Overview of Bell X-1 Inspired RC Aircraft: USC's Submission for Design Build Fly

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The Bell X-1, a rocket-propelled aircraft developed in 1944, played a crucial role in the advancement of supersonic flight. Launched from the belly of a Boeing B-29 Superfortress, the Bell X-1 became the first aircraft to break the sound barrier, marking a pivotal moment in aviation history. In the 2025 AIAA Design Build Fly competition, teams are challenged to simulate this iconic aircraft and its launch platform. This paper presents a detailed overview of the University of South Carolina's submission to the competition, providing insight into the team's approach to administrative organization, design considerations, and overall aircraft development. The paper explores the key systems engineered for the aircraft, including propulsion, flight control, and glider systems, as well as the integration of these systems for competition missions. In addition to the design aspects, the paper highlights the use of advanced materials and manufacturing techniques that were incorporated into the project. The team employed composite materials, such as carbon fiber reinforced polymers, and additive manufacturing methods were utilized to fabricate complex geometries. Finally, the paper outlines the verification and testing procedures employed to qualify the aircraft. This includes the use of Computational Fluid Dynamics (CFD) and Finite Element Analysis (FEA) simulations to predict aerodynamic behavior and structural integrity. Additionally, the team conducted component-level load testing to ensure reliability and safety. Full-scale test flights were carried out to replicate scenarios described by the competition. Through these testing methods, the team ensured that the aircraft would meet all competition requirements and perform reliably under considered conditions. This project demonstrates the application of modern engineering techniques to legacy aircraft in the design and construction of this representative X-1 and B-29.

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I. Introduction

This report details the design process for a radio-controlled airplane and autonomous glider created by the University of South Carolina for the AIAA Design/Build/Fly 2024-25 competition. The aircraft and X-1 themed glider will be constructed according to the competition rules, performing three flight missions inspired by the X-1 supersonic flight program. The project is divided into sub-teams, each responsible for specific systems of the airplane and glider. A roadmap for detailed design, manufacturing, and testing was established to ensure consistent progress throughout the project. sensitivity study identified key design parameters that significantly impact the final competition score. The study's results set goals for critical missions. Preliminary designs for the airplane and glider, along with manufacturing and testing plans, were developed in the first four sections of this report, highlighting the state-of-the-art facilities at the University of South Carolina. During the detailed design phase, the focus shifted to creating the lightest possible airframe to maximize payload capacity for mission 2. This was achieved by using carbon fiber reinforced thermoplastic and thermosets for all load-bearing airframe structures, ensuring both strength and lightness. The composites research at USC enabled the development of a composite airframe that meets competition standards.

The glider design underwent significant revisions, reducing drag and improving flight predictability by referencing research on similar gliders. The final design prioritized ease of manufacturing and assembly, ensuring that the flight control and propulsion systems fit into the airframe and could be adjusted for optimal weight and balance. Motor selection influenced several design decisions, prioritizing thrust to enhance aircraft speed for the missions. The aircraft, shown in its mission 2/3 configuration with the glider and payload, is illustrated in Fig. 1.

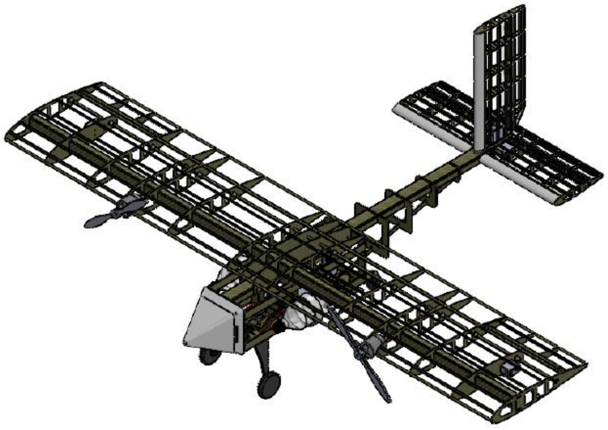

Fig. 1 Detailed CAD Model

II. Management Summary

This section provides an overview of the team organization, project schedule, and budget for the DBF team at the University of South Carolina. The team, composed of 32 undergraduate and graduate students primarily from aerospace and mechanical engineering disciplines, has worked to design and build an aircraft for the fly-off competition. The section outlines the structure of the team, the timeline of project milestones, and the funding sources supporting the initiative. Despite some setbacks, including delays in the design phase and funding adjustments, the team is on track to complete a flight-capable aircraft for the competition, with valuable lessons learned for future endeavors.

A. Team organization

The DBF roster at the University of South Carolina consists of 32 undergraduate and graduate students, primarily from aerospace and mechanical engineering disciplines. This is the first DBF team formed at USC since 2017, with the goal of being the first to complete a flight mission at the fly-off. Fig. 2 presents the organizational structure. A project manager and three lead engineers oversee three design teams: aerodynamics, structures, and electronics. The lead engineering team also handles glider design, manufacturing, and testing. Faculty and industry advisors offer expertise as needed.

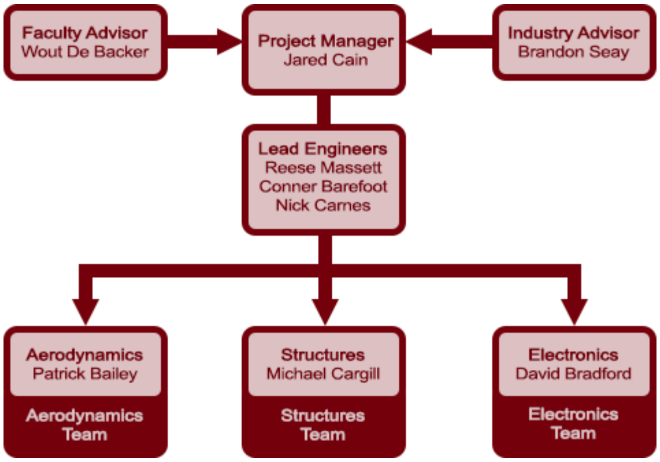

Fig. 2 Organizational Structure

B. Timeline and Funding

The project roadmap was initially created to track progress, with weekly meetings to review accomplishments and plans. However, the schedule proved overly optimistic, leading to delays, particularly during the design phase. The glider's initial design issues also limited prototyping and testing. Despite being behind schedule, the team is now in the manufacturing phase and expects to have a flight-capable aircraft ready for the competition.

Funding comes from donations, student government, and student clubs, with corporate outreach for additional support. Travel expenses will be covered by the club, and components will be funded mainly through the student government. Initially, four team members were set to attend the fly-off, but surplus funds may allow for more students to attend, providing valuable experience. Despite a reduction in student government funding, the team remains confident the project will be completed within budget, with support from university facilities and materials.

III. Conceptual Design

The design process began with a thorough analysis of the rules and mission scoring, as outlined in Table 3. This analysis focused on how the mission requirements would influence the sub-system requirements in the design, with particular attention to the most impactful factors

C. Sensitivity Study

After the initial mission score analysis, a sensitivity study was conducted in MATLAB to determine which missions most affect the final score. Further investigations focused on missions 2 and 3, as mission 1 was a pass-fail mission and did not require additional analysis. The ground mission was not analyzed further, as skill and ease of assembly were identified as the key design factors.

The study's findings indicated that the final score is most sensitive to mission 3, followed by mission 2. For mission 2, mission time was found to be more sensitive than fuel weight. In mission 3, the number of laps was more critical than X-1 weight. Additionally, bonus points in mission 3 have the greatest impact on the score, with a loss of approximately 0.25 and 0.50 points if the only difference between the maximum team score and the team's score is the 1 or 0-point bonus, instead of the 2.5-point bonus.

D. Design Approach

Following the sensitivity study, mission parameter goals were established based on the results. As mission 2 and mission 3 design parameters are most critical to the final score, targets were set for lap times, laps completed, and payload weights.

For mission 2, the target is a payload of 8 lbs and a total mission time of 180 seconds. For mission 3, the goal is to complete 6 laps and ensure the X-1 glider lands in the maximum bonus zone, without prioritizing a weight goal under 0.55 lbs until a glider design that reliably completes the mission is achieved. The ground mission will undergo extensive practice, including several mock technical inspections, to maximize the chances of meeting the goals for missions 2 and 3, especially since the University of South Carolina has not previously achieved a mission score beyond the technical inspection.

E. Preliminary Designs

The aircraft's initial weight estimates were calculated using reference aircraft from previous DBF reports, with an empty weight of 12 lb and a max takeoff weight of 20 lb, including the fuel payload and X-1 test vehicle. A conventional aircraft configuration was chosen for simplicity, with a rectangular wing for easier manufacturing and twin propellers mounted on a high wing for better ground clearance and to avoid propeller wash. This design aims to improve the glider release and maximize landing accuracy during Mission 3. Payloads are mounted both externally and internally using off-the-shelf water bottles. A Monokote-style film will cover the airframe for aerodynamics.

Missions 2 and 3 require more thrust due to the added weight of the test vehicle and fuel. The propulsion system is designed to meet the higher demands of these missions, which focus on completing laps in the shortest time. A single 39.6 Wh battery is selected to comply with competition rules, providing sufficient power for the dual propellers. The propulsion system includes a motor, ESC, telemetry receiver, propellers, battery, and servos, all optimized for Mission 2 and 3 performance.

IV. Detailed Design

The following sections detail the subsystems of the aircraft: wing/tail, fuselage, propulsion, flight control, and glider. Each section covers the final design parameters and how they integrate with the assembled aircraft.

F. Wing

The wing design process focuses on creating a wing that supports the aircraft's required 2.5 kg load at the wing tips and handles forces from the two electric motors. The first step is ensuring sufficient lift, with a target take-off weight of 27.5 lbs and a design lift coefficient (CL,design) of 0.48 [1]. The wings are designed with a taper ratio of 1 and an unswept rectangular shape for better aerodynamic efficiency at low subsonic speeds. After considering two airfoils, the NACA 2416 was chosen due to its higher lift coefficient, and favorable stability characteristics. The comparison between the aerodynamic characteristics of the NACA 2412 and NACA 2416 can be seen in Fig. 3.

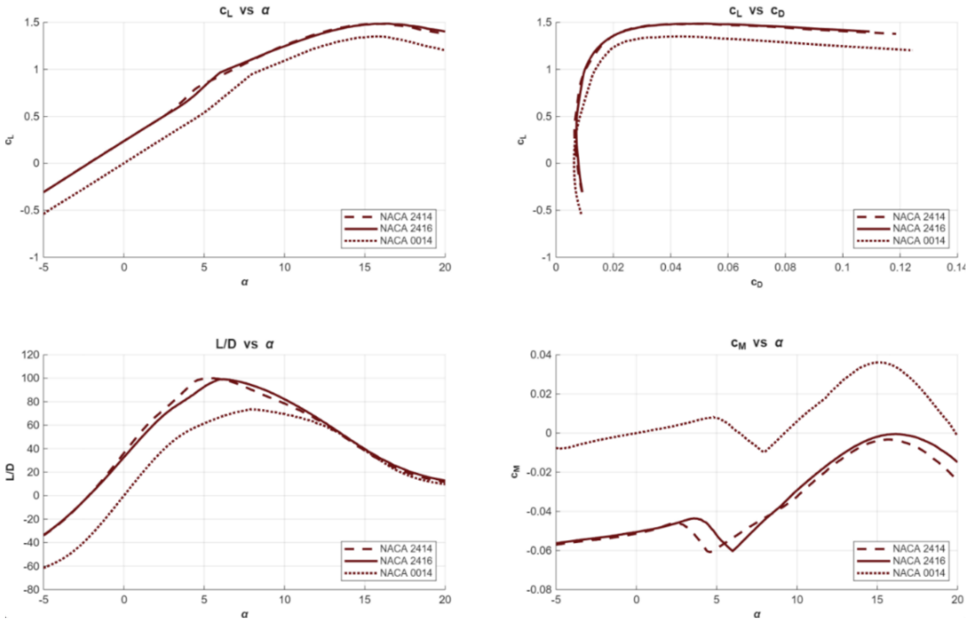

Fig. 3 Plots of C_L, C_D, and C_M vs Angle of Attack

Design checks confirm stability, with the unswept wing's increased aspect ratio of 4.8 contributing to reduced pitch-up tendencies [1]. The cantilever ratio was calculated to be 15, indicating an appropriate structural design for a small RC plane. The next steps include constructing the 3D wing, developing lift curves, and assessing the wing's performance in different flight conditions. The lift curve of the wing can be seen in Fig. 4 [2].

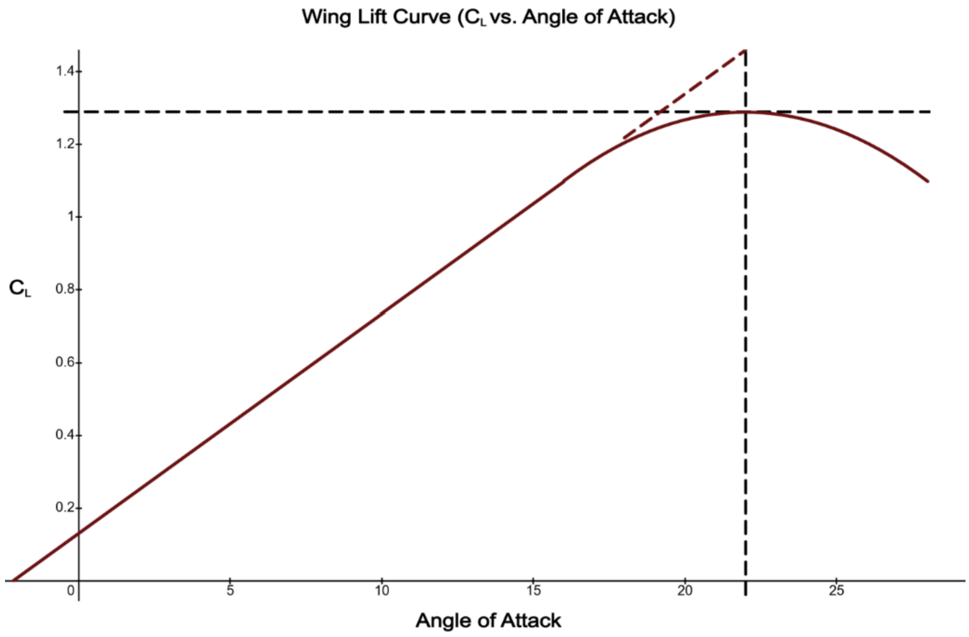

Fig. 4 Lift Curve for the Designed Wing

Key aerodynamic parameters, such as the incidence and stall angles, are calculated. The incidence angle is determined to be 4.3°, and the stall angle is found to be 21.48°. The wing’s aspect ratio of 4.8 satisfies the required conditions for high aspect ratio wings [1].

The wing will be constructed using carbon fiber composites, with motor mounts integrated into the leading edge and clear covering film applied to the surface. A detailed CAD model of the wing can be seen in Fig. 5 and further manufacturing processes are outlined in section VI.

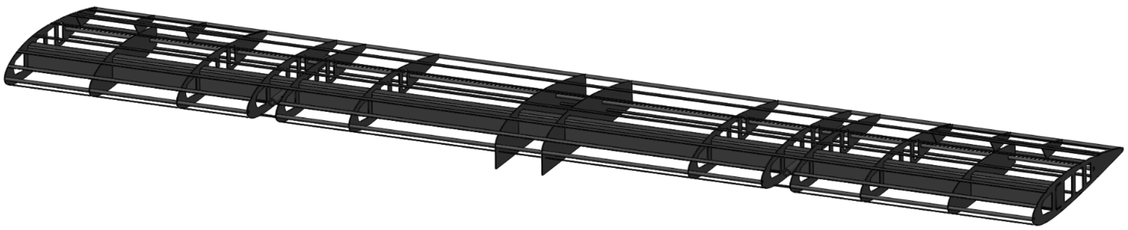

Fig. 5 CAD Model of the Wing

G. Tail

The aircraft will feature both horizontal and vertical tail surfaces, with their sizing verified using Raymer's method and volume coefficients [1]. The horizontal tail volume coefficient and vertical tail volume coefficient are calculated using specific equations, with reference aircraft data providing average values of VH = 0.7 and VV = 0.075. The vertical tail surface area is estimated at 90 in^2, and its moment arm is calculated to be 64.8 inches. Similarly, the horizontal tail surface area is estimated at 180 in^2, and its moment arm is 31.5 inches.

The vertical stabilizer's height is found to be too short, prompting a plan to increase it for the final design. The tail is positioned in-plane with the main wing, avoiding the wing wake during high-angle stalls, which is beneficial for subsonic flight, seen in Fig. 6 [1].

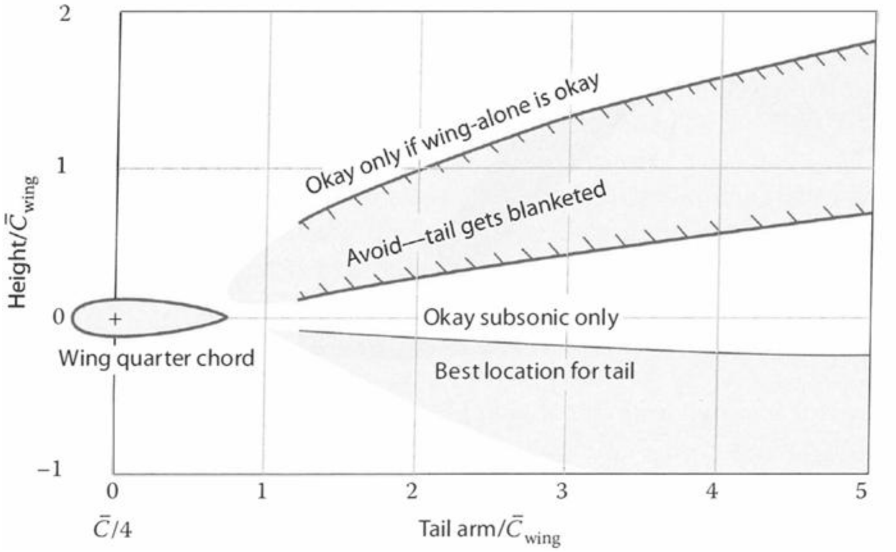

Fig. 6 Aft Tail Positioning [1]

The tail design, constructed from carbon fiber composites, includes a rudder and elevator spanning the full surface area of both stabilizers. The leading edges of the tail will be 3D-printed, and the tail is located 33 inches from the main wing. The CAD Model for the tail can be seen in Fig. 7.

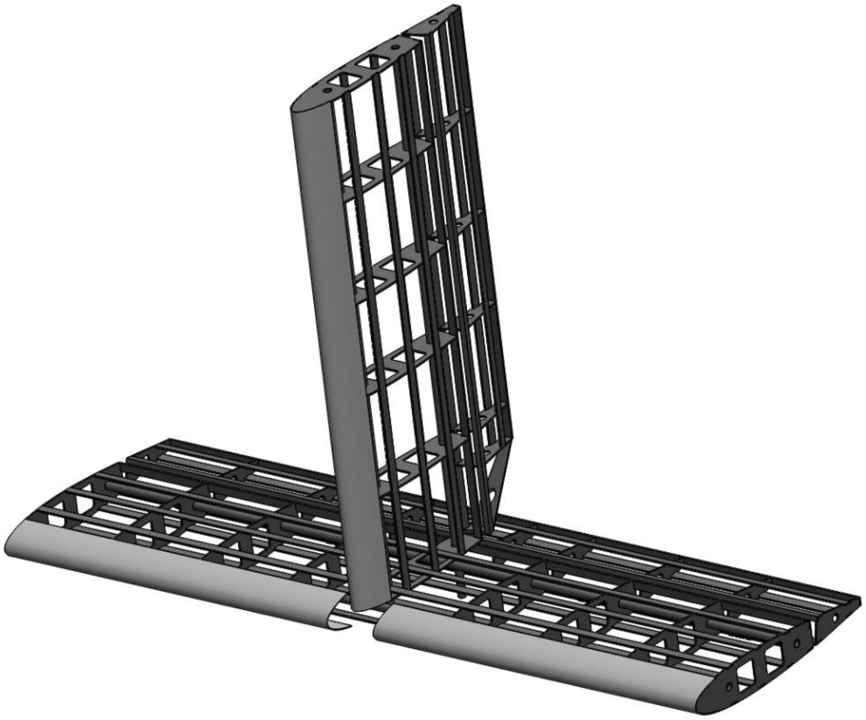

Fig. 7 Tail CAD Model

H. Fuselage

The fuselage is designed to accommodate electrical components and support various configurations of payloads, with a simple rectangular section that tapers to the tail and a pointed nose cone serving as the access door. The design includes a spar running along the fuselage's length, supported by bulkheads and stringers to facilitate the application of Monokote film. The fuselage also supports a taildragger landing gear configuration and houses one interior water bottle payload, with two exterior payloads. The interior payload is used for weight and balance optimization for efficient flight during Missions 2 and 3. The fuselage incorporates a C- Channel spine that serves as the mating surface for the wing and empennage assemblies, ensuring structural integrity by transferring loads through the strongest components of the design. The CAD design for the fuselage can be seen in Fig. 8.

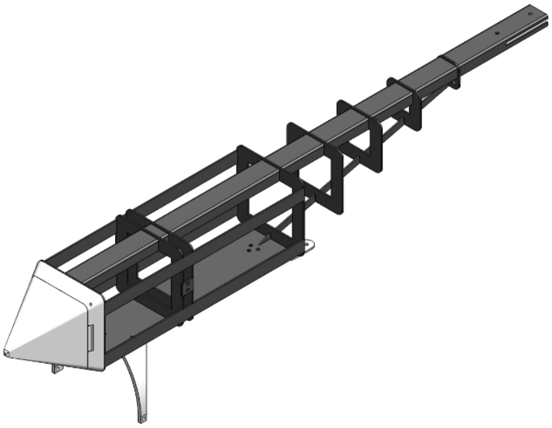

Fig. 8 Fuselage CAD Model

I. Electrical

The aircraft's propulsion system includes two E-flite Power 60 Brushless Outrunner motors for optimal power and efficiency, paired with a 22.2V 1800mAh 6S 50C Smart G2 LiPo battery to provide the necessary thrust while staying within competition energy limits. A 12x8 propeller balances takeoff power and cruise efficiency. The Avian 80-Amp Brushless Smart ESC ensures reliable performance with telemetry and active cooling.

For control, the DX6 G3 Transmitter and AR637T DSMX Receiver provide precise handling, with built-in stabilization for smooth flight. Spektrum S6020 servos actuate the ailerons, elevator, and rudder, which are sized for stable control. The glider release uses a servo-less mechanism with a pull-tab to activate the glider's light circuit during the third mission.

A fail-safe mode ensures safe operation in case of communication loss. The ailerons may also function as flaperons during landing to assist in speed control. All components are chosen to maximize performance, stability, and ease of operation for the competition. The electrical schematic for the aircraft can be seen in Fig. 9.

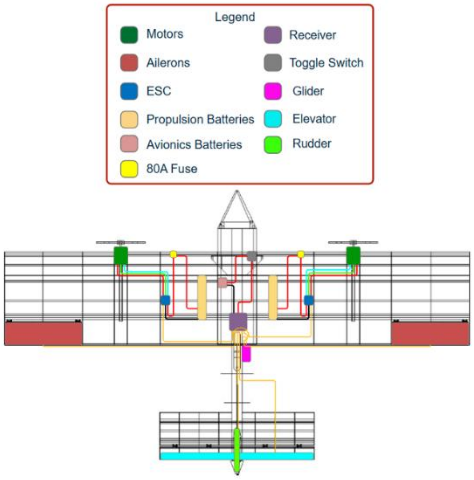

Fig. 9 Aircraft Wiring Schematic

J. Glider

The glider design underwent significant changes from the preliminary to detailed design phase. Initial prototypes revealed that the designs were too thick, resulting in excess drag and instability at cruise speed. As a result, the design was simplified to a basic "paper airplane" shape, see Fig. 10, with the electronics placed on the underside of the wing. Research on the aerodynamics of paper airplanes validated this new design approach, showing that the glider would perform well under the competition conditions [3].

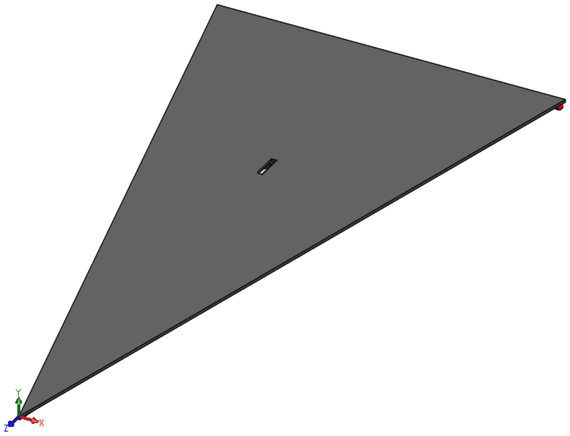

Fig. 10 Glider CAD Model

The glider features flashing red and green lights powered by a simple electrical circuit attached to the underside. A pull-tab release mechanism will detach the glider from the main craft. The glider’s structure is made from carbon fiber composite with a low ply count for weight reduction, and its weight is well below the required 0.55 pounds. Weight distribution remains a key focus for testing.

Concerns about the brightness of the LED lights have led to the exploration of multiple variants to ensure visibility at a distance of over 100 feet, especially under varying weather conditions. The glider's aerodynamic design includes a casing over the circuit and light to induce a spiraling descent to meet mission requirements. The anticipated drop zone and trajectory are also being considered in the final design.

V.Manufacturing

The airframe will be constructed using carbon fiber reinforced polymer (CFRP) for key structural components, such as fuselage bulkheads, wing ribs, the wing spar, and supports running along the fuselage. Glass fiber reinforced polymer (GFRP) will be used for the landing gear to provide better damping during rough landings. A Monokote style film will cover the wing and fuselage, while the nose will be 3D printed using PLA or TPU. The glider will be made entirely from CFRP, with rapid prototyping to achieve a consistent design.

The lightweight design, coupled with CFRP’s strength, enables the aircraft to perform well in mission 2 by reaching higher speeds and in mission 3 by achieving longer flight endurance. The airframe’s structural integrity will withstand aerodynamic forces and handle loads during operation. The flexible glider design minimizes time and cost for part replacement and repair, allowing for iterative design improvements.

Fig. 11 Ingersoll Lynx AFP Machine

The manufacturing process includes Automated Fiber Placement (AFP) using the Ingersoll Machine Tools "Lynx" AFP machine, Fig. 11, where flat panels are produced and consolidated in an autoclave, to ensure strong and lightweight parts. The panels are then water jet cut into final shapes. For the C-spars, hand lay-up techniques are used with custom tooling to maintain precise geometry, seen in Fig. 13. Final assembly will involve integrating the electronics and flight control systems, followed by testing to identify weak spots for reinforcement.

Fig. 12 AFP Panels Undergoing Consolidation via Autoclave

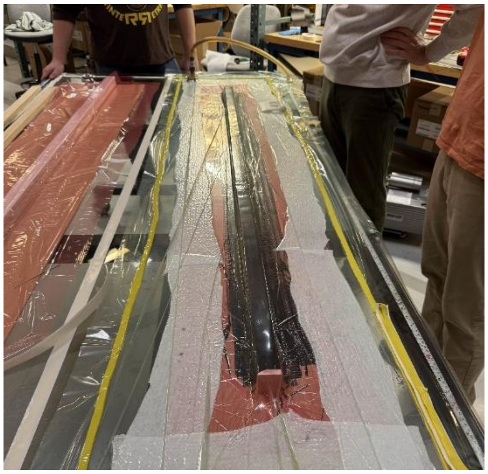

Fig. 13 C-Spars After Hand Layup

The manufacturing flow, leveraging advanced techniques like AFP and autoclaving, ensures high-performance composite parts. Testing and final assembly will focus on achieving an optimized and reliable aircraft ready for flight. Collaboration with an industry advisor will help maximize material efficiency and manufacturing quality.

VI.Testing Plan

A comprehensive testing plan will be implemented during and after the manufacturing process, both on the ground and in the air, to verify the results of CFD and FEA simulations and ensure the aircraft meets the requirements for the fly-off missions. The focus will be on confirming the aircraft is ready for technical inspection, with mock technical inspections conducted before flight testing. Key tests include wing tip load testing, drop testing for the landing gear, and flight control and flight testing.

Wing load testing will be prioritized as it is critical for ensuring participation in the fly-off missions. A test rig will be constructed to support both wing tips while a 2.5g load is applied from the fuselage, likely from the landing gear connection or glider attachment point. This test will also be used to experimentally determine the center of gravity location, which must be marked on the vehicle for technical inspection.

After passing the necessary technical tests, the aircraft will proceed to mission testing. This phase will focus on preparing for the ground mission and ensuring proficiency in the staging phase, with repetition until the staging can be completed within the required 5-minute window. Following that, flight testing will begin to verify the aircraft's ability to fly and land. Test flights will also focus on analyzing the glider's flight pattern after release and adjusting its aerodynamic surfaces.

At the time of reporting, flight control and thrust testing have been completed, confirming the motors can produce the required thrust for mission speeds. Deep cycle battery testing has also started to ensure battery health and longevity over multiple charge cycles. Drop tests will be conducted to assess the landing gear's durability and resistance to rough landings. These tests will determine if further design modifications to the landing gear are needed. Each flight will be logged for performance tracking, documenting any inconsistencies and changes in performance due to various factors such as battery cycles or airframe impacts.

VII.Conclusion

At the time of publication, the project is still in the manufacturing phase, with component-level testing completed for the propulsion and flight control systems. No test flights have been conducted yet, but predictions will be compared to actual results as flight data is collected.

Fig. 14Fig. 12Fig. 14 shows all in-house parts, including water jet components and the two spars made through hand layup by the DBF team at USC. With all parts now in-house, assembly will begin, followed by flight testing and adjustments to ensure a competitive aircraft for the fly-off in April. Despite being behind other schools at this phase due to a decade-long absence from the competition, the team considers this year a successful first entry for the aerospace engineering undergraduate program at USC and looks forward to presenting the final aircraft to the competition judges in Tucson.

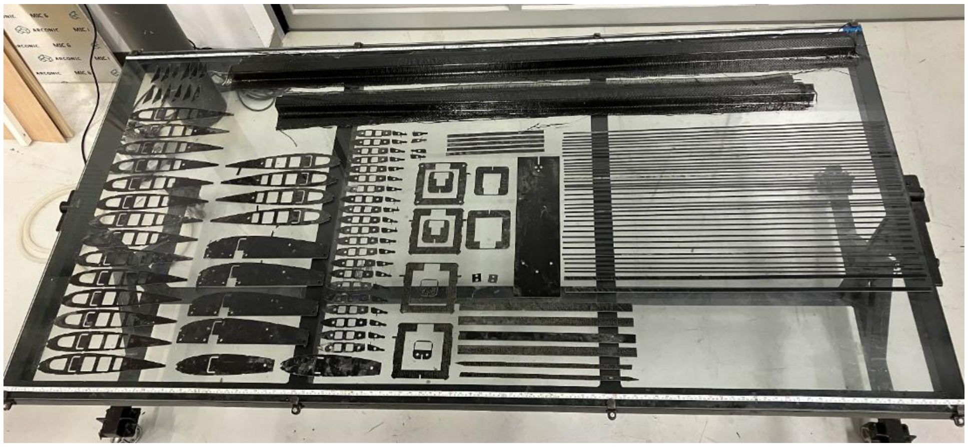

Fig. 14 Waterjet Components Ready for Assembly

Acknowledgments

The USC Design Build Fly team would like to express thanks to the project advisor that generously donated their time and energy to this project, Brandon Seay, whose career experience working with composite materials allowed the team to come this far and have a chance to make it to Tucson.

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