WesternU
High-Altitude Balloon (HAB)
Preliminary Design Review

A student led project from the
Centre for Planetary Sciences and Exploration (CPSX)

Matt Svensson[a], Alexis Pascual[b], Gavin Tolometti[a], Mohammed Chamma[c], Chimira Andres[a], Kelsey Doerksen[b], Nicole Devos[b], Bryan Southwell[b], Nikol Posnov[a], Bita Azad[d], Rafael Nascimento de Aguiar[b], Stephen Amey[b,c], and Jonathan Kissi-Ameyaw[b]

a - Earth Science, b - Electrical and Computer Engineering, c - Physics and Astronomy, d - Microbiology and Immunology, e - Mechanical and Materials Engineering

The University of Western Ontario

List of Figures

List of Tables

Summary of Major Changes

- **Page 26:** Updated Timeline and Task Allocation to team members
- **Page 6 and Appendix A:** New “Mason Jar” design of sample chamber, with over-center latch for improved sealing
- **Appendix A:** Mechanical drawings of sample chamber
- **Page 13:** Included description of thermal design

- **Appendix B:** Complete requirements matrix, including specific experimental requirements
- **Page 4, 15, 17:** Improved experimental use of control chambers: now three chambers (clean, ground, and flight control chambers)
- **Page 23:** Included description of post-flight analysis of bioaerosols

Executive Summary

The goal of the Centre for Planetary Science and Exploration's (CPSX) High-Altitude Balloon (HAB) initiative is to sample bioaerosols along a vertical transect through the atmosphere. Bioaerosols in the upper atmosphere are poorly studied and comprise a significant gap in the scientific literature. The present study assesses whether the inaccessibility of the upper troposphere and atmosphere can be circumvented using a stratospheric balloon platform. This research will provide additional resources for studying the distribution and character of bioaerosols vertically through the atmosphere and would comprise the first study detailing the utility of stratospheric balloons as a platform with which to study them.

This document includes detailed descriptions of the sample chamber design, the experimental design and associated procedures, a listing of all equipment necessary for payload construction, the thermal plan for managing temperature within the payload, a requirements matrix, and a description of the testing procedures. In addition we include updated timelines and task allocations for each team member, as well as an updated budget.

The sampling system will be modified from Bryan et al. (2014) in order to better integrate with the Stratos gondola and to accommodate a higher sampling resolution. Each chamber designed to sample microbial aerosols will hold 20 Rotorods ® each with a surface designed to sample via impaction. Our suggested design involves an aluminum chamber with a drawer mechanism driven by a linear actuator and sealed by an over-center latch. The main flight computer is an Arduino Mega 2560, with add-ons for data logging, ethernet port interface, and a GPS module. Cameras mounted inside the Pelican case provides visual confirmation of the opening and closing of the chambers. Cerafelt blankets will be used as insulation to mission critical components.

The project timeline can be broken down into five main phases: (1) logistics and design, (2) assembly and testing (3) dedicated testing (4) flight and sample collection (5) data analysis and interpretation. Each phase has its own internal timeline for completion. **Phase 1:** January - March. **Phase 2:** March - July. **Phase 3:** June - August. **Phase 4:** August Phase 5: September and onward.

Our team has a total projected cost of $6505.45 CAD with approximately 68% allotted for payload design, construction, and testing. In addition, 32% of the total projected costs is alloted for travel and flight day logistics. With a 15% margin we are above the guaranteed amount of funding available from CPSX ($5000). We are developing a sponsorship package to acquire additional funding from sources outside the CSA and Western.

Through the Centre of Planetary Science and Exploration (CPSX), the team has multiple avenues for outreach including Space Day presentations, high school Seminars and the Summer Space Explorers Camp. The significance and merit of High Altitude Balloon projects

will be discussed during these events in order to generate interest in space among youth groups.

Introduction

Bioaerosols can be associated with the spread of disease in humans and animals, and the pollination of plants. Studies of bioaerosol content is often used to assist allergists in their treatment of patients by identifying taxa distribution and concentration. Fungus, bacteria, viruses and pollen are all bioaerosols that can be found within the planetary boundary layer of the atmosphere. Some human diseases associated with the spread of bioaerosols include pneumonia, whooping cough, influenza, hepatitis, chicken pox and the common cold. The study of bioaerosols is also relevant to astrobiological studies and mission preparation. Viable cells found in the upper atmosphere could help identify microbial genes and/or enzymes that contribute to the development of radiation resistance. Samples from the Earth's upper atmosphere could also be employed to explore whether organic aerosols could have been synthesized in the atmosphere, and if airborne transport of microbials influenced their subsequent speciation and mutation. Understanding the populations of bioaerosols in the upper atmosphere also allows us to study the resilience of life in extreme environments such as the upper atmosphere.

We seek to build a payload system that can sample bioaerosols at different altitudes and that, after retrieval of the payload, will allow us to study the characteristics of these bioaerosols in a lab on the ground. Bryan et al. (2014) showed that hundreds of cells could be captured at altitude using a rotorod sampling mechanism, a sampling method where cells impact and stick to a rod coated in an adhesive. We will iterate on their design and build a payload that allows sampling at a higher resolution and for a longer duration, which will enable a more thorough application of the method outlined in Bryan et al. (2014). In addition, we aim for our payload to control contamination effectively enough to allow robust identification of bioaerosol species at different altitudes, which was not possible with the setup used by Bryan et al. (2014).

Our experiment will achieve this primarily through the design of a sampling chamber that can be sealed and unsealed automatically during the flight when the balloon reaches an altitude of interest. The sample chambers will be small enough (due to the small size of the rotorods) that many of them can be placed inside the payload, including chambers that will serve as controls for contamination. One control chamber will remain closed during the entirety of the flight; this allows to measure and understand what can enter through the seal and coat the rods. Subtracting this "background" contamination from what is detected on the other sample chambers allows us to uniquely identify bioaerosol species with specific altitudes. Another control chamber will remain open during the entire flight, on the ground at the launch site, to sample the bioaerosols at ground level. A final control chamber will remain in a clean room at Western University where all the sampling rods will be loaded into their chambers, to gauge the level of contamination caused by the assembly process. We do this to enable accurate characterization of the species of bioaerosols sampled.

Understanding the bioaerosol fauna of the atmosphere not only has scientific benefit but the opportunity to inspire Canadians to seek the skills and training obtained from engaging in space exploration and planetary science research. Our project incorporates electrical and computer engineering, micro-biology, immunology, physics and astronomy, and earth sciences. Additionally, our mission can stress the importance of monitoring Earth's atmosphere and show how Earth observation plays a vital role in the everyday life of Canadians.

Technical Experiment and Procedures

Full System Specifications

Sampling Chamber Design

The role of the sample chamber is to collect bioaerosols at a target altitude, and to protect the collected samples from contaminants. Thus the following requirements must be met for a suitable sample chamber design:

- The chamber must have a seal when closed that prevents the entry of bioaerosols
- Chamber should equalize air pressure inside with the environmental air pressure without allowing the entry of bioaerosols
- Opening the chamber should expose most or all of the sampling media, to maximize the chance of capturing bioaerosols
- The chamber must be easy to sterilise and allow loading of sampling media without exposing it to contamination

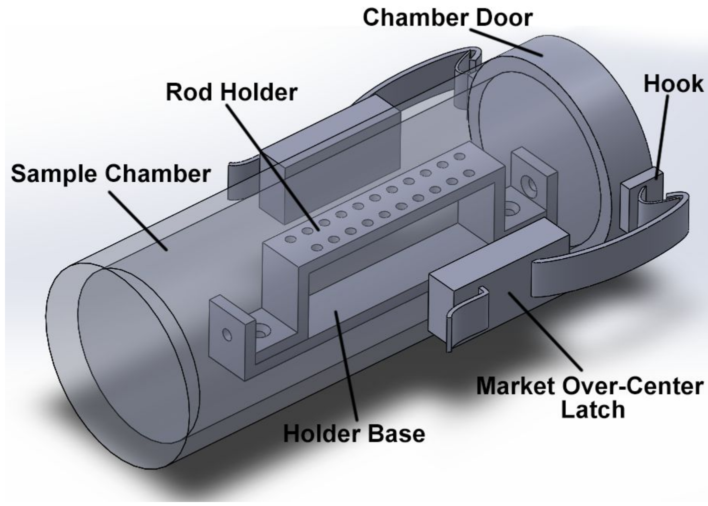
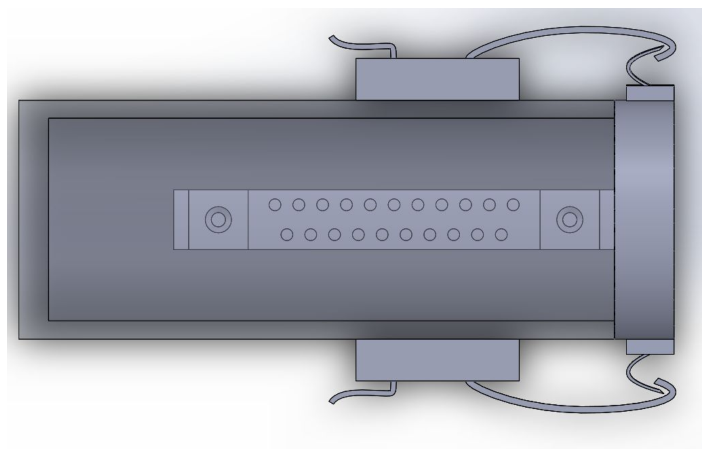
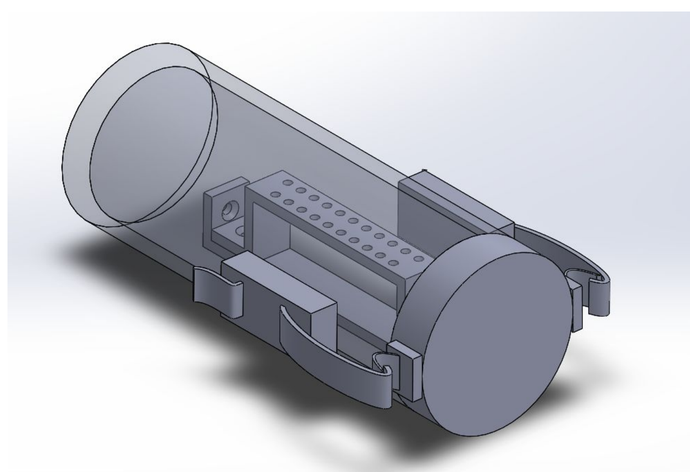
Our preliminary design for meeting these requirements can be seen in the images in figures 1-3, and mechanical drawings are included in Appendix A.

Our sample chamber employs an over-center latch, as suggested to use during our PDR presentation, and is similar to a mason jar. A linear actuator controlled by the flight computer will pull on the handles of the over-center latch. The latch's hooks will be attached to the hooks on either side of the chamber door, and will pull open the chamber door as the latch releases. A linear translation of just 5cm by the latch will be enough to expose all of the sampling media. The latch can be custom made, though many market over-center latches are suitable, and an example of such a latch is the SouthCo 97-30-160-12 model.

The sampling media will be thin rotorods that are 1.6mm in diameter and 22mm in length. Each sample chamber will be able to hold up to 21 rotorods. A rubber seal will be placed between the sample chamber door and the chamber to prevent airflow into the chamber, and a smaller hole at the back of the chamber will be equipped with a Luer Lok with a syringe filter with a 0.22 micron sized pore size, to allow air into the chamber to equalize the pressure while preventing the entry of bioaerosols.

The rotorods will be placed in a rod holder that is bolted to the chamber door. These will be loaded and bolted to the chamber door in a clean environment, and the rod holder with the chamber door will be placed in a sterile bag. On-site, we can then attach the door to the chamber and seal it with the latch before cutting the outside end of the sterile bag. This method of loading the rods allows minimal contamination when preparing the payload for the experiment.

Mechanical drawings with the dimensions of all the components of the sample chamber can be found in Appendix A. The body and components of the chamber will largely be machined from aluminum. Note that the hole for the Luer Lok syringe filter is not yet included in the drawings, but will be placed at the back of the chamber, opposite the chamber door.

Figure 1. Annotated Sample Chamber Assembly with dimensions 11cm x 4cm	
Figure 2. Top View of Sample Chamber Assembly	
Figure 3. Front View of Sample Chamber Assembly	

On Board Computer and Data Handling

The chosen On-Board Computer (OBC) is the Arduino Mega 2560. The Arduino Mega 2560 possesses a sufficient amount of peripheral buses to support the mission and has been proven to work in high altitudes and low temperatures. Table 1 below summarizes the specifications of the Arduino.

Table 1. On board computer specifications.

Component	ATMega2560 Microcontroller
GPIO Pins	54
Analog Input	16 (10 bits)
UART Pins (RX/TX)	4
PWM Output	14
SPI	1
Operating Voltage	7-12V
Operating Temperature	-40°C to 85°C
Dimensions	101.52mm x 53.3mm
Weight	37 g

The 28V output from the gondola will be fed through a 12V voltage regulator, which will then power the OBC. To record data, an ethernet shield (Figure 4, Table 2), which is run by a W5500 chipset will be stacked on top of the OBC. The ethernet shield contains a microSD card slot, which will then store all housekeeping data. Since the ethernet shield will be stacked on top of the OBC, its power will come directly from the OBC. In addition, the W5500 chipset also has an operating temperature of -40°C to 85°C. The ethernet shield is available through adafruit.com.

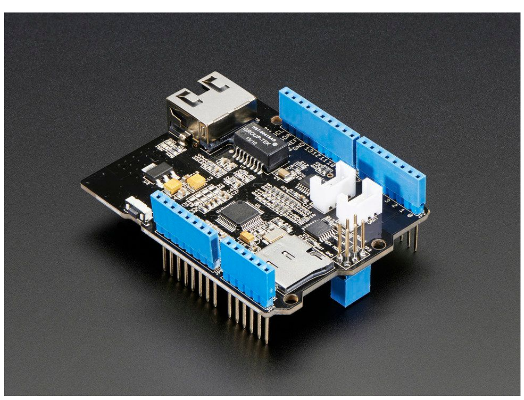


Figure 4. Ethernet Shield from adafruit.com

Table 2. Ethernet Shield Specifications

Component	W5500 Ethernet Shield
Operating Voltage	5V
Operating Temperature	-40°C to 85°C
Dimensions	71.0mm x 53.0mm x 23.0mm
Weight	25 g

On Board Sensors

Environmental Sensor

The on board sensors will provide the conditions within the payload all throughout the flight. To measure the temperature, pressure, and humidity inside the Pelican case, a BME280 sensor will be used. The BME280 sensor interfaces with the OBC either through I2C or SPI. The sensor can be purchased with an integrated PCB where the voltage input can be powered by the 3.3V or the 5V logic from the OBC. The operating ranges of the BME280 sensor is shown in Table 3.

Table 3. BME Sensor Specifications

Component	BME280 Environmental Sensor
Interface	SPI
Operating Voltage	3.3V or 5V
Operating Temperature Range	-40°C to 85°C
Operating Pressure Range	300hPa to 1100hPa
Operating Relative Humidity Range	0 to 100%
Dimensions	9.0mm x 18.0mm x 3.0mm
Weight	1 g

GPS Module

Since the mission requires that the sampling chambers be open at set altitudes, a GPS module will be included in the payload. The requirements for the GPS module is that it can operate beyond 18,000 m in altitude *and* read up to 1000 knots in speed. This requirement is in place because the balloon is expected to go higher than 18,000 m and can experience bursts of speed faster than 1000 knots. For these reasons, the NEO-6M GPS module is selected. The specifications of the NEO 6M GPS module is shown in Table 4.

Table 4. GPS Module Specifications

Component	NEO 6M GPS Module
Interface	UART
Operating Voltage	3.3V or 5V
Operating Temperature Range	-40°C to 85°C
Operating Altitude Limit	50,000 m
Operating Velocity Limit	500m/s
Operating Acceleration Limit	4 g's
Dimensions	16.6mm x 12.3mm x 2.6mm
Weight	1.6 g

Camera

To record the opening and closing of the chambers, a camera will be placed inside the Pelican case, such that all the chambers and actuators will be within the field of view of the camera. The chosen camera module is the Adafruit Mini Spy Camera (Figure 5, Table 5), which is a very cheap and easy to use module. The module can be powered directly from the OBC with a 5V output, and the trigger is simply an input from a GPIO pin. If the trigger (or the GPIO pin) is held on for less than half a second, a picture will be taken and stored within the module's own SD card. If the trigger is held on for over half a second, a video will start recording, and will only stop once the trigger is held on again for over half a second. Take note that the video and images will not be included in the telemetry and will only be stored locally in the microSD card of the camera module

Table 5. Camera Module Specifications

Component	Adafruit Mini Spy Camera
Interface	GPIO
Image Resolution	1280 x 720
Video Resolution	640 x 480
SD Card Maximum Capacity	32 GB
Operating Voltage	5V
Dimensions	28.5mm x 17mm x 4.2mm
Weight	2.8g

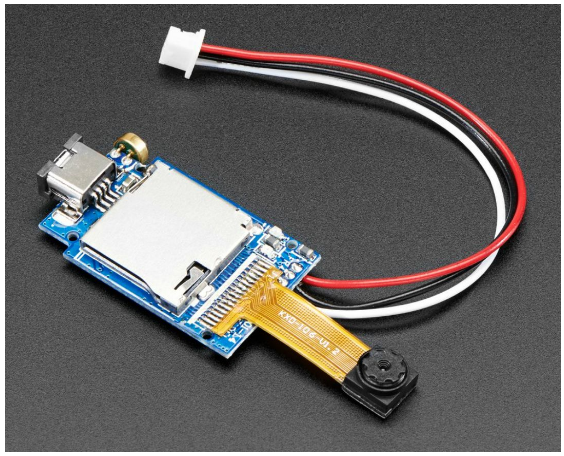


Figure 5. Adafruit Mini Spy Camera Module

Actuators and Controllers

Linear Actuator

The chamber doors will be opened and closed with the Actuonix P16 Linear Actuator (Table 6). The p16 actuator features a 100mm movement, spanning the whole length of the chamber itself. This is necessary because exposing all the sampling rods require that the doors that carry the sampling rods be linearly translated by about 70mm. Since the minimum operating temperature for the actuator is -10°C, thermal solutions would be put in place to keep the temperature of the actuators at 0°C. This will be discussed in detail in the following section. Once the actuator's position is fixed, the actuator will hold its position as long as the applied load is less than the maximum static force. This acts as a redundancy in keeping the doors closed should the latches fail.

Table 6. Linear Actuator Specifications

Component	Actuonix P16 Linear Actuator
Movement	100 mm
Stall Current	1000 mA
Peak Power	250 N @ 2.5mm/s
Mechanical Backlash	0.3mm
Maximum Static Force	500N
Operating Voltage	12
Operating Temperature	-10°C to 50°C
Actuator Closed Length	147 mm
Weight	110g

Actuator Controller

The L298 Dual Channel H-Bridge Controller (Figure 6, Table 7) will power and control the movement of the actuator. The H-Bridge will receive a 12V input directly from the voltage regulator which will then pass the power through the actuator depending on the signal from a GPIO pin from the OBC. The direction of the current could also be controlled through the H-Bridge through the GPIO pins. Since will be controlling 7 linear actuators on board, we would also need 4 H-Bridge Controllers.

Figure 6. L298 Dual H-Bridge Controller.

Table 7. L298 Dual H-Bridge Controller

Component	L298 Dual H-Bridge Controller
Operating Voltage	7V to 24V
Maximum Current Output	2 A
Dimensions	55 mm x 50 mm x 29 mm
Weight	35g

Thermal Control

Two major components have been selected for thermal control. They are Cerafelt insulating blankets and Polyimide Insulated Flexible Heaters. The Cerafelt blankets will be wrapped around critical components like the on-board computer and linear actuators. The thermal control system is currently designed to passively maintain desired internal insulation temperatures at ambient temperatures of -25 °C. Meaning, the insulation around components will sustain them within operational and survival temperatures when the ambient temperature is -25 °C. Through the layers of the atmosphere where temperatures reach -50 °C the heaters will run when necessary (determined by temperature sensors within the insulation).

The heaters will activate for a specific period of time within the vicinity of the linear actuators before they operate. The reason for this is because the actuators do not dissipate heat to the environment and will likely need to be warmed up before operation, especially for temperatures below -25 °C. Each actuator will operate at different altitudes and we must design for the worst case scenario. This plan will be tested and validated using the freezer chambers at Western University. Fewer layers of insulation will be used to simulate a larger temperature differential for colder than -25 °C altitudes since the chambers are not capable of getting any colder. It is quite possible that changes to this plan will be made and the purpose of the test is to determine those necessary changes.

The required number of layers of insulation to maintain internal 0 °C temperatures was determined using the following equation:

$$\mathrm{Ta} = \frac{\mathrm{q}\left(\frac{1}{\mathrm{ha}} + \frac{\mathrm{DelX}}{\mathrm{k}} + \frac{1}{\mathrm{hb}}\right)}{\mathrm{A}} + \mathrm{Tb}$$

The heat transfer through the insulation is an estimated value based on the desired temperature difference between the outside and inside of the insulation. An explanation of each variable and their values can be seen in Table 8 below. Based on these parameters, it was determined that five layers of insulation are required. While testing the computer in the freezer chambers it will also be possible to calculate its heat dissipation based on temperature sensor readings.

Table 8. Table of terms and their values (T_a calculated)

Term	Symbol	Value	Units
Area	A	0.045	m^2
Inside Temp	**Ta**	**272**	Kelvin
Outside Temp	**Tb**	**248**	Kelvin
Inside Conv	ha	10.45	W/m^2K
Insulation Thickness	DelX	0.065	m
Insulation Conduction	k	0.07	W/mK
Outside Conv	hb	27	W/m^2K
# Insulation Layers		**5**	
Heat Transfer	q	1	W

Of further interest is the heat flux through the thickness of the pelican case. To determine this, the case will be placed in sun for six hours and temperature sensors will measure the internal and external surface temperatures of the case. This will tell us the temperature differential through the case thickness that we can expect during the mission. To more accurately simulate mission conditions, a day will be chosen with as little wind as possible since the balloon and gondola experiences no relative convection as it travels with the wind.

Miscellaneous Essentials

Voltage Regulator

The power lines that will be provided by the gondola outputs 28V unregulated. Since our components use at most 12V DC, a voltage regulator has to be put in place to provide constant and consistent power to the OBC, H-Bridge controllers, and the Polyimide heaters. To accomplish this, the D24V22F12 Step Down Voltage Regulator will be used. It can take up to 36V input, and can step it down to 12V with 4% accuracy. At the same time, it can output a maximum current of 2.2A.

Table 9. D24V22F12 Step Down Voltage Regulator Specifications

Component	D24V22F12 Step Down Voltage Regulator
Maximum Input Voltage	36V
Minimum Input Voltage	12.7V
Maximum Output Current	2.2A
Output Voltage	12V
Dimensions	17.78 mm x 17.78 mm

microSD/SD Cards

For data storage, the Ethernet Shield requires a microSD card. As for the camera, a full sized SD card is required. We will then use 32 GB cards, the maximum size capacity that these components could accommodate. We estimate that the house keeping data would not take up more than 50MB. As for the videos, we estimate that they would not take up more than 300 MB.

Luer Lok with Syringe Filter

The chambers themselves are designed to be airtight to avoid contamination during the flight. However, this would provide problems regarding air pressure during the flight. For example, the chamber that opens first at the lowest altitude remains closed all throughout the flight. Once the gondola reaches maximum altitude, there will be a positive pressure build up inside this particular chamber. This would exert a force of about 1000N on the chamber doors, which could break the latch as well as the actuator. The opposite would be true for the chamber open during the level flight, where the doors would be pushed inward once the gondola descends. However, this would present problems in opening the chamber doors. To solve this problem, a Luer Lok with a syringe filter attachment will be placed at the back of the sampling chambers to let air through. The syringe filter would have 0.22 micron pore size, filtering out the bacteria.

Sampling Method

Bioaerosol sampling would be accomplished with the use of Rotorod sampling rods, which are made of polystyrene. Once exposed to the air, bioaerosols that impact the rods will adhere to the silicone grease adhesive coating the rods. The rods themselves have a length of 22mm and a diameter of 1.6mm, having an effective sampling surface area of 35.22mm^2.

Requirement Verification and Compliance Matrix

Please see Appendix B.

Launch Day Pre-flight Procedures

Prior to launching the science payload, a series of checks are required to ensure all electronics and equipment are functioning and communicating properly. The team will also be checking the tools and sampling equipment required to collect bioaerosols before inserting them into the Pelican case. The team will check the power connection to all on-board electronics, ensure the S.D. card is secured and check that the computer is logging the required data. The computer should be logging the GPS coordinates, temperature, pressure ambient humidity, camera feed and actuator position. Additionally, the team will ensure actuator functionality by running an open-close sequence prior to loading the sampling rods. The team will also ensure the payload is structurally sound and ensure that the insulation pads are intact, free of any punctures or tears.

Sample Chamber Preparation

The latest samling chamber design allows for the preparation and loading of the sampling rods with minimal environmental contamination.The rotorods will be prepared and loaded onto the rod holders in a positive pressure clean lab at Western University. In the same clean lab, the rod holders will be bolted to the chamber door and the whole assembly will be placed into a sterile bag, that will remain sealed up until the last steps of payload assembly.

On-site, the chambers themselves (without the doors, since they are in a sealed bag with the rotorods) will be cleaned by 2-3 team members with ethanol. These team members will wear gloves/masks as necessary. The sterile bag with the door and rotorods will then be loaded onto the chamber like a cartridge, and the latches will seal the rotorods in before we cut open the end of the bag that is sticking outside of the chamber. The sides of the bag will be secured to the side of the chamber and the next time the chamber opens (during flight), the rods will be exposed to the air for the first time.

Launch Day In-flight Procedures

The in-flight procedures include the opening and closing of the sampling chambers at preset altitudes for the collection of bioaerosol samples. The sample chambers in the Pelican case are assigned target altitudes to open and collect bioaerosols. At eight ideal target altitudes, the sampling chambers are programmed to collect samples. Figure 7 and Table 10 shows the target altitudes. One sample chamber is to be kept closed for the duration of the flight to determine whether any organisms collected are contaminates from the launch site. The chambers open within 1-2 kilometers of the target altitude to ensure they are open for the duration of the target altitude. Chambers 1 to 6 sample for set altitudes, chamber 7 samples for the duration of extended level flight and chamber 0 remains on the ground as a ground-level control sample.

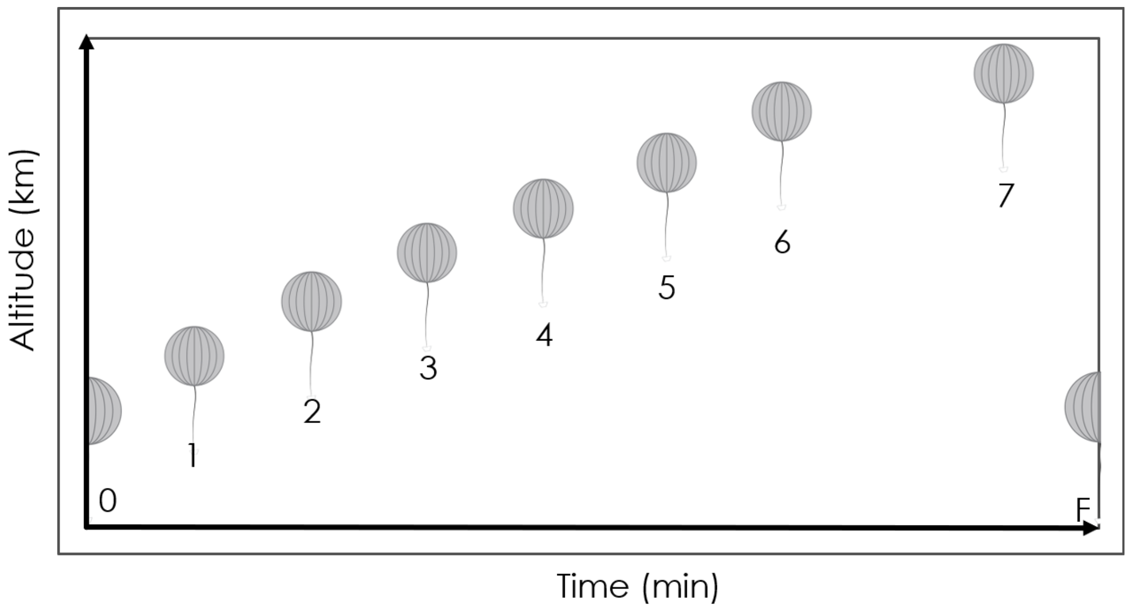


Figure 7. In-flight sampling intervals and parameters.

Table 10. In-flight sampling intervals and parameters.

Point	Initiation Altitude	Flight Time
0	0 km	0 min
1	5 km	15 min
2	10 km	30 min
3	15 km	45 min
4	20 km	60 min
5	25 km	75 min
6	30 km	90 min
7	34 km	105 min (Long Duration)
F	0 km	9–12 hrs

Launch Day Post-flight Procedures

Upon locating and retrieving the payload, the team will check the condition of the electronics and the sampling rods and carry out the following procedure:

1. Assess payload damage
    a. Depending on where the balloon lands, the payload may experience mechanical or electronic damage. The sampling chambers, GPS, Sd card, on-board computer, and actuators will be checked to evaluate any damage.
2. Retrieve the SD card
    a. The SD card will be retrieved immediately before any other equipment as it contains the flight information (altitudes, chamber logs, and coordinates).
3. Chambers stored in a sealed container and kept in a cooler.
4. Salvage any electronics or equipment in the Pelican case
    a. Electronics such as the GPS and equipment such as the actuators can be reused if they have not experienced a significant amount of damage and are still functioning.
5. Cooler ice is replenished during transport
6. Samples stored in freezer at Western

Technical Risk Assessment

As of the submission of the Preliminary Design Review Document, technical risks with the design and manufacturing process has not been encountered yet as the team is still finalizing the design. The plan remains the same that the machining of the parts will be left to the machine shop employees so as to keep the risks minimum.

Human

Table 11. Machining risk assessment.

MACHINING	**Injury or maiming**	
Probability	L	Untrained students have a high chance of misusing the machining tools however the team would not be handling the machines themselves.
Consequence	H	Injury and/or maiming could be caused by improper handling of machines during manufacturing.
Mitigation Plan	All the machining and manufacturing will be handled by the University Machine Services. The team will only be involved in the design and conception of the payload and only the machine shop employees will handle the machining.	
Contingency Plan	In case any of the students are injured, a hospital within the campus is readily available for emergency services.	

Technical & Environmental

Table 12. Actuator Failure Risk Assessment

	Actuator Failure	
Probability	M	Mechanical failure of the servos powering the linear actuator could occur as they are only rated to operate at -10℃.
Consequence	H	Opening and closing the chamber doors would not be possible at all, rendering the experiment fruitless.
Mitigation Plan	Testing the operation of the linear actuators in a freezer that goes below -25℃ will be conducted. In this test, the actuators will be wrapped with a felt thermal insulation and placed inside the Pelican case. If needed, additional resistance heaters will be placed next to the actuators to heat them up before operation begins.	
Contingency Plan	Positional feedback from the actuators will be recorded and transmitted to see if the actuators indeed opened and closed at the set intervals. Also, an on board camera would provide visual evidence of the opening and closing of the chambers upon recovery.	

Table 13. Sampling Rods Contamination Before the Flight Risk Assessment

	Sampling Rods Contamination Before the Flight	
Probability	H	The sampling method of the rods is via impaction with the atmosphere. If the rods are exposed to the air even for just a short time during loading, there is a high probability that bioaerosols on the ground would contaminate them.
Consequence	H	Since the aim of the experiment is to sample bioaerosols at different altitudes, the sampling rods coming into contact with air in the ground level would severely impact the results of the experiment.
Mitigation Plan	Eight sampling rod holders attached to the chamber door will be wrapped with a sterile bag prior departure to Timmins. These rod holders would then be loaded into the chamber before the flight to minimize contamination during transport and loading.	
Contingency Plan	If in case there is contamination with the rods, the control chamber on the ground as well as in the Pelican case would provide a baseline for what bioaerosols to look for that are not present in the control chambers.	

Table 14. Sampling Rods Contamination During the Flight Risk Assessment

	Sampling Rods Contamination During the Flight	
Probability	L	The sampling rods during the flight may be contaminated if the chamber doors are not sealed properly or if there are leaks within the chamber.
Consequence	H	Contamination of the sampling rods by bioaerosols in the inappropriate altitudes should be avoided at all costs.
Mitigation Plan	The new mason jar design with the over center latches will provide an air-tight seal between the door and the chamber. As well, the Luer Lok pressure equalization system will use a .22 micron syringe filter to keep bioaerosols out.	
Contingency Plan	If in case there is contamination with the rods, the control chamber on the ground as well as in the Pelican case would provide a baseline for what bioaerosols to look for that are not present in the control chambers.	

Table 15. Sampling Rods Contamination in case of a Rough Landing Scenario Risk Assessment

	Sampling Rods Contamination in case of a Rough Landing Scenario	
Probability	L	In the event of a rough landing, the sampling chambers may become distorted, thus breaking the seal and exposing the sampling rods to the atmosphere.
Consequence	M	Contamination of the sampling rods with ground-level atmosphere would invalidate the experiment as the goal is to sample bioaerosols at different altitudes during the flight
Mitigation Plan	The chambers will be made out of aluminum to provide a lightweight and relatively strong structure. To make sure that the sampling chambers remain intact, multiple impact testing will be carried out a drop test at different heights. If in case the test fails, a foam board or similar materials could be enveloped around the chamber to protect the chamber from the impact.	
Contingency Plan	It is highly unlikely that all of the sampling chambers will be distorted and all the seals will be broken upon landing. But, recognizing the fact that it could indeed happen, the recovery and subsequent analysis of the surviving chambers will still carry on. Although the sampling resolution decreases, the experiment could still present valuable results.	

Table 16. Sampling Rods Contamination During Transport Risk Assessment

	Sampling Rods Contamination During Transport	
Probability	L	Once the sampling chambers are recovered, the sampling chambers will not be opened until the analysis begins in a sterile environment at Western.
Consequence	H	Contamination during transport will most likely invalidate the results of the experiment
Mitigation Plan	The sampling chambers will be stored in a sealed container and will be put inside a cooler with ice during transport back to Western.	
Contingency Plan	If in case there is contamination with the rods, the control chamber on the ground as well as in the Pelican case would provide a baseline for what bioaerosols to look for that are not present in the control chambers.	

Table 17. Degradation of Bioaerosols Before Payload Recovery Risk Assessment

	Degradation of Bioaerosols Before Payload Recovery	
Probability	H	It could take up to 48 hours before the gondola is recovered and the payload is secured
Consequence	H	Bioaerosols would not survive without nutrients for an extended period of time at relatively high temperatures.
Mitigation Plan	A cooler full of ice will be handed over to the recovery team so as to freeze the sampling chambers right after the gondola is recovered. Full instructions will also be provided for recovery and storage.	
Contingency Plan	Analysis and characterization will proceed as planned to see if there are any surviving bioaerosols.	

Hazardous Materials: The payload design does not include any materials classified as hazardous substances by Canada's Hazardous Products Act.

Expanding on the risk tables shown previously, the potential failure points that the team could forsee at this point are listed below:

1. **Actuator failure** - The whole experiment hinges upon the successful opening and closing of the sampling chamber doors. Mechanical failure of the servos powering the actuator could occur, which could be caused by the low temperatures to be experienced by the payload. To mitigate this, freezer testing the actuators will be conducted to see if the actuators could still operate with the thermal insulation set in place. If the test is successful, we can be confident that the actuators will operate during the flight. If in case the test fails and the actuators fail to open the chamber doors, additional thermal solutions will be put in place, such as deploying an active heating element or adding a thicker and better insulation material. During the flight, a camera would confirm the opening and closing of the chamber doors to provide a visual reference to the science team during post flight analysis.
2. **Sampling chamber structural integrity in case of a rough landing** - In the event that the gondola experiences a rough landing, the chambers could be damaged and accidentally opened up, thereby nullifying the whole experiment. To make sure that the sampling chambers remain intact, multiple impact testing will be carried out. If in case the test fails, a foam board or similar materials could be enveloped around the chamber to protect the chamber from the impact.
3. **Flight computer failure** - Similar to how the linear actuators could fail in low temperatures, the flight computer itself is susceptible to the same risk. If in case the flight computer fails during the flight due to low temperatures, the data log in the microSD card as well as the videos recorded by the camera would provide the history of the payload. The chambers that successfully opened and closed

during the flight will still be examined by the science team. However, the flight computer will be insulated similar to the actuators and testing will be conducted to make sure that the insulation is enough to protect the flight computer. If in case the testing fails, additional active heating elements will be put in place.

4. **Sampling rod contamination** - Contamination of the sampling rods must be avoided at all costs because the results will not be reliable if bioaerosols were to be sampled at inappropriate altitudes. Contamination prior to the flight and during transport back to Western are the most probable risks that could happen. However, there are mitigation plans in place to keep the contamination at minimum. For instance, pristine sampling rods will be prepared in Western and will be sealed with a sterile bag before departing to Timmins. These rods will then be loaded and sealed prior to the flight, and will only be exposed to the air once the chamber doors are opened. Once the payload has been recovered, the sampling chambers will only be opened in a clean environment, and will be stored in a cooler with ice on the drive back to Western.
5. **Degradation of bioaerosols before payload is recovered** - Biological organisms will not be able to survive without sustenance for a long period of time. This is especially true for bacteria and microorganisms. However, when kept at close to freezing temperatures, the bacteria could survive for an extended duration. For this reason, a cooler with ice or preferably dry ice will be provided to the recovery team so that the chambers could be kept at low temperatures immediately after the payload is found. Also, the sampling chambers will be kept at a low temperature during the transport back to Western.

Experiment Testing

This section will list most of the battery of tests we plan on performing to ensure the health of the payload during flight and the quality of the samples retrieved. We are in the process of purchasing materials and waiting for their arrival (expected mid-March) before testing and building begins.

Freezer Test (Late March):

- We will place the actuator, Arduino, and prototype sample chamber into a freezer that can reach -25°C for approximately 6 hours. This is to verify that the Arduino will continue to operate during the entire duration of the flight, and that the actuator will be able to open and close the sample chamber. We will also use this test to determine the amount of insulation required for the payload. This will also serve as a test of how the electronics will behave in response to any condensation that will occur.

Drop Impact Test (Early April):

- We will study the effect landing has on the sample chambers by loading them with dummy rotorods (e.g. toothpicks) and dropping them from higher and higher

altitudes. We want to know how much the chambers can be jostled and bumped before (a) the rods fall out of the holder and (b) the chamber door latch fails.
- Vibration test: At the same time we will manually vibrate the payload to determine how much disturbance is required to dislodge any equipment or electrical connections. This will ensure that all critical components are secured adequately.

Wind Tunnel Test (April):
- The Pelican case will be placed in a wind tunnel located at Western that will allow us to determine an appropriate fan (if required) for pulling an adequate amount of air into the Pelican case. This is to ensure that the rotorods in our sampling chambers will be exposed to enough air that they actually are able to pick up bioaerosols. This will be done with some basic, conservative assumptions: if each chamber will only be open for roughly five minutes, how much air flow is required for the rotorods to be reasonably exposed?

Biological Analysis Dry-Run (April-May):
- To practice the biological analysis and to assess any logistical problems that might arise a week or so will be dedicated to collecting a dummy, ground sample from the Western campus and analysing it as if it had been obtained from one of the sample chambers of the payload. In addition to identifying problems with the procedure this will also give us an idea of what level of analysis is practical given our budget and team member constraints. This will also help us determine what bioaerosol species to focus on, in the event that a complete analysis is not possible.

Payload Preparation Rehearsal (May-June):
- To rehearse our roles at the launch site we will have two-three rehearsals where the payload is prepared for flight. This includes preparation of the rotorods, assembly of the chambers, and any and all pre-flight checks. We do this to ensure there are no surprises when assembling at the launch site.

Flight Rehearsal (May-June):
- With the payload mostly complete, we will simulate the flight with a program that will feed simulated GPS data to the flight computer as if the payload is flying. We will then observe that the actuators open and close the chambers at their target altitudes, and all close on the descent phase. We will also verify that all the logging and camera recordings are stored as expected.

Plan for Data Analysis and Results Interpretation

The biological aim of this project is to characterize the variation in microbiological communities present among different altitudes within the troposphere and lower stratosphere. In order to do this, we intend to taxonomically identify bacteria using 16S sequencing. 16S rRNA gene sequences are the most common genetic markers used today to study bacterial taxonomy. This method is efficient, cost effective, and has been used to identify bacterial bioaerosols in the past.

The post-flight procedures we have designed are inspired by the Bryan *et al.,* (2014) paper which we have also used to design our sampling chambers. Upon the return of the gondola to earth, the sealed sampling chambers will be extracted and placed on ice, to limit the growth of microorganisms collected on the sampling rods. To limit post-flight contamination of the rods, the sampling chambers will remain closed until an aseptic environment is created, in a room with closed doors and windows. Following standard aseptic techniques, the surface we will operate on will be wiped down with 70% ethanol. A portable Bunsen burner, will be used to draw air currents upwards and minimize contact of the sampling rods with microorganisms present in the air. Sterile gloves will be worn during the transfer of the sampling rods to our sealable sterile chilled liquid media tubes. Samples in media will be held at 4°C until further lab work is conducted.

In lab, rod adhesive will be scraped from the rods into the media to maximize bacterial collection. This media will then be filtered to remove adhesive remnants, and the media will be split in two for the analysis of culturable and viable non-culturable bacteria. Culturable bacterial colonies will be isolated through culture-based recovery assays and cryopreserved for subsequent 16S V4 sequencing (Smith *et al.,* 2018). Viable, non-culturable bacteria will be directly analyzed using 16S V4 sequencing (Smith *et al.,* 2018). Before 16S sequencing, DNA extraction will be performed, followed by polymerase chain reaction (PCR) for DNA amplification of the 16S rRNA gene. Primers will be designed based on the sequences found in the Smith *et al.,* (2018) paper. Basic Local Alignment Search Tool (BLAST) will be used to map the most probable taxonomic affiliation of both culturable and non-culturable bacteria. To account for contaminants resulting from the experimental process, species identified from our negative-control rods will be removed from the list of taxonomic groups identified from our sample rods in an abundance-dependent manner. The clinical and environmental significance of each identified taxonomic group will be determined through subsequent literature reviews.

Although we believe that 16S sequencing is the best method for classification of bacterial species, the feasibility of this approach relies on whether the funding for our project will support it. As an alternative approach, cultured bacteria and fungi can be plated on agar plates. Individual colonies can then be isolated and microscopically analyzed for morphological characteristics. Colony forming units can be measured in an attempt to investigate the quantity of each group present. Although this approach will not provide specific taxonomic characterization, it could reveal interesting variability in the quantity and morphology of isolated culturable microbiological species across different atmospheric altitudes.

Project Management Update

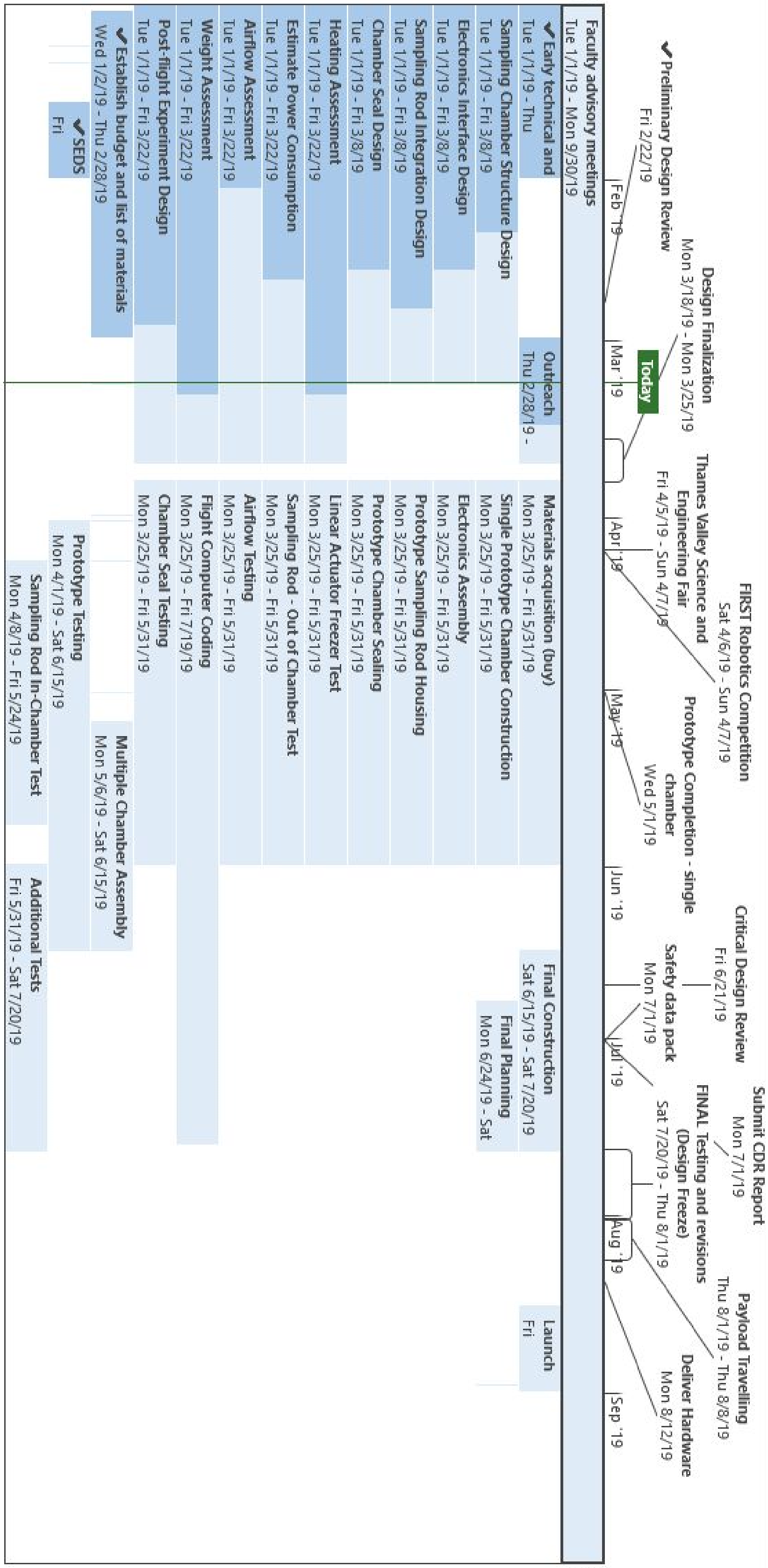


Figure 8. Timeline of scheduling and team tasks.

The timeline has been updated to include upcoming outreach events, additional design phases regarding the accommodation of an active airflow system, a tighter chamber seal, and the assurance of sample non-contamination. Testing has been included throughout the assembly phase and has received a dedicated phase immediately preceding the launch of the balloon. The timeline shown in the preceding figure extends beyond September for continued experimentation but the only the relevant phases for this report were displayed.

Figure 8 shows the designated tasks and roles of each team member during the design, development, budgeting, outreach, and pre-, in- and post-flight procedures. Additional members have joined the mission to contribute towards designing, testing and developing the payload, and providing advice and expertise on bioaerosol sampling and microbial taxonomic identification. Three new members from the Department of Mechanical and Materials Engineering at Western University have joined the engineering and science team, with backgrounds in fluid mechanics and biomedical engineering. We also gained support and expertise from Dr Amrjeet Bassi, a faculty member in chemical and biochemical engineering who is advising our science and engineering team on the post flight procedures. Dr. Bassi is offering lab space for sample preparation, and the support of his graduate students to help with the analysis. All team members and their backgrounds are listed below and their position in the team structure is shown in Figure 9. Additionally, the overall structure and roles of the team members can be determined from figure 10.

CPSX-HAB Student Team Members

1. Matthew Svensson (*Project Manager* | *Clay Mineralogy, Impact Cratering and Stable Isotope Chemistry*)
2. Alexis Pascual (*Engineering Lead / Assistant Manager* | *Materials and Software Engineering*)
3. Mohammad Chamma (*Assistant Manager* | *Math, Physics and Astronomy*)
4. Gavin Tolometti (Outreach *Lead* | *Radar Remote Sensing, Impact Cratering and Volcanology*)
5. Chimira Andres (*Logistics Lead / Science Team* | *Glacial / Periglacial Geomorphology and Remote Sensing*)
6. Bita Azad (*Science Lead* | *Microbiology and Immunology*)
7. Nikol Posnov (*Microbiology and Impact Cratering*)
8. Jahnavi Shah (*Remote Sensing*)
9. Kelsey Doerksen (*Aerospace, Electrical and Computer Engineering*)
10. Nicole Devos (*Mechatronics and Robotics Engineering*)
11. Rafael Nascimento de Aguiar (*Software, Electrical and Computer Engineering*)
12. Stephen Amey (*Software Engineering and Astrophysics*)
13. Bryan Southwell (*Aerospace and Robotics Engineering*)
14. Jonathan Kissi-Ameyaw (*Electrical and Computer Engineering*)

15. Matthew David Mahaffy (cross-listed: science team | *Biomedical and Mechanical Engineering*)
16. Broderic Clement-Thorne (*Mechanical and Materials Engineering*)
17. Dwaipayan Sarkar (*Fluid Mechanics and Mechanical Engineering*)

Faculty Advisory / Staff

18. Dr. Gordon Osinski (*Ph.D. Earth Sciences | Acting Director of CPSX*)
19. Dr. Parshati Patel (*Ph.D. Physics and Astronomy | CPSX Outreach Coordinator*)
20. Dr. Matthew Bourassa (*Ph.D. Aerospace Engineering | Research Staff*)
21. Dr. Amarjeet Bassi (*Ph.D. Chemical and Biochemical Engineering | Faculty Advisor*)
22. Dr. Kenneth McIsaak (*Ph.D. Electrical Engineering | Faculty Advisor*)
23. UWO Research and Laboratory Technical Staff
24. CPSX Outreach Staff and Interns

High School Involvement (HS)

25. TBD

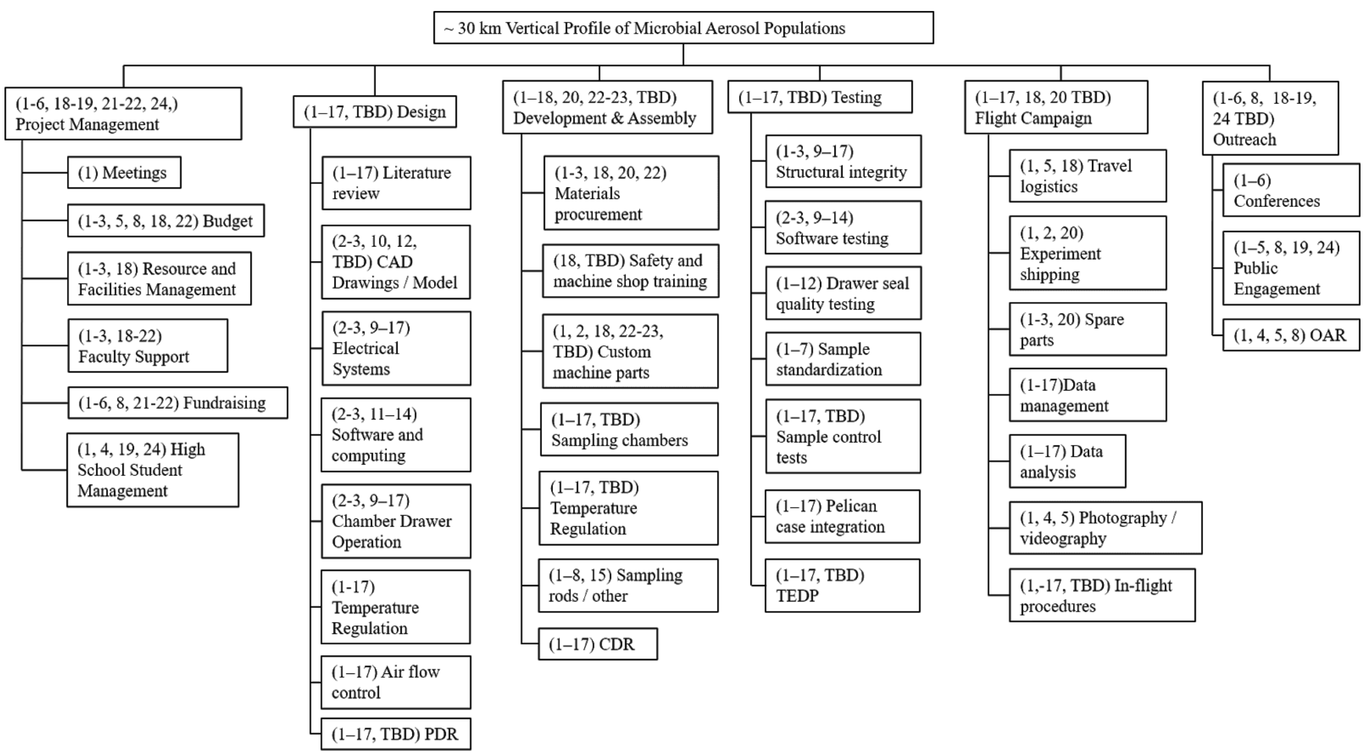


Figure 9. Designated roles for each CPSX team member (students, staff, faculty, and volunteers). Each team member is assigned to a specific task associated with major components of the project.

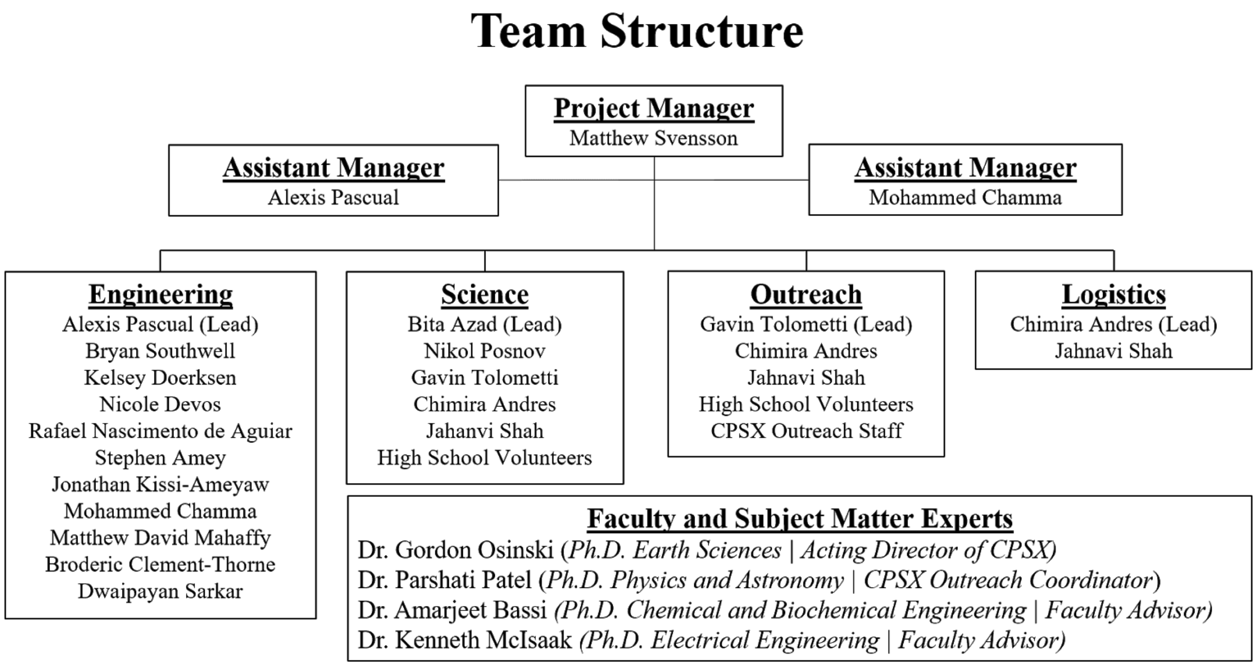


Figure 10. HAB Western U team structure. Name of each team member and their associated team.

Outreach Update

The outreach lead and team members have contacted the communications and public affairs digital content manager at Western University to schedule a social media training session in May. This training is mandatory in order for the team to use the CPSX social media accounts (twitter, instagram, etc.) to promote mission progress. Meetings on the 31st of March with AFN interns (students from Western's Faculty of Education) have been confirmed. These meetings will discuss the collaboration of high school students with the payload development and testing ,and the post-flight laboratory analysis section of the mission. High school students can put forward some of their free time to assist in the mission, which will contribute towards their mandatory community services hours.

The outreach team will also assist in contacting potential sponsors listed below in the budget section of the report. Team members 1, 3-5, and 8 will have a role in developing relationships with potential sponsors and creating a sponsorship package for the mission.

Budget
Please see Appendix C for a detailed breakdown.

Team members 1, 3, and 5 will be responsible for tracking expenses and funds with additional support from CPSX administrative staff . The project manager, assistant managers and logistics team will be responsible for developing and submitting applications for additional funding. The team is developing a sponsorship package that leverages CPSX's large social media presence and the exposure through conference presentations to attract potential sponsors. Currently, the team has reached out to administrative personnel responsible for dictating what sponsors can be contacted and will move forward with the potential funding sources outlined in appendix C as soon as possible. The possible funding sources include the Western University Experiential Learning Initiative and grants to selected payload providers by the CSA. By highlighting the interdisciplinary nature of this project and the external collaborating groups, the UWO team stands a strong chance of being selected for funding from Western's Experiential Learning Initiative. Additional funding sources could include, Robotshop, LEDC,Tech Alliance London Chapter, OSHTEC Inc, and Avro Pattern Inc who will be provided with the aforementioned sponsorship package.

Travel expenses for 3 individuals to Timmins for an estimated time of 1 week is expected to be approximately $1540 (budgeting for accomodation, food and gas). If funding is available, the team intends to send up to 5 additional team members for the day of the launch with an estimated cost of $550. With a 15% expense buffer the cost to send the minimum number of individuals is $1771 and $2403 for the maximum number of individuals (inclusion of an additional 5 for launch). The added expenses shifts the total cost of the project to $6505.45 with the note that $200 for conference attendance has been removed given that conference attendance is confirmed to be covered by individual research groups.

References

[1] Actuonix Motion Devices, “Miniature Linear Motion Series · L16”, Linear Actuator Data Sheet, Sep.
2016.

[2] Adafruit, “Ethernet Shield for Arduino - W5500 Chipset”, Ethernet Shield Data Sheet, n.d.

[3] Adafruit, “Mini Spy Camera with Trigger for Photo or Video”, Camera Data Sheet, n.d.

[4] Arduino, “Arduino Mega 256”, Flight Computer Datasheet, n.d.

[5] Bosch, “BME280 Combined humidity and pressure sensor”, Temperature Sensor Data Sheet, May
2015.

[6] Bryan, N.C., Stewart, M., Granger, D., Guzik, T.G. and Christner, B.C., 2014. A method for sampling
microbial aerosols using high altitude balloons. *Journal of microbiological methods*, *107*, pp.161-168.

[7] DasSarma P, DasSarma S. 2018. Survival of microbes in Earth’s stratosphere. Curr Opin Microbiol
43:24 –30. https://doi.org/10.1016/j.mib .2017.11.002.

[8] Energizer, “ENERGIZER L91 Ultimate Lithium”, Energizer Lithium Battery Datasheet, n.d.

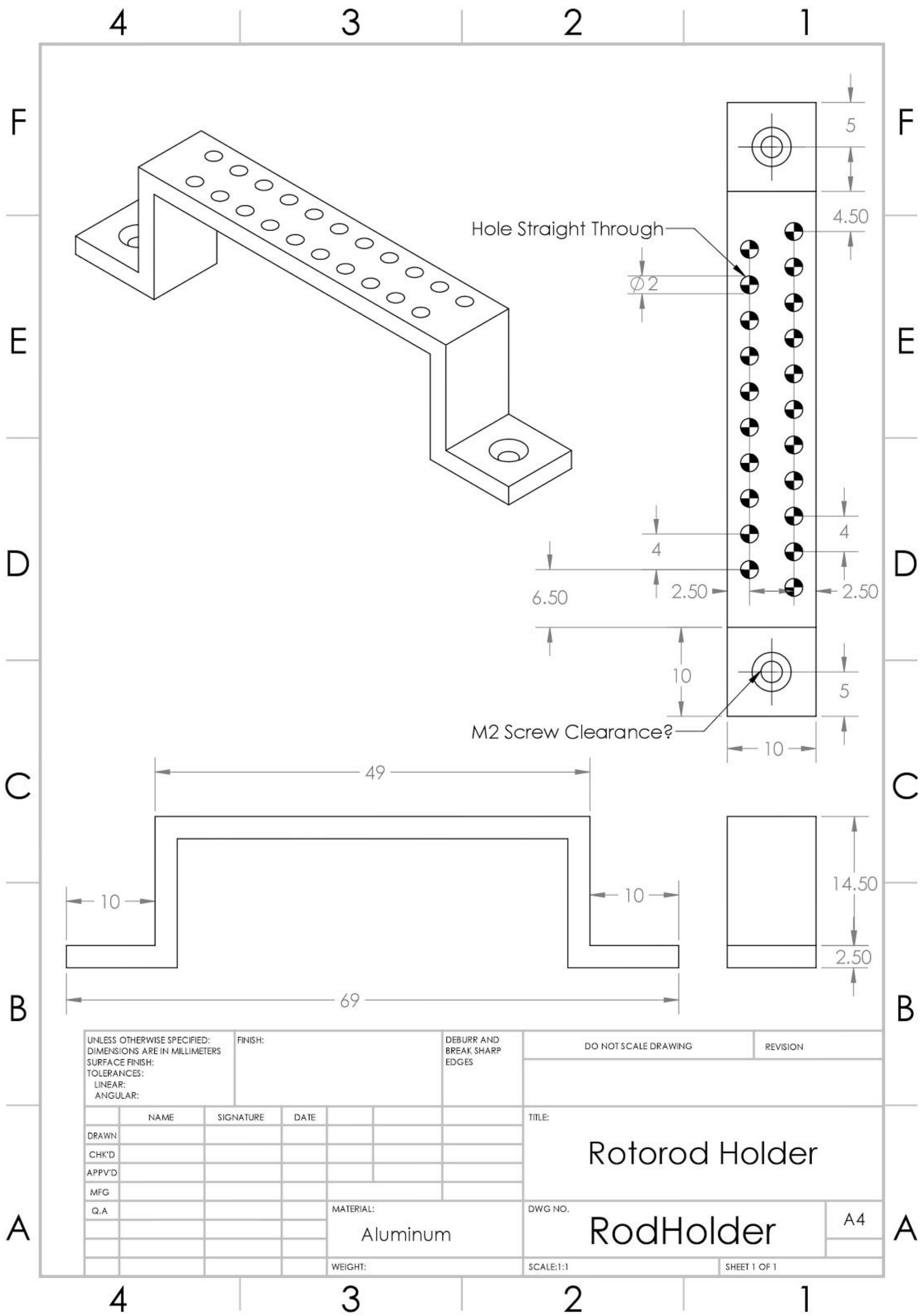
[9] Morgan Advanced Materials, “Cerafelt and Cerachrome Felt”, Cerafelt Data Sheet, Feb. 2016.

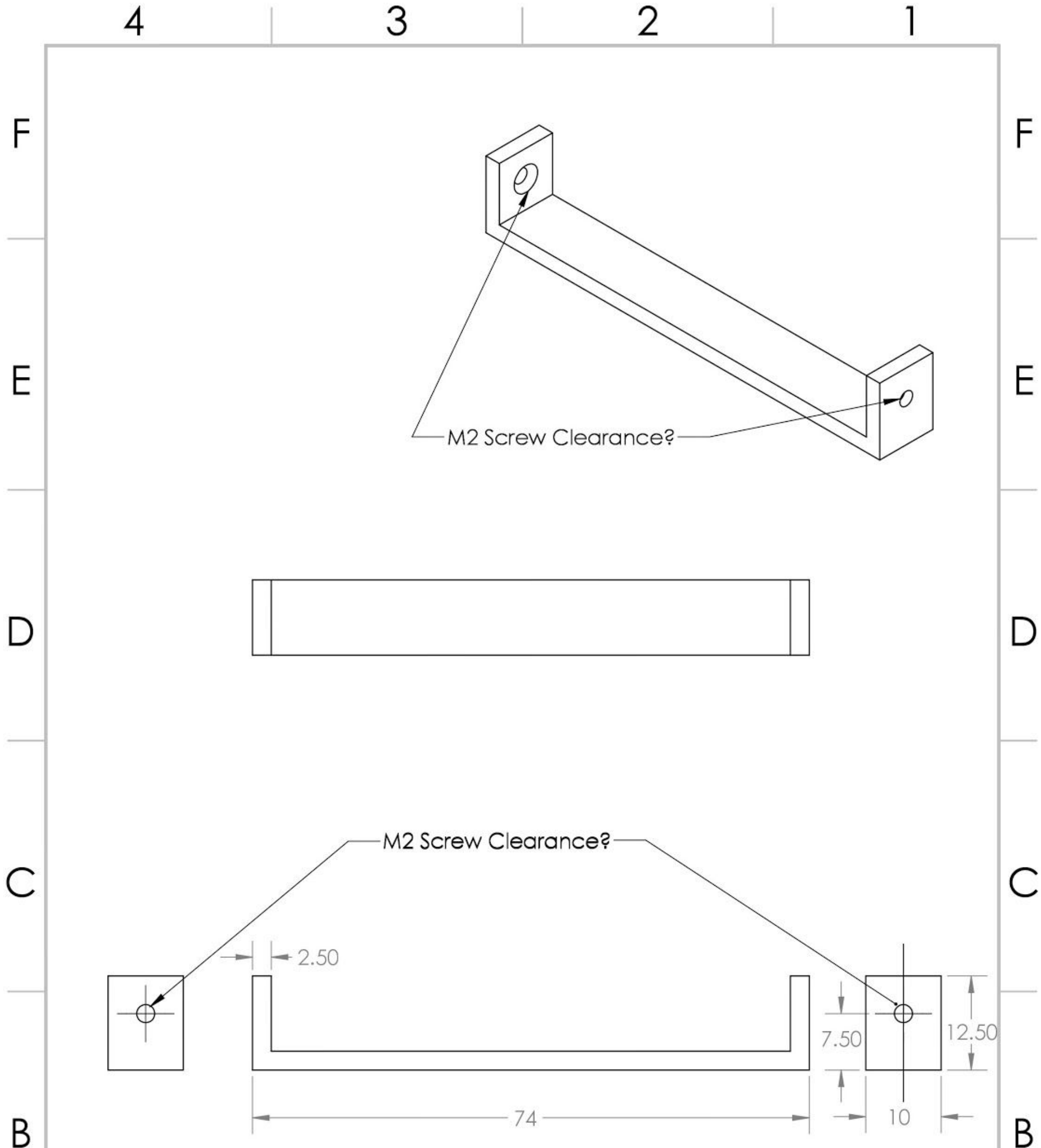
[10] “RB-Ite-141 L298 Dual H-Bridge DC Motor Controller Datasheet”, Linear Actuator Control Board
Data Sheet, n.d.

[11] Ublox, “NEO-6 u-blox 6 GPS Modules”, GPS Module Datasheet, May 2011.

[12] Smith, D. J., Ravichandar, J. D., Jain, S., Griffin, D. W., Yu, H., Tan, Q., ... & Martinez, P. (2018). Airborne Bacteria in Earth's Lower Stratosphere Resemble Taxa Detected in the Troposphere: Results from a New NASA Aircraft Bioaerosol Collector (ABC). *Frontiers in microbiology*, *9*.

Appendix A: Sample Chamber Drawing





UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN			
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

MATERIAL:

WEIGHT:

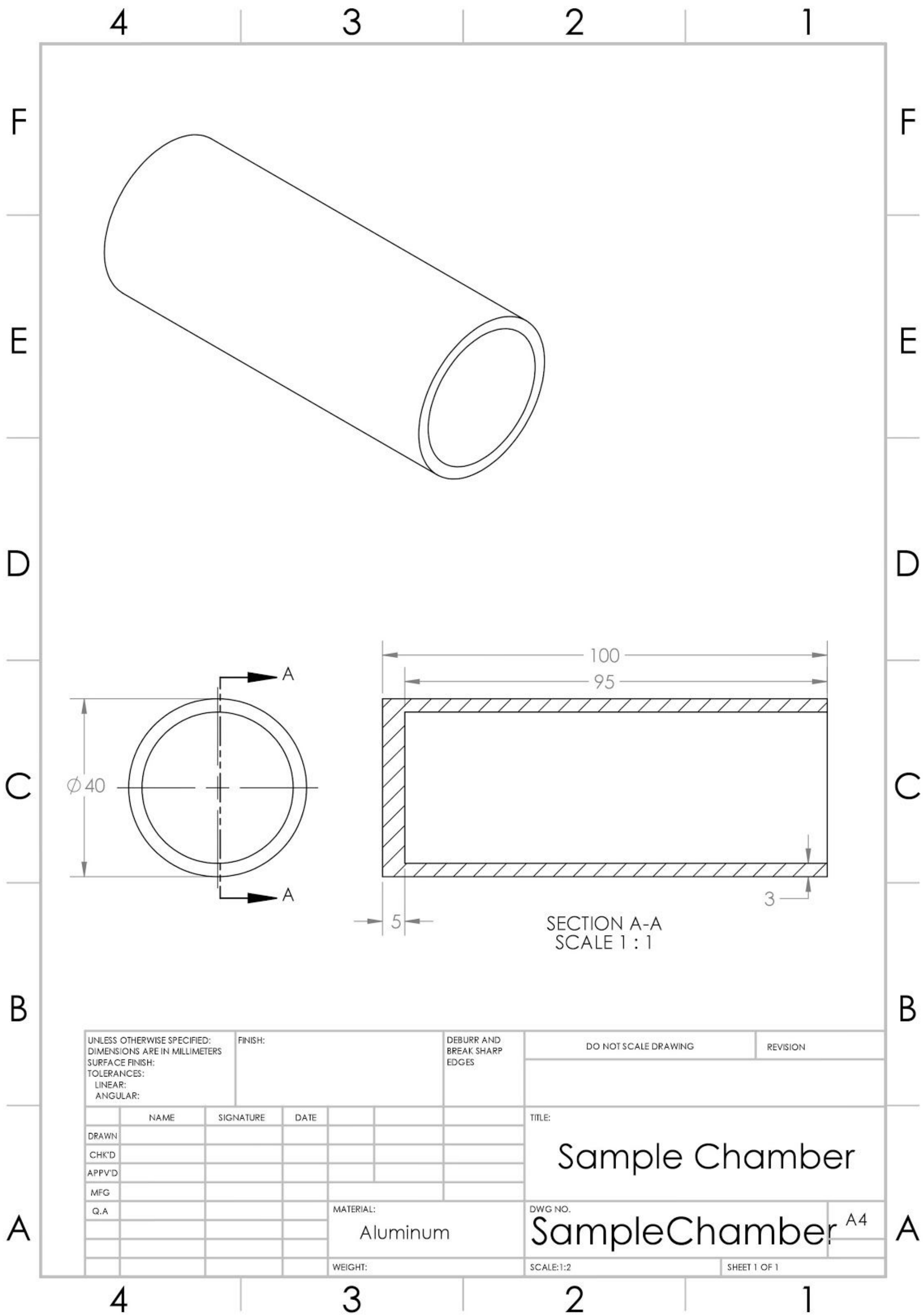
DWG NO.

HolderBase

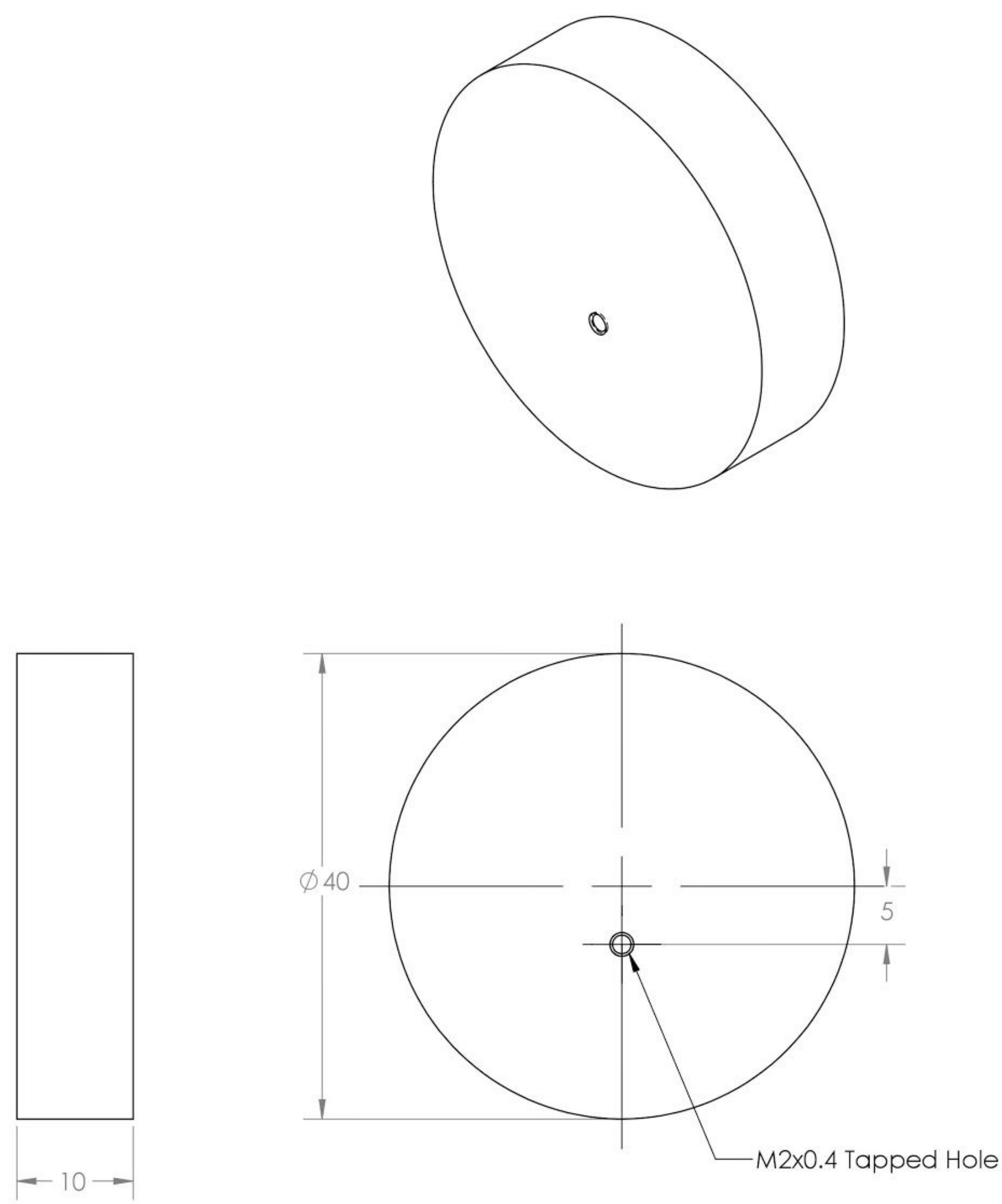
A4

SCALE:1:1

SHEET 1 OF 1



A
A
ϕ40
100
95
5
3
SECTION A-A
SCALE 1 : 1
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
CHK'D
APPV'D
MFG
Q.A
TITLE:
Sample Chamber
MATERIAL:
Aluminum
DWG NO.
SampleChamber
A4
WEIGHT:
SCALE:1:2
SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN			
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:
Chamber Door

MATERIAL:
Aluminum

DWG NO.
ChamberDoor

A4

WEIGHT:

SCALE:2:1

SHEET 1 OF 1

Appendix B. Requirement Verification and Compliance Matrix

Category	Requirement	Verification Method	Description	Compliance	Remarks
Experiment Structure	Payload must be contained within the Pelican case	A/T/I		C	
	Payload must weigh less than 12kg	A/T/I		C	
	Payload must be compatible with the gondola	A/T/I		C	
	Payload must survive a violent landing (up to 2 g)	A/S/T		NC	Testing still has to be executed
	Sampling chambers must remain uncontaminated in the case of landing in water	S/T/I	Purity of the sapling rods must be maintained during the mission	NC	Testing still has to be executed
Electrical and Power Requirements	Power consumption must be less than 30Wh	A/T/I		C	
	Components must need less than 28V	A/T		C	
	Electrical Components	A/T/S		PC	Analysis show that the

	must operate at low temperatures and low pressures				components would be operational but testing still has to be executed
	Memory cards should be able to survive rough or water landing	S/T/I	Even if the other electrical components do not survive the rough landing, the memory cards should at least be recovered	NC	Testing still has to be executed
	Electrical Components should survive condensation	S/T/I		NC	Testing still has to be executed
Experimental Requirements	Sampling rods must be able to capture bio aerosols	S/T/I		PC	Proof has been shown by a previous research but testing still has to be executed
	Airflow through the Pelican case must be adequate during sampling	A/S/T/I		NC	Calculations and simulations are currently in progress
	Sampling chambers must be open at pre-set altitudes during the ascent phase	S/T/I		PC	Software can determine the set altitudes but this can only be confirmed after the flight

	of the flight				
	Sampling chambers must not be open at any other altitudes	S/T/I		PC	Software can determine the set altitudes but this can only be confirmed after the flight
	Sampling chambers must be closed during the descent phase of the flight	S/T/I		PC	Software can determine the set altitudes but this can only be confirmed after the flight
	The opening and the closing of the chambers must be confirmed and recorded	S/T/I	The experiment hinges upon the opening and closing of the chambers so they must be confirmed and recorded	C	Sensors and camera on board will record actuator movement and position
	Sampling chamber doors must be sealed air tight	S/T/I	To avoid contaminatio n, the doors must remain air tight	PC	The current design affords the air tight seal of the doors, but must be confirmed with testing
	Sampling chamber must be able to equalize pressure with the environment	S/T/I	Since the doors would be sealed air tight, pressure equalization between the chamber and the environment	PC	The current design allows for the pressure equalization through the Luer Lok, but must be confirmed with testing

			must be realized		
	One control chamber must remain closed all throughout the flight	S/T/I	This control chamber would provide a context for the rest of the sapling chambers	C	No actuator will be attached to this control chamber and thus will remain closed
	A control chamber on the ground not included in the flight must be open for the duration of the flight	S/T/I	This control chamber would provide context as well for post flight analysis if in case the rods are contaminate d on site	C	A sampling chamber would be left open on the ground before flight begins
	A control chamber must remain within a clean room for a baseline	S/T/I	The clean room control chamber would establish the absolute baseline for the contaminatio n state of the sampling rods even before the flight	C	A sampling chamber would be left open in the clean room at Western before the campaign begins

Appendix C. Calculated and projected expenses, and known funding amounts and sources.

Estimated Expenses ($-CAD)					
Project Tasks		Labour	Material	Travel	Other
Project Management	Meetings	-	-	-	-
	Resource and Facilities Management	-	-	-	-
	High School Student Management	-	-	-	-
	Faculty Support	-	-	-	-
	Subtotal	**0**	**0**	**0**	**0**
Design	CAD Drawings	-	-	-	-
	Printed Prototype	-	-	-	-
	Electrical Systems	-	-	-	-
	Temp. control system and parameters	-	-	-	-
	Airflow control system and parameters	-	-	-	-
	Subtotal	**0**	**0**	**0**	**0**
Development	Custom Machined Parts	643.5	342.38	-	-
	Materials and Tools	105	1,033.42	-	-

	Machine shop training	-	-	-	-
	Chamber sealing	-	-	-	-
	Sampling rods	-	240	-	-
	Shipping	300	-	-	-
	Subtotal	**1048.5**	**1615.8**	**0**	**0**
Testing	Structural testing	-	-	-	-
	Software testing	-	-	-	-
	Chamber seal testing	-	-	-	-
	Standardization	100	-	-	-
	Control tests	400	-	-	-
	Pelican case integration	-	50	-	-
	Subtotal	**500**	**50**	**0**	**0**
Flight Campaign	Travel to Launch Site	-	-	200	-
	Accomodation	-	-	1000	-
	Meals	-	-	540	-
	Experiment shipping	100	-	-	-
	Spare parts	-	-	-	-
	Data management and collection	-	-	-	-
	Data analysis	600			
	Documentation / videography	-	-	-	-

	In flight procedures	-	-	-	-
	Subtotal	**700**	**0**	**1740**	**0**
Outreach	Conferences	-	-	-	-
	High school Involvement	-	-	-	-
	Public engagement	-	-	-	-
	Subtotal	**0**	**0**	**200**	**0**
Subtotal (15% margin)		**5654.3** (total) **|** **6502.45** (15% margin)			
Total (estimated)		**6505.45**			
Estimated Funding ($-CAD)					
Funding	Western University	(?)			
	Centre for Planetary Science and Exploration	$5,000			
	CSA Funding	(?)			
	Robotshop	(?)			
	LEDC	(?)			
	Tech Alliance London	(?)			
	Avro Pattern Inc.	(?)			
	OSHTEC Inc.	(?)			
	Subtotal (15% margin)	$5,000			
	Total (estimated)	$5,000			