Vertical Takeoff and Landing Tailsitter for the California Unmanned Aerial System Competition

Maxwell J. Weaver, Cristian Rosete, Kyle Loutzenhiser, & Peter Husch

San Diego State University, College of Engineering, San Diego, CA 92115

This project presents the design, fabrication, and preliminary flight testing of a vertical takeoff and landing (VTOL) tailsitter unmanned aerial system (UAS) developed for the California Unmanned Aerial Systems Competition hosted at the Mojave Air and Space Port. The primary objective was to create an efficient and innovative aircraft capable of both vertical hover operations and high efficiency forward flight, while satisfying mission requirements such as waypoint navigation, package delivery, and autonomous sensing tasks. The team evaluated multiple configurations and selected the tailsitter layout for its structural simplicity, reduced mechanical complexity, and aerodynamic efficiency.

I. Introduction

The California Unmanned Aerial Systems Competition is hosted by California State University Los Angeles at the Mojave Air and Space Port. The event challenges student teams to design, build, and test an unmanned aerial vehicle that can complete several autonomous missions. These missions include waypoint navigation, circuit time trials, package pickup and delivery, and target identification. In addition to mission performance, the competition places significant weight on innovation in aerodynamics, structural design, controls, and manufacturing. The team developed "Quetzal", a vertical takeoff and landing tailsitter aircraft, to meet these requirements. The design effort began with an evaluation of several aircraft concepts, including a quadrotor layout, a tiltrotor layout, and a hybrid layout. The tailsitter concept was selected because it offers mechanical simplicity, low part count, fewer failure modes, and efficient forward flight without the need for additional actuators or rotating mechanisms. The simplicity of the configuration also supports rapid prototyping and consistent fabrication.

The main goals of the project were to design and fabricate a functional tailsitter unmanned aerial system, to demonstrate stable vertical takeoff and forward flight, to integrate a modular avionics suite capable of autonomous control, and to evaluate the aircraft through structured testing. The final intent was to create a platform that could complete the competition missions and serve as a foundation for continued development. This report presents the design choices, fabrication methods, aerodynamic justification, testing procedures, and initial flight results of the prototype aircraft. The report is written with the objective of allowing others to reproduce the work performed by the team while also providing clear documentation of aircraft performance and the steps needed for future improvements.

II. Literature Review

Source 1: Gupta et al., "Optimal Transition Trajectory of a Quadrotor Biplane Tailsitter"
https://docs.px4.io/main/en/frames_vtol/ [1]

This source informed the team's understanding of the fundamental challenges associated with transition flight in quadrotor biplane tailsitter aircraft. This source analyzes the forward transition maneuver using a simplified dynamic model and demonstrate how hybrid VTOL vehicles experience highly unstable, low-speed, high–angle-of-attack conditions during mode change. The team used this work to validate that the tailsitter configuration selected for Quetzal faces known and well-documented control and stability challenges during transition, reinforcing the need for careful configuration selection and control system development. The team leveraged this study as a conceptual and analytical reference to justify the feasibility of a quadrotor biplane tailsitter aircraft layout.

Source 2: PX4 Autopilot Documentation – VTOL Frames
https://www.researchgate.net/profile/Vikram-Hrishikeshavan/publication/269247606_Performance_and_Testing_of_a_Quad_Rotor_Biplane_Micro_Air_Vehicle_for_Multi_Role_Missions/links/548f0c8e0cf2d1800d861fc2/Performance-and-Testing-of-a-Quad-Rotor-Biplane-Micro-Air-Vehicle-for-Multi-Role-Missions.pdf [2]

This source provided the team with an authoritative, industry-standard overview of existing VTOL aircraft configurations and their practical tradeoffs. The PX4 documentation categorizes common VTOL frame architectures including tiltrotors, tilt-wings, and tail sitters, and discusses their relative mechanical complexity, control challenges, and operational characteristics. The team used this reference to frame the initial configuration trade study and to justify the selection of a tailsitter configuration based on its mechanical simplicity. The team grounded its design decision in established autopilot and flight-control practices and demonstrated that the selected quadrotor biplane tailsitter configuration aligns with real-world VTOL implementations supported by mature control software frameworks

Source 3: Hrishikeshavan et al., "Performance and Testing of a Quad-Rotor Biplane Micro Air Vehicle for Multi-Role Missions"

Hrishikeshavan, V., Bogdanowicz, C., and Chopra, I., "Design, Performance and Testing of a Quad Rotor Biplane Micro Air Vehicle for Multi Role Missions," *International Journal of Micro Air Vehicles*, Vol. 6, No. 3, Sept. 2014, pp. 155–171. https://doi.org/10.1260/1756-8293.6.3.155. [3]

This source provided the team with experimental and analytical guidance for designing a quad-rotor biplane aircraft operating at low Reynolds numbers. Hrishikeshavan et al. present flight testing and performance data showing how moderately cambered, low-Re airfoils improve lift-to-drag characteristics for small biplane UAVs, particularly in forward flight following vertical transition. The team used these findings to justify the selection of low Reynolds number airfoils for Quetzal, ensuring predictable lift generation and acceptable drag performance within the expected cruise speed range. In addition, the study discusses aspect ratio selection and vertical wing spacing as key parameters affecting aerodynamic efficiency and interference between lifting surfaces. These results directly informed the team's decisions regarding wing aspect ratio and the minimum spacing between the upper and lower wings, helping to minimize aerodynamic interaction while maintaining a compact, structurally efficient biplane layout suitable for a quadrotor tailsitter configuration.

Source 4: Hepperle, "Flying Wings: Airfoil Design and Selection"

Hepperle, M., "Airfoils for Flying Wings and Tailless Airplanes," *MH-AeroTools*, May 2018, https://www.mh-aerotools.de/airfoils/foil_flyingwings.htm [4].

This source provided the team with direct justification for selecting the MH60 airfoil for a tailless biplane tailsitter configuration. Hepperle outlines the design objectives of the MH40 and MH60 airfoil series, emphasizing low drag performance, small quarter-chord pitching moment coefficients, and improved maximum lift coefficient relative to other low-moment airfoils. The team used these stated design goals to support the selection of the MH60 airfoil, as Quetzal lacks a conventional horizontal tail and therefore benefits from an airfoil with a benign pitching moment and predictable aerodynamic behavior. Additionally, the documented use of the MH60 in flying-wing applications provided confidence that the airfoil performs reliably in tailless configurations at low Reynolds numbers, reinforcing its suitability for a compact UAV biplane designed for both high-angle-of-attack transition flight and efficient forward cruise.

Source 5: California Unmanned Aerial Systems Competition (C-UASC) Rules, Rev. 2 (2025)

https://www.calstatela.edu/sites/default/files/C-UASC%202026%20Competition%20Rules%20rev%202025-11-10.pdf [5]

The C-UASC Competition Rules served as the primary set of external constraints governing the design, configuration, and mission capabilities of the Quetzal aircraft. The team used this document to define allowable aircraft types, confirming that a VTOL configuration was permitted alongside fixed-wing and multirotor designs, and to ensure compliance with FAA Part 107 weight and operational limitations. The rules also directly informed key sizing and performance requirements, including autonomous waypoint navigation, package delivery with strict impact force limits, turning radius constraints, and operation within a defined geofence. These mission definitions and scoring criteria guided the team's emphasis on forward-flight efficiency, precise low-speed control, and payload handling capability. Additionally, the rules' explicit focus on innovation in aircraft configuration, aerodynamics, structures, and control systems reinforced the team's decision to pursue a quad-rotor biplane tailsitter architecture rather than a conventional quadcopter, aligning the final design with both mission performance objectives and design-competition evaluation criteria]

Source 6: Crowell Sr., "The Descriptive Geometry of Nose Cones"

http://servidor.demec.ufpr.br/CFD/bibliografia/aerodinamica/Crowell_1996.pdf [6]

The bulk of the rationale for which nose cone shape was chosen came this source. This document covers the geometry, typical uses and practicality of a variety of nose cone shapes. This includes, Conical, Bi-Conic, Power Series, Tangent and Secant Ogives, Elliptical, Parabolic Series, and the mathematically derived Haack Series (including the Von Karman). The primary information used from the paper was pertaining to elliptical nose cones, since Crowell identifies this geometry as ideal for subsonic flight due to its blunt profile which minimizes drag at low speeds. We also used the paper's formulas for wetted area and volume to calculate the nose cone's mass properties and the center of pressure location to aid in the drone's stability.

"The primary aim of VTOL designs is to combine the advantages of both fixed-wing aircraft, such as speed and endurance, with the hovering and vertical capabilities of multi-rotor systems [14,15]" [1]

III. Rationale for Design Choices

The Quad-Rotor Biplane Tailsitter aircraft configuration was carefully considered and weighed against a few candidate aircraft configurations, and ultimately chosen for its mechanical simplicity, ease of manufacturability, and efficiency. The aircraft configuration requirements are laid out in the "C-UASC 2026 Competition Rules" [ref#] which states that "The UAS aircraft configuration can be a: Rotocopter, Fixed-Wing Vehicle, or VTOL (Vertical Takeoff and Landing) Vehicle." The rules also lay out additional requirements pertaining to aircraft configuration, stating it must adhere to FAA Part-107 small UAS limitations, must be capable of fully autonomous flight, and must be able to turn within a 150-foot radius. In addition to the limitations, the rules lay out mission requirements and scoring guidelines that were taken into consideration when choosing an aircraft layout. The rules laid out 6 flight missions including Waypoint navigation, Circuit time trial, Package Drop, Package delivery, target localization, and package recovery – of which 4 flights will be selected by the team to be completed and scored. Lastly, the rules also stated that in addition to the competition scoring, there will be a design competition where judges will evaluate "Well formulated engineering processes, analysis, and methodology, Well described engineering design features, Well described manufacturing processes, Innovation in processes or materials, Innovation in aircraft configuration, aerodynamics or structure, Innovation in control systems, autonomy or computer vision, Innovation in package-delivery system.

While most teams choose a standard quadcopter for its simplicity and reliability, the SDSU team decided to pursue a VTOL aircraft capable of efficient fixed-wing flight to retain the precision needed for package-delivery missions while gaining the aerodynamic efficiency necessary for fast circuit laps. This approach also aligned with the competition's emphasis on innovation in configuration, aerodynamics, and system integration. With this goal in mind, several VTOL concepts were evaluated for quetzal.

There are 4 widely recognized types of VTOL aircraft, each with their own drawbacks and benefits, each of these VTOL designs were evaluated by the team.

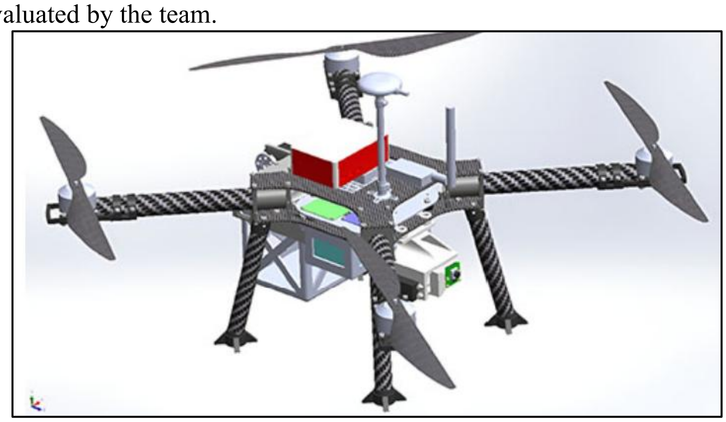


Figure 1: Quadcopter VTOL Aircraft (source last year's team)

At one end of the spectrum are conventional quadcopter multirotor aircraft, as depicted in figure 1 which achieve VTOL through multiple vertically oriented rotors but lack fixed-wing cruise efficiency. Quadcopters are well suited for maneuverability but poorly optimized for high-speed forward flights.

Figure 2: Standard VTOL (source px4)

Winged VTOL configurations integrate fixed wings for efficient cruise. One such configuration of fixed wing VTOL is the standard VTOL depicted in figure 2 which has "Separate rotors/flight controls for multicopter and forward flight. Takes off and lands on belly" (source px4) this configuration is desirable due to its simplicity, and ease of controllability due to the separate forward flight/ hover motors. Its drawbacks lie in efficiency – the hover motors and propellors are not used in forward flight, meaning they create unnecessary drag and weight when the aircraft is in forward flight.

Figure 3: Traditional Vertical Takeoff and Landing Single Airfoil Drone

The third type of VTOL aircraft is the Tiltrotor – also a fixed wing design taking advantage of fixed wing efficiency, but instead of having separate rotors for forward and vertical flight, the "Rotors swivel 90 degrees to transition from multicopter to forward flight orientation" (source px4). This configuration benefits from increased maneuverability and controllability in vertical to horizontal transitions due to the tilting ability of the rotors and solves the standard VTOL's problems of drag inefficiency by using every motor, however it suffers from weight inefficiency and increased mechanical complexity due to the addition of the motor tilting mechanism.

Figure 4: VTOL Tailsitter aircraft

The fourth type of VTOL aircraft is the Tailsitter, this vehicle's rotors are "permanently in fixed-wing position." And it "Takes off and lands on its tail. The whole vehicle tilts forward to enter forward flight" The benefits of this configuration are that there is no added drag, weight, or mechanical complexity from the flight transition system since the entire aircraft tilts to transition from hover to forward flight. The drawbacks of this configuration are controllability, the wing acts as a drag surface in hover flight, making hover inherently harder to control, especially in the presence of gusts. Additionally, these types of designs oppose having a long moment arm for a vertical tail, if they include a vertical tail at all, meaning that they usually lack static stability and require a closed loop stability program for forward flight.

After careful consideration, the team selected the tailsitter configuration due to its mechanical simplicity, as well as the opportunity it provided for cross-disciplinary innovation. Since Quetzal is a cross-collaborative effort between SDSU's Mechanical, Aerospace, and Electrical-Computer Engineering departments, the tailsitter architecture offered each discipline a meaningful technical challenge: the ECE team could develop and tune a full closed-loop transition and flight-stability control system, the Aerospace team could research and implement aerodynamic lifting surfaces to improve forward-flight efficiency, and the Mechanical Engineering team could design a lightweight and robust airframe capable of withstanding both vertical landings and fixed-wing cruise loads.

Figure 5: VTOL Quadrotor Biplane Tailsitter Drone "Quetzal"

As noted in the Pixhawk article, *"*within each of the main VTOL types, there are many possible variations in motor count, geometry, and flight surfaces*"* Meaning there are several different configurations the team could implement for the tailsitter configuration. The Aerodynamics team elected to implement a biplane layout for several reasons. First, the biplane configuration accommodates a square rotor arrangement, allowing the aircraft to function as a conventional quadcopter in hover, simplifying control during vertical flight, as well as allowing for full control authority using differential thrust. Second, using two lifting surfaces in parallel enables the aircraft to achieve significantly greater total lift without increasing wingspan, thereby maintaining a compact footprint while improving forward-flight efficiency. Third, the symmetric layout with space between the wings provides a convenient location for a fuselage section to contain avionics, onboard computing hardware, and computer-vision payloads. Finally, although the absence of a traditional tail introduces inherent static stability challenges, this was not a limiting factor, but rather an opportunity for the ECE team to develop a robust closed-loop flight-stability and transition-control system capable of actively managing the vehicle's stability. These considerations made the biplane tailsitter configuration the most balanced and strategically advantageous layout for Quetzal.

Since Quetzal is a small biplane UAV with a chord of 12 inches, targeting cruise speeds of 40-65 mph, the corresponding Reynolds number range fell within Re = (3.6-5.9) x 10^5. Airfoils designed for full scale aircraft typically experience early separation and degraded lifts to drag performance below Re = 5x10^5, therefore the design team determined a low Reynolds number airfoil would be optimal for Quetzal's layout. This is consistent with the findings made in "Performance and Testing of a Quad Rotor Biplane Micro Air Vehicle for Multi Role Missions" [ref#] which performed a comprehensive analysis of low Re, moderately cambered airfoils in a QRBP tailsitter configuration. Three candidate airfoils were chosen for comparison, and their aerodynamic characteristics were considered, using X-foil graphs from airfoiltools.com to compare their aerodynamic characteristics at the expected Re range.

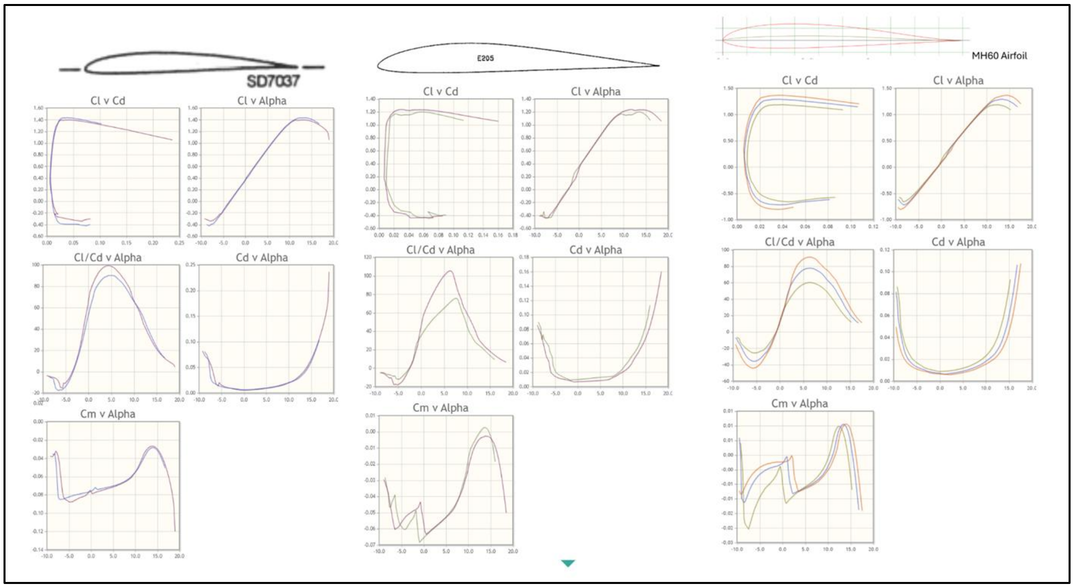


Figure 6: Airfoils Selected for Analysis and Their Corresponding Aerodynamic Characteristics

The airfoils chosen were as follows: The SD7037, commonly used in high-performance RC sailplanes, the Eppler E205, with a thick profile for structural packaging, and the Martin Heppler MH 60, commonly used in UAV and flying wing applications.

Trade Study		Scores (out of 10)		
Design Criteria	Weight (%)	SD7037	E205	MH60
Cl/Cd at Cruise	10%	8	6	9
Drag Bucket	15%	6	7	8
Stall Behavior	15%	7	8	9
Pitching Moment (Cm0)	25%	3	6	10
Linear Lift Range	10%	8	7	9
Thickness / Packaging	10%	6	9	8
Proven Usage	15%	8	6	9
Total Weighted Score	100%	6.1	6.85	9

Design Criteria	SD7037	E205	MH60
Cl at Cruise (α ≈ 0–10°)	0.40-1.30	0.32-1.15	0.10-1.40
Drag bucket (Cd below stall α)	< 0.3, broad/flat, slight uptick at high α	<0.02, less broad starts increasing at α=6	<0.02, broad and rounded for predictable drag
Cl/Cd Peak	100	105	95
Linear Lift Range (deg)	0–10	0–8	0-10
Stall AoA (deg)	12	11	14
Stall Character	Moderate	Smooth	Very smooth
Cm0 (Zero-Lift Moment)	-0.08	-0.05	-0.01
Thickness (%)	9.20%	10.48	10.08
Historical Usage	RC gliders	Eppler low-Re foil	Flying Wings, UAVs

Figure 7: Airfoil Selection Trade Study

A trade study, depicted in figure 7, was conducted to carefully compare the following characteristics of each airfoil: Cl vs α and linear range, Cd at cruising lift coefficients (0.15-0.3), Cl/Cd at cruising lift coefficients, Stall onset, and stall softness, zero lift pitching moment (Cm0) Airfoil thickness, and historical usage.

The lift-curve slope and linear range (Cl vs. α) were examined to ensure predictable lift generation during forward flight and during high angles of attack (AoA) maneuvers expected of a tailsitter. The "Drag Bucket" or the variation of drag at cruise AoA was emphasized because minimizing drag in this range directly improves endurance and reduces the required cruise power. The lift drag ratio (Cl/Cd) was a primary metric for aerodynamic efficiency, with higher values indicating lower power consumption for sustained flight. Stall onset and stall softness were evaluated, with a gentle stall being desirable for a tailsitter that must remain controllable through transition and at high angles of attack. The zero-lift pitching moment (Cm_0) was especially important since the quadrotor biplane setup lacks a horizontal tail and the open loop stability that comes with it – a higher magnitude of Cm_0 directly corresponds to the instability of the aircraft, which is undesirable as it creates more complexity in the closed-loop stability program developed by the engineering team. For these reasons a "benign" (less than -0.1) Cm_0 was desirable. Airfoil thickness was considered both for structural reasons - greater thickness supports spar tubes, servos, and mounting hardware - and for aerodynamic reasons, as thick airfoils may broaden the drag bucket at the expense of peak Cl/Cd. Finally, historical usage and published performance were incorporated; airfoils with extensive use in small UAVs or RC aircraft (such as the SD7037 and MH60) provide confidence in their low-Re performance and manufacturability.

Based on the trade study results and quantitative aerodynamic comparison, the MH60 airfoil was selected as the optimal choice for Quetzal. MH60 achieved the highest weighted score, driven by its broad drag bucket, smooth stall characteristics, and benign pitching moment. Importantly, MH60 was intentionally developed for tailless and flying-wing configurations, with design goals of *"low drag values, small torsion coefficients, and improved maximum lift coefficient"* (Hepperle, 2018). These design features directly support Quetzal's stability and controllability requirements as a tailless biplane tailsitter.

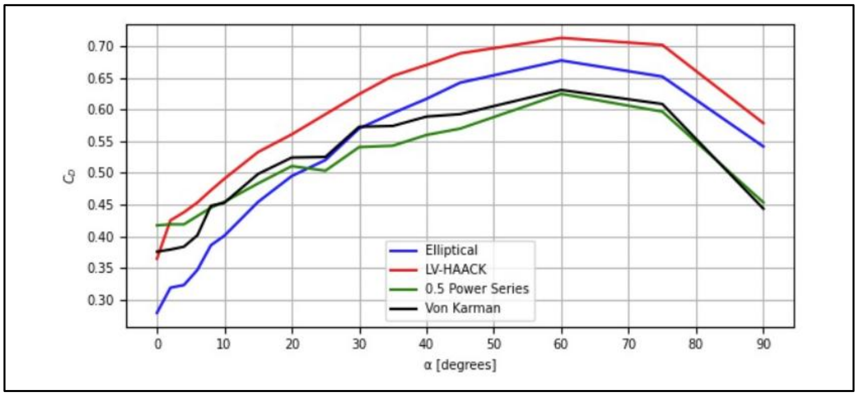


Figure 8: α $(angle\ of\ attack)$ $vs. C_d$

The function of the nosecone on the drone is twofold. Firstly, it provides protection for the fragile electronics housed inside, but it also functions to improve the aerodynamics of the drone, reducing drag and improving the L/D ratio at typical flight angles. Considering that the aerodynamic will come into play when the drone is in horizontal flight, at low Mach numbers, designs were considered that minimized the drag coefficient and maximized the L/D ratio at low angles of attack (0-20 degrees). To find the best shape for a cowl, studies were done on the subsonic flight of rocket nose cones, focusing on the Elliptical, 0.5 Power series, LV-HAACK series, and the Von Karman since their performance lines up best with our goal. An elliptical shape was settled on after studying the "*Descriptive Geometry of Nodes and Cones"1996, by Gary A. Crowell Sr*., which says "In strictly subsonic model rockets, a short, blunt, smooth elliptical shape is usually best." Also, the elliptical cone has the least drag out of the chosen options, from 0° to 20° angle of attack, which can be seen in figure above.

Even though the main shape of the nosecone is conical, adjustments had to be made to the base since the baseplate that it mounts on is a square. To solve this and allow construction, a simple lofted (square to circle) base was modeled in SolidWorks, with the inside remaining hollow to reduce weight and leave room for the electronics. Since then, the design has remained the same, besides the addition of ventilation holes on the top and sides to cool the interior. The cowling was 3D printed using standard ABS filament and was mounted to the base using a low-tolerance friction fit for testing, but this might be adjusted to use screws or magnets for the competition.

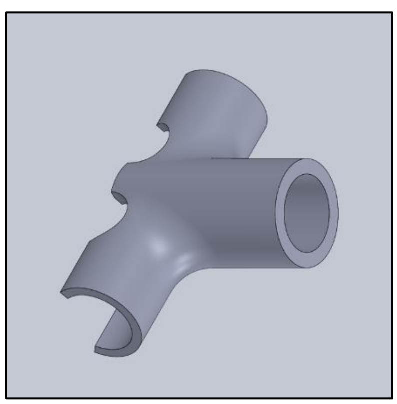


Figure 9: The t-connection piece used to hold the airframe together, rendered in SolidWorks.

The carbon fiber tubes were connected with each other with snapping t-connection pieces, allowing for easy and modular assembly and disassembly. The connection pieces were designed using SolidWorks, a computer aided design tool, and were optimized for their strength, and flexibility to absorb changes in directional forces. The t-connection pieces were 3D printed in carbon fiber. During the fabrication process, resin a strong glue-like substance, and carbon tow, a strong carbon fiber rope, were used to bind them securely to the carbon fiber airframe. An image showing the connection pieces provided below.

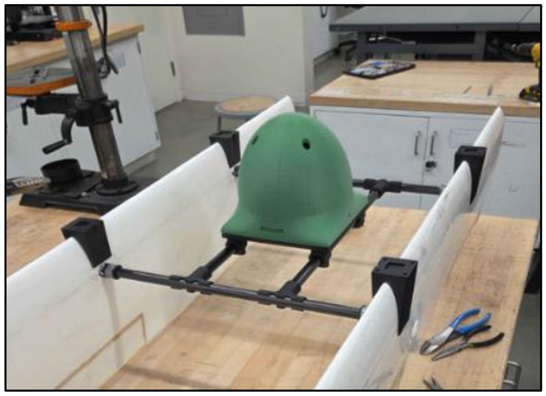


Figure 10: The airframe connected to the airfoils, with the 3D printed t-connections visible.

The aircraft size was dependent on a certain list of factors, the main center baseplate must have been able to fit the electrical and computational components needed for flight, along with future modules for autonomous flight, as well as a future mechanism to retrieve and deposit payloads. The wing sizes needed to be able to lift the baseplate and its components, as well as a nose cone and the airframe. The distances between the airfoils were dependent on the chord length of the airfoils themselves and must separate by a minimum distance so the aerodynamic forces would not interact with each other. The baseplate size was designed to be 8 inches by 8 inches, allowing for room for the largest components as well as room for future components. This size was reasonable and like drones of similar capabilities. To lift this as well as the carbon fiber airframe, a long set of wings was needed. The chord length, the length from the front of the wing (the leading edge) to the back tip of the wing (the trailing edge), was manufactured to be 12 inches. We determined for the most optimal lift generation and maneuverability at low speeds, the aspect ratio of each wing, the ratio between the length and width (span) of the wings should be 4. This made each set of wings be 4 feet in length. The minimum separation between each wing was determined to be 150% of the length of the chord length, so from wing to wing, the airframes extended to be 18 inches. These principles determined the final sizing of our aircraft to be a 12”x4”’x18” boxlike structure.

Motor		Trade Study					
Design Criteria	Weight (%)	U5 KV400		MN3510 KV700		EMAX KV470	
Cost	30	10	$0	10	$0	10	$0
Thrust	40	3	2.85kg	2	2.2kg	1	1.32kg
MTBF	5	7	1600h	4	1000h	4	1000h
Weight	15	6	195g	8	118g	8	93g
Power Requirement	5	6	850W	8	555W	9	192.4W
Current	5	7	30A	8	25A	9	13A
Totals	100	61		60		57	

Figure 11: Motor Trade Study Results

The propulsion system for the Quetzal VTOL tail-sitter biplane was selected through a inventory constrained trade study emphasizing operational reliability and cost minimization. The design had to balance the conflicting demands that operation in both vertical and horizontal flight presents, which called for high static thrust for stable vertical operations and high aerodynamic efficiency for fixed-wing cruise. Our goal was to get a thrust-to-weight ratio of 2.0 so that there was a significant safety margin for vertical flight. However, given the need to leverage existing components to save time and money, the design criteria highly weighted thrust performance (40%) and the use of inventory (30%), which is displayed in the trade study matrixes in figures 11. The matrix concluded with the selection of the T-motor U5 KV400 motor. Though it incurred penalties for greater mass and power consumption due to its rivals, the U-5 KV-400 secured the highest overall score of 61 points due to its essential performance attributes. Its superior 2.85 kg maximum thrust was crucial for meeting the minimum required thrust-to-weight ratio, guaranteeing safety and control authority during vertical flight. Furthermore, its high-quality construction provided outstanding reliability, highlighted by a 1600-hour MTBF. This selection confirmed the strategic decision to prioritize maximum thrust and reliability, thereby absorbing moderate efficiency trade-offs to capitalize on the substantial cost and schedule benefits of using existing inventory. To integrate the low KVU5 motor, the team utilized the T-Motor NS15x5 (15-inch diameter, 5-inch pitch) carbon fiber fixed pitch propeller, chosen to achieve the necessary balance between static lifting thrust and the required pitch speed for 40 to 65 mph cruise. The system was finalized with the electronic speed controller (ESC), which provided a critical 30-amp current to manage the motors peak power demands during vertical takeoff. The empirical flight data successfully validated the design compromise: the power required to maintain static cover was the same power input that accelerated the aircraft to 26.6 mph in forward flight. Future design efforts are already being made to add more optimized aerodynamic control surfaces, such as ailerons and elevons, to refine control authority. This approach will shift the burden of attitude control from the differential thrust of the motors to the airframe, allowing the propulsion system to operate closer to its maximum electrical efficiency point during forward flight.

IV. Final Design

The final configuration of the Quetzal unmanned aerial system represents the outcome of an iterative design process guided by aerodynamic analysis, mechanical considerations, electrical requirements, and the mission structure of the California Unmanned Aerial Systems Competition. The design team selected a quad rotor biplane tailsitter layout that satisfies both the constraints of the competition and the functional requirements of vertical takeoff, efficient forward flight, and autonomous navigation.

The airframe is built around a carbon fiber structural skeleton composed of pultruded circular tubes connected using custom printed joint pieces. These joints were designed in SolidWorks and printed using carbon fiber reinforced polymer to provide strength with minimal mass. Each joint snaps onto the tubes and is bonded with resin and carbon tow to increase stiffness while still allowing modular replacement. The resulting frame is lightweight, rigid, and capable of supporting vertical landing loads as well as aerodynamic loads during forward flight. A central baseplate measuring 8 inches by 8 inches houses the electrical and computational components including the flight controller, power distribution board, GPS module, companion computer, and associated wiring. The size of this baseplate was chosen to ensure that the aircraft can support current onboard systems while allowing room for additional payloads needed for package delivery and recovery missions. The wings were fabricated using an expanded polystyrene foam core cut with a hot wire machine, followed by a layer of fiberglass cloth and resin. Each wing has a chord length of 12 inches and a span of 4 feet which yields an aspect ratio of 4. This geometric arrangement was determined from aerodynamic studies of low Reynolds number flight where predictable lift and low drag are required for efficient cruising. The two wings are spaced 18 inches apart. This spacing prevents aerodynamic interference between the lifting surfaces and preserves their individual performance. The chosen airfoil for the wings is the MH60. The selection was based on a trade study comparing three candidate airfoils commonly used in small unmanned aerial vehicles. The MH60 provides a favorable combination of low drag, predictable stall, and a very small pitching moment at zero lift. These characteristics are ideal for a tailless aircraft which relies entirely on motor differential thrust and small trailing edge control surfaces for pitch and roll stability. The nose cone serves two important functions. It protects electronics onboard while also improving the aerodynamic efficiency of the vehicle during forward flight. A survey of subsonic nose geometries was conducted to compare drag performance at low Mach number conditions and low angles of attack. An elliptical profile was selected after reviewing the analysis shows that a short and smooth elliptical contour minimizes drag for subsonic flow. The cone tapers into a square loft at its base to interface with the square central baseplate. The part was printed using ABS and includes ventilation openings to maintain acceptable internal temperatures.

The propulsion system consists of four brushless motors equipped with 15 inch by 5 inch carbon fiber propellers. The motors are arranged at the corners of the frame in a square pattern which allows the aircraft to function as a conventional quad rotor when in hover. During forward flight, the motors provide both thrust and control authority. The symmetric layout improves controllability and enables differential thrust to be used for roll and pitch stabilization.

The result is a compact, structurally efficient vehicle capable of transitioning between hover and forward flight while carrying sensing payloads and mission equipment. The completed design of Quetzal incorporates aerodynamic, mechanical, and electrical subsystems into a cohesive and reliable platform. It meets the competition's requirements while providing a foundation for continued development in future semesters. The configuration supports autonomous control, package handling modules, and further improvements to stability, endurance, and mission performance.

V. Test Procedures

Quetzal will be competing at the California Unnamed Arial System competition. Therefore, all testing procedures must verify that the drone can perform all selected tests. The interdisciplinary team has determined that the drone will compete in the following missions: Waypoint navigation, Circuit Time Trials, Package Delivery, and Package Recovery.

A method to verify that the concept of a Vertical Takeoff and Landing Tailsitter drone is maneuverable in real world cases the team designated a first flight procedure. The first test procedure verified the drone was able to take off and hover under control of a pilot. The second test procedure verified that the drone can pitch with an angle of 90 degrees, making the drone fly in forward fight configuration The final test verified that the drone could transition back to vertical position and land safely.

For the second version of the Quetzal. Before our drone can compete, we must verify that the unmanned system is able to demonstrate that the drone can take off, perform a simulated breach of a small geofence, and return to land (RTL) safely. The verification for the takeoff procedure will be conducted in an open field where the ground control station (GCS) will relay the takeoff command to the drone. The drone will then proceed to the loiter in place for 30 seconds. This will verify that the drone has received and executed the takeoff command from the GCS. The second procedure will be verified by constructing a small geofence about 15 feet by 15 feet; the drone will be relaying its current location when outside the geofence. Once the message has been received by the GCS, the drone will have an allotted time to return within the boundaries. Finally, the drone must perform the RTL procedure. This requirement will be verified by instructing the drone to autonomously navigate itself to its origin and then land safely. Once the drone has recognized its height to be ground level and the motors throttle to be at 0%, the system shall display a return to land message on the GCS monitor.

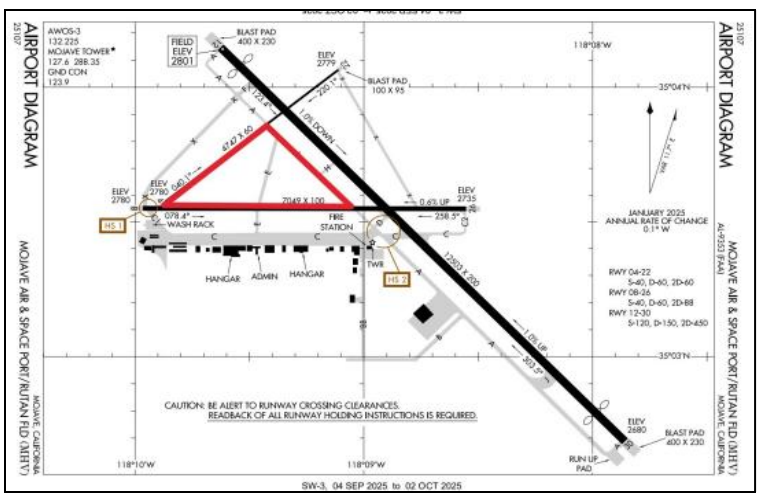
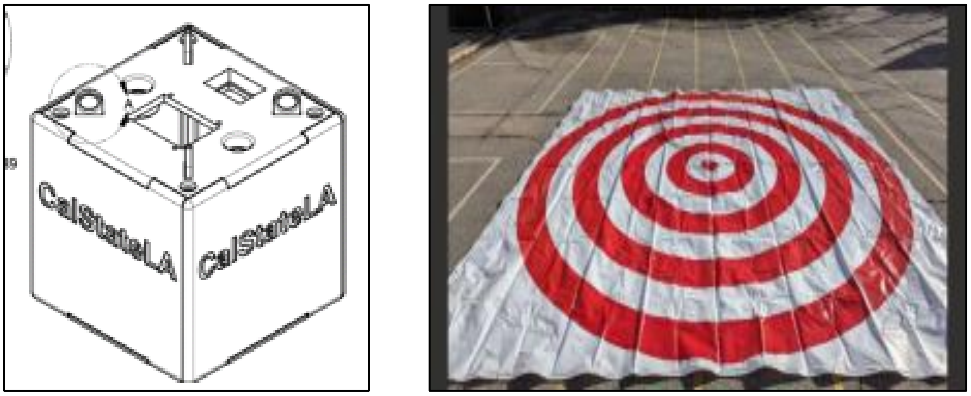


Figure 12: Mojave Airfield Geofence

The Waypoint Navigation mission is defined as a flight within the geofence (figure 12) where the UAS shall fly a path of its own determination passing through each defined waypoint. The drone shall complete the waypoint navigation flight in less than 10 minutes. Therefore, the method of verification for this flight will comprise of three testing procedures. The first testing produce will instruct the drone to fly through all 7 given waypoint locations autonomously. The second test procedure will be verified once the system has an accuracy of being less than 3 feet off each waypoint. The third test procedure will verify that the drone can undergo the flight plan in under 10 minutes. The team will run 5 flights plans and verify the drone's average time is less than 8 minutes. Completing the flight within the allotted 8 minutes will give the team leverage during the actual competition.

The Circuit Time Trial mission is defined as a flight plan like the waypoint navigation mission. The main difference from the prior flight is that the drone shall be able to pass between waypoints rather than through them. The team will have a maximum of three flights, and the competition will keep the fastest flight time. The main test procedure for this flight plan will be that the drone must fly at least 5% faster than its previous flight. This will give the team, in theory, an optimized flight time of at least 10% of its original flight time. The second test procedure will be that the drone passes through each waypoint pair within two meters. The GCS will determine the distance from the drone and waypoints through excel calculations.



A) *B)*

Figure 13: A) Package and B) Identifier

The Package Delivery mission is defined by the drone's ability to deliver a package to a well-marked target (figure 13: B). The drone shall deliver the package (figure 13: A) with an impact of less than 5 g which is approximately 5 $\frac{m}{s^2}$. The drone shall complete the package delivery flight in less than 10 minutes. The first test procedure will verify that the system's grabbing mechanism is able to locate and grab the cube from ground level. The second test procedure will verify that the grabbing mechanism maintains a grip on the cube at speeds near 35 $\frac{m}{s}$. The third test shall be that the system will deliver the package with an accuracy of at least half a meter from the center of the bullseye. Finally with an accelerometer the system shall deliver the payload with a reading of less than 5 g, the team will commit to deliver the payload with an average maximum force of less than 4 g.

A) *B)* *C)*

Figure 14: A) Target Location Identifier, B) Payload Package and C) Compass Rose

The Package Recovery mission is defined by the drone's ability to fly to the package location identifier (figure 14: A), pick up payload and then maneuver to the compass rose (figure 14: C) located within the geofence. The UAS can choose to release the package (figure 14: B) before landing or landing with the package. The package will be placed on a designated marker and will weigh between 1 and 2 kilograms. There will be a total of 4 test procedures to verify that the drone is able to fully complete the flight autonomously. The first test procedure will verify that the drone is able to locate the target location identifier within the given geofence. The second test procedure will verify that the UAS is able to pick up the package autonomously. The third test procedure will verify that the UAS can transport the given payload under forward flight or traditional quadcopter configuration. The final test procedure will verify that the drone is able to locate the center of the compass rose and deliver the package.

VI. Future Improvement

Quetzal is currently configured to be a proof-of-concept drone. The team has designated that the second iteration shall have implemented new features that will satisfy the requirements set forth by the test procedure noted in section five of the document. The following sections shall be installed and upgraded for the second iteration of the drone.

Figure 15: Motors to be used for control surfaces

The second model will include optimized control surfaces located at the trailing edge of the airfoil. The control surface will be attached to the main airfoil with a thinner and lighter Kevlar that will provide a quicker response time when pitching the surfaces up or down. The model will also include an upgrade to the servos, providing a new torque of about 22.8 $kg * cm$ per unit. The increase in torque will allow the flaps to pitch when experiencing higher velocities over the airfoil. The spacing in between the face of the control surface and main airfoil will be increased as well to provide a more efficient hinge point. The greater the space in between the faces the greater pitch angles that can be reached.

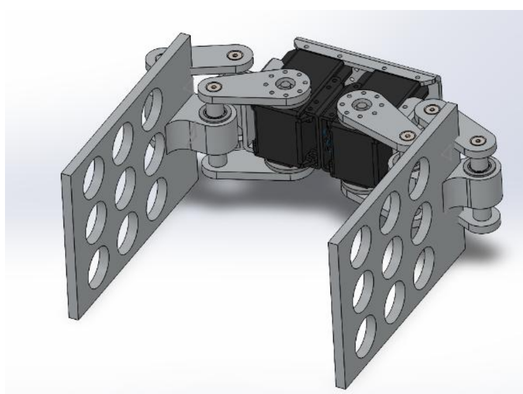


Figure 16: Future rendering of grabbing mechanism

Quetzal will also retrieve and hold a designated payload for the competition. This installation will satisfy the requirements set forth in section five of the document. The current design for the grabbing mechanism will be comprised of a clamp that is controlled via the software loaded into the drone motherboard. The clamping force will be imposed by a pair of servos that can provide about 45 kg *cm of torque per unit. The increase in torque needed by the servos is due to the clamping strength needed on the payloads during forward flights at high velocities.

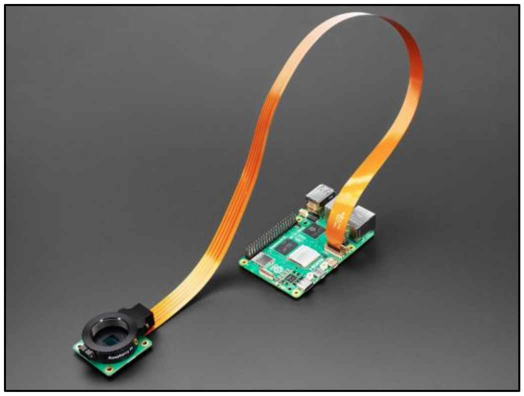


Figure 17: Raspberry Pi 5 FPC Camera Cable

For the team to be eligible for the competition the drone must be able to recognize spots of delivery and pick marked on the floor. Quetzal version two will have two raspberry pi cameras mounted at the tip of the nose cone and at the base located near the latching mechanism. This feature will satisfy the requirement referenced in section five regarding payload pick up and package delivery.

VII. Data Analysis

A successful series of proof of flight was performed, firstly, a vertical loiter was verified, proving that the aircraft was in fact capable of sufficient motor thrust to lift off the ground. Afterwards, the aircraft was taken to a nearby park and a flight plan that created to evaluate the efficiency of our aircraft in horizontal flight. The flight would begin with a vertical take-off, followed by a pitch downwards and transition into a horizontal configuration, then a horizontal cruise, and another transition to vertical for a landing. This flight was successfully performed, and the throttle pitch angle, and airspeed were logged by the aircraft's internal sensors and computer.

For transition into horizontal flight, the only active mechanism was throttle vectoring, as during our early test flights, we did not have our control surfaces activated, due to software being very early in iteration, as well as the motors for the control rods being too weak, due to a manufacturing oversight, where the material that holds the control surfaces to the wing was too strong. With more advanced and integrated software, and with wiser wing fabrication techniques, these issues can be overcome and the transition from horizontal to vertical flight will use control surfaces as well as thrust vectoring.

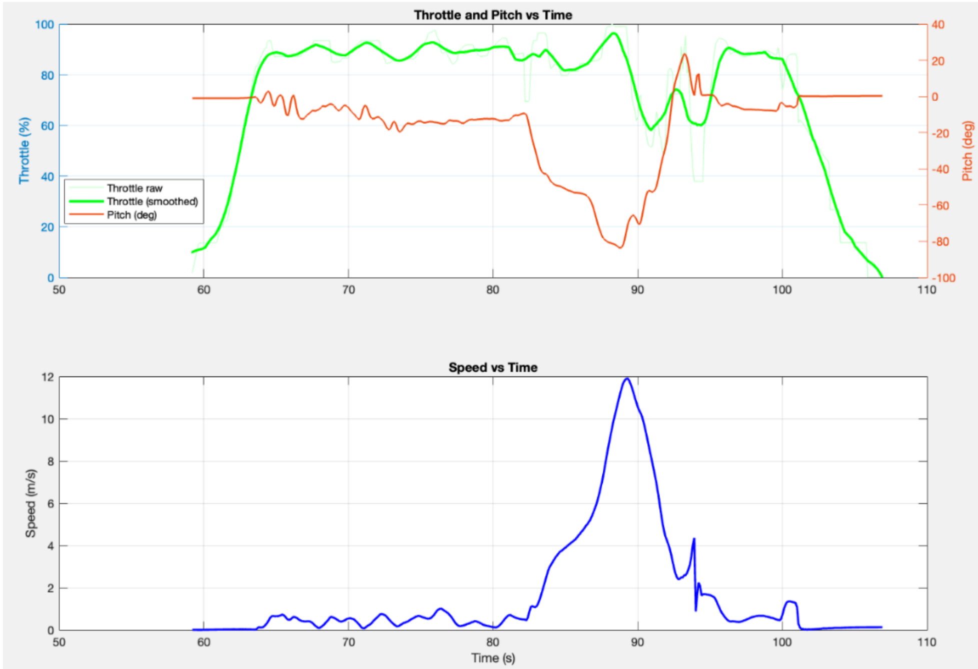


Figure 17: Throttle percent, pitch, and air speed versus time during test flight

From the data recorded in the test flight, the most useful information extracted would be throttle percentage, speed, and pitch. Pitch to verify the aircraft was in fact in a horizontal configuration, throttle to see if any electrical and work savings from the motors could be observed, and airspeed to see if there is a reduction or addition to speed during the horizontal flight duration. From the graph in Figure 5, the pitch towards horizontal flight is visible as the red line, and goes to a maximum of 85.7 degrees, meaning the aircraft is in a perfectly flat configuration, with the wings providing their maximum amount of lift. The green line, throttle, levels out during the entire flight, thus providing the team with information that horizontal and vertical take-off use the same amount of power to the motors. This alone would not verify efficiency except for the data collected for air speed. The lower graph shows a sharp increase in speed. The blue line which shows the speed peaks during horizontal flight and reaches a maximum speed of 26.6 miles per hour. The speed graph shows the total magnitude of the drone's velocity, being the horizontal and vertical flight speed. With preliminary software, horizontal and vertical speed were not individually recorded, but this data is sufficient to confirm that horizontal flight is more efficient because pitch angle was simultaneously recorded. This increase in speed during horizontal flight verifies that our aircraft is more efficient than a standard quadcopter drone configuration and is an improvement in innovation. For a future test flight, from this data a hypothetical increase in speed is viable, along with a longer duration flight. The increase in duration of horizontal flights will increase the power savings from the motors.

VIII. Conclusion

Quetzal was designed, fabricated and flight tested to satisfy the proof of concept the team wanted to verify before installing all additional modular units for autonomous flight. The tailsitter configuration, combined with the biplane wing layout, provided high speed when traveling in forward flights, a goal set forth by the team in preliminary designing.

The initial flight successfully demonstrated vertical takeoff, hover, transition to forward flight and return to landing maneuvers. Results provided by the drone's software confirmed higher velocity when configured to forward flight. These results validate the viability of the quad rotor biplane tailsitter configuration as a competitive design for the waypoint navigation, circuit time trails, and payload missions that are outlined within the C-UASC rulebook.

The Quetzal VTOL Tailsitter Drone is a proof-of-concept platform at its current state, and several upgrades have been identified for next semester. The team will upgrade key features on the drone, leading to a high chance of winning first place in the flight competition and the innovative design. Additional testing will focus on fully autonomous execution of competition flight missions and further improvement of closed loop flight control algorithms to improve stability, endurance and mission accuracy.