The Whitney's logo can be manipulated in different ways to serve various purposes (Whitney Graphic Identity 2013)



Another example of dynamic branding is OCAD University. This institution has a standard window framework for their logo that has an interchangeable fill. Each year, the university invites a group of graduating students to design a new fill for the logo. Through classes and iterations, OCAD University's logo has seen "a library of identities... with records of ideas and aesthetics gathered over time" (Mau, n.d). Figure 31 shows how this logo has evolved over the years to create imaginative and compelling visuals within the recognizable window frame.

Figure 31*OCAD U Logo Evolution (Mao, n.d)*

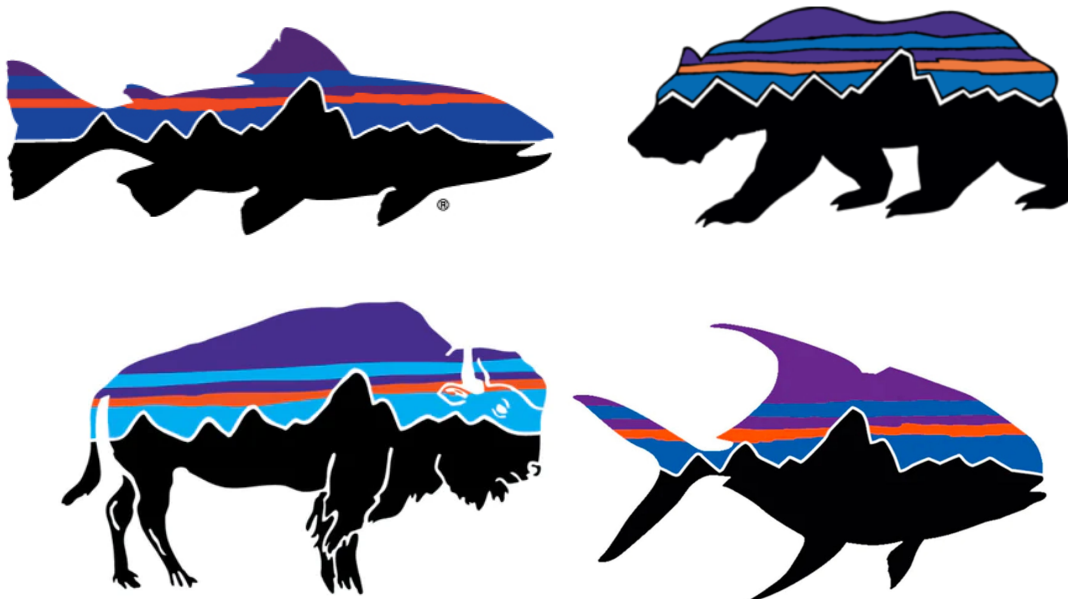
This concept of dynamic branding is not unique to large institutions - outerwear brands have begun to utilize this concept as well. For example, Patagonia has an incredibly recognizable logo that incorporates bright colors, and the Monte Fitz Roy silhouette from their namesake Patagonia mountains. Figure 33 shows the standard Patagonia logo. However, rather than use this standard logo for all product lines, Patagonia has evolved this logo into a series of animal inspired variations, where the base logo is clipped by an outline of an animal. Figure 34 shows examples where the mountain silhouette is clipped by a trout, a grizzly bear, an American bison, and a panfish.

Figure 33*Patagonia Standard Logo*



Figure 34

Patagonia Adaptive Logos using Animals



These adaptive logos serve two purposes. First, they connect the brand to the animals and nature that Patagonia seeks to protect. This connects to Patagonia's core mission to "protect and restore the stability, integrity and beauty of the web of life" (*Our core values - Patagonia, n.d.*). And second, these adaptive logos help connect the brand to the user. For example, a fisherman

may be more interested in Patagonia products featuring the trout logo than products featuring the standard logo.

The future of logos in the outdoor industry will see a continuation of adaptive logos and adaptive branding to create product lines that feel cohesive across multiple product categories.

Branding

The companies who brand themselves the best are able to combine their logo, color palette, and graphics trends to create products that look and feel cohesive across their entire product line. One excellent example of this is The North Face.

This dynamic brand identity can also be achieved in a soft-goods space to create lines that feel cohesive across many different products. One brand that does an incredible job of this is The North Face. The North Face has some iconic looks, such as their yellow jacket with black chest panels. They are able to extend the design language, color blocking, and colors from this product across many different product areas to create an entire array of items that all resonate cohesively. Figure 35 shows how this brand identity translates from the classic recognizable jacket to a tent and a blanket.

Figure 35

Cohesive Branding by The North Face



Because The North Face has these iconic styles, colors, and designs, they can play with their design rules to create fun and interesting new products that share the heritage and consistency of the rest of their line. For example, the printed jacket in Figure 36 remains recognizable by sharing the iconic “TNF” panel configuration, but with different colors and fun prints. Similarly, the hoodie in Figure 36 uses color blocking to be reminiscent of a TNF jacket and feels like a much more technical garment than it actually is.

Figure 36

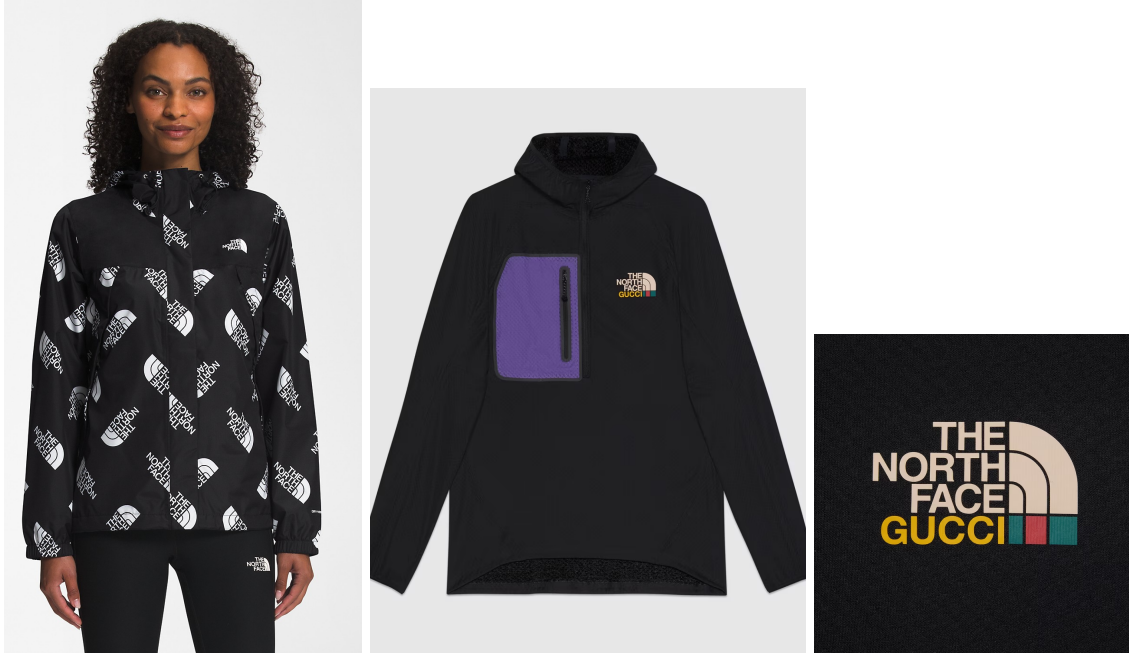
The North Face Printed Jacket and Hoodie



The North Face also uses its logo in interesting ways. They start with clear and consistent logo usage: their recognizable logo is placed in a high-contrast color (usually black or white) on the top-left chest panel of their jackets. From these consistent rules, they break away and use their logos in new and exciting ways. For example, they have begun using their logo as prints for many of their products as shown in the Antora jacket in figure 37. They also change their logo for some of the high-profile collaborations that they release. For example, figure 37 shows how they modify their logo for a Gucci collaboration.

Figure 37

The North Face Printed Antora Jacket and The North Face x Gucci Collaboration



The North Face exemplifies consistent and exciting branding. They start out by establishing cohesive and recognizable brand guidelines that customers grow used to and familiar with. They do this through color, graphical elements, and logo usage. They then break these guidelines in compelling and interesting ways to create eye-catching and exciting products that stand out. The future of branding in the outdoor space will likely follow The North Face's exemplary usage of color, graphics, and logos to create cohesive product lines.

Quantitative Research

This section will explore the academic research surrounding the physiology, biomechanics, and psychology of ski mountaineering.

Physiology of Ski Mountaineering

There are three key components to ski mountaineering physiology: VO₂ max, heart rate, and thermoregulation. This section will explore the academic research about the role that each of these physiological metrics plays in ski mountaineering performance.

VO₂ Max

Ski mountaineering is an incredibly demanding endurance sport that is “viewed by athletes and practisers as one of the most exhausting endurance sports” (Duc et al., 2011). It also takes significantly longer to travel uphill than it does to ski downhill. This means that an athlete’s physical conditioning can make a larger impact on their times than their skiing ability. As such, cardiovascular indicators such as VO₂ max are the best indication of athlete ability in ski mountaineering (Hutchinson et al., 2021).

The impact of VO₂ max is especially significant because ski mountaineering typically takes place at high elevations, with some events occurring as high as 13,000 feet in elevation. This can have a huge impact on athletes, because “for every 3,000 feet of elevation, VO₂ max declines by about six percent” (Hutchinson et al., 2021). Therefore, not only is physical conditioning critical for athlete performance but so is altitude acclimatization.

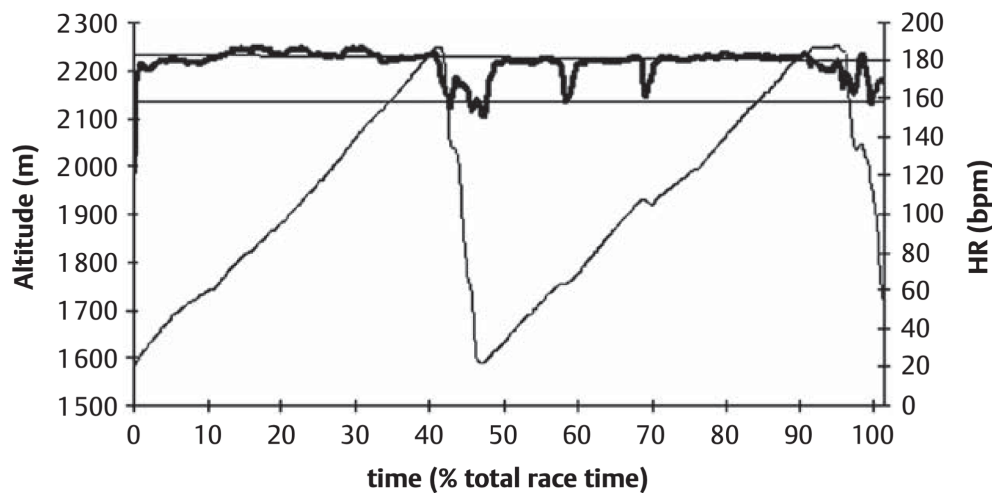
Heart Rate

When looking at ski mountaineering racing, the best strategy for top-level athletes is to maintain a constant heart rate throughout the entire race. For longer races, the ideal heart rate is typically around 87% of the athlete’s maximum heart rate (Duc et al., 2011). What is particularly interesting is that during races, elite athletes typically maintain this heart rate during both the uphill and downhill sections of the race. This is because although the athlete may not be working as hard during the downhill sections, the speed, excitement, and adrenaline from skiing downhill

maintain an elevated heart rate (Duc et al., 2011). Figure 38 shows an example of how a ski mountaineering racer's heart rate stays relatively constant throughout the course of a race.

Figure 38

Athlete Heart Rate and Elevation Data during a SkiMo Race (Duc et al., 2011)



Thermoregulation

Thermoregulation is an essential component of ski mountaineering. The combination of high-output work and cold snowy alpine environments makes it easy for athletes to get too hot or get too cold, especially as work output and weather conditions change. While exercising, the athlete's metabolic heat production "usually increases well above the rate of body heat loss" even in extreme cold (Bergeron et al., 2012). This means that the athlete likely will not experience hypothermia during high-output activity, but may experience heavy sweating, especially if their apparel system does not provide sufficient breathability and ventilation. Research has shown that improper "clothing and protective gear can measurably increase thermal strain" which causes sweating and decreases athlete performance (Bergeron et al., 2012).

This sweating can then lead to hypothermia when the athlete stops high-output activity to transition or take a break. Sweat causes the athlete's body to be prone to rapid cooling and

hypothermia, because “moisture next to your skin can suck heat away from your body four times as fast as air” (Larsen, 2020). Heat loss can be detrimental to performance, by causing shivering and exercise-induced asthma (EIA). Shivering is an effective mechanism for warming the body, but wastes energy. EIA is caused by a parasympathetic nervous reflex to cold, and has been shown to occur in over 50% of elite athletes in sports similar to ski mountaineering such as nordic skiing and biathlon. EIA is also detrimental to athletic performance (Bergeron et al., 2012).

This research shows the importance of creating an apparel system that provides functional thermoregulation, to keep the athlete warm, dry, and sweat-free throughout the entirety of their ski mountaineering expedition.

Biomechanics of Ski Mountaineering

There are two key components to ski mountaineering biomechanics. During the uphill, the biomechanical focus is on stride length, while during the downhill the biomechanical focus is on injury prevention. This section will explore the academic research about the role that each of these biomechanics plays in ski mountaineering performance.

Stride Length

Although the mechanism for skinning uphill in ski mountaineering is similar to cross-country skiing, there are some key differences. Because skins do not glide as well as cross-country skis, and because ski mountaineering courses can be steeper than cross-country skiing courses, ski mountaineering athletes take shorter, quicker strides than cross-country skiing athletes. Additionally, as the terrain gets steeper, ski mountaineering athletes adapt by both shortening their stride length and slowing down the frequency of their strides. This is different

from cross-country skiers who maintain the same frequency of stride but shorten each stride (Hutchinson et al., 2021).

Injuries

While ski mountaineering, it is important for athletes to maintain best practices to avoid injury. The vast majority of injuries occur during downhill travel, with only 22% of injuries occurring during the ascent (Mueller et al., 2019). Based on the similarities between alpine skiing and the descent in ski mountaineering, it would be expected that the injuries between the sports would be similar. However, there are several surprising differences in both the injury rate and the types of injuries observed.

The injury rate in ski touring and ski mountaineering is 7.0 injuries per 1000 days of sport activity (Mueller et al., 2019). Alpine skiing has a much lower injury rate of only 2.6 injuries per 1000 skier days (Davidson & Lalotis, 1996).

However, the types of injuries observed are also quite different. In alpine skiing, the most commonly injured anatomical region is the knee, with ACL and/or MCL ligament injuries accounting for the most injuries (Davey et al., 2019). This is contrasted by ski touring and ski mountaineering. In these sports, throughout an entire 10,955-hour study, zero ligament knee injuries were reported (Mueller et al., 2019). The knee injuries that were reported in this study were all abrasions and bruises. Table 7 shows an analysis of ski mountaineering and alpine skiing injuries by anatomical region.

This significant contrast between injury types is shocking. How can knee ligament injuries make up the majority of alpine skiing injuries, yet not affect ski mountaineering and touring descents, despite the similarities between the sports? One possible explanation is that uphill travel during ski touring builds muscle in the quadriceps and other supporting knee

muscles, which protects the knee ligaments during crashes (Mueller et al., 2019). However, further research would be needed to prove this theory.

The higher overall injury rate in ski mountaineering and ski touring is also interesting. This could be explained by icy conditions in the backcountry compared to the groomed runs and man-made snow at ski resorts. The majority (52%) of injuries during ski tours occurred with icy conditions (Mueller et al., 2019). However, further research would be needed to prove this theory.

Table 7

Ski Mountaineering and Alpine Skiing Injury Rate by Body Part.

Anatomical Region	Ski Mountaineering Injury Rate (Injuries per 1,000 days) (Mueller et al., 2019)	Alpine Skiing Injury Rate (Injuries per 1,000 days) (Davidson & Lalotitis, 1996)
Hand	2.24	0.45
Knee	1.40	0.88
Foot/Ankle	0.84	0.57
Thigh	0.84	0.55
Hip	0.56	0.37
Arm	0.56	0.19
Ribs	0.56	0.48
Head/Face	0.28	0.76
Neck	0.28	0.21

Shoulder	0.28	0.39
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Psychology of Ski Mountaineering

This section will explore academic research surrounding ski mountaineering psychology. First, there are the psychological benefits of ski mountaineering. Spending time outdoors and in the mountains has been clinically proven to boost mental health. There also are important psychological factors related to risk management in the backcountry. This section will break down both of these factors.

Psychological Benefits of Ski Mountaineering

Ski mountaineering can provide not only physical benefits from exercise but also psychological benefits from spending time in nature. An observational study that followed 395,369 individuals for 21 years demonstrated that long-distance skiing reduces the risk of depression to nearly half that of non-skiers (Svensson et al., 2019).

World-famous ski mountaineer Greg Hill has discussed how ski mountaineering has improved his mental health. “The mountains have given me time to work on getting rid of all the clutter that makes you focus on things that don’t matter. I believe being out there helps you figure out how to be happy” (Morgan, 2019). Hill also discussed the importance of appreciating these mental benefits while also being mindful of the risks associated with ski mountaineering. “There’s always about 20 percent of my brain that’s focused on the hazards and evaluating them constantly. And because I know that 20 percent is focusing on that, I can free up the other 80 percent to enjoy and to understand how lucky I am to be there” (Morgan, 2019).

Psychology of Backcountry Risk Management

Ski mountaineering exposes athletes to serious and potentially lethal environmental hazards such as avalanches, dangerous falls, physical injury, and hypothermia. Given that this sport typically occurs in the backcountry, it is up to the individual athletes to understand and mitigate these risks. A great deal of research has been conducted to better understand how athletes make decisions about risk in this backcountry environment, particularly when it comes to avalanche dangers. Most athletes participate in ski mountaineering in teams of at least two so that teammates can help each other out in the event of an injury or avalanche burial. Therefore, it is especially important to understand how risks are evaluated by groups and teams.

One study surveyed 467 athletes and discovered that social admiration plays a critical role in these decisions. This means that athletes are likely to accept risks that they may otherwise feel uncomfortable accepting if their team members who they admire determine the risk to be acceptable (Mannberg et al., 2018).

Clinical psychologist and ski mountaineer Dr. Sara Boilen teaches backcountry safety courses and has discussed the psychological factors in backcountry decision making in great depth. A number of factors such as confirmation bias and opportunity cost can cause skiers to take on more risk than they may realize. In order to combat these psychological traps, Dr. Boilen recommends ski mountaineering teams elect one group member to be the devil's advocate for the day. This person's job, she explains, is to "come up with valid arguments against whatever the group is moving toward" (Menzel, 2019). Strategies such as this can help make the group more carefully examine all of the risks, especially as weather and conditions change throughout the course of the day.

Research Methods

Athlete interviews will be the primary method used for collecting user insights on how athletes currently use their apparel. The author prepared a list of questions to guide the interview, but also relied on conversational skills and follow-up questions to extract valuable information relevant to the project. The prepared questions are as follows:

1. What is your typical layering system for your ski mountaineering trips? How does this layering system change based on weather and temperature? How does this system change based on the length and type of trip?
2. What features do you look for when purchasing a shell jacket?
 - a. Do you prefer hardshell or soft shell?
 - b. What pockets do you need?
 - c. What kind of hood do you prefer? What are your thoughts on the adjustment hardware on hoods?
3. What features do you look for when purchasing shell pants?
 - a. Do you prefer hardshell or soft shell?
 - b. What pockets do you need?
 - c. How often do you use side vents in your pants?
 - i. Do you prefer vents on the inside or outside?
4. What features do you look for when purchasing insulated mid-layers?
5. How often during an all-day ski-mountaineering expedition do you typically stop to change your layering system? How long do these stops take?
6. How easy is it for you to regulate your temperature with your current layering system?
 - a. When do you find you are too cold?

- b. When do you find that you are too warm?
 - i. What areas get the most sweaty?
7. What would the perfect ski mountaineering jacket look like? If the perfect technology existed, what would it be?

In addition to interviews, the author used the “try-it-yourself” method by spending time ski mountaineering on Mt. Hood and surrounding peaks. This process will help the user understand how exactly the athletes are using their apparel, and how the Mt. Hood environment impacts apparel decisions. Figure 39 shows the author and his family on a casual ski mountaineering adventure on Mt. Hood on November 27, 2022.

Figure 39

The Author and his Family Ski Mountaineering on Mt. Hood.



The author also used observation as a research method. The author went on several ski mountaineering trips with friends and observed outfits, layering systems, and how often people

stopped to change layers. Figure 40 shows documentation of what the friends were wearing on one of these trips on November 11, 2022.

Figure 40

Ski Mountaineering Apparel Observed on Mt. Hood on November 11, 2022



Athlete Insights

For this project two elite ski mountaineering brothers, Jason and Andrew Dorias, were interviewed. These brothers are some of the fastest ski mountaineers in the world, and they

currently hold the world record for the fastest known time (FKT) skiing the Grand Teton in 5:17:33 (this time includes both the uphill and the downhill) and previously held the FKT for ski mountaineering Mt. Rainier at 3:57:55 (Landers, 2013) (Romeo, 2011). Figure 41 shows these athletes after setting the FKT on Mt. Rainier. These athletes are currently ramping up their training as they attempt to set several more FKTs on traverses of Utah's Wasatch and Oquirrh Mountains this season. The goal of interviewing these athletes was to better understand how they use their apparel systems and what the pain points are in their current apparel systems.

Figure 41

Andrew and Jason Dorias celebrate setting the FKT on Mt. Rainier (Landers, 2013)



The author interviewed these athletes over the phone, separately. The author had prepared questions, but the interviews generally followed a back-and-forth conversational flow. This section will highlight some of the key takeaways from speaking to these athletes.

First, the athletes were asked about what current products they use. Both of these athletes are currently on the La Sportiva team, which limits their apparel selection to some extent. As

Andy said, "I don't necessarily think that La Sportiva makes the best apparel in the world, but it is high quality and the price is right." La Sportiva has an extensive product line geared towards ski mountaineering, which means that these athletes still have options to choose from. Jason and Andy both usually bring standard La Sportiva base layers, both down and Synthetic jackets, hard shell wind-resistant jackets, and soft shell pants with them on their trips.

Next, the athletes were asked about their layering system. These brothers prefer wearing only a base layer while climbing uphill unless conditions are especially cold, snowy, or windy. Wearing as few layers as possible while climbing helps them regulate heat and water vapor during their massive ascents. During the downhill, these athletes don either their shell jacket or a puffy to help stay warm.

This changes depending on the type of route they are skiing. For example, if they are climbing a mountain and then descending, they will typically add layers at the summit. However, during a traverse that has many shorter climbs and descents, changing layers for each section becomes cumbersome and time-consuming. In this scenario, without changing layers, they will be either too hot while climbing or too cold while descending. They always choose to be too cold during the descents because sweat accumulation will hurt them in the long run.

On the topic of thermoregulation, the athletes were asked about what areas generally get the sweatiest. They noted that under the backpack is always an area of concern, and also brought up that the chest area usually gets fairly sweaty.

Next, the athletes discussed how their layering systems change based on where they are training. Their ski mountaineering journey began in Utah's Wasatch Mountains, where the snow is significantly lighter and dryer than in other areas, so Jason and Andy originally exclusively used soft-shell jackets and pants, which provide them with adequate environmental protection

and also afford more stretch than hard shell options. Then, as Jason and Andy began training in the Pacific Northwest which has wetter, heavier snow, they transitioned to hard shells for better waterproofing. Today, they prefer soft-shell pants, which have superior stretch and mobility, and a hard shell jacket, which is lighter and more packable than a soft shell would be. Both brothers also noted that hardshell pants are excessively loud which gets annoying during long days on the mountain.

Next, the athletes discussed mobility, range of motion, and sizing. As noted earlier, athletes typically opt for soft shell pants for a greater range of motion. Andy also noted that he generally “sizes up a size or two” with his jackets and his pants because he prefers a roomier fit that will not inhibit his range of motion. Anything that inhibits their range of motion at all will slow skiers down.

Next, the athletes were asked about the durability of their products and what areas seem to wear out the fastest. With pants, “it always seems to be around the ankles,” noted Jason. With jackets, the athletes have had problems with snagging on trees and scrub oaks, which tears their sleeves.

Next, the athletes discussed what features are most important to them. They noted that more pockets are always better. Some technical jackets remove pockets to save weight, but Jason noted that this is a mistake. Both Andy and Jason said that they always find themselves using their pockets for energy bars, storing gloves, and other small items, which saves them from having to remove their pack to access these items. The athletes also were not too keen on the pit vents in their jackets. “If I need to unzip my pit vents, I will just take my jacket off,” said Andy. However, the thigh vents on their pants are a different story, given that it is pretty much impossible to quickly remove pants in the backcountry. The athletes also said that they never use

adjustment hardware in their apparel, such as hood adjustments. These features, they say, are impossible to use while wearing gloves and do not work very well. Instead, they just look for hoods that are helmet compatible and do not wear their hoods unless they are wearing a helmet.

Next, the athletes were asked “what would the perfect ski mountaineering jacket look like? If the perfect technology existed, what would it be?” Andy and Jason had similar feedback, noting that the perfect jacket would be super light, stretchy, fit well, breathe extremely well, provide insulation, and block the wind.

Project Alignment with Author's Strengths and Goals

Clifton Strengths Finder

1. Achiever
2. Self-Assurance
3. Activator
4. Includer
5. Ideation

The Golden Circle

The Why: I want to empower others to enjoy the great outdoors through inclusivity, accessibility, and optimism.

The How: I will incorporate my creative design process, bonding expertise, and passion for prototyping and creating.

The What: Beautiful, durable, and performance-oriented ski mountaineering apparel.

How Thesis Project Aligns with Golden Circle

The ski industry, and ski mountaineering, in particular, has historically not been the most inclusive space. This project will allow me to push the boundaries of this sport and create

products that not only outperform other products on the market but also are more inclusive and adaptable for all athletes.

How Thesis Project Supports Career Goals

After graduating from the University of Oregon's Sports Product Design program, I hope to find employment in the ski industry designing outerwear. This project will help me pursue this career by demonstrating my knowledge and expertise in ski apparel to future employers. This project will also show my creative problem-solving skills, and my ability to bring a new perspective to the design process by applying my engineering background to develop innovative solutions.

Platform Technology: Active Insulation

For this project, a new material technology was developed. This material technology implemented into the garments as a way to improve thermoregulation and stretch. This section will discuss how this material is made, what the key benefits are.

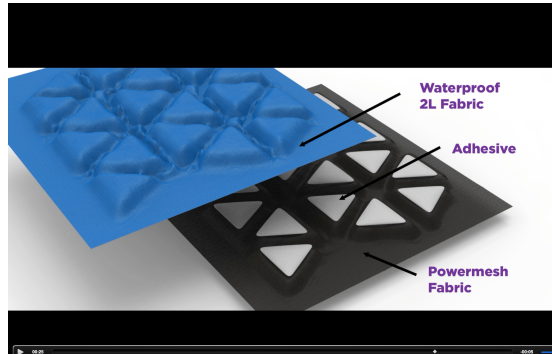
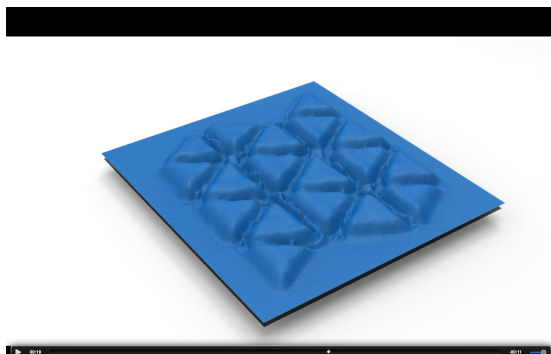
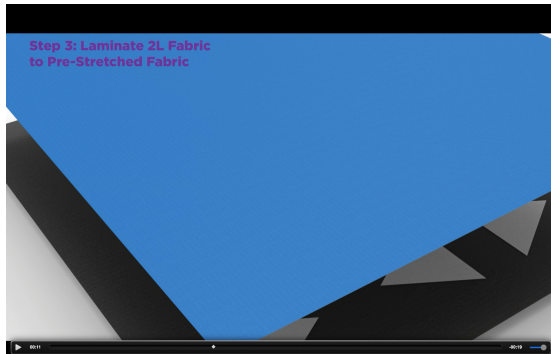
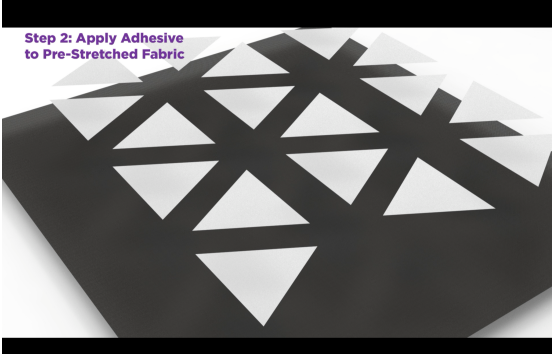
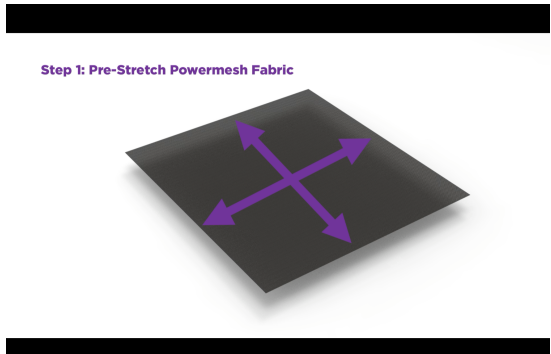
Manufacturing Process

This material is made with a 3-layer stackup: a knit powermesh fabric, lasercut adhesive, and a 2L waterproof face fabric. The first step in making the material is to pre-stretch the powermesh fabric over a heatpress. Then, while the mesh is in the stretched state, the adhesive is

laminated to the face. Next, the 2L waterproof fabric is laminated to the mesh, again in the stretched state. Next, the powermesh is relaxed, which creates a unique texture pattern. Figure 42 shows this process, and the final textured fabric, and a call out of the various layers.

Figure 42

Active Insulation Manufacturing Process.



Active Insulation Benefits

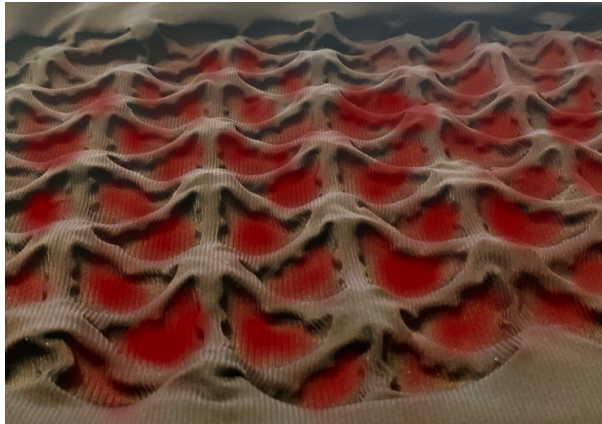
The active insulation material innovation has three key benefits: Insulation, ventilation, and stretch. The insulation is provided by the air cavities. Air is a great insulator, and is the foundation of all other apparel insulations. For example, down, polyfill, and fleece are all materials that are designed to trap warm air around the body of the user.

While trapping air is the key to insulation, air flow is the key to ventilation, cooling, and moisture management. Getting fresh air from the environment to replace the warm, sweaty air around the body is essential for cooling and avoiding sweat buildup. This is why most ski mountaineering shells have zippered vents on the thighs and armpits that can open to provide ventilation. The design of this material creates air channels that allow the cool air to pass through the body much more efficiently than otherwise would be possible.

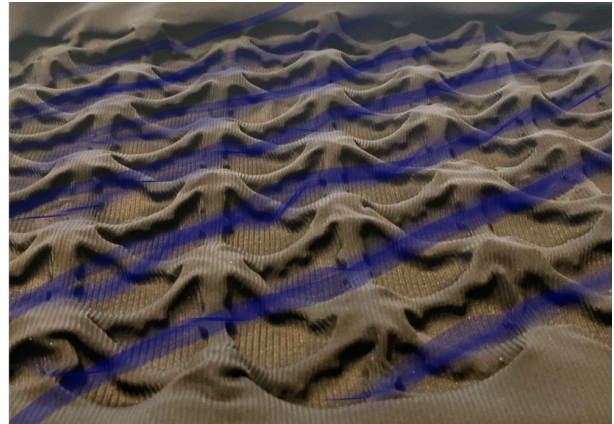
Figure 42 shows a close-up of the inside of the active insulation, and how the textured surface can either trap air for insulation or create air channels for ventilation and cooling.

Figure 42

Active Insulation Can Trap Air For Warmth Or Facilitate Ventilation For Cooling

**Vents Closed**

Cavities trap warm air
against the body

**Vents Open**

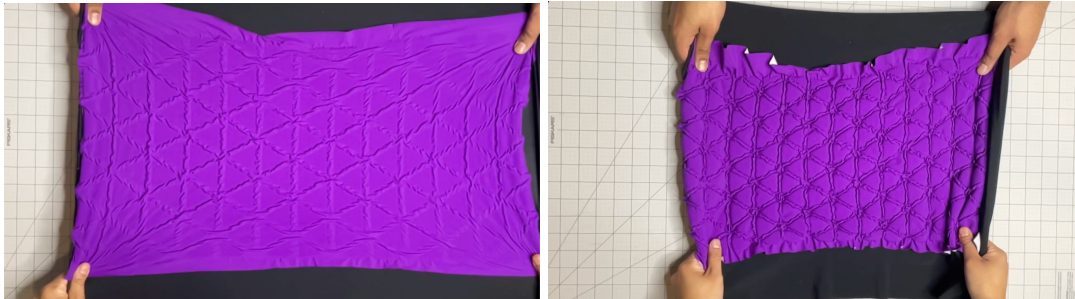
Open cavities facilitate
ventilation and cooling

Active insulation also has another key benefit: stretch. Adding stretch to waterproof garments is challenging, and most solutions have tradeoffs such as durability, breathability, and weight. Currently, Gore-Tex Pro Stretch is considered to be one of the market leaders in terms of stretch waterproof fabrics. This fabric has a 4-way stretch with a 20% stretch ratio. Active insulation has a much superior stretch, with a 4-way stretch with a 50% stretch ratio. Figure 43 shows a comparison between Gore-Tex Pro Stretch and Active Insulation.

Figure 43

Active Insulaiton (Top) has a stretch ratio of 50%.

Gore-Tex Pro Stretch (Bottom) has a stretch ratio of 20%.

**Performance Testing Plans**

The overall goal of this project is to improve the thermoregulation of ski mountaineering apparel. Therefore, in the testing plan, it is incredibly important to prove that the apparel designed for this project thermoregulates better than products currently on the market.

The testing plan below has been broken down by item. It should be noted that while the collection as a whole focuses on thermoregulation, each item has slightly different objectives. The primary objectives for the shell layers are ventilation, mobility, and fit. This section outlines how each item will be tested. For all test plans, it is assumed that consent forms will be collected in advance from all participants.

Before testing, it is important to clearly define success for this project. The objective of the project is to improve thermoregulation by creating garments that provide thermal comfort over a larger range of conditions than existing garments. Therefore, in order for this project to be successful, the apparel must provide more thermal insulation when the vents are zipped and closed, and less insulation when the vents are opened. Figure 44 illustrates success for this project.

Figure 44

Defining Success For Project.



In order to complete this testing, a thermal manikin will be used. The Boise State University Thermal Manikin Laboratory has generously agreed to use their thermal manikin for this testing. The thermal manikin measures how much insulation a garment provides in watts

(W). This is done by blowing warm air into the manikin at body temperature (around 37 °C). The air is circulated through the entire manikin body, and then blown out. The temperature of air coming in and air going out is measured, and the difference in these temperatures is used to calculate the energy loss in watts. This method has been proven to be highly repeatable and accurate. The garments designed for this project will be measured using the thermal manikin, and compared to benchmark products.

Testing Results

In order to start testing, prototypes were made integrating active insulation into apparel.

Figure 44 shows the process of building garments using the active insulation.

Figure 44

Integrating Active Insulation Into Ski Mountaineering Apparel



Next, the author traveled to the Boise State Thermal Manikin Laboratory. Figure 45 shows the author with Dr. Uwe Reschl, inventor of this thermal manikin, in the laboratory.

Figure 45

Author with Dr. Uwe Reischl at the Boise State Thermal Manikin Laboratory

Laboratory Testing
Boise State University Thermal Mannequin Laboratory

Thermal mannequin measures how much insulation a garment provides in Watts.
More Watts = Warmer Garment.

Dr. Uwe Reischl
Boise State University

Dr. Reischl invented Boise State's patented thermal mannequin, and graciously helped conduct this research.

Next, several tests were conducted using the thermal manikin. The first test was to compare the insulation provided by the prototype jacket to the insulation provided by a baseline product: the Arc'teryx Rush. The Rush is a hardshell jacket that would commonly be used for ski mountaineering. The prototype jacket and the competitor shell jacket were tested on the thermal manikin in three configurations:

1. With all zippers and vents closed
2. With the vents unzipped and the front zipper closed
3. With the front zipper and the vents unzipped

These results are recorded in Figure 46. The prototype jacket provides far more insulation than the competitor garment when zipped up, and less insulation than the other garments with the zippers and vents open. This means that not only does this garment provide better insulation than the other garments, but it also offers more reliable ventilation and cooling. This means that the prototype jacket can provide appropriate insulation over a much larger range of temperatures and climates than the competitor shell jackets.

All tests were conducted in a wind tunnel with a wind speed of 0.8m/s. Figure 46 shows the measured insulation of each garment.

Figure 46

Comparing Prototype Jacket Insulation to Baseline Product

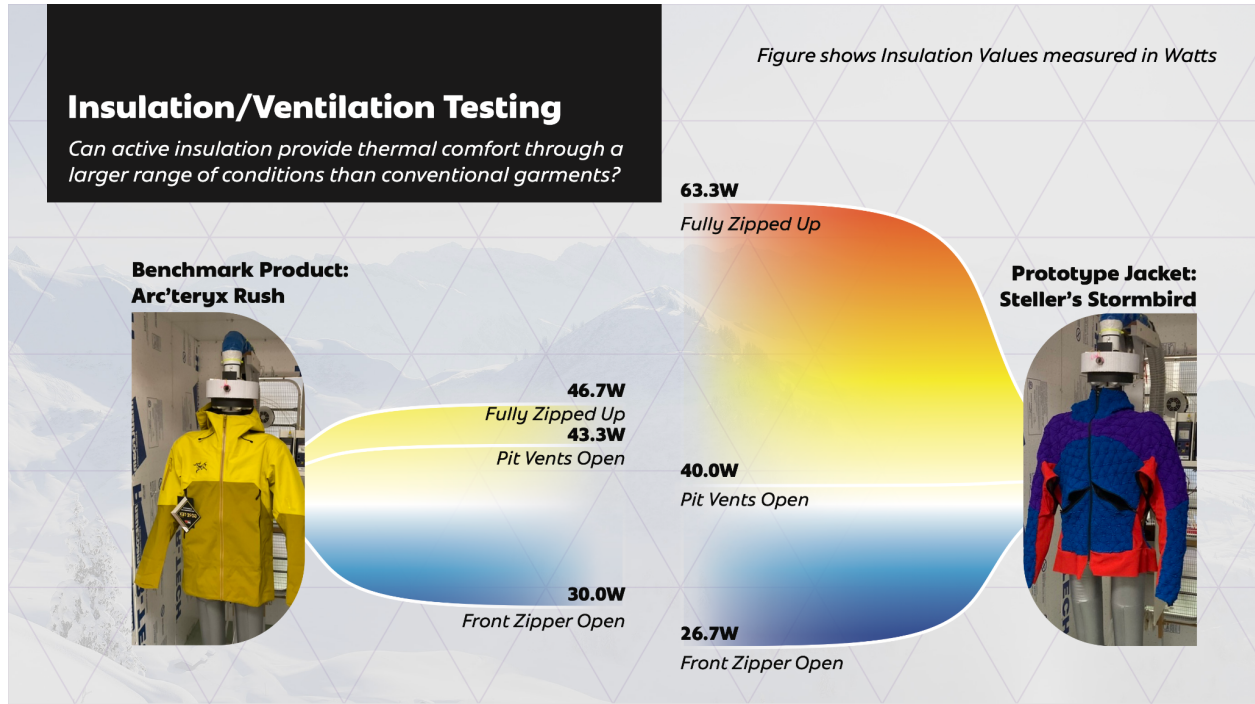
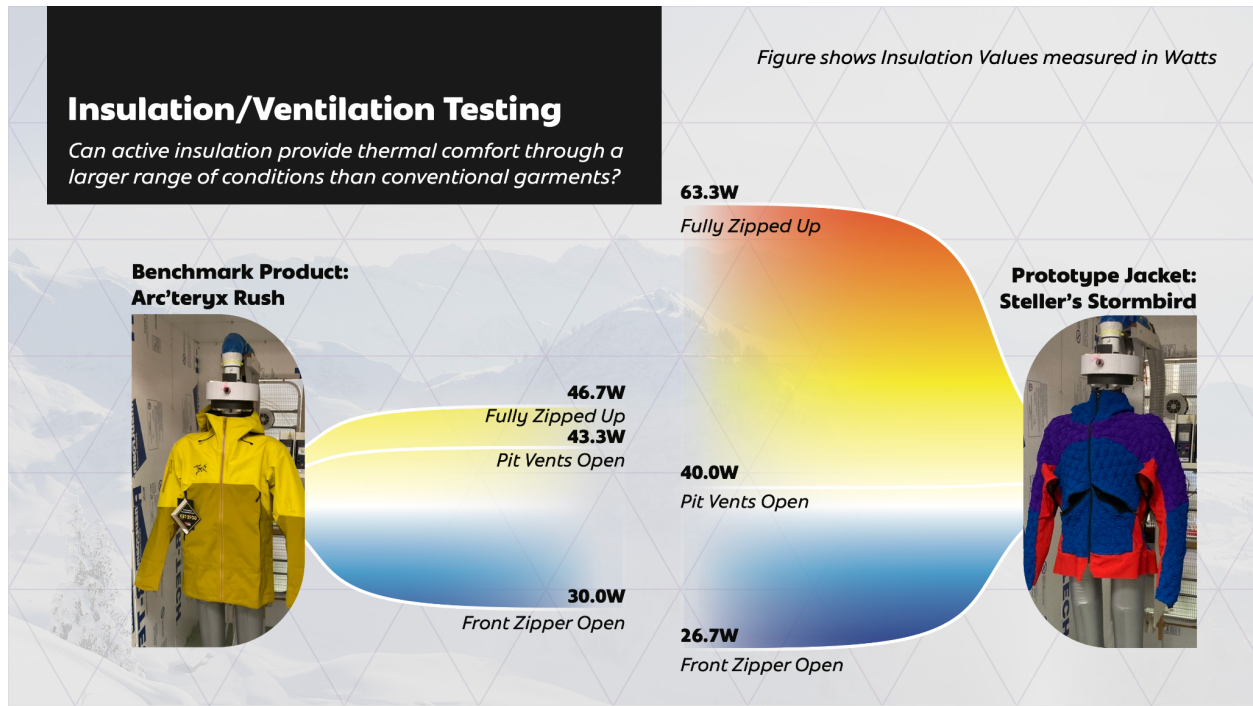


Figure 47

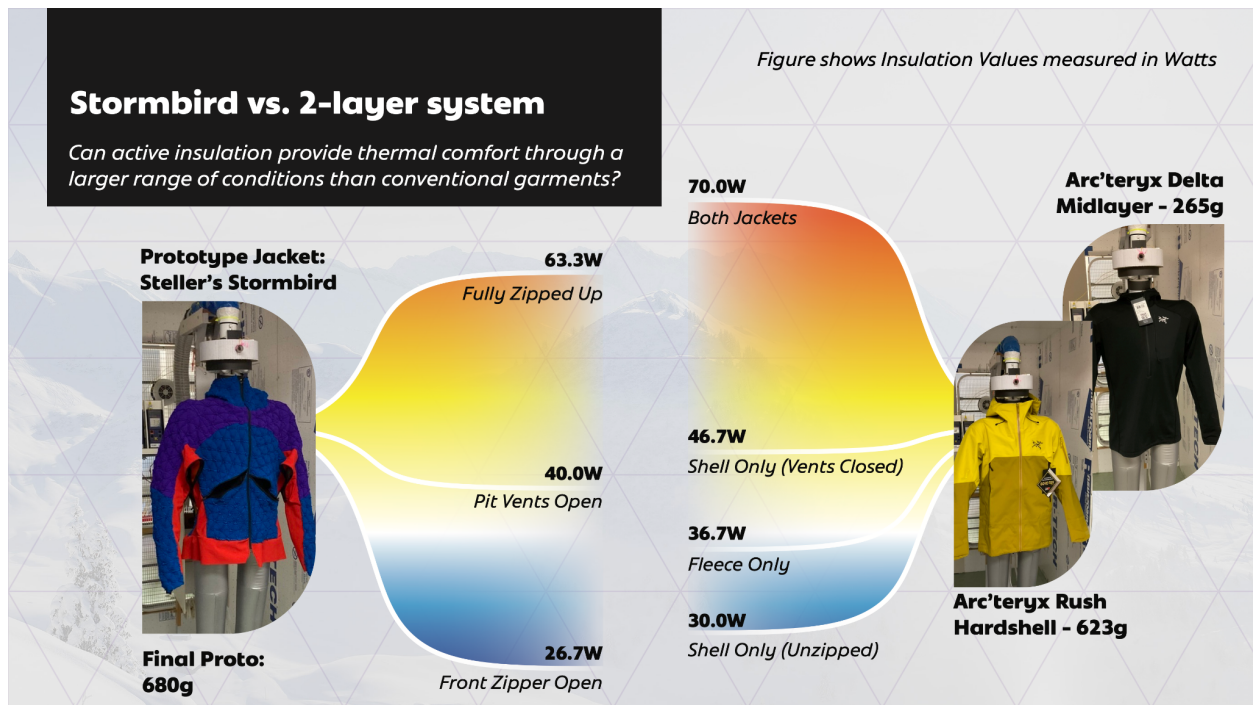
Comparing Ventilation of Prototype Jacket to Benchmark Products



Next, the prototype jacket was compared to a combination of two layers, the Arc'teryx Rush Hardshell jacket and the Arc'teryx Delta. Figure 48 shows these results. The prototype jacket was able to achieve a very similar range of insulation as this two-garment system. This shows that by using a jacket featuring Active Insulation, athletes can comfortably carry one fewer garments, saving weight and also saving time because athletes will have to spend less time transitioning from one garment to another.

Figure 48

Comparing Prototype Jacket to 2L System



Proof of Mentorship

My mentors will include Alice Clemans, an apparel pattern designer for Bemis Associates, and Chris Pew, the CEO of TREW Gear. I have discussed my project in detail with these individuals and have emailed agreements from them to mentor me. Figure 49 shows these emails.

Alice Clemans, Apparel Pattern Designer, Bemis Associates

Alice Clemans is a pattern expert who I currently work with at Bemis. She has already provided extremely valuable insights into my project, and I am extremely excited to continue to work with her. Alice and I will meet once a month for one hour and she will provide expertise on design, patterning, and assembly.

Chris Pew, CEO TREW Gear

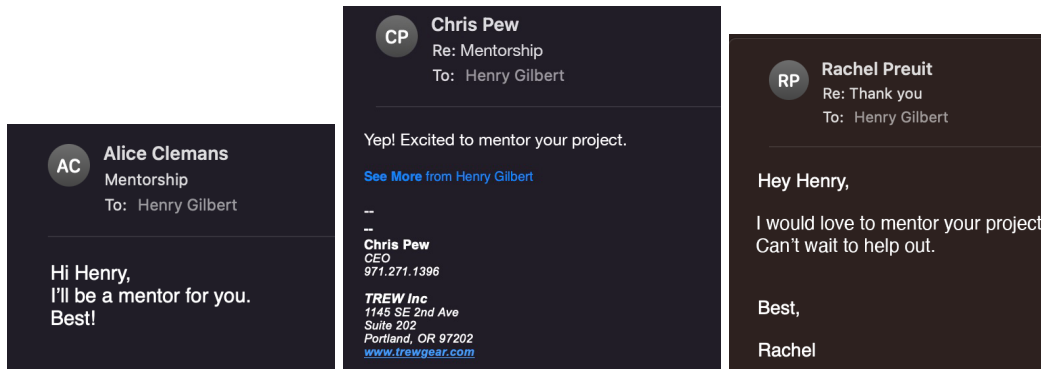
Chris founded and continues to direct TREW Gear, a ski and snowboard outerwear company in Portland, OR. Chris and I will meet once per month for one hour and he will provide expertise on branding, design, and consumer expectations in the ski outerwear space.

Rachel Preuit, Outerwear Developer, Black Diamond

Rachel is not only an incredible developer with a ton of experience with backcountry ski apparel, but also a tremendous skier herself. Rachel and I will meet once a month for an hour and she will provide feedback and guidance to ensure my project is appropriate and marketable for the target users.

Figure 49

Proof of Mentorship Emails



Final Designs

Line Plan

The Steller's Skiwear project features two garment collections: the Stormbird collection which is geared towards winter use, and the Bluebird collection which is geared towards spring skiing and warmer temperatures. Figure 50 shows these two collections

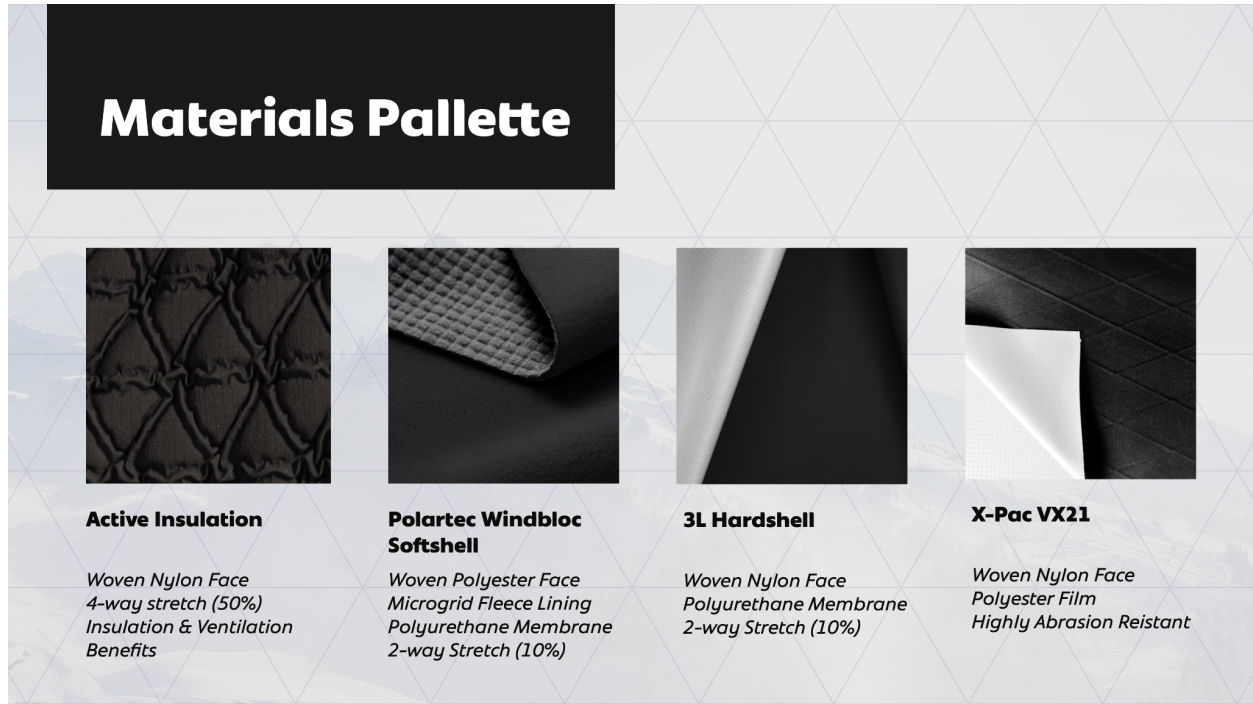
Figure 50

Line Plan



Materials Palette

In addition to Active Insulation, this project uses several other materials. Polartec Windbloc softshell fabric has a microgrid fleece lining, and is used for areas that need a soft next to skin feeling. A 3 layer hardshell fabric is used for areas that need a more durable fabric. And X-Pac is used for the kick panels of the pants for extra abrasion resistance.



Body Mapping

The next step was to consider the athlete needs in this sport. These considerations include sweat zones, regions of temperature sensitivity, areas where items like a climbing harness or backpack would be worn over the garments, areas with high abrasion, and areas where the athlete will need a lot of stretch. This information was used to map out where each material could provide the most benefit to the athlete. Figure 51 shows these regions of consideration.

Figure 51:



Trends

This project also integrated various industry trends into the design. These trends include a technically advanced aesthetic, blending style and function, design language that feels harmonious with the environment, and using the texture of active insulation to create a tactile connection between the user and their apparel.

Logos & Branding




Stellar's Jay

Stellar Adjective


- Of the stars
- Outstanding




Stormbird Jacket




Stormbird Jacket
Features and Benefits




Active INSULATION




Oversized Chest Pocket for Climbing Skins



Stretch-Tech Hood: Stretches to fit with or without a helmet




Articulated Fit for Extra Mobility




Pit Vents for Ventilation


Stormbird Pants




Stormbird Pants
Features and Benefits




Active INSULATION




Integrated Gaiters and Kick Panels



Quick-Access Snack Pocket



Beacon-Ready Pocket



Thigh Vents for Ventilation

Bluebird Vest

Bluebird Vest

Features and Benefits



Short Sleeves for
Extra Vitamin D



Fleece-Lined Hood for
All-Weather Comfort

Bluebird Pants

Bluebird Pants

Features and Benefits



Bottoms transition
from pants...



Into snow gaiters

Final Collection



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