# 1. Executive Summary

This document proposes the design, analysis, manufacturing, and testing processes of the Johns Hopkins Design, Build, Fly team (JHU DBF) in preparation for the 2024/2025 AIAA Design Build Fly Competition. The team aims to manufacture a remote-controlled airplane optimized to complete the design challenge and succeed in this year's missions of maximizing payload weight and speed and engineering an autonomous X-1 test vehicle.

The aircraft will have a 70 inch wingspan and 12 inch chord length (aspect ratio of 5.8) which is mounted on the top of the fuselage. Two 1.5 L bottles and the X-1 test vehicle are mounted under the wing. A lightweight carbon fiber tube will act as the wing spar to support the load. The fuselage is a small streamlined container for the necessary electrical components. Extending from the fuselage is a carbon fiber tube which connects to a conventional tail 60 inches from the propeller. In mission 2, it will cruise with a speed of 100 ft/s while carrying 10 lbs of payload, completing the mission in 90 seconds. For mission 3, the plane will complete 11 laps before releasing the X-1 test vehicle, which is a flying wing made out of foam core weighing 0.25 lb. The team is developing a custom autopilot software to direct its landing into the bonus box. Various cutting, printing, and compositing techniques will be used to manufacture the plane. Finally, the team will conduct rigorous testing of individual components, followed by a sequence of ground and flight tests to validate the plane's structural integrity, control, and propulsion systems. Data from these tests will then be used to inform refinements of the prototypes, ensuring the aircraft performs optimally in competition conditions.

# 2. Management Summary

## *2.1 Team Organization*

The Design, Build, Fly club at Johns Hopkins University is a student-run team with 10 undergraduates and 2 graduate students. A faculty advisor connects members with relevant professionals and organizations in addition to providing administrative and technical advice.

The organization of the team is divided into administrative and technical teams (Figure 1), with administrative members additionally partaking in their respective technical teams. Administrative roles (i.e. president and treasurer) drive organization direction, strategize plans, lead the acquisition of, and manage funds. They are adept at recruitment, budgeting, writing grant proposals, and acquiring sponsorship deals. Technical roles (i.e chief engineer, chief pilot, and sub-team captains) make key technical decisions, provide design feedback, and are responsible for the overall integration of the various components in the aircraft. These roles are skilled at training newer members, communicating, piloting, and have a deep understanding of aerodynamics, flight propulsion, software development, CAD design, and manufacturing processes, and other areas as listed in Table 1.

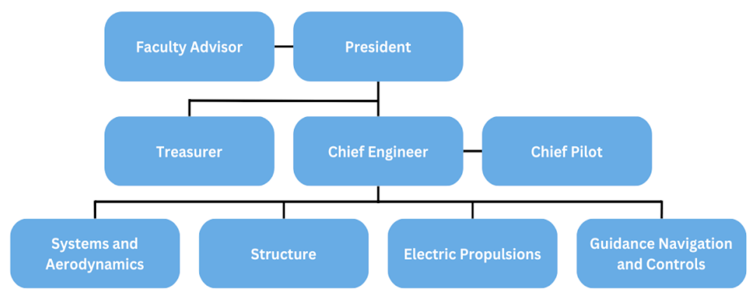


**Figure 1: Team Organizational Chart**

| Subteam | Role | Skill |
|---|---|---|
| System & Aerodynamics | • Perform sensitivity analysis<br>• Decide overall design parameters and sizing<br>• Airfoil selection<br>• Design tail, wing, and control surfaces<br>• Fabricate the wing | • Knowledge of aerodynamics, aircraft stability, aircraft designing process<br>• Knowledge in CFD, AVL or XFLR5 and XFoil |
| Propulsion & Electronics | • Propeller, motor, battery, and ESC selection<br>• Propulsion testing<br>• Develop avionics for remote control and data - logging | • Knowledge in propulsion calculations and electronics, such as ESC and microcomputers |
| Structure | • Design aircraft structure<br>• Material selection<br>• Oversee manufacturing<br>• Perform structural testing | • Proficiency in CAD and structural analysis software (FEA)<br>• Knowledge in material sciences |
| GNC (Guidance, Navigation and Control) for X-1 test vehicle | • Design/implement autopilot for the X-1 test vehicle<br>• Test system in simulation and hardware | • Knowledge in flight dynamics, control systems, guidance algorithms and navigation systems<br>• Proficiency in software development<br>• Knowledge in microcontrollers |

Table 1: Subteams responsibilities and skill set

## 2.2 Schedule

The team's schedule, outlined in Figure 2, is reviewed periodically to update progress on tasks and ensure that deadlines are met. Key milestones primarily relate to test flights, which give the team valuable information about how to refine the initial aircraft design. The deadline for the completion of the first prototype is JHU's Fall Recess, beginning on November 25. After returning from break, subsequent prototypes will be built and tested, aiming to complete the final plane a month before the competition.

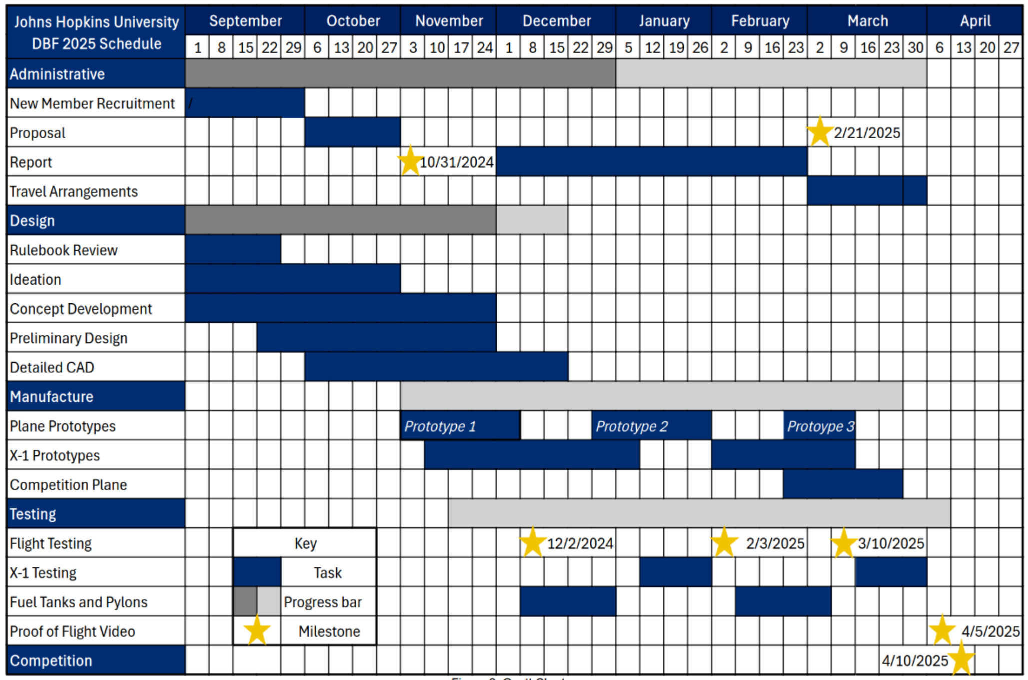

Figure 2: Gantt Chart

## 2.3 Budget

As shown in Table 2, the team's 2024-2025 competition budget is primarily funded by a combination of corporate sponsors and various departments of the university. This year, the team has upscaled the budget significantly, leading to the purchase of all-new sets of tools and materials to accommodate more advanced design and construction requirements. The budget is divided into three main areas: construction and manufacturing, electronics, and travel, with the largest portion allocated for team travel.

| Categories | Allocated | Items | Cost |
|---|---|---|---|
| Construction and Manufacturing | $5,650 | Wood (Balsa, Bass, Ply), Composites (Carbon fiber) | $1,932 |
| | | Landing Gear, Propellers, PLA filament | $175 |
| | | Foam boards, XPS foamcore, Monokote | $486 |
| | | Laser cutting, Milling Machine, Tools, Adhesives | $3,057 |
| Electronics | $1,934 | Motors, ESC, Batteries, Servo Motors | $1,253 |
| | | Receiver, Transmitter, Flight Controller, Sensors | $681 |
| Travel | $9,227 | Flight Tickets (10 members), Car rental | $4,732 |
| | | Hotel (5 nights), Food | $4,495 |
| Total | $16,811 | | $16,811 |

Table 2: 2024-25 Budget

# 3. Conceptual Design Approach

## 3.1 Mission and Sub-System Requirements

This year's four missions include Delivery Flight (M1), Captive Carry Flight (M2), Launch Flight (M3), and Ground Mission (GM). These direct the sub-system requirements of the aircraft. The missions, their requirements, and their impact on the design of the sub-systems are outlined in Table 3. The Total Mission Score is the sum of each individual mission score. The final aircraft must be easily configurable to ensure flight preparations can be done within the 5-minute staging window and to optimize the score of the ground mission. Additionally, the center of gravity must be balanced independently of the payload, so each component must maintain the aircraft's center of gravity. Mission 2 requires the plane to be optimized to maximize the weight of the fuel tanks, encouraging the use of heavier materials in the fuel tanks and adding additional fuel tanks. Mission 3 encourages flying the aircraft in as many

| Mission | Mission Requirements | Scoring | Sub-System Design Requirements |
|---|---|---|---|
| M1 | No payload. Prepare aircraft (install battery packs) within a 5-minute staging window. | 1 | • Balance Cg in no payload configuration. |
| M2 | Payload of X-1 test vehicle and minimum of 2 external fuel tanks. Prepare (battery packs, X-1, fuel tanks) in 5 minutes. Fly 3 laps within a 5-minute flight window. | $1+\frac{\left(\frac{Fuel_{weight}}{time}\right)_{team}}{\left(\frac{Fuel_{weight}}{time}\right)_{max}}$ | • Balance Cg in full payload configuration. <br>• Maximize fuel tanks weight and flight speed. |
| M3 | Payload of X-1 and minimum of 2 external fuel tanks. Prepare (battery packs, X-1, fuel tanks) in 5 minutes. X-1 released at 200 ft altitude. On release, turn 180 degrees and turn on light. Glide to target landing zone. Fly within a 5-minute flight window. | $2+\frac{\left(\#Laps+\frac{BonusBox}{X_{weight}}\right)_{team}}{\left(\#Laps+\frac{BonusBox}{X_{weight}}\right)_{max}}$ | • Balance Cg in semi-full payload configuration. <br>• Minimize X-1 test vehicle weight. <br>• Land X-1 in bonus box landing zone. <br>• Maximize number of laps flown prior to dropping X-1. <br>• Remote release of X-1 test vehicle. |
| GM | Start with no payload. Timed installation of pylons, fuel tanks, and X-1 test vehicle. Aircraft remains grounded. Test-release X-1. | $\frac{time_{min}}{time_{team}}$ | • Minimize time to install payload. <br>• Remote release of X-1 test vehicle. <br>• Ensure payload is configurable when grounded. |

Table 3: Mission Summary

laps as possible before deploying the X-1, so the plane must be optimized for speed. Additionally, since the flight window is limited to 5 minutes, the X-1 must land quickly to allow more flight time before deploying the X-1.

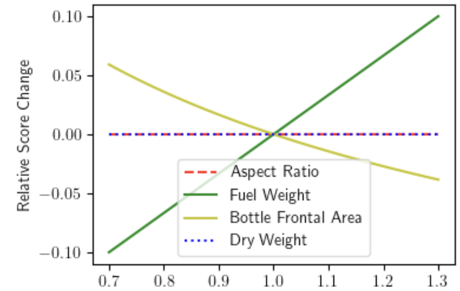

Figure 3: Mission 2 Scoring Sensitivty

### 3.2 Sensitivity Study of Design Parameters

Custom python scripts simulated the performance of the plane from input parameters of wing geometry, weight, payload mass, thrust at range of airspeeds, and drag coefficients of the fuselage and payloads. The script runs iteratively, varying angle of attack or airspeed to find a solution where all forces are balanced. Results were compared with those from MIT AVL, which verified our scripts.

For the sensitivity analysis, the assumed base parameters were 10 lbs for dry weight, 10 lbs for full fuel tank weight, 0.5 lbs for empty fuel tank weight, 0.25 lbs for glider weight, a wing aspect ratio of 6, 45 in$^2$ frontal area, and a $C_d$ of 0.55. Another assumption is that the glider will always go into the 2.5-point bonus box. A base score was calculated with the base parameters, and each parameter was changed one at a time and a new score was simulated with the new parameters. The new score was compared to the base score, as shown in Figures 3 and 4.

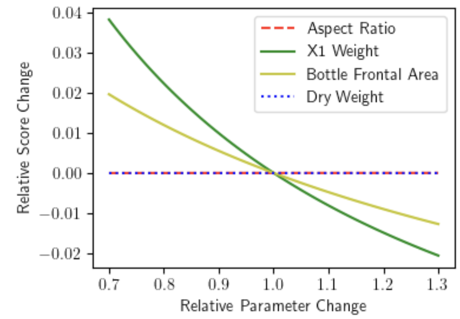

Figure 4: Mission 3 Scoring Sensitivty

As shown in the graphs, dry weight and wing aspect ratio do not change the mission performance of the plane significantly compared to the other parameters. Increasing wing aspect ratio decreases induced drag. Increasing dry weight increases the total weight and requires a higher angle of attack, which also increases the drag. However, in the region of airspeed where the plane operates, the parasitic drag of the fuselage and payload dominates and the effect of such drag is subdominant. The bottle frontal area changes the drag of the plane significantly, as it allows the plane to fly faster. The most significant contributor to mission performance was the fuel weight for mission 2 and glider weight for mission 3.

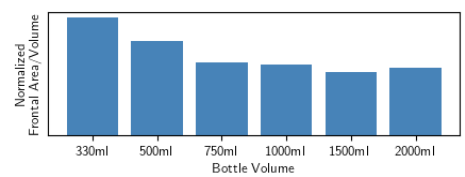

Figure 5: Water bottle frontal area/volume

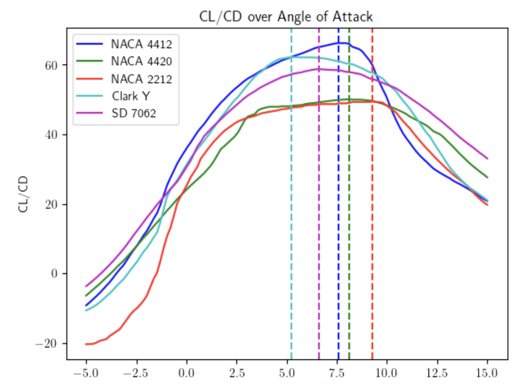

Figure 6: Airfoil Efficiencies

### 3.3 Trade Studies With Results

The team conducted several trade studies to optimize the aircraft design for the competition missions, focusing on maximizing payload capacity and cruise speed. As a relatively inexperienced team, we prioritized reliability through simplicity. We selected a monoplane aircraft configuration with a conventional tail and single motor. Despite a dihedral's stability benefits, we chose a single continuous carbon fiber tube spar for the wing structure to avoid complex joints at the high-stress midpoint.

The sensitivity analysis indicates the importance of reducing the frontal area while increasing the payload weight. Analysis of commercial beverage containers (Figure 5) informed the decision to use 1.5 L bottles for optimal volume-to-frontal-area ratio.

NACA 4412 airfoil was chosen based on its high Cl/Cd over a wide range of angles of attack, high stall angle for a good margin of safety, and progressive stall characteristics.

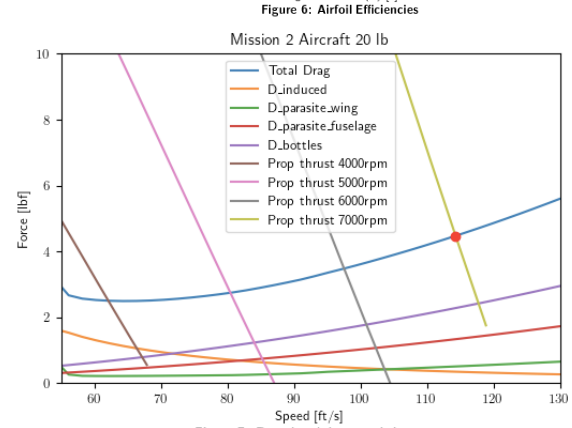

Figure 7: Drag breakdown and thrust

The propulsion system, identified as the primary limiting factor, was prioritized in design decisions. Battery options were constrained to 100 Wh, leading to either 6-cell 4500 mAh or 8-cell 3300 mAh LiPo configurations. Mission 3's 5-minute flight requirement limited average power consumption to 1200 W. T-Motor AT-4130 450 kv with a 17x10 inch propeller was selected as the optimal balance between performance and landing gear complexity, as large propellers require large landing gears for ground clearance.

The wingspan of 70 inches was chosen with 2 inches to spare per the competition rules. With an estimated 10 lb dry mass and the target of 10 lb of payload derived from carrying two 1.5 L bottles, many simulations were run with varying the chord length of the wing. A chord length of 12 inches was derived based on the fact the plane will cruise at an angle of attack of 2 degrees with its maximum payload, as shown in Figure 8. Figure 7 shows the breakdown of drag and thrust provided by the propeller, with the red point indicating the maximum cruise speed.

Trade studies for the X-1 test vehicle are shown in Table 4 and 5. As shown in the sensitivity study, reducing the weight is most critical. A flying wing design using XPS foam construction was selected, prioritizing both minimal weight and survival of potential rough landings to ensure scoring opportunities, even with suboptimal autopilot performance.

| Configuration | Pros | Cons | Score (1-5) |
|---|---|---|---|
| Flying Wing | efficient aerodynamics Compact, lightweight structure | Inherent stability challenges | 4 |
| Conventional Tail | Easier flight control integration | Higher weight and drag | 2 |
| V-Tail | Reduced wetted area | More complex aerodynamics | 3 |

**Table 4: X-1 Airframe Configuration Trade Study**

| Material | Strength-to-Weight Ratio | Cost | Manufacturability | Score (1-5) |
|---|---|---|---|---|
| XPS Foam | High | Low | High | 4 |
| Carbon Fiber | Very High | High | Low | 2 |
| Balsa Wood | Medium | Low | Medium | 3 |

**Table 5: X-1 Structural Materials Trade Study**

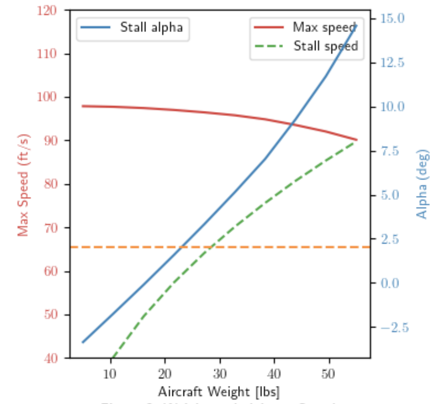

**Figure 8: Weight and alpha vs Speed**

## *3.4 Preliminary Design*

The team used the sub-system requirements and trade studies as guidelines when creating the preliminary design of the aircraft, which consists of a small streamlined fuselage at the very front which contains only the main electrical components (i.e. motor, ESC, battery pack, etc.). Extending from the fuselage is a carbon fiber tube which connects to the empennage, 60 inches from the propeller. The aircraft wingspan was set to 70 inches and chord length of 12 inches. The wing is mounted on the top of the fuselage to allow for better ground clearance for the payload, which is mounted underneath the wing. The wing has a carbon fiber spar with 0.860" outer diameter and 0.055" wall thickness which has Tensile Strength of 130,000 psi. The locations of fuel tanks were optimized to balance the bending moment on the wing spar in the air and on the ground. The spar can support 285 lb·ft of bending moment. In flight, 15.6 lb·ft of bending moment is expected and 6.25 lb·ft on the ground. We chose a high safety factor to allow for a forgiving piloting experience. The spar can handle large G maneuvers and rough landings. The sizes of the tail and the control surfaces were decided based on *Aircraft Design: A Conceptual Approach* by Raymer. A 17 inch diameter propeller with a pitch of 10 inches was chosen with T-motor AT-4130 450 kv, which is expected to spin the propeller at 7000 RPM. The static thrust of the motor is 14.4 lbf. A 6-cell LiPo battery with 4500 mAh capacity is chosen to utilize 99.9% of 100-watt-hours competition regulation. The dry mass of the aircraft is estimated to be 10 lb.

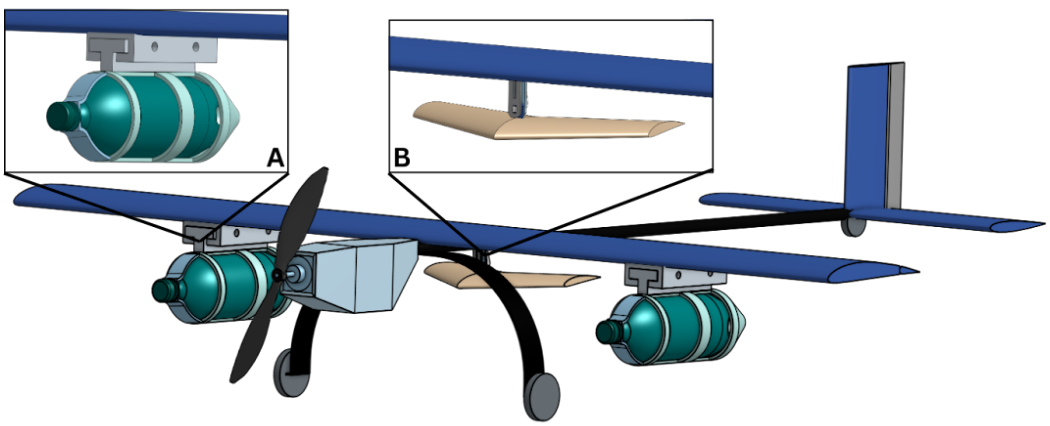

**Figure 9: 2025 Preliminary Design**

## *3.5 Design Approach for Each Mission*

For the ground mission, the aircraft must be configured for flight within a 5 minute window. This involves attaching the X-1 test vehicle to the aircraft, the pylon to the wing, inserting the fuel tank into the pylon, and installing the battery pack. The pylon, designed with a cylindrical frame and a conical base, accommodates the fuel tank while streamlining airflow and reducing drag (Figure 9a). A hinged hook locking mechanism at the top of the frame allows the fuel tank to slide in. The two hooks come together around the fuel tank's neck and lock in place using two pins. The pylon is then attached to the wing using a sliding bracket, secured with nuts and bolts. The battery is simply slid into the fuselage. The X-1 test vehicle has a pin holder protruding out the top that slides in between two additional pin holders attached to the aircraft. All three pin holders line up so that a hook can slide in them, holding up the aircraft securely. The hook is moved with a servo motor for remote releasing of the X-1.

For mission 2, the goal is to maximize fuel weight and lap time. The target fuel weight is 10 lb, using two 1.5 L plastic bottles each filled with 5 lb of sand. Sand was selected for its high density and accessibility, while avoiding liquid's sloshing concerns. At 100 ft/s cruise speed, each lap takes 26 seconds. Turns will be done with a bank angle of 75 degrees which results in a load factor of 4 g. The total mission time from takeoff through 3 laps is expected to be 90 seconds. Operating at 100% throttle throughout consumes 1800 W, utilizing approximately 60% of battery capacity by landing.

For mission 3, it is critical to fly as many laps before releasing the X-1 and autonomously land the X-1 on the target. The X-1 test vehicle features a flying wing design with 16 inch wingspan, 6 inch center chord, 3 inch tip chord, and 45 degree sweep. This configuration balances electronics integration with stability, leveraging the favorable scaling of mass (cubic) versus turbulence effects (square). The 0.25 lb (115 g) vehicle comprises a hot-wire cut foam core (65 g) and essential electronics (50 g) including flight computer, IMU, barometer, GPS, and LED indicators. A modified Ardupilot implementation provides state estimation and glide path control. A modified version of Ardupilot will be made to fit the mission requirement of landing at the target area and controlling LED lights. Use of Ardupilot is chosen to exploit the state estimation algorithm which fuses data sensors to get the location, velocity, and attitude of the vehicle. Its guidance algorithms will be modified to add the ability to navigate the gliding vehicle without any thrust.

The X-1 test vehicle will conduct a U-turn and head to the edge of the landing zone after the release. Once it reaches the area above the landing zone, it will enter into a large bank angle turn, around the center of the landing zone. The nominal bank angle is set to 60 deg and pitch attitude of - 20 which will give a rate of descent to be 25 ft/s. It is estimated to take 5 seconds of flying to the landing zone and 12 seconds of descent. The plane will conduct 11 laps with cruise speed of 95 ft/s before releasing the X-1 test vehicle. During cruise, the throttle is set to 80% which consumes 1000 W of energy. Combined with full thrust during take off and climb which uses 1800 W, the battery will be nearly fully depleted at the end of mission 3. The X-1 test vehicle gets released by a servo motor unhooking it from the aircraft's belly.

# 4. Manufacturing Plan

## *4.1 Manufacturing Flow*

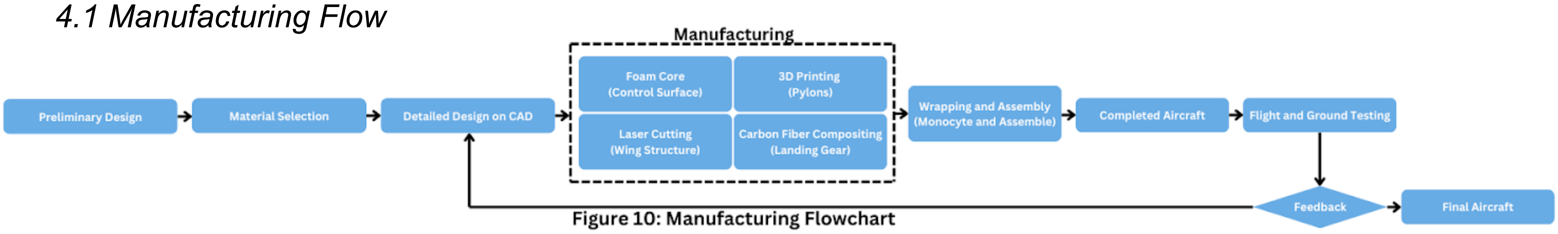


**Figure 10: Manufacturing Flowchart**

The preliminary design has been developed, per section 3.3. Next up is material selection and analysis. The components of the aircraft will use a combination of balsa wood, MonoKote, XPS foam, PLA filament, and carbon fiber to reconcile strength, flexibility, and weight requirements. Following material selection, CAD will be used to model each component individually, as well as their relationships to each other (i.e. how they fit/move together). After modeling in CAD, manufacturing occurs. This includes laser-cutting balsa wood parts (60W $CO_2$ laser cutter), cutting carbon fiber tubes to size, hot-wiring XPS foam (heated nichrome 80 wire), and 3D printing custom PLA parts (Bambu Lab X1C). Once parts are manufactured, they can be assembled using applicable fasteners and adhesives including epoxy, wood glue, and cyanoacrylate (superglue). Upon construction, each subsystem and the fully assembled prototype will then undergo testing (detailed in section 5) so that the team may identify any areas of improvement and create subsequent designs and prototypes.

### *4.2 Critical Processes and Technologies*

The wing will use balsa wood ribs with a carbon fiber tube as a spar to create the structure, with a MonoKote skin for a strong, aerodynamic exterior. Additionally, the leading edge will be made with XPS foam cut with a heated nichrome 80 wire to form a smoother curve than the wood can. The control surfaces will similarly be made with the XPS foam. The fuselage will be made with balsa wood and MonoKote reinforced with a carbon fiber tube that extends to the be the boom, similar to the main structure of the wing. These materials were chosen for their light but strong characteristics, as well as ease of manufacturing. The landing gear will use a custom carbon fiber frame to further maximize strength, requiring a wet layup. The X-1 test vehicle will be made out of XPS foam to achieve a durable but light structure. Smaller, more intricate designs such as the X-1 release mechanism and pylon will be 3D printed due to their complex geometry and small size.

## 5. Test Planning

### *5.1 Component and Ground Test Plan.*

Testing will incorporate qualitative performance tests in addition to quantitative evaluations. Before the first prototype is flown, each component is tested and evaluated by ground testing to ensure their proper function. To verify the structural integrity of the wing, a force equal to twice the expected flight load, accounting for a safety factor, will be applied to the wing spar by suspending weights at multiple locations along the spar. Motors and propellers will be tested on a static thrust stand with a variety of LiPo batteries, Electronic Speed Controllers, and propellers to determine the thrust in static condition to validate the required thrust. This will be repeated in the university's large wind tunnel to conduct tests for in-flight conditions. Discharge rate is measured simultaneously to estimate the number of laps the aircraft can complete. In addition, range-of-motion tests on control surfaces will be performed as well as the range of the radio-controller. The flight controller for the X-1 test vehicle is tested in the Simulation-in-the-Loop (SIL) environment for the Hardware-in-the-Loop (HIL) to verify the hardware. Results from ground testing will be used to optimize the design of the plane if the results are significantly different from the expected values. Once the aircraft has passed these ground tests, mission tests begin. Ground mission testing will be conducted to verify the ease of installation of payloads under time pressure.

### *5.2 Flight Test Plan*

The aircraft will go through pre-flight checks consisting of the center of gravity location, control surface deflections, and propulsion system. The tests will include flying the airplane in an unloaded configuration (no payload) in level flight, turns, and landings. A test course mirroring the competition flight course will be used to obtain lap times as well as measure performance such as takeoff distance, in-flight stability, and overall mission compliance. Additional flights following the guidelines of competition missions 2 and 3 will follow, including testing in different wind conditions. For the duration of the test flights, a microcontroller equipped with an array of sensors, including accelerometers, gyroscopes, an altimeter, a GPS receiver, and an airspeed sensor, will be installed onboard to capture data logs. The data will be analyzed to assess the accuracy of the models used to optimize the design variables and if necessary, the model will be updated. The X-1 test vehicle will have similar sensors to collect data that will be used for improving the guidance and control systems. The results obtained from the testing, in conjunction with feedback from pilots, will serve as the basis for enhancing the design of subsequent air vehicles, culminating in the final competition aircraft.