UAS Avalanche Mitigation Mission Analysis

AERO F658 - Unmanned Aircraft Systems Operations
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Table of Contents

List of Figures

1. **Mission Description**

For this mission, our team will be gathering data to predict avalanche risk and choosing locations to potentially trigger a controlled avalanche, both using Unmanned Aircraft Systems (UAS). This includes two phases: photogrammetry and triggering of a controlled avalanche. For the first phase, we will be using photogrammetry to create a 3D model of a test location, which for this mission will be Moose Mountain, just northwest of Fairbanks. We will be taking photos and looking at factors that might cause an avalanche, such as dry vs wet snow, slope angles, cracks forming in snow leading to spontaneous release, recent heavy snowfall, and significant and rapid temperature changes. Once we have created a map and decided on optimal payload deployment locations, we will then conduct the second phase of the mission, which is actually dropping the explosive payloads at these locations. For the purposes of this course, we plan on only testing the deployment mechanism, without actually triggering any avalanches. The use of UAS systems allows controlled avalanches to be triggered, without the need for people to be around for the deployment of the explosives. Successfully completing this mission can create another way for UAS to be involved in avalanche mitigation in Alaska, while also integrating UAS systems into the National Airspace System.

2. **Mission Objectives**

The objective of this avalanche mitigation mission can be broken down into two submissions:

a. Data Collection and Analysis

For this phase of the mission, our objective is to create a repeatable, reliable, and precise method to gather and analyze data yielding our desired data products. With this information we will be able to identify areas of high avalanche risk and select an optimized drop location for an explosive payload.

b. Trigger a controlled avalanche

Using our data products from phase 1, phase 2 aims to demonstrate a proof of concept for delivering an explosive payload to an optimized drop location in order to trigger an avalanche.

3. **Environment**

To create a sample 3D model, the flight mission will be conducted at Moose Mountain, approximately 10 miles northwest of the Fairbanks International Airport. This area is outside of the controlled airspace, making it simple to get permission to fly, but also close enough to Fairbanks to be practical (figure 1). The approximate location is noted on the sectional chart below. The ideal time of year to conduct the flight would be the beginning of spring, when the snow thickness is at its greatest, but it is just beginning to warm up with increasing temperatures. We would be flying either the first or second week of April, with expected temperatures to be within a range of 30-45 degrees Fahrenheit. The average wind temperature at Moose Mountain during April 2023 was 1.5 mph, with a high of 15.8 mph and a low of 0 mph.

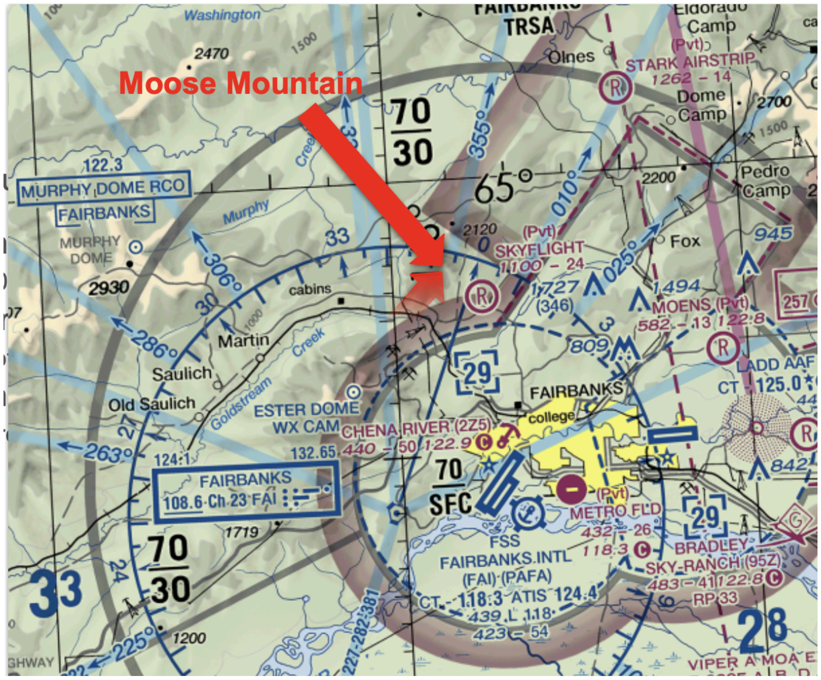

Figure 1: Airspace of area including and around Moose Mountain [1]

4. Benefactors and Collaborators

There are many potential customers and collaborators with avalanche mitigation. In Alaska, this might include Alaska parks and Outdoor Recreation, Alyeska Resort, Arctic Valley, Skeetawk, Tordrillo Mountain Lodge, and Chugach Powder guides. Additionally, the Federal Aviation Administration (FAA) issued its first ever approval for the Alaska Department of Transportation and Public Facilities (DOT & PF) and Alaska Railroad (ARRC) to carry explosives on board for avalanche mitigation (Glasset, 2023). Collaborating with these groups could help expand the applicability of UAS for avalanche mitigation in Alaska.

5. Performance Requirements

Performance requirements that are deduced from this mission set involve payload deployment, photogrammetry, and collection of thermal data. Payload deployment involves requirements of a UAS being capable of carrying 1 kg of explosive payload, must be capable of carrying a payload housing, and must be capable of carrying other potential components that would need to be integrated such as a receiver and battery for the payload deployment system. UAS Photogrammetry involves requirements of being user friendly to set up the predetermined paths for the UAS to follow, including a 3-axis stabilized gimbal for capturing images, and easily changeable batteries for flight endurance. Collection of thermal data involves requirements of the sensor system: must have thermal data to be added to locations on a modeled map, must store data onboard the UAS for further reduction, and must work in aerial applications and withstand the cold temperatures. Details about flight requirements during missions are explained further in this report.

6. **Desired Data Products/Results**

In phase 1 of this mission we will be conducting a series of remote sensing flights in order to map areas of high avalanche risk and select an explosive drop location. We will be conducting one flight for each of the following desired data sets:

- Photogrammetric data (photos including time and position information)
- Temperature data (simultaneously recorded with drone position and time)

With the data collected from these flights, we will use photogrammetric and data processing software to create the following data products:

- Elevation map 2D orthomosaic (for detecting areas of avalanche prone slopes)
- Surface temperature 2D plot
- Combined overlaid map representing avalanche risk

In addition to these products, we will also need to reference a baseline digital elevation model (DEM) that clearly shows the ground terrain and elevation. This baseline DEM will help us to understand the condition underneath the snowpack, as well as identify avalanche anchors (topographical features resisting avalanche conditions) and study the variable snow accumulation. This DEM must be developed from missions flown in previous years without snow on the ground. With these data products, we will have achieved the objective of phase 1 of the mission by assessing the target area's avalanche risk and providing information to select an optimized payload drop location.

7. **Technical Implications**

Technical implications from this mission include the navigation and altitude control, communications, controls and autopilot, payload, multi-vehicle solutions, and launch and recovery systems. The UAS would need to be suited with navigation and altitude controls as it is important for the UAS to know where it is at all times to relate all sensor data to its location. This includes visual imagery and snow surface temperature. Software will be used to record and relate positioning and time for post flight analysis. Communications between the drone and ground station would allow seamless switching between autonomous and manual flight modes, all while informing the ground station with telemetry data to follow where the UAS is at all times and ensure it remains within its path. For the data collection UAS, its sensor suite payload would involve a visual camera and IR thermometer. For the payload deployment UAS an explosive and deployment mechanism would be involved. As shown by the payloads, separate drones would be used to perform their respective tasks though will not need to interact with each other or share any information during their flights. Lastly, it is important to consider the environmental effects on the drone flight such as snow-covered takeoff and landing zones, high wind environments on the mountain slopes, and cold temperature effects on the sensor systems. It would need to be ensured that the sensors onboard the UAS remain within their operating temperatures. Details about payload requirements to complete this mission are explained further in this report.

8. Ideal/Realistic System Description

a. UAS System

Our ideal UAS systems can be divided into two sections: payload deployment and photogrammetry. The specifications and performance of each potential system will be discussed here and the webpage to view each UAS is linked in the appendix. To start with photogrammetry, we decided that the DJI Matrice 300 RTK would be an ideal choice. Some of the specifications include a 55 minute flight time, 7000 meter service ceiling, 12 m/s (~27 mph) wind resistance, and a maximum of 3 attachable payloads (2.7 kg total payload capacity. This flight time, service ceiling, and wind resistance make it a good option for flights in mountainous terrain, which is primarily where missions would be conducted. This UAS system also has features ideal for photogrammetry, such as live mission recording of aircraft movement, gimbal orientation, and photo shooting. These advanced flight features combined with high quality Zenmuse camera options provide high-precision data. The Matrice 300 RTK can be seen in Figure 2 below:

Figure 2: DJI Matrice 300 RTK [2]

Looking at a more ideal photogrammetry system, we have the DJI Inspire 1. This UAS system only has a single flight time of 18 minutes, but the batteries are easily changeable and we have access to 8 batteries total. This system can also operate at temperatures between -10 and 40 ℃, which should be sufficient for the time of year that we would be testing (early spring). This UAS also has a wind resistance of 22 mph, just slightly lower than the ideal UAS system above. Lastly, one big advantage of this system is that it is easy to transport, prepare for flight, and can be flown with very minimal piloting experience. The drone is also already available to us through the Duckering aerospace lab. The disadvantage of this drone is that it has minimal payload attachment points, besides the built in attachment point for a Zenmuse camera. This makes it ideal for photogrammetry, but an additional drone is required for payload deployment. The DJI Inspire 1 can be seen in Figure 3 below:

Figure 3: DJI Inspire 1 [3]

Looking specifically at payload deployment, the ideal system would be the DJI Flycart 30. This UAS system is designed specifically for payload carrying. The hovering endurance is 29 minutes empty (65 kg with two DB2000 batteries), 18 minutes with a 30 kg weight load, and 8 minutes with a 40 kg weight load. This allows us to fly with much heavier payloads than any other UAS system that is currently available to us. With a 30 kg payload, it also has a max flight distance of 16 km. Other specifications include a 6000 meter maximum flight altitude, a 12 m/s wind resistance (~27 mph), and an operating temperature of -20 to 45 ℃. This system also has an optional winch system, allowing us to lower and deploy the payload without having to make any UAS modifications. Because of the size of this aircraft, we would need a certificate of authorization (COA) to operate it. This would require prior planning, to give the FAA up to 60 days to conduct a comprehensive operational and technical review. An image of the DJI Flycart 30 can be seen below:

Figure 4: DJI Flycart 30 [4]

For the realistic payload deployment system, our team has decided to use the DJI S1000. This UAS system has a 15 minute hover time at 9.5 kg total weight. The empty weight of the UAS is 4.2 kg. This UAS is more difficult to operate than some of the other DJI systems, due to having a less familiar operating system (FrSky transmitter with a pixhawk flight controller). Because of this, we would need to be trained by a more experienced pilot to operate this system. The advantages of this drone are that it is easy to assemble/disassemble and transport, has adequate room and attachment points for payload systems, has a high wind resistance, and can operate at temperatures between -10 to 40 ℃. The payload carrying and deployment system would have to be designed to adapt to this UAS system, as it does not have a built in option to use a winch. The DJI S1000 can be seen below:

Figure 5: DJI S1000 [5]

b. Payload Deployment

For an ideal payload deployment, we would use an RC winch, such as the RC4WD 1/10 Warn 8274 Winch, which has a standard capacity of 25 lbs. This winch weighs 93 g and can operate using a 3S lipo battery, with an operating voltage between 6-12.4 V. The carrying capacity would vary depending on the rope used to raise or lower the payload. The housing for the explosive payload and the winch could be created by 3D printing. This mechanism would simply lower the payload to the ground, and continue to unwind the rope until it detaches from the winch. The payload housing would also need a servo to lower a hatch, allowing the payload to lower to the ground. All servos and winches would ideally be integrated into the current UAS systems, using the same receiver and transmitter that the UAS is flown with.

At least for the first iteration of a payload deployment mechanism, this would not be realistic with the supplies we have available to us currently. For example, we were unable to find any RC winch currently on hand, let alone the ideal one mentioned above. The plan for the first iteration is to have the payload hatch open, and have a roller lower the payload mechanism. This idea can be seen in figures 6. The lowering of the mechanism would be controlled by gravity, and could be slowed by adding friction at the ends of the roller. Although this mechanism should work, it wouldn’t be ideal as the team can’t stop the payload deployment once it has begun. The first iteration would also include a separate receiver and transmitter to control the servo that opens the payload hatch. This allows for simple lab testing without any power being supplied to other parts of the UAS. The servo used would be a DSSERVO RDS3218. The dimensions of this servo are 64x55.6x20 mm, weighing 60 g total. The input voltage for this servo is 4.8-6.8V, also being powered with a 3S lipo battery. The total weight of the 3D printed housing is unknown as it has not been designed.

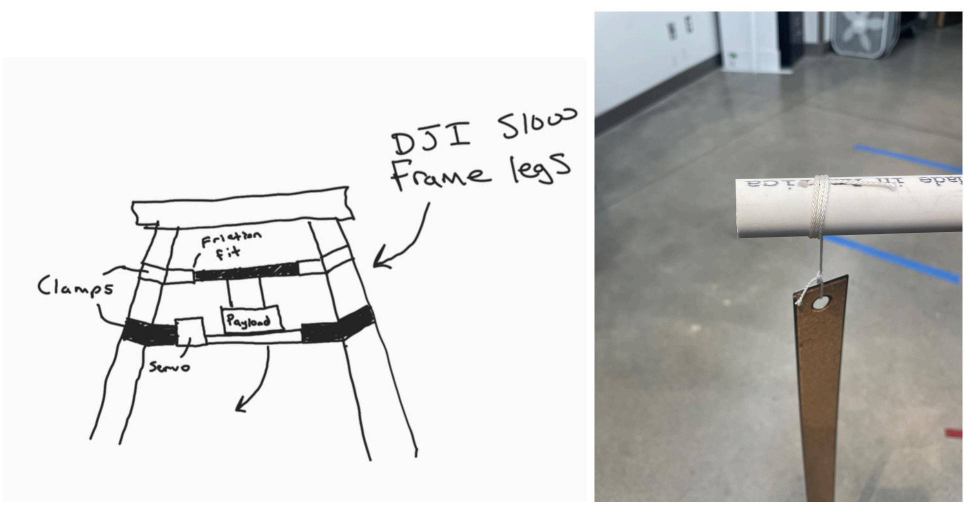

Figure 6: Payload deployment mechanism idea

c. Snow Depth

When looking into the causes of avalanches, one significant factor is the layering of snow, causing slab avalanches when a weaker layer collapses under a stronger layer [6]. In an ideal UAS sensor suite, a DJI Zenmuse L2 sensor system would be used. This sensor system can collect both LiDAR and color visible data. The figure below shows the DJI Zenmuse L2 sensor system. The built in visible color camera is suitable for photogrammetry. The LiDAR camera would provide snow depth measurements, measuring the changes in the density of snow layers and then onto the ground [7]. This sensor system is also compatible with the DJI Matrice 300 Series and integrates smoothly with DJI's live data transmissions [8]. The full webpage to this sensor can be found in the appendix.

Figure 7: DJI Zenmuse L2 sensor system [9]

Though the DJI Zenmuse L2 sensor system would easily detect snow depth and snow layering, it is very expensive. To simplify this, a single point snow depth measurement can be taken along the UAS path though alternative LiDAR cameras that effectively detect snow depth also are not cheap. From this it was concluded to turn to other more cost-effective methods of avalanche detection.

d. Thermal Imaging

Another important factor when looking into causes of avalanches is the separation in snow layers caused by weaker layers formed by refreezing cycles of snow [6]. With the DJI FLIR Zenmuse XT2 camera both thermal and color visible data can be collected, with the 20MP visible color camera being suitable for photogrammetry [10]. Figure 8 shows the DJI FLIR Zenmuse XT2 sensor system. This sensor system is also able to combine the two images taken showing temperatures on a constructed map. Being DJI branded, this sensor system is compatible with the DJI Matrice 600 and 200 series platforms and has smooth integration with DJI's live data transmissions and allows for spot metering to quickly identify the temperature of any point in view [11-13]. Figure 9 shows an example of how the sensor system is able to record temperatures and combine the two images to easily see what the temperatures would relate to. The full webpage to this sensor can be found in the appendix.

Figure 8: DJI FLIR Zenmuse XT2 sensor system [11]

Figure 9: DJI FLIR Zenmuse XT2 thermal imaging [11]

Though the DJI FLIR Zenmuse XT2 sensor system can easily merge visual and thermal maps, it is very expensive. A practical solution for this would be with the use of an IR Thermometer to check temperatures at different locations at a 1 meter distance from the ground to find where snow has melted. This data would be stored on an onboard LabQuest. This thermal data would also need to be manually overlaid onto a map to show the locations it was taken from. Figure 10 shows a IR Thermometer planned to be used and figure 11 shows a LabQuest system that will collect and store the data. The full webpages to the LabQuest System and IR Thermometer can be found in the appendix.

Figure 10: IR Thermometer to measure surface temperature [14]

Figure 11: LabQuest System to collect and store temperature data [15]

e. Visual Imaging

For visual data, the camera that is included with the DJI Inspire 1 will be used. With this camera visual imagery of the snow surface can be taken and used to create 3D maps of where avalanche slope angles exist. For the best image quality, a 60 to 70 percent forward overlap and 20 to 40 percent lateral overlap will be used and for a 20MP camera, a minimum distance from the ground of 50 meters is recommended to capture images of quality for mapping [16, 17]. The figure below shows the DJI Inspire 1 camera unit. The full webpage to this sensor can be found in the appendix.

Figure 12: DJI Inspire 1 camera unit [18]

9. Potential Payloads

As a whole, a realistic system and potential payloads accessible by ACUASI would include a DJI S1000 with a 3D printed deployment mechanism attached. For photogrammetry mapping, a DJI Inspire 1 will be used with a DJI Inspire 1 camera unit to map the pitch of the varying slopes to identify areas of high risk, between 30 and 38 degrees [19]. Additionally onboard the DJI Inspire 1 would be an IR Thermometer to spot check temperatures at different locations to find areas where snow has melted creating unstable snowpack layers. This involves mapping surface areas that have been heated by the sun that pose a high risk of an avalanche occurrence. To record and store this thermal data will be a LabQuest system mounted on board DJI Inspire 1.

10. Mission Software

For each phase of this mission, we will be using a series of software tools for each step along the way. For phase 1 of the mission, our workflow will utilize the following software:

<u>Flight Planning - DJIFlightPlanner (Inspire 1)</u>

DJIFlightPlanner is a software tool that allows us to create a completely autonomous flight program for our remote sensing missions [19]. This software gives full control over important UAS/sensor variables including flight height, ground speed, forward overlap, side overlap, ground pixel size & imaging frame rate. This software will be useful for automating our photogrammetry flight path, and then adjusting that same flight path to a lower elevation for our temperature sensing flight. Once we have specified our mission parameters, this software allows us to export the flight file and import directly into our flight operations software Litchi. This is the software sequence that we will be using for our photogrammetry mission with the DJI Inspire 1.

Flight Planning and Operation - 3DR Pixhawk 1 Flight Controller running PX4 (S1000)

The S1000 that we will be using uses a 3DR Pixhawk 1 autopilot which is able to run PX4 software. This PX4 software provides a mission planning, operations and quick analysis interface for use with the flight controller on our S1000. The 3DR Pixhawk 1 Flight Controller is now discontinued, but still works well with the S1000 that we will be flying [20, 21].

Flight Operations - Litchi (Inspire 1)

Litchi is an extremely capable operations software that serves as an excellent interface for both automated and manual flight operations. One of the key features of Litchi is a readily available mode switching button for easy toggling between automated and manual flight modes. This is an important feature for safety considerations, as we may need to reclaim manual control of the UAS at any given time during flight in an emergency situation. This software boasts a thorough in-flight interface detailing the performance of the UAS and sensor via real time data link. The detailed description of the important features that Litchi offers, directly imported from Litchi's software specifications can be found in the appendix.

Data Analysis - DJIAfterFlight

DJIAfterFight is a powerful data visualization software that allows the user to quickly view the resulting data products from a photogrammetry mission [22]. The software quickly forms a sample data product including a map constructed with photographs from the flight. We will utilize this software tool after our mission before leaving the mission site to perform a preliminary analysis of the photogrammetric data to ensure that we have all the data we need. The detailed description of the capabilities of DJIAfterFlight directly from the website's software description can be found in the appendix.

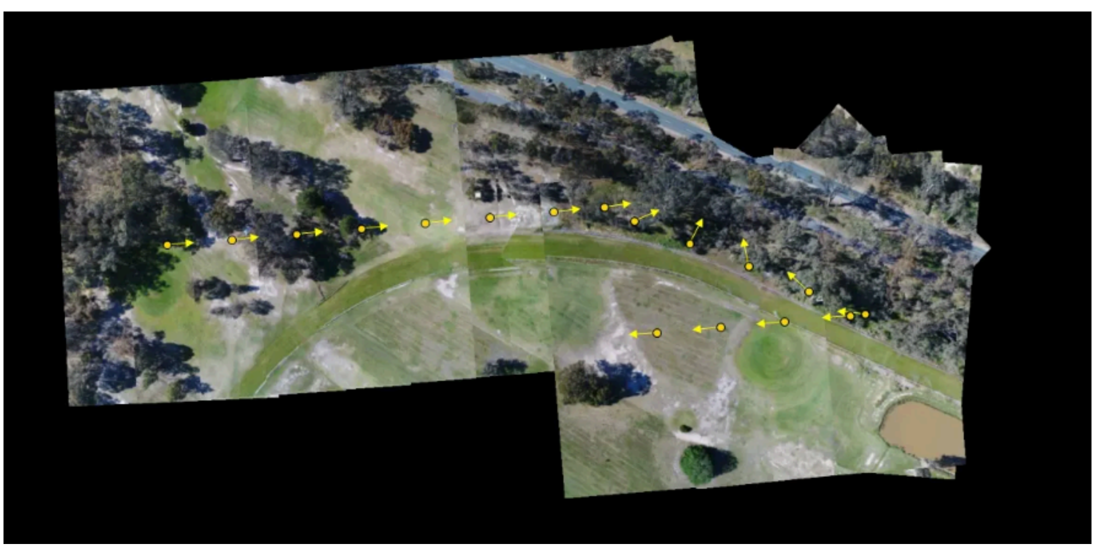

Figure 13: Example of desired data product from mission

Photogrammetry/Mapping - iWitnessPro V4, Drone Deploy, ArcGIS, Matlab, R

iWitnessPro V4 is a high powered photogrammetry software which quickly takes photogrammetric data and creates powerful 2D and 3D maps [23]. We will use this software after the mission when we are performing a thorough data analysis. This software will yield our final versions of our desired data products including an elevation map 2D orthomosaic, surface temperature 2D orthomosaic, and a combined overlaid map representing avalanche risk. One of the key features of this software is that it is designed to easily combine automatically and manually recorded data and map them together. This will be an important feature as we attempt to combine our automatically generated photogrammetry map with our manually recorded temperature data.

In the process of analyzing our manually recorded temperature data, we will need to use a data analysis software to plot temperature and position against time. If during our experimentation with iWitnessPro V4 this data proves easy to combine with automatically generated maps, we will be able to complete our data analysis solely using this software. However, if we experience difficulties plotting this data, we will need to export the flight position/time data from Litchi as well as the temperature/time data from the LabQuest and plot them together using software such as Matlab, Python, or R. With this data plotted, we will simply scale and overlay our plotted data onto the automatically generated photogrammetry map.

Additionally, we are planning to use iWitness Pro V4 to generate an elevation gradient (slope) map. If we have difficulties getting this software to generate our desired data products, we have backup softwares that we are prepared to use. Drone Deploy is a software that is compatible with the DJI Inspire 1 and provides flight planning, operations interface, and after flight analysis. This will serve as a substitute for the aforementioned software tools in the case that we are displeased with the resulting data products. If we struggle to generate slope maps using iWitness Pro V4, then we will use ArcGIS online for mapping slopes. The detailed breakdown of iWitness ProV4's capabilities directly from the software's online description can be found in the appendix.

11. Conceptual Mission Architecture & Flow

a. 3D Mapping

For the 3D mapping, the first step is to prep the DJI Inspire 1 drone. This includes inspecting all parts of the drone (propellers, motors, batteries, etc.) and making sure everything is operational, such as the gimbal mechanism and raising and lowering of the landing gear. Once the drone has been evaluated, the batteries will be fully charged and packed along with the drone. We will then transport the drone to the test location, which in this case is currently Moose Mountain. Once there, we will deploy the drone, taking photos of the terrain, varying the angles and altitudes that photos are taken at. Once these photos are collected, we will conduct the data analysis and use these photos to create maps of target areas detailing the avalanche risks. Once this is complete, we can select an optimized payload drop location for the second part of the mission. The area we are covering is roughly 0.83 square miles, as seen in Figure 14. With the DJI Inspire 1 flying at 2.5 m/s (~5.6 mph), we can cover 1.68 miles per flight. The region will be split up into different paths that the drone will sweep, taking pictures of the surrounding terrain. Each flight path is designed to be 1-1.2 miles in total length, leaving some battery reserves just in case. Each path also starts and ends on one of the ski paths for easy deployment and retrieval. Each line that the UAS will fly is also 0.3 miles or less, minimizing the number of observers needed to complete the mission. For this mission an image width of 264 feet is required to capture the entire area below the UAS during its pre-programmed path to ultimately create a full map. A 37 meter height will be sufficient for this mission while a higher altitude will allow for a larger forward overlap in images. Figure 15 shows 15 flight paths that cover the entire area of the mountain. To completely sweep the area once, it would take about 3.75 hours, assuming each flight is 15 minutes (the maximum length of one flight). One limitation is the number of batteries available to us. Currently we have 8 batteries, so we can complete 2 hours of flights without recharging. With 20 minutes allotted for moving between each launch location, it would take around 4.5 hours to complete 8 flights. It would take 2 days to cover the whole area at one altitude. To mitigate the image distortion, sensor slant range, and obstructions to the view of the terrain, images will be taken at 3 different altitudes at different angles, 30, 40, and 75 degrees.

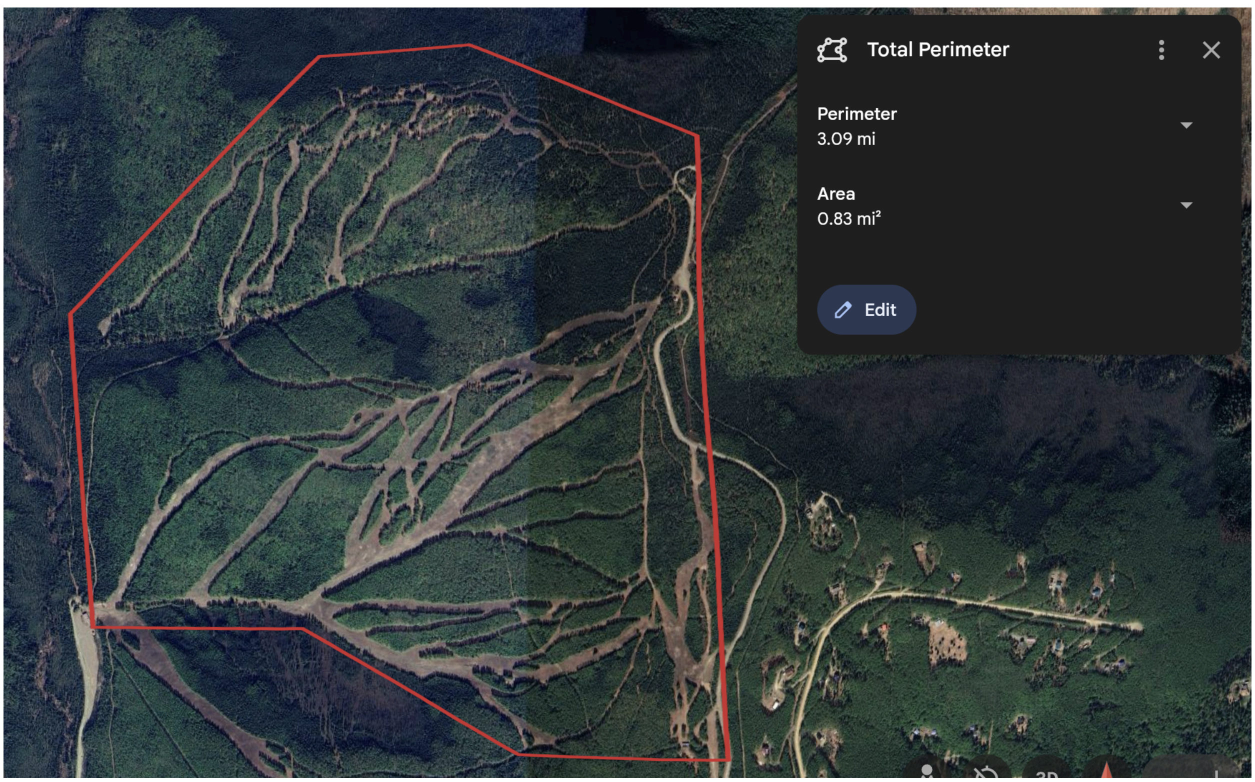

Figure 14: Perimeter of the Photogrammetry Area Flown

Figure 15: Individual Flight Paths

b. Payload Deployment

For the payload deployment, we must first design and assemble the housing and deployment mechanism for the payload. This will include 3D printing of certain parts, such as clamps, a payload platform, and a lowering mechanism. Once all the parts needed are printed, we will securely attach it to the landing gear of the S1000 drone. Other components will be integrated for the first iteration, such as a receiver and small battery to operate the servo, which will lower a hatch so the payload can deploy. Once the mechanism has been fastened to the S1000 drone and we have printed a makeshift payload (one that does not actually include any explosives), we will test the lowering mechanism in the aeronautics club lab, without supplying power to the S1000 drone. Once we have successfully deployed the payload in the lab, we can then go conduct a simple flight test, where the S1000 will be hovered near the ground and we will drop the payload below.

12. Data Reduction/Analysis

For the photogrammetry, this will include identifying areas where the slope angle matches those where an avalanche is expected to occur. We can also predict snow depth by looking at reference points, such as trees, bushes, or rocks to estimate the snow depth and certain points. With the IR thermometer, we will identify areas where the snow has melted, leading to create weak snowpack layers that can lead to slab avalanches. Lastly, we will use real time position data from the S1000 and overlay temperature data onto a 2D orthomosaic from the photogrammetry.

13. Timelines

The timeline the mission plan is as follows:

- Week 1
  - Mission analysis (Friday March 29)
  - 3D print housing for payload (and create representative 3D printed payload)
- Week 2
  - Final mission analysis (TBD)
  - Draft mission operation plan (Friday April 5)
  - Flight test Moose Mountain
- Week 3
  - Attach S1000 payload and lab test
  - Conduct S1000 flight test
- Week 4
  - Likely last week for potential flight tests, payload testing
  - Use software to create 3D model of Moose Mountain region
- Week 5
  - Final mission operation plan (Monday April 22)
  - Final team briefings will be the same week
  - Team video, complete any remaining tasks

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Appendix

Websites for ideal/realistic UAS System descriptions:
DJI Matrice 300 RTK:
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DJI Inspire 1:
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