Harvard Undergraduate Aerospace Collective
UAV Team - Crimson VTOL System

Design and Validation of a VTOL Hybrid UAV for Fire Suppression Missions

Harvard College
Cambridge, MA

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Chief Engineer

May 1, 2026

Executive Summary

Over the course of the past semester, the Harvard Undergraduate Aerospace Collective (HUAC) UAV Team has developed a hybrid VTOL wildfire response aircraft designed to complete the 2026 DBVF mission scenario focused on rapid wildfire suppression, payload delivery, and autonomous re-supply operations. The aircraft combines the efficiency and endurance of fixed-wing forward flight with the precision vertical takeoff and landing capabilities required for confined waypoint operations and payload pickup missions. The design was specifically optimized around the competition's emphasis on wildfire response, requiring accurate sandbag payload deployment, stable hover performance, rapid transitions between mission phases, and reliable operation under strict safety and autonomy constraints.
The aircraft was engineered to transport and vertically deploy up to five 0.5 lb fire suppressant (sandbag) payloads from 30ft AGL while remaining within the competition's dimensional, weight, battery, and safety requirements respectively being: less than 8ft x 8ft x 8ft, less than 25lb, less than or equal to two 6s batteries in series, containing an external battery plug and comms kill switch). Key design choices included a lightweight foam-and-carbon-fiber airframe, distributed VTOL propulsion system, front-mounted cruise motor configuration, externally accessible propulsion battery disconnect, and independent avionics and propulsion power systems.

To support the wildfire mission profile, the team developed a custom payload pickup and deployment mechanism capable of repeatedly collecting and dropping payloads during flight without requiring human interaction with the aircraft. It consists of a modular, single servo-powered radial expansion mechanism for payload deployment with an intentional breakaway design for the payload containment to separate upon ground impact.

Throughout the semester, the team followed an aggressive design-build-test schedule that emphasized rapid prototyping, iterative CAD development, and subsystem integration. Major milestones included completion of the wiring architecture, airframe manufacturing, avionics integration, payload mechanism validation, and full-system assembly prior to flight testing. The final aircraft represents a balance between manufacturability, mission performance, reliability, and compliance with DBVF safety and operational requirements, resulting in a practical and competition-focused wildfire response platform.

Team and Schedule Overview

The Harvard Undergraduate Aerospace Collective (HUAC) is an organization of passionate students dedicated to innovation in the field of aerospace, and the HUAC - UAV Team specifically focuses on research and development of UAVs.

David Clarke, the Extended Tarr Family Professor of Materials in the Harvard School of Engineering and Applied Sciences (SEAS), serves as our current faculty advisor and oversees the entirety of HUAC.

Our team is structured with a **Chief Engineer (Chloe Bednar '27)** leading and managing all aspects of the project and providing support to the team's subteam leads and members listed below:

Airframe Lead (Oliver Price '27)

- lead airframe design, structural integrity, weight management, assembly strategy, durability and repairability, horizontal and vertical flight integration.

Payload Lead (Genevieve Hill '27)

- Lead the payload subteam to converge on a system for procuring and safely deploying fire retardants (sandbags) with a fully integrated, shatter-compliant mechanism.

Autonomy & Ground Control Station Lead (Mark Rifkin '27)

- lead flight controller configuration and designed failsafe behaviors, mode switching, override behaviors, telemetry, command logic, avionics, and controls

Power & Controls Lead (William Tang '28)

- Assisted in the design, selection, and integration of major flight components, wiring plan and documentation, battery compliance, and power distribution

Members: **Hugh Salva '27, Moana Gorezi '28, Aidan Vissers '29, and Nina Lin '29**

Our schedule followed an eleven-week plan, breaking ground on the project on Feb 13th, with a fly-off date of May 1st. We held weekly team meetings in addition to independent work conducted throughout the week, and closely followed the timeline below:

- [x] **Feb 2nd** - Begin research and design phase
- [x] **March 13th** - All major components ordered, beginning to have physical prototype
- [x] **March 20th** - Wiring Plan complete
- [x] **April 10th** - Basic propulsion system testing
- [x] **May 5th** - Fly-off Date
- [x] **May 30th** - Final Technical Report (FTR) complete

Question 1:

What is your aircraft and why did you design your aircraft this way?

Our aircraft is a lift-plus-cruise VTOL fixed-wing aircraft designed to combine the precision of a multirotor with the efficiency of a conventional airplane. The aircraft uses four vertical lift motors for takeoff, landing, hovering, payload pickup, and payload drop positioning, while a dedicated forward cruise motor that's mounted to the front of the fuselage provides efficient horizontal flight between mission waypoints. This configuration was selected because the competition requires both precise vertical maneuvering and repeated long-distance transit within a strict 10-minute mission window; therefore, we sought to optimize the horizontal travel and reduce battery usage in this configuration.

We considered several aircraft configurations, including a conventional quadcopter, tiltrotor, tailsitter, and lift-plus-cruise design. A conventional quadcopter offered mechanical simplicity and strong hover control, but it was inefficient for sustained horizontal travel because all lift and propulsion must come from vertically oriented rotors, which were also slower in horizontal transit. A tiltrotor or tailsitter offered efficiency benefits but introduced additional mechanical complexity, control risk, and payload-orientation challenges. The lift-plus-cruise configuration provided the best balance of reliability, endurance, payload stability, and mission versatility.

Simple VTOL Airframe Comparison

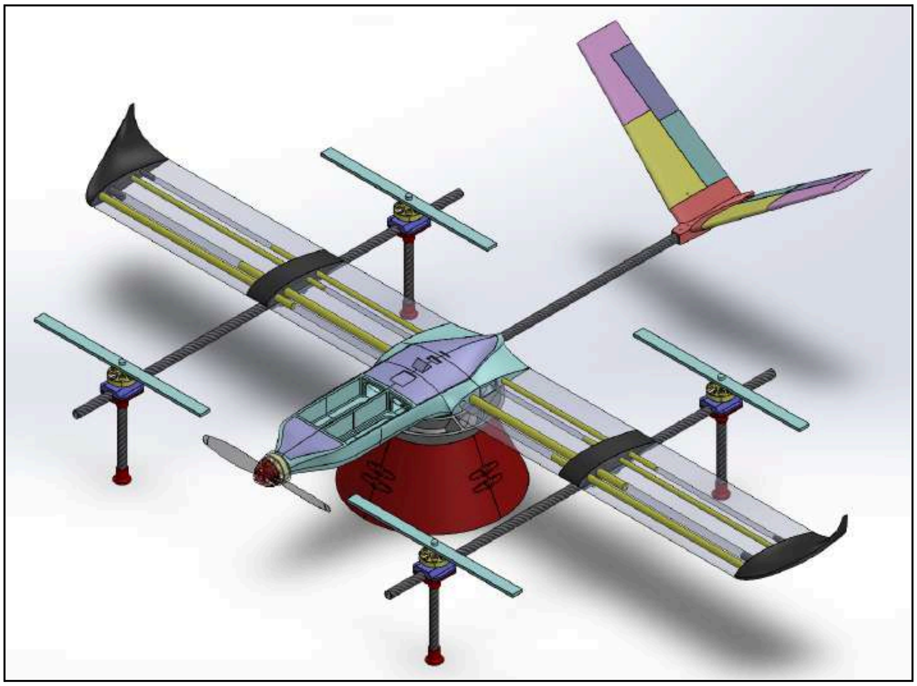
Baseline (Datum): Quadcopter

Criteria	Quadcopter	Triplane	Quadplane	Tiltrotor	Hexacopter	Tailsitter
Easy to build	0	-1	-1	-1	0	-1
Not too heavy	0	0	0	0	-1	0
Simple mechanically (few moving parts)	0	-1	0	-1	0	-1
Feels stable in hover	0	-1	0	0	+1	0
Likely efficient in forward flight	0	+1	+1	+1	0	+1
Easy to repair	0	+1	+1	0	0	0
Electronics easy to mount	0	0	0	-1	0	-1
Battery easy to place near middle	0	0	0	0	0	-1
Not too risky during transition	n/a	-1	0	-1	n/a	-1
Ease of payload integration	0	+1	+1	+1	0	-1
Net	**0**	**-1**	**+2**	**-2**	**0**	**-5**

Legend: +1 = Better than baseline 0 = Same as baseline −1 = Worse than baseline n/a = Not applicable to this concept

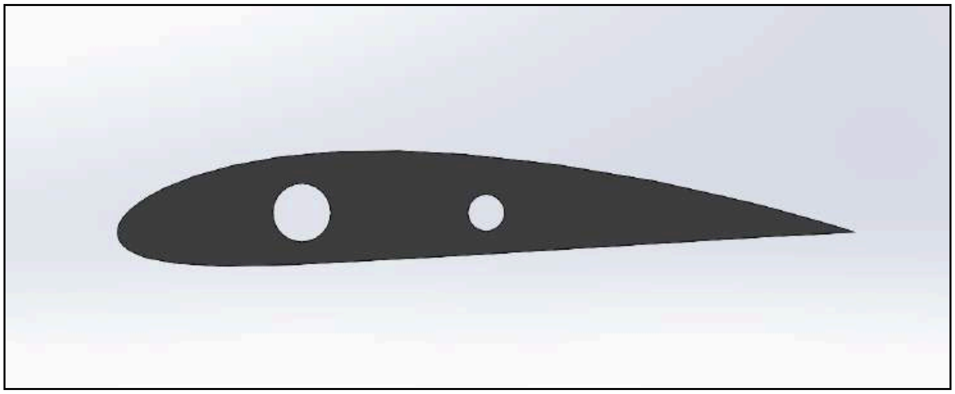
Initial Airframe Design Pugh Matrix

A major design decision was placing a dedicated cruise propeller at the front of the aircraft. This configuration provides clean forward thrust during cruise and improves airflow over the wing, helping the aircraft accelerate into efficient fixed-wing flight after vertical takeoff. Separating the cruise motor from the lift motors also simplifies control: the vertical motors can be optimized for hover and payload operations, while the cruise motor can be optimized for forward-flight efficiency.

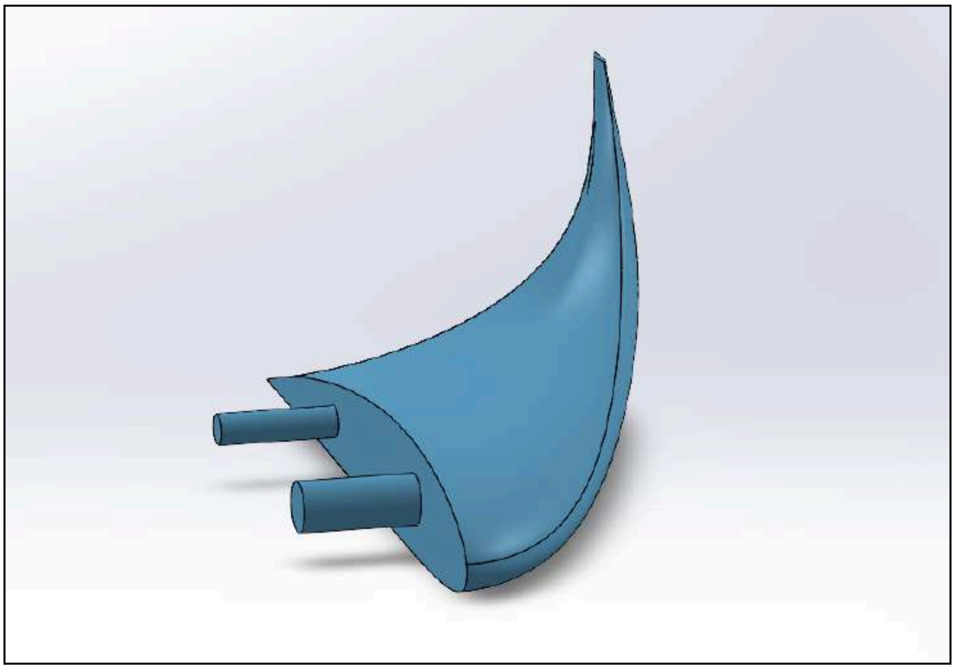


Quadplane V1 CAD Assembly

The wing was designed to support efficient cruise while carrying wildfire suppressant payloads. We selected a cambered airfoil to generate strong lift at moderate speeds (30-45mph), reducing the required cruise power and improving endurance. The wingspan was chosen to provide enough lifting area for stable fixed-wing flight while remaining within the competition's size constraints. Wingtip design was also considered to reduce induced drag and improve stability during cruise, both of which are important for conserving battery energy.



Airfoil CAD Design



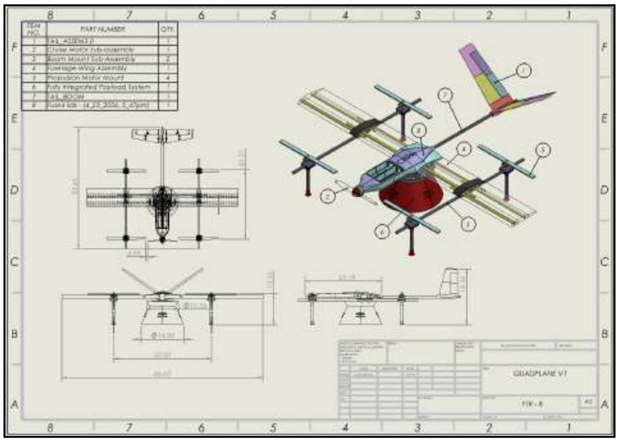
Wingtip CAD Design

The tail was placed at a sufficient distance behind the wing to increase control authority. A longer tail moment arm allows the elevator and rudder to generate greater stabilizing torque for the same control surface force, improving pitch and yaw stability during cruise and transition.

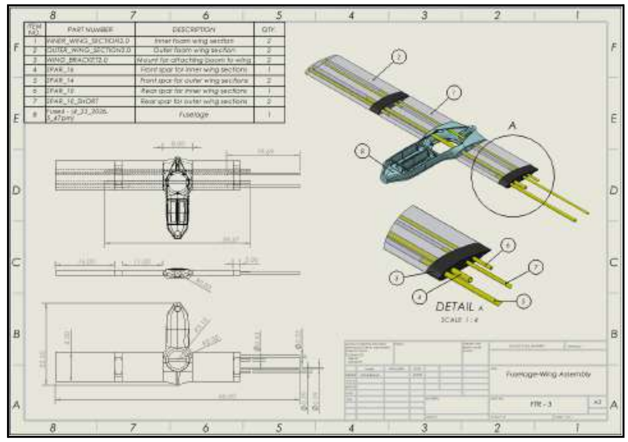
Overall, the aircraft was designed around the specific demands of the wildfire-response scenario: vertical takeoff and landing, accurate payload handling, efficient transit, repeated resupply, and reliable operation under time constraints. The lift-plus-cruise configuration gives our aircraft the ability to operate like a helicopter when precision is needed and like an airplane when efficiency matters most, which makes it better suited than a conventional quadcopter for a mission that requires both accurate suppressant delivery and rapid repeated travel across the course.

Drawing Package

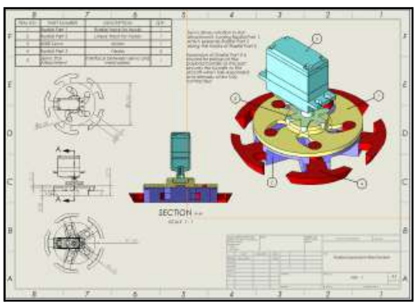
Included below are the main assembly, subassemblies, and parts for our V1 quadplane design:



Assembly 1



Subassembly 1



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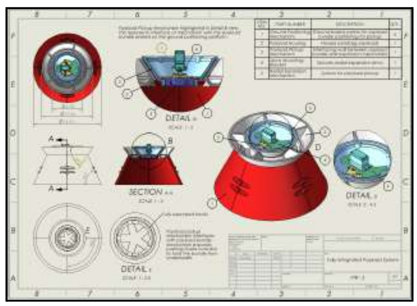

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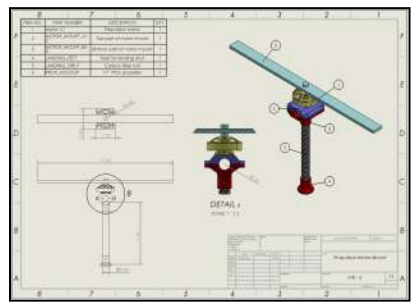
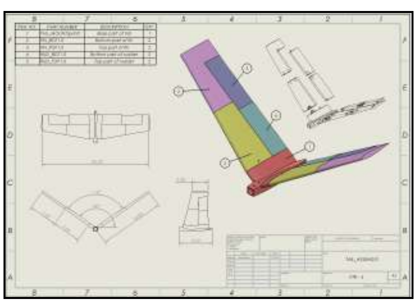
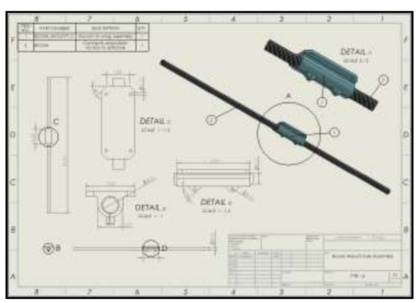


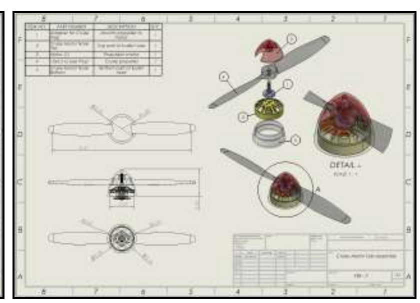
Subassembly 4



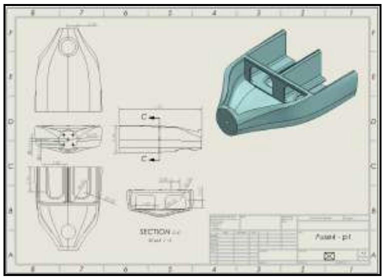
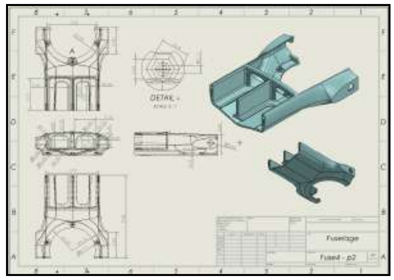
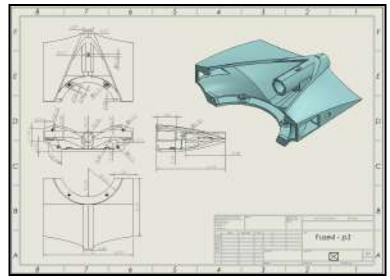
Subassembly 5



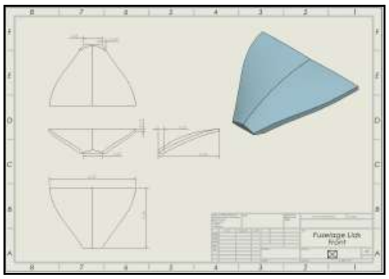
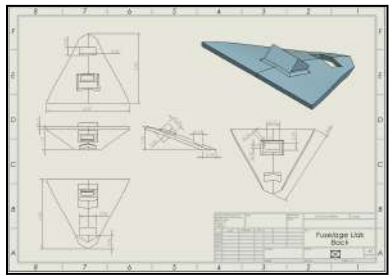
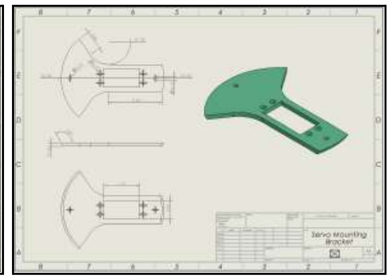
Subassembly 6



Subassembly 7

Part 1 *Part 2* *Part 3*

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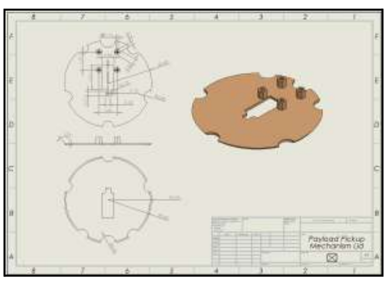
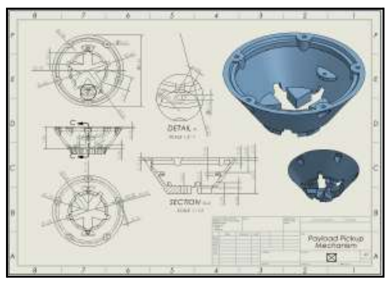
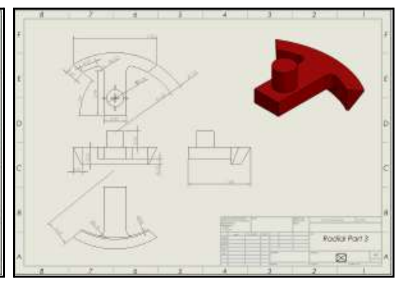

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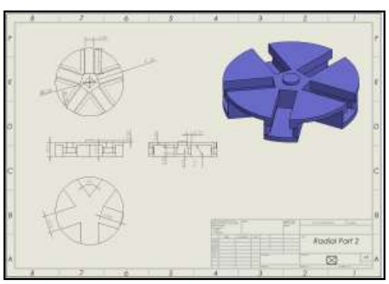
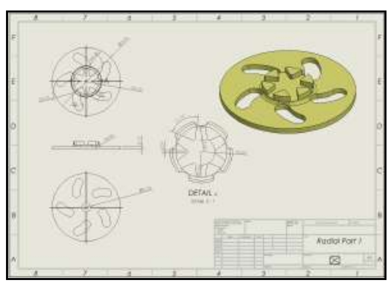
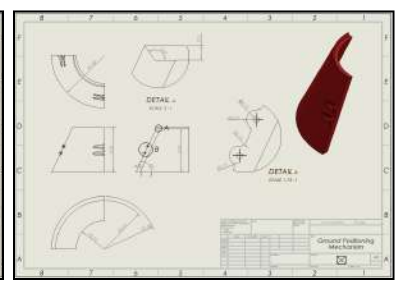
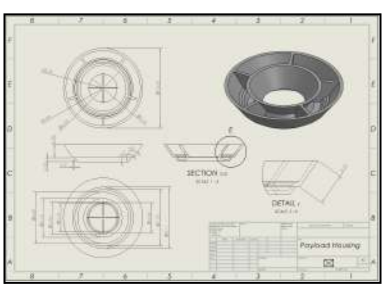
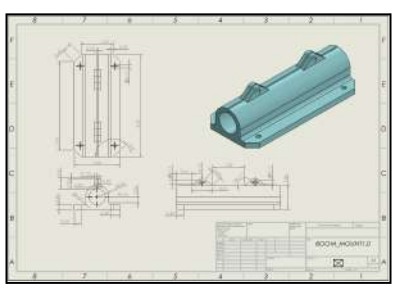
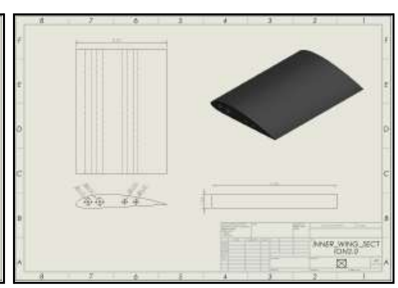




Part 10 *Part 11* *Part 12*

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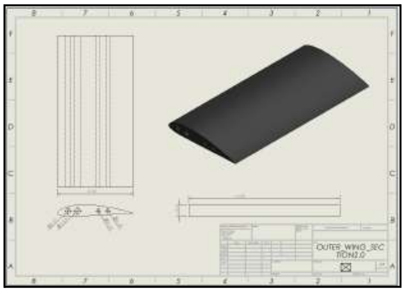

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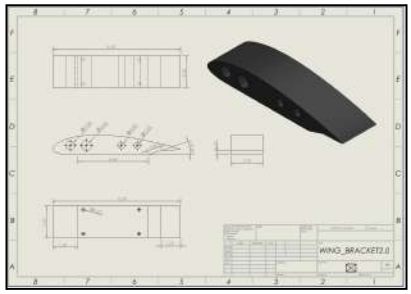

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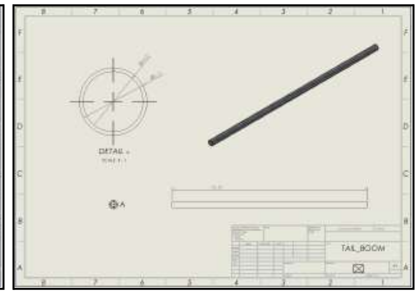

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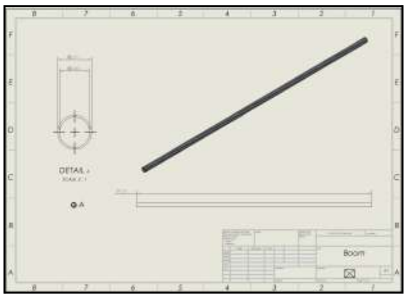

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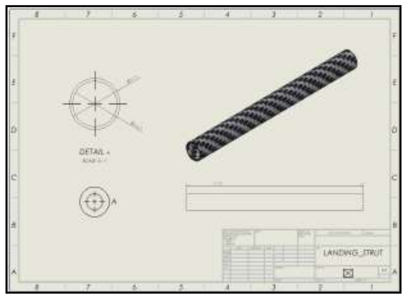

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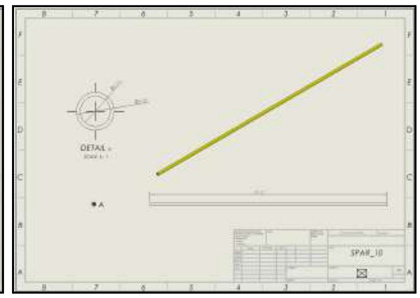

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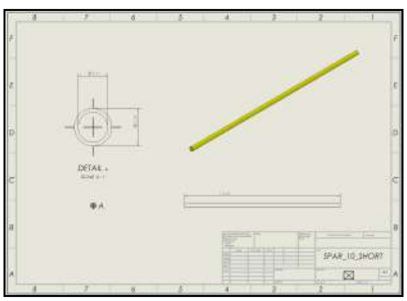

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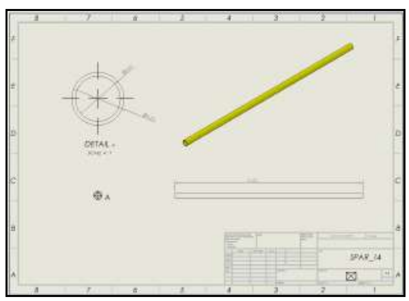

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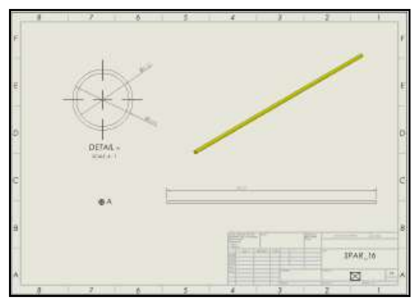

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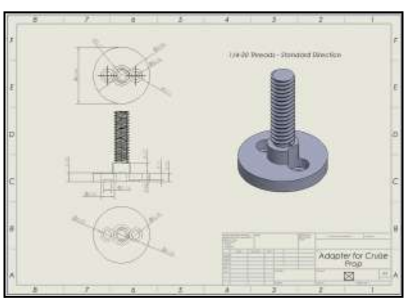

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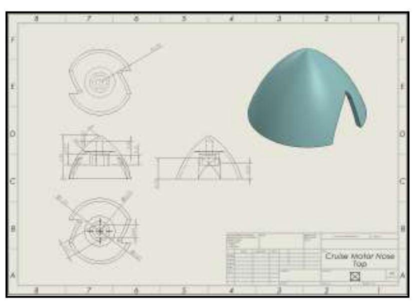

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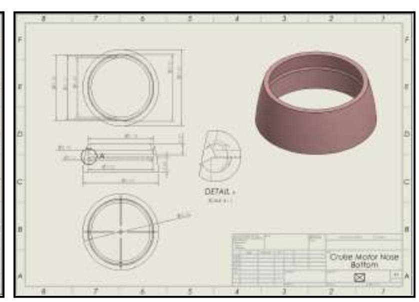

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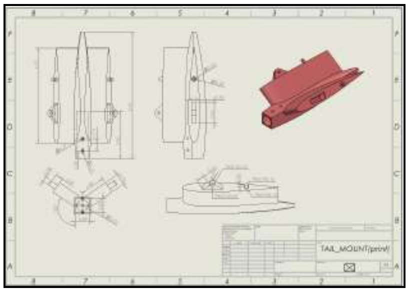

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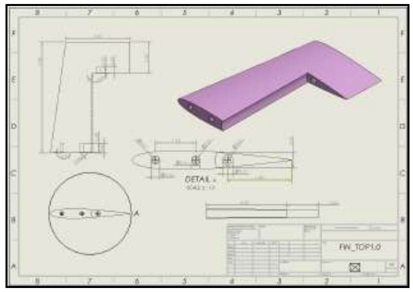

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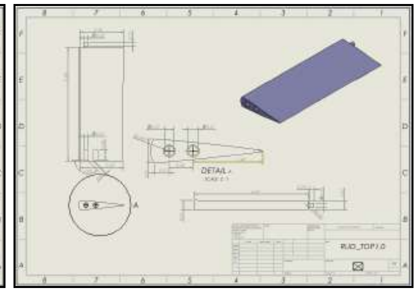

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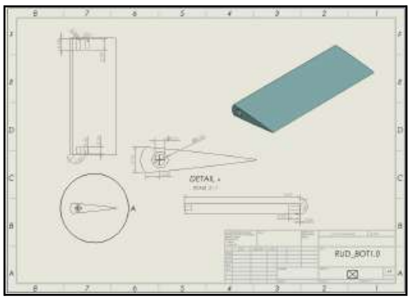

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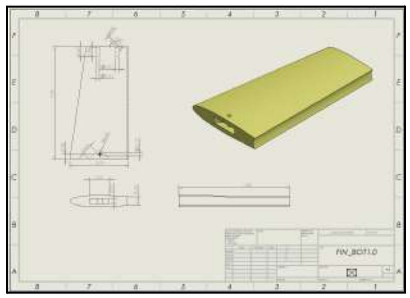

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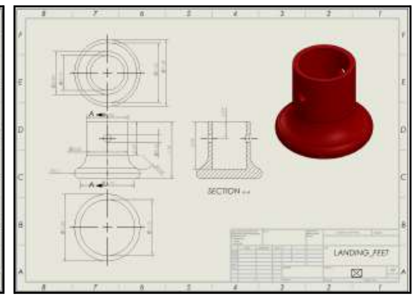

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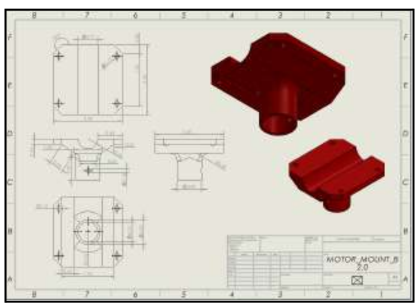

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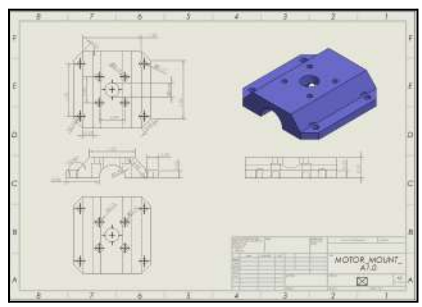


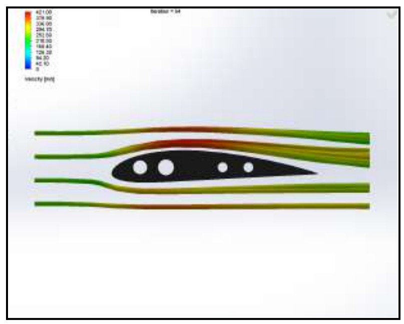
Part 35

Question 2:

How did you build, test, and validate your aircraft?

Building our V1 quadplane design from the ground up required most, if not all, of our 3D modelling to be done in SolidWorks in determining theoretical metrics and calculations, including dimensioning, mass, center of gravity, and fluid dynamics for developing the ultimate size, shape, and functionality of our aircraft. Under a tighter time constraint, the team opted to take a more mid-fidelity approach to manufacturing, with many of the components and fixtures being made of FDM plastic that we 3D printed in our lab, including major components such as the fuselage, tail, and motor mounts.

3D Printed Components

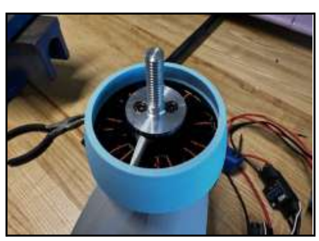


Airfoil CFD

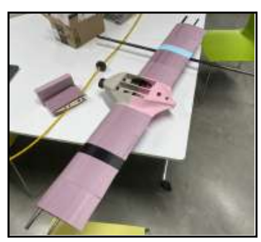
UAV Dry Assembly

Additional manufacturing processes utilized were foam cutting for creating the foam wings and a CNC lathe for a custom aluminum component for mounting the cruise propeller to the motor due to a lack of adaptability within the part itself. On the electrical side, we also soldered all of the components, including the power distribution board, flight controller, and the ELRS receiver.

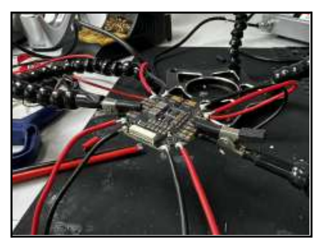
Hot-Wire Cutting



CNC Turned Part



Dry-Fit Wings



Soldered PDB

Our ground testing methods showed much room for improvement, as this was an aspect of our project that was heavily underdeveloped, in that, due to time constraints, we very much neglected flight validation over structurally finishing the airframe itself. Much of the ground testing done was towards the final days of our project timeline, was very minimal, and mainly served to validate that our system was functioning properly. Future work involved delving deeper into testing and creating an apparatus with load cells for validating the stability of our UAV.

Validation of Quadplane Electrical Functionality

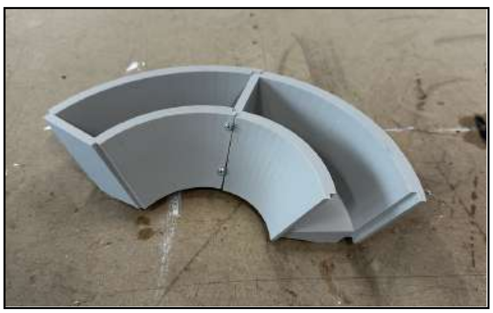
Our flight testing was comprised of a single unsuccessful flight, ending in a destroyed fuselage, two broken propellers, and a hunger to iterate our design to build a stable and functioning UAV by the following semester, set to fly in the Vertical Flight Society's Design-Build-Vertical-Fly competition in 2027.

Quadplane Maiden Flight

In validating our design choices, we took a very hands-on approach. In relation to the airframe, much of our work stood on the shoulders of current quadplane literature, so much of our validation centered around the payload deployment mechanism we designed. We ran different design-build-test cycles in this regard, specifically, one test was designed to determine the most optimal payload housing to meet the competition constraint: "When dropped, payloads and their respective attachments must never shatter. If any individual payloads or their respective mounting mechanisms break apart into more than one piece, this will count as a shatter. If a payload bundle breaks into multiple individual payloads and mechanism(s), but all payloads and mechanism(s) individually remain in one piece, this will not be considered a shatter.” We initially opted for a solid, shatter-proof design; however, this proved impractical due to material constraints, including FDM printing restrictions and weak fixture points failing on impact. We ran various drop tests from the competition height of 30ft AGL, and ultimately decided to play into the break-apart method for each payload bundle.

30ft AGL Drop-Test Area

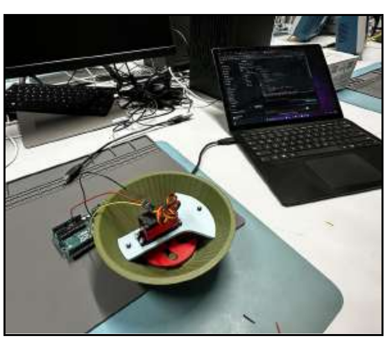
Shattered Payload Bundle



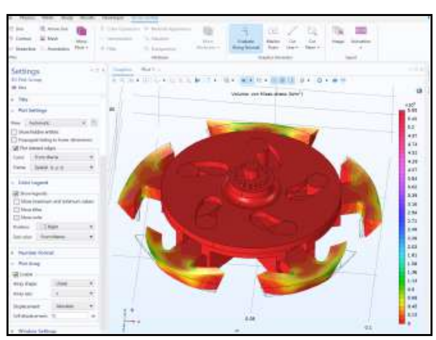
Bundle Screw Fastening

Bundle Breakaway Design

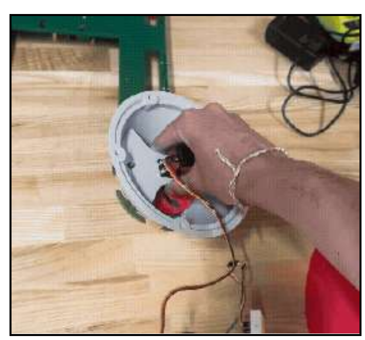
Additional validation tests took place with the payload deployment mechanism in manual and servo-powered tests of the radial expansion system to determine not only its functionality, but also its durability under the substantial 2.5lb payload bundle load and its ability to pick up and deploy the payloads effectively. We also ran finite element analysis tests in COMSOL to validate the rigidity of the system with the PLA plastic material we chose to utilize in our design.



Radial Expansion Test



COMSOL Stress Validation



Payload Deployment

Question 3:

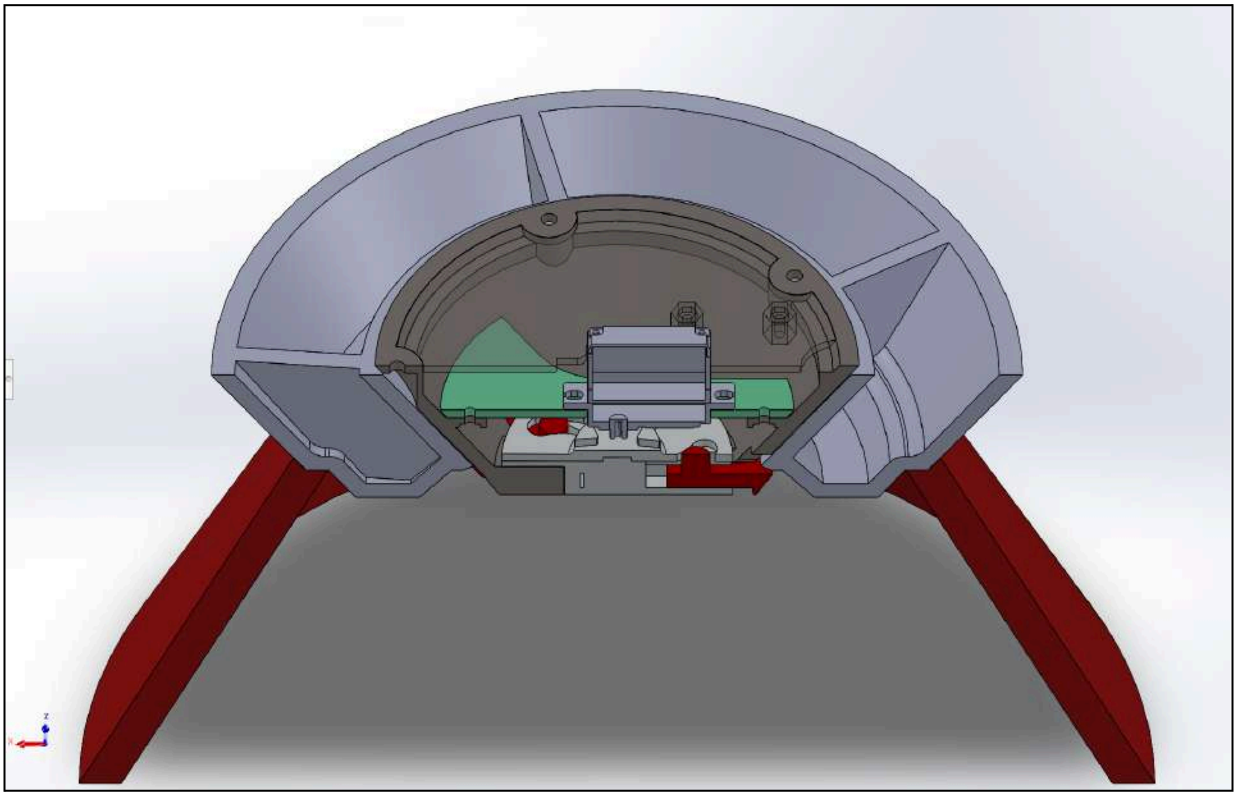
What is innovative about your aircraft and why does this matter for the competition's focus on wildfire response?

Our aircraft introduces several mission-specific innovations designed to improve the speed, efficiency, and practicality of aerial wildfire response operations.
Most notably, we implemented a lift-plus-cruise VTOL configuration rather than a conventional quadcopter platform. Unlike quadcopters, which continuously expend energy generating lift through vertically oriented rotors during all phases of flight, our aircraft separates vertical lift from forward propulsion. After takeoff, the aircraft transitions into fixed-wing cruise flight, dramatically improving aerodynamic efficiency during long horizontal transits between mission waypoints. This results in reduced power consumption, increased endurance, faster mission completion, and improved payload-carrying capability within the competition's strict 10-minute operational window.

Finished Quadplane V1 Airframe

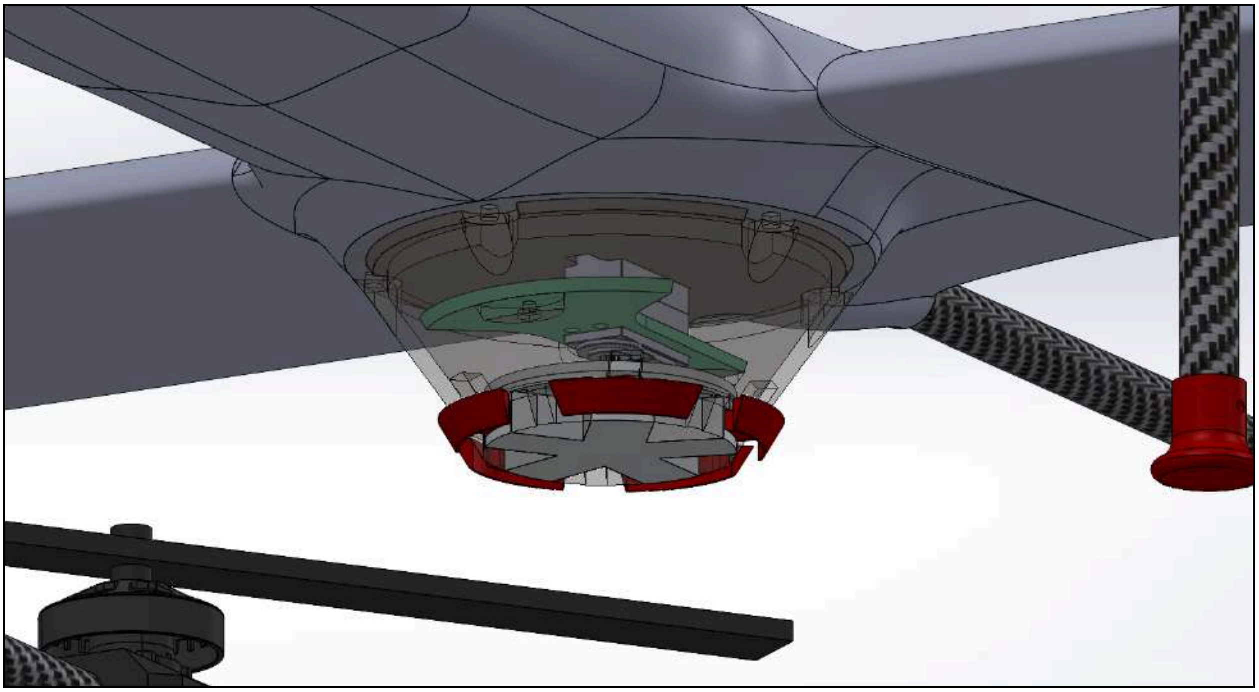
This matters directly in wildfire response scenarios, where rapid repeated transit between fire zones and resupply locations is critical. Increased range and efficiency allow more suppressant payloads to be delivered in less time while reducing battery strain and operational downtime.

Additionally, our payload system was specifically designed around the operational constraints of payload deployment. Because our payload bundles utilize an open-top architecture requiring a constant upright orientation during flight, a tilt-rotor or tailsitter configuration would introduce instability and increased risk of payload displacement. The lift-plus-cruise configuration allows the payloads to remain level throughout all phases of operation while still maintaining precise VTOL capability for confined-area pickup and deployment.



Fully Loaded Payload Bundle With Open Top

Our payload pickup and deployment mechanism also introduces a modular and platform-agnostic design approach. The system mounts using only a flat circular interface, allowing integration onto a wide variety of UAV architectures without requiring a complete airframe redesign. Furthermore, the fully symmetrical funnel-based pickup geometry allows payload acquisition from any compass orientation, eliminating the need for precise docking alignment during pickup operations. This reduces acquisition time, simplifies autonomous navigation logic, and improves reliability under dynamic flight conditions.



Payload Deployment Mechanism Integration with Airframe Underside

Together, these innovations prioritize rapid deployment, operational efficiency, modularity, and repeatable payload handling, all of which are critical factors in scalable autonomous wildfire containment missions.

Reflection & Next Steps

Many of our findings throughout the design process have revealed themselves in our final V1 prototype, that have emphasized the importance of testing during the building process. To begin, much of our design was done theoretically rather than creating an initial prototype, testing it, iterating on it, and testing it again, we ended up doing more so longshot prototyping where we designed everything for the final prototype and only tested at the very end of our project timeline, inevitably ending in failure due to lack of UAV aerodynamic flight knowledge, instability in the system, and overall rigidity failures.

Most of the challenges encountered (luckily) were fairly intuitive in solving the problem. For example, in designing the servo-powered mechanism for deploying payloads, a major concern was that the two surfaces interacting with each other would cause too much friction, therefore rendering the servo's torque rating useless, as it was too weak to overcome the 2.5lb of the sandbag payload system weight in order to retract and deploy the system. The simple fix to this problem was reducing the surface area of the payload system in contact with the servo-powered mechanism, which worked perfectly for solving the problem.

All other challenges were fairly minor and somewhat anticipated, such as adjusting the fuselage design to accommodate the center of gravity focused directly over the payload deployment, which was slightly more difficult than anticipated since we were accounting for both the center of gravity of the VTOL portion of the aircraft and the fixed-wing portion, in which case the center of gravity needs to be perfectly aligned, which presents challenges when anticipated weights of components are somewhat different than the actual weights due to the use of FDM plastic and change in infill in draft versus final prototypes.

Even though our design process itself needs improvement, we were still able to identify issues within our V1 prototype, as mentioned, so in our upcoming V2 model, we'll be able to create a more robust, steady airframe capable of completing the mission by implementing smaller design-build-test cycles throughout the upcoming semester to ensure success in our design. Our next steps are redesigning the fuselage and airframe as a whole to be able to fly steadily and consistently before going about mission-specific capabilities.