Valiant Aerotech

Phase One – Proposal

Wildfire Detect-and-Respond System

Prepared For:
Aerial Evolution Association of Canada (AEAC)

Abstract

The team is developing a hybrid VTOL fixed-wing drone designed to improve wildfire management by combining rapid detection and suppression capabilities. Equipped with a thermal imaging system and GPS navigation, the drone autonomously detects hotspots and delivers a water payload to suppress fires in remote areas. The hybrid design enables efficient forward flight and stationary hovering for precise water drops. The features include a tractor motor for stability, a slosh-reducing water tank, and a lightweight, customizable 3D-printed frame. The drone is powered by an Orange Cube flight controller and uses MissionPlanner for autonomous navigation and real-time data processing. With its ability to reduce response times and minimize risks to human firefighters, this UAV offers a cost-effective solution to mitigate the growing threat of wildfires.

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Introduction

Wildfires pose a growing threat to natural ecosystems, infrastructure, and public safety, with devastating consequences for the environment. Rising global temperatures, prolonged drought conditions, and increased human activity have intensified the frequency and severity of wildfires in recent years. As a result, traditional firefighting methods, which rely heavily on human intervention and resource-heavy deployments, are often too slow and reactive to contain fires before they escalate. These limitations underscore the urgent need for innovative solutions that improve both the detection of fire outbreaks and the speed of suppression efforts.

In response to this challenge, the team is developing a multi-functional drone that addresses critical gaps in wildfire management by combining detection and suppression capabilities into a single, unified system. The UAV is equipped to handle both fire detection and suppression. The system integrates infrared sensors to identify heat signatures associated with fire sources, a visual mapping system for navigation and site assessment, and a water payload delivery system to suppress fires with precision and efficiency.

This dual-function approach enhances the speed and accuracy of wildfire response efforts, significantly reducing the need for multiple specialized vehicles and improving overall mission effectiveness. Early detection through infrared imaging allows the drone to identify fire hotspots before they spread, while the onboard suppression system provides immediate intervention. The UAV simplifies logistics, reduces operational costs, and increases the safety of firefighting teams by minimizing their exposure to hazardous conditions.

Beyond the core functionality of the system, this project places a strong emphasis on reliability and safety. Rigorous testing protocols to validate the performance of each subsystem will be implemented, ensuring that the drone operates effectively in demanding environments. Additionally, our comprehensive risk management plan addresses potential failure modes and outlines mitigation strategies to ensure the system remains reliable during critical missions.

This proposal outlines the approach to developing this innovative solution, including a detailed analysis of alternative designs, system-level testing procedures, and risk mitigation strategies. By leveraging advanced technologies and integrating them into a single drone platform, the project aims to contribute to a more proactive and efficient approach to wildfire management. Through early detection, rapid suppression, and cost-effective deployment, we hope to support the protection of natural landscapes, critical infrastructure, and human lives from the growing threat of wildfires.

Analysis of Alternate Solutions

The vehicle type chosen for this competition was a hybrid VTOL (Vertical Takeoff and Landing) Fixed-wing UAV, this configuration allows the vehicle to take off and land in place, as well as hover over target tanks, while still gaining the advantage of improved flight efficiency that wings provide. The chosen type also improves surveillance and payload-dropping performance while optimizing battery life, all of which are crucial criteria for Tasks 1 and 2. The hybrid configuration is achieved by mounting four vertical motors on a boom tail aircraft, which is illustrated in Figure 1 below.

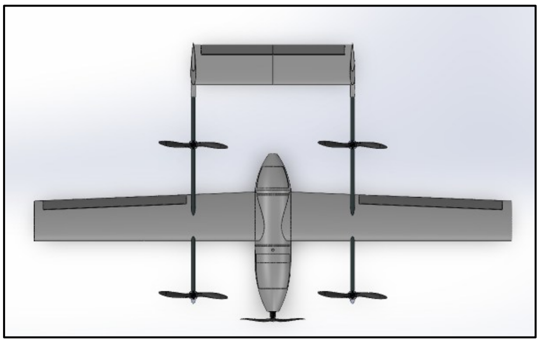


Figure 1- SolidWorks assembly of the hybrid boom tail aircraft

The booms allow better distribution of forces on the tail, which improves flight control. They also provide structural rigidity to the wing and fuselage, by supporting the VTOL motors. A tractor motor was used due to its decreased downwash effect and improved control benefits. [1]

Approach to Mission Requirements

Our vision is to develop a drone capable of detecting and suppressing wildfire ignition points across extensive areas with minimal human intervention. The drone's design prioritizes long-endurance flight and precision, with a payload capacity of up to 4 kg. Leveraging an autonomous mission planner as our ground station, we aim to enhance efficiency, minimize human error, and ensure seamless task execution.

Task 1 Strategy

For wildfire detection, the mission planner will autonomously set flight boundaries and termination responses. The drone's initial heading will be manually aligned toward the helium balloons, which approximate the IR emitters' locations. A spiral flight pattern will be employed to maximize detection efficiency, while the onboard camera relays real-time video to the ground station for analysis. The IR filter will be toggled to visually confirm fire sources. Once all emitters are identified, the drone will autonomously return to the takeoff point. A KML file will be auto-generated, with only the fire source manually inputted.

Task 2 Strategy

For water distribution, the mission planner will use GPS data to identify source and target tanks. The drone will autonomously take off, land on the source tank to fill water, and distribute it equally across the target tanks. Transitions between hover and forward flight modes will be automated based on distance, optimizing efficiency and precision.

Our approach ensures a streamlined, autonomous system that reduces human intervention while maintaining high accuracy and reliability.

IR Detection & Visual Inspection

Our hotspot detection and visual inspection systems are designed to operate seamlessly as part of an integrated control and feedback loop. At the core of this system is an infrared (IR) camera mounted on our drone, capable of capturing real-time thermal imagery. This IR camera provides critical visual data, continuously transmitted to a ground station for analysis and decision-making.

At the ground station, the data from the IR camera is processed using a custom algorithm designed to meet the competition tasks. The algorithm is optimized for detecting thermal anomalies, identifying potential hotspots, and performing precise visual inspections. The algorithm processes the data to identify patterns, measure temperature gradients, and assess the environment.

The ground station operates using a modified version of MissionPlanner, our ground station control software. MissionPlanner interfaces seamlessly with ArduPilot, the autopilot system onboard the drone. Control signals are sent back to the drone once the processed data is analyzed and decisions are made.

The entire process is executed in a continuous feedback loop. The drone captures visual input through its IR camera, transmits the data to the ground station for processing, and receives updated control instructions.

Mapping System

Our mapping system is designed to accurately identify the coordinates of important features and generate KML files in compliance with the competition rules.

A vertical line of red helium balloons simulates the primary indicator of fire. Our drone's initial task is to locate this distinct feature, which serves as the reference point for the mapping process. The drone utilizes its onboard camera and image processing algorithms to identify the red balloons amidst the surrounding environment.

Given the competition constraint that all hotspots are located within a 100-meter radius of the fire source, our mapping system employs a modified Depth First Search (DFS) algorithm to identify and map all hotspots in the vicinity systematically. The DFS algorithm ensures thorough area coverage by prioritizing nearby unexplored regions before branching outward.

The drone captures GPS coordinates of the identified features throughout the search and mapping process. These coordinates are stored in real-time and are continuously updated as the drone detects new hotspots or returns to previously identified locations for verification. The system utilizes a custom-built KML file generator to generate the required KML files. The stored coordinates of the detected features are formatted into the KML structure. Each KML file includes markers for the fire source and identified hotspots.

A new KML file is generated and submitted whenever a new hotspot is discovered. Only the final submitted KML file will be evaluated per the competition rules. The system is designed to perform this process automatically.

The mapping system operates as part of a real-time feedback loop, integrating feature identification, coordinate localization, and KML file generation into a cohesive workflow. The drone continuously collects visual and positional data, processes it on the ground station, and adapts its flight path based on the processed results.

Design and Operation of the Water Payload System

The water payload system of our firefighting drone is designed for efficiency, reliability, and precision in water loading, transportation, and release. Each aspect of the system has been engineered to maximize operational performance while ensuring safety and consistency.

Water Loading

To minimize power consumption and maximize operational efficiency, our drone is designed to land directly on the water tank rather than hover during the water loading process. A pump, located in the aft section of the drone, lowers a pipe into the water tank and pumps approximately 4 liters of water into an onboard storage tank. This process ensures a consistent and reliable water transfer system, reducing the likelihood of mechanical failures or malfunctions. The simplicity of the design reflects our focus on robustness and ease of use.

Water Transportation

The onboard water tank is constructed with integrated baffles along its walls to mitigate the sloshing of water, which could otherwise affect the drone's center of gravity (COG) and stability during flight. To ensure structural integrity and prevent leaks, the tank is sealed with high-performance sealants and coated with water-resistant materials. The tank is strategically placed at the drone's center of gravity, minimizing moment arms and ensuring balanced flight even at maximum carrying capacity. All design calculations account for the drone operating at full payload, providing a lower bound for flight time and ensuring safe operation under all conditions.

Water Release

The water release system incorporates a precision-engineered opening at the bottom of the tank, controlled by a waterproof linear actuator located inside the tank. This actuator governs the release of water, with actuation time correlated to the desired volume of water to be discharged. This feature allows for precise control of the water flow rate and volume, ensuring targeted and effective firefighting. The edges of the tank opening are filleted to direct the water in a linear trajectory and prevent adhesion to the surface, further enhancing the accuracy and efficiency of the release process.

Novel Elements

The drone incorporates several novel technological elements that distinguish it from conventional unmanned aerial systems (UAS) and will help increase effectiveness in completing competition tasks. These elements consist of a dual-function fire detection and suppression system, a nearly fully 3D-printed design, and the use of the Orange Cube flight controller. [4]

Unlike typical UAS designs that specialize in either detection or suppression tasks, this drone is uniquely capable of performing both functions with the use of a single vehicle. Equipped with an onboard camera and thermal sensors, the drone can detect simulated fire indicators during its flight path, as is required for task 1. Then for task 2, with the collected GPS coordinates, the drone will drop the water payload from the onboard tank with precision. This dual-function capability not only simplifies mission logistics but also increases the operational efficiency of the UAS by reducing the need for multiple specialized vehicles.

One of the most distinctive features of the drone is its nearly fully 3D-printed frame and structural components. By using this technology, the team is able to optimize the drone’s design for lightweight durability and customization. The use of 3D printing will also allow the team to make quick changes on structural components, and make any needed adjustments based on the results of future performance testing.

To control the drone's flight path and operational tasks, we integrated the Orange Cube flight controller into the system. The Orange Cube is known for its reliable performance and flexibility across various drone platforms. It will enable autonomous flight, real-time data processing, and easy integration with onboard sensors. The real-time capabilities will be crucial in ensuring the drones success. [5]

Single Point Failure Modes

From a UAV reliability perspective, it is necessary to examine the effects of failure modes in the system and take preventative measures to ensure fault avoidance. These failure modes were identified and categorized using tools such as FMEA (Failure Mode and Effect Analysis) and CA (Criticality Analysis). All probable failure modes, including subsequent effects, criticality, and recommended actions are documented in the tables below. [2]

Table 1 -. Color-coded rating for category severity

Category	Description	Mishap Definition
I	Catastrophic	A failure which may cause System ou UAV Platform loss
II	Critical	A failure which may cause major system damage which will result in a UAV mission loss.
III	Marginal	A failure which may cause minor system damage which will result in a delay or loss of availability or mission degradation.
IV	Minor	A failure not serious enough to cause system damage, but which will result in unscheduled maintenance or repair.

Table 2 - Color-coded rating for occurrence probability

Level	Occurrence	Probability
A	Frequent	O > 0.2
B	Reasonable probable	0.10 > O > 0.2
C	Occasional probability	0.01 >O > 0.10
D	Remote probability	0.001 > O > 0.1
E	Extremely unlikely probability	O < 0.001

Table 3 - Failure modes, effects, and criticality (FMEA and CA)

Failure Mode	Cause(s)	Local Effect(s)	End Effect	Occurrence	Severity	Recommended Actions
Excessive Vibrations	1. Faulty design 2. Improper motor installation angle 3. Structural looseness 4. Irregular airflow 5. Propeller imbalance	Difficult to control/Fatigue	Deviation from flight path	D	III	1. Ensure all connections are tight and properly supported 2. Ensure Motors are properly mounted and correctly oriented 3. Ensure propellers are not chipped, and mounted properly.
Pump Fault	1. Damaged connection 2. Faulty component	No pump control	Loss of water tank system	E	II	1. Check all connections prior to flight
Actuator Fault	1. Damaged connection 2. Faulty component 3. Improper mounting	No actuation	Loss of water tank system	C	II	1. Check all connections prior to flight 2. Ensure proper seal when actuator is extended
Motor Failure	1. Firmware issue 2. ESC Fault/Failure 3. Overloading	No control	Loss of propulsion	D	I	1. Attempt safe landing through flight termination
Battery Failure	1. Depletion 2. Damage	Loss of power	System inactivation	D	I	1. Measure Voltage during pre-flight check 2. Monitor battery life 3. Automatic flight termination when battery life is below minimum threshold.
Motor Overheating	1. Torque overloading 2. Faulty component	Motor damage	Fatigue, eventual loss of propulsion	E	III	1.Inspect motor behaviour prior to takeoff 2. Take temperature readings during testing
Controller Failure	1. No Calibration 2. Firmware issue 3. Faulty component	No control	System inactivation	D	I	1. Calibrate controller before takeoff 2. Attempt safe landing through automatic flight termination

Table 4 - Failure modes, effects, and criticality (FMEA and CA) cont.

Failure Mode	Cause(s)	Local Effect(s)	End Effect	Occurrence	Severity	Recommended Actions
Connection Loss	1. Range exceeded 2. Inteference 3. Firmware not updated	No control	Flight termination	B	II	1. Do not exceed maximum specified telemetry range 2. Ensure VLOS at all times to minimize interference 3. Attempt safe landing through automatic flight termination
Structural Failure	1. Fatigue 2. Faulty design 3. Unaccounted external influence 4. Airframe limitations exceeded	Possible loss of control	Flight termination	E	I	1. Ensure airframe limitations are respected, especially during manual control 2. Account for wind speed and direction. 3. Attempt safe landing through flight termination
Ruptured Water Tank	1. Faulty design 2. Excess forces/displacements (during maneuvers, landing) 3. Improper seal	Loss of water tank system	Damage/destruction of internal components due to water	C	II	1. Visually examine the water tank for any cracks/flaws before takeoff 2. Assess criticality and size of leak if possible 3. Evacuate any water from the tank and attempt a safe landing
Incorrect Transition Between Flight Modes	1. Firmware Issue 2. Flow seperation 3. Transition done below stall speed	No control	Flight termination	D	II	1. Abort transition as soon as possible 2. Attempt safe landing through automatic flight termination
Flyaway	1. Compass interference 2. Operator error 3. GPS malfunction	Difficult to control	Deviation from flight path	E	III	1. Attempt to regain manual control of the vehicle 2. Attempt safe landing through flight termination if control attempt is unsuccesful
IR Camera Fault	1. Ground control issue 2. Firmware issue 3. Connection loss 4. Faulty component	No visual feedback	Flight termination	D	III	1. Remote reset of the camera system 2. Re-establish connection with the camera 3. Return to flight line if issue persists
Wrong Reaction to Failure	1. Operator error 2. Inadequate training	Possible loss of control	Flight termination	C	II	1. Feedback from visual observer 2. Attempt safe landing through automatic flight termination

System Level Testing

Subsystem Testing

Individual components will be tested independently to confirm functionality and reliability:

Pump and Water Loading System: Verifying consistent water transfer from an external supply to the onboard tank.

Actuator and Water Release Mechanism: Testing precision and responsiveness to control water discharge accurately.

Flight Control Systems: Assessing stability and maneuverability under various payload conditions through simulations and controlled flights.

This phase will identify potential issues early, ensuring each component performs as intended.

System Integration Testing

Once subsystems are validated, they will be integrated to verify seamless operation. The main integration tests will be:

Confirming compatibility between mechanical, electrical, and software systems.

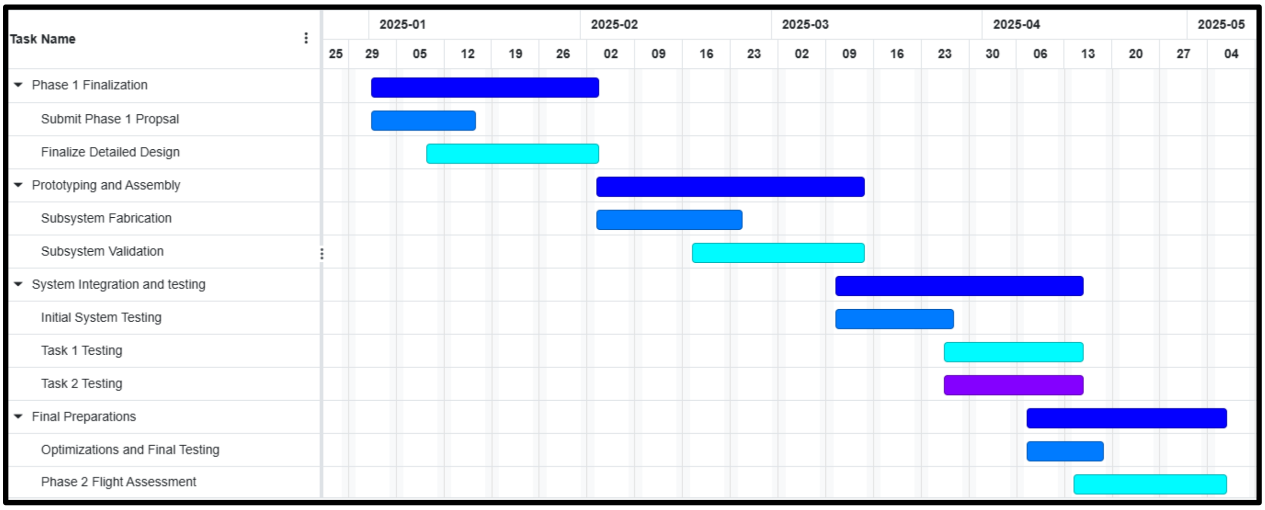
Simulating full mission workflows, including the water loading, transportation, and release.

Ensuring stability during flight, particularly with a full payload, through balance and control tests.

Integration testing ensures that all components function in harmony under operational conditions.

Schedule

Table 5 - Gantt Chart showing the tentative dates for the project



Risk Management Plan

During the design of your UAS, what risks may affect your ability to compete, and how are you addressing the risks? [3]

Technical Risks

Challenges with drone design

Balancing the drone with a full water payload is critical. While placing the tank at the COG minimizes moment arms, there is still a risk of instability during rapid flight maneuvers.

Likelihood: Medium.

Impact: High–instability could lead to system failure or an inability to complete the mission.

Mitigation: Extensive simulation and physical testing under various flight conditions to validate stability. Use of baffles and dynamically tuning the flight controls for payload adjustments.

Failure of critical systems

Components like the pump, actuator, or camera could malfunction.

Likelihood: Low to Medium-depends on component reliability.

Impact: High–any failure could result in disqualification or an incomplete task.

Mitigation: Redundancy in critical systems, routine inspections. Ensure all parts are working and running up to standard.

Software glitches

Navigation, water release controls, or automation systems could encounter bugs during the mission.

Likelihood: Medium.

Impact: High– software issues could lead to improper operation or mission failure.

Mitigation: Continuous software testing, including worst-case scenarios, and maintaining backup manual controls for critical functions.

Programmatic Risks

Timeline risks

The team may not complete the system or testing by the competition deadline.

Likelihood: Medium.

Impact: High–an incomplete system may disqualify the team from competing.

Mitigation: Develop a detailed project timeline with milestones, and allocate buffer time for unexpected delays. Use regular progress meetings to track status and adjust priorities.

Supplier Delays

Critical components or materials may arrive late, delaying assembly or testing.

Likelihood: Medium.

Impact: Moderate–delays could limit testing and optimization time.

Mitigation: Order components early and identify multiple suppliers as backups.

Team coordination

Miscommunication or knowledge gaps among team members could slow progress.

Likelihood: Low to Medium.

Impact: Moderate–could affect efficiency and final quality.

Mitigation: Assign clear roles and responsibilities, encourage communication, and conduct team workshops or training if necessary.

Budget Risks

Funding limitations

A tight budget could prevent the purchase of higher quality components.

Likelihood: Medium.

Impact: High–budget constraints could reduce reliability or performance.

Mitigation: Seek sponsorships, reduce costs by leveraging university resources, and prioritize spending on critical components.

Unexpected expenses

Unforeseen costs, such as repairing damaged parts or additional testing equipment, might strain the budget.

Likelihood: Medium.

Impact: Moderate–could limit testing.

Mitigation: Allocate a contingency fund and carefully track expenses to avoid overspending.

Other Possible Risks

Testing environment risks

Windy/unsuitable weather could delay outdoor testing or cause variation in the performance data.

Likelihood: Medium.

Impact: Moderate–limited testing could affect the optimization.

Mitigation: Schedule testing in advance during favorable weather conditions and secure access to an indoor testing area as a contingency.

Regulatory compliance

Failure to meet drone flight laws or safety regulations could disqualify the team.

Likelihood: Low.

Impact: High–non-compliance could result in disqualification.

Mitigation: Research federal and provincial regulations thoroughly and obtain all necessary permits and licenses before the competition.

Budget Estimate for 2024 - 2025 Competition Season

The estimated budget for the upcoming competition 2024-2025 is split into four main categories: miscellaneous expenses, travel, electronic equipment, and mechanical equipment. These categories and their specifics, along with the cash flow and the sponsorship development plan, are presented below.

Construction Materials

Tables 6 and 7 outline the projected procurement costs of mechanical and electrical components procured from reputable suppliers, including all tax and shipping costs. These are the materials the team requires to build the project and take part in the competition.

Table 6 - Mechanical Equipment Cost Breakdown

Equipment	Qty.	Spare Qty.	Unit Price (CAD)	Extension (CAD)
3D filament (PLA, PETG)	2	2	30.0	138.0
3D filament (Aero)	1	0	58.0	66.7
20mm x 18mm x 1.2m pultruded CF rod	2	2	58.4	268.6
6mm x 5mm x 1.2m pultruded CF rod	2	2	5.4	24.9
4mm x 3mm x 1.2m pultruded CF rod	4	4	3.7	33.7
1" x 1" x 8' Aluminium 90 angle	1	1	14.8	33.9
Misc. Equipment (Fasteners, servo arms, propellers)	1	0	100	115
Safety Money (Unforseen Expenses)			500	500
Note: All extension prices include shipping and GST where applicable			**Subtotal ($)**	1180.82

Table 7 - Electrical Equipment Cost Breakdown

Equipment	Qty.	Spare Qty.	Unit Price (CAD)	Extension (CAD)
9g Servos	4	6	1.9	21.8
SunnySky X3520 Throttle Motors VTOL	4	0	47.0	216.2
SunnySky X3250 Thrust Motor	1	0	47.0	54.0
80A ESC 3-6s	5	0	41.9	241.0
CubePilot Cube Orange Flight Controller	1	0	504.4	580.0
3DR 500MW 915MHz Telemetry	1	0	71.0	81.6
Gimball Camera	1	0	421.8	421.8
12V Pump	1	0	28.6	32.9
9000mAh 6s Lipo Battery	1	1	173.4	398.7
Micro Linear Actuator	1	0	53.2	53.2
PIR long-distance sensor	1	0	100.0	115.0
VTX Camera Transmitter	1	0	47.5	54.7
Misc. Equipment (Wires, arduino microcontrollers, plugs, circuit items)	1	0	100	115
Safety Money (Unforseen Expenses)			1000	1000
Note: All extension prices include shipping and GST where applicable			**Subtotal ($)**	2385.99

Travel Expenses

Table 8 details the budgets for travel costs of 8 of the team members who will take part in the Annual National Student Unmanned Aircraft Systems (UAS) Competition. These travel costs include transportation, meals, and accommodation, which will facilitate the team's attendance at the event as smoothly as possible.

Table 8 - Travel Expenses Cost Break down

Item	Qty.	Unit Price (CAD)	Extension (CAD)
Flights (Roundtrip from St. John's, NL-YYT to Medicine Hat, AB-YYC from May 8-12, 2025)	8	600	4800
Rental Vehicle Cost (6 person capacity each)(Full size SUV)	2	650	1495
Fuel price (Roundtrip from YYC to YXH) (300km one way)	1	600	600
Note: All extension prices include shipping and GST where applicable		Subtotal ($)	6895.00

Miscellaneous Costs

We are expecting 4407.30 in other necessary expenses, such as the entry fee for the competition, operating licenses for the UAS, and the costs associated with team building. All these are required to participate in the contest and promote unity within the team.

Table 9 - Miscellaneous Expenses

Item	Qty.	Unit Price (CAD)	Extension (CAD)
Team Registration Fee	1	600	690
Onsite Team Member Fee (Includes accomodation and meals for most days*)	8	330	3036
Advanced Drone Operations Exam (One pilot member requires advanced certification through Transport Canada)	1	25	25
Licensing Cost (Quoted flight reviewer cost for licensing)	1	400	400
Refreshements during test launches	1	50	57.5
Team T-shirts	8	14	128.8
Banking Costs	1	50	50
Marketing (Flyers)	20	1	20
Note: All extension prices include shipping and GST where applicable		Subtotal ($)	4407.30

Cash Flow and Sponsorship

With the help of the Student Design Hub Special Award program, Valiant Aerotech aims to cover all expenses for acquiring necessary items and keep aside suitable contingency funds. Exceeding funds will be rolled into the following competition cycles. All expenditures will be controlled and monitored monthly to avoid going over budget, which will help estimate whether a competition cycle can be funded. To secure local sponsorships and the connection with the design teams in and around Memorial University, the team intends to obtain the $1,000 necessary from local businesses wanting to market to the event. All groups will be given a lucrative sponsorship offering consisting of a range of pre-set maximum payments made to a single cause with the expectation of increased financial inflow.

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