

Design Packet Spring 2026

Executive Summary

This capstone project details the design, fabrication, and testing of a fixed-wing vertical take-off and landing (VTOL) drone, engineered to collect thermal and optical imagery for post-fire assessment. The system addresses critical capability gaps identified through direct coordination with CAL FIRE, the U.S. Forest Service, and municipal fire departments, grounding our engineering targets in operational reality. Currently deployed platforms lack the endurance, thermal discrimination, communication reliability, and field-service modularity required to efficiently map large burned areas and isolate residual hotspots.

Interviews with emergency response personnel highlighted four primary limitations in existing commercial fleets: (1) inadequate endurance (typically 20–45 minutes), (2) severe telemetry degradation in beyond-visual-line-of-sight (BVLOS) environments, (3) insufficient thermal resolution for post-burn inspection, and (4) slow field servicing hampered by proprietary hardware. While DJI’s Matrice series previously set a performance benchmark with ~45-minute flight times and high-quality radiometric sensors, they are cost-prohibitive, restricted by closed software ecosystems, and now entirely non-viable for agency deployment following the FCC ban enacted on December 23rd. Compliant U.S.-made alternatives frequently suffer from weaker telemetry and even steeper price points.



Figure 1: Final system in vertical takeoff.

Our solution is a long-endurance, NDAA-compliant VTOL platform built entirely on open-source autopilot and perception frameworks. The airframe utilizes a tri-motor layout inspired

by the Flightory Stallion, featuring two front tilt-rotors driven by 2807 1300kV brushless motors for vertical lift, and a fixed rear motor for efficient forward flight.

Payload operations are driven by a Teledyne FLIR Boson 640 radiometric core ($\pm 2^\circ\text{C}$ accuracy [1]), providing lightweight, high-resolution thermal mapping. Georeferencing is achieved via GNSS, while an NVIDIA Jetson Orin Nano 8GB running ROS 2 handles onboard image processing and target detection. At the hardware level, an ArduPilot-based avionics stack, managed by a Cube Orange flight controller, ensures highly stable VTOL transitions, robust failsafe behaviors, and seamless integration with open-source mission planning suites [2].

Ultimately, this system delivers a modular, easily field-serviceable wildfire intelligence platform optimized for endurance, autonomous operation, and cost-effective deployment.

1 Introduction and Background

Wildfires in California have grown more frequent and destructive due to drought, high fuel load, and expanding wildland–urban interfaces. In the 2025 fire season, CAL FIRE reports over 523,000 acres burned, 7,745 wildfire incidents, and 31 fatalities across the state [3]. These numbers highlight an urgent need for rapid, high-resolution fire intelligence that existing methods cannot consistently deliver. Satellite passes occur on 12–24 hour cycles, helicopter surveys are costly and weather-limited, and ground crews often operate with incomplete thermal information, slowing containment and exposing personnel to unnecessary risk.

Unmanned aerial systems have become a valuable supplement, particularly quadcopters such as the DJI Matrice 30T and 4T. These platforms provide radiometric thermal imagery, automated mapping, and stable flight in adverse conditions [4]. However, direct feedback sessions conducted with agency stakeholders—including Dirk Giles, head of the U.S. Forest Service drone program, alongside CAL FIRE and the Los Angeles Fire Department—reveal four persistent limitations in current systems: flight endurance typically limited to 20–45 minutes, severe telemetry degradation beyond visual line of sight (BVLOS), weak thermal differentiation during post-burn inspection, and proprietary hardware that slows field servicing. Furthermore, following the FCC ban enacted on December 23rd, agencies are strictly mandated to deploy NDAA-compliant, domestically operated platforms. Yet, existing American alternatives tend to carry prohibitive costs while providing weaker communication links.

Performance analyses on the sensing side indicate that while DJI’s 640-pixel radiometric cores previously set the benchmark [4], the Teledyne FLIR Boson 640 offers comparable radiometric accuracy ($\pm 2^\circ\text{C}$) in an open, lightweight module suitable for custom airframes [1]. In terms of system architecture, autonomy research highlights the respective strengths of open-source flight stacks: ArduPilot provides mature fixed-wing VTOL transition performance and survey tools [2], whereas PX4 offers robust, modular ROS 2 integration for real-time onboard processing [5].

This project builds on these findings to develop an open-source, long-endurance VTOL platform tailored directly to the operational realities of California fire agencies. By integrating a tri-motor VTOL airframe, high-fidelity radiometric thermal sensing, robust telemetry, and

onboard image processing, the system specifically targets the endurance, reliability, and data-quality gaps identified by field operators. The objective is a deployable, NDAA-compliant wildfire-mapping tool that expands access to critical aerial intelligence for local fire departments, research institutions, and emergency response teams.

2 Design and Analysis

The mechanical and electrical architecture of the system balances the proven aerodynamic efficiency of the Flightory Stallion platform with extensive custom engineering. To clearly articulate our engineering rationale, this section details the target specifications, structural design, and system integration for the complete airframe and each custom-engineered sub-assembly.



Figure 2: The completed VTOL airframe staged on its launch stand during pre-flight preparation, with the avionics hatch open prior to takeoff. The tilt-rotor booms, antennas, and payload nose are visible in their integrated configuration.

2.1 System Level Architecture

Required System Specifications

- **Target Endurance: 90 minutes**

Motivation: Agency feedback indicated that 20–45 minute flight times are insufficient. A 90-minute endurance fully maps a 0.25×0.25 mile plot (40 acres) and allows loitering for hotspot monitoring.

- **Operational Radius: 10 miles**

Motivation: Wildfire environments require BVLOS operations where high-bandwidth

video links fail. This radius ensures reliable command and control over large burn scars.

- **All-Up Weight (AUW): <4.0 kg**

Motivation: Provides the necessary mass allowance for a high-density power system and dual-sensor payload while remaining portable for a single ground operator.

- **Airframe Material Strategy: High Thermal Resistance & Low Mass**

Motivation: Standard PLA warps under the extreme heat of fire zones. The system requires materials with high thermal resistance for the core, while minimizing mass on aerodynamic surfaces to extend endurance.

2.2 Electronics Architecture

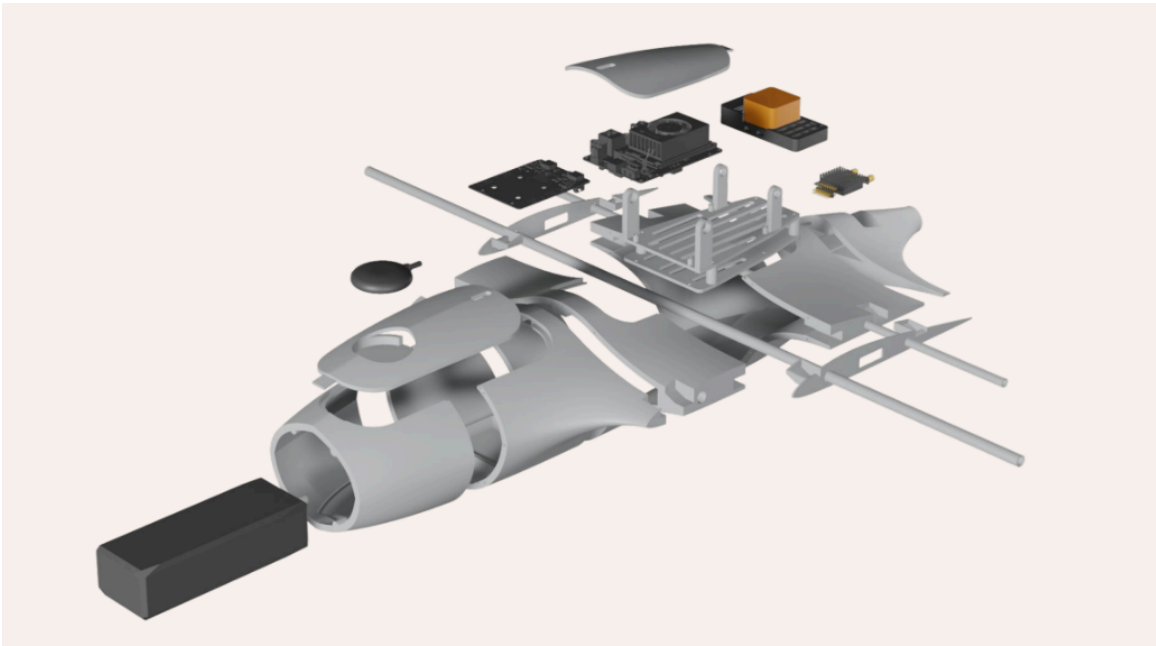


Figure 3: Exploded view of the full airframe and avionics stack, showing the modular payload nose, central avionics chassis, wing and tail subassemblies, and the major electronics components.

Required Electronics Specifications

- **Robust Autopilot and Companion Compute Architecture**

Motivation: Autonomous wildfire mapping requires a reliable real-time flight control system while simultaneously processing high-bandwidth sensor data. The electronics architecture must therefore separate deterministic flight stabilization from computationally intensive perception tasks to maintain safe aircraft control.

■ High-Integrity Power and Communication Infrastructure

Motivation: The system must distribute high current to propulsion while providing clean, regulated power to sensitive avionics and compute hardware. Reliable communication links and sensor interfaces are required to maintain navigation accuracy, telemetry, and payload data transmission during extended BVLOS (beyond visual line of sight) missions.

Description of Electronics Design

The avionics architecture is divided into two functional layers: real-time flight control and high-level perception and processing.

Low-level aircraft stabilization and actuator control are handled by a Cube Orange+ flight controller, running the ArduPilot RTOS. The flight controller interfaces directly with the propulsion system (ESCs and motors), control surface servos, GNSS module, and telemetry radio, ensuring deterministic timing and reliable flight behavior.

High-level perception and payload processing are managed by an NVIDIA Jetson Orin Nano 8GB companion computer, mounted on an ARK Electronics Just-a-Jetson carrier board. This custom carrier board streamlines integration by providing a robust, low-profile interface for our sensor suite. The Jetson receives image streams from the FLIR Boson 640 thermal camera and the RGB camera, performing onboard processing and target detection using ROS 2-based software pipelines.

Communication between the companion computer and flight controller occurs through MAVLink over serial telemetry, allowing the Jetson to provide mission-level commands while the flight controller maintains full authority over safety-critical stabilization tasks.

Power distribution originates from the 6S LiPo battery, which feeds a central power distribution board supplying the three propulsion ESCs. Dedicated voltage regulators provide isolated 5V and 12V rails for avionics components including the Jetson, flight controller, telemetry radio, GPS module, and sensors. This separation prevents electrical noise from the propulsion system from interfering with sensitive compute hardware.

The resulting architecture creates a modular, fault-tolerant avionics stack, where real-time flight control remains independent from high-bandwidth perception workloads, improving system reliability and enabling scalable onboard intelligence for autonomous wildfire mapping.

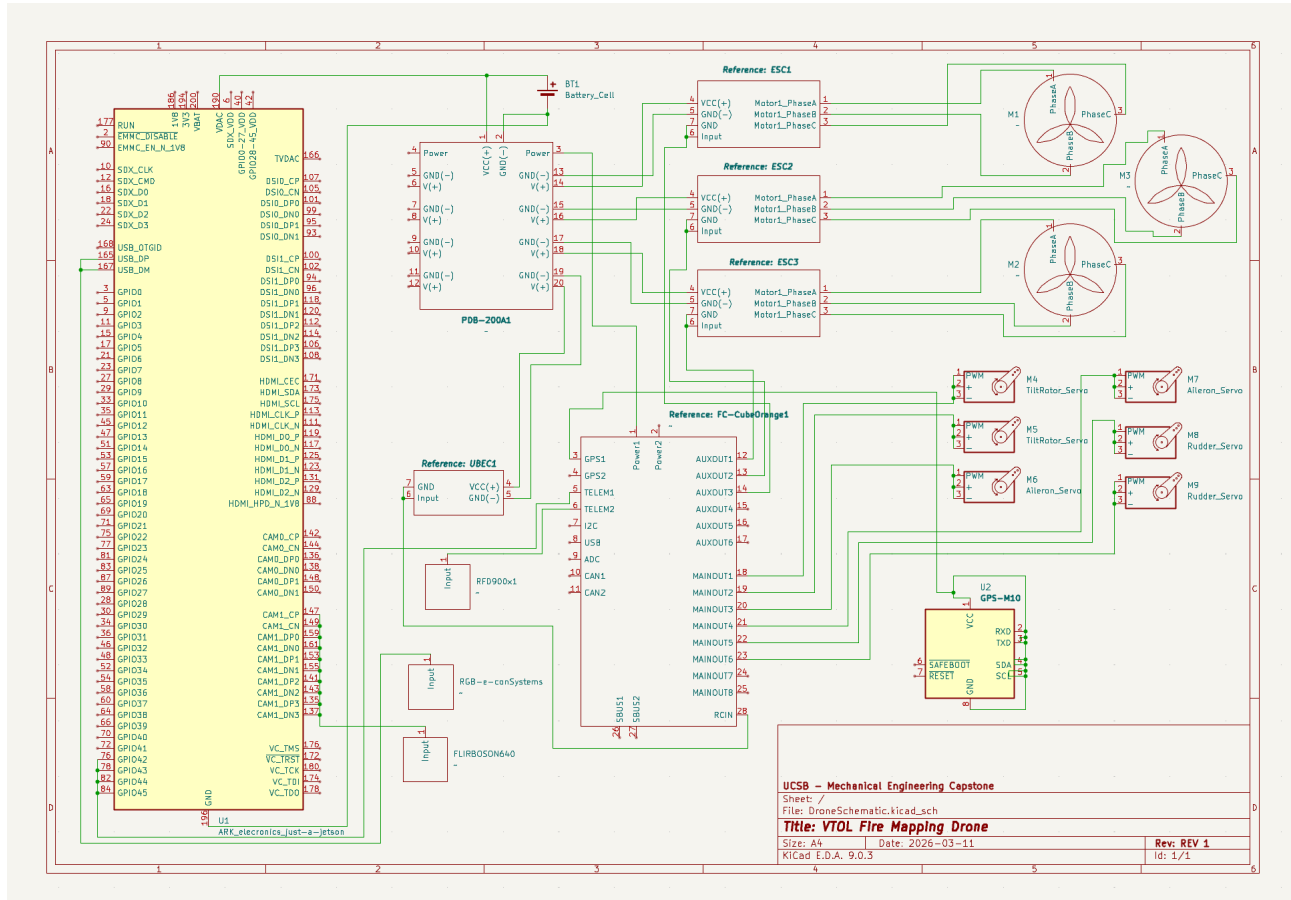


Figure 4: Avionics architecture demonstrating the separation of low-level RTOS flight control and high-level perception.

2.3 Modular Payload Fairing (Nose)

Required Nose Specifications

- **Strict CG Management: 60mm aft of LE**

Motivation: The heavy thermal payload must be utilized as a cantilevered mass to offset the tail-heavy rear motor, pulling the Center of Gravity (CG) to the strict aerodynamic requirement of 60mm aft of the Leading Edge (LE).

- **Vibration & Impact Mitigation**

Motivation: Radiometric mapping requires pristine image quality; the sensors must be isolated from motor resonance and physically protected from lens abrasion during rough landings.

Description of Nose Design

The custom nose cone serves as the primary payload housing. It rigidly consolidates the Teledyne FLIR Boson 640 and RGB camera into a single modular pod. To prevent lens abrasion, the camera faces are deeply recessed within the PA6-CF structure. Mounting points incorporate localized dampening to isolate the radiometric core from the high-frequency resonance generated by the front tilt-rotors. This modular pod also allows rapid access to the wire harness, routing directly back to the Jetson Orin Nano 8GB for efficient field maintenance.

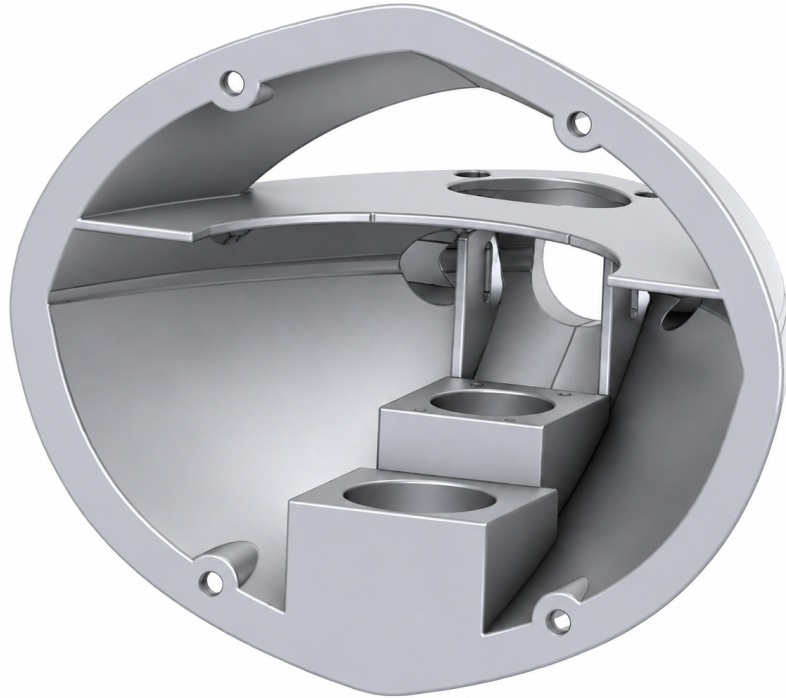


Figure 5: CAD render of the custom PA6-CF payload fairing, highlighting the recessed camera bays for the Boson and RGB sensors.

2.4 Central Avionics Chassis (Cradle)

Required Cradle Specifications

■ Structural Airframe Integration

Motivation: High-density components (battery, Jetson) cannot rely on the outer skin for support; they must transfer load directly to the main spars to prevent airframe flex during high-G VTOL transitions.

■ Power Isolation & Volumetric Efficiency

Motivation: The chassis must organize a complex wire harness, physically separating the noisy 6S propulsion bus from the cleanly regulated 5V/12V avionics logic, while keeping the heavy battery as far forward as possible.

Description of Cradle Design

The internal chassis is the structural heart of the avionics bay. It mounts directly to the internal carbon fiber wing spars, securely anchoring the Power Distribution Board (PDB), the NVIDIA Jetson Orin Nano 8GB, and the Cube Orange+ flight controller. It anchors the main 6S 8000mAh battery at the absolute front of the bay, working in tandem with the payload pod to maintain the CG target.

Electronically, the chassis organizes the bifurcated logic system. The Cube Orange+ handles real-time RTOS flight stabilization, while the Jetson operates ROS 2 to handle high-bandwidth data from the FLIR Boson. Power is strictly segmented: the 6S battery drives the three 50A ESCs directly, while discrete 5V and 12V buck converters shield the logic boards from inductive voltage spikes.

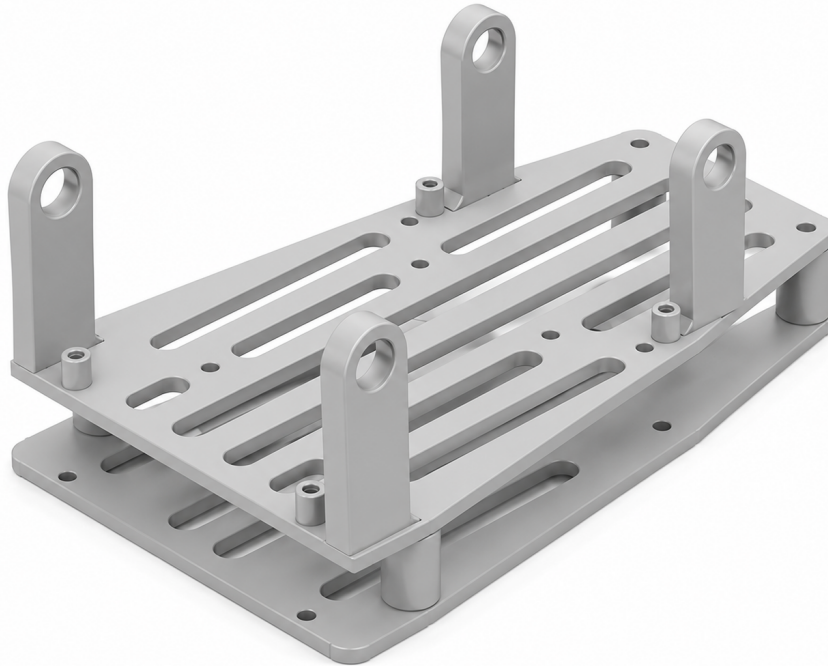


Figure 6: Internal CAD view of the central avionics chassis mounting directly to the carbon fiber spars, housing the Jetson Orin Nano and main battery.

2.5 Front Hatch (GPS Lid)

Required Front Hatch Specifications

- **Electromagnetic Interference (EMI) Isolation**

Motivation: The magnetometer is highly sensitive. It must be physically distanced from the high-current DC cables and PDB to prevent severe heading variance and navigation failsafes mid-flight.

Description of Front Hatch Design

The main top-mounted front hatch was redesigned to incorporate a custom, elevated enclosure for the ARK SAM GPS and integrated magnetometer. This structural modification elevates the sensitive compass vertically away from the high-current DC cables in the central chassis directly below it, mitigating EMI while simultaneously maintaining an easily removable lid for rapid access to the avionics bay.



Figure 7: The custom GNSS/Magnetometer enclosure, designed to physically isolate the compass from internal electromagnetic interference.

2.6 Rear Fuselage (RFD 900 Tail)

Required Rear Fuselage Specifications

- **RF Signal & Link Budget Optimization**

Motivation: A 10-mile C2 radius requires optimal antenna polarization. The 900MHz transmissions must also be physically separated from the main avionics to prevent signal swamping.

Description of Rear Fuselage Design

To guarantee a robust C2 link, the rear fuselage was heavily modified to house the RFD900x telemetry radio. We engineered specific geometric cutouts and internal mounting structures into the tail that allow the dipole antennas to protrude cleanly from the extreme rear of the aircraft. This physical modification optimizes antenna polarization and maximizes the RF link budget while isolating the powerful transmissions from the primary flight controller.

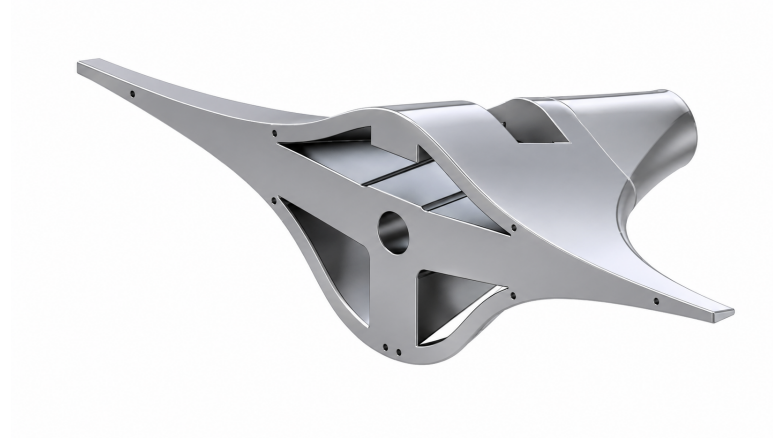


Figure 8: Tail-mounted RFD900 transceiver housing, optimizing antenna polarization and minimizing RF interference with the main flight controller.

2.7 Power System

Required Power System Specifications

A core requirement for the power architecture was to keep the system simple and highly integrated, minimizing wire clutter and potential points of failure while managing extreme power demands. To ensure flight stability and prevent brownouts during high-draw VTOL transitions, the centralized power distribution system must supply stable voltage and adequate current across four distinct electrical domains:

- **Propulsion (Direct 6S LiPo Bus, 22.2V–25.2V):**
 - 3× 50A ESCs and 2807 1300kV Brushless Motors ($\sim 150\text{A}$ peak draw combined).
- **Actuation (5V–6V via 15A UBEC to FC Servo Rail):**
 - 2× DS041MG Tiltrotor Servos ($\sim 4.0\text{A}$ stall peak combined).
 - 4× MG995 Control Surface Servos ($\sim 4.8\text{A}$ stall peak combined).
- **Avionics & Compute (Direct PDB & Dedicated FC Power):**

- NVIDIA Jetson Orin Nano 8GB (ARK Electronics Just-a-Jetson carrier board powered directly from the PDB via internal regulator; $\sim 6.0\text{A}$ peak).
 - Cube Orange+ Flight Controller (Powered via the dedicated FC power cable from the PDB; $\sim 0.5\text{A}$ at 5.3V).
 - Teledyne FLIR Boson 640 & RGB Camera (Low draw, routed via Jetson).
 - ARK SAM GPS & RC Receiver (Low draw, powered via FC ports).
- **Communication Links (Isolated 5V via Dedicated 3A UBECs):**
 - RFD900x Telemetry Radio ($\sim 1.0\text{A}$ peak, driven by standalone 3A UBEC).
 - Long-Range VTX ($\sim 1.5\text{A}$ peak, driven by standalone 3A UBEC).

Description of Power System Design

The power system is designed around a single 6S 8000mAh LiPo battery, chosen to provide the high discharge rate required for hovering while maintaining the energy density necessary for fixed-wing endurance. To select the appropriate power distribution hardware and voltage regulators, we conducted a worst-case peak current (amp load) analysis across all major system categories:

1. **Propulsion (Direct 6S Bus):** The VTOL configuration utilizes three 2807 1300kV brushless motors driven by 50A ESCs. During a high-G VTOL transition or aggressive climb, the motors can saturate the ESCs, resulting in a theoretical peak draw of **150A** ($3 \times 50\text{A}$).
2. **Actuation (FC Servo Rail via 15A UBEC):** The airframe utilizes two high-torque DS041MG servos for the front tiltrotors (approx. 2.0A stall current each) and four standard MG995 servos for the control surfaces (approx. 1.2A stall current each). To safely manage this maximum theoretical draw of **8.8A**, the flight controller's servo rail is driven by a dedicated **15A UBEC** wired directly from the PDB. This provides a robust safety margin to prevent servo brownouts during aggressive maneuvering.
3. **Compute & RF (Isolated Logic Rails):** The NVIDIA Jetson Orin Nano 8GB ($\sim 6.0\text{A}$ peak) and Cube Orange+ FC ($\sim 0.5\text{A}$) handle the core logic and perception. The Jetson utilizes an ARK Electronics Just-a-Jetson carrier board, allowing it to be powered directly from the PDB's main voltage due to its built-in internal regulator. The Cube Orange+ is powered cleanly via the dedicated FC power cable provided with the Airbot PDB. To prevent the high-power communication systems from inducing noise or sagging these primary avionics voltages, both the 1W RFD900x telemetry radio and the long-range VTX are strictly isolated. Each is powered by its own independent **3A UBEC**, routed directly from the PDB.

Combining the propulsion load with the necessary step-down current for actuation and logic results in a worst-case system peak draw of approximately 165A to 170A. Based on this calculation, and the requirement for a simple, integrated power solution, we selected the **Airbot Mini PDB PRO v2 – 200A**. This single-board solution centralizes our distribution, eliminating the need for complex, multi-board wiring harnesses, while providing an essential 15–20% safety margin. This ensures the board can effortlessly manage peak VTOL transition loads without thermal throttling or risking a catastrophic mid-air electrical failure.

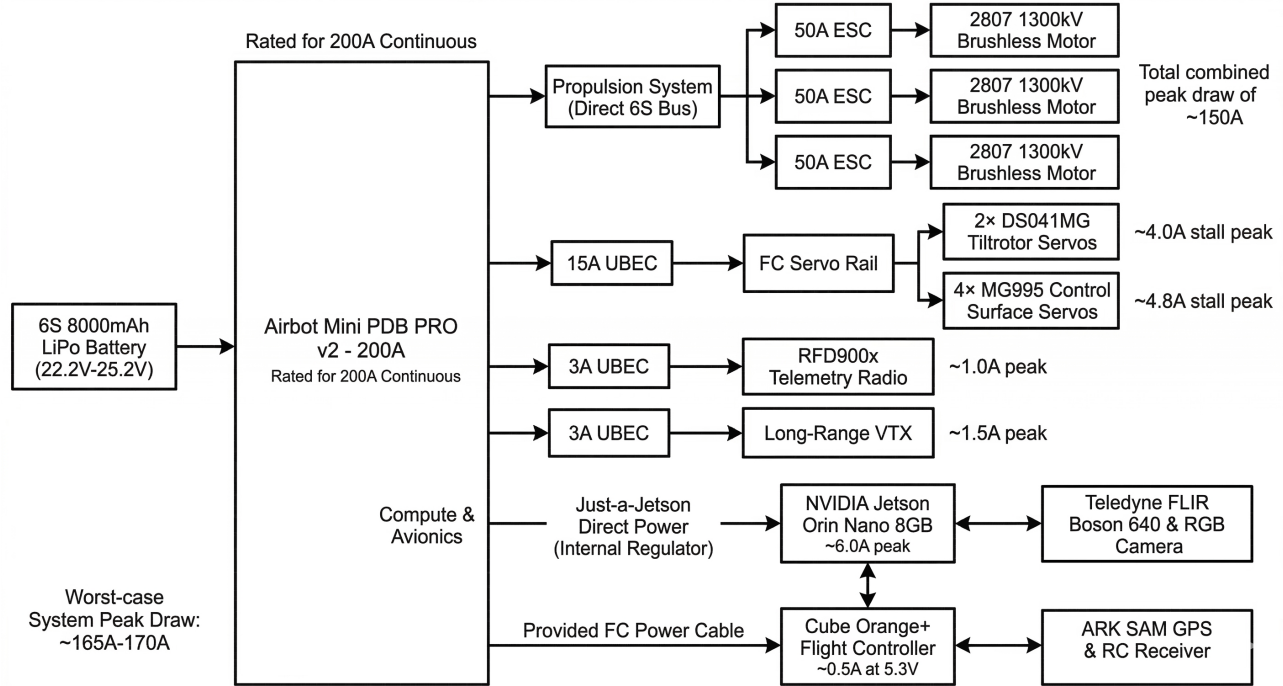


Figure 9: Power routing diagram illustrating the 6S high-current distribution through the 200A Airbot Mini PDB PRO v2, highlighting the direct routing to the Just-a-Jetson carrier board and the isolated UBECs for actuation and RF links.

2.8 Individual Part Drawings

Overall Assembly

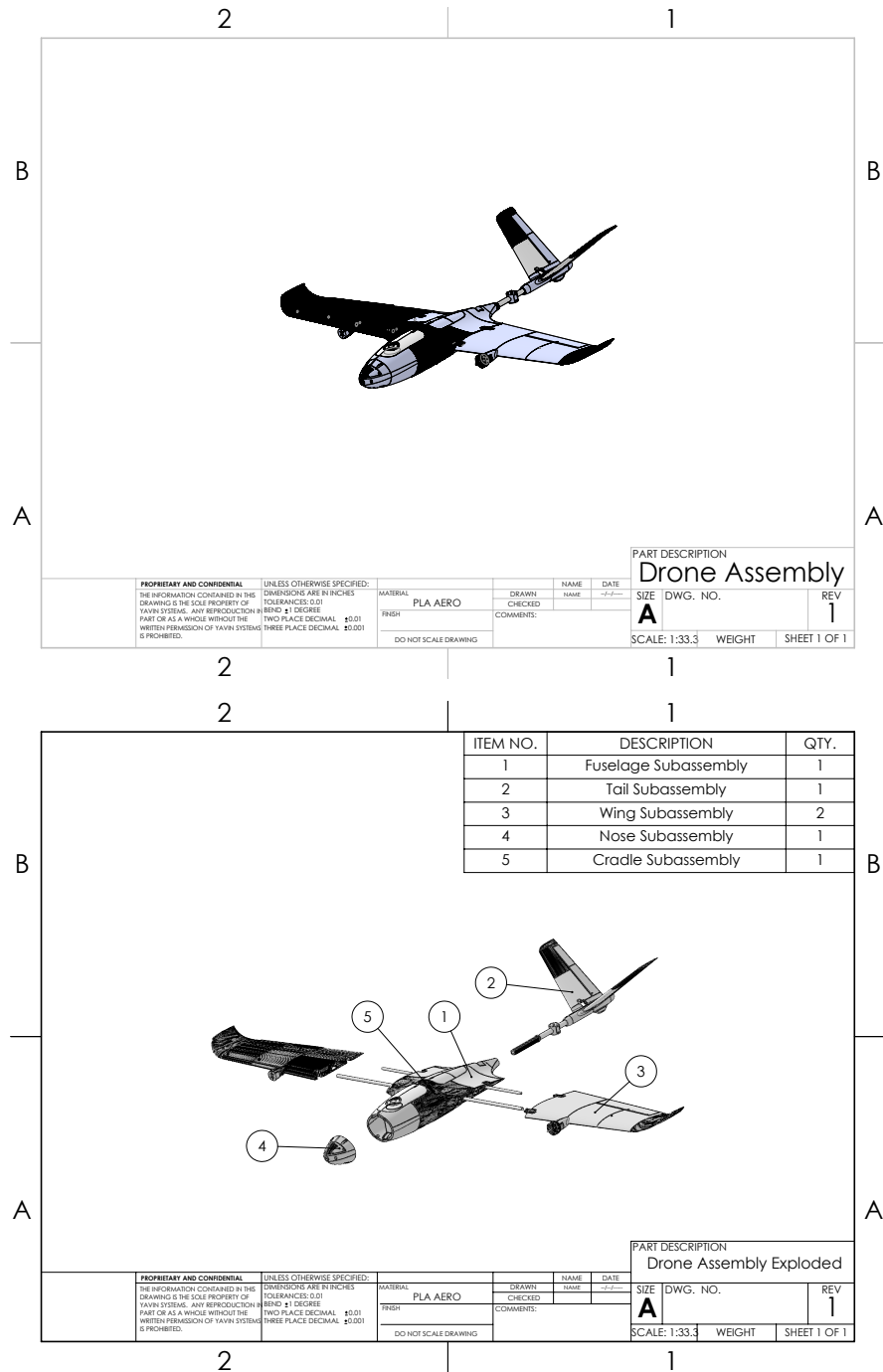


Figure 10: Overall and exploded assembly drawings of the VTOL fire mapping drone.

Nose Subassembly

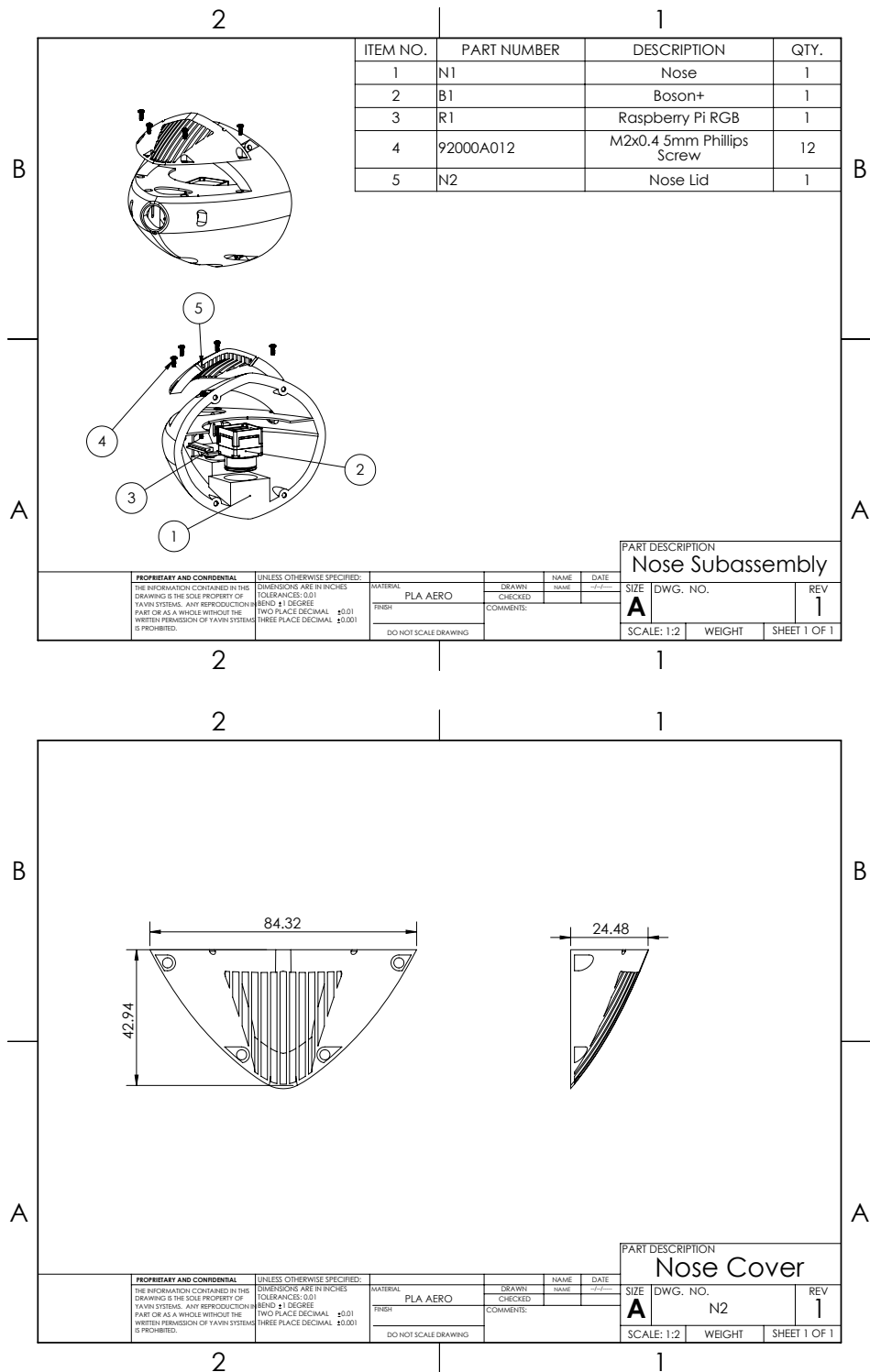


Figure 11: Modular payload fairing subassembly and nose cover drawings.

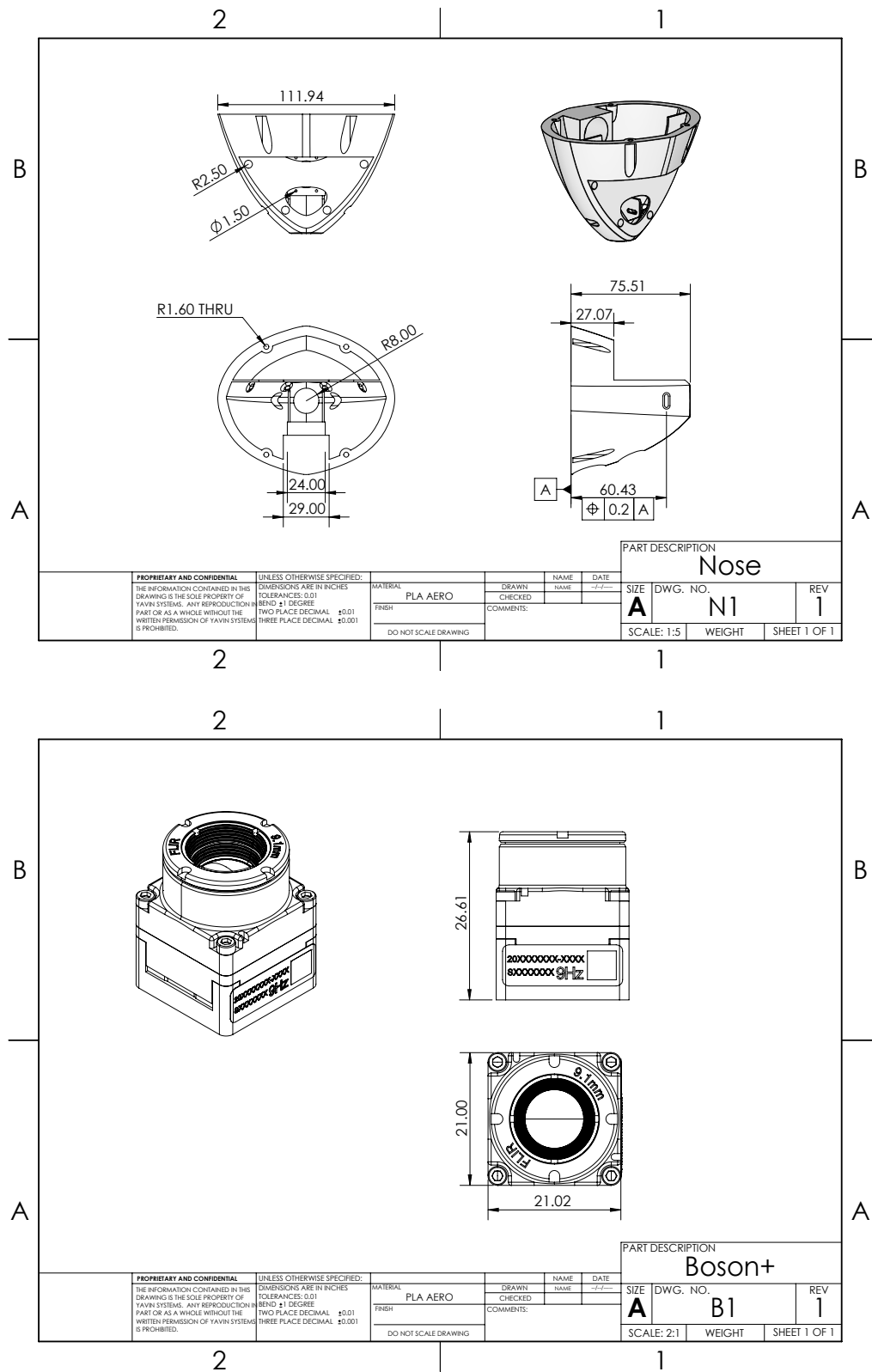
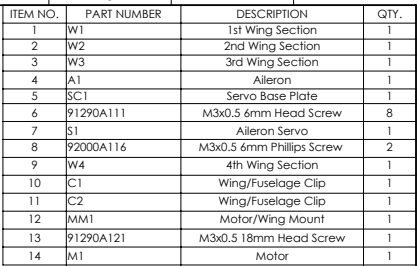


Figure 12: Primary nose structure and FLIR Boson mounting geometry.



Wing Subassembly

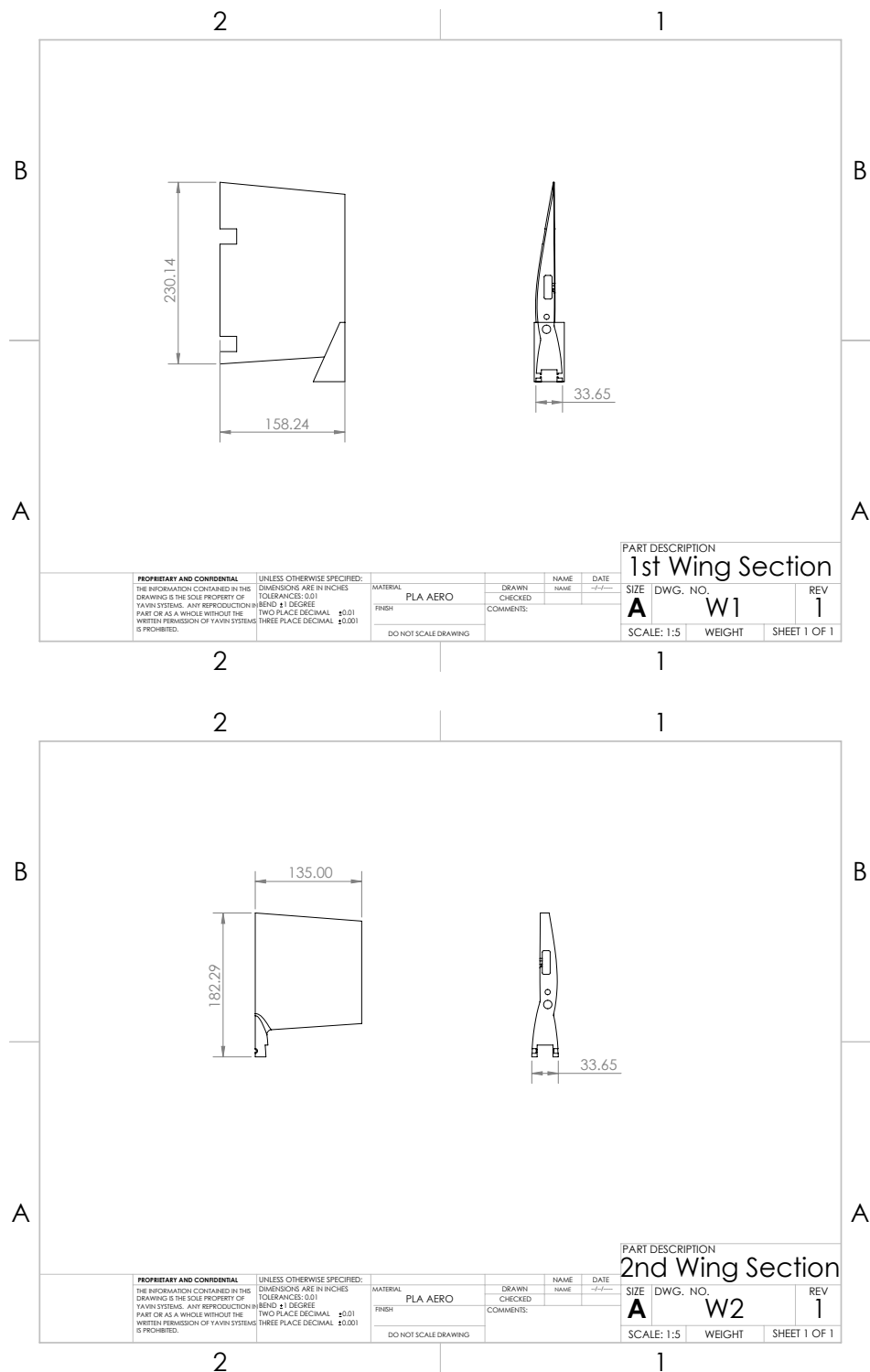


Figure 15: Wing structural components W1 and W2.

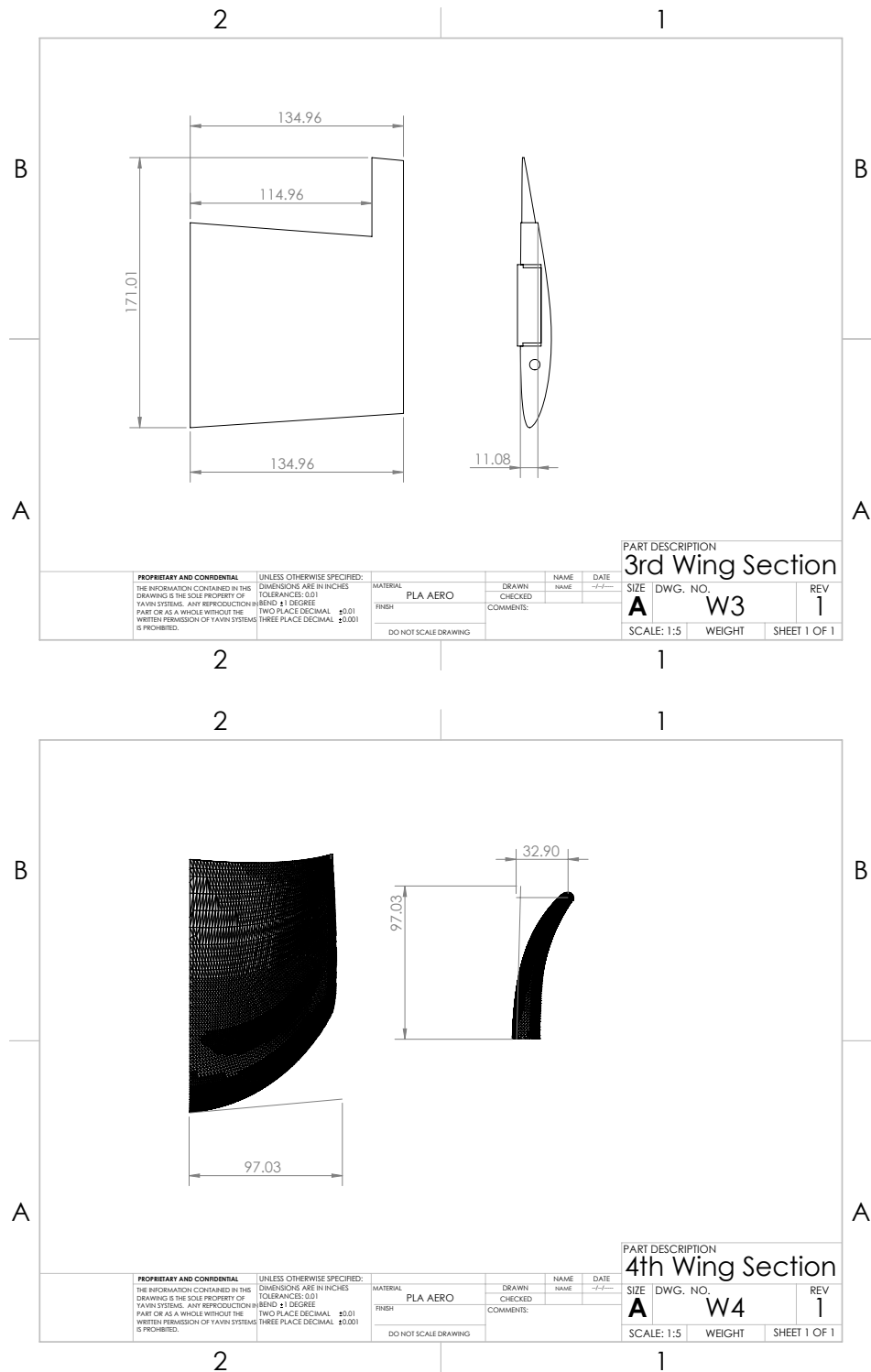


Figure 16: Wing structural components W3 and W4.

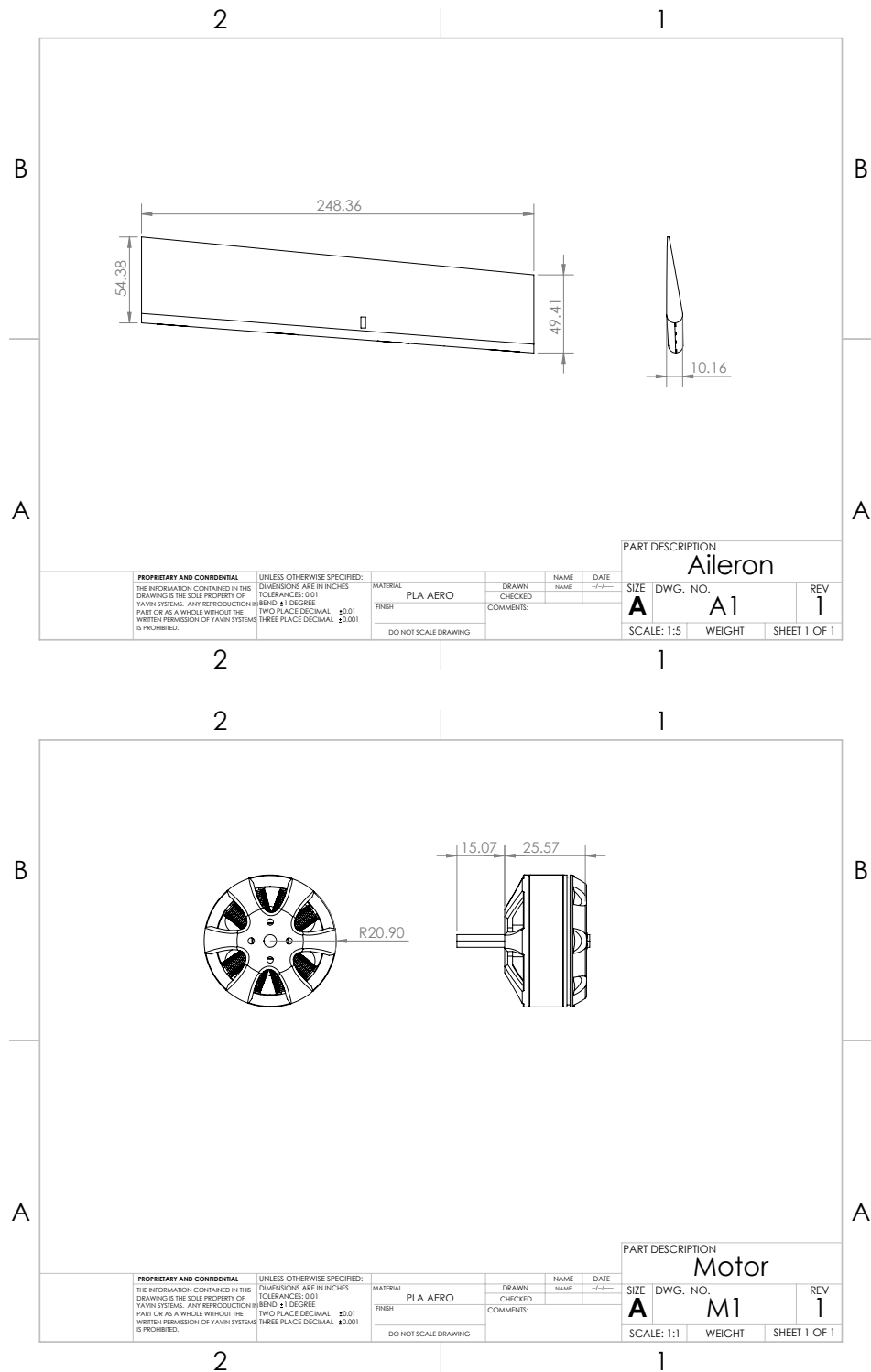
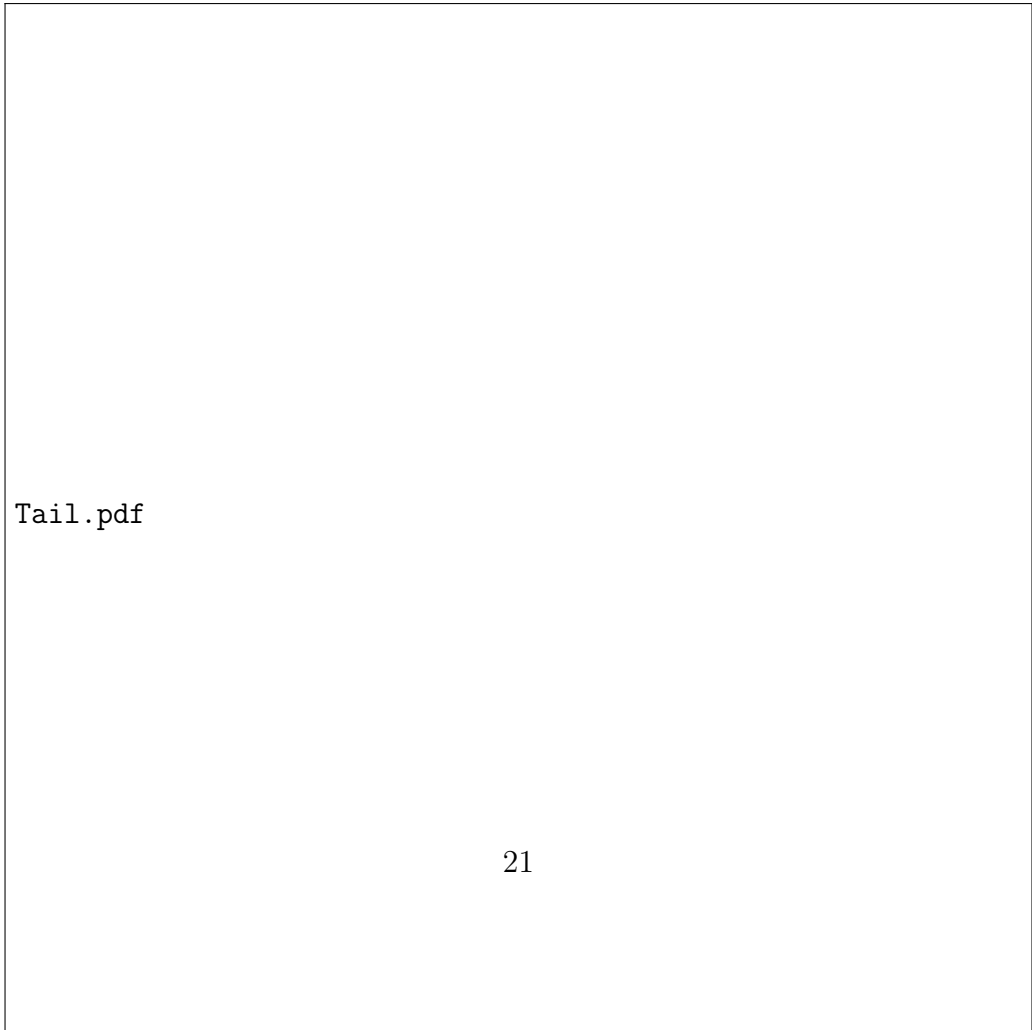
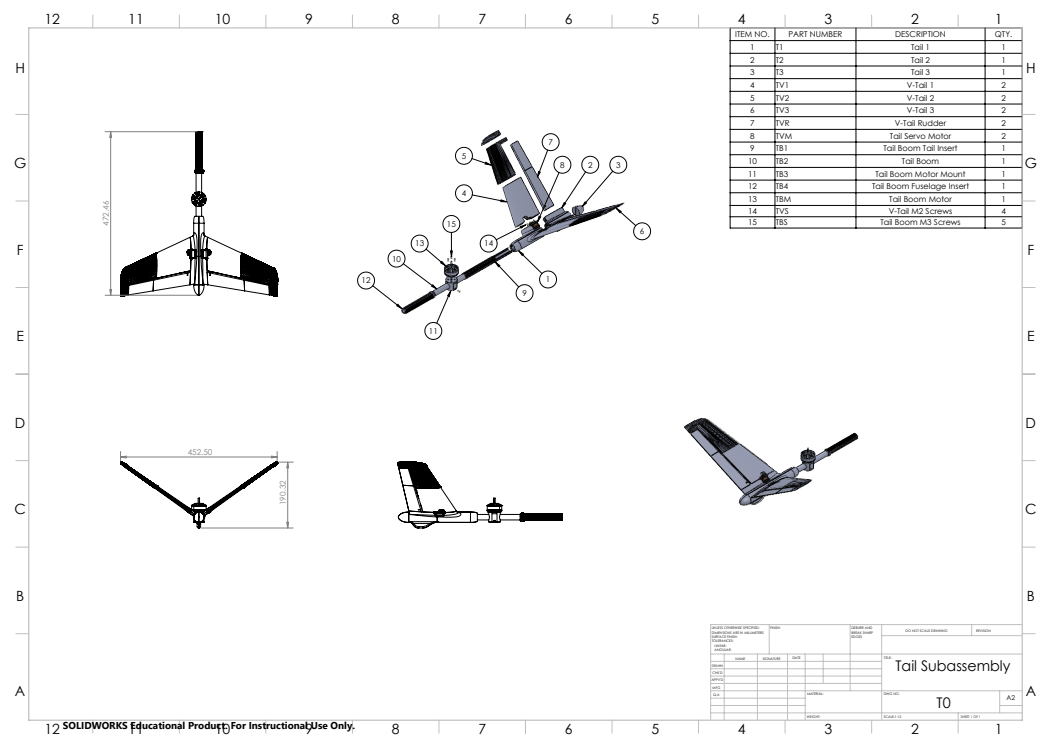


Figure 17: Wing attachment component and motor mount drawing.

Tail Subassembly



Tail.pdf

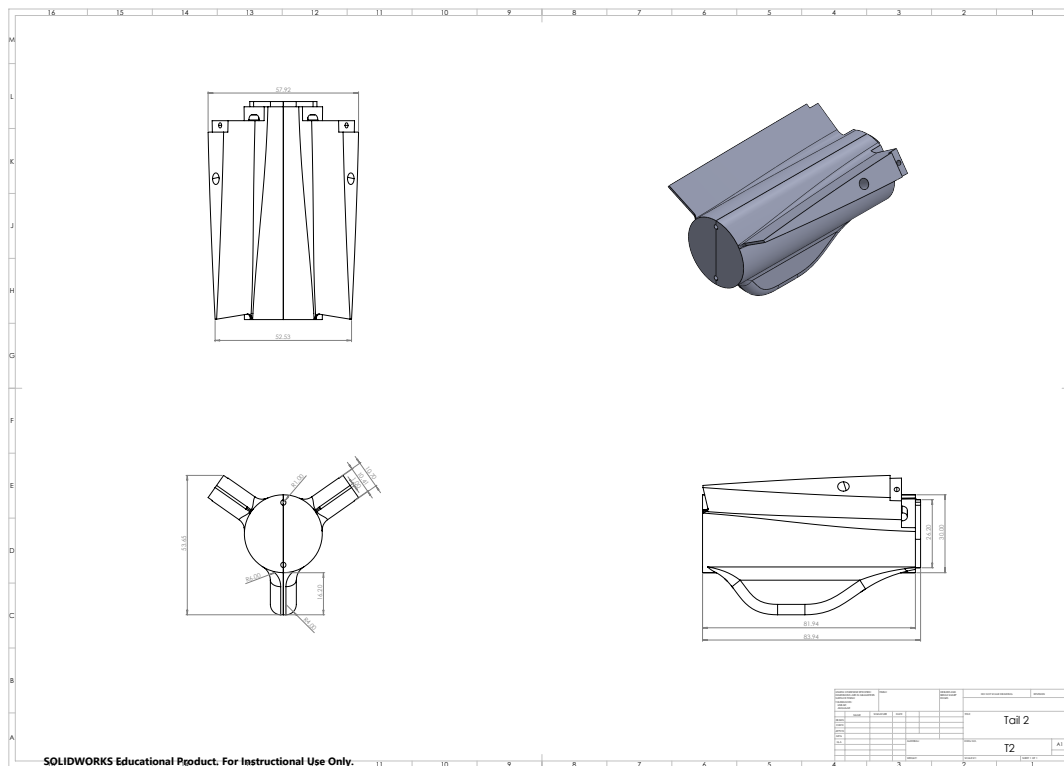
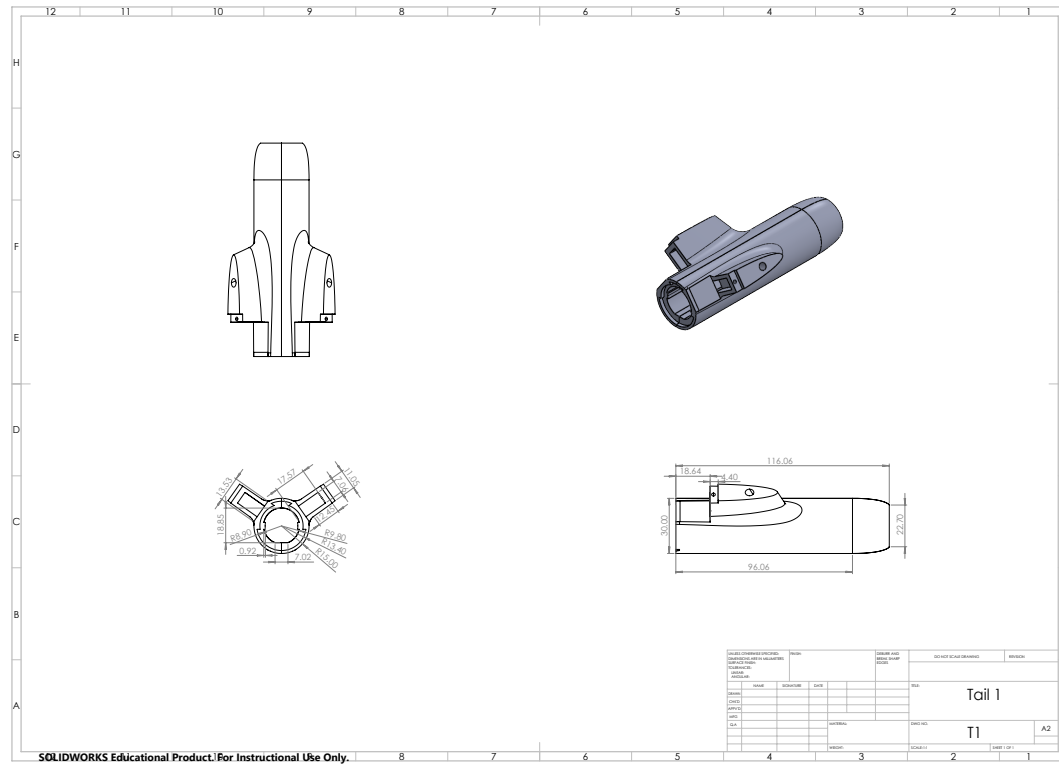


Figure 19: Tail structural components T1 and T2.

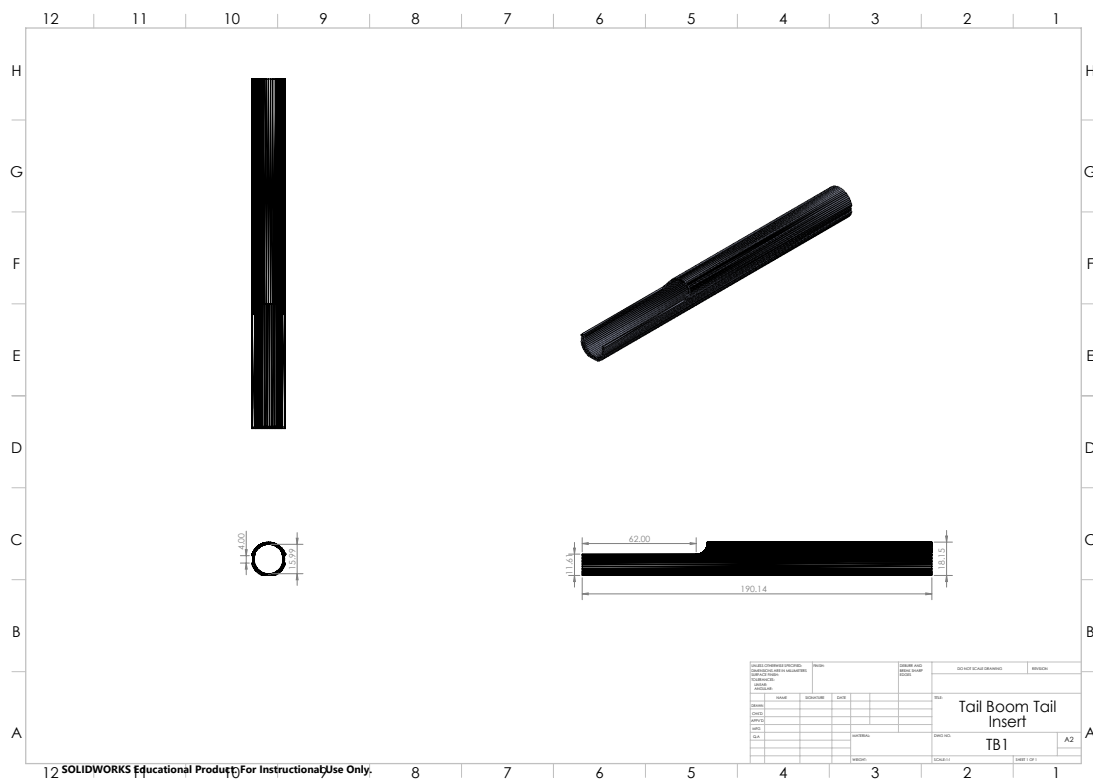
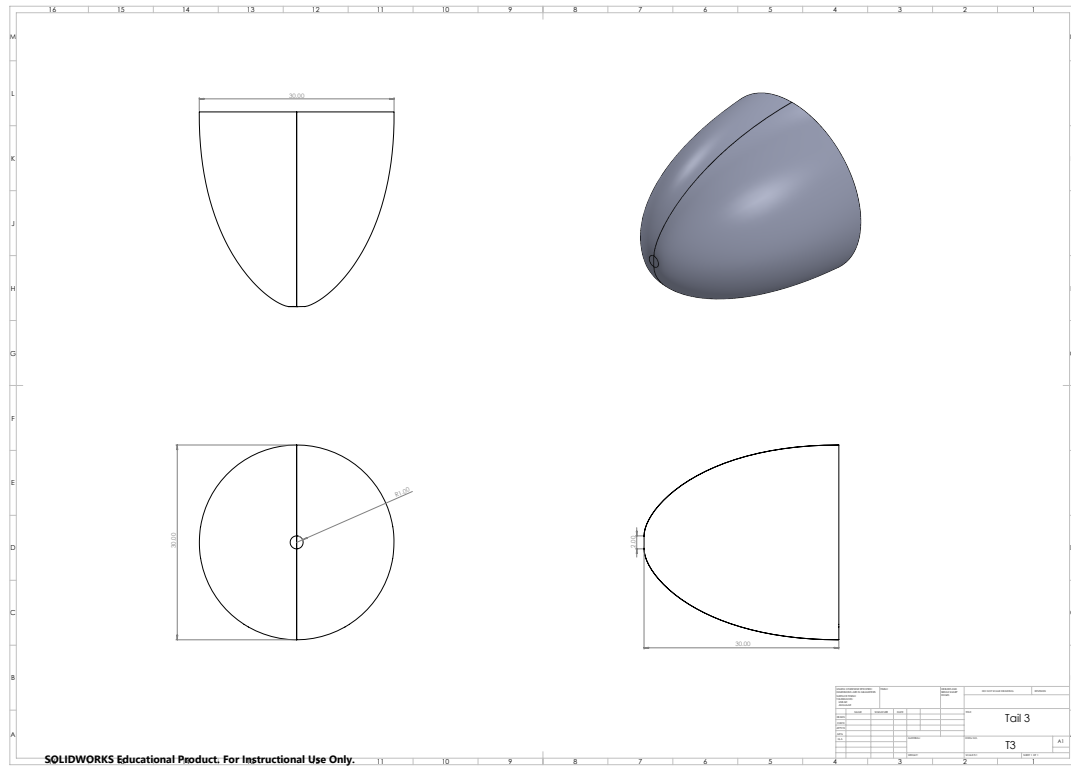


Figure 20: Tail component and boom structure.

Fuselage Subassembly

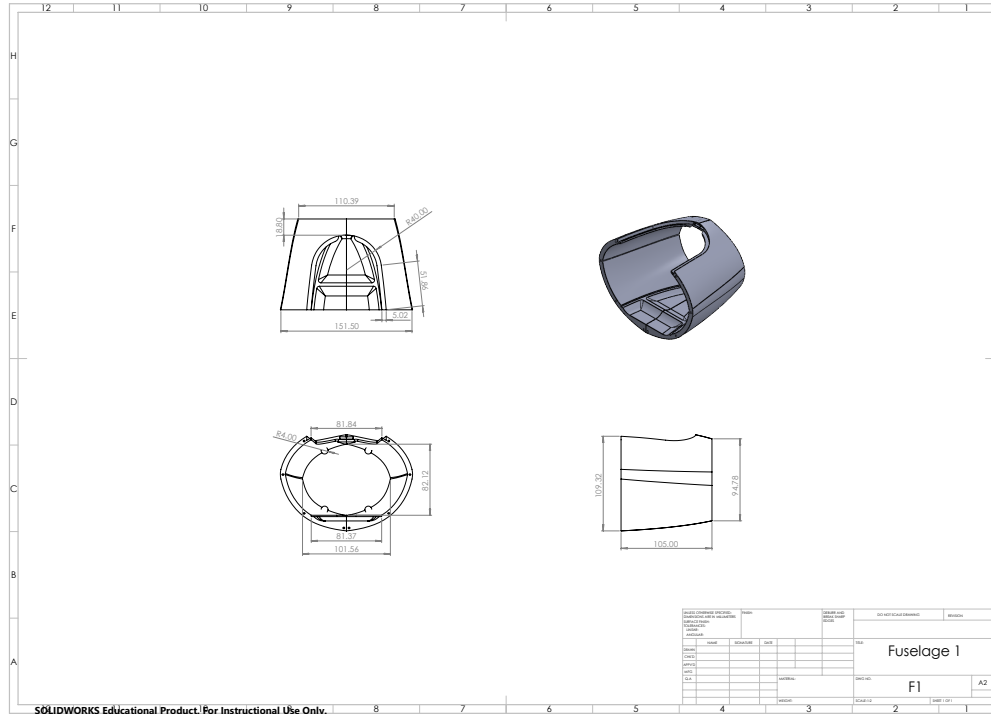
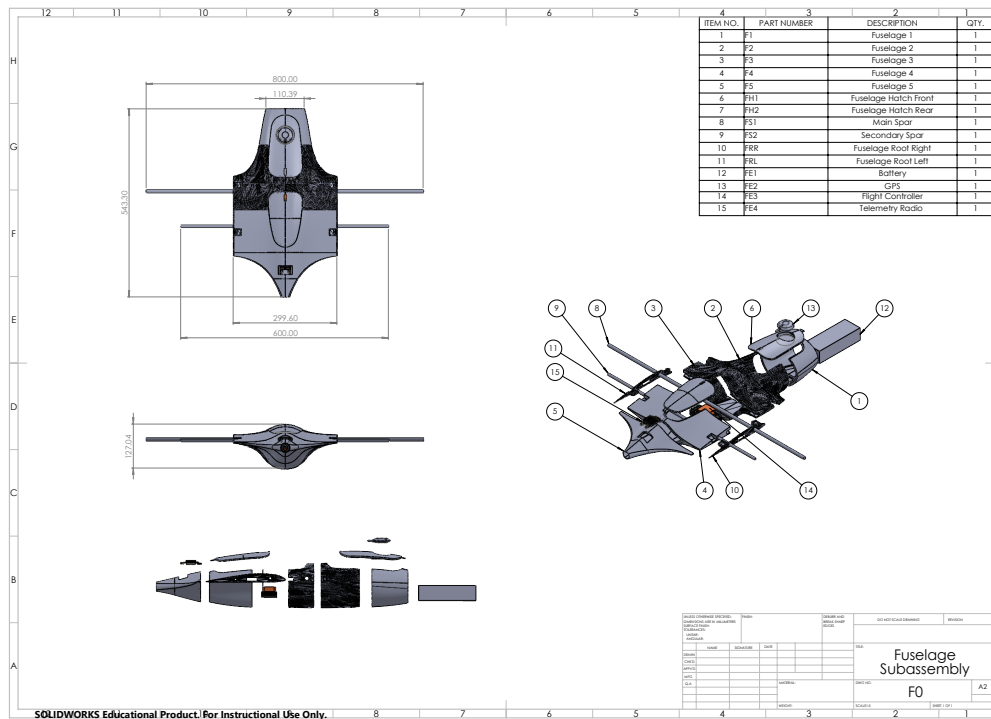


Figure 21: Fuselage assembly and structural component F1.

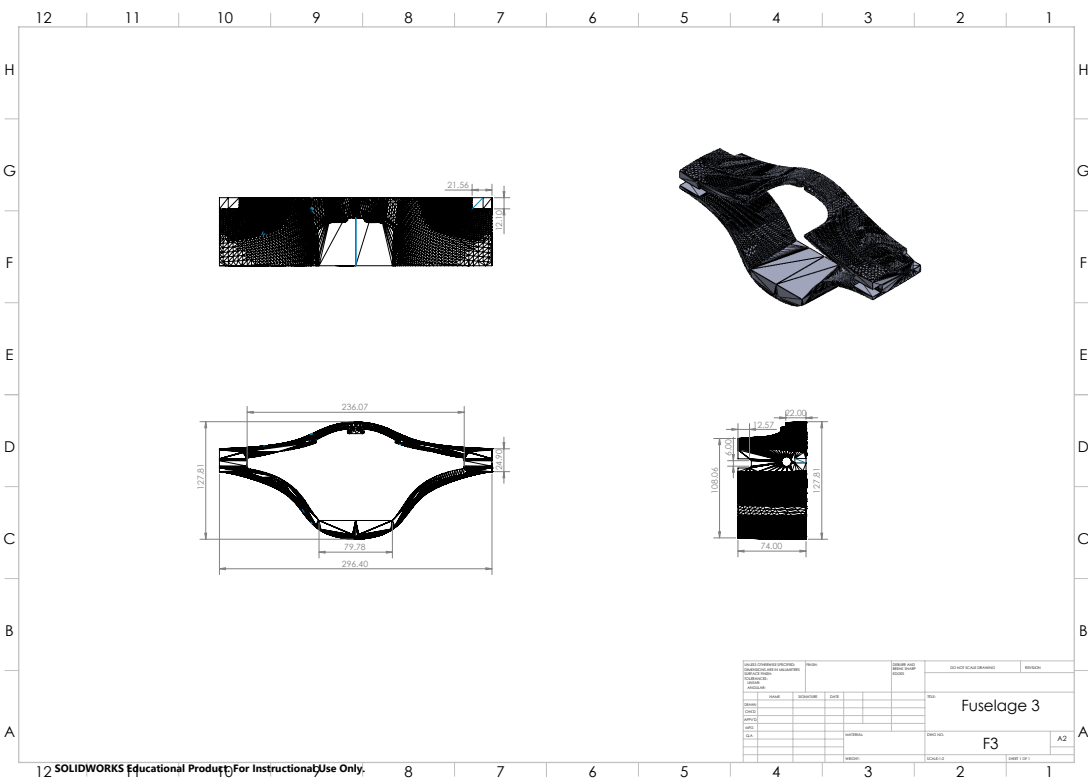
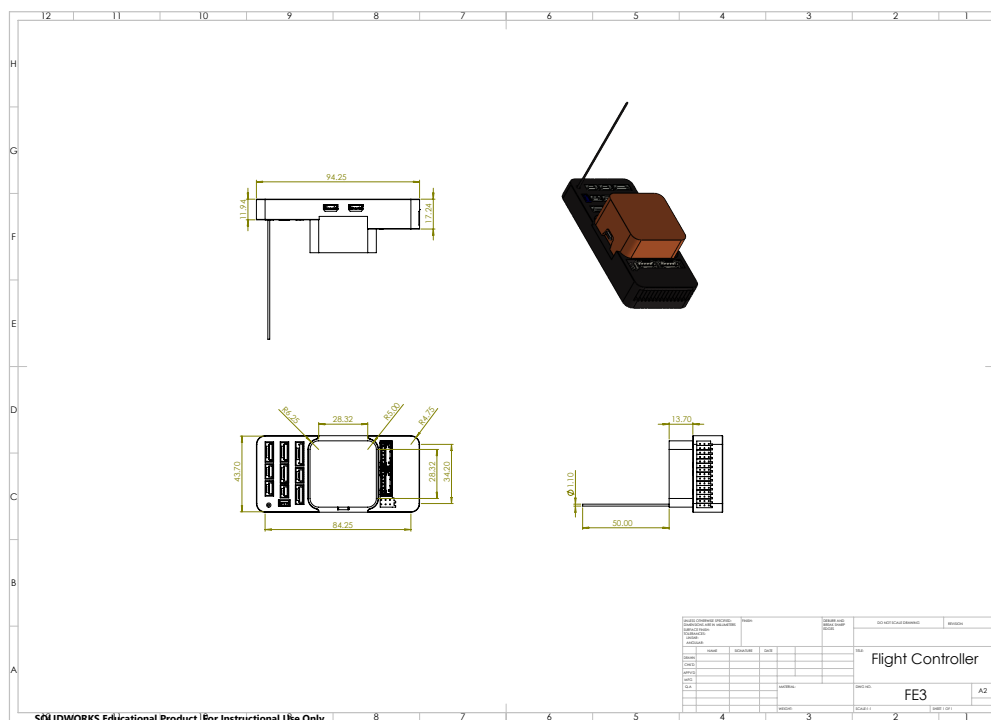


Figure 22: Fuselage structural components F2 and F3.



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3 Bill of Materials and Budget

The project is currently supported by an entrepreneurial innovation grant (\$3,000) alongside Undergraduate Research and Creative Activities (URCA) funding. The tables below detail the allocation of these funds across the structural and electronic sub-assemblies.

Table 1: Bill of Materials: Airframe and Structural Components

Item #	Part Name / Description	Material / Specification	Qty
1	Modular Nose & Sensor Pod	PA6-CF (Carbon Fiber Nylon)	1
2	Central Fuselage Core	PA6-CF (Carbon Fiber Nylon)	1
3	Front Hatch & GNSS Enclosure	PA6-CF (Carbon Fiber Nylon)	1
4	Rear Fuselage & Telemetry Tail	PA6-CF (Carbon Fiber Nylon)	1
5	Main Wing (Left & Right)	LW-PLA (Lightweight PLA)	2
6	V-Tail Stabilizers	LW-PLA (Lightweight PLA)	2
7	Main Wing Spar	Carbon Fiber Tube (10mm OD)	1
8	Tail Spars	Carbon Fiber Tube (6mm OD)	2

Table 2: Bill of Materials: Electronics and Payload Integration

Item #	Part Name / Description	Manufacturer / Spec	Qty
9	Primary Flight Controller	CubePilot Cube Orange+	1
10	Companion Computer	NVIDIA Jetson Orin Nano 8GB	1
11	Carrier Board	ARK Electronics Just-a-Jetson	1
12	Radiometric Thermal Camera	Teledyne FLIR Boson 640	1
13	High-Resolution RGB Camera	Sony IMX219	1
14	VTOL Brushless Motors	2807 Stator Size 1300kV	3
15	Electronic Speed Controllers (ESC)	50A ESC	3
16	Control Surface Servos	MG995	4
17	Tiltrotor Servos	DS041MG	2
18	Long-Range Telemetry Radio	RFD900x	1
19	GNSS & Magnetometer Module	ARK SAM GPS	1
20	Main Flight Battery	6S 8000mAh LiPo	1

4 Gantt Chart

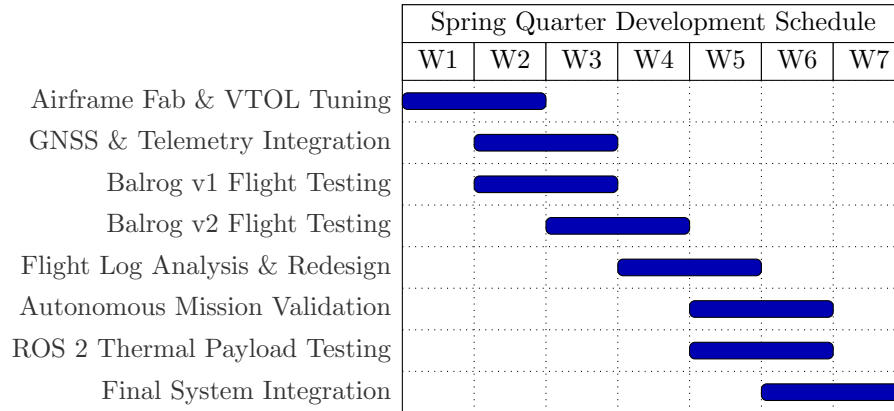


Figure 24: Project Gantt chart outlining the critical path from airframe validation and flight testing to autonomous mission validation, thermal payload verification, and final system integration.

5 Schedule

The Spring 2026 development effort followed a seven-week iterative prototyping and testing cycle focused on validating critical flight, autonomy, and sensing capabilities prior to full system integration. This approach was directly informed by the Winter 2026 quarter, during which the team conducted extensive flight testing of the primary VTOL airframe. Winter testing successfully demonstrated both vertical takeoff and fixed-wing horizontal flight, validating the core aerodynamic concepts of the platform. However, a crash event during that period introduced risk into the schedule and highlighted the danger of coupling airframe development with payload and pipeline validation. To protect progress on the mapping system, the Spring schedule was structured to validate the thermal and RGB mapping pipeline on a stable, low-risk quadrotor surrogate before integrating onto the VTOL airframe, ensuring that a future airframe anomaly would not jeopardize the autonomy and sensing work.

- **Weeks 1–2: Surrogate Airframe Development and Baseline Flight Validation**
 - **Critical Path Focus:** Establishing a low-risk surrogate platform to begin mapping pipeline development, given that vertical takeoff and fixed-wing flight modes had already been validated on the primary VTOL airframe during the prior quarter.
 - **Execution:** A surrogate quadrotor airframe was assembled and configured with the mission compute stack. With core flight dynamics de-risked, early integration of the FLIR Boson 640 payload and ROS 2 data collection framework began in parallel, allowing mapping pipeline development to proceed independently of VTOL airframe iterations.

- **Weeks 2–3: Navigation and Telemetry Integration on Surrogate Platform**

- **Critical Path Focus:** Validating autonomous navigation and long-range communication on the surrogate airframe to support end-to-end mapping pipeline testing.
- **Execution:** The ARK SAM GPS, magnetometer, and RFD900x telemetry systems were integrated and validated on the surrogate platform through autonomous hover and position-hold testing, confirming the navigation stack required for waypoint-driven mapping missions.

- **Weeks 3–4: Mapping Pipeline Validation**

- **Critical Path Focus:** End-to-end validation of the thermal and RGB mapping workflows using the surrogate airframe, leveraging the already-validated fixed-wing and VTOL flight modes as a baseline.
- **Execution:** Waypoint navigation, flight logging, and ROS 2 data collection were exercised across multiple surrogate flights. Thermal and RGB imagery from the FLIR Boson 640 was captured and processed, confirming pipeline integrity from sensor acquisition through post-flight data handling.

- **Weeks 4–5: Continued Mapping Validation**

- **Critical Path Focus:** Expanding mapping pipeline coverage and data quality through additional surrogate platform missions.
- **Execution:** Additional mapping sorties were conducted using the surrogate airframe, refining waypoint patterns and validating thermal and RGB data collection across varied conditions. Pipeline outputs were reviewed to confirm consistency and readiness for integration onto the primary platform.

- **Weeks 5–6: System Integration and Mapping Pipeline Transfer**

- **Critical Path Focus:** Integrating the validated mapping pipeline with the primary VTOL platform and confirming end-to-end system behavior.
- **Execution:** The FLIR Boson 640, Jetson Orin Nano, Cube Orange+, and RFD900x telemetry architecture were brought together on the final aircraft configuration. Mapping workflows validated on the surrogate were transferred to the integrated system, with continued mapping missions used to verify that sensing, compute, and autonomy subsystems operated cohesively.

- **Weeks 6–7: Final System Integration and Mapping Completion**

- **Critical Path Focus:** Finalizing all subsystem integration and completing the full mapping pipeline on the primary platform.

- **Execution:** Supporting avionics and the full sensor suite were finalized on the integrated platform. Further mapping missions were completed to validate the end-to-end wildfire mapping workflow, confirming that all subsystems (sensing, compute, telemetry, and autonomy) were ready for mission-level deployment.

6 Prototypes

The prototype development effort followed an iterative systems-engineering approach focused on progressively reducing technical risk prior to full system integration. Rather than attempting to validate the complete wildfire mapping platform in a single development cycle, the project was divided into a series of increasingly capable prototype configurations, each designed to evaluate specific airframe, avionics, autonomy, and sensing objectives.

A major design philosophy throughout development was the use of modular subsystems that could be independently fabricated, tested, and replaced. Key subsystems included the PA6-CF payload fairing housing the FLIR Boson 640 and RGB camera, the carbon-fiber reinforced avionics cradle supporting the Cube Orange+ and Jetson Orin Nano, the GPS-integrated front hatch designed to minimize magnetic interference, and the telemetry tail section optimized for long-range RFD900x communications. This modular architecture allowed individual components to be rapidly redesigned and validated without requiring complete airframe reconstruction.

Development also emphasized early separation of flight-critical and mission-critical functions. Flight validation focused on the tri-motor tilt-rotor airframe, power distribution system, navigation hardware, and transition behavior, while autonomy and perception capabilities were developed independently using surrogate flight platforms. This approach reduced integration risk and enabled parallel development of the thermal mapping pipeline, autonomous navigation stack, and onboard compute architecture.

The final prototype configuration integrates all major mission systems, including long-range telemetry, autonomous navigation, radiometric thermal sensing, onboard processing, and geo-referenced mapping capabilities. Detailed testing procedures, prototype iterations, flight results, and subsystem validation activities are presented in the following Testing and Analysis section.

7 Testing and Analysis

7.1 Quarter Testing Summary

A structured testing campaign was conducted throughout Spring 2026 to validate the major flight, avionics, autonomy, and mapping requirements of the wildfire mapping VTOL platform. All flight operations were conducted in accordance with the pre-flight verification and flight procedures documented. Testing focused on validating hover stability, VTOL transition capability,

GPS-assisted navigation performance, telemetry functionality, airframe reliability, autonomous flight behavior, and the thermal mapping pipeline.

Table 3 summarizes the status of each major engineering specification and the outcome of testing performed during this quarter.

Table 3: Summary of Spring 2026 Testing Results

Specification	Target	Status	Result Summary
VTOL Hover Stability	Stable Hover	PASS	Balrog v2 and Elsa demonstrated stable GPS-assisted hover and position hold with minimal pilot input.
VTOL Transition Capability	Successful Transition	PASS	Multiple successful VTOL-to-fixed-wing transitions were completed across Balrog v1 and Elsa.
GNSS Navigation Performance	Reliable Position Hold	PASS	GPS and magnetometer integration enabled stable autonomous hover and navigation.
Telemetry Communication	Live Telemetry Link	PASS	RFD900x telemetry successfully transmitted real-time flight data throughout testing.
Airframe Crash Survivability	Protect Critical Electronics	PASS	Following the Balrog v2 crash, all major avionics components remained operational and recoverable.
Flight Controller Integration	Stable Autopilot Operation	PASS	Cube Orange+ successfully managed VTOL operation, transitions, navigation, and telemetry interfaces.
Autonomous Flight Capability	Autonomous Flight	PASS	Elsa demonstrated stable autonomous flight and waypoint execution using the integrated navigation stack.
Thermal/RGB Mapping Pipeline	Autonomous Data Collection	PASS	Thermal and RGB mapping outputs were generated successfully using the integrated perception pipeline.
90 Minute Endurance	90 min	NOT TESTED	Full endurance testing has not yet been conducted with the final integrated aircraft.
10 Mile Operational Radius	10 miles	NOT TESTED	Long-range BVLOS testing remains scheduled for final system validation. More terrain needed.
Final Integrated Flight Test	Complete System Validation	UP NEXT	The final aircraft has been fully integrated but has not yet completed flight testing with the complete payload stack installed.

7.2 Prototype Flight Testing

The Spring 2026 testing campaign followed an iterative development process consisting of three primary prototype configurations: Balrog v1, Balrog v2, and Elsa. The objective was to progressively validate flight-critical subsystems prior to integration of the complete wildfire mapping payload. All flight testing was conducted according to the procedures outlined.

7.2.1 Balrog v1

Balrog v1 was developed to validate the fundamental aerodynamic and propulsion architecture of the tri-motor VTOL platform. Two flight tests were conducted, each lasting approximately 20 minutes.

The first flight was performed prior to full GPS integration and exhibited poor hover stability, requiring continuous pilot correction. Following installation of the GNSS and magnetometer system, the second flight demonstrated significantly improved hover performance and successfully completed the aircraft's first VTOL-to-fixed-wing transition. Stable forward flight was achieved at approximately 15 mph, validating the core aerodynamic concept and control architecture.

Flight log analysis confirmed the observed improvement in hover stability following GPS integration and verified successful transition into fixed-wing flight. Although the aircraft remained controllable, the front tilt rotors were not yet utilizing their full range of motion, limiting cruise performance and transition optimization. Nevertheless, Balrog v1 successfully demonstrated the feasibility of the tri-motor VTOL architecture.



Figure 25: Balrog v1 during early hover testing. The prototype successfully demonstrated VTOL operation and completed its first transition into fixed-wing flight.

7.2.2 Balrog v2

Balrog v2 incorporated the fully actuated tilt-rotor system, telemetry architecture, and navigation stack. During a five-minute flight test, the aircraft demonstrated stable autonomous hover, reliable GPS position hold, successful telemetry transmission, and nominal operation of all propulsion, avionics, and mechanical subsystems.

The aircraft subsequently completed its transition into forward flight but experienced a loss-of-control event shortly thereafter. Post-flight analysis of the flight logs showed no faults within the propulsion system, servos, flight controller, telemetry architecture, power system, or structural airframe. Analysis of the attitude and transition data indicated that the aircraft successfully entered fixed-wing flight; however, the control surfaces were unable to generate sufficient pitching moment to counteract the aircraft's forward center of gravity. As airspeed increased, the aircraft developed an unrecoverable nose-down attitude, resulting in the crash.

This analysis allowed the root cause to be isolated to aerodynamic controllability rather than hardware reliability. The resulting design modifications were incorporated into the Elsa prototype.



Figure 26: Balrog v2 demonstrating stable autonomous hover and GPS position hold prior to transition testing.

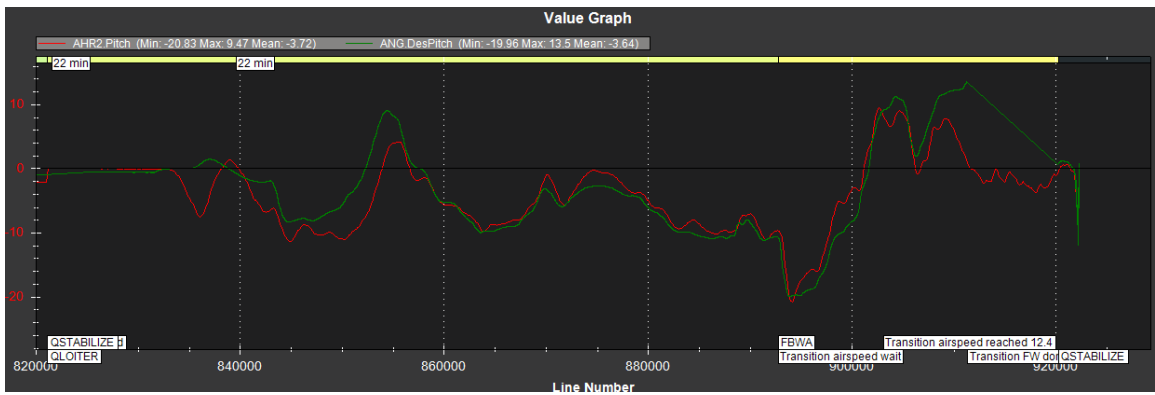


Figure 27: Representative Balrog v2 flight log showing stable hover behavior followed by the loss-of-control event during forward flight. Flight log analysis identified insufficient pitch authority as the primary failure mode.

7.2.3 Elsa

Lessons learned from Balrog v2 were incorporated into the Elsa prototype. Modifications focused on improving pitch authority and overall aerodynamic stability during forward flight.

Flight testing demonstrated stable hover, successful transitions, and stable autonomous fixed-wing flight. These results validated the corrective design changes implemented following

the Balrog v2 investigation and substantially increased confidence in the final airframe configuration. The successful operation of Elsa confirmed that the previously observed instability originated from aerodynamic controllability limitations rather than avionics, propulsion, or structural deficiencies.

In parallel with airframe development, autonomous flight capabilities were validated using a surrogate quadrotor platform. This test vehicle was used to develop and verify waypoint navigation, autonomous mission execution, telemetry communication, and flight logging prior to integration with the final VTOL airframe. Successful autonomous missions demonstrated reliable navigation performance and reduced integration risk for the final wildfire mapping system.

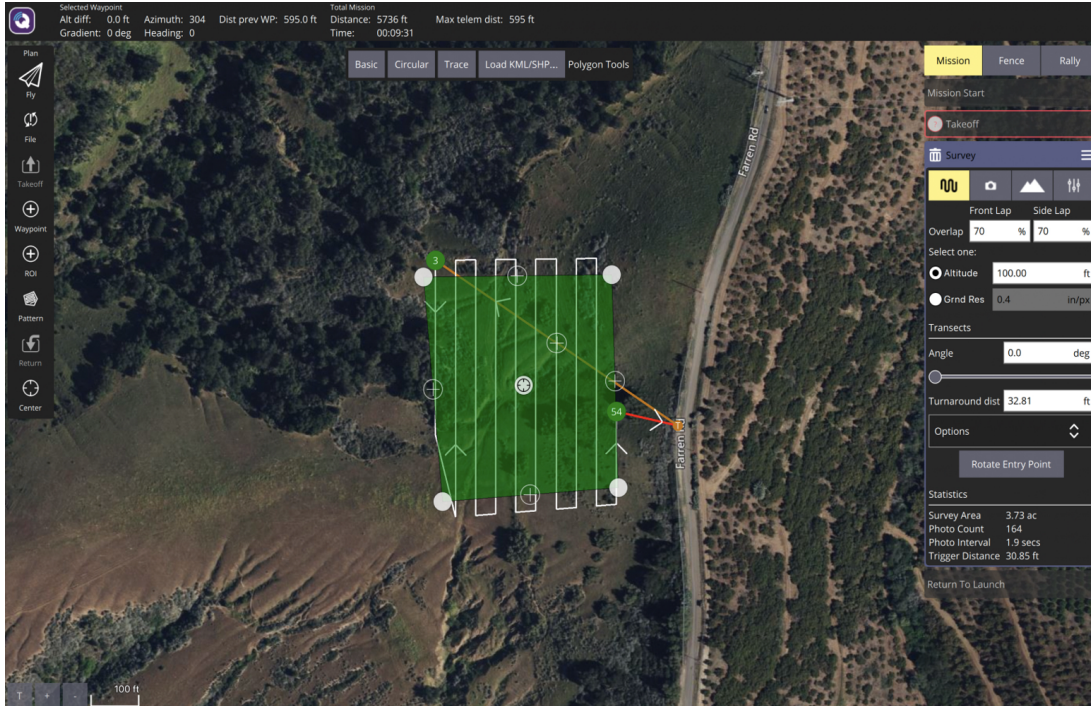


Figure 28: Autonomous mission executed using a surrogate flight platform. The test validated waypoint navigation, telemetry communication, and autonomous mission execution prior to deployment on the final VTOL aircraft.

7.3 Thermal Mapping Pipeline Validation

In parallel with VTOL airframe development, the perception and mapping subsystem was validated independently using the surrogate quadrotor platform introduced during the Elsa testing phase. Rather than waiting for the primary airframe to reach full integration readiness, the team mounted the complete sensing pipeline on the stable surrogate to begin validating data collection workflows early. The complete sensing pipeline consisting of the FLIR Boson 640 thermal camera, RGB imaging system, onboard compute architecture, and mapping software

stack was successfully integrated and tested in this configuration.

Autonomous data collection and processing produced synchronized thermal and RGB mapping outputs suitable for wildfire intelligence applications. The successful generation of georeferenced thermal products validated communication between the sensing, compute, and software subsystems and demonstrated readiness for transfer onto the final integrated aircraft.

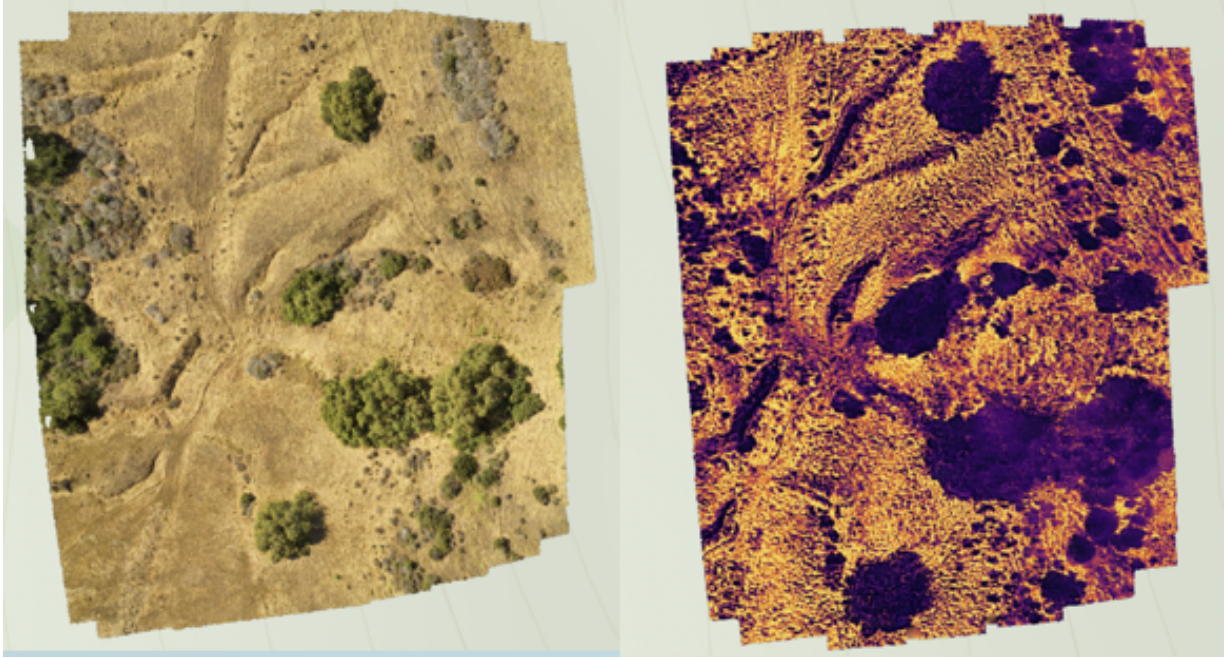


Figure 29: Representative output from the autonomous perception pipeline showing synchronized RGB and thermal imagery generated by the integrated sensing architecture.

7.4 Conclusion: Final Integrated System Status

At the conclusion of the quarter, the final wildfire mapping aircraft had been fully assembled and integrated with the Cube Orange+, Jetson Orin Nano, FLIR Boson 640 thermal camera, RGB camera, telemetry radio, and supporting avionics hardware. All major subsystems have been individually validated. The only remaining validation activity is flight testing of the fully integrated aircraft with the complete wildfire mapping payload installed.

Consequently, endurance testing, long-range operational radius testing, and full mission-level validation remain the primary outstanding activities prior to deployment.

Throughout the project, the team successfully progressed from early prototypes to a fully integrated wildfire mapping platform while validating the majority of the flight, autonomy, and sensing architecture. One of the most important lessons learned was the value of defining clear engineering requirements, test criteria, and subsystem-level objectives early in the design process. Breaking the system into smaller, independently testable subsystems significantly reduced integration risk and enabled rapid identification of design deficiencies during flight

testing. This project should continue next year, with initial efforts focused on final integrated flight testing, endurance characterization, BVLOS communication validation, and operational deployment of the thermal mapping payload.

References

- [1] Teledyne FLIR, “Boson/Boson+ Radiometric Thermal Camera Core Datasheet,” 2023. [Online]. Available: <https://www.flir.com/products/boson/>.
- [2] ArduPilot Dev Team, “QuadPlane / VTOL,” ArduPilot Documentation. [Online]. Available: <https://ardupilot.org/plane/docs/quadplane-vtol.html>.
- [3] CAL FIRE, “2025 Incident Archive,” California Department of Forestry and Fire Protection. [Online]. Available: <https://www.fire.ca.gov/incidents/2025/>.
- [4] DJI Enterprise, “Matrice 30 Series User Manual,” 2023.
- [5] PX4 Autopilot, “ROS 2 User Guide,” PX4 Documentation. [Online]. Available: <https://docs.px4.io/main/en/ros/ros2.html>.

Appendix

8 Standard Operating Procedures

The following reports document the major validation activities conducted during the Spring 2026 testing campaign.

VTOL Waypoint-Based Autonomous Flight Test

SOP-YS-003 | Yavin Systems | UCSB ME Capstone

Author:	Yavin Systems
Department:	Mechanical Engineering
Test Location:	Elings Park, Santa Barbara, CA — Open Outdoor Field
Date Approved:	
Approved By:	

Acknowledgement

By signing below, I acknowledge that I have read and understand the contents, requirements, and responsibilities outlined in this SOP.

Name (Print)	Signature	Date

1. Description

This SOP describes the procedure for testing autonomous waypoint-based flight on the Yavin Systems tilt-rotor VTOL aircraft. The aircraft is commanded to fly a pre-programmed mission consisting of GPS waypoints uploaded to the Pixhawk flight controller via Mission Planner or QGroundControl. The mission includes VTOL takeoff, transition to forward flight, navigation between waypoints, transition back to VTOL mode, and autonomous landing.

This test validates the aircraft’s ability to navigate accurately in autonomous mode and verifies GPS reliability, compass accuracy, and radio link integrity under real-world conditions. Successful completion of this test is a prerequisite for the final VTOL mapping flight (SOP-YS-004).

2. Hazards Overview

FMEA Risk Assessment:

Severity	Occurrence	Detection	RPN
9	7	2	126

Primary Failure Modes: GPS error, compass interference, and radio link loss.

Identified Hazards:

- **GPS error / position drift:** Multipath reflections, poor satellite geometry, or electromagnetic interference cause the aircraft to deviate from the intended flight path.
 - Confirm HDOP < 1.5 and satellite count ≥ 10 before arming.
 - Plan waypoints with generous clearance from obstacles and the perimeter fence.
 - Set geofence limits in ArduPilot to prevent flyaway.
- **Compass interference:** Magnetic interference from on-board electronics, motors, or nearby ferromagnetic structures causes heading errors.
 - Perform compass calibration at the test site, away from vehicles and metal structures.
 - Verify heading agreement between internal and external compass.
- **Radio link loss:** Loss of the RC control link removes the pilot's ability to intervene.
 - Configure RC failsafe to RTL (Return to Launch).
 - Verify telemetry link is independent of the RC link. Monitor via ground station.
 - Perform a range check before the mission.
- **Loss of control / crash:** Autonomous flight at speed with potential navigation errors.
 - Ensure the tilt-rotor transition has been validated per SOP-YS-001 before this test.
 - Maintain a 50 m safety perimeter. Pilot ready to take manual control at all times.
- **Propeller / airframe hazard:** Standard crash risk.
 - Safety glasses required. Clear perimeter enforced.

3. Required Personal Protective Equipment (PPE)

- ANSI Z87.1-rated safety glasses for all personnel within 50 m.
- Closed-toe shoes for all ground crew.
- High-visibility vest for the spotter and safety officer.
- Sun protection as appropriate.

4. Waste Disposal

Damaged LiPo batteries must be stored in a fireproof bag and disposed of properly. All other waste is non-hazardous. Minimize generation.

5. Accident and Emergency Procedure

- **Fly-away / loss of link:** If the aircraft does not respond to RC commands and does not execute RTL, note last known GPS position from telemetry. Notify Elings Park management. Do not pursue the aircraft on foot in hazardous terrain.
- **Crash:** Disarm via transmitter. Wait 60 seconds. Inspect for LiPo damage before handling.
- **LiPo fire:** Class D extinguisher or sand. Evacuate upwind. Call 911 if uncontrolled.
- **Personal injury:** First aid on site. Call 911 for significant injuries. Notify the advisor.

6. Approvals Required

- Faculty advisor approval is required before the first run of this procedure.
- Flights must be registered and approved through UCSB's drone protocol which can be found at

<https://www.ehs.ucsb.edu/programs-services/risk-management/uas-drones>

- Successful completion of the tilt-rotor transition test (SOP-YS-001) is a prerequisite.
- The safety officer must give verbal clearance before each flight.

7. Procedure

7.1 Assembly and Setup

- Assemble the VTOL aircraft per standard procedures. Verify all linkages and fasteners.
- Install the flight battery and confirm nominal cell voltages.
- Connect telemetry and verify ground station link.
- Upload the waypoint mission to the Pixhawk via Mission Planner / QGroundControl.
- Review the mission on the ground station map. Confirm waypoint positions, altitudes, transition points, speeds, and the landing waypoint.

7.2 Pre-Run Checks

Navigation Validation:

- Confirm GPS lock: minimum 10 satellites, HDOP < 1.5.
- Perform a compass calibration at the test site if not done earlier that day.
- Verify compass heading matches a known reference (e.g., smartphone compass or landmark).
- Confirm geofence is active and set to a safe radius encompassing the mission with margin.
- Perform an RC range check: walk to the farthest planned waypoint distance and confirm solid RC link.

Flight Readiness:

- Verify tilt-rotor transition function on the ground (per SOP-YS-001 Pre-Run Checks).
- Verify failsafe configuration: RC loss → RTL; GCS loss → continue mission; battery low → RTL.
- Confirm wind conditions: do not proceed if sustained winds exceed 15 km/h for initial auto tests.
- Clear the 50 m safety perimeter. Brief all personnel.
- Verify first-aid kit and fire extinguisher are accessible.

7.3 Run

- Arm the aircraft in QSTABILIZE (hover) mode.
- Perform a manual VTOL takeoff and climb to 15 m AGL. Confirm stable hover.
- Announce “**Switching to AUTO**” to all personnel.
- Switch the flight mode to AUTO. The aircraft will begin executing the waypoint mission.
- Monitor the ground station display continuously. Track the aircraft’s position relative to the planned path.
- Observe the transition to forward flight. Confirm smooth and symmetric tilt.
- Monitor GPS accuracy (cross-track error), altitude hold, and groundspeed at each waypoint.
- **Abort criteria:** Take manual control (switch to QSTABILIZE) immediately if:
 - Cross-track error exceeds 20 m.

- The aircraft deviates from planned altitude by more than 15 m.
- Telemetry reports compass variance warnings or GPS glitches.
- The aircraft approaches the geofence boundary.
- Allow the mission to complete, including the autonomous VTOL transition and landing.
- If autonomous landing is not yet trusted, take manual control for the landing phase.

7.4 Post-Run

- Disarm and disconnect the battery.
- Download the flight log from the Pixhawk.
- Analyze waypoint tracking accuracy (cross-track error, altitude deviation).
- Review GPS quality metrics throughout the flight (satellite count, HDOP, position variance).
- Review compass health and heading accuracy.
- Document results, anomalies, and any parameter adjustments in the test log.
- Secure the aircraft for transport.

Full Mission Execution Test

VTOL Mapping Flight (Full Mission)

SOP-YS-004 | Yavin Systems | UCSB ME Capstone

Author:	Yavin Systems
Department:	Mechanical Engineering
Test Location:	Elings Park, Santa Barbara, CA — Open Outdoor Field
Date Approved:	
Approved By:	

Acknowledgement

By signing below, I acknowledge that I have read and understand the contents, requirements, and responsibilities outlined in this SOP.

Name (Print)	Signature	Date

1. Description

This SOP describes the procedure for conducting a full mapping flight using the Yavin Systems tilt-rotor VTOL aircraft with the integrated RGB and FLIR Boson thermal camera payload. This is the culminating test in the flight-test campaign: it combines the validated tilt-rotor transition (SOP-YS-001), waypoint-based autonomous navigation (SOP-YS-003), and the proven mapping payload (SOP-YS-002) into a single, end-to-end mission.

The aircraft executes a VTOL takeoff, transitions to forward flight, flies an autonomous lawnmower-pattern survey grid at the specified altitude and speed, transitions back to VTOL mode, and lands. Both the RGB and thermal cameras capture imagery throughout the survey for subsequent ortho-mosaic and thermal map generation.

2. Hazards Overview

FMEA Risk Assessment:

Severity	Occurrence	Detection	RPN
8	7	6	336

*This test carries the highest RPN (336) in the project FMEA. It combines the risks of all preceding tests. Proceed **only** after successful completion of SOP-YS-001, SOP-YS-002, and SOP-YS-003.*

Primary Failure Modes: Inaccurate mapping sweeps due to GPS error; control surfaces not optimally functional under the combined payload and mission demands.

Identified Hazards:

- **GPS-induced mapping inaccuracy:** Position drift during survey legs produces gaps or excessive overlap in the mapping swath, resulting in unusable data.
 - Confirm GPS health (≥ 10 satellites, HDOP < 1.5) before and during flight.
 - Use RTK GPS if available for centimeter-level accuracy.
 - Plan survey overlap conservatively (70% frontal, 60% sidelap minimum).
- **Control surface degradation:** Combined aerodynamic loads, payload-shifted CG, and extended flight duration may reveal control surface flutter, servo fatigue, or trim issues not apparent in shorter tests.
 - Inspect all control surface hinges and linkages before flight.
 - Monitor servo current and control deflections via telemetry during flight.
- **Vibration-induced image degradation:** The VTOL airframe may have different vibration characteristics than the surrogate quadcopter.
 - Ensure the payload was validated on the surrogate airframe (SOP-YS-002) first.
 - Use vibration-dampened camera mount. Review imagery promptly after landing.
- **Extended flight duration risks:** Battery depletion, motor/ESC overheating, or thermal camera overheating during a long mapping mission.
 - Plan mission duration within 80% of the tested battery endurance.
 - Monitor battery voltage, current, and motor temperatures via telemetry.
- **All hazards from SOP-YS-001 and SOP-YS-003:** Transition failure, GPS error, compass interference, radio link loss, crash, and LiPo fire.
 - All mitigations from those SOPs apply here and must be followed.

3. Required Personal Protective Equipment (PPE)

- ANSI Z87.1-rated safety glasses for all personnel within 50 m.
- Closed-toe shoes for all ground crew.
- High-visibility vest for the spotter and safety officer.
- Sun protection as appropriate.
- Hearing protection recommended during extended hover phases.

4. Waste Disposal

Damaged LiPo batteries must be stored in a fireproof LiPo-safe bag and taken to a certified disposal facility. All other waste is non-hazardous. Minimize waste generation.

5. Accident and Emergency Procedure

- **Fly-away / loss of link:** Note last GPS position from telemetry. Do not pursue on foot. Notify Elings Park management and the faculty advisor.

- **Crash:** Disarm via kill switch. Wait 60 seconds. Inspect for LiPo damage and camera damage. Photograph the crash site for documentation.
- **LiPo fire:** Class D extinguisher or sand. Evacuate upwind. Call 911 if uncontrolled.
- **Personal injury:** Administer first aid. Call 911 for significant injuries. Notify the advisor.
- **Camera / payload damage:** If the thermal camera shows signs of overheating (image artifacts, case hot to the touch after landing), power it down and allow it to cool before inspection.

6. Approvals Required

- Faculty advisor approval is required before the first run of this procedure.
- Flights must be registered and approved through UCSB's drone protocol which can be found at <https://www.ehs.ucsb.edu/programs-services/risk-management/uas-drones>
- **Prerequisites:** Successful completion of SOP-YS-001 (transition), SOP-YS-002 (surrogate mapping), and SOP-YS-003 (waypoint flight) is **mandatory**.
- The safety officer must give verbal clearance before each flight.
- All team members present must confirm readiness before arming.

7. Procedure

7.1 Assembly and Setup

- Assemble the VTOL aircraft per standard procedures. Verify all structural fasteners, control linkages, and tilt-rotor mechanisms.
- Mount the mapping payload (RGB camera + FLIR Boson) to the vibration-dampened payload plate on the VTOL airframe.
- Confirm all camera fasteners are tight. Apply safety wire or zip-tie backup.
- Perform a ground shake test: confirm nothing shifts or rattles.
- Verify CG position with the payload installed. Adjust battery placement if needed.
- Install the flight battery. Confirm nominal cell voltages.
- Connect telemetry and verify ground station link.
- Upload the mapping mission (survey grid) to the Pixhawk via Mission Planner / QGroundControl.
- Review the mission plan: confirm survey altitude, speed, leg spacing, overlap settings, transition waypoints, and landing waypoint.

7.2 Pre-Run Checks

Payload Checks:

- Power on the RGB camera and FLIR Boson. Confirm both are operational and storing to their respective media (SD card / internal storage).
- Verify camera trigger mechanism (time-based or distance-based) is configured and tested.
- Confirm the FLIR Boson is outputting valid thermal imagery (not a flat/saturated image).

Navigation and Airframe Checks:

- Confirm GPS lock: minimum 10 satellites, HDOP < 1.5.

- Verify compass heading is accurate.
- Verify tilt-rotor transition on the ground (per SOP-YS-001 Pre-Run).
- Verify all control surfaces move freely and in the correct direction.
- Confirm geofence is active with appropriate margins.
- Confirm failsafe settings: RC loss → RTL; battery low → RTL.
- Check wind: do not proceed if sustained winds exceed 15 km/h.
- Clear the 50 m safety perimeter. Brief all personnel on emergency procedures.
- Verify first-aid kit and fire extinguisher are at the ground station.

7.3 Run

- Arm the aircraft in QSTABILIZE (hover) mode.
- Perform a manual VTOL takeoff to 15 m AGL. Confirm stable hover.
- Confirm cameras are recording (if manual start is required, trigger now).
- Announce “**Switching to AUTO**” to all personnel.
- Switch to AUTO mode. The aircraft will climb to the survey altitude and begin the transition to forward flight.
- Monitor the transition. Confirm symmetric tilt and stable forward flight.
- Monitor the survey legs on the ground station map. Confirm the aircraft is tracking the planned lines.
- Continuously monitor: GPS accuracy, cross-track error, altitude hold, battery voltage, motor temperatures, and servo loads.
- **Abort criteria — take manual control (QSTABILIZE) immediately if:**
 - Cross-track error exceeds 15 m during survey legs.
 - Battery voltage falls below the planned threshold.
 - Any compass or GPS warning appears.
 - Control surface oscillation or flutter is observed.
 - The aircraft approaches the geofence boundary.
- Allow the mission to complete. The aircraft will transition back to VTOL and execute an autonomous landing.
- If autonomous landing is not trusted, take manual control for the final approach.

7.4 Post-Run

- Disarm the aircraft. Disconnect the flight battery immediately.
- Power down the cameras. Remove the SD cards / storage media.
- Inspect the airframe: check tilt mechanism, control linkages, propellers, motor mounts, and payload mount for any looseness, heat, or damage.
- Download the flight log from the Pixhawk.
- Analyze mapping coverage: verify survey legs have adequate overlap and consistent altitude.
- Spot-check imagery from both cameras: confirm no motion blur, rolling shutter artifacts, or thermal sensor saturation.

- Compare image geotags against the planned survey grid.
- Process imagery into ortho-mosaics and thermal maps using photogrammetry software.
- Document all results, anomalies, parameter changes, and lessons learned in the test log.
- Secure the aircraft and payload for transport.

Surrogate Airframe Mapping Payload Validation Flight

SOP-YS-002 | Yavin Systems | UCSB ME Capstone

Author:	Yavin Systems
Department:	Mechanical Engineering
Test Location:	Elings Park, Santa Barbara, CA — Open Outdoor Field
Date Approved:	
Approved By:	

Acknowledgement

By signing below, I acknowledge that I have read and understand the contents, requirements, and responsibilities outlined in this SOP.

Name (Print)	Signature	Date

1. Description

This SOP describes the procedure for conducting a mapping flight using a standard quadcopter as a surrogate airframe. The surrogate platform is a conventional multirotor with known, reliable flight characteristics. The purpose of this test is to validate the mapping payload — consisting of an RGB camera and a FLIR Boson thermal camera — independently of the tilt-rotor VTOL airframe.

By isolating the payload on a stable, vibration-characterized platform, the team can confirm image quality, trigger timing, georeferencing accuracy, and camera mount rigidity before integrating the payload onto the more complex VTOL aircraft. This test also establishes baseline imagery for comparison against later VTOL mapping flights.

2. Hazards Overview

FMEA Risk Assessment:

Severity	Occurrence	Detection	RPN
7	5	4	140

Primary Failure Mode: High-frequency vibration transferring to the payload, causing motion blur or rolling shutter artifacts in the captured imagery.

Identified Hazards:

- **Vibration-induced image degradation:** Motor harmonics and propeller wash cause high-frequency vibrations that transfer through the airframe to the camera mount.
 - Fly the surrogate airframe first **without** the mapping payload to characterize vibration levels.
 - Use vibration-dampening mounts (e.g., silicone grommets or a gimbal) for payload attachment.
- **Payload detachment:** Inadequate mounting may allow the camera assembly to shift or detach in flight.
 - Secure the payload with redundant fasteners (primary bolts plus safety wire or zip-tie backup).
 - Perform a shake test on the ground before flight.
- **Loss of control / crash:** Added payload mass shifts the center of gravity and increases motor loading.
 - Verify CG position with payload installed before flight.
 - Confirm motor thrust margins are adequate (hover throttle below 60%).
- **Propeller strike / debris:** Standard multirotor crash hazard.
 - Maintain 30 m safety perimeter. Wear safety glasses.

3. Required Personal Protective Equipment (PPE)

- ANSI Z87.1-rated safety glasses for all personnel within the test perimeter.
- Closed-toe shoes for all ground crew.
- High-visibility vest for the spotter/safety officer.
- Sun protection as appropriate.

4. Waste Disposal

Damaged LiPo batteries must be placed in a fireproof LiPo-safe bag and disposed of at a certified facility. All other waste (broken propellers, packaging) is non-hazardous and may be placed in general waste. Minimize waste generation.

5. Accident and Emergency Procedure

- **Crash:** Disarm immediately. Wait 60 seconds before approaching. Inspect for LiPo damage.
- **LiPo fire:** Use a Class D extinguisher or sand. Evacuate upwind. Call 911 if uncontrolled.
- **Personal injury:** Administer first aid. Call 911 for significant injuries. Notify the advisor.

6. Approvals Required

- Faculty advisor approval is required before the first run of this procedure.
- Flights must be registered and approved through UCSB's drone protocol which can be found at <https://www.ehs.ucsb.edu/programs-services/risk-management/uas-drones>
- The safety officer must give verbal clearance before each flight.

7. Procedure

7.1 Assembly and Setup

- Prepare the surrogate quadcopter. Verify all propellers, motors, and arms are secure.
- Install the flight battery and confirm cell voltages are nominal.
- Connect telemetry and verify ground station link.

Phase A — Baseline flight WITHOUT payload:

- Leave the mapping payload off the aircraft for the first flight.
- This flight characterizes the surrogate's baseline vibration profile and hover behavior without the added mass of the cameras.

7.2 Pre-Run Checks

- Confirm GPS lock (minimum 8 satellites).
- Verify failsafe settings (RC loss → RTL, battery → LAND).
- Check wind conditions: do not proceed if sustained winds exceed 20 km/h.
- Clear the 30 m safety perimeter.
- Verify first-aid kit and fire extinguisher are accessible.

If payload is installed (Phase B):

- Mount the RGB camera and FLIR Boson thermal camera to the vibration-dampened payload plate.
- Confirm all camera fasteners are tight. Apply safety wire or zip-tie backup.
- Perform a ground shake test: grip the aircraft and shake vigorously for 10 seconds. Confirm nothing shifts.
- Verify CG location with payload. Adjust battery position if necessary.
- Power on cameras and confirm they are recording or triggering correctly.

7.3 Run

Phase A (no payload):

- Arm and take off in Stabilize mode. Climb to 20 m AGL.
- Hover for 30 seconds. Observe stability and listen for abnormal vibrations.
- Execute a slow, straight-line pass at mapping speed (~5 m/s). Return and land.
- Review flight logs for vibration data (IMU accelerometer FFT).

Phase B (with payload):

- Arm and take off. Climb to the planned mapping altitude (e.g., 40 m AGL).
- Execute the planned mapping pattern (lawnmower grid) at the target ground speed.
- Ensure the cameras are actively capturing throughout the pattern.
- Monitor telemetry for abnormal vibration levels, motor current spikes, or attitude oscillation.
- Complete the mapping pattern and land in hover mode.

7.4 Post-Run

- Disarm and disconnect the battery.

- Remove the payload. Inspect camera mounts for looseness, wear, or damage.
- Download flight logs and camera imagery.
- Review images for motion blur, rolling shutter artifacts, or focus issues.
- Compare vibration data between Phase A and Phase B flights.
- Document results and any corrective actions in the test log.

Tilt Rotor VTOL-to-Horizontal Transition Test

SOP-YS-001 | Yavin Systems | UCSB ME Capstone

Author:	Yavin Systems
Department:	Mechanical Engineering
Test Location:	Elings Park, Santa Barbara, CA — Open Outdoor Field
Date Approved:	
Approved By:	

Acknowledgement

By signing below, I acknowledge that I have read and understand the contents, requirements, and responsibilities outlined in this SOP.

Name (Print)	Signature	Date

1. Description

This SOP describes the procedure for testing the transition of the Yavin Systems fixed-wing tilt-rotor VTOL aircraft from vertical (hover) flight mode to horizontal (forward) flight mode. The tilt-rotor mechanism employs servo-actuated nacelles that rotate the motor assemblies from a vertical orientation to a horizontal orientation, enabling the aircraft to shift from multirotor-style hover to efficient fixed-wing cruise flight.

The primary objective of this test is to verify that the tilt mechanism transitions symmetrically and completely, that the aircraft maintains stable attitude throughout the transition envelope, and that the ArduPilot flight controller (Pixhawk) correctly manages the handoff between hover and fixed-wing control surfaces. This test addresses a high-severity failure mode identified in the project FMEA.

2. Hazards Overview

FMEA Risk Assessment:

Severity	Occurrence	Detection	RPN
9	4	4	144

Primary Failure Mode: Asymmetric tilt mechanism failure (e.g., actuator stall, servo linkage binding) leading to uncontrollable roll/yaw during transition, or the mechanism not transitioning fully.

Identified Hazards:

- **Loss of control / flyaway:** Asymmetric rotor tilt generates unbalanced thrust vectors, potentially causing rapid, unrecoverable roll or yaw divergence.
 - Conduct all initial transitions at sufficient altitude to allow recovery time.
 - Pilot maintains readiness to revert to VTOL mode at all times via a dedicated failsafe switch.
- **Ground strike / crash:** Incomplete transition at low altitude may cause the aircraft to lose lift and descend uncontrollably.
 - Maintain a minimum transition altitude of 30 m (100 ft) AGL.
 - Establish a clear safety perimeter of at least 50 m radius around the test area.
- **Servo mechanical failure:** Servo stall, gear stripping, or linkage binding during tilt.
 - Inspect all servo linkages and fasteners before every flight.
 - Verify servo travel range and centering on the ground before arming.
- **Propeller strike / debris:** In the event of a crash, propeller fragments may be ejected.
 - All personnel remain behind the safety perimeter during powered flight.
 - Wear safety glasses within 50 m of the aircraft.

3. Required Personal Protective Equipment (PPE)

- ANSI Z87.1-rated safety glasses for all personnel within the test perimeter.
- Closed-toe shoes for all ground crew.
- High-visibility vest for the spotter/safety officer.
- Sun protection (hat, sunscreen) as appropriate for outdoor conditions.
- Hearing protection recommended when within 10 m of the aircraft at full throttle.

4. Waste Disposal

LiPo batteries that are damaged, punctured, or swollen during testing must not be disposed of in general waste. Place damaged batteries in a fireproof LiPo-safe bag and transport them to a certified electronics recycling or hazardous-waste drop-off facility. All other waste generated (zip ties, packaging, broken propellers) is non-hazardous and may be disposed of in general waste. Minimize waste generation.

5. Accident and Emergency Procedure

- **Crash / Fly-away:** Immediately disarm the aircraft via transmitter kill switch. Do not approach the aircraft for at least 60 seconds to allow motors to stop and batteries to stabilize. Visually inspect for smoke or swelling before handling.
- **LiPo fire:** Do not attempt to extinguish with water. Use a Class D fire extinguisher or sand to smother. Evacuate all personnel upwind. Call 911 if the fire cannot be controlled.
- **Personal injury:** Administer first aid from the on-site kit. For lacerations from propellers or significant injury, call 911 immediately. Notify the faculty advisor.
- **Property damage:** Secure the area, document damage with photographs, and notify the faculty advisor and Elings Park management.

6. Approvals Required

- Faculty advisor approval is required before the **first** run of this procedure.
- Flights must be registered and approved through UCSB's drone protocol which can be found at <https://www.ehs.ucsb.edu/programs-services/risk-management/uas-drones>
- The designated safety officer must give verbal clearance before each individual flight.
- All team members present must confirm readiness before arming.

7. Procedure

7.1 Assembly and Setup

- Transport the aircraft to Elings Park in a protective case. Unpack on a flat, debris-free surface.
- Attach the wing panels and verify all control surface linkages are secure and move freely.
- Mount the tilt-rotor nacelles and verify that each servo horn is correctly indexed to its spline.
- Install propellers. Confirm correct rotation direction (CW/CCW) for each motor.
- Install the flight battery. Verify voltage is within the nominal range (confirm per cell voltage is between 3.7 V and 4.2 V for LiPo).
- Connect the telemetry radio and verify data link with the ground station laptop.

7.2 Pre-Run Checks

Ground-Based Servo Validation (Critical):

- Perform a full transition sweep first without propellers, then repeat with propellers installed while the aircraft is physically restrained to a weighted test stand or heavy ground anchors. Use the minimum throttle necessary to confirm vectoring logic; ensure the airframe is secured by heavy-duty straps and tape to prevent lifting or shifting (preferably attached to a heavy table).
- Visually confirm that **both** nacelles tilt symmetrically and reach the full forward position.
- Command a return to vertical mode and confirm both nacelles return to the hover position.
- Repeat the cycle three times. Listen and feel for binding, hesitation, or asymmetry.
- Verify servo directions are correct: if a servo is reversed, correct it in ArduPilot parameters before proceeding. **Do not fly if any servo direction is incorrect.**

Flight Controller Checks:

- Confirm GPS lock (minimum 8 satellites, HDOP < 1.5).
- Confirm compass calibration is current and heading matches the known orientation.
- Verify failsafe settings: RC loss triggers RTL; battery failsafe triggers LAND.
- Confirm the transition switch on the transmitter is mapped correctly in ArduPilot.
- Verify airspeed sensor reads zero (or near zero) on the ground.

Site Safety:

- Designate a safety officer. Brief all personnel on emergency procedures and the safety perimeter.
- Confirm wind conditions: do not proceed if sustained winds exceed 15 km/h for initial tests.
- Clear the 50 m safety perimeter of all non-essential personnel.

- Verify a first-aid kit and fire extinguisher are accessible at the ground station.

7.3 Run

- Arm the aircraft in QSTABILIZE (hover) mode.
- Perform a vertical takeoff and climb to the designated transition altitude (minimum 30 m AGL).
- Confirm stable hover. Verify telemetry is streaming and being logged on the ground station.
- Announce “**Transitioning**” to all personnel.
- Flip the transition switch to initiate forward flight mode. The tilt mechanism will begin rotating the nacelles forward.
- Monitor aircraft attitude closely throughout the transition. Observe for any uncommanded roll, yaw, or pitch oscillation.
- **Abort criterion:** If the aircraft exhibits uncommanded bank angle exceeding 30° or significant yaw divergence, **immediately revert to vertical flight mode** by flipping the transition switch back. The pilot must be prepared to execute this at all times.
- If the transition completes successfully, fly a straight-and-level pass at a comfortable altitude and observe stability, airspeed, and power draw.
- Command transition back to VTOL mode and verify the nacelles return to vertical.
- Execute a controlled VTOL landing.

7.4 Post-Run

- Disarm the aircraft. Disconnect the flight battery immediately after landing.
- Inspect tilt mechanism: check servo linkages, motor mounts, and nacelle pivots for looseness, heat, or damage.
- Download and review the flight log from the Pixhawk. Analyze servo output channels for symmetry and timing.
- Record observations (transition smoothness, any anomalies, wind conditions) in the test log.
- Charge or swap batteries as needed for subsequent runs.
- Secure the aircraft for transport.