EDNS 151 Design Report

5 Blue (BESTTEAM)

Liam Homburger
Calvin Tran
Catalina Cronin
Gautier Moreau
Sophia Giglio

Revised March 12th, 2023

EDNS151 Section L

Spring 2023

Dr. Allam

Table 1: Revision history

Revision	Date	Comments
New	February 1, 2023	Created
Rev - 2	February 7, 2023	• Added individual sections. • Added module 1 contents.
Rev – 3	February 10, 2023	• Minor typos and references
Future		•
Future		•
Future		•
Future		•

Contents

1.3. Introduction

1.3.1 Background

An avalanche occurs when a mass of snow, rock, ice, or soil slides swiftly down the face of a mountain. They are extremely lethal and are the cause of hundreds of deaths every year. According to the National Weather Service, an average of 6 people die each year in Colorado due to avalanches [1] and Colorado leads the nation in Avalanche related deaths since the 1950’s, having nearly double the number of fatalities every year compared to the second most (312 in Colorado vs 167 in Alaska) [2, fig. 1]. Avalanches are a threat to anyone who skis, snowboards, snowmobiles, or hikes in the winter, and despite mass efforts from state and federal agencies, avalanche deaths across the United States have hovered around 25 people per year [3]. There are four main branches of avalanche safety that professionals focus on improving to reduce annual avalanche fatalities: prevention, control, recovery, and information distribution. Many of the solutions that already exist in this realm are expensive, require training to operate, and are difficult to implement in remote areas.

Other control and mitigation efforts include providing avalanche forecasts, snow grooming, snow barriers, snow retention devices, mechanical/explosive intervention, ski cutting (causing small avalanches to prevent larger ones), and other less common practices.

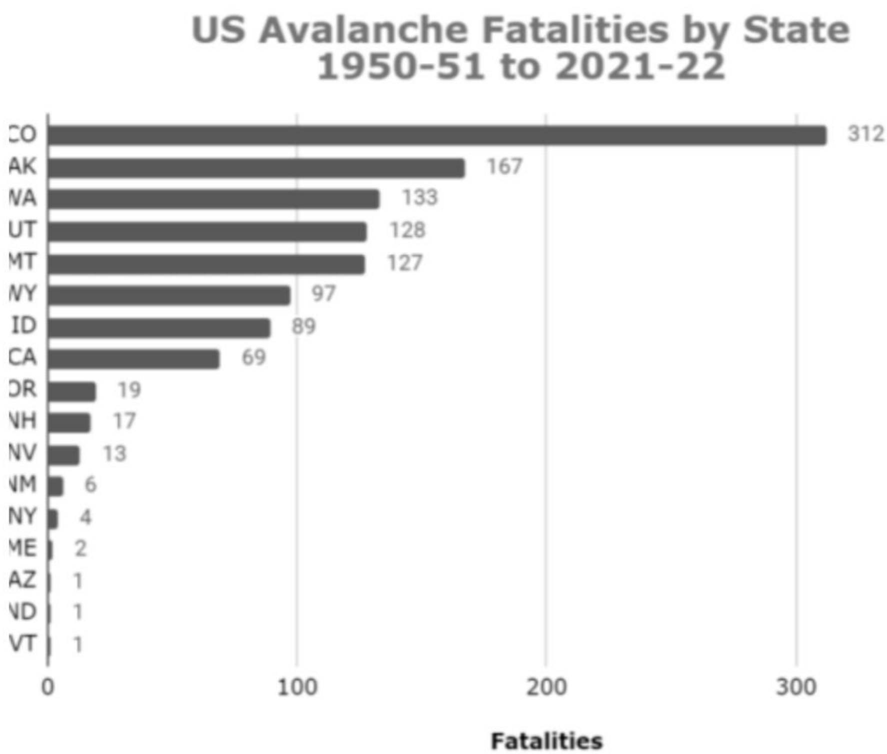


Figure 1. US Avalanche Fatalities by state [2]

1.3.2 Problem Definition

How can we aid avalanche-buried persons in the rescue process?

1.3.3 Context of the Problem

1.3.3.1 Source and Root of the Problem

Avalanche danger depends on weather conditions such as snowfall, temperature, and the surrounding environment. The most vital areas to protect are ones where mass amounts of people travel, such as mountain resorts and highways, but sometimes the most severe avalanches are in less visited places where state agencies do not check.

In addition to environmental concerns, there is an increased danger of avalanches wherever people recreate. Skiing, Snowboarding, Hiking and especially Snowmobiling are all common causes of human caused avalanches.

1.3.3.2 Key Stakeholders

1. Mountaineers – Skiers, Snowboarders, Snowmobilers, Cross Country Skiers, Hikers, etc.
2. Avalanche Forecasters and Snowpack Modelers
3. Equipment Manufacturers and Distributors
4. Search and Rescue Teams
5. Ski Patrol
6. Governments

1.3.3.3 Geographic Boundaries and Locale

1. Snowy, mountainous countries
2. Ski resorts
3. Snowy back country areas

1.3.4 Existing Solutions

Currently, the most successful method of recovery relies on a second person being present within the first 15 minutes of burial to recover the victim (figure 2). Examples of technology used are beacons, probes, and shovels. Beacons are radio broadcasting devices that operate at 457 kHz, the internationally adopted standard for avalanche beacons. These beacons allow party members and search teams to use receivers to find the victim under the snow of an avalanche, however they can be made useless if met with interference from cellphones, snow mobiles, and other electronics [5]. Probes are long rods used to find trapped Snowsports enjoyers before a shovel is used to rescue them from the snow [6]. Although basic, probes are easy to carry, but can be expensive. Then again, the cost to be without one could be far greater.

The time at which the victim is rescued in an avalanche is paramount. According to the Utah Avalanche Center, using current technology/methods, if recovered within the first 15 minutes, the chances of survival are about 92% and the odds of survival decrease to about 27% at 60 minutes post-burial [7, fig. 2]. Ill equipped Snowsports enjoyers could be ineffective in recovering avalanche victims, calling for the use of helicopters and search teams which cost the county money. This also puts others in danger for the survival of one.

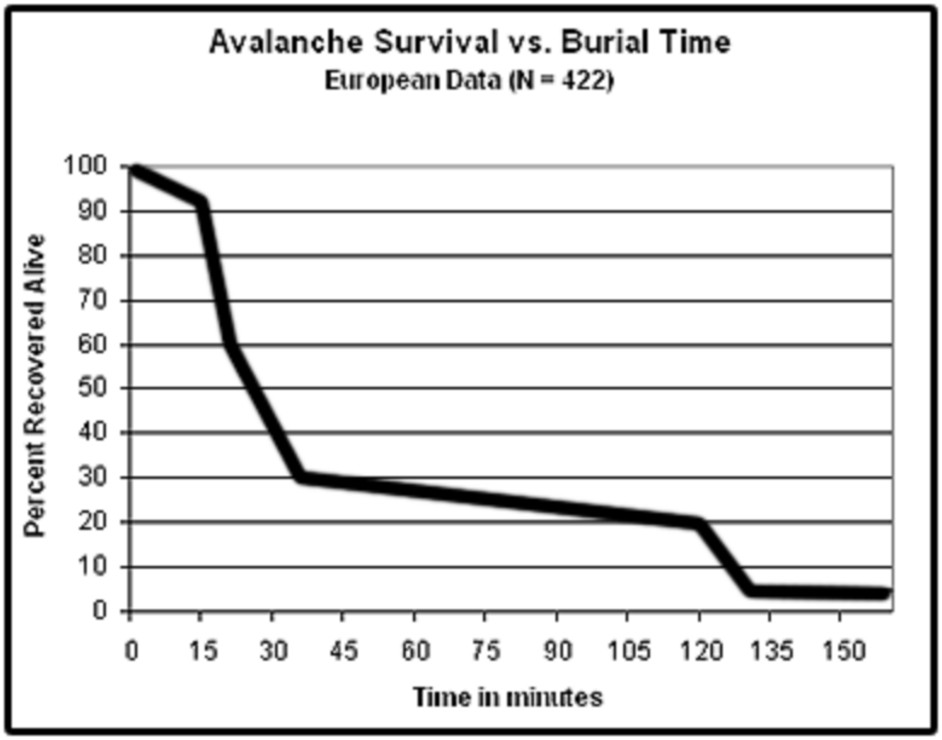


Figure 2. Avalanche survival vs burial time [7]

1.3.5 Ancillary Issues

The primary responsibility of avalanche safety lies with the mountaineers. State and federal agencies supply current data to help inform enthusiasts [8], but if they are unable to access/do not understand the data, they can put themselves in dangerous situations. Private companies provide a variety of avalanche safety equipment, but this can lead to a false sense of security, such as amateurs using apple air tags as beacons. It is important to have both good equipment and good training. Training is a non-technical policy issue, but equally important to the topic of avalanche safety as our technical solution.

1.4 Stakeholder Outreach

Table 1: Members and their Stakeholders

Liam	Calvin	Cat	Sophia	Gautier
x2 SME (Subject Matter Expert) talks (4)	SME talks (2)	x2-SME talks (4)	SME Talk (2)	SME Talk (2)
x1 Documentary (2)	CAIC Phone interview (2)	CAIC Phone Interview (2)	Documentary (2)	Arapahoe Search and Rescue in

				person Interview (3)
Phone Interview with Rep from backcountry.com (2)	**A-basin Search and Rescue In-person interview (5)**	**CDOT Phone Call (2)**	**Scholarly Article (1)**	**CAIC Phone Interview (2)**
Google Meets with CAIC (2)		**Scholarly Article (1)**	**Recreate conditions (3)**	**Recreate conditions (3)**
In person stakeholder interview (3)			**In-person stakeholder interview (3)**	

1.5 Stakeholder Outreach

1.5.1 – Liam Homburger

1.5.1.1 – Stakeholder Engagement

Backcountry.com Gear Representative

The first stakeholder I engaged with was a representative from the website backcountry.com [9], a winter gear store. Despite selling winter clothing, they also offer a robust catalog of avalanche protection equipment and have representatives that specialize in snow safety equipment. I sent a cold email and got a warm response where I talked with on the phone about the ins and outs of avalanche protection.

Some of the key takeaways I got from this conversation were that current avalanche protection equipment is focused on three areas: search and rescue, personal protection, and large-scale mitigation. Since backcountry.com only sold personal protection and basic search gear, I decided to narrow my questions to focus on those parts of avalanche safety.

Firstly, I learned that avalanche beacons use an internationally recognized frequency of 457 kHz. This low frequency allows beacons to penetrate snow and go long distances without disturbance [10]. One thing that the representative mentioned was how cell phones and other electronic signals can interfere with beacon signals and cause faulty reception of lifesaving signals.

Secondly, the rep talked about the modes of search: course search, fine search, and probing. When someone is lost in an avalanche, the first procedure is to do a course search. Because of possible interference from snowmobile electronics, this must be done on foot or skis, which puts the searcher at risk in the avalanche field (Figure 3 shows a searcher during “fine search”, locating a buried avalanche victim on a hillside). After they locate a signal, they change to fine search which adds an arrow vector pointing toward the beacon of the lost person. The searcher must traverse the avalanche field to find the person before probing down to locate them exactly.

Every step of this process is a risk and poses significant threats to the safety of the searcher. The snow can still be unstable after an avalanche, which may lead to more severe problems. It is safe to say many parts of the immediate search process are problems that can be solved with engineering solutions.

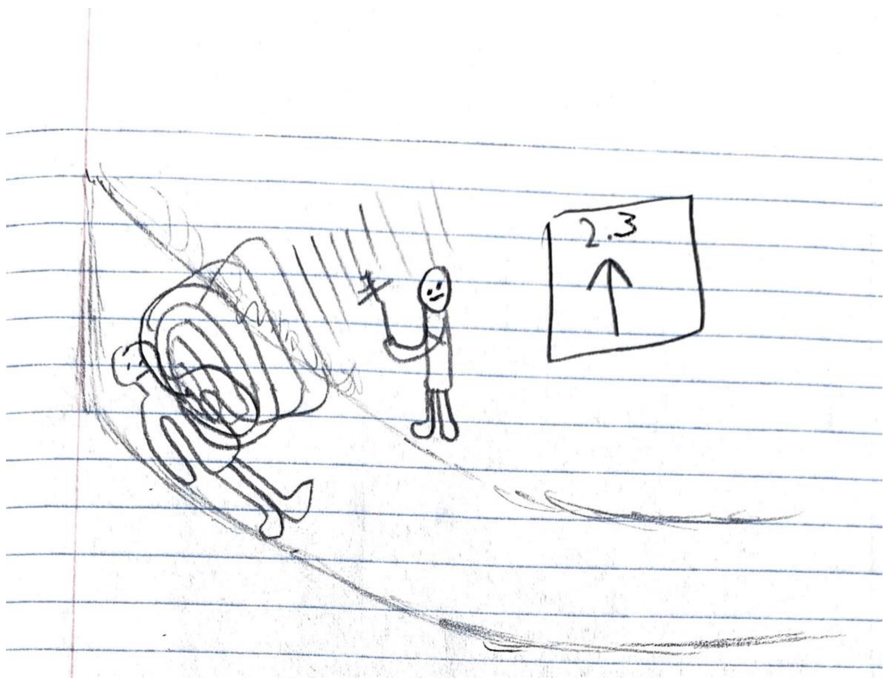


Figure 3: Searcher looking for an avalanche victim. Box shows beacon display.

Canadian Snow Wars Documentary

The second stakeholder engagement I did was watching a documentary [11] on avalanche mitigation in the Canadian Rockies. This documentary followed the lives of snow forecasters and army personnel who were tasked with keeping a stretch of highway open during the winter (Figure 4 shows a Canadian team shelling a mountainside to create controlled avalanches).

This documentary mostly focused on large-scale mitigation techniques and the technology used. One tool the forecasters use is an isolated mountaintop where they take samples of snow year-round, taking great care not to disturb the local snowpack. This is all done by employees of the Canadian government's park service. They do tasks such as cutting snow core samples, weighing sections of snow, and "slide" tests to see how prone the snowpack is to avalanches. If they determine it is high, they issue the order for the army to shell the mountainside as seen in figure 4 or use helicopters to drop explosives.

Some engineering problems I noticed in the documentary included nonautomated processes for sampling snow, informal and not strictly scientific tests for avalanche conditions (a snow forecaster would cut a large section of snow from the mountainside and jump on it with skis to see if it would slide), and the use of WW II technology that costs $250 a shell plus labor to eliminate threats of avalanches. In addition, they mentioned how costly it is to use a helicopter to drop ammonia nitrate explosives on snowpack. Lastly, there is always a danger to the fieldworkers when they are testing conditions on the side of avalanche-prone mountains.

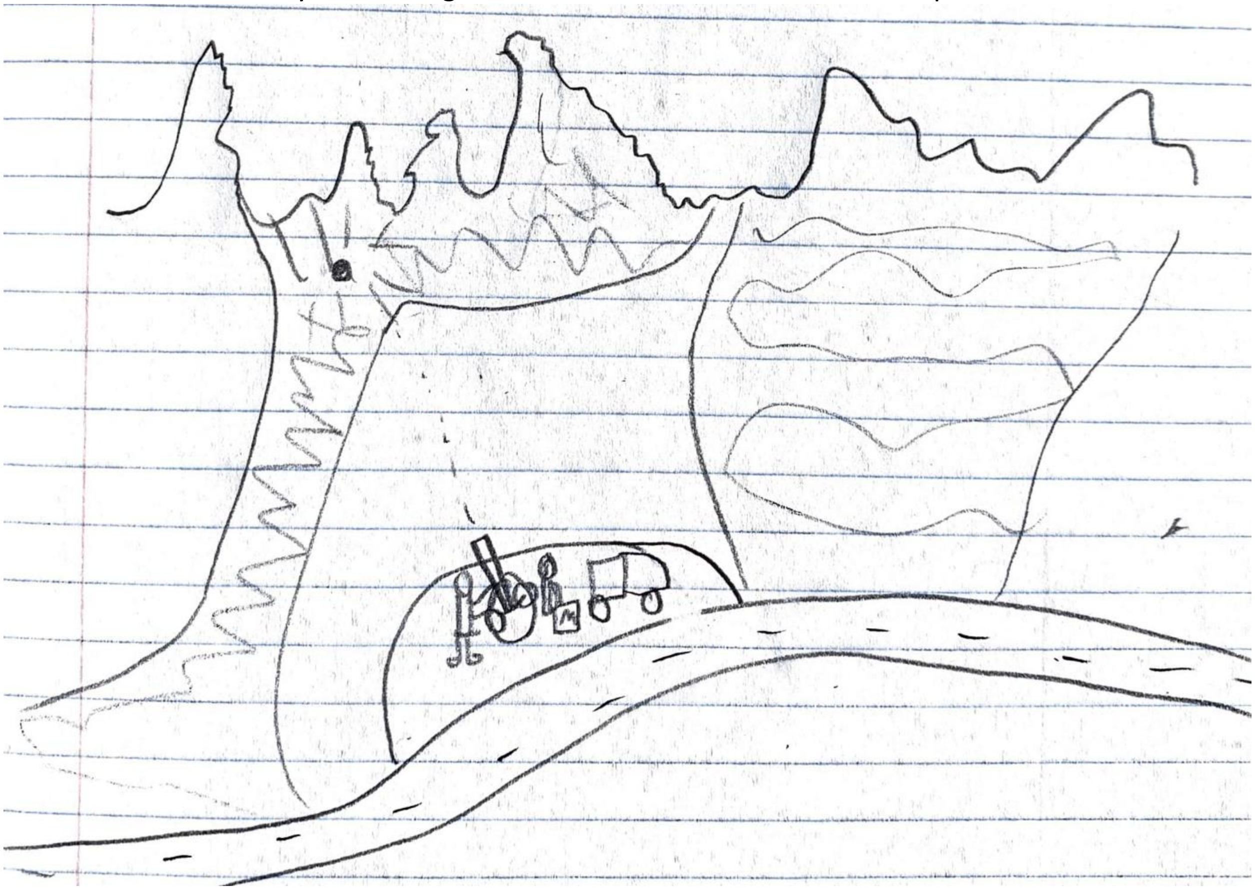


Figure 4: Canadian army using Howitzer cannon to cause controlled avalanches near a highway in a prebuilt artillery offshoot of the highway.

Colorado Avalanche Information Center

The third stakeholder engagement I did was with Jason Konigsberg of the Colorado Avalanche Information Center [12]. Jason is a forecaster working to compile the daily avalanche forecast for backcountry skiers. My initial line of questioning consisted of finding current problems/limitations with forecasting techniques/discovering what would be beneficial to have to make a more precise forecast.

According to Jason, weather data, including temperature, humidity, and wind speed/direction are vital to modeling snowpack. In addition, radiation measurement of snowpack was mentioned by Jason as a tool to make snowpack models. When asked about limitations in modeling the snowpack in the backcountry, Jason talked about how empirical data was vital, especially observations of previous backcountry avalanches along with slope face heading and location (Figure 5 shows a backcountry group reporting a recent avalanche in a valley).

We also asked Jason about search and rescue operations, including current beacon technology and how a general avalanche search works for a missing person. He mentioned current beacon technology is already quite good, and how most clothing manufactures are sewing in high strength radar reflectors for use with radar location systems like “Recco.” [13]

Figure 5: Backcountry group phoning in a report of a recent avalanche on an eastward facing slope. Sun is beating down towards the hillside creating dangerous conditions for future snowpack.

Chris Gueffroy Conversation

Lastly, I talked with a stakeholder on campus, Chris, an avid back country skier who also lives on my dorm floor [14]. In addition to back country snow sports, he mentioned his dad is a ski patroller, which adds a layer of depth to his knowledge. I first asked him about what he would want to see as a backcountry skier regarding personal safety equipment, and he answered cheaper, higher quality personal protection equipment. I also asked about his current beacon equipment, which he responded was suitable, but still had issues when near cell signals or other electronics. He also said the buttons on the beacon can get bumped while skiing and turn off the beacon. In addition to these problems, he showed me how expensive transceivers are [15]. One of the cheapest from amazon is nearly $300, a prohibitive cost for someone just starting a sport.

1.5.1.2 - Remaining Unknowns

Every stakeholder I engaged with echoed the same rhetoric regarding avalanche education. At the end of the day, they each explained or showed how a precise forecast is useless without comprehension. If backcountry mountaineers simply look at the color on the map without any of the supplementary details, they run the risk of putting themselves in dangerous situations that could have easily been prevented with proper education and guidance. This is inherently a non-technical problem that needs to be addressed with policy, and while there may be opportunities for technical delivery of educational materials in the future, it is not our intent to pursue this avenue.

Besides education, the challenges Jason brought up as an avalanche forecaster presented unique problems that could be solved with technical solutions, such as getting more accurate avalanche and snow data, making it easier to get empirical reports, and allowing snowpack forecasters to get data remotely/more efficiently. These are all remaining unknowns we may wish to pivot too.

It would be useful to know more about what government/private initiatives are in place to further research into avalanche safety. Agencies like the Colorado Avalanche Information Center (CAIC) focus on forecasting and distribution of information, but don't develop/fund modern technologies in the field of avalanche safety. Secondly, it would also be useful to know more about current avalanche education initiatives so our solution can integrate into current curricula. Lastly, we should do more research into the development of remote sensing. As mentioned by Jason of the CAIC, snowpack modeling is only as sophisticated as the data they receive. From talking with him further, our group recognized the need for more reliable and efficient data collection, especially in remote areas.

1.5.1.3 - Summary

Overall, through expert interviews, enthusiast conversations, documentaries, and parts of SME talks, I was able to piece together the challenges we face with avalanches, and parts of the industry that could be improved to serve the end goal, saving more lives. There are multiple deaths each year due to avalanches, and it is of top importance to tackle an issue that can prevent more deaths. Through understanding ancillary issues, such as the ones outlined above, we can get an even clearer picture of the situation to ensure our solution integrates flawlessly.

1.5.2 – Calvin Tran

Colorado Avalanche Information Center

Aside from the SME talks, my first stakeholder engagement was a phone interview with a CAIC (Colorado Avalanche Information Center) representative named Jason Konigsberg. As Liam's stakeholder engagement sections stated, Jason's primary role at CAIC is as an avalanche forecaster. Jason interprets recent temperature, wind, precipitation, and past avalanche data and compiles an avalanche forecast that lists danger levels depending on each region. The danger levels list the current danger level of a natural avalanche [Fig. 6] and the danger level of a human caused avalanche. Our questioning was focused on current forecasting techniques, his thoughts on the matter, and ways in which the team can improve upon the current methods. Although current professional forecasters can compile data and try to predict avalanche danger levels, observational data is necessary; it is vital to have a record of recent avalanches in the area and snowpack conditions. Most specifics are listed in Liam's section, but this interview was incredibly helpful in narrowing our problem's scope, it helped us to make our overly broad problem statement much more specific.

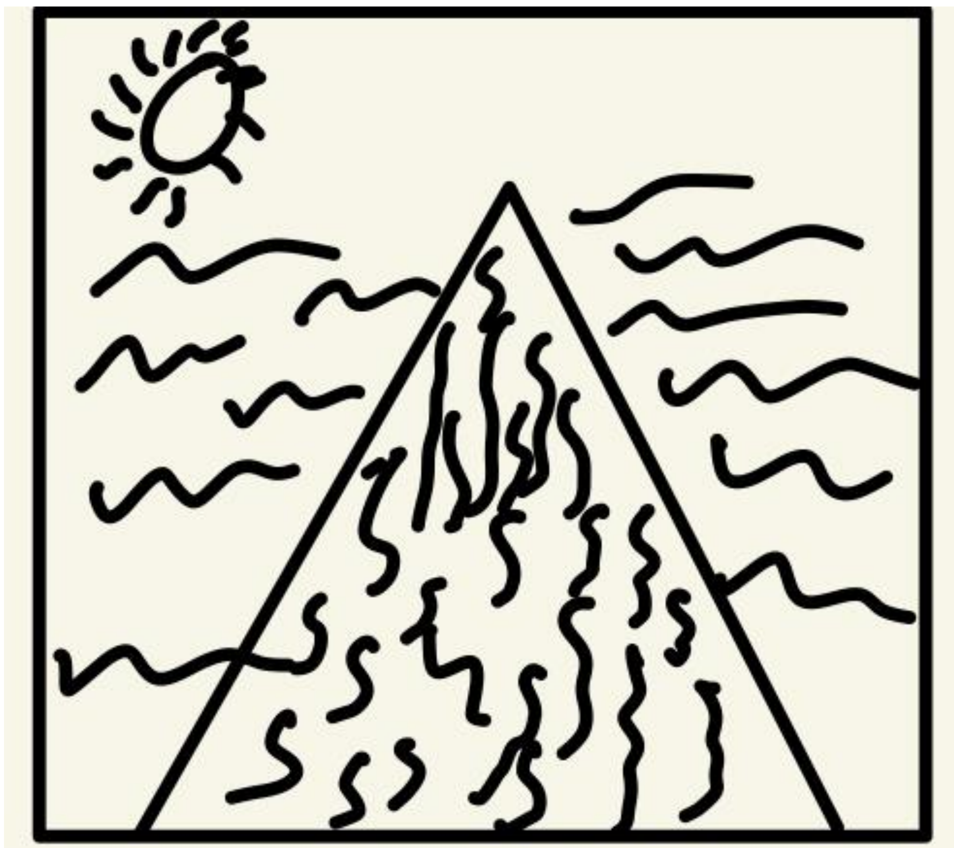


Figure 6: A natural avalanche occurring due to high wind conditions.

Arapahoe Basin Patrol Lead Interview

My next stakeholder engagement is an in-person site visit interview with Arapahoe Basin's Patrol Director, Ryan Evanczyk. Ryan has been in open communication with our team, but we have not yet met for the interview. The team plans on meeting in the coming week, sometime between February 13-16. I hope to question him about his thoughts on the current mitigation efforts, possible in-boundary avalanche recovery/mitigation systems, and his overall thoughts on pitfalls with current methods and technologies. This will also help to narrow my team's scope of understanding and allow us to dial in on the issue at hand. Figure 7 depicts a burial where a search and rescue team had put down probe lines to help find the buried victim to no avail.

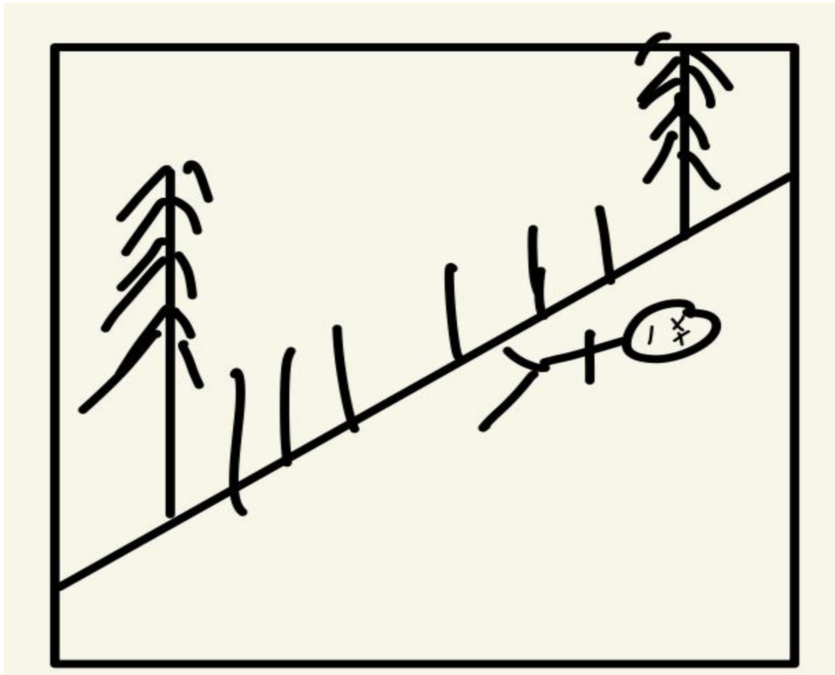


Figure 7: An avalanche burial with a probe line breaking the surface.

1.5.3 – Gautier Moreau

SME Talks

My first stakeholder engagement was with the SME talks. It allowed me to get a general understanding of what the common problems with water were. One common theme that I noticed was often brought up was waste of water. However, after discussing with my group, we decided that we wanted to go a more creative route and we settled on working on avalanche safety and mitigation.

Arapahoe Basin Search and Rescue Interview

My first stakeholder engagement regarding avalanche safety and mitigation was with one of my floormates, Jack Hickish, who is a member of the Arapahoe Search and Rescue team. The Search and Rescue (SAR) team is often one of the first responders when it comes to avalanche accidents, so it was immensely helpful and interesting to understand their point of view. During the interview, there were two main problems that were brought up. The first was the issue regarding the role of SAR in avalanche rescue. When a victim is caught and buried in an avalanche, they usually have a life expectancy of around 15 minutes. This is a problem as it is almost impossible for SAR to get to the zone of the accident within that frame. This means all the responsibilities of the avalanche rescue process rest on the victim's backcountry companions. The role of SAR is to aid these companions exiting the accident zone after they rescue the victim. The problem here is that unless the people at the scene of the accident are trained in avalanche rescue, the accident will result in a casualty.

The second problem that was brought up is in the actual rescue equipment. Avalanche rescue is done using a transceiver which is device that emits and detects radio waves to help a rescuer locate a victim under the snow [16]. Jack explained that the issue with current avalanche transceivers is that any device that has a battery placed too close can interfere with the signal emitted by the beacon. This can result in an inaccurate victim localization and failure to dig them out of the snow as shown in Figure 8. In today's day and age, everyone carries multiple devices with batteries in the backcountry. This is a severe problem that has resulted in multiple casualties in the past.

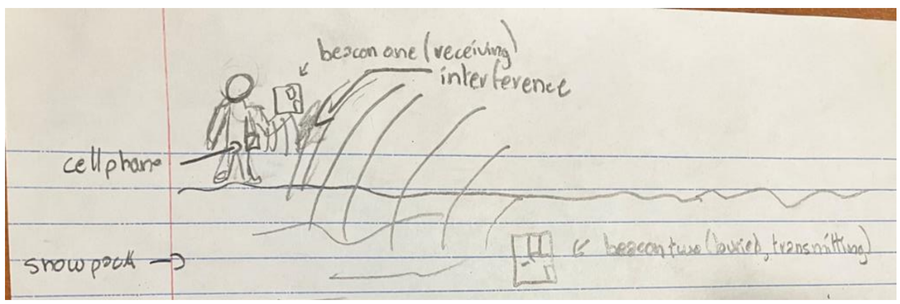


Figure 8: Battery Interference with Beacon

Equipment Investigation/Interaction

For my third stakeholder engagement, I decided that I wanted to gain a better understanding of the avalanche rescue process, to better understand what Jack and future stakeholders were discussing. I gathered some avalanche equipment including two beacons and went out to test them out. Something that struck me was how rudimentary some of the equipment was, such as a simple probe and shovel, as shown in Figure 9. As a backcountry skier myself, it never occurred to me how simple and old some of this equipment is. After some tests it became obvious to me that there were a few problems with the rescue process. One of them was, as mentioned by Jack, the interference of batteries with beacons. I could notice firsthand how much they blurred the signal and made it challenging to find the other beacon and I realized how much of a problem this would create in a critical rescue situation. This experience also helped me realize how hard it would be to rescue an avalanche victim without a beacon.

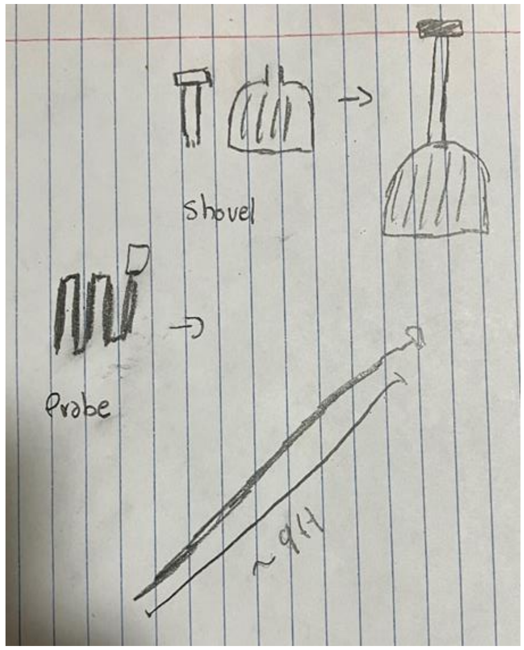


Figure 9: Avalanche beacon and probe

Colorado Avalanche Information Center

My last stakeholder engagement was an online interview with a representative of the Colorado Avalanche Information Center (CAIC). I wanted to understand what was done to protect backcountry users on a broader scale, not just at the individual level. The main thing I learned about was the lengthy and complicated process done to create an avalanche forecast. An avalanche forecast is a guide for backcountry users, explaining where avalanche activity is likely to happen to help them journey safely and avoid these areas. The main problem brought up is that to create a forecast, CAIC relies a lot on snowpack evaluation, which requires an employee to go into the field to conduct that themselves. There currently is not a way to do this remotely which means CAIC needs a lot of power to conduct avalanche forecasting for the entirety of Colorado. Although there are solutions that are being explored for the individual and at a global forecasting level, nothing concrete has been put in place yet.

1.5.4 – Sophia Giglio

1.5.4.1 – Stakeholder Engagement

SME Talk

I participated in an SME Talk which involved water waste in pipes and long-term solutions for water shortages in impoverished areas. The presentations were highly insightful, but they did not pertain to our topic, avalanches. They did, however, give a look into what the design process is like. The nontechnical issues proved to be a much greater obstacle than anticipated. There also seems to be an inevitability in problems occurring down the line. The pipes are bound to burst or fracture, despite all the effort to prevent that. The design process consists of many unseen and hidden aspects.

Buried: The 1982 Alpine Meadows Avalanche

I watched the 2022 documentary *Buried: The 1982 Alpine Meadows Avalanche* [19]. As someone with practically zero skiing experience, and not even growing in the vicinity of mountains, I have almost no perspective on our topic. This documentary showed the impact of an avalanche and the culture surrounding skiing. Skiers adore the mountains and will spend as much time as possible on the slopes. Unfortunately, this can lead to careless behavior, which may even lead to death.

The documentary introduced ways that avalanche control would prevent avalanches. There were explosions with gelatin dynamite. They also did ski-cutting, which is where ski patrol themselves would ski across fracture lines to try and trigger mini avalanches. Routinely, military artillery was used. Across Alpine Meadows, there were 300 possible avalanche starting zones that ski patrol would have to watch and activate when needed. They took great care of attempting to mitigate avalanches, but sometimes not even military-grade equipment can prevent such power.

I saw in the documentary that avalanches are powerful; much more than I had previously known. They not only just knock someone over, suffocating them, but they can destroy whole buildings. At Alpine Meadows, the Summit Terminal Building was decimated; the only part left was its frame [Figure 10]. An avalanche can throw a single person much further than from where they were last seen. This adds unpredictability of where a person could be.

Figure 10: The Summit Terminal Building after the avalanche

When searching for the eight missing persons, they used much of the same equipment we use today despite this happening 40 years ago. There were Skadi beacons and probes and a lot of digging. It took five days to find everyone, and only one survived. She survived because she was trapped in an air pocket between planks and lockers. The other seven were in the snow. Even just a few hours after the avalanche, the first body found was dead. If there is a chance of survival for someone entrapped in the snow, there must be immediate action and discovery.

In-person questioning

Nine out of ten avalanches are caused by the individual themself, so I thought that I should ask individuals what they do for avalanche preparation. Most of the answers were that they do nothing to prepare themselves, and that they would be helpless in such a situation. But these people constrain themselves to resorts where there is constant avalanche control and almost no need to be concerned. The select few that had any preparedness all were similar in that they carried equipment. Commonly on hand were beacons, probes, and collapsible shovels [Figure 11]. I further asked these people if there were any problems with this equipment. They stated that the beacons did not have much range and were not the most reliable. This led me to question how we could possibly improve beacons, or if there was a way to have a more effective signal sending device.

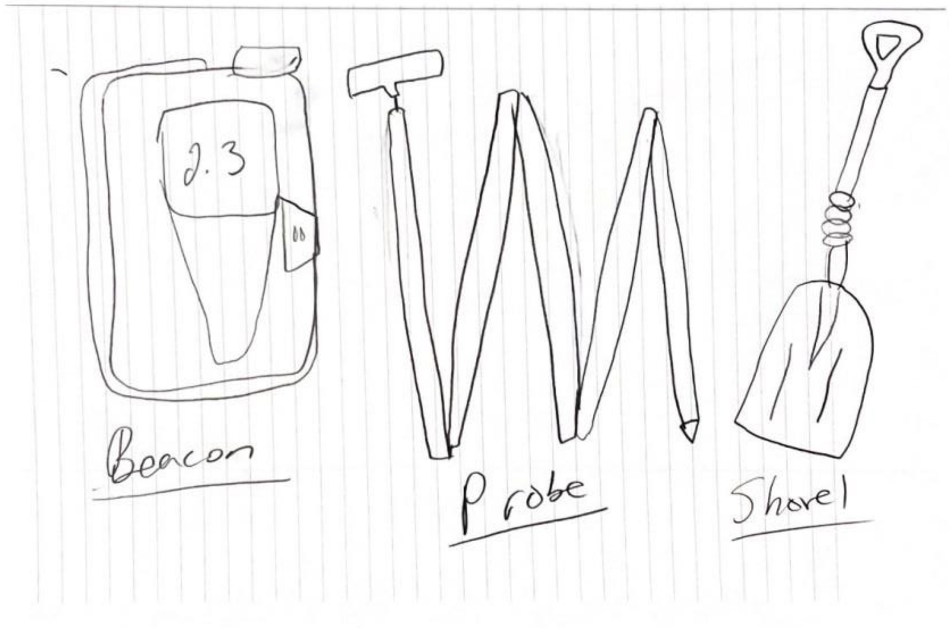


Figure 11: Avalanche Equipment

1.5.4.2 - Remaining Unknowns

The documentary showed what a rescue search was like 40 years ago, but I need to research what one is like today. There is similar equipment, but what technological improvements are there today that would have made the Alpine Meadows search last however much shorter? I also want some firsthand experience at a ski resort to simply witness the setting of an avalanche scenario.

1.5.4.3 - Summary

Overall, I feel like I have expanded my horizons in the world of mountain life. The documentary was incredibly eye-opening and gave me a perspective on what ski patrol goes through. Stakeholder engagement has already led me to brainstorm possible ideas.

1.5.5 – Catalina Cronin

1.5.5.1 – Stakeholder Engagement

Beyond my attendance of two of the Subject Matter Expert talks, my first stakeholder interaction was reaching out and contacting the Colorado Avalanche Information Center (CAIC) [12]. As the main source of updated and current avalanche conditions in Colorado, we hoped to gain more insight into the effort and steps required to accurately forecast and monitor the avalanche prone landscape of the Rocky Mountains. We were directed to Jason Konigsberg, a forecaster at CAIC working on their daily avalanche forecasts. He gladly answered our questions about how the forecasts were created and their limitations as well as general search and rescue operations.

Using environmental variables such as temperature, wind, and humidity, CAIC can use snowpack models to evaluate the risk of avalanches in a general area. The main limitation of CAIC models is that the data required to increase accuracy of the models is exceedingly difficult to obtain and is often submitted by recreational enjoyers of the backcountry.

Jason's insight helped us to identify a possible corner in which we could look for a more specific problem definition. Talking to a representative from CAIC has made me more aware of the several factors that contribute to go into avalanche forecasts and general avalanche information, which will hopefully help us to take another perspective into account in our solution.

My second stakeholder interaction involved Region 3 of The Colorado Department of Transportation (CDOT), which I called. The only available phone number led me to a customer service representative who informed me about CORA, the Colorado Open Records Act, and how to access CORA documents from CDOT. Additionally, my phone number was passed on to the engineers at CDOT and I later received a message with the phone number of the Winter Operations Manager. Unfortunately, however, my attempts at contacting Jamie Yount were unsuccessful.

My third stakeholder outreach is a scholarly article detailing a survey of backcountry travelers regarding their choice of avalanche safety gear and levels of avalanche training if any. This report additionally focused on the frequency of advanced avalanche gear such as artificial breathing devices (Avalung) [Figure 12] and avalanche air bags [Figure 13], as well as the perceived effectiveness of these safety options.

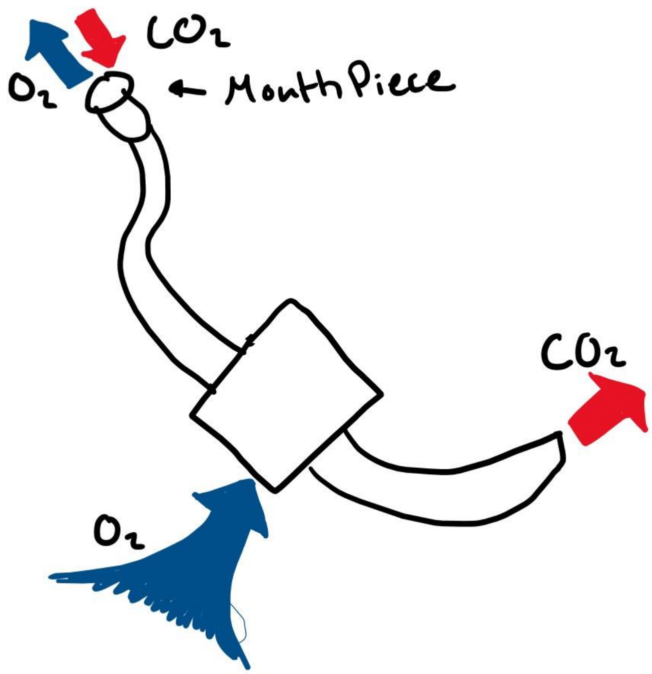


Figure 12: Basic Function of An Avalung

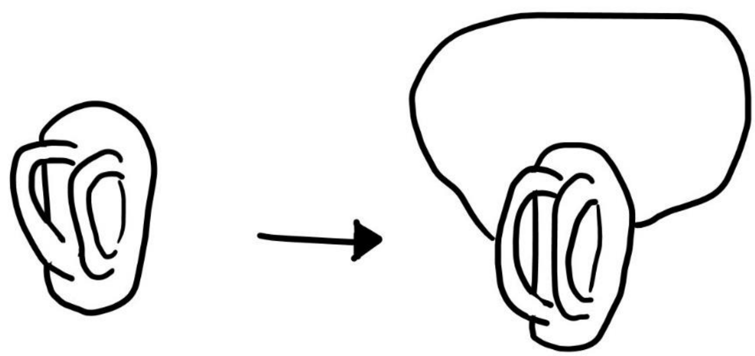


Figure 13: Expansion of An Avalanche Air Bag

The most impactful information I got out of this report was that Skiers/snowboarders are most likely out of all backcountry activities to have attended a safety course and often have standard safety equipment with them. A skier and snowboarder myself, when thinking about backcountry activities other activities tend to be of less obvious concern, however, this article highlighted that activities such as snowshoeing and snowmobiling are at higher risk of injury and death if caught in an avalanche because of lower rates of safety equipment and avalanche safety education [18]. Ultimately, this article opened my perspective to other core stakeholders in avalanche safety and allows me to create a more effective solution through considering the variable requirements of different backcountry sports.

My fourth stakeholder interaction is planned to be an in-person interview with Ryan Evanczyk, the Patrol Director of Arapahoe Basin (ski resort). Avalanche safety and the approaches to it can vary greatly between in bound or resort skiing and out of bounds, backcountry travel. Talking with Ryan Will hopefully allow us to understand these differences better and be able to take another perspective into account when continuing the narrowing of our problem statement and solution development.

1.5.5.2 – Remaining Unknowns

A prominent remaining unknown is how the partially non-technical issues of education and monetary barriers to high quality equipment contribute to the danger of avalanches. These are not necessarily issues or problems that we can tackle with engineering/ technical solutions, however, they will be important to consider accurately if we want to make a solution that is better and for more people.

1.5.5.3 – Summary

From my stakeholder engagement I was able to broaden my understanding of who the core stakeholders in our problem are and several examples of current limitations of technology that make avalanches a continuous hazard for many recreational and professional backcountry travelers.

2.0 Module 2

2.1 Affected Stakeholders and Existing Alternative Solutions

Our primary stakeholders are backcountry skiers, and more specifically, avalanche victims. Our solution's primary objectives are to either 1) Help inform skiers about snow conditions and avalanche probability levels or 2) Improve the chances of survival post-burial. Existing solutions to the core problem of death by avalanche include avalanche forecasting, beacons, probes, shovels, airbags, and more. While these solutions can be successful, they are only effective with training and precise use. Beacons, probes, and shovels are all used in tandem to locate and dig out buried victims, but that's assuming the victim is not alone, and that no other party members were buried in the same avalanche. Airbags are helpful to decrease your body's overall density and help you float, but about 20% of avalanche victims with an airbag are still critically buried. Therefore, a need to create a new, innovative solution exists.

Since each stakeholder the team is working for, skiers, snowboarders, snowmobilers, etc., all use the same avalanche protection equipment, there is a real opportunity to improve the functionality of one part of the avalanche recovery process and save many lives. People of all cultures and demographics are victims of avalanches, and inventing a solution for all of them is within the realm of possibility.

2.2 Requirements, Customer Needs, and Technical Specifications

Across the stakeholders the team spoke to, a prevailing theme emerged. Every stakeholder talked about how time is critical when conducting an avalanche rescue. This was validated by the Utah Avalanche Center, indicating that the chance of survival greatly decreases after 30 minutes of being buried. This led us to consider the conditions faced by victims while buried. Oxygen deprivation was one of the most important problems to tackle.

Airbags are already on the market, but could an airbag also provide a critical supply of oxygen for the trapped victim? The team believes the answer to our customers' needs is an airbag that both lowers the density of the victim, but also provides oxygen to the victim while trapped under the ice. Table 2 describes our qualitative goals.

Table 2: Specifications

Specification	Value	Notes
Weight	< 10 kg	Stakeholders emphasized weight in the backcountry is critical to get low
Size	Fitting to everyone	
Air	>15 minutes	>15 min extra time
Cost	Retail for less than $500	
Failure Rate	Minimal failure rate	
Satisfy Stakeholders	Does not detract from back country recreation	

2.3 Individual Looks Like Prototypes

2.3.1.1 Prototype Description – Snow Scout by Liam Homburger

The Snow Scout is an all-encompassing solution to many common problems in the back country. It primarily serves as a weather station on the ground, relaying data to relevant state agencies like the CAIC. According to Jason Konigsberg, weather forecaster of the CAIC, the most problematic part of the process of predicting avalanche conditions in input data [12]. While not directly his subject expertise, he mentioned that snowpack models are already very advanced, and forecasters are very capable of precision forecasting, however the CAIC lacks the data to make an advanced model. The snow scout contains an array of sensors such as a barometer, thermistor, and wind gauge, as well as a variety of snow sensors, primarily a snow level sensor on the supporting pole that allow it to make accurate measurements of the day to day, hour to hour, and even second to second snow levels. Furthermore, the mechanism of the snow level sensor is accompanied by a capacitive density sensor, which uses the variable dielectric effects of snow to calculate the density of different layers, invaluable data for snowpack modelers.

Once measured, this data is relayed through the iridium satellite network to a database where it is compiled for use by forecasters and modelers.

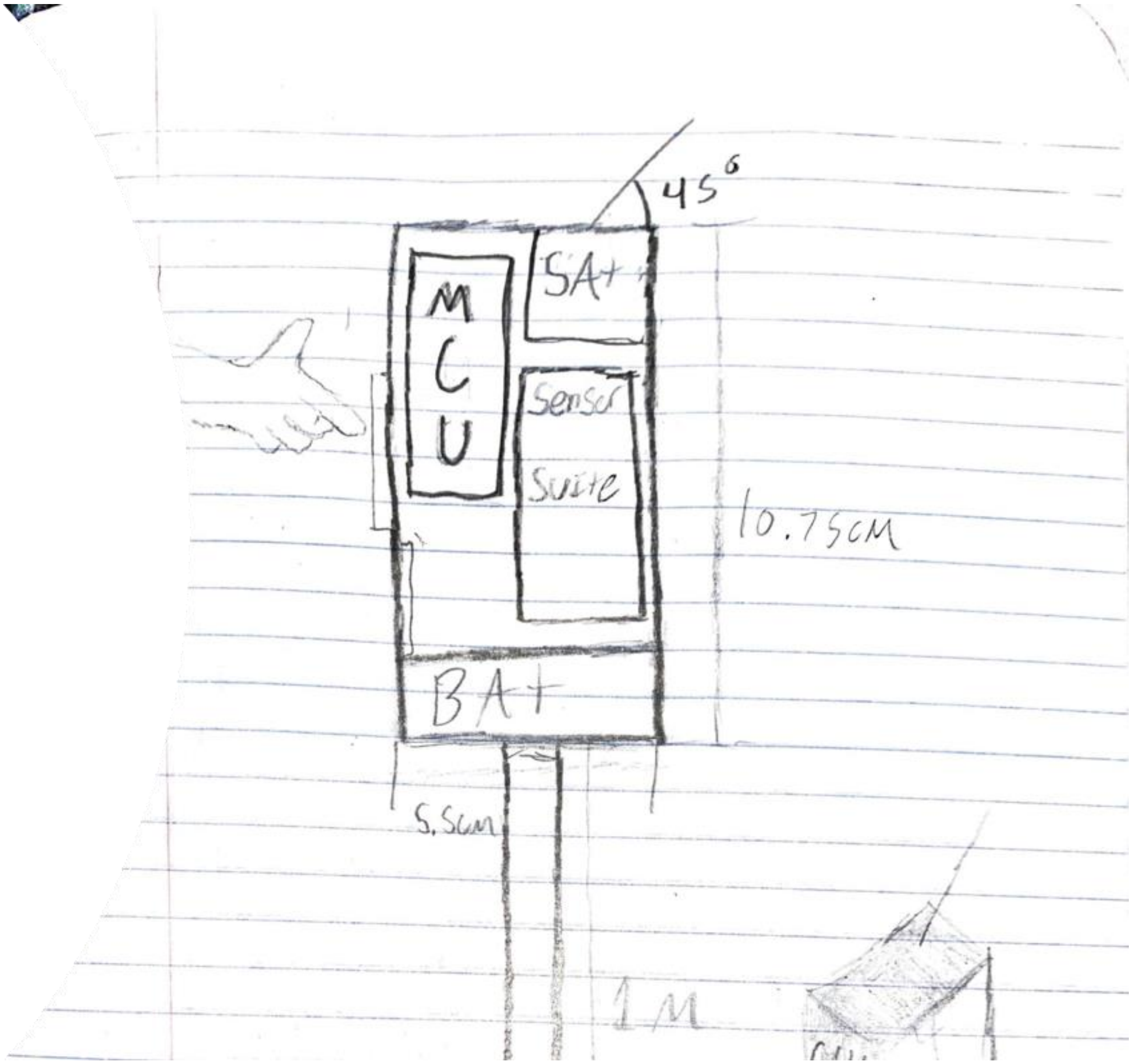
The Snow Scout also contains a camera used to record empirical data. Mr. Konigsberg talked about how empirical data is some of the most valuable for forecasting, especially reports of recent avalanches, so the snow scout contains a camera which can take hourly pictures of avalanche prone faces and send them back to analysts for use.

Lastly, the Snow Scout contains an emergency call button that alerts the county search and rescue team through iridium. It also increases the frequency of the camera which sends more photos of the situation to a search team. Since each station is placed accurately by installation teams, no GPS module is needed to locate the Scout. (Position of button visible in figure 14)

The Snow Scout is designed for power efficiency and minimal maintenance. It uses Lithium Iron Phosphate batteries which are suited for the cold. It also contains a solar panel for continuous power during the day when the camera, one of the most “power hungry” module is active. In the event of an emergency where the battery is unexpectable drained, a microUSB and apple Lightning port are attached to allow users to use their phone battery to power the call button and iridium modem. (Shown in figure 15)

Overall, the snow scout provides valuable weather data to forecasters and modelers and is a lifeline for anyone in distress in the backcountry.

2.3.1.2 Sketch



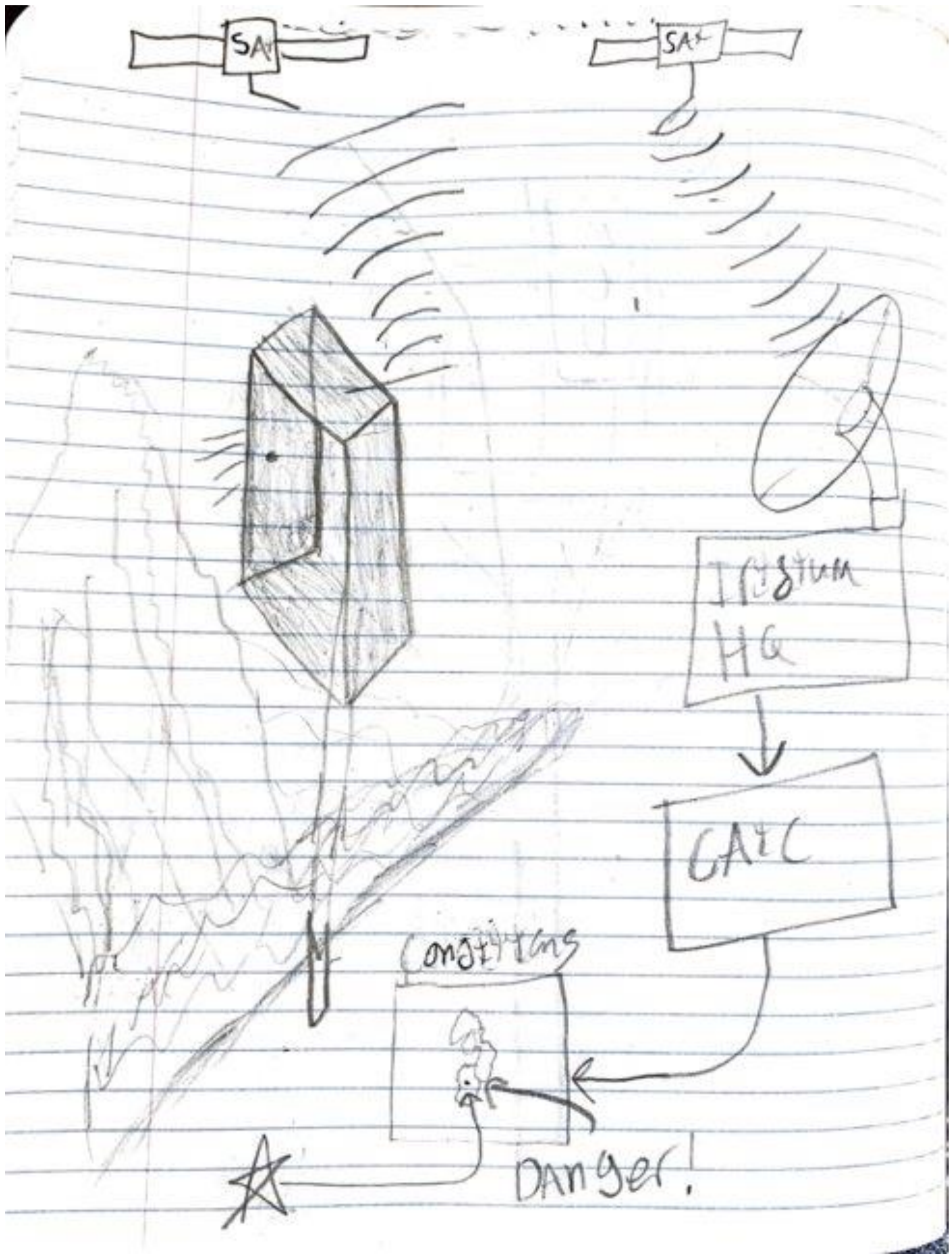


Figure 14 and 15: Above: Technical sketch of the snow scout with a user interacting with the call button. Below: The snow scout transmitting an image of a recent avalanche over iridium to the CAIC where it gets processed into the forecast.

2.3.1.3 – Photos

Figures 16 and 17: Front view of the Snow Scout showing the battery, MCU, Iridium Modem and Housing. Below: Isometric view of antenna and call button.

2.3.1.4 - Summary

This project amalgamates multiple problems the team originally identified while staying true to our final problem definition. With the widespread adoption of the Scout, no part of the backcountry would truly be remote. A Scout in avalanche prone areas means in the event of a disaster, any party members could call for help regardless of cell signal. The precise mapping of the scouts means S&R teams could easily locate the victims, reducing burial time.

The Scout also provides vital data to forecasters in the hope that a more accurate forecast means there would be less of a need for victim survivability technology in the first place.

2.3.2.1 Prototype description – Handheld Snowpack Monitor – Cat Cronin

This solution is designed to be a portable device that allows back country travelers to monitor the real time condition and risk level of a body of snowpack. By pointing this device at the snowpack [as seen in figure 18], the device would be able to use different methods of data collection to determine the stability of the snowpack and the risk of triggering an avalanche if it were to be disturbed by a person. The device is designed to be easily portable, with a long-lasting rechargeable battery as well as bright accent colors and an adjustable strap to prevent it from getting lost [Seen in fig. 19, 20].

It allows an objective source of risk judgement to be brought into the backcountry and would be incredibly easy to use with an interactive screen and basic functions. Currently most risk assessments are done by an individual with basic safety gear such as a shovel making them an easily skippable precaution that is dependent on the knowledge and experience of the person conducting the test. This device aims to make acquiring information about a slope and section of snowpack easier and more reliable allowing backcountry travelers to make the best decisions and more objective risk assessments in their activities.

2.3.2.2 Field Sketch

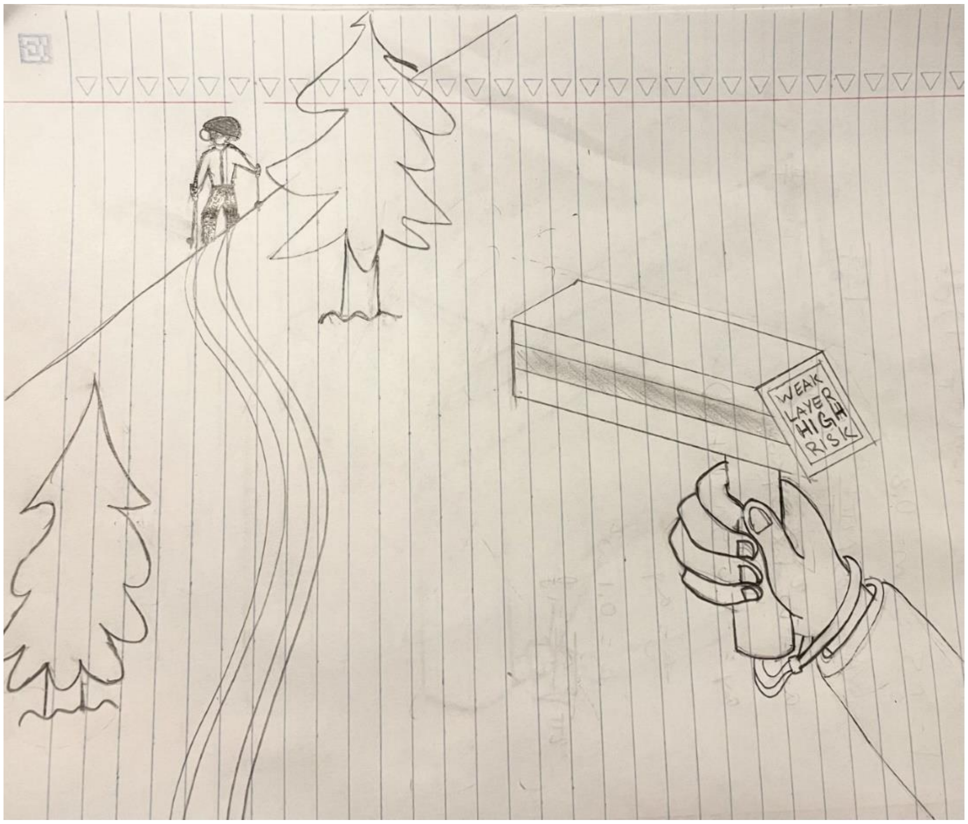


Figure 18: Sketch of Snowpack Monitor Usage

2.3.2.3 Looks-like Photos

Figure 19: Outside view of Handheld Snowpack Monitor

Figure 20: Inside View of Handheld Snowpack Monitor

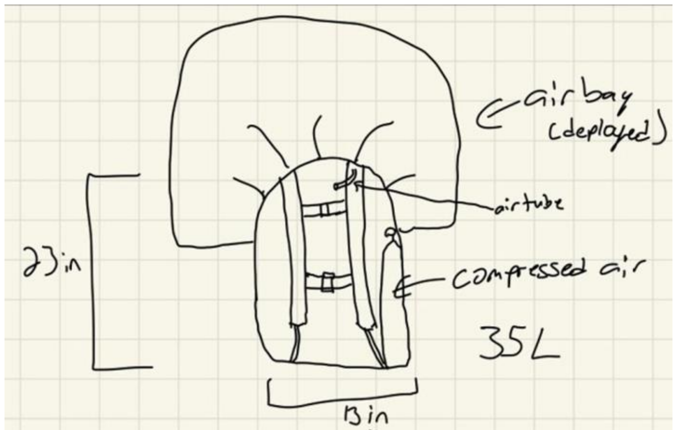
2.3.2.4 Summary

This solution addresses the issue of information at the individual level, providing users with a reliable way to acquire the information they need about the snowpack to make the best decisions in each circumstance. A handheld snowpack monitor would be a preventative measure to help ensure that fewer people get caught and buried in avalanches. It focuses on providing backcountry travelers with another tool to prevent the triggering of dangerous avalanches rather than seeking to improve their safety and chances of survival when caught in an avalanche.

2.3.3.1 Prototype description – The AirShield – Calvin Tran

The idea behind this solution was to expand upon the already existing avalanche airbag. The modern airbag device is essentially a backpack with a compressed air canister attached to an airbag that you would trigger in the case of an avalanche. It essentially works by decreasing the density of your body before you're buried, and therefore if you're when the snow settles, you will be higher up, and therefore have less snow weighing on top of you and be easier to dig out. In addition to that function, the airbag also offers protection from blunt force trauma. The AirShield [fig. 21, 22] expands upon this idea by recycling the air from the airbag and essentially creating an environment where you can breathe and reduce the likelihood of dying of suffocation before you are recovered.

2.3.3.2 Field Sketch



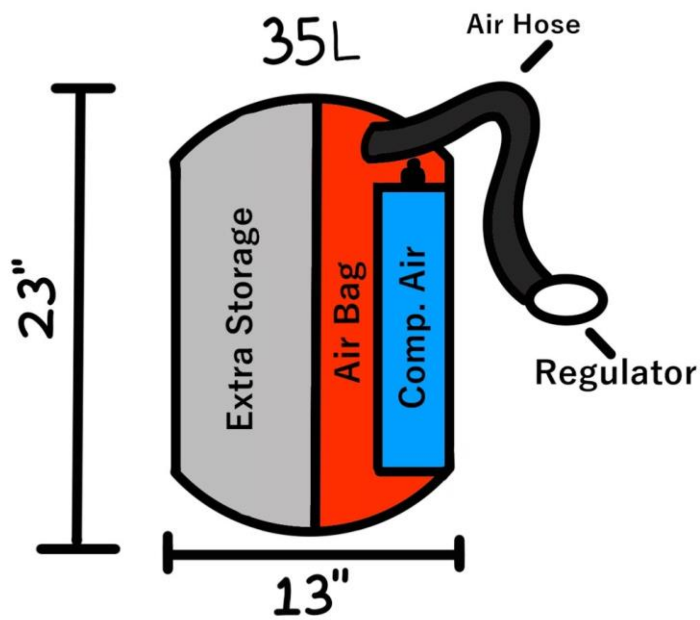


Figure 21 and 22

2.3.3.3 Looks-like Photos

Figure 23

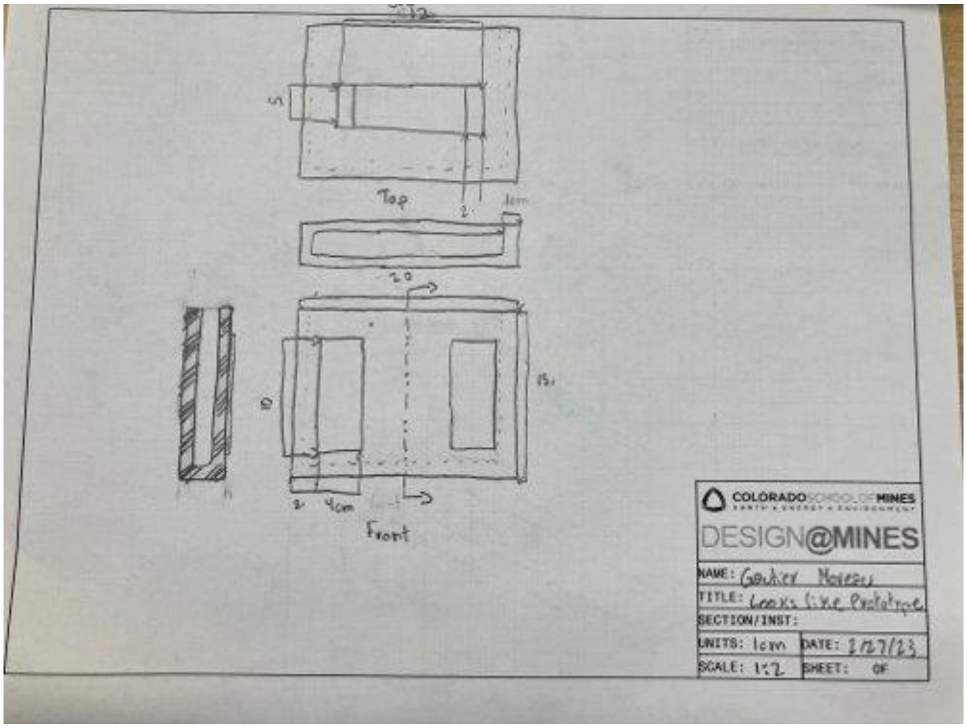
2.3.3.4 Summary

The AirShield is a personal safety device that incorporates both an airbag and the storage of air to be used as a breathing device into a backpack for backcountry skiers and mountaineers. The Airshield would help bridge the effectiveness gap of a traditional airbag and provide protection to the ~20% airbag users who are still critically buried even after deploying the airbag. At its core, this device is aimed at extending the recovery window of buried victims.

2.3.4.1 Prototype description - Isolating Pouch – Gautier Moreau

This prototype is designed to be a portable solution to the problem of EM wave interference in the avalanche rescue process. This device is essentially a simple carrying pouch that is lined with an EM wave absorbing material, such as carbon nanotubes which absorb radio waves [20]. The pouch is designed to hold common electronic items that a backcountry skier would carry, such as a phone and earbuds. When placed in the pouch, these items which usually create interference with avalanche beacons used in the rescue process, would be harmless. This would allow for more precise pinpointing of buried victims when using a beacon to locate them.

2.3.4.2 Field Sketch



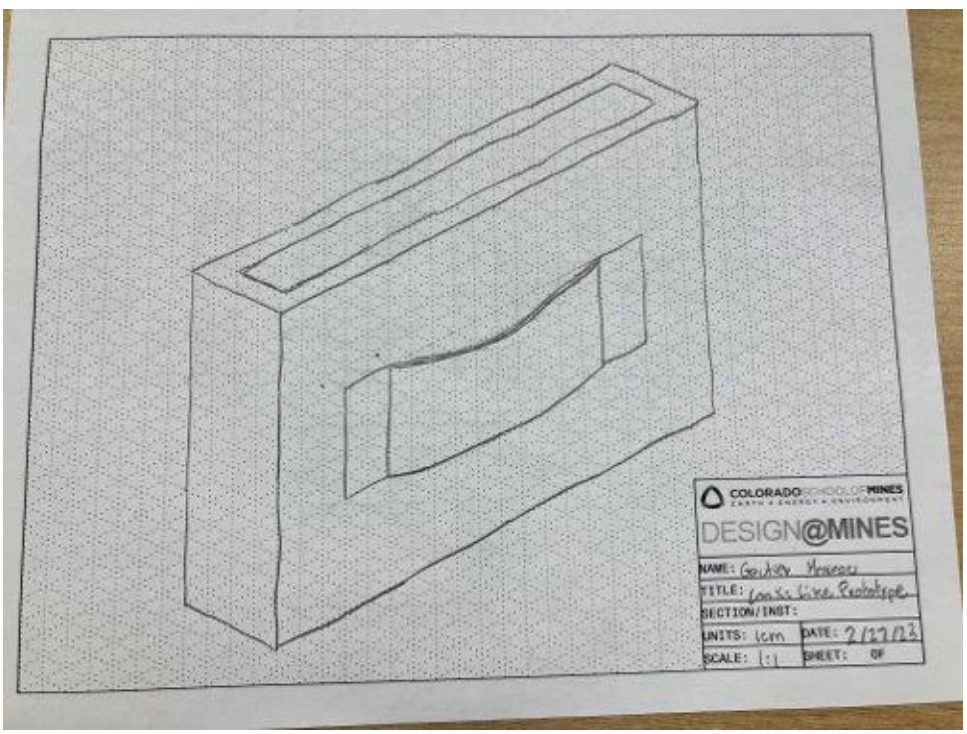


Figure 24 and Figure 25

2.3.4.3 Looks-like Photos

Figure 26

2.3.4.4 Summary

This solution addresses the issue of obstacles in the rescue process. During an avalanche accident, rescue must happen quickly to avoid fatality due to suffocation. This device specifically addresses the issue of pinpointing the buried victim in the least amount of time possible. It does so by making sure that the primary tool for this part of the rescue process, the beacon, is as effective as possible. This is done by blocking any possible interference being created by devices which contain a battery, such as a smartphone, ensuring a smooth and fast recovery process.

2.3.5.1 Prototype Description Reverse Probe by Sophia Giglio

The Reverse Probe is designed as the inverse to the already existing avalanche probes. As opposed to an avalanche probe – which is poked in the snow after an avalanche to find victims – the Reverse Probe pokes out of the snow. The probe can be placed in a backpack and will be lightweight so it will not cause any discomfort to the mountaineer. There would be pressure detectors on all six sides of a box, and when a significant amount of snow is detected, a probe will shoot out, penetrating through layers of fabric, dirt, and/or snow as seen in Figure 32. This aspect will make it much easier to find and pinpoint the location of a victim. Once activated, a signal like that of an existing avalanche beacon will be sent out, notifying party members or search teams of the person's location.

A problem that arises with this design is what if the person just happens to trip and fall, triggering a pressure detector. Or a person could be on top of the Reverse Probe in an avalanche. In either case, there will be a sensor on the end of the probe that can detect skin and will not harm the mountaineer. This situation does nullify the novelty of this solution in an avalanche, reducing it to simply an avalanche beacon. Also, if the backpack or box is lost, it can send rescuers in a different direction, away from where the victim is.

2.3.5.2 Sketch

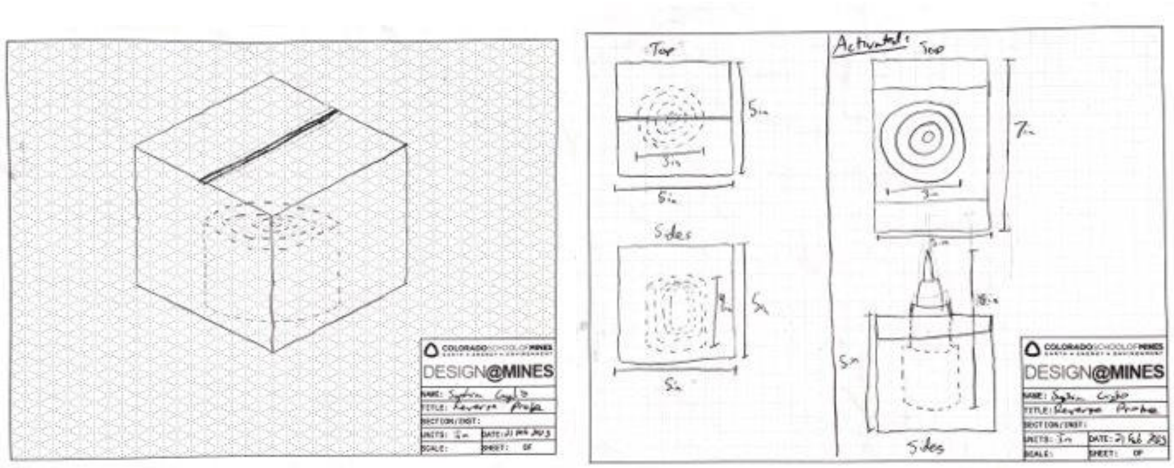


Figure 27 And Figure 28: The Reverse Probe in its box

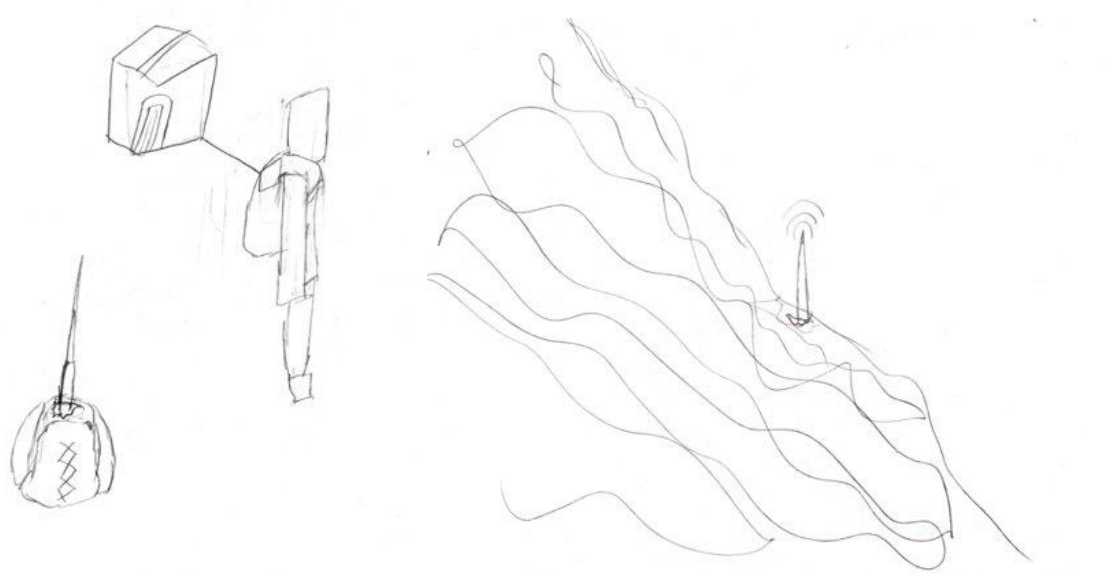


Figure 29 And Figure 30: The Reverse Probe in the backpack and activated in an avalanche.

2.3.5.3 Photos

Figure 31: Looks-Like Prototype of the Reverse Probe

2.3.5.4 Summary

Overall, the Reverse Probe is a unique idea but may not be the most realistic solution. It would be effective in finding a person buried under the snow, if circumstances and luck were in play, such as the person fell correctly, which cannot be counted on. There are too many problems that could easily arise and potentially cause more harm. Therefore, the Reverse Probe is not a viable solution for aid in avalanche rescue.

2.4 Concepts Considered and Decision Process

Our team considered a variety of practical solutions to our problem including information collection on both a large and individual scale, improving the odds of survival of a backcountry skier, and in particular, an avalanche victim and extending the amount of time available to rescue the victim. Using a decision matrix, as seen in fig. 32 we numerically scored our prototypes using feasibility, viability, desirability, interest, practicality, sustainability, and safety as our main criteria (weighted as seen in fig. 32 to come up with a ranking.) [Appendix IV] Using the results of our decision matrix as a skeleton, the team approached our possible designs again but intending to choose one winner. After talking through our personal preferences, we found that they lined up perfectly with the numerical analysis of the decision matrix leaving us with an undisputed winner, the oxygen tank and airbag, or AirShield.

Factor	Weight	Remote Sensing Stations	Isolating Pouch	Handheld Snowpack Monitor	Backpack Reverse Probe	Oxygen Tank and Airbag
Feasability	1.5	2.5	4	3	3.5	4
Viability	1.5	4	3	4	2.5	4.5
Desirability	1	4.5	3	4	2.5	4.5
Interesting	1	3.5	2	3.5	4	4
Practicality	1.5	2.5	4	4	3.5	3
Sustainability	1	3	4	3	3	3.5
Safety	2	5	4	4	3.5	4.5
Totals		34.5	33.5	35	30.75	38.25

Figure 32: Prototype Design Matrix with conditional formatting

2.5 Final Design

For our final design, we decided to go with the AirShield. The AirShield is a solution to two different problems we noticed while conducting stakeholder research. Firstly, it includes the functionality of an avalanche airbag, a device that lowers the density of the victim, in turn helping them “float”. Secondly, in the event the victim is buried in the snow, it uses the oxygen in the airbags to provide a lifeline to the victim. Through a scuba-like hose on the chest, the victim can breathe oxygen from the airbags, which have already served their purpose. This oxygen is intended to extend the time the victim can remain trapped, increasing the likelihood they will be rescued alive.

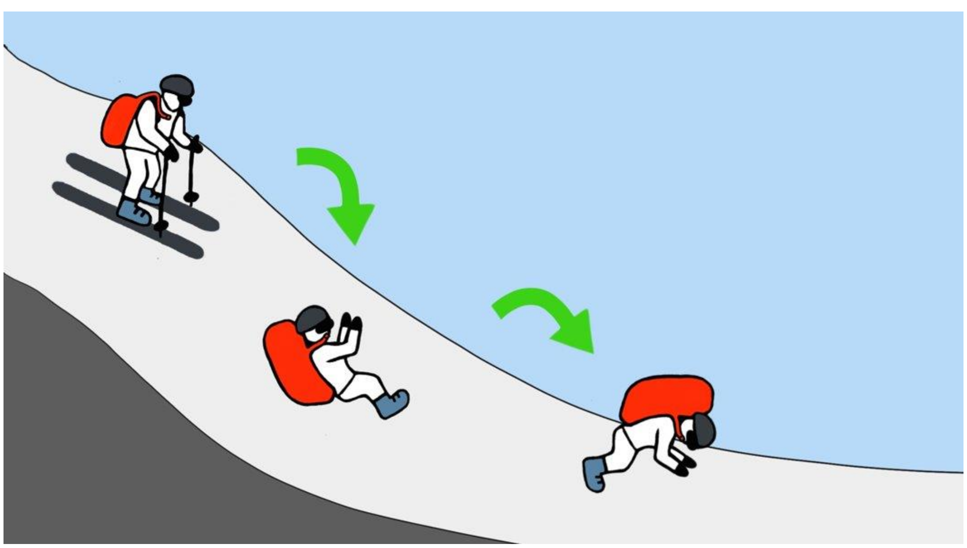


Figure 33: The AirShield in action

2.6 Summary

Overall, we had a multitude of interesting ideas that would be effective in the field. And while considering our research, users' needs, and overall practicality, we were able to conclude that the AirShield was the solution that best fit our criteria.

3 Module 3

3.1 Subsystem Descriptions

3.1.1 Liam Homburger – Command and Control

3.1.1.1 Top Level Description and Overall Objective

The overall goal of the Command-and-Control Subsystem is to manage the activation sequence of the AirShield. More pointedly, it is to receive the user's input, a pull of the activation toggle, and activate the inflation device to fill the airbag. In the scaled-up solution, this is critical to the functionality of our project as user input is the sole factor for the activation of our device.

The subsystem consists of three main components. The activation toggle, the CO2 cartridge, and an activation mechanism. The activation toggle is the main point of input from the user, the CO2 cartridge is the energy/gas used to inflate the airbag, and the activation mechanism is the device that translates the user input to the CO2 cartridge opening.

3.1.1.2 Subsystem Workings and Outputs

The activation toggle is a custom embroidered fabric toggle which clearly stands out in the snow (Figure 34).

Figure 34: The AirShield Toggle

The toggle is designed to be large and visible in any situation that may call for the use of the AirShield. Attached to the user's chest strap, it is conveniently placed for the user to pull.

If pulled, the toggle releases the firing pin which is propelled by two springs into the solder cap of the cartridge. After pressure is released, the springs retract and the gas escapes into the airbag through the venting holes. Figure 35 shows the assembly. (Note the springs are left out of the drawing, and the CO2 cartridge is intentionally left undermentioned)

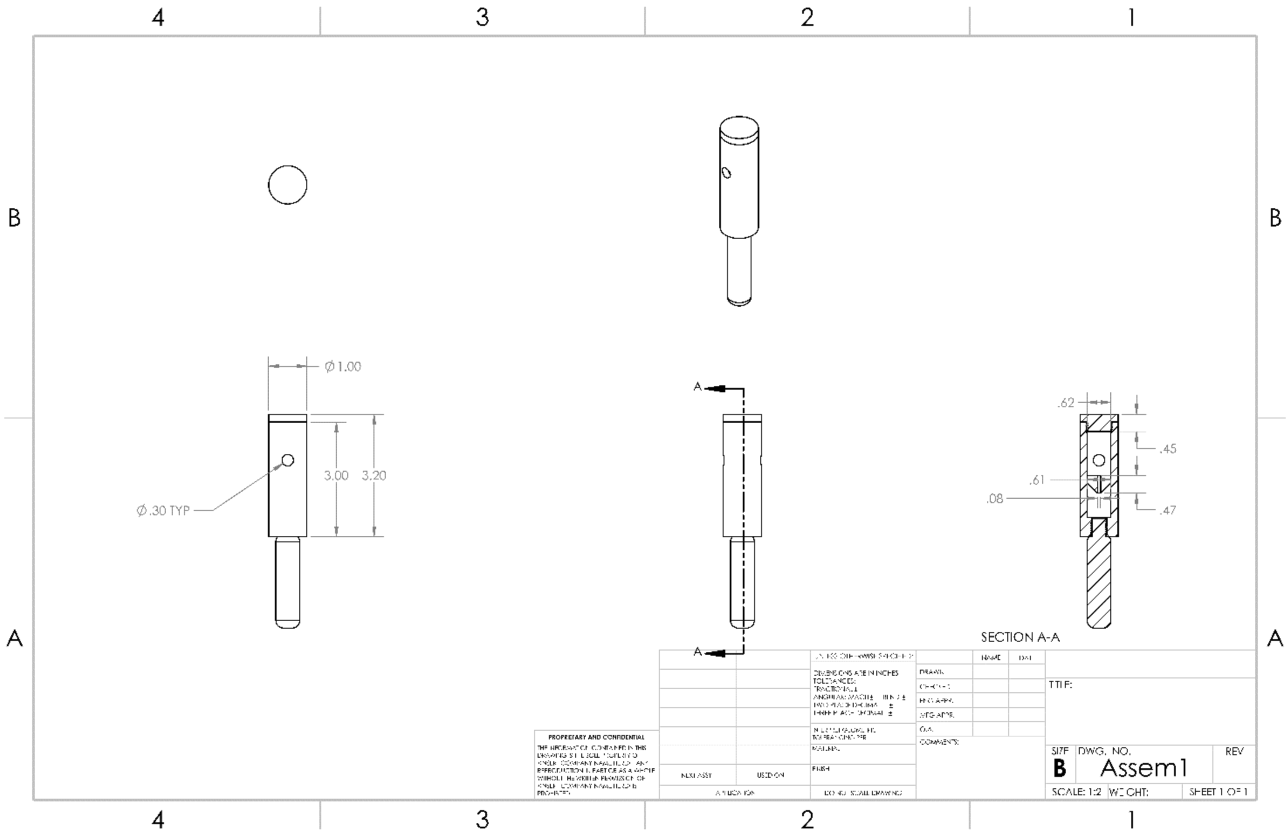


Figure 35: Assembly drawing of trigger mechanism.

Lastly, the CO2 cartridge is a 16g bicycle CO2 canister you can buy from a bike store or online retailer. We decided to use these for our works-like prototype as they are not controlled, they are cheap, and they are easy to use. For a commercial product, we intend to use a similar setup, but with a 220g oxygen canister. This will provide breathable gas for the user while also still being lightweight. Large scale oxygen canisters already exist for medical purposes, so we would need to partner with a medical supply manufacturer to produce specialty airbag canisters with 220g of oxygen.

It is critical that our final design uses exactly 220g of oxygen. This is derived from the volume of our final airbag (150L) and the ratio of 0.03125 moles per gram of oxygen. This converts to 0.7 L per gram, so we need 220 grams to fill our airbag of 150 L and provide a minor amount of static pressure.

The overall output of this subsystem is to inflate the airbag quickly and reliably. It must be inflated to the proper pressure and must not fail in any user orientation.

3.1.1.3 Subsystem Inputs

The primary subsystem input is the activation toggle. This is the strap on the chest of the user that releases the firing pin into the cartridge. Other than the user data input, the entire subsystem is mechanically linked to the backpack and the activation mechanism is specifically attached to the inside of the airbag. Despite using a solenoid for the firing pin release, there are no electrical inputs.

3.1.1.4 Key Subsystem Components

The key components that must function for the subsystem to achieve the output of the airbag inflation include the toggle, activation mechanism, and the gas canister. Each of these needs to function flawlessly every time the Air Shield is activated to ensure the airbag inflates in a potentially dangerous situation for the user.

Validation 1 includes a basic analysis of the safety of the device. Other validation sections discuss the reliability of the subsystem and how we plan to ensure it works every single time it is used.

3.1.1.5 Itemized List of Off the Shelf Components

1. CO2 cartridge (Works-Like Prototype. Figure 36)
    a. A 16-gram cartridge of CO2 used in place of oxygen for our works-like prototype. Screws into the bottom of the activation mechanism with an 3/8 24 TPI thread, the industry standard for small, compressed gas canisters [21].
2. Toggle (Figure 34)
    a. A red toggle is used as the means of activation from the user. When the user pulls the toggle, the airbag inflates. Ordered from amazon.
3. Aluminum Rod Stock (Figure 37)
    a. 6061-T6 aluminum rod stock. Machined into the final activation mechanism.
4. Solenoid (Figure 39)
    a. 12 V solenoid with 10 mm of travel used to release the firing pin.

Figure 36: 16g 3/8 24 TPI CO2 cartridges used on the works-like prototype.

Figure 37: 6061-T6 alloy aluminum [22]

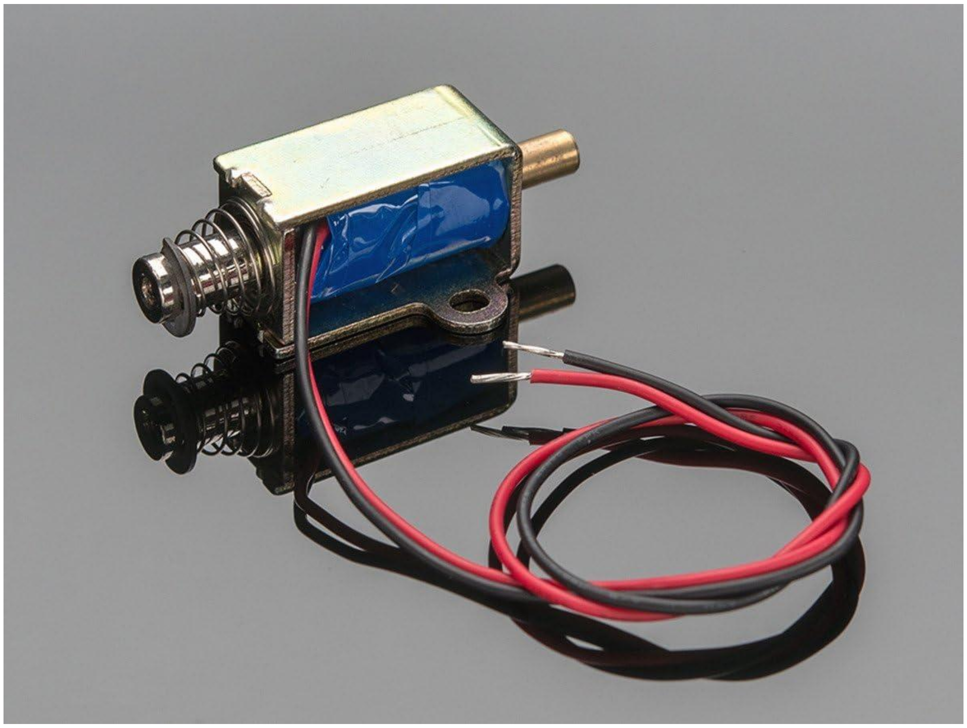


Figure 38: Push pull 12VDC solenoid with 10 mm travel

3.1.2 Physical Properties

Weight Breakdown:

Toggle: 50g

Activation wire: 50g

CO_2 cartridge: 200 g

Activation mechanism: 250g

Solenoid: 50g

Total Weight: 600g (about 1.32 lbs)

Materials:

Activation Mechanism: 6061 T6 aluminum [22]

Solenoid Mount: PLA plastic 25% infill

Activation wire: Galvanized steel wire (does not contact aluminum activation mechanism)

Construction:

Activation mechanism: Manually machined to meet the unique and specific design goals of the subsystem.

Solenoid Mount: 3D printed. Not structural/pressure vessel.

Dimensions:

Activation Mechanism: See figure 35.

Toggle: 1 inch by 5 inches with a 1 in OD keychain.

Overall, this subsystem meets the design goals and requirements set forth in the report organizer. The large 1x5 in toggle is clearly visible to the user or an external user and does not require much fine articulation. The mechanism is purely mechanical with the option to add electric activation. This provides futureproofing for an automatic activation system while not relying on electric components for manual activation. To arm the activation device, the user only needs to put a spring between the cap and the firing pin and screw in the CO_2/O_2 cartridge. This makes it easy to replace a spent cartridge. The combined weight of the system is small at only 0.6 kg making it not much of an inconvenience for the user. This system is useless if users refuse to wear it, so weight is of utmost importance.

3.2 Ideas and Design Choices

Some alternatives considered for this subsystem's activation mechanism included pyrotechnic deployment, a scuba buoyancy control device (BCD), and our final design of a combination of the CO_2/O_2 cartridge and scuba BCD. To generate these ideas, the team looked at existing airbag solutions, and narrowed it down to what we believed was achievable as students and would fit our situation. Due to these restraints, the team ruled out fan inflation techniques due to concerns around reliability. A fan inflation system requires a battery pack and large fan which require lots of maintenance. They also weigh a lot and are ineffective at rapidly inflating the airbag. Many current avalanche airbag systems use pyrotechnic deployment mechanisms which use an explosive charge to propel the firing pin into a gas cartridge which inflates the airbag. This is an effective solution as it is cheap, easy to use, and super reliable. Because of these benefits, this was the first avenue perused. Testing this method involved using a specially designed apparatus which was designed to eject the fumes from the charge and then allow the gas from the canister to vent into the airbag.

Before testing, the team considered a variety of explosive materials to use. Our parameters were 1) safety. 2) Reliability. 3) Procurement. We seriously considered 4f black powder or silver fulminate and settled on 4f black powder. The silver fulminate was strongly considered as we would not need to manufacture it (can get it from those small ground poppers), it is super sensitive to impact, and it is powerful in small quantities. However, the 4f Black Powder was ultimately chosen for its lower sensitivity to impact (Both a pro and a con), its ease of procurement, and ultimately, the finer control we have over its burn rate.

The test consisted of the prototype 3D printed activation mechanism with 2g of 4f black powder mixed with 0.5g of Titanium Dioxide to slow the explosion. The mixture was compacted around an E-match. The test resulted in the assembly rapidly disassembling. Reference [23] is a video showing the second test. (All participants were protected with trash bin PPE)

After the failed test, an attempt was made to analyze what went wrong and it was narrowed down to these factors:

1) Incorrect ratios
2) Infill

Firstly, we based our BP formula on what we use for low oxygen environments, and although we adjusted the ratio of potassium nitrate and charcoal, clearly it was insufficient and resulted in severe deflagration even in a closed chamber. Secondly, we added titanium dioxide to slow the combustion of the BP, although 0.5g was not enough to have a measurable effect.

The infill of the prototype was a hexagonal 30%. After analyzing the remnants, it appeared that the firing pin was stuck within the assembly and unable to travel. This would result in no way for the fumes to escape, and instead the assembly would explode as we saw.

All combined, this test proved one thing. A purely mechanical solution was the best option.

For a mechanical system, we considered using a solenoid powered firing pin, and spring-loaded firing pin, and a lever arm with a firing pin. The solenoid firing pin is promising for its reliability, however a large amount of current would be needed to get the force needed to puncture the cartridge. A lever arm would be easy to use and provide the user mechanical feedback on how hard they would need to pull the activation toggle. This is also a severe limitation as the force required may be too much for users. Lastly, a spring-loaded firing pin activated by a solenoid emerged as an optimal solution. This solution allows for little force to be exerted on the toggle (only enough to activate a switch), while the solenoid does the job of removing a bulkhead from the firing pin, releasing the pin into the cartridge.

Validation 2 includes commentary on the testing of this mechanism.

3.3 Validation

3.3.1 Validation 1: Analysis and Calculations/Safety

The trigger mechanism is made of 6061 aluminum alloy which has an ultimate tensile strength of around 42,000 PSI, meaning based on an area of 0.4785 in^2, the ultimate tensile yield of the mechanism is about 20,000 Pounds, about 20x the maximum expected pressure of the CO2 cartridge giving this device a factor of safety from an ultimate tensile failure of 20x. As for shear stress, since this is not a thin-walled pressure vessel standards are harder to find on how to confirm its strength. Instead, the group opted to significantly over-engineering the strength of the assembly. This ensures that even if the cartridge is punctured but the firing pin does not retract, it can hold the pressure of the cartridge. This was also tested during my length of travel test where I closed the venting holes and let it sit while pressurized. It successfully held the pressure, although slowly vented the gas.

The threads that interface with the cartridge were designed to be at 75% engagement. This leaves little room for the gas to escape, which it did. Tighter threads or an O-ring may help prevent leakage in a second iteration.

3.3.2 Validation 2: Test Results

Test: CO2 Puncture Test

Aspect Requiring Testing:

Puncture travel distance

Responsible Party:

Liam Homburger

State your Hypothesis:

It will take 1/8 of travel to puncture a co2 canister

Steps for Testing:

1. *Secure canister with vice.*
2. *Screw on assembly with firing pin*
3. *Count revolutions until puncture (24 TPI)*

Materials Needed:

1. *Vice*
2. *Activation Mechanism*
3. *Cartridge*
4. *PPE*

Record Results:

About ¼ inch of travel needed to puncture the cartridge

3.3.3 Validation 3: Secondary Research

When designing the mechanism, I looked towards applications that already use rapid CO2 deployment. One notable use case is in high powered rocketry. Since black powder burns worse above 20,000 feet, many rocketeers chose to use CO2 instead. There are two prevailing mechanisms for this, one which uses a small, highly oxidized black powder charge, or one which uses an extension spring to release a firing pin into the cartridge. To arm, the spring and firing pin are retracted up the assembly, and a string is used to hold the firing pin back. When deployed, the string is cut, and the firing pin releases into the CO2 cartridge. [24]

Although not scholarly, the number on many rocketry forums for puncturing a CO2 canister seal is 40 lbs. One way many seemed to reach this with springs is to use a needle to puncture the solder. By focusing the pressure to a point, like a needle, we can puncture the CO2 canister easier.

3.1.1.B Cat Cronin: Inflation

3.1.1.1.B Objective Description and Objective

The Inflation subsystem's objective is to successfully and consistently inflate the design's airbag. This system includes the inflation mechanism, the air tank, air bag, as well as all the connections between these components.

3.1.1.2.B Subsystem Workings and Output

This subsystem is very reliant on the products of the command and control and containment subsystems. Using the activation mechanism of command and control, the system releases the compressed CO2 from the CO2 cannister and funnels it into the airbag. The airbag, comprised of a two-layer body with a Nylon outer shell and a thin airtight inner plastic lining as shown in Figure 41 below, allows for the expansion of the compressed gas once the cannister is punctured. The airbag expansion creates a large body with low density allowing the user to rise above the denser snow of an avalanche.

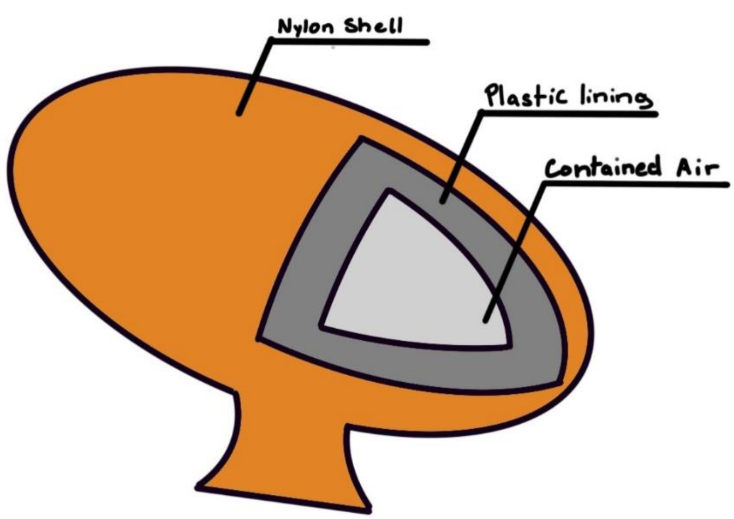


Figure 39: Drawing of two-layer airbag

3.1.1.3.B Inputs

To activate the inflation subsystem, the physical input from command and control as well as containment are necessary as shown in Figure 40 below. With the help of the activation mechanism, the CO2 cannister is punctured and the compressed gas is released. The airtight seal provided by the containment system ensures that the released gas is funneled into the airbag ultimately inflating the airbag.

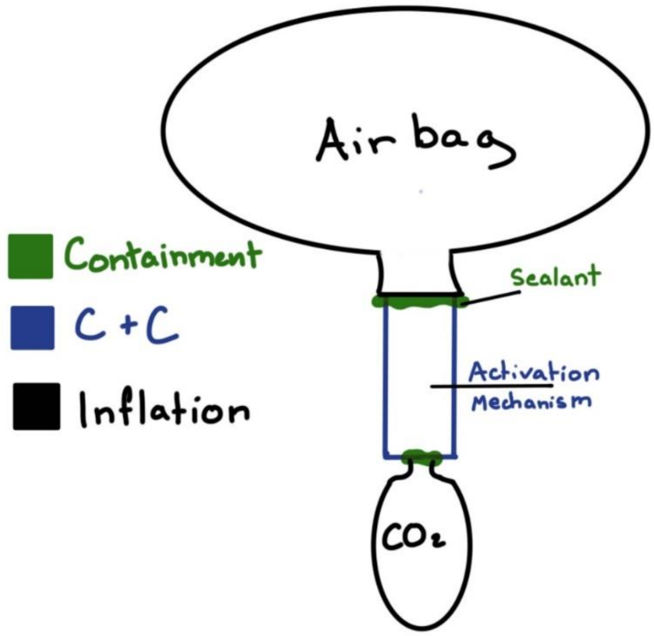


Figure 40: Diagram of physical inputs to inflation subsystem (Note: C+C Stands for Command and Control)

3.1.1.4.B Key Components

The key components of this subsystem include the compressed CO2 cannister, the sewn fabric shell of the airbag, and the plastic liner. The CO2 Cannister is responsible for the ultimate inflation of the airbag should it be required to inflate, the other role of the cannister is to keep the gas compressed so that it can be easily stored and transported in a backpack. The nylon shell and plastic liner together compose the inflatable airbag as shown in Figure 39 above. The plastic liner ensures that the airbag contains a gas and is airtight while the nylon shell protects the thin liner from damage and gives it its shape.

3.1.1.5.B Off the Shelf Components

Trash Bag: This item is used as the thin plastic lining on the inside of the Airbag see Figure 43 below.

Figure 41: Glad trash bag (https://www.walmart.com/ip/Glad-ForceFlex-Tall-Kitchen-Trash-Bags-13-Gallon-120-Bags-Fresh-Clean-Scent-Febreze-Freshness/149720974)

16g CO2 Cannisters: used to inflate airbag system. This item will ultimately be replaced by a different compressed air container for a final design. (See Figure 41. above)

3.1.2.B Physical Properties

Air bag (Deflated):

Materials: Nylon Shell, Plastic trash bag lining

Dimensions: 23 ½ X 12 ¼ in

Weight: ~50g

16g CO2 Cannister:

Weight: 200g

Dimensions: 89mm x 22mm diameter

3.2.B Idea Generation and Decision-Making Tools

While deciding on how to best manufacture an airbag we went through several options and have had to make decisions on our final design. The main challenge we faced was finding a way to ensure that the airbag was airtight. We looked at sourcing material that is coated in silicon to ensure that the main airbag material is airtight but decided that it would be too costly. To be more cost efficient, we decided on creating a main body that was not made of airtight material and lining it with an airtight sealed bag like a trash bag that might be too weak without the extra lining. Although we did not use any formal decision-making tools, thorough conversation and deliberation amongst team members, taking our restrictions and limitations into account, helped us to reach our final decision.

3.3.B Subsystem Validation

3.3.1.B Analysis and Calculations

Since we are using a 16g CO_2 canister for our works-like prototype, we needed to calculate the approximate volume of the airbag. If we assume the gas is ideal, we can easily approximate the volume using the ideal gas equation ($PV=nRT$). Using an atmospheric pressure of 1 atm, a temperature of 25 C*, and 44.01g/mol as the molar mass of CO_2 we find that the approximate volume of gas that will be held by our system is around 8.90 L of gas.

Using the earlier calculations, we got a minimum volume requirement, but that does not easily translate into construction dimensions for a textile body. To start the translation from volume into construction dimensions, we created a very rough estimate of the airbag shape in Solidworks as shown in Figure 42. The dimensions of the model helped to create a sense of scale so that we could ensure that we would meet the minimum volume requirement what it came time to construct the textile shell of the airbag.

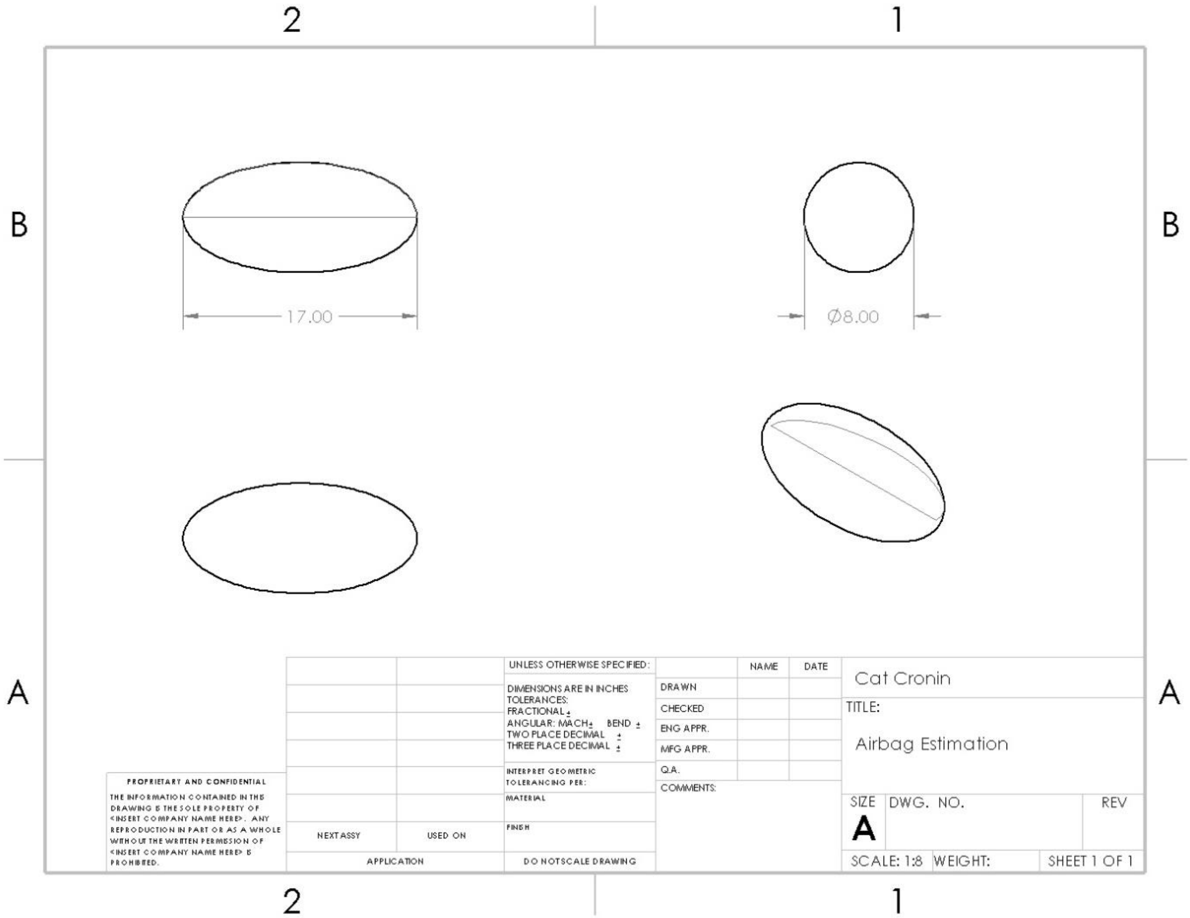


Figure 42: Drawing of airbag volume estimation

3.3.2.B Test Results

After the Initial construction of the airbag, it was crucial to test whether the bag was big enough to allow the compressed air to fully expand. Using the numbers that resulted from the volume calculations we ran a test to ensure that the airbag was large enough to accommodate the CO2 cannisters. We used water which we could easily measure out to ensure that the airbag was large enough, more details on the test can be found in the test protocols Appendix I. The results of this test ensured that there was enough volume as the airbag was able to hold significantly more than the calculated 8.9 L minimum volume. With this data we can move on to connecting the entire system together and testing multiple subsystems at once.

3.3.3.B Secondary Research

When first approaching how to construct our works-like prototype, we concluded that we would have to manufacture our airbag. Since avalanche airbags already exist as well as many products with similar functions, such as inflatable sleeping pads, researching current manufacturing processes was the first step in our process.

We had direct access to a NEMO Tensor ultralight sleeping pad, so we were able to directly inspect the construction. The pad has an almost laminated construction, where all edges are sealed together trapping the insulation layers in between the outer shell. We were able to conclude that the sealing was either done by melting the synthetic materials, gluing them, or some combination of the two. The seams are threadless, and no sewing is present. Using the inflation/deflation port, we inspected the inside of the pad. After physical inspection, it was clear the outer shell material had a coating on the inside to ensure the pad remained airtight despite being constructed out of a woven synthetic fabric.

Continued research beyond the sleeping pad was able to back up the qualitative inspection. We found that most vehicle airbags are constructed with a coated nylon [25], using the impressive tensile strength to mass ratio of the synthetic material to create a compactable, but strong final product.

From this research, we concluded that if we could have professional manufacturing of our product, it would be ideal to have it made with a coated nylon constructed like the sleeping bag, without stitching. We do not have these manufacturing capabilities however, so we aimed to replicate the same effects using alternative construction and materials.

To replace the coated nylon, we simply split the one shell into an outer shell of nylon with an airtight lining of plastic. This replacement also allowed for our construction to be simplified because the nylon was no longer responsible for creating the airtight seal allowing for a simple sewing construction.

3.1.3 Sophia Giglio – Delivery

3.1.3.1 Subsystem Objective and Description

Delivery is the flow of oxygen from the airbag to the individual. This subsystem is a crucial part that separates the AirShield from a simple airbag. Delivery is meant to allow the user to have a steady source of oxygen if they get buried under snow. Suffocation is a serious cause of death in avalanches and this subsystem aims to mitigate that risk.

3.1.3.2 Subsystem Inputs and Outputs

The input to delivery is oxygen from the airbag and suction from the user. The regulator only works if the user is trying to receive oxygen. Outputs are oxygen to the user and more time for rescue. If the user is not at risk of suffocation for a while, that gives more time to any search and rescue teams.

3.1.3.3 Key Subsystem Components

A key component of delivery is that the oxygen does not seep out of the airbag through the delivery system and slowly deflate the airbag if the user is not trying to receive oxygen. This is done through the regulator needing a user to be attempting to inhale oxygen for anything to leave the airbag. Also, the delivery system needs to control the pressure at which the oxygen leaves the airbag to a level that is suitable for humans.

3.1.3.4 Off-The-Shelf Components

1. Regulator [Figure 43]
    a. IST SCUBA Adjustable Octopus Regulator
    b. Polymer resin
    c. Brass housing
2. Hose [Figure 44]
    a. SCUBA Apeks Hose
    b. Low Pressure with swivel
    c. Double braided
    d. Chromed brass fittings
    e. 3/8-inch male to 1st stage and 9/16-inch female to 2nd stage

Figure 43 And 44: The regulator and the hose

3.1.2.C Physical Properties

1. Regulator
    a. Weight: 160g
    b. Greatest width: 10.5cm
    c. Greatest length: 7cm
2. Tube
    a. Weight: 120g
    b. Length: 73cm
    c. Width: 1.25cm
3. Total System [Figure 47]
    a. Weight: 280g
    b. Length: 82cm

Figure 47: The total system of the regulator and hose

3.2.C Idea Generation

With existing solutions such as the Avalung and airbags that fill with CO2, it was difficult to come up with a novel solution. The delivery system became the key part in setting our avalanche solution apart from the rest. The AirShield utilizes the delivery subsystem to transport oxygen from the inflated airbag to the individual.

Our idea for the delivery system is derived from how SCUBA equipment works, but instead of a tank, it is an airbag. Originally it was much more rudimentary with just a simple tube that could deliver the oxygen to the user, but we looked over existing solutions and realized how similar this subsystem is to scuba diving. We were able to get actual SCUBA equipment and will be able to implement it into our entire system.

3.3.C Validation

3.3.1.C Validation 1: Analysis and Calculations

The hose and regulator can both withstand 3000 psi, which is a much greater pressure than when would be exiting the airbag. The regulator is equipped to lower the pressure that escapes the airbag to a much more appropriate level for a human user.

Both parts of the system were donated from a SCUBA instructor. The equipment received was somewhat faulty, so the subsystem may not work exactly as expected, but it should suffice.

3.3.2.C Validation 2: Test Results

Test: Suction

Aspect Requiring Testing:

If the regulator works appropriately

Responsible Party:

Sophia Giglio

State your Hypothesis:

I believe that the regulator will work smoothly and be easy to breathe through

Steps for Testing:

1. *Hold regulator to mouth*
2. *Breathe normally, as one would do without a regulator*

Materials Needed:

1. *Regulator*
2. *Hose*

Record Results:

The regulator was a bit more difficult to breathe through than expected, but it may be due to the equipment being somewhat faulty. With how the regulator works now, it would be difficult for someone who is exhausted and stuck in an avalanche to breathe through it, but likely with modifications and a refined regulator, it should work ideally.

3.3.3.C Validation 3: Secondary Research

A human breathes on average a pressure of 14.7 psi. The regulator ideally lowers the pressure from the airbag to a little bit more than that. A human also uses approximately 2g of oxygen per minute.

3.1.4 Calvin Tran - Containment

3.1.4.A.1 Objective Description and Objective

Before outlining the objective description and objective, this subsystem is closely tied to the inflation subsystem, so this portion of the report will be concise. The objective of this subsystem is to maintain airtight seals inside of the airbag and the airbag system itself. This includes the joint where the air canister is connected to the airbag and the connection between the airbag and the breathing tube / regulator.

3.1.4.A.2 Subsystem Inputs and Output

Because this subsystem is so closely tied to the inflation subsystem, the inputs are similar, but the outputs are different. The inputs of this subsystem are mostly the outputs of the command-and-control subsystem, primarily the rush of compressed C02. The output of this subsystem is to produce an airtight seal around the joints where air is most likely to leak. Figure 45 below depicts the joints that need to be airtight especially while under pressure of the rushing air.

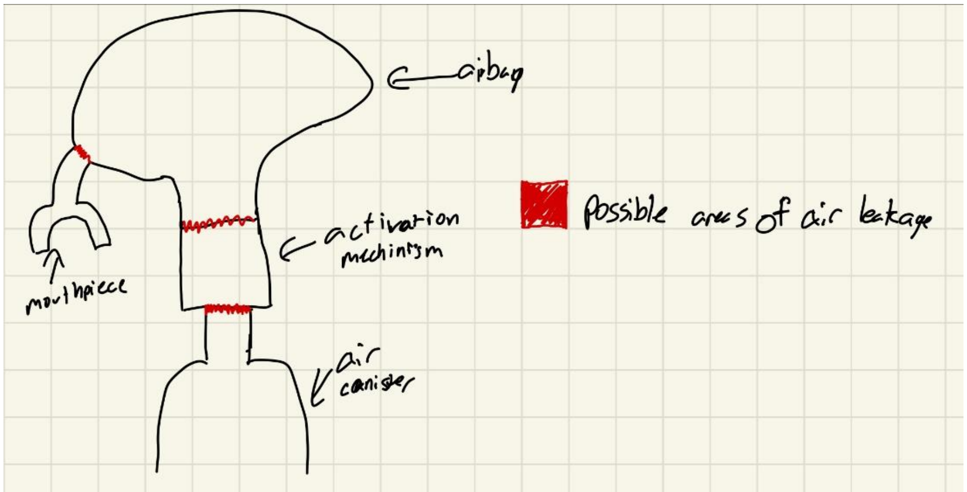


Figure 48: A photo of possible points where air may leak, spots highlighted in red are the biggest points that need a sealant to maintain air pressure throughout the system.

3.1.4.A.3 Key Components

The key components of this subsystem include the compressed CO2 cannister, the inflation subsystem's components (The fabric shell and the liner), and sealant. The CO2 Cannister's key role is outlined in 3.1.1.4.B and 3.1.1.2, the role of the inflation subsystem in section 3.1.1.B, and the role of the sealant is to create an airtight seal that can withstand the pressure of the air released by the C02 cartridge and that maintains that seal while air is being breathed out of the airbag itself.

3.1.4.A.4 Off the Shelf Components

1. Liquid Nails Fuze It construction adhesive
    - This is a construction grade adhesive made from a hybrid-polymer blend capable of withstanding 400 psi.

3.1.4.B.1 Idea Generation and Decision-Making Tools

To decide on a sealant, no formal decision-making tools were used, but a small, localized test was performed to determine the best sealant. The sealants considered were a silicon-based sealant, a polymer blend sealant, epoxy, and a contact adhesive.

3.1.4.B.2 Subsystem Validation

Test: Adhesion strength test

Aspect Requiring Testing:

Adhesive strength to airbag material

Responsible Party:

Calvin Tran, Catalina Cronin

Steps for Testing:

1. Fill the edges of the hole of the glove with the adhesive, following the procedure listed on each adhesive
2. Allow adhesives the set and cure (24 hours)
3. Cut hole in one of the gloves fingers
4. Inflate the glove through the new hole
5. Seal off the hole via twisting or holding the finger the hole is in
6. Apply pressure to the glove
7. Note an
8. y deformations, air leakage, or adhesive wear

Materials Needed:

1. *Gloves*
2. *Adhesives (Silicon based, polymer, epoxy, and contact)*
3. *Scissors*
4. *Caulk gun*

Record Results:

Polymer based sealant had the best results.

In figure 49 below is a depiction of the test setup:

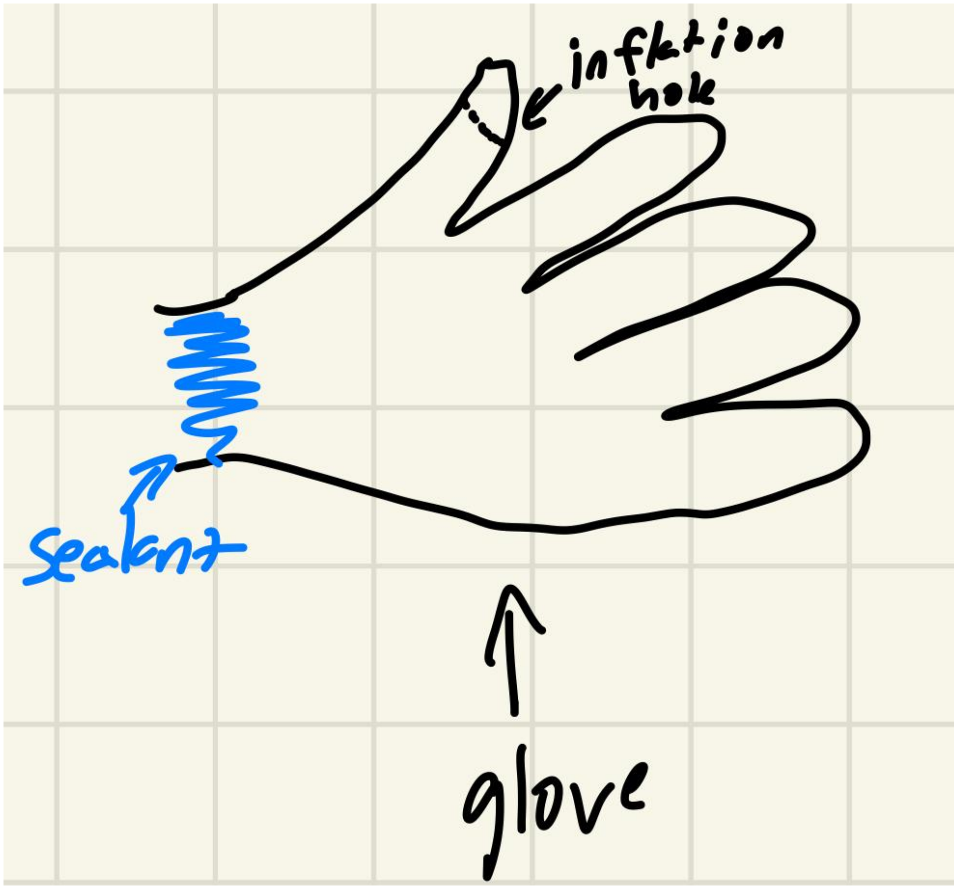


Figure 49: representation of the testing setup. Depicted is a glove with sealant at the base and a hole cutout to inflate the glove and test its integrity.

3.1.4.C.1 Test Results

After the test listed in 3.1.4.B.2 was completed, it was determined that the polymer blend had the best seal, withstanding the most amount of pressure without coming undone.

3.1.4.C.2 Secondary Research

For this subsystem, it was important to determine the types of sealant/adhesives that would be used. There were a couple important criteria: the sealant needed to be strong, affordable, and to be able to withstand abuse. Through research, several types of sealants stood out as viable. During an interview with Tay, who is a lifetime construction contractor, he was questioned about different sealants and their purpose. Tay stated that some of the best types of seal that could be used for this application are caulk sealants; either silicone or latex caulk due to their flexibility and airtightness [28][26]. And through scholarly research, epoxy was also a great candidate. Epoxy has been historically used to seal aircraft in case of cracks, even while in the air. Meaning that it can withstand considerable amounts of air pressure while maintaining strength and adhesion [27].

Methods of which residential homes are sealed to prevent air leakage were also considered; caulk seems to be a very viable method of sealing any gap under ½'' [30]. According to an interview with a different contractor, Phu, concurs that an epoxy and a caulk are viable options for this seal application.[31]

From this research, a small pool of possible sealants/adhesives were put together and purchased for testing.

3.1.5 Gautier Moreau – Storage and Integration

3.1.5.1.B Objective Description

The overall goal of the Storage and Integration subsystem can be broken down into two main components. The first is to provide a solution for transporting the other subsystems after they have combined in a way that is both efficient and safe. Secondly, the Storage and integration subsystem provides a straightforward way for the user to use the overall solution by making the Airshield triggering device easily accessible.

3.1.5.2.B Subsystem Workings and Output

This system will function by providing the user by simplifying the use of the solution to just pulling the activation strap and breathing through the respiratory device. This will be done using a custom backpack containing all the subsystems. The custom activation handle will be placed on the right shoulder strap of the backpack. This handle will run through the strap into the main compartment of the backpack where, when pulled, it will activate the air releasing mechanism. From that main compartment, the respiratory device connected to the airbag will be routed to the right shoulder strap where the mouthpiece is available to the user, as shown in figure 50 below.

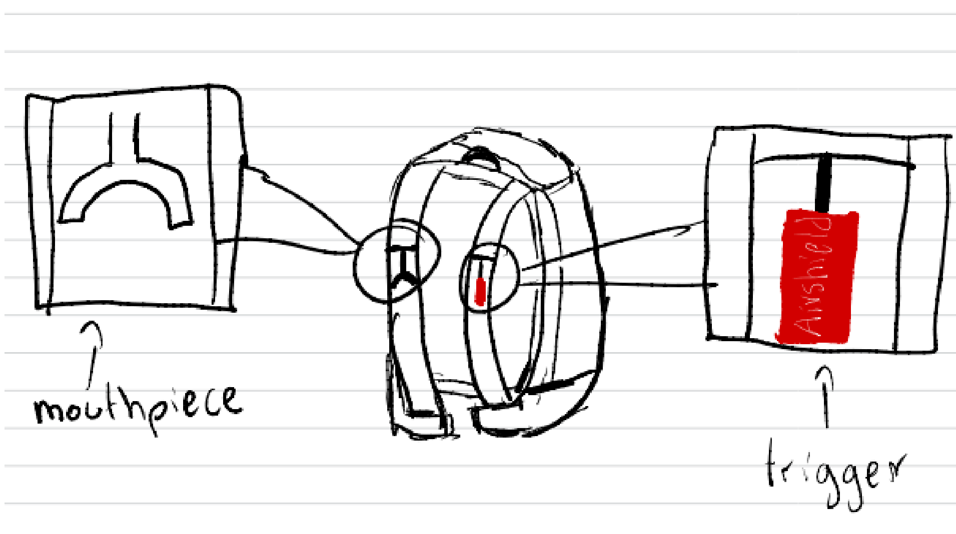


Figure 50: Layout of Input and Output of the subsystem

As the airbag is deployed, it will expand, ripping the Velcro on the side of the airbag and expanding outside the backpack to provide the user with additional surface area in the avalanche, as shown in figures 51 and 52.

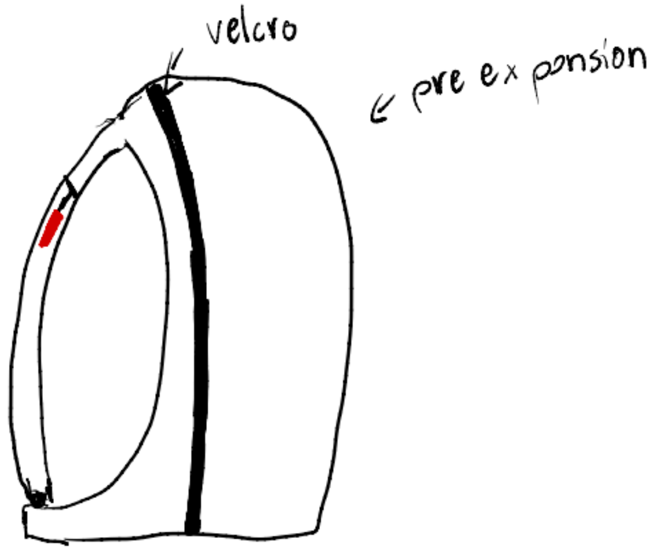


Figure 51: backpack before airbag expansion

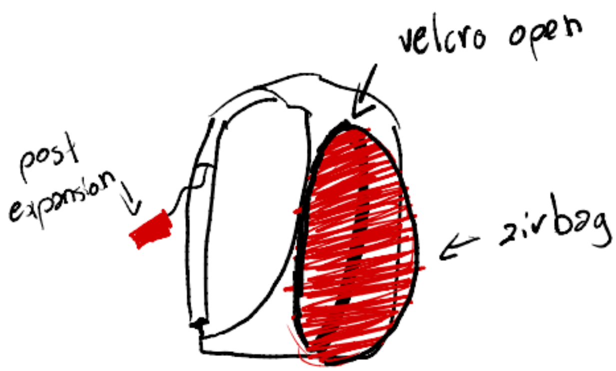


Figure 52: Backpack after airbag expansion.

3.1.5.3.B Inputs

The main input of this subsystem is the trigger mechanism. As this is the device that allows the deployment of the airbag. As the airbag is deployed, the user can access the mouthpiece placed on their shoulder and start breathing normally. The air expanding mechanism is a secondary input of this system, as it allows the airbag to expand, set off the Velcro straps and exit the backpack to expand the surface area of the user.

3.1.5.4.B Key Components

The two key parts of this subsystem are the hollowed-out backpack straps as well as the Velcro straps for the expanding airbag. The hollowed-out backpack straps allow the triggering and air delivery subsystems to be easily accessible to the user and to keep them safe from elements outside the system. The Velcro straps that rip out when the airbag is expanding allow the backpack to properly and safely store components when the airbag is empty, and at the same time allow the airbag to exit the backpack to increase surface area effectively when it is inflated.

3.1.5.5.B Off the Shelf Components

Backpack:

Used to contain all the subsystems, needs to have camelback like straps to run activation wire and respiratory device. Should be at least 30L. ~10 of these liters will be allocated to the airbag and other subsystems, 20L will be for other storage, this is an estimate based on industry standards for avalanche airbags [29].

Velcro Straps:

Used for containing the deflated airbag and allowing space for expansion of inflating airbag.

Dimensions: ¾ in * 1.5ft in length on each side of the backpack.

3.1.2.C Physical Properties

Weight Breakdown:

Backpack: 210g

Velcro: 49g

Total Mass: 269g

Note: This is not accounting for the mass of other subsystems being integrated into the backpack, but solely the mass of the backpack and modifications done to it.

Dimensions:

20.7cm x 20.3cm x 7.1cm (dimensions of backpack with airbag deflated).

3.2.C Idea Generation

When generating ideas for a backpack to store an avalanche airbag, the main problem to solve is how to store all the different components of the airbag while also making it easy to carry. A backpack solves this problem because it allows us to have a specialized compartment that is designed to fit the airbag itself, along with its canister. It also allows the carrier to have additional pockets and compartments for storing other necessary items such as a shovel, probe, water, food, and extra layers, all necessary in backcountry travel [32]. This will make it easier to access these items quickly when needed. Additionally, since this system will have significant mass, it makes sense to have carried on the user's back as the back allows for the weight to be evenly distributed throughout the body [33], which is important while exercising as it minimizes the risk of injury.

3.3.C Validation

3.3.1.C Validation 1: Analysis and Calculations

The constraint of this backpack is that it needs to be able to hold all the other subsystems while still having room for other storage for the user. Most of the components that are going to be used for the airbag are on the heavier side and will therefore be placed towards the bottom of the pack and closest to the back of the use for maximum comfort while carrying. The airbag components will also be placed in a separate pocket to avoid damage due to other items that could be carried in the backpack. That compartment will need to be of at least 15 liters, as the measurements of the subsystems total about that equivalent volume.

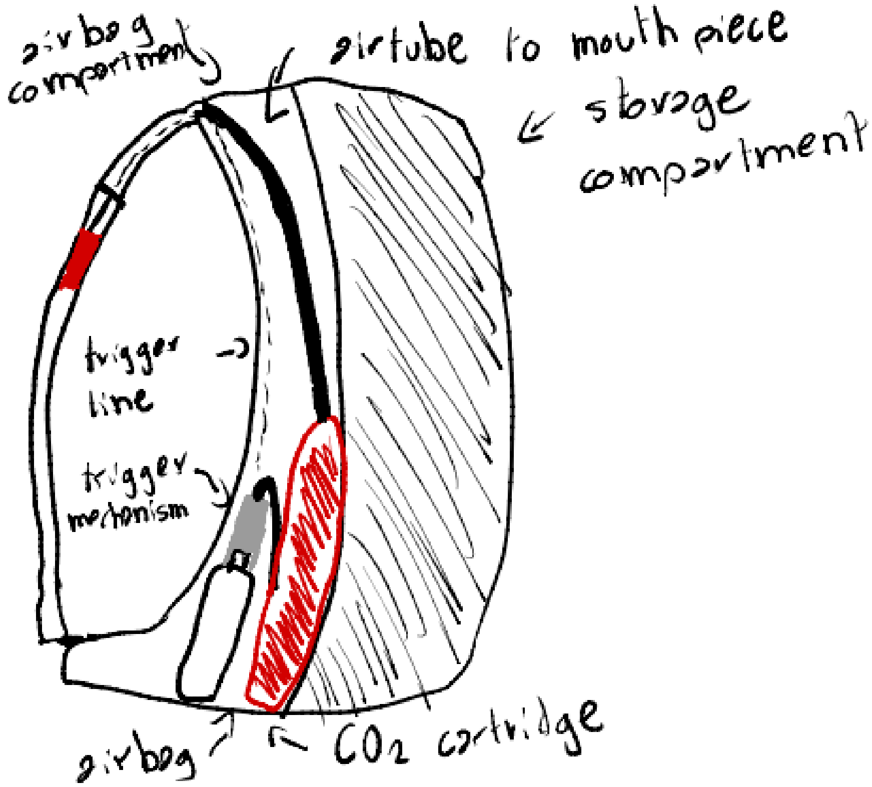


Figure 53: Storage of other subsystems

3.3.2.C Validation 2: Test Results

Apart from testing that all the subsystems will be able to fit into the prototype, which cannot be tested until all prototypes are complete, the only test that had to be complete was that the airbag would be able to open the Velcro strap. To test this, a latex balloon was placed in a cardboard box which was closed using Velcro. The balloon was then inflated using a 16g CO2 cartridge, the same version that will be used in the prototype. The balloon was able to open the cardboard box, which shows that the airbag will be able to do the same with the Velcro strap.

3.3.3.C Validation 3: Secondary Research

When thinking about how to design a system that could effectively contain other subsystems and make them easily accessible, I decided to look at solutions from comparable products. Although other avalanche airbag systems do not have a respiratory device like ours, their triggering mechanism is still remarkably similar in that they use a pulled trigger to set off a gas canister and inflate the airbag [34]. This gave me the idea to position the trigger for that mechanism on the shoulder strap of the backpack as this is often where it is positioned in these systems. I also noticed that these airbag systems often position the actual airbag as close to the user as possible because this allows for extra protection as well as extra flotation in an avalanche [35]. These are the features from existing solutions that I decided to implement in my design as shown in figure 53.

3.4 Interfaces and Integration

Each subsystem has a clear connection to another. The main system which includes Command and Control (C&C), Inflation, Containment, and Delivery all have physical connections through the flow of air, and activation. C&C's connection to the inflation system is evident in the activation mechanism of C&C which ultimately sets off the inflation system. The Inflation, containment, and delivery systems all come in contact and rely on the compressed Gas present in the system. Inflation is also dependent on the success of the containment subsystem to achieve its ultimate output of prolonged inflation. The containment subsystem is quite literally the glue between the three other subsystems that allows them all to interface successfully with as little escaped air as possible. The delivery system is directly interconnected with the inflation subsystem and is reliant on the pressure change allowed by the large volume of the airbag to ensure safe delivery to the respirator. Surrounding all of this is the storage and integration subsystem which molds around the main system to make a usable product.

3.4.1 Description of Each Interface

Main system:

C&C to Inflation: These two subsystems are connected physically and through the physical input energy of C&C. This process starts with the user input of pulling the deployment tab and is physically carried to the activation mechanism. The activation mechanism of C&C is ultimately responsible for the triggering of the inflation process as it punctures the compressed CO_2 cannister. The released gas expands to ambient pressure and flows through the sealed connection between the two subsystems and into the inflation subsystem, enabling the achievement of the desired output, inflation of the airbag.

Inflation to Containment: As previously touched on, the containment subsystem is responsible for strengthening and securing the physical connections between the other subsystems within the main system, including inflation. Without the improvement of these interfaces the inflation subsystem would quickly deflate after initial activation. The sealant provided by the containment subsystem prevents any significant gas loss from the system enabling the prolonged inflation of the airbag and the opportunity for expanded air to be available to the delivery subsystem.

Delivery to Inflation: The delivery system as it is designed now does not have a mechanism for lowering the pressure of the compressed gas in the cannister, nor does it have a direct physical connection. Instead, the delivery system is physically attached to the inflation system and relies on the large volume provided by the airbag to lower the pressure of the gas to a level that is safe to breathe through a second stage (mouthpiece). Without the inflation subsystem, the delivery mechanism would require an extra mechanism to lower the pressure of gas, such as the first stage of a SCUBA diving set up.

Containment to C&C and Delivery: This connection is a very straight forward physical attachment as the sealant of the containment subsystem glues the various parts of the main system together. The only other connection is that through its connection to the inflation subsystem, the containment subsystem enables the successful operation of delivery.

Storage and Integration to Main System: The storage and Integration subsystem is the physical buffer between the main system and the user. It physically contains the entire main system in a way that allows the user to easily interact and transport the whole design. Our goal demographic of consumers are backcountry travelers meaning that long-distance transport and ease of use are incredibly important to the success of the product overall. These two goals are achieved through the wearability and convenience of containing the system in a backpack and routing the respirator and activation pull tab to easily accessible locations.

3.4.2 Diagrams

For a clear visual of the system and its subsystem breakdown look at figure 54 below. The interfaces of all the subsystems are shown below in Figure 55

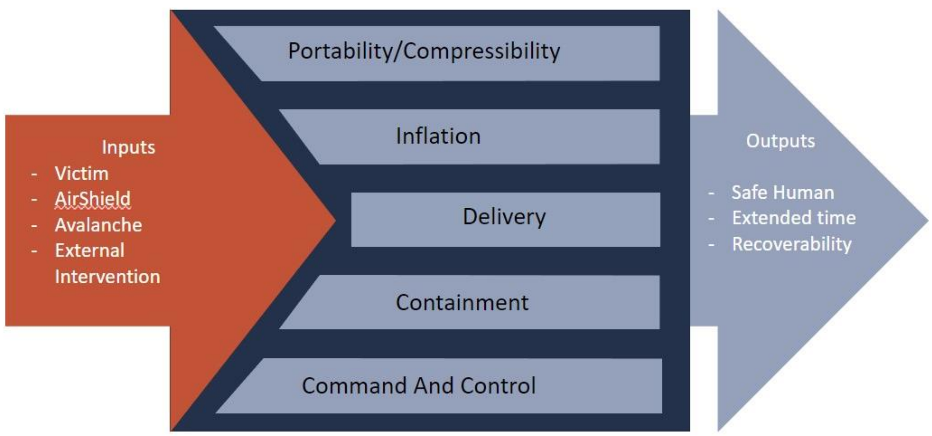


Figure 54: AirShield System Diagram

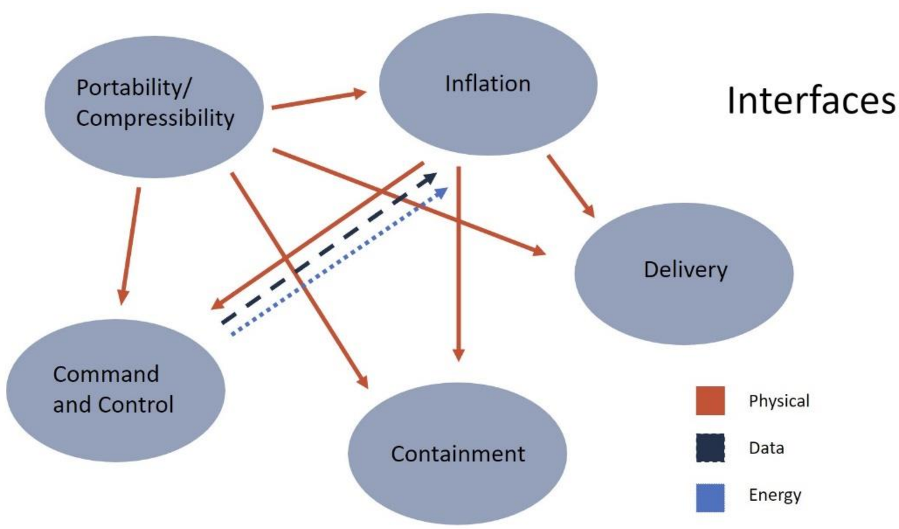


Figure 55: Diagram of Subsystem Interfaces

4.0 - Module 4

4.1.1 - Solution Value Proposition

In accordance with our problem statement, we have developed an engineering solution to a problem with plagues snow sports enjoyers across the world. Our problem statement "How can we assist avalanche-buried persons in the rescue process?", tasked us to address a problem that kills on average 6 people in our home state of Colorado a year, and many more across the world. After careful evaluation, stakeholder engagement, and secondary research into the problem, it was determined the easiest way to assist avalanche buried persons in the rescue process was to ensure that they were not buried in the first place, and if they were, to prolong their expected survival time to allow rescuers to reach them. To do this, the AirShield was developed. The AirShield is a novel solution to an old problem. An all-in-one system that combines the avalanche saving airbag, with a respirator to utilize the breathable gas in the airbag. Since 85.7% of avalanche deaths are due to asphyxiation [35], the respirator component of the AirShield is critical. By providing a source of clean oxygen for the user, the effect of CO_2 buildup is negated. Although half of our design does not directly address our problem statement, it would have been a missed opportunity to include an airbag as a reservoir for the oxygen.

At the end of the day, the consumer has a wide variety of choices when it comes to avalanche safety equipment. With countless airbags on the market, the AirShield is the only one that incorporates scuba respirator technology with an airbag, ensuring the maximum survivability for the user.

4.1.2 – Prototype Cost Breakdown

Table 3: Prototype Cost Breakdown

Item	Description	Cost per Unit	Source	Notes
6061 T6 Aluminum Rod Stock	**Aluminum for activation mechanism**	**$7.50 (1 inch OD, 8 inches long)**	**Aluminum Futures (CFTC)**	
Trash bag	**Seal for Airbag**	**$21.98/110**	**Costco**	
Airbag Fabric	**Fabric for Airbag Exterior**	**$10**	**Design Lab**	
CO2 Cartridge	**Gas for test deployment**	**$3**	**[37]**	
35 L Backpack	**Packaging for AirShield**	**$35**	**Calvin**	**Temporarily using Calvin's backpack**
Toggle	**Red Toggle for User to Pull**	**$3 generic red toggle**	**Makerspace**	

Liquid Nailz	**Sealant**	**$8 (for entire tube)**	**[38]**	

4.1.3 – Final Design Cost Breakdown

Table 4: Final Product Cost Breakdown

Item	Description	Cost per unit	Source	Notes
6061 T6 Aluminum Rod Stock	**Aluminum for activation mechanism**	**$7.50 (1 inch OD, 8 inches long)**	**Aluminum Futures (CFTC)**	
Airbag Fabric (Industry grade Silicon Coated Nylon)	**Fabric for the manufacture of the airbag**	**$64 (20 sq ft)**	**[39]**	**Prototype uses fabric substitute**
220 g oxygen canister	**Pressurized oxygen canister**	**$7 (Cost of CO2 cartridge, $2, plus $5 for added cost of new pressurized oxygen assembly line**	**General Air and Safety Supply, Denver, Colorado**	**Extrapolated based on CO2 cost assuming MSRP is per metal cartridge, oxygen costs around $1 per 220 g, and $4 for new assembly line.**
Toggle	**Red Toggle for User to Pull**	**$3 generic red toggle**	**Manufacture from fabric**	
5 N 10 mm Release solenoid	**Solenoid for release mechanism**	**$2**	**AliExpress. Cost reduces for bulk orders**	
35 L Backpack	**Housing for assembly**	**$40**	**Wholesalers**	**Generic backpack with no insignia**
Activation Mechanism Machining	**CNC Lathe manufacturing time**	**$10 (Assuming 15 min CNC lathe time per unit)**	**In house manufacturing**	
Oxygen Canister Production	**Production and shipping costs of oxygen canisters**	**$15.36 ($3,550 container shipping and**	**Based on existing specialty manufacturing quotes and current**	

		duty, $130,000 contract for initial 10,000 canisters + $20,000 nonduty taxes)	**shipping rates with a heavy tax rate of 27% resulting in a value of $74,074 for the $10,000 canisters**	
Premanufactured Scuba Regulator	**Regulator and Hose for Delivery System**	**$75 per piece (most likely cheaper at larger volumes)**	**[40]**	(Shipping details are unclear) There is also the possibility to establish in house manufacturing of a more suitable design for a final product

4.1.4 – Benefits

The benefits of the AirShield are indescribable. Since this is the device that may save your life, it truly depends on an individual's appetite for risk. Of course, we can still quantify some aspects of the AirShield. For one, snowmobilers are far more likely to be caught in avalanches. In addition to this, experienced males are the most likely demographic to be a victim in an avalanche [41]. Given experienced individuals aptitude for risk, they have the highest opportunity cost in buying the AirShield. Beyond experienced individuals, back country athletes are also at an elevated risk of being trapped in an avalanche, and as such should invest in an AirShield to protect their life. If someone offered you a onetime payment for insurance on your life, would you take it?

4.1.5 Pitches

4.1.5.1- Consumer Pitch

Don't become one of the thousands who have perished in an avalanche, today, for the low price of $300, you can protect you or a loved one's life in the event of an avalanche. All it takes is one click.

4.1.5.2 – Investor Pitch

Every year in the United States, around 24 people die in avalanche related deaths. What's more, many victims are forever haunted by paralysis, broken bones, and brain damage from avalanches. Avalanche airbags have done wonders in reducing this number down to 24 deaths per year, but the fact of the matter is, one death is too many. That is why we have invented the next novel avalanche personal protection device, the Air Shield. The Air Shield incorporates two solutions to two common problems. The Air Shield functions like a common avalanche airbag in that when deployed, it lowers the user's density, raising them up in the horror of an avalanche. It also combats a secondary problem. When an airbag is not successful, a user may get trapped beneath the snow to await rescue from other party members or a search and rescue team. In this event, a critical problem is CO2 deposition in the surrounding snow. CO2 can build up in snow surrounding the victim, and eventually suffocate them. Our solution to this is twofold. We developed a system to utilize the oxygen in the airbag to directly support the victim beneath the snow. The victim has access to a respirator attached directly to the airbag which when activated, sends oxygen to the victim, negating the effects of CO2 saturation. We project this could extend the time a victim could survive to an additional 30 minutes, a critical amount of time for rescuers to arrive and locate the victim.

The production of the air shield would require many current off the shelf components as well as a few novel products. Firstly, common scuba equipment can be repurposed for the AirShield. Many current systems have 2 stage respirators which work to limit the intake of CO2 while allowing the user to breathe from a tank, or an airbag. The airbag itself would need to be specially manufactured to the correct size unless a product can be found that fits our parameters. It will also need a scuba inlet on the side for an attachment to the respirator stage.

The backpack housing can be bought from a wholesale backpack supplier and embroidered with the AirShield Insignia. The 220-gram oxygen canisters would need to be made custom, although many steps of the process would be repurposed from existing solutions. Firstly, we would need to purchase empty canisters. These can be supplied from many industries, most notably, the home brewing industry offers canisters around the size we need in bulk. Using these canisters, we would fill them with a prespecified amount of cryogenic oxygen. While cold, we would then seal the caps with a solder mask designed to be punctured by the activation mechanism. The cost to run a production line with these processes would be high, however we would likely be able to find an existing supplier and contract it to them. Although this would be expensive, an existing supplier is likely more knowledgeable and suited to doing the task more efficiently. A breakdown of our estimated manufacturing costs is in the final design costs table.

4.2 – Risk Mitigation

4.2.1 – Risk Discussion

Since the AirShield's use case is always a potentially deadly situation, great care has been taken to ensure that risks are mitigated to an extremely low level. Our risk mitigation table shown in 4.2.2 explicitly overestimates risks when in doubt, and provides comprehensive mitigation plans for each failure mode to both prevent the failure and mitigate it.

Firstly, to address the issue of the user not reaching the respirator, a design has been chosen which prioritizes ease of use with the respirator, and a clause in the manual encourages users to practice retrieving the respirator before use. This is vital for when a user is implicated in a situation where they rapidly need the respirator, it should be second nature.

Baring other user error issues (all can be resolved with practice), the risk of no deployment is a notable situation. To mitigate this problem, the activation mechanism will be tested thoroughly, and an official manufacturer replacement program will be instituted to certify and replace used components to ensure the AirShield works every time.

These are the pertinent full-scale issues with the AirShield. A deeper discussion into the intricacies is laid out in 4.2.3.

4.2.2 – Risk Mitigation Table

Table 5: Failure Mode and Effect Analysis

Risk	Likelihood X	Impact =	Magnitude	Mitigation Plan (only for MEDIUM, HIGH, and EXTREME Risks)
Early Deployment	*Unlikely*	*Minor*	*LOW*	
No Deployment	*Unlikely*	*Major*	*MEDIUM*	*To reduce impact, we will verify the activation mechanism works in various conditions before mass manufacturing and certify each AirShield for a specified service time.*
Airbag Leak	*Unlikely*	*Moderate*	*LOW*	
Scuba Pipe Disconnect			*MEDIUM*	*To reduce impact, we will add extensive instruction in the assembly instructions to ensure the user attaches the scuba respirator to the airbag, and that they check before using.*
Scuba Regulator Failure	*Unlikely*	*Moderate*	*LOW*	
User cannot deploy	*Unlikely*	*Major*	*MEDIUM*	*To reduce impact, we will ensure the toggle is in an ergonomic position, and that the manual emphasizes practice pulls with the cartridge detached.*
User cannot reach respirator	*Likely*	*Major*	*HIGH*	*To reduce impact, we will ensure the respirator is in an ergonomic position and that the manual puts emphasis on practice using the respirator.*
Airbag Overinflates	*Unlikely*	*Major*	*MEDIUM*	*To reduce the impact of the airbag over inflating, we can use a proprietary connector for our oxygen cartridge to ensure that only our perfectly sized oxygen canisters interface with the airshield.*
Airbag Underinflates	*Unlikely*	*Major*	*MEDIUM*	*To reduce the impact of the airbag under inflating, we can use a proprietary connector for our oxygen cartridge to ensure that only our perfectly sized oxygen canisters interface with the airshield.*

Airshield Packing is Challenging	*Likely*	*Moderate*	*MEDIUM*	*To reduce impact, we will include detailed instructions on how repack an AirShield, as well as video tutorials.*
Part Needs Replacement	*Likely*	*Moderate*	*MEDIUM*	*To reduce impact, we will offer a limited time acceptable use warranty program and an official repair service. Certain parts will also be available for order individually, although servicing your own AirShield will void its warranty.*
Pressure Vessel Malfunction	*Unlikely*	*Major*	HIGH	*To reduce impact, we will specify a service regiment for the firing pin to ensure it does not get stuck. We will also grease the internal activation mechanism from the factory to prevent this failure.*
User Fails to Activate Airshield	*Unlikely*	*Major*	*MEDIUM*	*To reduce impact, we will emphasize the importance of using the airshield even when unsure.*
AirShield Blocks Entry to Ski Lift	*Likely*	*Minor*	*LOW*	
Death	*Unlikely*	*Major*	*MEDIUM*	*You've got bigger problems than an avalanche....*

4.2.3 – Mitigation Plan

For the activation mechanism, it was decided to use off the shelf components for actuating the CO_2 due to dangers and reliability issues pertaining to the initial design. This has mitigated much of the risk of the device not releasing the CO_2 when actuated.

Secondly, the numbers for the cost to manufacture a custom oxygen canister have been determined, which helps in ensuring that only the proper size canisters are used for the AirShield. With a proprietary threading on our canisters, only the right type of certified canister can be used.

Many of the risks found in the inflation subsystem can be mitigated by accurate analysis of the airbag system, such as overinflation and underinflation. Other issues such as leaks and breaking can be mitigated through means of testing and professional production and manufacturing standards.

The delivery mechanism, or the scuba regulator, is being sourced from outside sources and failure is unlikely if adequate maintenance is maintained.

Mitigation of the various user errors and failures is being done by ensuring that stakeholder testing is used to ensure an intuitive user-friendly device, with features such as an easily accessible activation toggle and easily accessible regulator. This accompanied clear instructions are provided to ensure an effective product.

Lastly, transport of compressed oxygen can be dangerous, especially when in a hostile environment such as the back country. To mitigate the risk of a pressure vessel failure, each canister is thick walled and built to withstand severe force before rupturing.

5.0 Module 5

5.1 Real World Concept Description

The real-world environment our invention is designed for is backcountry traversing in countries across the world. Our device is purchased with comprehensive manuals in every local language, and the nature of the product lends itself to its omni-cultural status, not requiring specific language or cultural understanding to operate.

5.1.1 CAD Design

Release Mechanism:

This is the isometric view of the release mechanism as seen with an example compressed gas cylinder, regulating screw, adapter and interface. This is sewed into the backpack shown below.

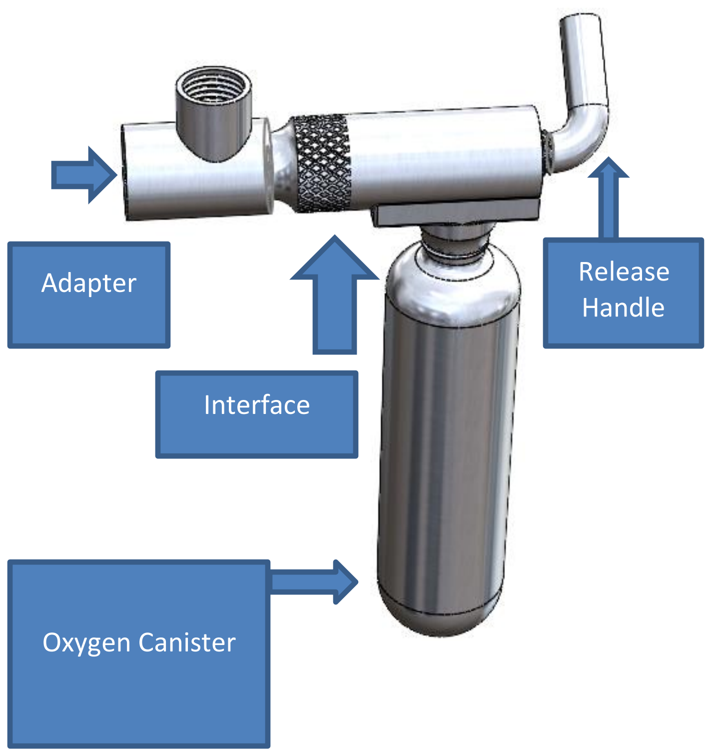


Figure 56: Gas Release Mechanism, 6061 – T6 Anodized Aluminum.

Figure 57: A user breathing from the respirator after pulling the inflation toggle (in green).

Figure 58: 50th percentile sized woman with the AirShield fully deployed. The inflation mechanism is housed inside the base backpack.

5.2 Full-Scale Design Solution

The AirShield is a device which combines the lifesaving abilities of an avalanche airbag with a respirator, allowing the user to breathe while buried, therefore extending their expected survival rate. To do this, the AirShield uses a small and compact activation mechanism which combines a compressed gas cylinder and an adapter to deliver oxygen both to a respirator and an airbag, fulfilling the purpose of the device, to save lives through lowering the density of the user, and supplying them with a lifesaving amount of oxygen.

The estimated weight of the device is as follows, based on the following specifications of the final design. The activation mechanism, made of Anodized 6061 – T6 Aluminum, weighs approximately 400 g based on the density of aluminum, and the ancillary parts required for the system including O-Rings, Anodizing, etc. The device is 74 mm long as measured from the airbag exhaust port to the end of the lever arm. This allows it to be easily packaged into the chosen backpack for the AirShield, and in theory, any 35L backpack. (Although this is not recommended)

The airbag material, silicon coated nylon, adheres to the relevant standards [42]. In addition, it will be thoroughly tested to ensure perfect compatibility with the AirShield's demanding environment.

6061 – T6 aluminum is perfectly situated as a lightweight appropriate material for the activation assembly, which must withstand high pressure. The final design does not follow the principles of a thin-walled pressure vessel, and as such, the analysis in 3.3.1 stays the same, including the conservative Tresca criterion assumption.

Aluminum is also fittingly situated for this design as it shows a moderate decrease in ductility with little increase in brittleness as temperature drops [43]. This makes it perfect for the extreme cold backcountry environment the AirShield is used for.

The quick release system is fully Complient with ASTM F1792-97, the relevant standard defining the design of oxygen valves [44].

The pull toggles are large and visible for the user. Their position on the shoulder of the user makes them easily assessable for the user to use in the event of an avalanche. On the opposite shoulder is the respirator, also in an easy-to-use spot for the user.

While the AirShield needs to be maintenance between uses, it is easy to replace the oxygen canister. A certified AirShield technician or the user can open the back compartment and replace the canister in less than 15 minutes.

A walk through of using the device in an avalanche is as follows:

1. Pull the activation toggle.
2. Wait up to 6 seconds for the airbag to inflate.
3. Try to stay buoyant on the snow.
4. If trapped, utilize surrounding oxygen for a few minutes, then transfer to the AirShield when breathing rate is lowered.
5. Await rescue.

5.2.1 Updated design requirements

Table 6 lists our design specifications while Table 7 lists the user specifications.

Table 6: New Specification Table

Type of Specification	Description	Specification	Units	Tolerance	Notes
Physical Dimensions	Product Size (L*W*H)	1 x 0.7 x 1.6	ft	+/- 0.2	
	Product Size (Inflated L*W*H)	3.5 x 1 x 2	ft	+/- 0.5	
	Product Weight	4000	g	+/- 350	Fully Assembled
Materials	Backpack	35	L	+/- 0	

	Gas Interface	6061 - T6			Rod Stock
	Oxygen Canister	6061 - T6			Sheet Stock
	Oxygen Regulating Pin	6061 - T6			Rod Stock
	Oxygen Adapter	6061 - T6			Rod Stock
	Airbag Fabric	Silicon Coated Nylon			
Physical Interfaces	Regulator-Backpack Strap	15	lbs	+/- 2	Peel Strength
	Release Handle	Embroidered Cotton			
	Release Handle Wire	1/16 Steel Rope			
	Pressure Hose	1000	PSI	+/- 100	FOS 10
Misc Specifications	Release Mechanism Enclosure	IP65			
	Inflation Time	5	s	+/- 1	
	Inflation Volume	150	L	+/- 5	
	Oxygen Volume	230	g	+/- 2	
	Failure Rate	0.10%		+/- 0.05%	

Table 7: User Specification Table

Type of Specification	Description	Specification	Units	Tolerance	Notes
Human Factors	Ergonomics	Fits 95% male body and 5% female.			
	Storage	Stored in dry, dark environment.			
	Warranty (Reasonable Use)	3	Years	+/- 0	
	Airbag Repack	15	Minutes	+/- 5	
	Canister Replacement	10	Minutes	+/- 5	
	Return	Without use OR 30 days OR defective product			
	Replacement Parts	Ordered from Manufacturer			
	Lifespan	5	Years	+/- 0	All instructions followed
	Uses	5		+/- 1	
Cost	MSRP	300	USD	+/- 20	

Manufacturing Cost	100	USD	+/- 10	See Cost Table

5.2.2 CAD and Validation

To validate our final design, we put all of our parts into an assembly and tested the fittings to ensure that our product interfaces correctly. Since our prototype involved off the shelf components, we utilized some of the design choices we noticed worked well in our final design, while we removed many choices that we found cumbersome. Here is a representation of the canister getting screwed in, and the release pin being removed (screw animations disabled for time) https://gyazo.com/adb7aeeb8521ce5f93253dc9e3af4f64

The key aspect of our prototype is the release mechanism, made of a Shrader valve bike inflator. Using aspects of this existing design, we created a mass manufacturable variation that uses a similar mechanism, a pin which is pushed in and out, releasing gas as it moves out. This proved very reliable, with the exception of O-Ring failure. The only major problem we encountered was the O-Rings sealing the system, which would freeze and crack after repeated use. To fix this, we require that the affected O-Rings are replaced after every use regardless of apparent status.

5.2.3 User Interfaces

The two primary user interfaces in the AirShield are the activation toggle and the respirator. Firstly, the activation toggle interfaces directly to the lever arm on the inflation mechanism. It is a critical point of user input as it is used in critical situations where the user needs instant relief. It must release the oxygen to the airbag and respirator within the desired inflation time (Table 8).

Secondly, the respirator is also a critical point of user interaction. When caught in an avalanche, the user can use the respirator to breathe the oxygen in the airbag and extend their life while awaiting rescue. The respirator is situated conveniently on the shoulder opposite of the pull toggle. It is easy to reach for any user and designed to be quickly freed from its Velcro restraints when needed. The Velcro peel strength is strong enough to hold it while enjoying the back country, but weak enough to pull apart in an emergency.

5.3 Concept Validation

5.3.1 Validation Based Decisions

The AirShield is a product of data driven design. Many aspects of the design were made with all 4 validation methods and each individual subsystem worked out bugs leading us to an effective final product. Please reference module 3 for each subsystem's individual validation.

After our works-like prototype was made, we did further testing and made small design changes to produce a reliable and safe product that accomplishes our problem statement of assisting avalanche buried victims.

5.3.2 Scholarly and Authoritative Research

5.3.2.1 Oxygen Supply

The most critical aspect of the AirShield is the Oxygen Supply. The industry standard for Airbags is 150L, so this is what we decided to use. This provides plenty of buoyancy on the snow, while remaining light weight. More importantly, we needed to understand how much oxygen the user will have to breathe in the event of an avalanche. According to Encyclopedia Britannica, the average human uses around 250 ml of oxygen per minute [45]. Given existing avalanche statistics, the average victim has around 30 minutes of CO2 free oxygen before they asphyxiate, and therefore, the added benefit of the air shield is after this window. Assuming the victim is calmer after 30 minutes of being trapped, and they only consume 4x the average 250 ml of oxygen per minute, we can calculate that the victim will have 150 minutes, or 2 and a half hours of extra oxygen. This extended time allows rescuers to reach the victim and will greatly increase the survival rate of avalanches.

5.3.3 Testing

As we built our final prototype, to validate our final product, we conducted multiple tests. Firstly, the team tested the inflation mechanism without the airbag, then the team tested the inflation mechanism with an early version of the air bag, then the team tested the inflation with the backpack, and finally the team did a test of the backpack on a person to ensure it would perform optimally in the field.

5.3.3.1 Inflation Mechanism Puncture Test

To test the inflation mechanism's puncturing ability, the team slowly tightened an CO2 canister to the assembly and confirmed the spring had enough force to puncture the canister (figure 59). This was needed to ensure that we could puncture a canister when the user activated the inflation system.

Procedure:

1. 2 11lb springs loaded into inflation mechanism.
2. Cartridge tightened onto inflation mechanism.
3. Team counted revolutions as cartridge is tightened onto inflation mechanism.
4. Team stops tightening when punctured.
5. Calculate force required.

Results:

After the test, the team calculated the force required to puncture a compressed gas canister at most 13.55 pounds with the standard firing pin. This was beyond what the current design was able to support, and as such, the team decided a new method was needed to release the compressed gas into the airbag. Only 2 tests were conducted due to the cost of the one-time use gas canisters. The table below shows our results.

Table 8: Test Results

Test	Revolutions	Force (lbs)
1	7.25	13.25
2	7.5	13.55

Figure 59: Conducting test 1

5.3.3.2 Inflation Mechanism with Airbag

To test our volume predictions, the team inserted a revised version of the inflation mechanism into the airbag. The airbag was lined with a trash bag of which the team knew the exact volume. The bag was timed to find the inflation time of the bag to ensure it is within specification.

Procedure:

1. Insert loaded inflation mechanism into airbag.
2. Pull toggle to activate the inflation mechanism.
3. Use a stopwatch to find the total inflation time.

4. Stop the stopwatch once fully inflated.
5. Check for over/under inflation and leaks.

Results:

The team found that the inflation time was very favorable, with the average time being 2.353 seconds. This is well within our specification of 5 seconds +/- 1, and what a user would expect when using a commercial avalanche airbag. (The team only conducted 3 tests due to the price of compressed gas canisters)

Table 9: Test Results

Test	Inflation Time	Critical Error (Over/Under inflation)
1	2.12 s	False
2	2.45 s	False
3	2.49 s	False

5.3.3.3 Inflation Mechanism with Backpack

To test the inflation mechanism packaging with the backpack, the team secured the inflation mechanism to the backpack, and ran one test to ensure the toggle had ample room to actuate the inflation mechanism. Small compressed gas canisters were used.

Procedure:

1. Install airbag and inflation mechanism into backpack.
2. Activate inflation mechanism.
3. Check toggle clearances.

Results:

The test ultimately proved successful. Our first attempt required a re-gluing of a lever arm, but after that was resolved, the inflation mechanism fully inflated the airbag, and gas was dispensed from the respirator.

5.3.3.4 Inflation Mechanism with Backpack on Person

To fully test the ergonomics of the device, the team ran two tests of the AirShield on a user. The user reported their experience and comfort to the team. This data was used to revise certain ergonomic portions of the device to make it more comfortable for the user.

Procedure:

1. Install airbag and inflation mechanism into backpack.
2. Help user wear backpack.
3. Confirm free range of motion for the toggle.

4. Confirm respirator is installed and ready.
5. Confirm adapter is sealed to airbag.
6. Confirm canister is tightly secured.
7. User activates the AirShield.
8. User tests respirator.
9. User reports experience.

Results:

This was a qualitative test to primarily make adjustments to the ergonomic portions of the AirShield. The team found that the backpack was minorly uncomfortable (as can be seen from the side in figure 60), the lever arm on the inflation mechanism could sometimes get caught on the fabric, and that the respirator was uncomfortably heavy. To address the problem of the backpack, we specified the final design to use a 35L backpack instead of a 10L which was constrictive on the user (Figure 57). To address the problem of the lever arm getting caught on fabric, we designed a new mount for the cartridge on the fabric which in turn holds it in place eliminating the problem. Lastly, to fix the weight of the respirator, we shorted the tubing and moved it closer to the center of mass of the pack which, according to the user, eliminated the unwieldiness of the backpack.

Figure 60: The inflated airbag on the user.

5.3.4 Analysis and Calculations

5.3.4.1 Gas Volume

It has already been determined that the victim will benefit greatly from an AirShield, which can extend their air supply for hours. What has not been fully determined is the volume of oxygen canister the AirShield must use.

The volume of the airbag is approximately 150 L. In addition, the scuba regulator needs a slight amount of static pressure to "prime" and the volume of the inflation mechanism must be accounted for when calculating the size of the oxygen canister. Since the product requires a specific amount of oxygen to inflate the airbag, the team has accounted for the costs of manufacturing a custom oxygen canister.

The total volume of the final product is 150L for the airbag, 2 L for the inflation mechanism, and 0.5 L for the regulator. There are 15.998 g per mole of oxygen, meaning to fulfill the volume of 152.5 L of gas at standard temperature and pressure, the AirShield requires 214.35 g of oxygen. Rounding up to 220 g will provide us with enough pressure to prime the respirator.

It is critical that users only use properly sized canisters, and a proprietary threading was considered, however, the AirShield would then not align with the relevant ISO standards on oxygen interfaces and valves, making it hard to bring to market.

5.3.4.2 Ergonomics

Due to the global nature of the team's problem statement, it is critical that the AirShield fits people of all sizes. To do this, the team designed the AirShield to fit anyone larger than the 5th percentile female, and smaller than the 95th percentile male. The primary means of variability the AirShield contains is adjustable straps. These can be used to adjust the height of the backpack on the user, therefore making it adjustable for people of all sizes.

This feature is heavily dependent on the choice of backpack. Our prototype contains adjustable straps but even so, it remains tight on the user. A 35 L backpack used in the final product has much more flexibility in terms of sizing and will eliminate this current issue.

5.3.5 Stakeholder Interviews/Feedback

Firstly, the team met for a second time with Chris Gueffroy [46]. Mr. Gueffroy, an avid backcountry skier, previously advised us on our concept, providing valuable feedback that made it to our final design. The team reviewed both our prototype and final product idea with Mr. Gueffroy, and he expressed excitement, in particular towards the working prototype. Mr. Gueffroy discussed with the team how he appreciated the value proposition, and how the AirShield addressed both during and after an avalanche. When asked if he would wear a final product version of the AirShield, Mr. Gueffroy gave an enthusiastic yes.

Secondly, one member of the team had a call with a representative from backcountry.com discussing the AirShield and following up on the team's previous correspondence. The representative expressed how he believed the AirShield may provide value to groups beyond typical backcountry athletes, although he was worried about the reliability. We discussed our plan for a production model and the representative pointed us towards the SIA (Snowsports Industries of America) which maintains relevant standards of snow safety equipment, something the representative elaborated on. For the AirShield to be sold in the US by any reputable distributor, it must meet or exceed not only relevant ASTM and select ISO standards, but be approved by the SIA. This is an added cost we must take into account when estimating the price of the AirShield.

At the end of the day, this second round of stakeholder engagement helped the team believe in its design choices more, and presented many aspects we failed to consider, such as the obstacles to bringing a personal piece of safety equipment like an airbag to market.

5.4 Conclusion

Our team set out with the express goal of assisting avalanche buried persons in the rescue process. With many of us being snow sports enthusiasts ourselves, the team has a unique perspective on avalanche safety that has brought out unique ideas which we have implemented into our works like prototype, and our final product. We strived to create a prototype which demonstrates novel technology while minimizing complexity and unnecessary components. In addition, the team prioritized a final product which meets or exceeds our specifications and meets our value proposition of a device that could save a backcountry athlete's life.

The intuitive nature of the AirShield lends itself to effortless use, exactly what a stakeholder wants when in a potential avalanche. People across cultures and languages are capable of understanding the purpose of an airbag, and the intuitive design of the toggle indicates to every user "Pull me in an emergency".

Overall, the AirShield is a novel approach to an old problem that seeks to eliminate the leading cause of death in avalanches, asphyxiation, while also working to prevent a user from becoming a victim by lowering their density in the snow. With these two benefits, the AirShield makes itself a clear choice for the safety conscious wherever they may be in the back country. Although the AirShield may cost $300, your life is certainly worth more.

5.5 Citations and References

[1] N. O. A. A. US Department of Commerce, "Avalanche safety," *National Weather Service,* 04-Mar-2015. [Online]. Available: https://www.weather.gov/bou/avalanchesafety#:~:text=On%20average%2C%206%20people%20die,of%2030%20to%2045%20degrees. [Accessed: 30-Jan-2023].

[2] "Statistics and reporting," *Statistics and Reporting | Colorado Avalanche Information Center*. [Online]. Available: https://avalanche.state.co.us/accidents/statistics-and-reporting. [Accessed: 30-Jan-2023].

[3] “US accidents table: Colorado avalanche information center,” *US Accidents Table | Colorado Avalanche Information Center*, 09-Jan-2023. [Online]. Available: https://avalanche.state.co.us/accidents/us. [Accessed: 30-Jan-2023].

[4] K. Lodge, “Remote Avalanche Control System proposed for Berthoud Pass,” *SkyHiNews.com*, 09-Feb-2012. [Online]. Available: https://www.skyhinews.com/news/remote-avalanche-control-system-proposed-for-berthoud-pass/#:~:text=It%20is%20the%20only%20Gazex,system%20is%20%24100%2C000%2D%24150%2C000. [Accessed: 30-Jan-2023].

[5] E. Meister, “The effect of consumer electronics on Avalanche transceivers,” *THE EFFECT OF CONSUMER ELECTRONICS ON AVALANCHE TRANSCEIVERS,* 2014. [Online]. Available: https://arc.lib.montana.edu/snow-science/objects/ISSW14_paper_P4.13.pdf. [Accessed: 11-Feb-2023].

[6] H. Ballard, D. Atkins, and L. Ballard, “Probing for avalanche victims - Montana State University,” *PROBING FOR AVALANCHE VICTIMS*. [Online]. Available: https://arc.lib.montana.edu/snow-science/objects/issw-2004-343-348.pdf. [Accessed: 11-Feb-2023].

[7] “Frequently Asked Questions - Utah Avalanche Center,” *FAQ*. [Online]. Available: https://utahavalanchecenter.org/education/faq. [Accessed: 09-Feb-2023].

[8] “Home: Colorado avalanche information center,” *Home | Colorado Avalanche Information Center*. [Online]. Available: https://avalanche.state.co.us/. [Accessed: 10-Feb-2023].

[9] “Outdoor Gear & clothing for ski, Snowboard, camp, & more,” *Backcountry*. [Online]. Available: https://www.backcountry.com/. [Accessed: 05-Feb-2023].

[10] D. Lind, “Understanding the avalanche beacon for best performance David A. Lind,” *Understanding the Avalanche Beacon for Best Performance*. [Online]. Available: https://arc.lib.montana.edu/snow-science/objects/issw-1994-415-422.pdf. [Accessed: 11-Feb-2023].

[11] *Deadly Avalanches: Snow Wars in Canada*. Canada: Free Documentary, February 12th, 2020. [Online]. https://www.youtube.com/watch?v=oMFe4bNJ5WA

[12] J. Konigsberg “Avalanche Modeling and Forecasting” Stakeholder Interview February 8th, 2023

[13] “What is Recco?” *How does the RECCO® Avalanche Rescue Technology work?* 10-Feb-2022. [Online]. Available: https://www.sport-conrad.com/blog/en/what-is-recco-avalanche-rescue-system/. [Accessed: 08-Feb-2023].

[14] C. Gueffroy “Backcountry Safety” In person stakeholder interview February 7th, 2023.

[15] "Backcountry Access Tracker S Avalanche Transceiver - Amazon.com." [Online]. Available: https://www.amazon.com/Backcountry-Access-Tracker-Avalanche-Transceiver/dp/B07C8GY6HT. [Accessed: 09-Feb-2023].

[16] "Transceivers - how do they work? Snowsafe blog," *Snowsafe*, 04-Nov-2021. [Online]. Available: https://www.snowsafe.co.uk/transceivers-how-do-they-work/. [Accessed: 08-Feb-2023].

[17] D. Eidenbenz, F. Techel, A. Kottmann, V. Rousson, P.-N. Carron, R. Albrecht, and M. Pasquier, "Survival probability in avalanche victims with long burial (≥60 min): A retrospective study," *Science Direct*, 06-Jun-2021. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0300957221002148. [Accessed: 09-Feb-2023].

[18] P.Ng, W.R. Smith, A. Wheeler, S. E. McIntosh, "Advanced Avalanche Safety Equipment of Backcountry Users: Current Trends and Perceptions," Science Direct, 30-Apr-2015. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1080603215001453. [Accessed: 08-Feb-2023].

[19] J. Drake, S. Siig, "Buried: The 1982 Alpine Meadows Avalanche", Greenwich Entertainment, 14-Jan-2022. [Amazon Video]. [Accessed: 10-Feb-2023].

[20] C. Gao, X. He, F. Ye, S. Wang, and G. Zhang, "Electromagnetic wave absorption and mechanical properties of cnts@gn@fe3O4/pu multilayer composite foam," *Materials (Basel, Switzerland)*, 27-Nov-2021. [Online]. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8658525/#:~:text=Carbon%2Dbased%20materials%20such%20as,used%20as%20electromagnetic%20wave%20absorbers. [Accessed: 12-Mar-2023].

[21] Compressed Gas Cylinders https://www.amazon.com/16g-Threaded-CO2-Cartridges-Connection/dp/B076YVFGKC/ref=sr_1_1_sspa?crid=32WS6ODSZ90MN&keywords=compressed%2Bgas%2Bco2&qid=1680467492&sprefix=compressed%2Bgas%2Bco%2Caps%2C105&sr=8-1-spons&spLa=ZW5jcnlwdGVkUXVhbGlmaWVyPUEzVjFUVkwxSlBSUFVHJmVuY3J5cHRlZElkPUEwMDMzNTkxMjNLRE1FMlVYWTJZSyZlbmNyeXB0ZWRBZElkPUEwMzMwMzM3M0c3UFo1T0EySkpGUSZ3aWRnZXROYW1lPXNwX2F0ZiZhY3Rpb249Y2xpY2tSZWRpcmVjdCZkb05vdExvZ0NsaWNrPXRydWU&th=1

[22] Aluminum 6061-T6 material data sheet https://asm.matweb.com/search/SpecificMaterial.asp?bassnum=ma6061t6

[23] https://drive.google.com/file/d/1hiKB_6HmBCpqAeKnMhD0sbWJCbat_LMF/view?usp=sharing

[24] https://www.aeroconsystems.com/motors/Screamer_folder/ObCol_whip-it_hybrid.pdf

[25] S. Ali, I. Abdalla, M. E. Gibril, H. A. Ahmed, and X. Jiang, “Enhancing the properties of nylon 66 fabric coated with a combination of PVA and SiO2 nanoparticles composite for vehicle airbag application,” *Journal of industrial textiles*, vol. 51, no. 2_suppl, p. 3330S–3346S, 2022, doi: 10.1177/1528083721988961.

[26] “Chalk it up to caulk if your home’s airtight; It’s a bit leaky, you say? Seek gaps and seal them,” The Grand Rapids Press (Grand Rapids, MI), The Grand Rapids Press, p. L3–, 2007.

[27]“Self-heal system mends cracks: epoxy resin system automatically seals holes and cracks in aircraft even while in the air,” Professional engineering, vol. 21, no. 10, p. 44–, 2008.

[28] Tay Tran “Contractor interview” Interview April 3rd, 2023

[29] “Best avalanche airbag packs of 2023,” *Switchback Travel*. [Online]. Available: https://www.switchbacktravel.com/best-avalanche-airbag-packs. [Accessed: 09-Apr-2023].

[30] *Air sealing seal air leaks and save energy!* Washington, D.C: Office of Building Technology, State and Community Programs, Energy Efficiency and Renewable Energy, U.S. Dept. of Energy, 1999.

[31] Phu Tran “Contractor interview” Interview April 3rd, 2023

[32] “Backcountry Skiing Checklist for 2023,” *Switchback Travel*. [Online]. Available: https://www.switchbacktravel.com/backcountry-skiing-checklist. [Accessed: 09-Apr-2023].

[33] L. Hirsch, Ed., “Backpack Basics (for teens) - nemours kidshealth,” *KidsHealth*, May-2020. [Online]. Available: https://kidshealth.org/en/teens/backpack.html#:~:text=Backpacks%20are%20a%20better%20option,spread%20out%20across%20your%20body. [Accessed: 09-Apr-2023].

[34] “How avalanche airbags work,” *How Avalanche Backpacks Work: An Overview of Diverse Avalanche Airbag System*, 19-Feb-2023. [Online]. Available: https://www.sport-conrad.com/blog/en/how-avalanche-backpacks-work-an-overview-of-diverse-avalanche-airbag-systems/. [Accessed: 09-Apr-2023].

[35] B. Temper, “Avalanche Airbag Effectiveness - Something Closer to the Truth,” *Blog: Avalanche airbag effectiveness - something closer to the truth - utah avalanche center*. [Online]. Available: https://utahavalanchecenter.org/blog/15943. [Accessed: 09-Apr-2023].

[36] J. Zhang, J. Liu, and X. Zhou, "Effect of sulfide inhibition on nitrate reduction in a denitrifying phosphorus removal process," IEEE Transactions on Biomedical Engineering, vol. 55, no. 1, pp. 307-313, Jan. 2008. doi: 10.1109/TBME.2007.900614. [Online]. Available: https://pubmed.ncbi.nlm.nih.gov/18076300/

[37] Amazon.com. (2023, April 30). CO2 Cartridge Search Results [Online]. Available: https://www.amazon.com/co2-cartridge/s?k=co2+cartridge [Accessed: April 30, 2023].

[38] "Liquid Nails Fuze It Max 9 oz. Interior/Exterior All Surface Construction Adhesive (LN-3000)," The Home Depot. [Online]. Available: https://www.homedepot.com/p/Liquid-Nails-Fuze-It-Max-9-oz-Interior-Exterior-All-Surface-Construction-Adhesive-LN-3000/313740337. [Accessed: April 30, 2023].

[39] "Airbag Fabric - Silicone Coated Nylon," Rewilder. [Online]. Available: https://www.rewilder.com/products/airbag-fabric-silicone-coated-nylon. [Accessed: April 30, 2023].

[40] "Scuba Regulator Diving manufacturer," Alibaba. [Online]. Available: https://www.alibaba.com/product-detail/scuba-regulator-diving-regulator-diving-manufacturer_60112409405.html [Accessed: 23-Apr-2023]

[41] J. Lohmeyer, "National Snow and Ice Data Center (NSIDC)," [Online]. Available: https://people.uwec.edu/jolhm/eh3/group4/references/nsidc.htm. [Accessed: Apr. 23, 2023].

[42] ASTM D6476-12

[43] "Mechanical Properties of Structural Materials at Low Temperatures" US Department of Commerce. National Bureau of Standards. [Online]. Available: https://www.govinfo.gov/content/pkg/GOVPUB-C13-0db7cc6eaefa48f82095c56b41cabfc0/pdf/GOVPUB-C13-0db7cc6eaefa48f82095c56b41cabfc0.pdf [Accessed: 23-Apr-2023]

[44] ASTM F1792-97

[45] "Interplay of respiration, circulation, and metabolism" Britannica [Online]. Available: https://www.britannica.com/science/human-respiratory-system/Interplay-of-respiration-circulation-and-metabolism [Accessed: Apr. 23]

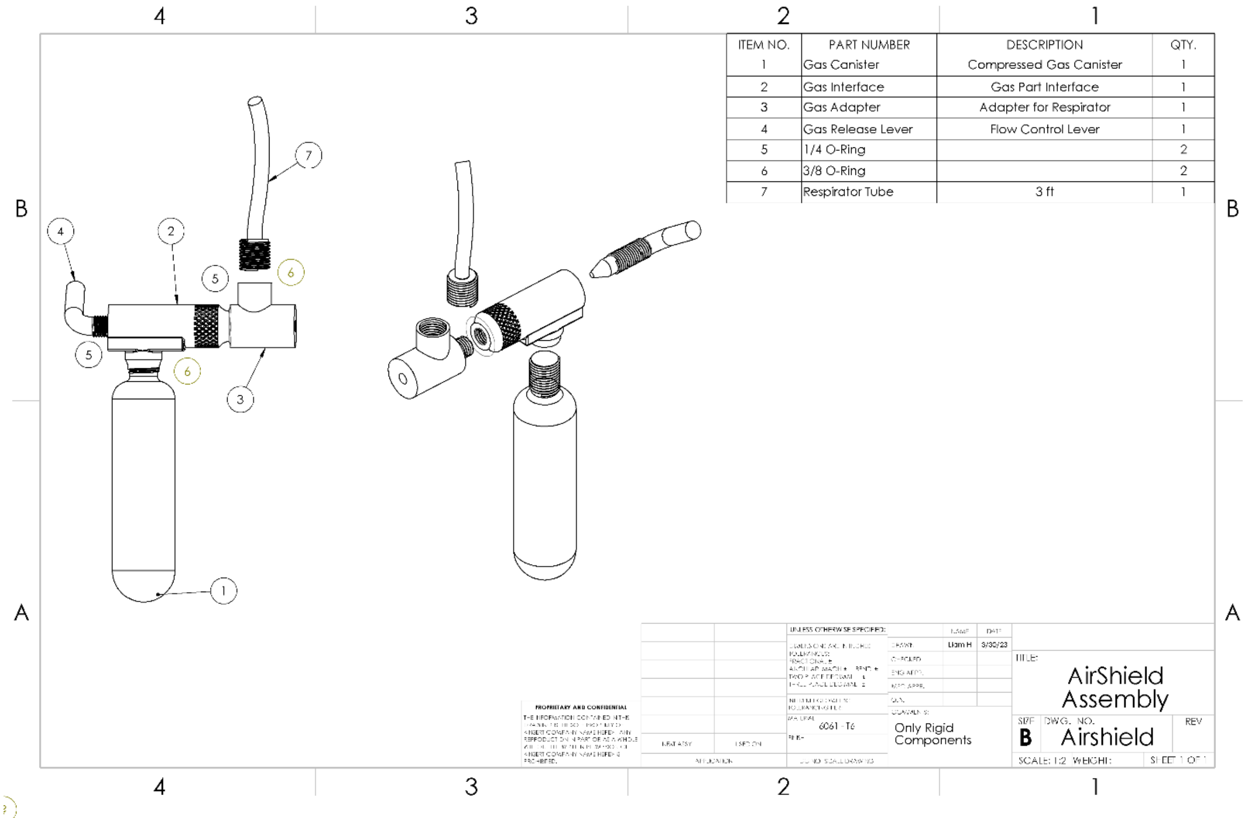
[46] Chris Gueffroy Second Interview

Appendix

[I]https://d.docs.live.net/1af38342dd47796e/Documents/Airbag%20Volume%20Testing%20Protocols.docx

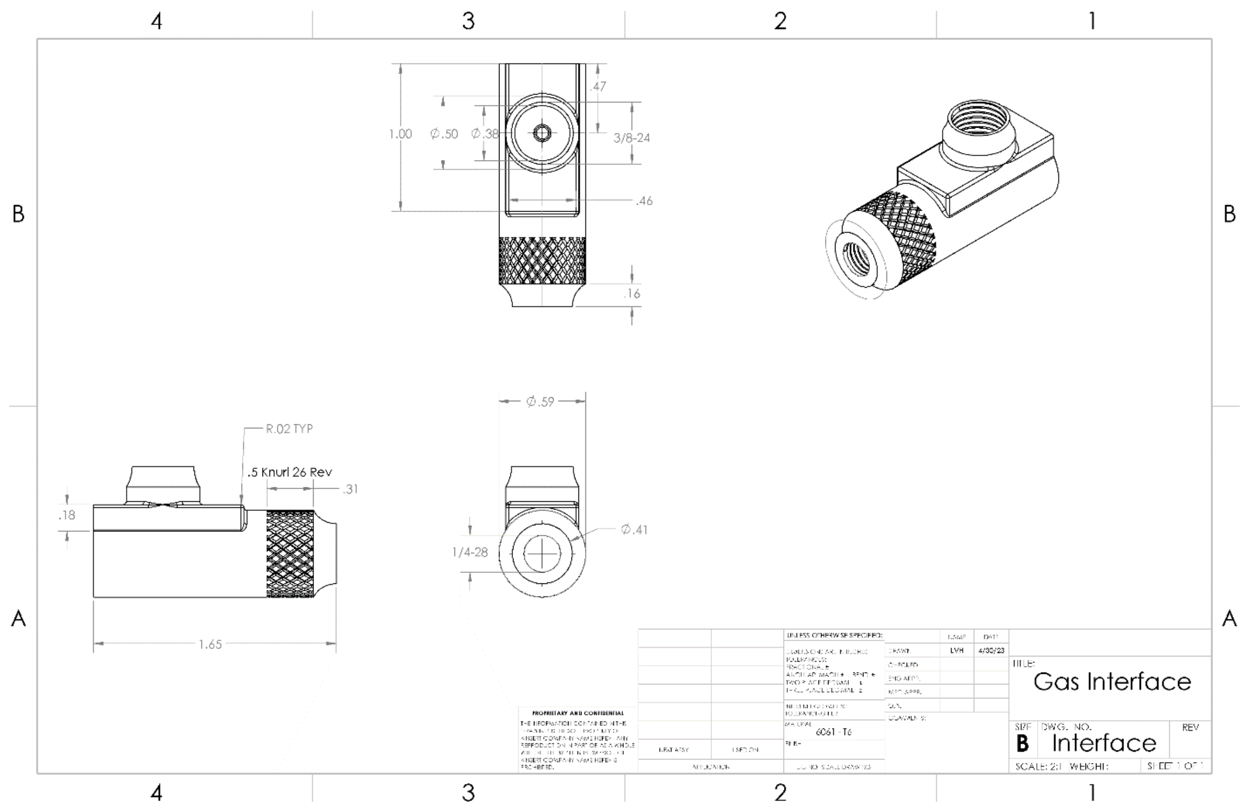
[II] Drawings

Assembly

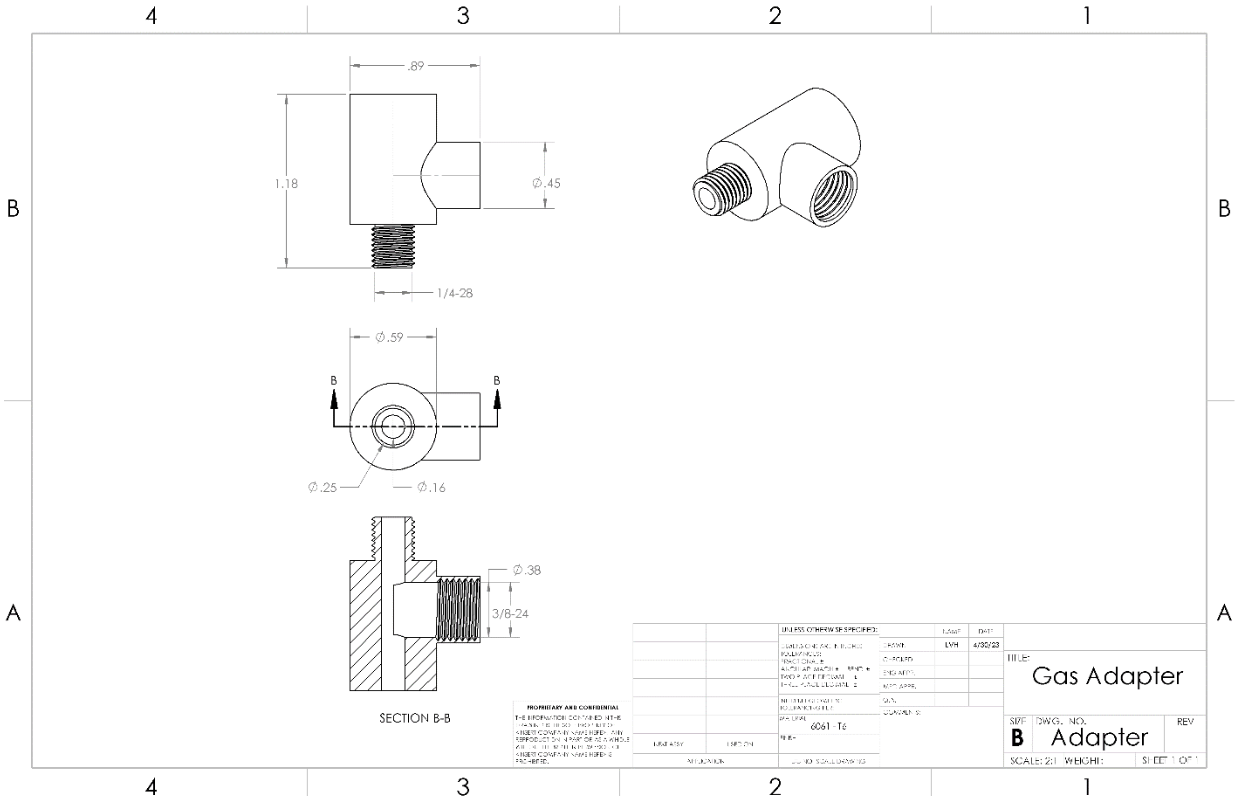


ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Gas Canister	Compressed Gas Canister	1
2	Gas Interface	Gas Part Interface	1
3	Gas Adapter	Adapter for Respirator	1
4	Gas Release Lever	Flow Control Lever	1
5	1/4 O-Ring		2
6	3/8 O-Ring		2
7	Respirator Tube	3 ft	1

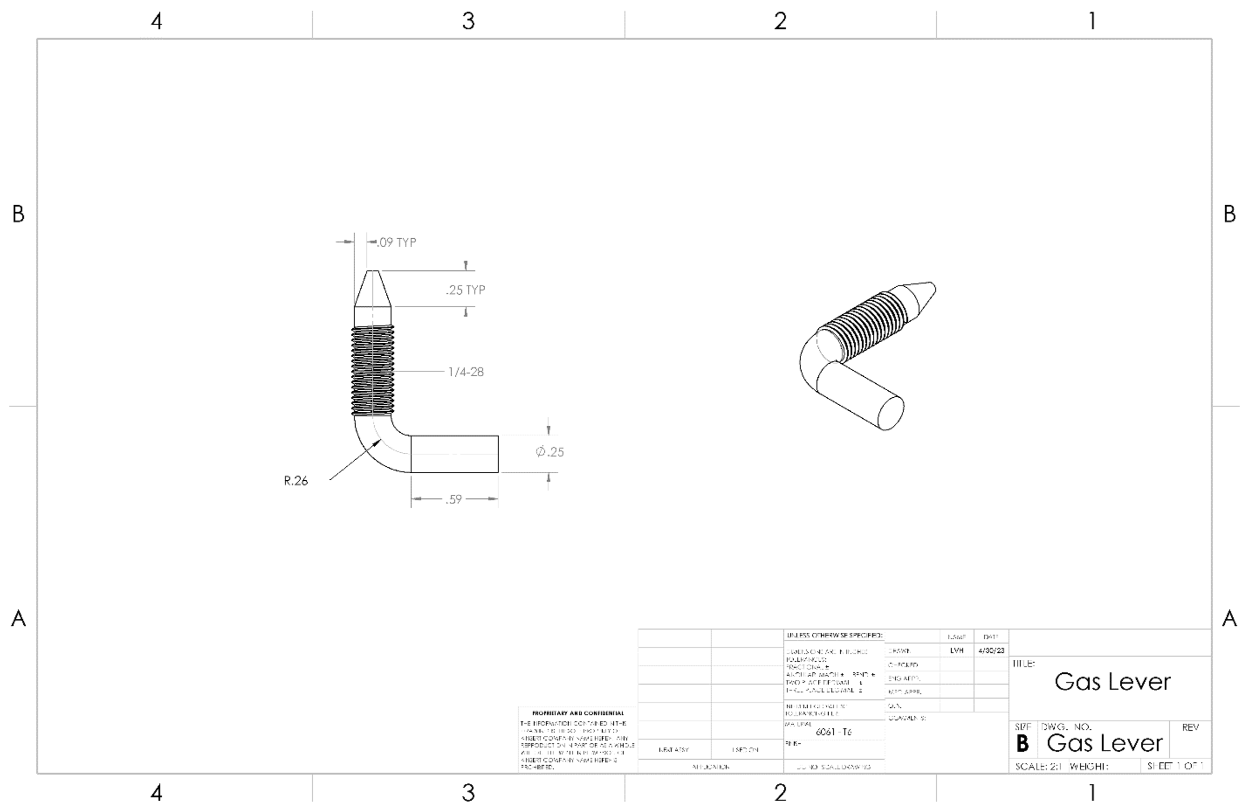
Sheet 2: Gas Interface



Sheet 3: Gas Adapter



Sheet 4: Gas Release Lever



Notes: The title blocks are filled out to the best extent possible.

[III] Team Profile


Figure 61: From left to right: Sophia, Gautier, Liam, Calvin, Cat.

Name: Sophia Giglio
Major: Electrical Engineering
Graduation Year: 2026
Background: CAD and Design courses and experience with machines
Design Goals: Understand what is actually required to solve a realistic real-world problem.

Name: Gautier Moreau
Major: QBE
Graduation Year: 2026
Background: High school engineering and design course
Design Goals: Improve my skills in the design process and help solve real-world problems.

Name: Liam Homburger
Major: Electrical Engineering
Graduation Year: 2026
Background: Basic making skills
Design Goals: To learn more about the design process and solve a real-world problem.

Name: Calvin Tran
Major: Computer Science
Graduation Year: 2026
Background: IBM design thinking certified, product delivery
Design Goals: Expand my design/engineering mindset and improve my problem-solving abilities.

Name: Cat Cronin
Major: Environmental Engineering
Graduation Year: 2026
Background: Childcare/Education/Environmental stewardship
Design Goals: Improve my ability to create a functioning solution to a problem rather than just identifying a problem.

[IV] Weight choices

We decided on our weighting based on what we collectively believe is most important for a successful project. This resulted in safety being one of the highest categories, and other critical categories to the success of our project also being weighted highly. This resulted in weights that reflected what the team valued to get the project done well, at the expense of possibly shutting down novel ideas. As for each rating, the team calibrated to the first option, and based our assessments relative to the first, providing an equal assessment for each.