University of Maryland, Baltimore County

AIAA Design, Build, Fly Proposal 2023-2024

Executive Summary

This proposal describes the design, manufacturing, and testing of the remote controlled (RC) unmanned aerial vehicle (UAV) created by the University of Maryland, Baltimore County (UMBC) AIAA Design, Build, Fly (DBF) team for the 2023-24 competition.

The objective for this year's competition is to design and build a modular aircraft capable of Urban Air Mobility (UAM) missions by carrying wooden dolls as crew and passengers along with gurney and Medical Supply Cabinet while adhering to the max dimensions of 5' wingspan and 2.5' overall in the parking configuration while being able to take-off within 20 feet of the start/finish line.

Based on the mission defined for this year, the airplane design will be lightweight with a rotating wing to fit inside the 2.5' parking limitation while having a 5' wing to accommodate the weight of the various payloads. Through a comprehensive sensitivity analysis, the optimal design was determined to be primarily energy efficient and maximize the payload. The team decided on using a single nose mounted motor to reduce drag and weight, and a Clark-Y high wing for stability, high lift and low drag, simple manufacturing, and predictable control behavior with a square fuselage and carbon fiber tubes to support the tail structure and to maximize the payload to aircraft gross weight (AGW) ratio of the design.

Management Summary

The UMBC DBF team structure and general sub-team duties are shown in **Figure 1**. The team is a part of the larger UMBC AIAA student organization, which performs administrative duties such as fulfilling funding and purchase requests from the team. Flight tests and training outside of general DBF times will test members' abilities to fly, and will be used to select the pilot for the competition. The team consists of 9 members and a faculty advisor. The advisor provides administrative support to utilize certain spendings and activities, connects the team with valuable on campus resources and external sponsors, and reviews the team's deliverables and other key decisions. The project lead schedules meeting times and agenda, assigns weekly tasks, and coordinates the three sub-teams. The responsibilities and skills required for each sub-team are shown in **Table 1**. Sub-teams continuously communicate their works with the entire team to assist with decision making and receive feedback. Due to small team size, members can temporarily shift to other sub-teams with more urgent and/or difficult tasks to keep the team on track with the Gantt chart.

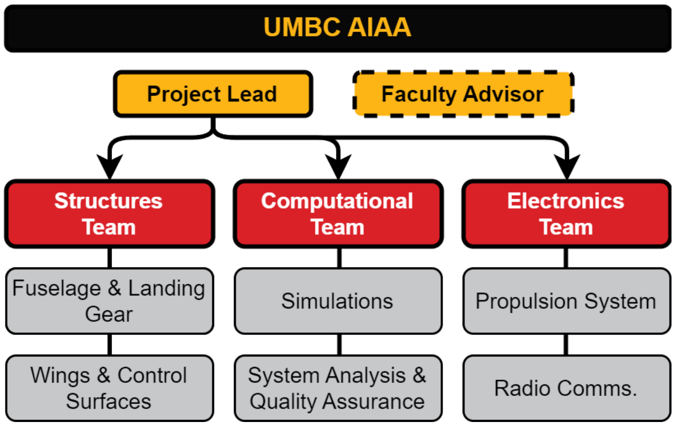

Figure 1: Organizational Chart

Table 1: Breakdown of sub-teams' responsibilities and individual skills required

Sub-Teams	Responsibilities	Skills required
Structures	Designing means of aircraft production, assembly, and manufacturing	Proficient in CAD, material selection, physical assembly, and experience with powered tools
Electronics	Identifying appropriate propulsion system and producing control mechanisms	Knowledge of electrical systems, circuitry, and soldering
Computational	Calculate the dimension and the values for the aircraft to gain the maximum points possible	Proficiency in MATLAB, FEA, CFD, Ansys, or XFLR-5. Decent math background

A Gantt chart, shown in **Figure 2**, was produced to keep the team on track for the major milestones, schedule time for components needed for the milestones, and prevent formations of roadblocks. During Fall and Spring semesters, the team meets regularly for 2 hours twice a week to update the group's current status on tasks, discuss competition related goals and solutions, and assign independent work outside of the regular meeting times. The number and/or duration of the weekly meetings may change throughout the year to keep on track with the Gantt chart. The majority of winter break will be utilized to manufacture the competition aircraft for testing purposes. The final aircraft will be tuned after submission of the design report for competition-readiness.

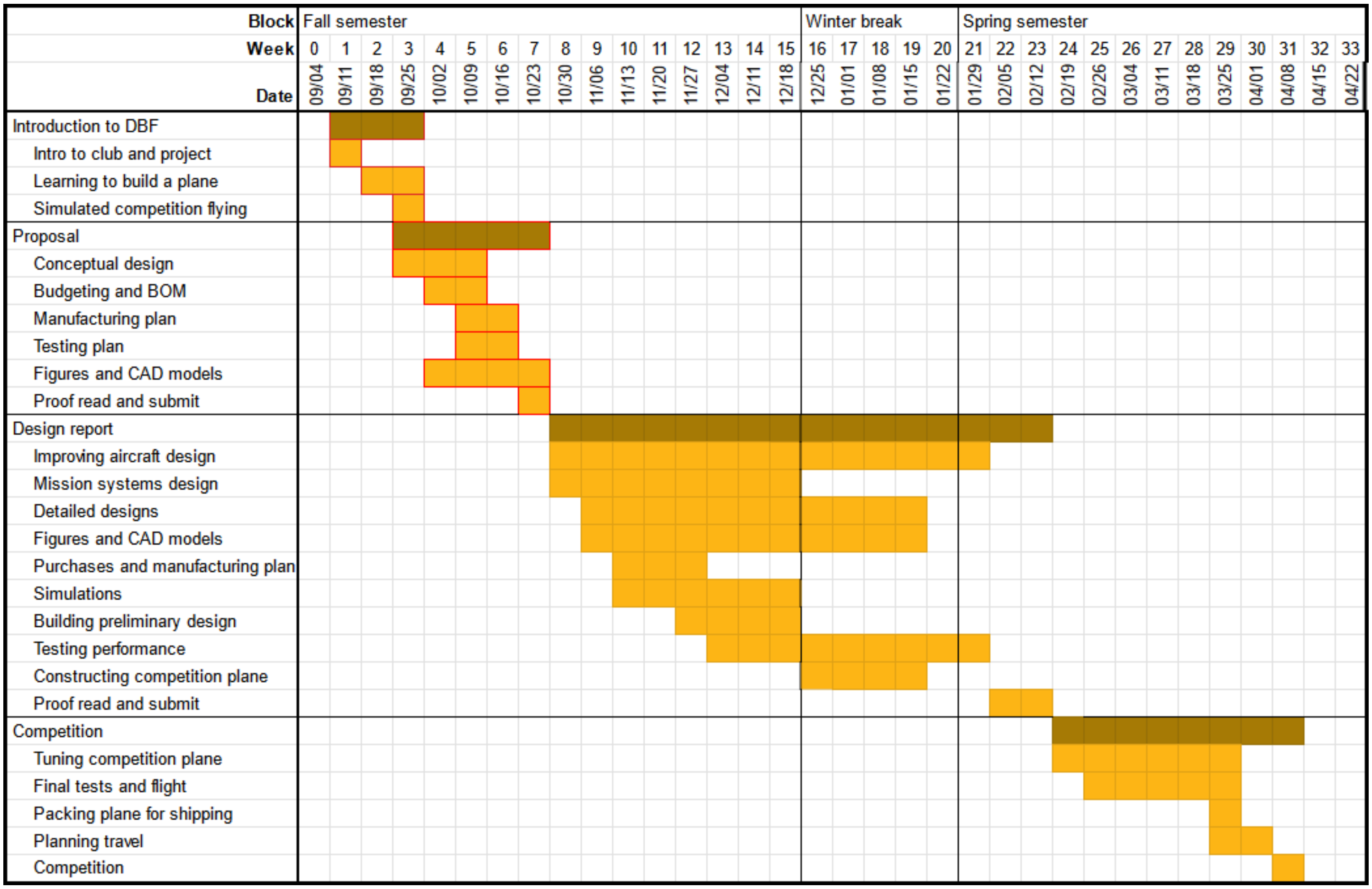

Figure 2: DBF 2023-2024 Gantt Chart

Table 2: DBF 2023-2024 Budget Estimate

Avionics	Cost	Manufacturing Materials	Cost	Travel	Cost
Motors & ESCs	$600	XPS Foam, Balsa, 3D printing filament	$230	Airfare (2-way×10)	$6,000
Batteries	$320	Composites (Epoxies, Fiberglass, Carbon Fiber)	$325	Lodging	$1,400
Propellers	$120	Carbon Fiber Rod and Aluminum	$270	Car Rental	$1,400
Remote ID	$400	Wooden Dolls for EMT & Patients	$90	Plane Transport	$500
Servos	$120	Other Equipment	$300	Food (3 meals, 4 days)	$2,400
Total	**$1,560**	**Total**	**$1,215**	**Total**	**$11,700**
Total Estimate					**$14,475**

The budget shown in **Table 2** outlines the projected expenses for parts and travel, based on the team's previous experiences and current online vendor data. To cover the needed expenses, the team submitted a budget to UMBC's Student Government Association through UMBC's AIAA student organization branch. Further funds will be pursued through UMBC's College of Engineering and Information Technology, Dept. of Mechanical Engineering, and Dept. of Computer Science and Electrical Engineering. Any overflow would be covered by the UMBC AIAA's carry-over and foundation account funds, which includes corporate donations and crowd funding. Currently, 10 members are expected to attend the competition. The competition plane will be shipped to Wichita, KS using a commercial postal carrier. Note that tools are excluded from this budget as they are considered a UMBC AIAA expense and not a DBF expense.

Conceptual Design Approach

Mission requirements were broken down in terms of factors affecting scores, and subsystems required for completing missions. For all missions, the general design requirements are: be able to change configurations, carry crew, securely restrain all passengers and payloads, take-off within 20ft, have a ground-speed of 15 mph to complete 3 laps in 5 minutes, contain a battery with a long duration to maintain flight time of at least 5 minutes, and land successfully. Mission specific requirements and subsystem objectives are shown in **Table 3**.

Table 3: Mission requirements and corresponding subsystem requirements

Mission	**Scoring**	**Additional mission requirements**	**Subsystems and respective requirements**
GM	$\mathrm{GM} = \frac{\min(T)}{N(T)}$	● Efficiently load and remove different configurations of the payload ● Change flight configurations ● Open and close hatches	● Payload restraint mechanisms: Must be able to effectively load and remove crew, EMTs, patient on gurney, medical supply cabinet, and passengers in a time-efficient manner ● Wing pivots to fit in 2.5' parking width
FM1	$\mathrm{M}_1 = 1$	● 3 laps in <5 minutes	● Propulsion: Must be able to consistently fly 3 laps in <5 minutes
FM2	$\mathrm{M}_2 = 1 + \frac{\mathrm{N}\left(\frac{W_{payload}}{T}\right)}{\max\left(\frac{W_{payload}}{T}\right)}$	● Carry crew, EMTs, patient, and medical supplies ● 3 laps in <5 minutes	● Propulsion: Must be able to fly 3 laps in as little time as possible ● Structure: Must be able to fly with as heavy payload as possible
FM3	$\mathrm{M}_3 = 2 + \frac{\mathrm{N}\left(\frac{n_{laps} \times n_{pas.}}{E_{battery}}\right)}{\max\left(\frac{n_{laps} \times n_{pas.}}{E_{battery}}\right)}$	● Swap internal configurations to hold passengers ● Carry crew and passengers ● # of laps in 5 minutes	● Propulsion: Must be able to fly as many laps as possible in 5 minutes ● Battery: Must minimize battery capacity ● Structure: Must be able to fly with as many passengers as possible

A sensitivity analysis was produced to determine the parameters that would produce the greatest increase in score. Wooden dolls, as described in the rules, were purchased and weighed; the payload carrying capacity, W, dictates the number of passengers that can be carried, $n_{pas} = \lfloor \frac{W}{W_{pas}} \rfloor$, assuming that maximum passengers are carried based on weight.

The GM, FM1, FM2, and FM3 equations were combined to produce a total score equation, while substituting the n_{pas} term. The baseline values for the sensitivity equations were $W = 2\text{lb}$, $T_{FM2} = 120\text{s}$, $n_{laps} = 10$, $E_{battery} = 50\text{Wh}$, and $T_{GM} = 45\text{s}$.

Each parameter in the above baseline was incremented with the others held constant to determine the effect on the final score. The effects of these parameters of interest on the total score are shown in **Figure 3**. Note that the step-like graph for W and n_{laps} is a result of these parameters being discrete instead of continuous. The results indicate that decreasing the time taken in FM2, the battery capacity in FM3, and the ground mission time, most increases the score. This is followed by increasing the payload carrying

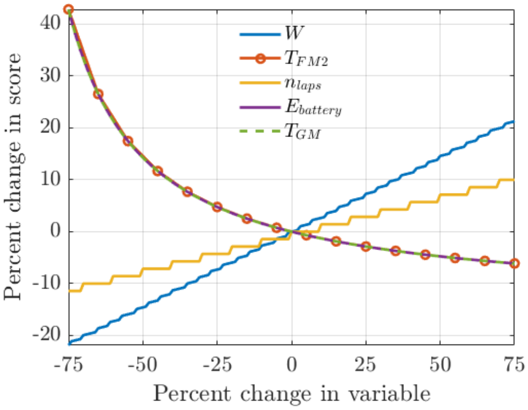

Figure 3: Sensitivity analysis on % change in final score due to parameters

capacity, and finally increasing the number of laps in FM3. Using this information, the design of the aircraft should be easily reconfigurable to increase the ground mission score, be capable of high speeds to increase FM2 score while simultaneously increasing the number of laps in FM3, and carry large loads for both FM2 and FM3, while simultaneously being energy efficient.

Using the results from the sensitivity analysis and mission requirement breakdown, a preliminary conceptual design was produced, shown in **Figure 4**. Tail weight is minimized to increase payload-to-AGW ratio to 0.2; two carbon fiber (CF) tubes support the tail surfaces while minimizing drag, energy consumption, and torque during deflections. The fuselage will consist of a 4.5” wide and 27” long hollow body. This design provides a 4" by 4" by 18" internal space for 2 crew members and a maximum of 21 passengers; this yields a payload weight of 2lb and AGW of 10lb which falls under the wing's lifting capabilities. A cockpit door and two side hatches will permit access to the crew and passenger compartments, respectively. The crew and passengers will be restrained in flight by removable plastic inserts 1.75” tall which will be secured to the floor and conform to the shape of the passengers, thereby preventing their movement or contact with other parts of the plane. The quickly accessible hatch and inserts reduce the GM task time. Bent aluminum flat bars with foam wheels will be used to make landing gears in tricycle configuration, attached to the bottom of the fuselage.

In flight configuration, the Clark-Y airfoil will be 5' with a chord length of 11”. This airfoil and size was selected for its high Cl/Cd ratio of 98.7 at $\alpha = 3.75°$, permitting the aircraft to cruise at 36 mph at maximum takeoff weight (MTOW); at this speed and α, the aircraft can complete 3 laps within 5 minutes, considering winds common in Wichita, KS. To fit within the 2.5’ parking spot, the wing's spar pivots on a central nut which retains wing integrity by a single CF tubular spar while also reducing the time taken for reconfigurations in the GM. To transition into parking configuration, the wing will be manually rotated clockwise. To return to flight configuration, the wing will be manually angled perpendicular to the fuselage and latches will be engaged to prevent the wing from torquing. A conventional tail was selected for its low surface area (hence low drag) and strong structural integrity.

A maximum thrust-to-weight ratio of 0.86 will allow for a maximum speed of 55 mph in the event of sudden 40 mph gusts, and allow for takeoff within 20ft. PROPDRIVE 4258 500KV nose mounted motor will be used with a 6S LiPo battery and 14x7E propeller to provide such thrust-to-weight ratio. MG90 servos will be used for control surfaces, and flaps will be used for additional lift during the 20ft takeoff.

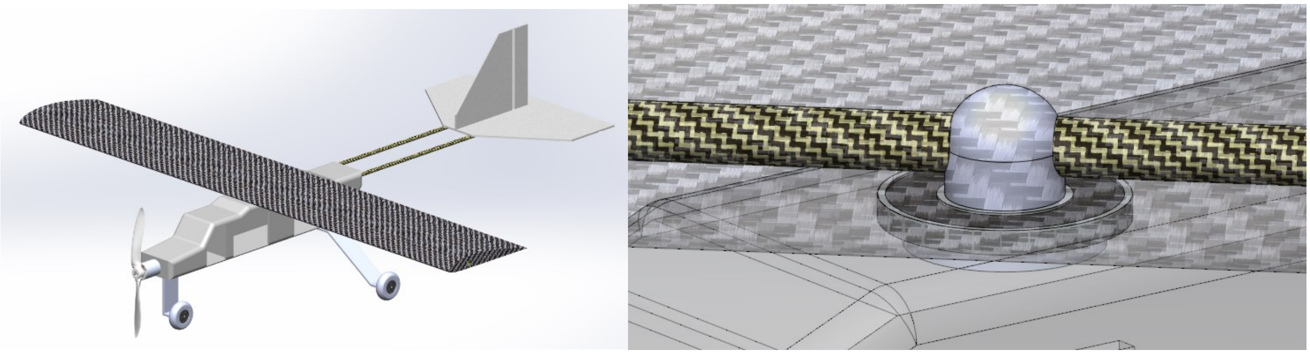

Figure 4: Conceptual model of structure of competition plane with hatch positions shown (left), and the central nut rotation mechanism for the wing (right)(wing and fuselage made partially transparent).

Manufacturing Plan

The manufacturing plan is optimized to closely integrate the design and testing phases together, shown in **Figure 5**. Once the first revision is made, results are directly fed back into the design so that a quantitative improvement is observed in the second revision. CAD designs are vital to this process because they provide precision and repeatability when the subsystems are fabricated. Computer simulations will be carried out to assist with material selection and design, which helps keep manufacturing costs down.

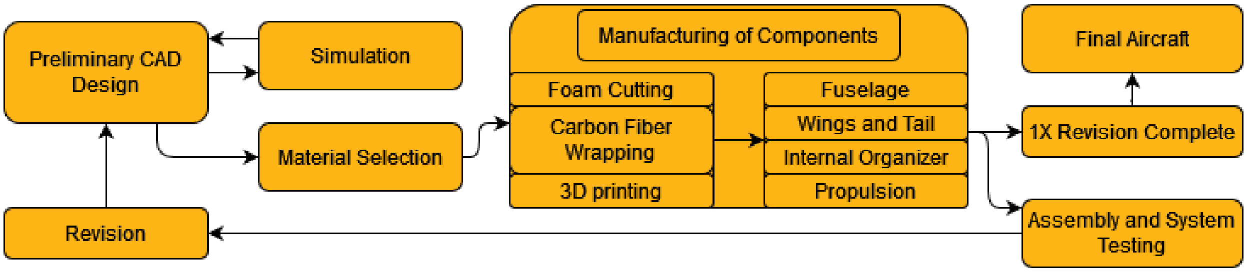

Figure 5: Manufacturing Flow Chart

The conceptual design called for favoring high efficiency and high payload carrying capacity. This decision necessitated the use of lightweight and rigid materials. Insulation foam epoxied with CF was selected for the wings because of its excellent strength-to-weight ratio. The carbon-fiber composite has unmatched characteristics under tension while the insulation foam provides the compressive strength. The fuselage will be produced with Foamular 250 epoxied with fiberglass to increase fuselage toughness and, unlike CF, allow radio communication with components inside the fuselage. The design makes use of specialty manufacturing techniques such as machining for the aluminum landing gear. 3D printing will be used to manufacture the passenger holder because of its intricate design. Vacuum bagging will be used to ensure that the resin completely impregnates the composite fabric, ensuring the strongest bond.

Testing Plan

Structural and mission-specific tests will be conducted to provide understanding about the plane's performance in the competition as outlined in **Table 4** in each phase of production as the team moves from initial design to the final aircraft.

Table 4: Major tests, their purpose, and the specific methodology of conducting the tests.

Tests	**Justification**	**Method**
Motors/ Thrust	Maximizes score in all flight missions by finding optimal motor/propulsion for our given design	Calculate motor efficiency based on design. Test static and dynamic thrust
Airframe	Prevents a loss of points from structural damage/component loss by ensuring that the plane will be intact throughout all flights	Plane frame will be filled with various weight and lifted at wing tips 5x beyond MTOW
Landing Gear	Ensures that a successful landing and takeoff can be done on the gear, a requirement for all flight missions	Incrementally apply weight to landing gear until landing gear handles plane MTOW + 5g's or fractures. Analyze and improve landing gear based off of max. weight
GM Test	Maximizes score in the Ground Mission by minimizing time to swap between configurations	Swap through all flight configurations. Passengers, EMTs, and Equipment also get loaded. CG is measured to make sure it stays in desired area in all configurations
Flight Performance	Optimizes plane for speed and time in order to improve all three flight mission scores, especially Missions 1 and 2	Plane flown to determine flight characteristics (flight speed, maneuverability, takeoff distance, turning radius) for various weights and all configurations
Flight Endurance	Reduce battery consumption during Mission 3	Plane flown at various weights in all configurations. Flight performance analyzed for max. distance for least battery consumption