UAS Avalanche Mitigation Mission Operations

AERO F658 - Unmanned Aircraft Systems Operations
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1. Mission Synopsis

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 focusing on the first phase of this mission, the photogrammetry portion. If time permits, the second phase (payload deployment) of the mission may also be conducted. 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. Location

The flight test will be conducted at Moose Mountain, about 10 miles northwest of Fairbanks. This location was chosen due to its proximity to town and its terrain. With the ski trails at the location, we can create a proof of concept 3D map, without having to travel to a location where avalanche mitigation methods would actually be used.

2.1 Transportation

For the transportation of personnel and equipment, we will use a 2007 Ford F-150. This vehicle has 5 seats, leaving room for the 3 people conducting the flight mission and some extra room for tools and equipment. The truck also has a 6.5 ft bed, leaving sufficient room for both the DJI Inspire 1 and the DJI S1000 UAS systems. Both of these multi-rotors will be transported in their respective pelican cases for safe transportation. The crew will leave from the UAF Usibelli building and will arrive at the mountain approximately 16 minutes later. The truck will also be used to transport supplies at the test location, since we will only be launching the drone from the Moose Mountain parking lot at the top of the hill. This test location will minimize the need for carrying supplies around by foot.

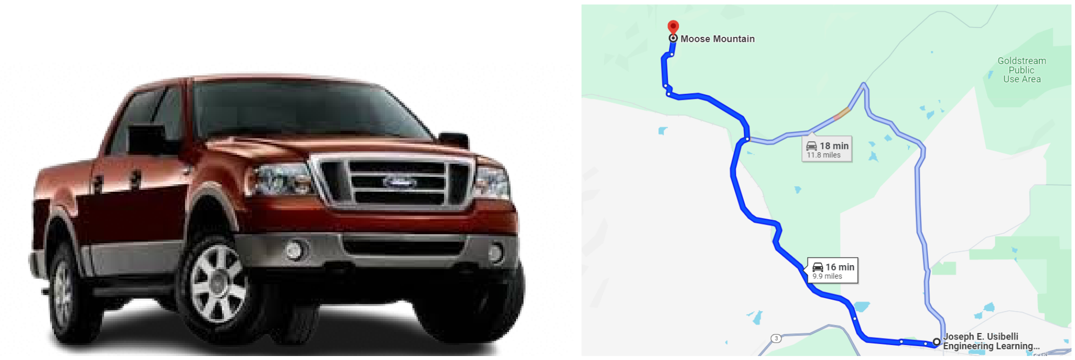

Figure 1: Vehicle Used for Transportation (Left) and Route to Test Site (Right)

2.2 Airspace

Moose Mountain is located outside of the class D controlled airspace that covers the Fairbanks area. Its approximate location can be found on the sectional chart in Figure 2 below. Although we are outside of the controlled airspace, we will still need to comply with the Remote ID rules set out by the Federal Aviation Administration (FAA). This provides identification and location information that can be received by other parties through a broadcast signal [1]. This is required for all drones being flown for recreation, business, or public safety purposes. Instructions for this can be found on the FAA website under “remote identification for drones”. For safety purposes, it would also be useful to monitor certain radio frequencies such as the Fairbanks tower frequency (118.3) or the Fairbanks approach/departure frequency (125.35). This will allow us to be aware of both incoming and departing traffic in the vicinity of the test location.

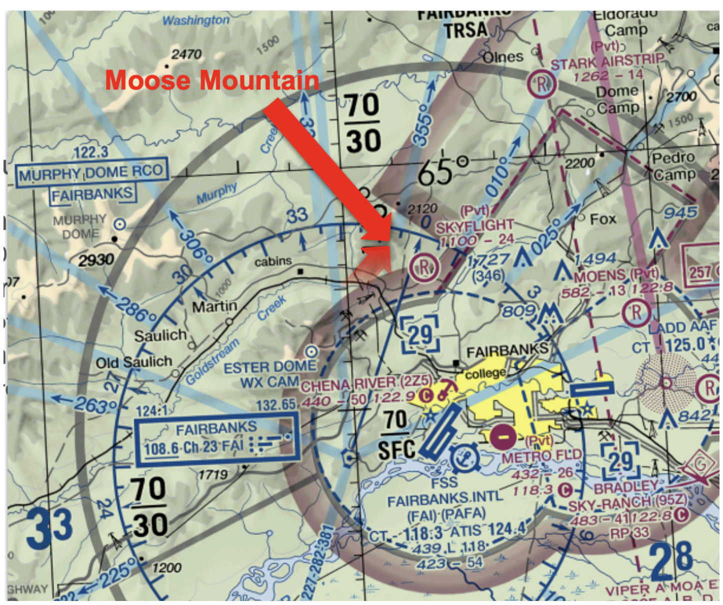

Figure 2: Fairbanks Area Sectional Chart [2]

3. Environment

Flying will be conducted on mountainous terrain, which can be seen from the aerial view of the test location below. The location that we will fly from is circled in red.

Figure 3: Aerial View of Moose Mountain

Since this mission would be flown towards the beginning of spring, in early April, we can expect temperatures to be near freezing (30-40 ℉). Most of the snow will be packed down from people skiing throughout the winter, it will still be important to bring snowshoes for potentially walking off of the ski trails. There is also some potential for winds, especially at the top of the hill, although there is not expected to be high winds. The average wind speed for April of last year in this location was 1.5 mph, with a high of 15.8 mph and a low of 0 mph as shown in Figure 4 [3]. As we are outside of Fairbanks, we will also want to be aware of potential wildlife. This would include lynx, moose, porcupine, and various birds. Although an unlikely encounter, it would also be important to plan for bear sightings as they come out of hibernation around this time of year. The lack of flat terrain also means that we will have to fly from either the road, or one of the parking lots. There are also some effects on the people and equipment in the area. For the equipment, the cold temperatures may result in reduced battery performance, so we will have to monitor them very closely. As this is a popular ski area, we will also need permission to fly in the area and make sure that we have set a boundary for the flight area. This is to help ensure that people are not skiing below us, unaware of the flight operations going on.

Summary
April 1, 2023 - April 30, 2023

	High	Low	Average
Temperature	49.2 °F	-4.0 °F	20.5 °F
Dew Point	34.8 °F	-11.2 °F	9.5 °F
Humidity	94 %	32 %	63 %
Precipitation	0.29 in	–	–

	High	Low	Average
Wind Speed	15.8 mph	0.0 mph	1.5 mph
Wind Gust	19.0 mph	–	1.6 mph
Wind Direction	–	–	South
Pressure	30.77 in	29.73 in	–

Figure 4: April 2023 Moose Mountain Wind Conditions [3]

4. Safety

Mission safety will be divided into many sections outlined below, including flight/equipment safety, communications, injury/emergency planning, and environmental safety, to name a few.

Flight safety: This will include carefully conducted preflight, during flight, and post flight inspections using the checklists provided by ACUASI with the DJI Inspire 1 drone. This covers equipment inspections, including propellers, electronics, and any additional payloads to check for damage. Checklists will also ensure that we follow any flight procedures without missing any important components.

Injury to ground personnel: Each role will include a job hazard analysis (JHA) that will familiarize them with the potential risks associated with their position. This might include risks associated with the terrain or risks with operating the aircraft. The crew will also have a site safety plan.

Equipment damage: Should one of the components be found to be inoperable, we will have backup equipment, tools, replacement parts, and crew members that are familiar with repairing the drone.

Weather: This will include checking the forecast ahead of time and on the morning of the mission. This is to make sure that the temperature and winds are as expected, and within the operating parameters of the UAS system. Weather checks are also important to make sure that crew members have adequate gear (jacket, hats, gloves, etc.) for the day.

Natural dangers: Crew members will be made aware of the potential wildlife in the area and terrain hazards. This includes uneven ground, bears, wolves, lynx, and moose. Bear spray will be carried by all personnel.

Communications: Mobile phones will have coverage since the flight operations are very close to Fairbanks. Additionally, radios will be provided to each crew member to make communications quick and easy between personnel.

Survival gear: A more comprehensive list of supplies will be provided below, with gear such as bear spray, coats, water, and food being covered.

First aid/buddy care: First aid kits will be located in the truck. At least one crew member should also be CPR certified.

Rescue/evacuation plans: The protocol for emergency evacuations will be to call for an ambulance.
Personnel training: All crew members should be familiar with all of the safety equipment and procedures. This includes knowing first aid locations, emergency procedures, and use of safety equipment.
Airspace: As covered above, it will also be important to monitor airport radio frequencies to ensure that we are clear of any potential incoming and departing traffic from the Fairbanks area.

5. Personnel

The mission will require at least 3 personnel. This will include 1 pilot and 2 observers. The pilot will be responsible for operating the DJI Inspire 1, as well as transporting the UAS between any flight locations. If the second phase of the mission is conducted, they will also be operating the DJI S1000 drone. The pilot will be responsible for inspecting any flight equipment and making sure it is assembled/disassembled properly. Each of the observers will watch the DJI Inspire 1 from different locations along the flight path. One observer will be next to the pilot and will be able to assist them if necessary. The other observer will be located along the flight path, down the hill. Observers will be responsible for transporting spare tools, supplies, and batteries that are necessary for flight operations.

6. Logistics

6.1 UAS Systems

As mentioned, the DJI Inspire 1 will be used for the photogrammetry phase of this mission. 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 °C, which should be sufficient for the time of year that we would be testing (early spring with highs of 50°F and averages of 20°F). 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 5 below:

Figure 5: DJI Inspire 1 [4]

The secondary priority will be the testing of the payload deployment system. The DJI S1000 would be used for this portion of the mission. 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 in the figure below.

Figure 6: DJI S1000 [5]

6.2 UAS Payloads/Sensors

6.2.1 Thermal Imaging

Temperature data will be taken with the use of a Vernier Infrared Thermometer to check temperatures at different locations. This sensor can measure a 65mm diameter circle at a 1-meter range to find where snow has melted. This thermometer can read temperatures down to -4°F and the operating temperature is a minimum of 32°F. Insulation of this sensor when onboard the UAS will be considered. 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 7 shows a IR Thermometer planned to be used and Figure 8 shows a LabQuest system that will collect and store the data. Some extra required equipment for this system include triple A batteries and a cable to connect the two devices. For our proof of concept 3D map, we will carry the IR thermometer by person, and walk from point to point that we want to measure. For a full scale 3D model for future missions, the sensor would be attached to the S1000 drone. The full webpages to the LabQuest System and IR Thermometer can be found in the appendix.

Figure 7: IR Thermometer to measure surface temperature [6]

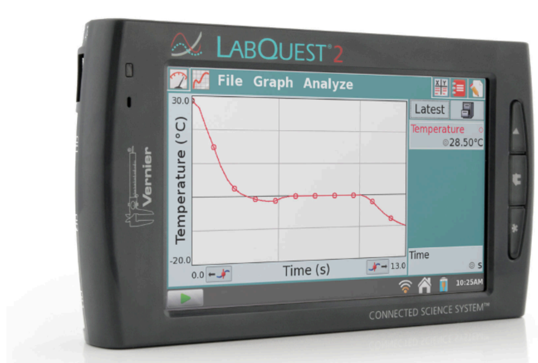

Figure 8: LabQuest System to collect and store temperature data [7]

6.2.2 Visual Imaging

For visual data, the camera that is included with the DJI Inspire 1 will be used, a DJI Zenmuse X3 12-megapixel camera. This camera has a 94° diagonal field of view and operating temperature above 32°F. 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 it was calculated that at a flight altitude of 150ft, a 322.56 foot image width will result. With this information the flight path and image capture widths will be determined. For a 20MP camera, a minimum distance from the ground of 50 meters is recommended to capture images of quality for mapping [8, 9]. The figure below shows the DJI Inspire 1 camera unit. The full webpage to this sensor can be found in the appendix.

Figure 9: DJI Inspire 1 camera unit [10]

6.3 Packing Lists

Tools and supplies:

Some of the main tools and supplies that will be packed include:

- Toolkit and hand tools for basic repairs of gear
- Cleaning Cloths/Solution for UAS and Sensors
- Binoculars for UAS Observers
- High Visibility Vests
- First Aid Kit
- Radios
- Caution Tape
- Whistles
- Trash Bags
- Safety Glasses
- Laptop

UAS and Sensors Packing List:

- DJI Inspire 1 and DJI S1000
    - Batteries
    - Storage Box
    - Backup Equipment (ex. Propellers)
    - Multiple SSDs
    - Cables and Charger

- Sensors
    - Visual Camera
    - IR Thermometer and LabQuest System
    - Battery and AAA Batteries
    - Cables and Charger

- Payload
    - Sample Explosive Payload
    - Payload Deployment Device

Personal Packing List:

- Food and Water
- Cell Phones
- Warm Clothing for Late Winter/Early Spring conditions
- Waterproof Boots

The complete packing list that covers all three of these sections can be found in the appendix at the end of this document.

7. Flight Plans and Schedules

7.1 Mission Operations Preparations

The first step in preparing for the mission will be to clean, prepare, and charge UAS batteries for a quick preflight setup. This will include an inspection of each component of the UAS and testing the connection between the UAS and the transmitter. We will also attach the Zenmuse camera to test the camera and gimbal function, to make sure we can take photos/videos and rotate the camera as required. Once the Inspire 1 has been carefully inspected, we will make sure that all operating software is up to date and maps are downloaded. The transmitter will be connected to a cell phone or tablet using the DJI Go app. This allows us to see that the camera is working, check GPS signal, and see flight positions and paths. It is important to make sure that this is set up and interfaced properly with the Inspire 1. In addition to checking the aircraft and camera payload, we will charge any laptops used and ensure data analysis software is up to date for quick inspection of data collected before leaving the test location. Finally, we will pack and prepare all personal items as outlined in the packing lists. Then everything will be packed into the vehicle for transportation.

7.2 Photogrammetry Operations Schedule

The flight operations will be conducted over 1 day. Although the mission was not completed due to the recent Remote ID requirements, the schedule was created for April 15th. The same schedule would be applicable for the date that the flight operations are moved to in the future. This schedule is meant to allot adequate time for things such as time en route, assembly/disassembly of the UAS, flight time, and time to have a mission debrief as well as properly store all equipment and tools back at UAF. The exact schedule can be seen below:

8am - Meet at UAF Engineering building and assemble packing list including the Inspire 1

9am - Mobilize to Moose Mountain

9:16am - Arrive onsite

9:30am - Safety meeting, go over flight schedules/site safety plan. Set up safety delineators, caution tape to mark off takeoff/landing zones according to SSP

10am - Assemble and carefully inspect UAS, sensors, communications and data reduction equipment. Test everything to ensure proper operation.

11am - Begin Flight Operations. We will perform 3 flights total at roughly 15 minutes per flight with a 15 minute break in between each flight.

12:30pm End Flight Operations. Use DJIAfterflight to perform a quick data analysis to ensure quality photogrammetric data. One person walks down the flight path, taking temperature/GPS readings every 2 minutes. Every time a temperature reading is made, this person will drop a pin on their phone that we can later use as position data.

1:00PM Inspect, maintain, and pack up all equipment for demobilization. Document the condition of all equipment.

2:00PM Demobilize, head to Ivory Jack's for lunch

3:00PM Head back to UAF, unload, store, and document all equipment.

4:00PM Mission debrief and assign data analysis work accordingly

7.3 Flight Paths

Because we are creating a proof of concept 3D map, we have decided to map a small portion of the mountain from the upper parking lot. We will have 1 flight path, which will be flown 3 times at different altitudes to get a variety of photos for the 3D model. The altitudes flown at are 120 ft, 160 ft, and 200 ft. The flight paths for each of these altitudes can be seen below.

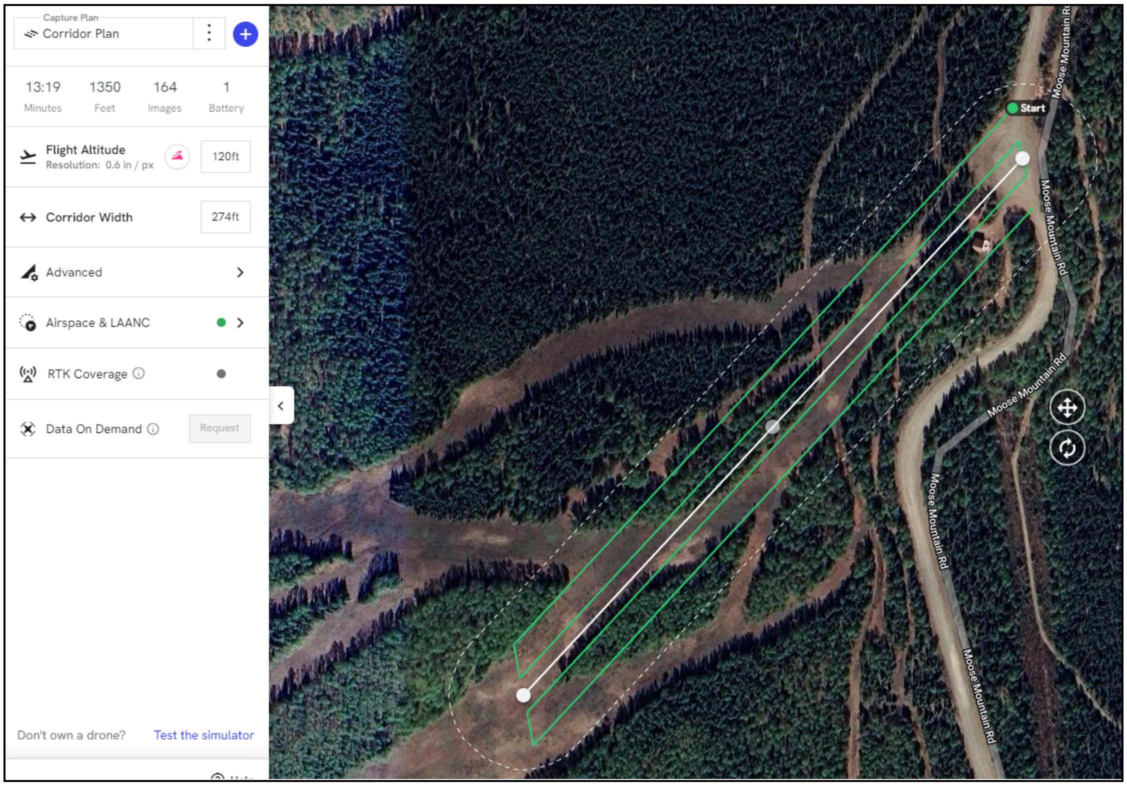

Figure 10: Flight Path 1 (120 ft)

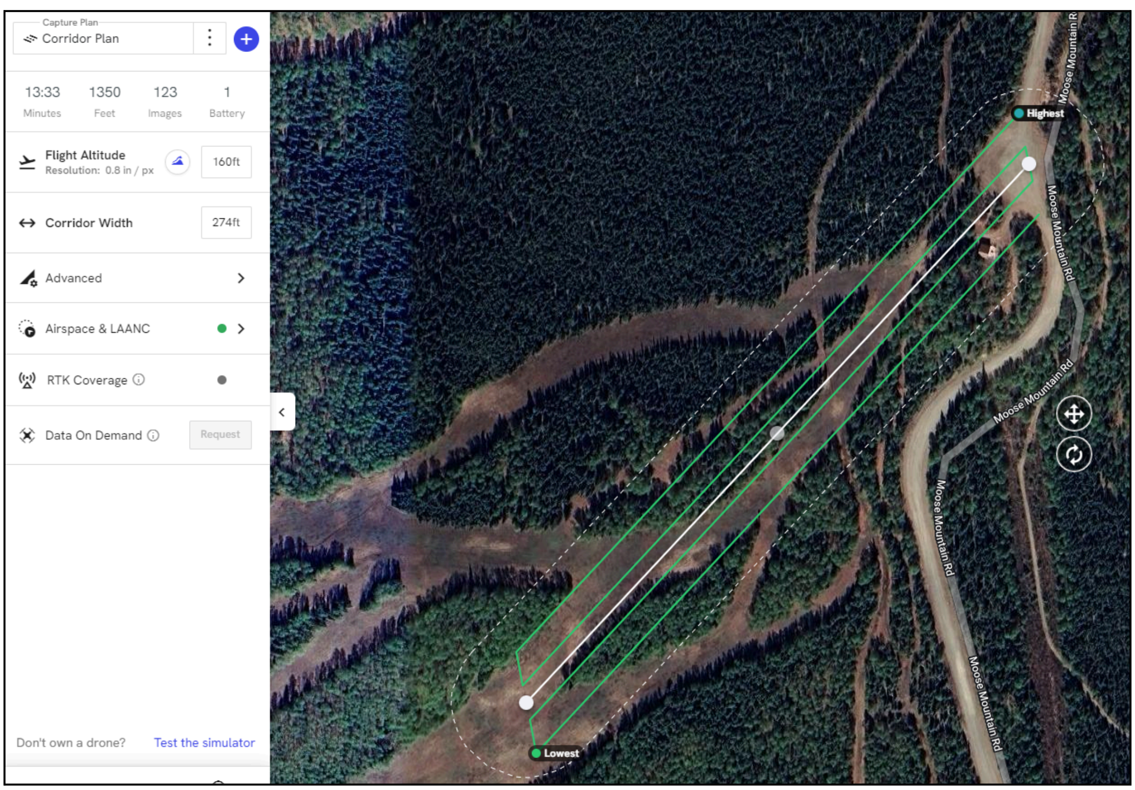

Figure 11: Flight Path 2 (160 ft)

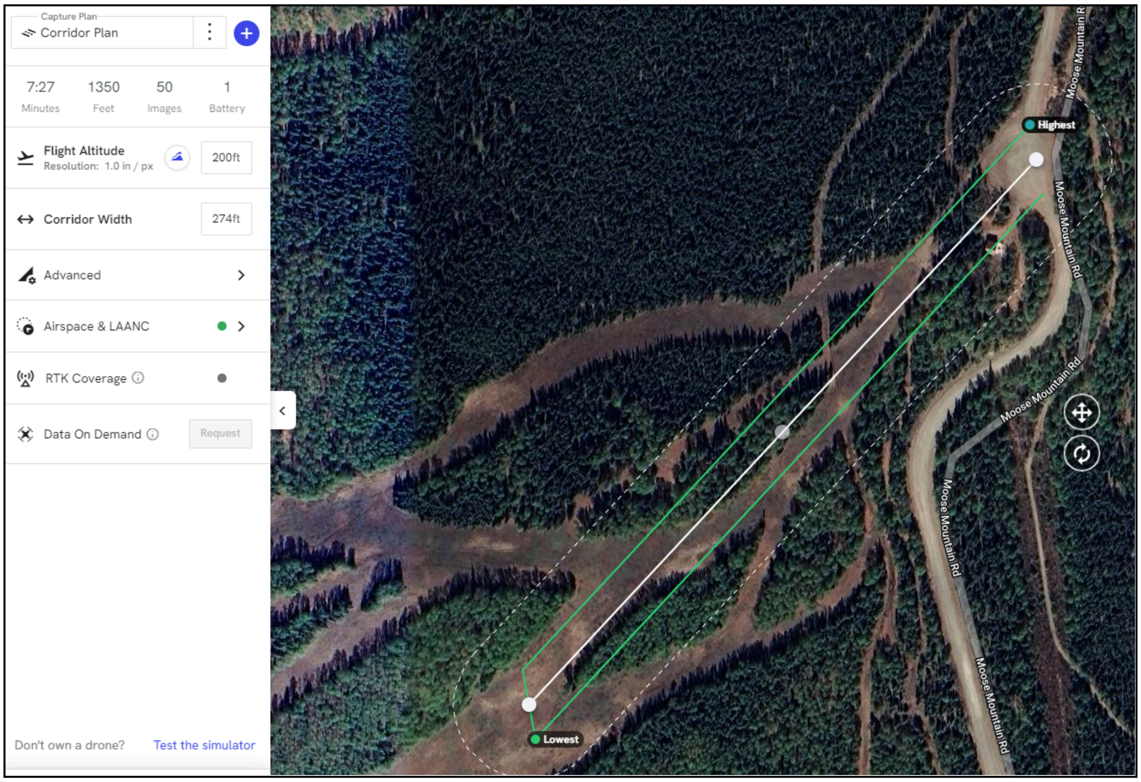

Figure 12: Flight Path 3 (200 ft)

As seen from the flight paths, the width between each pass flown is 274 ft. We will be flying this route at 5 mph, which gives a flight time of 13 minutes for flight paths 1 and 2, and a flight time of 7.5 minutes for flight path 3. With this corridor width of 274 ft, a minimum flight altitude of 120 ft is required for the camera to sufficiently cover the entire flight area. Flying the higher altitudes of 160 ft and 200 ft will allow us to create a large overlap in the photos (75% front overlap and 65% side overlap). Additionally, the flight area has some surrounding trees, which will give us a reference point for snow depth when comparing summer and winter maps. The location of the pilot, observers, takeoff, and landing can be seen in Figure 13.

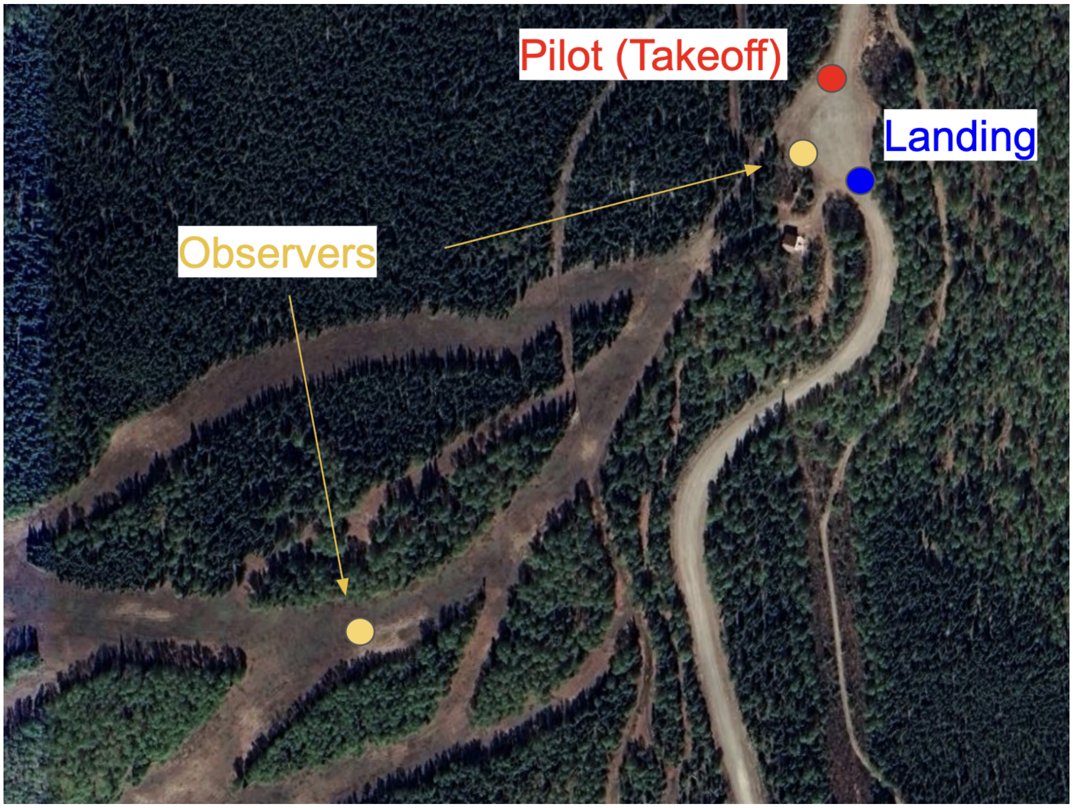

Figure 13: Location of Takeoff, Landing, and Personnel

The pilot and takeoff location are at the upper road of Moose Mountain. This provides a flat area to set up flight operations and launch the drone from. The landing location will also be in the same area. The blue dot shows the approximate end location of the flight path, but there are sufficient battery reserves to instead land right from the takeoff spot. In either case, both spots are in very close proximity (150 ft). One observer will be stationed next to the pilot, to both watch the drone and assist the pilot if necessary. The other observer will be placed down the hill along the flight path. The flight path is not very large and the distance between observers is only about 0.25 miles, but having the second observer ensures that we have sight of the drone at the other end of the flight path. They will also be able to assist with altitude reference at that end of the flight path, as it might be hard for the pilot and observer to predict the accuracy of the altitude from 0.25 miles away.

Terrain awareness will also be used to make sure that we are flying at the correct altitude. With the DJI Inspire 1, the altitude is determined by the GPS location, which may have some error. The pilots and observers will also be closely watching the altitude level to ensure that the altitude indication isn't significantly wrong. Figure 14 shows the relative altitude that will be maintained for flight path 1.

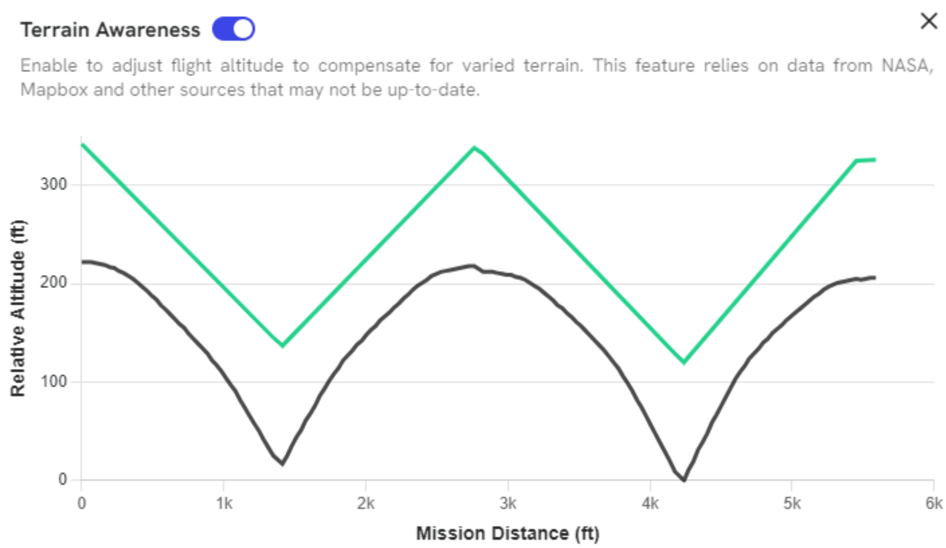

Figure 14: Relative Altitude for Flight Path 1

8. Communications

During the mission, each crew member will have a cell phone and radio. Cell Phones have coverage in the mission area and can be used for both contact between crew members and making emergency calls. Radios are provided for quick and simple communications between crew members and will be kept on person at all times. Additionally, a pre-mission meeting will take place when the crew meets at the University. This will cover the mission plan for the day, to make sure everyone is on the same page. There will also be a debrief meeting when we return to the University. This time will be used to make sure everyone knows their remaining tasks for data analysis and gives time to properly put all of the equipment away.

9. Mission Software and Data Analysis

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:

Flight Planning - DJIFlightPlanner (Inspire 1)

DJIFlightPlanner is a software tool that allows us to create a completely autonomous flight program for our remote sensing missions [11]. 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. The details of this softwares capabilities can be found in the appendix.

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 would use for our payload deployment [12, 13].

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 [14]. 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.

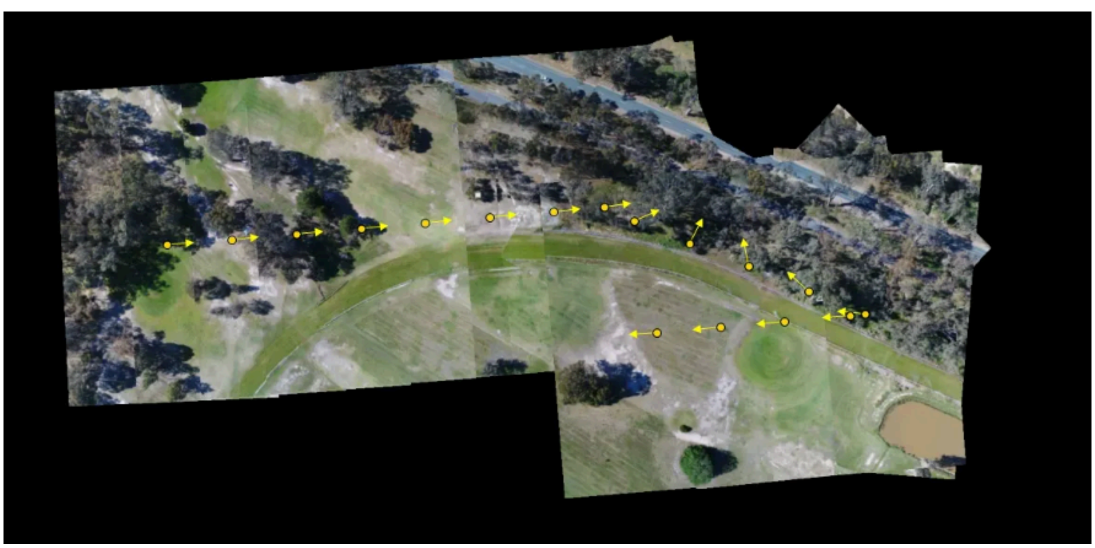

Figure 15: Example of Desired Data Product From Mission

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

iWitnessPro V4 is a high powered photogrammetry software which quickly takes photogrammetric data and creates powerful 2D and 3D maps [15]. 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 overlay, 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 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.

Drone Deploy - Flight planning, operations, quick analysis, and mapping

Drone Deploy is a software that is compatible with the DJI Inspire 1 and provides flight planning, operations interface, after flight analysis, and mapping. This will serve as a substitute for the aforementioned software tools in the case that we are displeased with the resulting data products. While this product is convenient, free, and easy to use, it also poses some limitations and provides poor user experience. We have explored Drone Deploy to make sure that it is a viable option as a backup software if we experience licensing or other technical issues with any one of our other software tools. While it may not provide a wonderful user experience, it does provide all the tools we need to plan, execute, and synthesize high level data products from a photogrammetry mission. The fully detailed capabilities of Drone Deploy can be found in Appendix A.

Data Analysis Workflow

Figure 16 visually demonstrates the sequence of software use as it relates to the mission workflow. Plan A represents our optimal software plan, and plan B represents our contingency plan accounting for each software tool from part A.

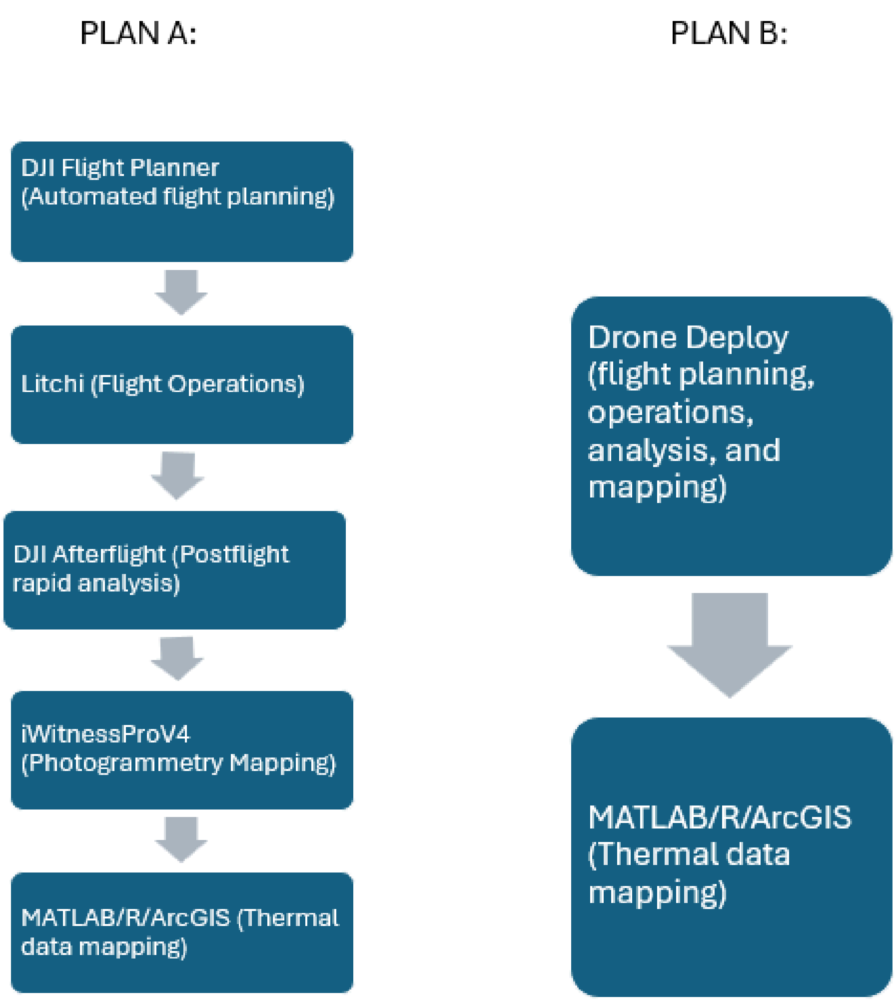

Figure 16: Data Analysis Software Flow Diagram

10. Payload Deployment

As mentioned above, the primary focus of the mission is the 3D mapping of a ski area. Should we also test the payload deployment, the payload deployment mechanism will be made as described below. The ideal scenario would be the method used in the future, when we would be able to purchase the necessary supplies. The realistic system description is limited to the materials and supplies immediately available to us, so we could complete initial testing this semester.

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.

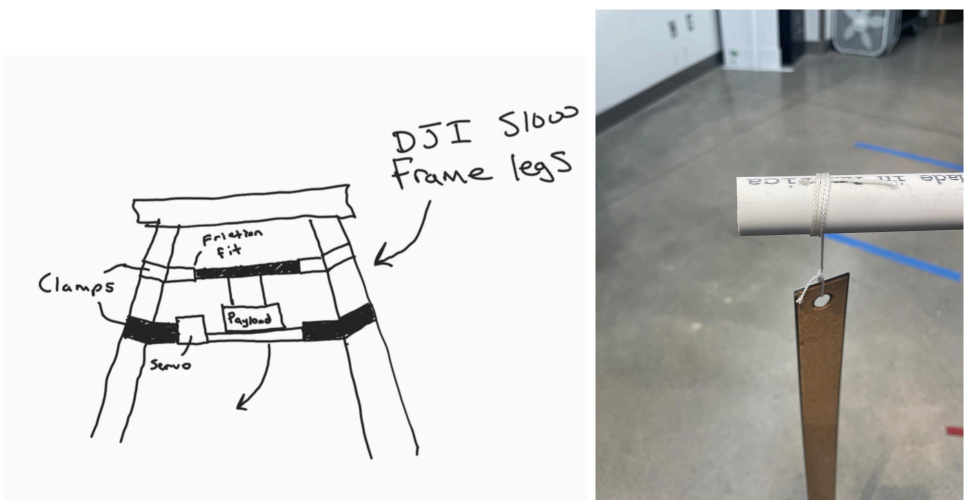

Figure 17: Payload Deployment Mechanism Idea

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https://www.photometrix.com.au/iwitnesspro-v4/.

Appendix

Appendix A: Websites for ideal/realistic UAS System descriptions

DJI Matrice 300 RTK:
https://enterprise.dji.com/matrice-300
DJI Inspire 1:
https://www.dji.com/inspire-1/aircraft
DJI Flycart 30:
https://www.dji.com/flycart-30
DJI S1000:
https://www.dji.com/spreading-wings-s1000
DJI Zenmuse 2:
https://enterprise.dji.com/zenmuse-l2
DJI Zenmuse XT2:
https://www.dji.com/support/product/zenmuse-xt2
DJI Inspire 1 Camera:
https://www.dji.com/inspire-1/camera
Vernier Infrared Thermometer:
https://www.vernier.com/til/1569
Vernier LabQuest 2:
https://www.vernier.com/product/labquest-2/
Litchi Flight Operations Software
https://flylitchi.com/help
Drone Deploy Overview
https://www.dronedeploy.com/resources/videos/product-overview
DJI Flight Planner Overview
https://www.djiflightplanner.com/#start.
iWitnessProV4 Overview
https://www.photometrix.com.au/iwitnesspro-v4/
DJI After Flight Overview
https://www.djiafterflight.com/gallery/.

Appendix B: Complete Packing List

Table 1: Photogrammetry Packing List

Photogrammetry		
UAS tools/equipment	Sensors	Safety
DJI Inspire 1	Camera/gimbal	food / water
8 batteries	LabQuest Pro	high vision vests x3
Storage box	IR Thermometer	safety glasses
Backup equipment (in box)	Battery backup	warm clothing
Basic toolkit for small repairs	cables/charger	first aid kit
Cleaning cloths/solution	AAA Batteries	cell phones x3
Binoculars		radios x3
Multiples SSDs		Site safety plan
USB, Lightning, Thunderbolt adapters/cords		safety delineators
RFID		caution tape
		whistles
		good waterproof boots
		binoculars
		baby wipes
		trash bags

Table 2: Payload Delivery Packing List

Payload Delivery		
UAS tools/equipment	Sensors/Payloads	Safety
DJI S1000	3DR Pixhawk 1 autopilot	food / water
batteries	payload deployment device	high vision vests x3
Storage box	sample payload	safety glasses
Backup equipment (in box)		warm clothing
Basic toolkit for small repairs		first aid kit
Cleaning cloths/solution		cell phones x3
Binoculars		radios x3
Multiples SSDs		Site safety plan
USB, Lightning, Thunderbolt adapters/cords		safety delineators
RFID		caution tape
		whistles
		good waterproof boots
		binoculars
		baby wipes
		trash bags