University of Maryland, Baltimore County
AIAA Design, Build, Fly Proposal

1. Executive Summary

This proposal encompasses University of Maryland, Baltimore County's (UMBC) management plan, mission analysis, and proposed design, manufacturing, and testing for the 2024–25 AIAA Design, Build, Fly (DBF) competition. This year's competition is to simulate the X-1 Supersonic Flight Test Program by demonstrating heavy fuel tank carrying capability, and the deployment and autonomous flight of a lightweight X-1. The team will additionally be scored on aircraft speed, flight endurance, and ability to swap through different flight configurations.

To maximize the team's score, the team selected a high-wing conventional aircraft with tapered wings, twin tractor motors, and a taildragger landing gear configuration to increase dynamic thrust, carrying capacity, flight time, and clearance for the X-1. The X-1 is a foam flying wing to minimize weight due to a fuselage and additional servos. The fuel tanks are strapped under the wing and in-line with the motors to reduce drag. This minimizes the setup time for the ground mission, maximizes the payload weight and speed in mission 2, and improves the mission 3 score for number of laps, landing accuracy, and X-1 weight.

To meet these goals, the team consists of an aerodynamics, electronics, and structures subteam to efficiently manage and organize tasks. A Gantt chart keeps the team on track, and active funding outreach ensures financial sustenance for the project. The mission requirements and scoring were analyzed and weighted to yield a high-performing aircraft design. Utilizing the manufacturing and testing plans, high-strength lightweight construction would be used to guarantee structural integrity and rigidity throughout flight without comprising the payload-weight ratio, thus increasing reliability of the structure and therefore decreasing the likelihood of failure.

2. Management Summary

2.1. Team Organization

The UMBC AIAA DBF project team is comprised of 12 undergraduate students. The arrows in figure 1 illustrates the chain of command in the team. Although the faculty advisor and the officers are not a key component of decision making, they are invaluable in reviewing the team's progress, decisions, and attaining external resources such as funding and advertising. The project lead is paired with an intern who is trained in leading the organization. In addition to assigning team objectives, the project lead and intern resolves design conflicts among subteams. The subteam leads are experienced veteran members who are in charge of setting subteam tasks and deadlines, and guiding subteam members. The responsibilities and skills for each team is listed in table 1. New members are taught on model aviation knowledge such as lift calculations and fuselage design, utilizing software such as MATLAB and LaTeX, and hands-on construction such as foam prototyping and composite layup.

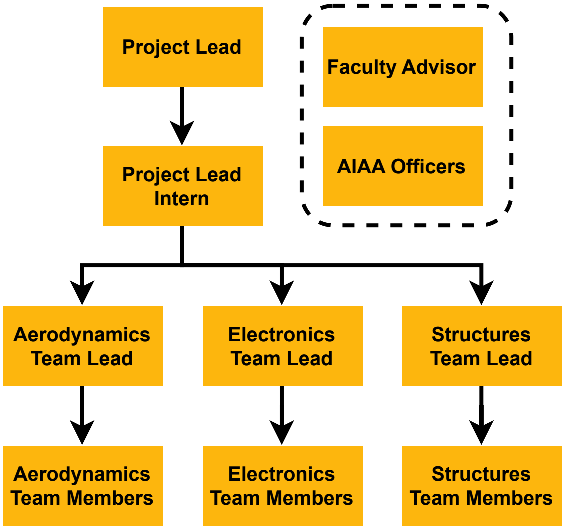


Figure 1: Team Organization Structure

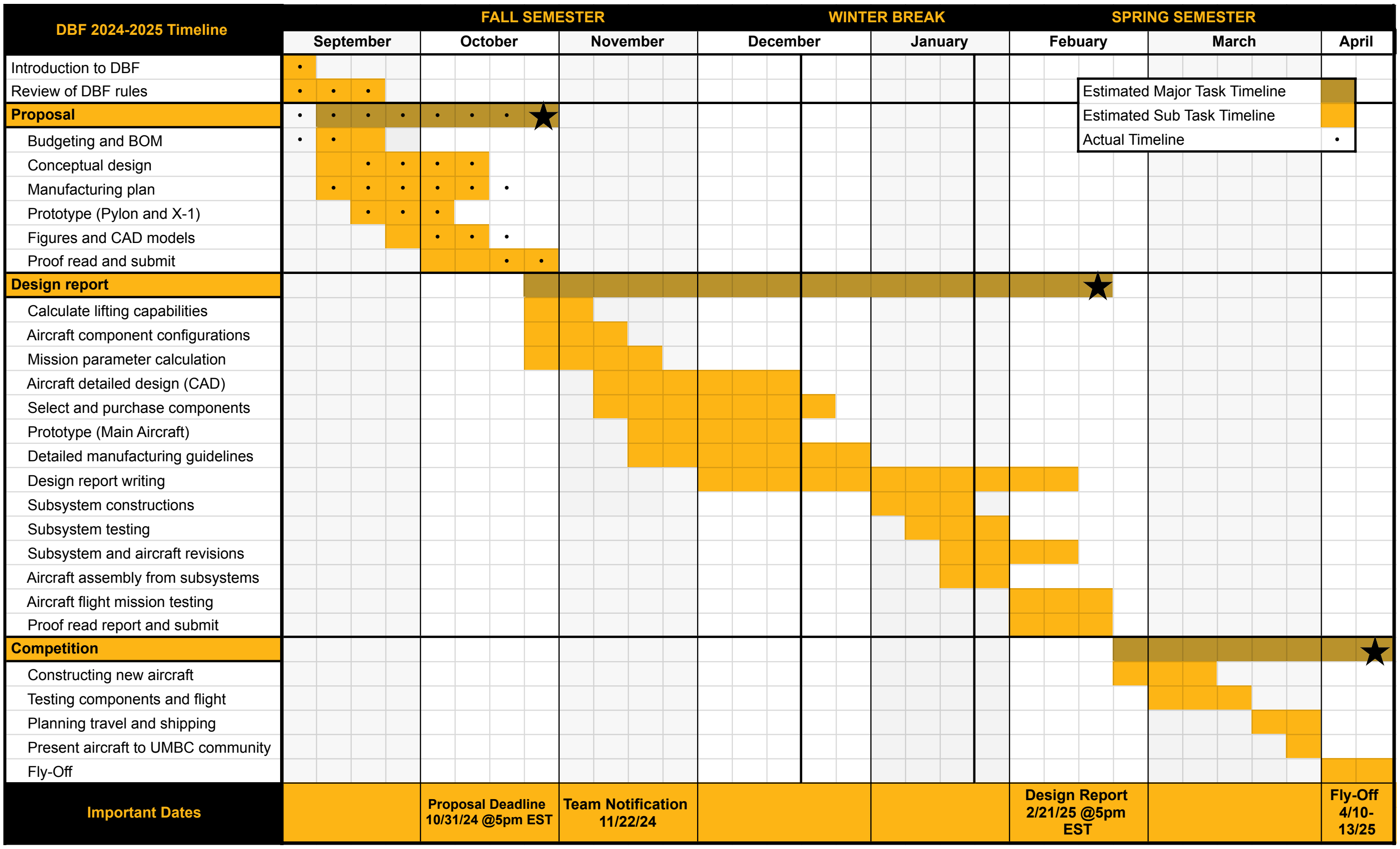
Table 1: Team Responsibilities and Skills Required

Aerodynamics	Structures	Electronics
• Understanding fluid dynamics • Calculate aerodynamic load • Design wing, empennage, and body geometries • Ability to use software such as SolidWorks CFD and XFLR5	• Estimate structural response due to aerodynamic load • Determine manufacturing plan for designs provided by aerodynamics team • Perform manufacturing duties of aircraft and testing platforms • Ability to use software such as SolidWorks FEA and GRBL	• Capable of designing testing systems • Ability to use computational languages such as MATLAB, Python, and C • Expertise in thrust, torque, and autonomy of aerial vehicles

2.2. Schedule

The Gantt chart in table 2 showcases the team's schedule and important due dates for the competition. Subsystems for the aircraft are constructed, tested, and assembled into a flight-ready aircraft along side the design report to cite real-world

Table 2: DBF 2024–2025 Gantt Chart



DBF 2024-2025 Timeline	FALL SEMESTER			WINTER BREAK		SPRING SEMESTER		
	September	October	November	December	January	Febuary	March	April

Introduction to DBF
Review of DBF rules

Proposal
- Budgeting and BOM
- Conceptual design
- Manufacturing plan
- Prototype (Pylon and X-1)
- Figures and CAD models
- Proof read and submit

Design report
- Calculate lifting capabilities
- Aircraft component configurations
- Mission parameter calculation
- Aircraft detailed design (CAD)
- Select and purchase components
- Prototype (Main Aircraft)
- Detailed manufacturing guidelines
- Design report writing
- Subsystem constructions
- Subsystem testing
- Subsystem and aircraft revisions
- Aircraft assembly from subsystems
- Aircraft flight mission testing
- Proof read report and submit

Competition
- Constructing new aircraft
- Testing components and flight
- Planning travel and shipping
- Present aircraft to UMBC community
- Fly-Off

Legend	
Estimated Major Task Timeline	■
Estimated Sub Task Timeline	■
Actual Timeline	•

Important Dates	Proposal Deadline 10/31/24 @5pm EST	Team Notification 11/22/24	Design Report 2/21/25 @5pm EST	Fly-Off 4/10-13/25

results. Team meetings are held during the workweek for debriefing and determining a plan of action as a group. Subteams meet separately to keep progress with their tasks. The project lead, intern, and team leads have additional meetings to discuss team progress and improvements with their specialized tasks, decide meeting agendas, and provide management feedback. Weekly weekend meetings are utilized for large tasks such as aircraft construction. Majority of the competition airplane construction will be held over winter break, and additional aircraft parts will continuously be built throughout Spring to mitigate any delays caused by damage due to flight testing.

2.3. Budget

The budget shown in table 3 is based on previous years' paid expenses and likely upgrades such as increased use of composite materials. Additional materials such as extensions for servos, adhesives, and PPE for carbon fiber (CF) sanding are considered. The team has requested and received funds from several UMBC departments, thereby meeting 75% of the total budget. Additional funds will be requested from external companies that UMBC AIAA alumni currently are employed at. This budget is adequate to produce one prototype and two final competition planes, and fulfill all member registration, travel, and living expenses. Currently, 10 members are expected to attend the competition. The competition plane will be dismantled and transported by air as an oversized checked bag.

Table 3: DBF 2024–2025 Budget Estimate

Electronics	**Cost**	**Manufacturing Materials**	**Cost**	**Travel**	**Cost**
Motors & ESCs	$288	Non-composite raw materials (wood, filament...)	$565	Airfare (2-way×10)	$6,000
Batteries	$217	Composite raw materials (carbon fiber cloth, ...)	$1,258	Lodging	$1,400
Propellers	$90	Pre-built materials (wheels, tubes...)	$532	Car Rental	$982
Radio	$268	Adhesives, fasteners, and tapes	$210	Plane Transport	$400
Servos & Ext.	$207	Tools & PPEs	$456	Food (3 meals, 4 days)	$2,400
Total	**$1,070**	**Total**	**$3,021**	**Total**	**$11,182**
Total Estimate					**$15,273**

3. Conceptual Design

3.1. Analysis of Mission Requirements

Table 4: Mission Requirements, Their Corresponding Design Considerations, and Mission Scoring

Mission	Mission Requirements	Required Design Considerations	Scoring
Ground	• Attach and detach pylons, fuel tanks, and X-1 • Demonstrate X-1 deployment and operational lights • Only ground crew may touch aircraft	• Pylons, fuel tanks, and X-1 can be attached/detached rapidly • These must be easily conducted by a single individual	$M_G = \lceil T_G \rceil$ (1)
Flight 1	• Fly 3 laps in 5 minutes	No *major* design considerations	$M_1 = 1$ (2)
Flight 2	• Fly 3 laps in 5 minutes • Carry X-1 and 2 external fuel tanks	• X-1 and 2 external fuel tanks must be attachable in the 5 minutes setup time • Pylons and X-1 mount must be durable to prevent unwanted release during flights and turns	$M_2 = 1 + \left\lfloor \frac{W_f}{T_2} \right\rfloor$ (3)
Flight 3	• Carry X-1 and 2 external fuel tanks • Release X-1 after first lap from altitude of 200 to 400 ft • After release, X-1 must stabilize, perform 180° turn, and land at target • X-1 lights must flash and remain flashing after deployment • Main aircraft must be airborne for at least 5 minutes	• X-1 must release reliably • Main aircraft must be optimized to sustain flight for 5 minutes while performing as many laps as possible • Adequate battery power must be available to land main aircraft • X-1 must reliably land to target zone, never cross the safety line, and lights must be durable enough for landing	$M_3 = 2 + \left\lfloor N + \frac{B}{W_x} \right\rfloor$ (4)

The aircraft shall perform three flight missions and a timed ground mission. The mission requirements, scoring criteria, and the imposed design constraints are summarized in table 4. In all flight missions, the ground crew must prepare the aircraft for flight, including connecting the propulsion battery and performing pre-flight checks. Successful landing is required to be eligible for scoring. Note that the $\lfloor \square \rfloor$ operator indicates that the team's results are divided by the maximum result among all teams; the $\lceil \square \rceil$ operator indicates that the team's result is the divisor of the minimum result among all teams; the $\square$ symbol indicates any arbitrary input. M_2 requires an aircraft that is capable of carrying a heavy fuel load W_f in the shortest possible time T_2, while M_3 requires performing as many laps N as possible while the X-1 of weight W_x lands at target thereby scoring B bonus points. The mission scoring is further analyzed to produce design decisions in section 3.2.

3.2. Sensitivity Analysis and Trade Studies

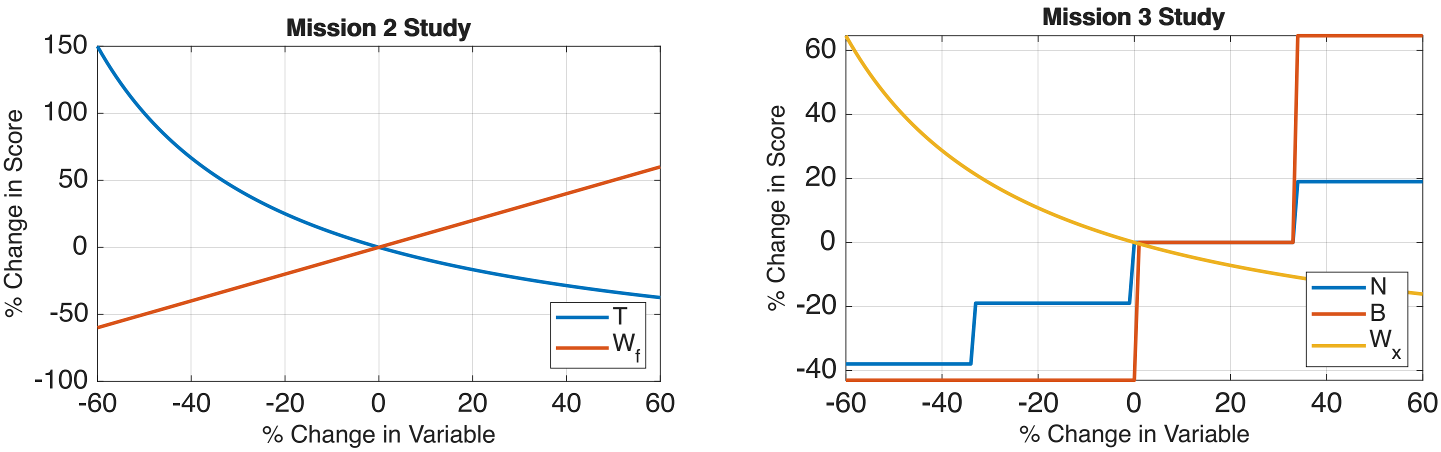


Figure 2: Sensitivity Analysis for Flight Missions

Equation 3 was utilized to produce the sensitivity analysis for mission 2 shown in figure 2. The plot illustrates that as the fuel carrying capacity increases, the score increases linearly, however, as the time taken to complete the mission decreases, the score increases exponentially. This figure reveals that optimal M_2 score can be achieved by prioritizing speed followed by an increased fuel carrying capacity. Equation 4 was utilized to produce the sensitivity analysis for mission 3 shown in figure 2. As the number of laps and the target accuracy is increased, the score increases in a step fashion due to the discrete nature of the parameters. Meanwhile, as the X-1 weight decreases, the score increases exponentially. Therefore, to maximize the M_3 score, the X-1 vehicle weight has to be minimized, followed by improving autonomous navigation of the vehicle, and finally by completing more laps. Note that the sensitivity analysis considers the inherent weight of the X-1's lights and drop mechanism, and its capability of performing a 180° turn to be eligible for scoring.

Table 5: Trade-Off Study for Selecting General Aircraft Configurations

Category	**Weights**			**Wing**			**Landing**		**Motor**		**Tail**		**X-1 style**			**X-1 control**	
Parameter	M2	M3	Relative Net	**High wing**	Mid wing	Low wing	Tri-cycle	**Tail dragger**	Single tractor	**Twin tractor**	Fuselage tail	**Boom tail**	High AR	Moderate AR	**Flying Wing**	No-autonomy	**Autonomous**
Number of laps	1	5	0.16						1	**2**							
Max flight time	1	1	0.05						1	**2**							
Top speed	5	3	0.22						1	**3**	1	**2**	1	2	**3**		
Weight	3	2	0.14	**3**	2	1	1	**3**	2	**3**	2	**1**	2	1	**2**	3	**1**
Flight stability	1	2	0.08	**3**	2	1			1	**2**			3	2	**1**	1	**3**
Aerodynamic	4	4	0.22				1	**2**	1	**2**	1	**3**	1	2	**3**	1	**3**
Autonomy	1	4	0.14													1	**3**
Total			1.00	**0.22**	0.14	0.07	0.12	**0.28**	0.33	**0.69**	0.23	**0.41**	0.32	0.39	**0.55**	0.28	**0.48**

The sensitivity analysis was utilized to determine the weights between 1 and 5 for the trade-off table shown in table 5. Since M_2 and M_3 have conflicting objectives, their weights were summed and normalized to yield a relative weight. The wing, landing gear, motor, and tail configurations were determined for the main aircraft. The wing aspect ratio (AR) and control mechanism for the X-1 was also determined. Each alternative design was scored between 1 and 3, with 3 indicating 'the best', and left blank if it had no significant effect on the parameter. Note that the 'weight' parameter indicates the 'ability to carry payload', either by increasing payload-weight ratio or *increasing clearance* for the payload. The study determined that the optimal design would be a conventional main plane with a high-wing, tail-dragger landing gear, twin tractor motors, and a tail consisting of a narrow boom; the X-1 would be a flying wing that is capable of autonomously-navigating to the landing zone using a GPS and a flight controller.

3.3. Design Approach

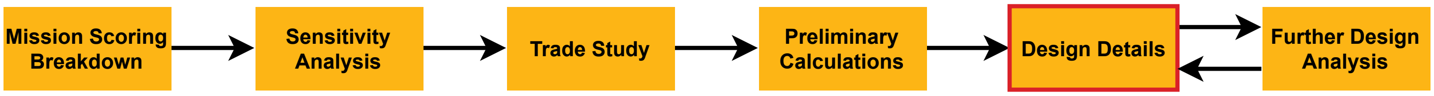


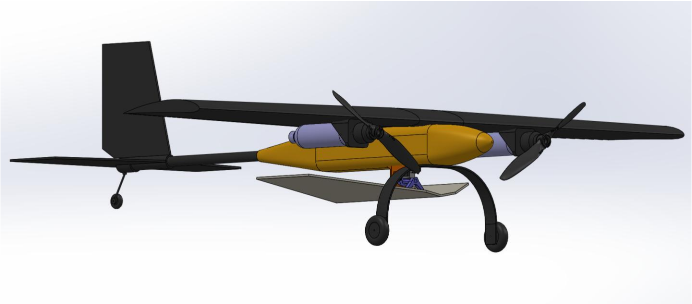
Figure 3: Design Methodology Flow Chart

Figure 3 visually summarizes the team's approach to the proposed aircraft design. The team's current phase in the design process is outlined in red. The mission scoring described in section 3.1 was utilized for the analysis and trade studies in 3.2. Preliminary calculations based on competition site weather and geography, additional rules on wing sizing and takeoff distance, the team's prototypes, and more were utilized to yield the design details described in section 3.4. Additional analysis such as CFD, FEA, and detailed cost-benefit analysis will be used to better optimize the proposed design.

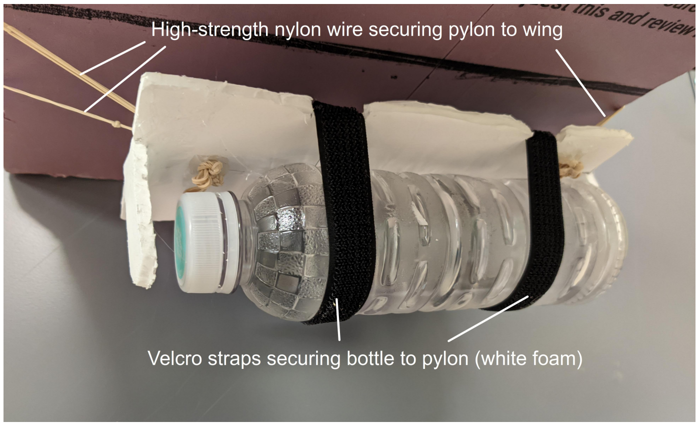
3.4. Preliminary Design

Choosing a conventional aircraft configuration is intended to enhance stability while carrying a payload. A rounded fuselage and blended tail boom are intended to reduce drag and maintain CG throughout different flight configurations. This allows greater top speeds to minimize T_2 in M_2 and maximize N in M_3, while simultaneously reducing the setup time since CG is maintained by default throughout different configurations. Additionally, the use of a CF tail boom will reduce the net weight of the aircraft to allow for a greater payload carrying capacity. The fuselage, including the boom, will be 52" long, with a maximum width of 4". The wing will utilize the entire 6' wingspan limit, and have an average aspect ratio of 5 to increase the lift needed to maximize W_f for M_2. The expected maximum takeoff weight (MTOW) is 15 lb. The expected payload weight is 5 lb comprised of lead weights in 17 fl.oz. bottles.

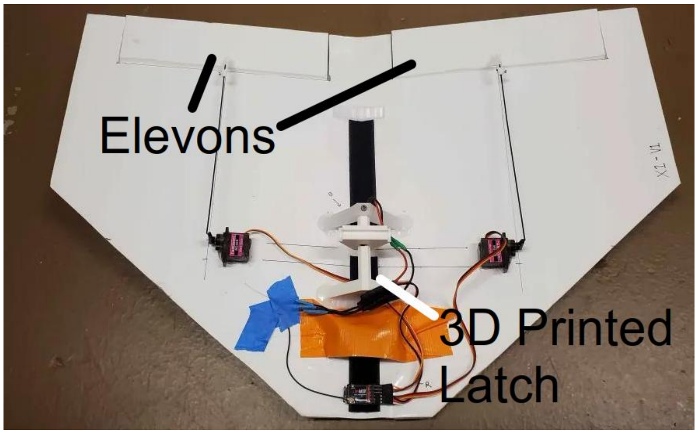
The team will perform sharp loaded turns for M_2 to minimize the arc distance travelled during turns and the time taken to complete the mission, and therefore requires high structural integrity in the wings. The wing will be tapered with an inner chord of 14" to increase the structural integrity at the root for M_2, and the outer chord will be 11" to minimize tip drag and therefore increase the number of laps completed in M_3. The NACA 2412 is selected as the airfoil shape as it offers a high C_L/C_D ratio which is crucial for achieving high speeds with a heavy load in M_2 while having a low C_D for the unloaded flight endurance needed for M_3. The proposed aircraft design is modelled in figure 4a.



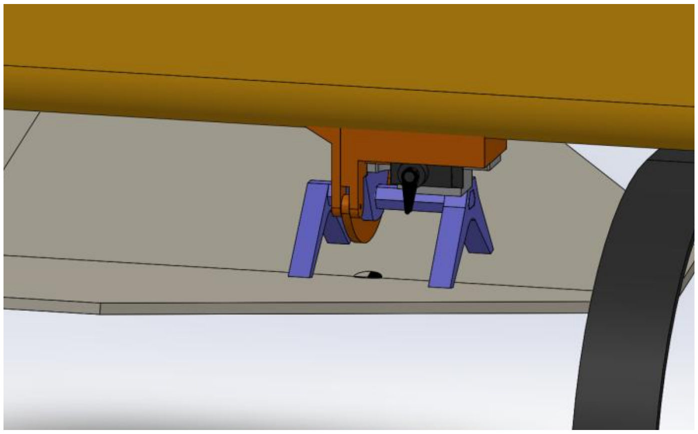
(a) Aircraft, Fuel Tanks, and X-1 assembly



(b) Prototyped Pylon Securing Fuel Tanks



(c) Prototyped X-1 Test vehicle



(d) Model of X-1 Release mechanism

Figure 4: Preliminary Designs and Prototypes

Twin tractor motors were selected to enable differential thrust for fast turns in mission 2, negate effects of p-factor to increase control, and reduce the propeller diameter to increase clearance for the X-1. These electric motors will be approximately 32 mm and 36 mm in stator diameter and height to maximize power throughput, and 950 KV to increase the angular spin speed to increase dynamic thrust needed to achieve high speeds in mission 2 and 3. These will be powered by two 6-cell 2200 mAh LiPo batteries to closely approach, but not surpass, the 100 Wh energy constraint, while simultaneously maximizing the number of laps in M_3. The motors will drive counter-rotating propellers of 12" diameter to increase clearance for the X-1 and 8" in pitch to increase the dynamic thrust needed for M_2. Two fuel tanks, consisting of rearwards-facing water bottles, will be placed below the wings in-line with the twin motors to minimize aerodynamic drag to achieve greater velocities for M_2. Current estimates suggest M_2 mission completion time to be approximately 90 seconds, excluding landing.

Removable velcro pylons, prototyped in figure 4b, will secure the fuel tanks; the pylon will be secured to the wing using externally accessible high-strength nylon wire to minimize the ground mission time T_G while mitigating structural failure. The mission requirements do not mandate an internal fuel tank and no points are gained by utilizing additional fuel tanks; therefore, only external fuel tanks will be utilized to minimize the drag by reducing the fuselage cross-sectional area and consequently improving the time taken in M_2 and number of laps in M_3. The fuel tank and motor will be placed 12" from the side of the fuselage; at this distance, the maximum bending moment in the wing spar is minimized, therefore increasing structural integrity in M_2. This additionally improves clearance for the X-1. A tailwheel-type landing gear configuration will allow sufficient space below the fuselage to mount the X-1 test vehicle while allowing steerability using the rudder.

The X-1 test vehicle will consist of a lightweight flying wing shown in figure 4c. The flying wing design eliminates a fuselage, reducing unneeded weight and drag to maximize M_2 and the first lap of M_3, and uses elevons to simplify autonomously-controlled flight while reducing unnecessary weight from having additional servos. Dihedral wings are used instead of a vertical stabilizer to improve lateral stability and further minimize weight. The prototype currently weighs $W_x = 0.44$ lb, and will be further reduced by using lighter foam, smaller servos, and lower surface area. The X-1 test vehicle will be attached to the aircraft via a 3D-printed hook, illustrated in figure 4d, on the underside of the aircraft fuselage interlocking with a latch on top of the X-1 test vehicle, and secured by a metal rod. The latch guarantees ≥ 0.25" separation of the X-1 and the aircraft. The metal rod will be moveable and controlled by a servo arm to enable separation, launching the X-1 test vehicle.

4. Manufacturing Plan

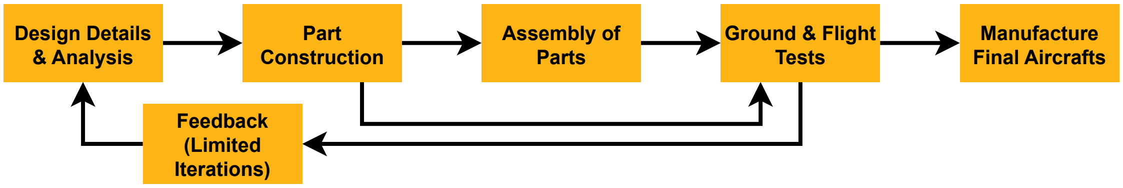


Figure 5: Manufacturing Plan For 2025 DBF Competition

Figure 5 details the manufacturing plan for the main aircraft, X-1, and the fuel tanks. The plan begins from the designs described in section 3.3. Parts are prototyped, assembled to an aircraft, tested, and finally reproduced for the final competition aircraft. The real-world tests will be utilized as feedback to improve aircraft design and construction, however the number of design and construction changes will be limited to efficiently utilize time and follow the schedule listed in section 2.2.

Vacuum bag with a pump, CNC hot wire foam cutter, and 3D printing are the primary high-expense manufacturing tools. The wings will be constructed out of vacuum-bagged CF on a hot wire cut foam mold with nylon 3D printed ribs and telescoping CF spars to increase the payload-to-weight ratio for M_2, and increase the structural integrity during sharp turns. The landing gears will be produced with S-glass fiberglass (FG) since it offers higher ductility and therefore higher shock absorption than CF. The fuselage will comprise of a CF and FG mix to increase its ductility while maintaining rigidity and therefore further absorb energy during landings. Additional rigidity will stem from the CF tail boom that extends into the fuselage. The tail surfaces will be produced by fiberglassing NGX150 foam under vacuum to reduce rear weight and therefore maintain CG. The X-1 will be constructed out of foam to reduce its weight and therefore reduce the W_x term in the M_3 score.

5. Testing Plan

Table 6: Major Tests, Their Purpose, and the Specific Methodology of Conducting the Tests

Tests	Justification	Method
Motors/ thrust	Maximize top speed for M_2 and M_3, while maintaining flight time of 5 min.	Strap a thrust test stand with motor on a car. Measure thrust, RPM, and power consumption at various speeds for various motor/propeller combinations.
Wing loading	Mitigate structural damage from excess weight and tight turns in M_2.	Fill frame with various weights and lift at wingtips $5\times$ beyond MTOW or until fracture
Landing gear	Ensure successful landing in all flight missions.	Incrementally apply weight to landing gear until $5\times$MTOW or fracture.
Ground mission	Maximize ground mission score and be capable of preparing aircraft for flight within the 5 min window.	Swap through all flight configurations involving pylons, fuel tanks, and X-1. Ensure CG balance throughout all configurations.
Flight performance	Maximize speed in M_2 and number of laps in M_3.	Fly aircraft to determine flight speed, maneuverability, take-off distance, and turning radius for various weights in all configurations.
Flight endurance	Maintain flight time of $\geq$5 min while increasing number of laps in M_3.	Fly aircraft at various speeds with a battery capacity sensor to determine maximum safe flight distance.
X-1 deployment	Guarantee release of X-1 to minimize flight risk in M_3 and ensure functioning lights for valid score.	Perform several release and deployment cycles to determine longevity and success probability of deployment.
X-1 autonomy	Satisfy 180° and stable flight requirement while maximizing landing bonus points.	Utilize Ardupilot simulations to determine flight path. Perform several real-world tests to verify reliability of autonomous navigation. Test failsafe to direct X-1 away from judges and participants in the event of GPS loss and uncontrollability.
X-1 endurance	Satisfy X-1 lighting requirement for M_3.	Apply forces on lights until failure to determine maximum force on landing.
Pylon strength	Mitigate risk of fuel tanks detaching in flight	Increase weight of fuel tanks attached to pylons until failure.

Table 6 showcases the various tests that will be performed. Non-flight tests will be conducted in-house, while flight tests will be performed at a local AMA-sanctioned flying field. Flight tests will utilize flight paths and setup method as described in the rules. A force meter, watt meter, laser-gate RPM sensor, and GPS-based speed sensing are available to obtain numerical results. The numerical results will be utilized to set aircraft operation maximums or improve design and construction if possible.