Team M-Town Flyers Design, Build, Fly Competition

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The overall objective for the 2023-2024 AIAA Design/Build/Fly competition is to successfully develop a remote-controlled aircraft capable of executing electronic urban air mobility missions within the given parameters provided by the AIAA. The University of Memphis's AIAA DBF team, M-Town Flyers, conducted research and analysis in order to maximize payload, speed, and strength in the design of the aircraft for this competition. The runway distance is limited to 20 feet with a maximum battery capacity of 100 Watt-hours. The aircraft and necessary components must fit within a parking space of 30 inches in the aircraft's parking configuration and have a total wingspan of less than 60 inches. The missions consist of completing 3 laps around the designated flight course with a 360-degree loop in the middle that will be scored based on both the time to complete 3 laps and how much weight and passengers that are able to be carried. Considering these rules and constraints, the planned approach to fulfill these objectives is to design a lightweight yet durable airplane that can take-off within the runway constraint. Accordingly, a dual motor driven aircraft with a rectangular high wing design and a Clark Y airfoil was chosen for these missions. These decisions will be fitted around a hinged balsa and plywood fuselage construction to fit within the 30-inch parking space while allowing an increase in stability and durability compared to a hinged wing. In relation to the structure and development of the physical aircraft, the necessary calculations will be performed and evaluated as the team progresses through the production of the aircraft to align within the AIAA parameters and limitations. With the current design, it has been determined that the third mission, which is scored based on time and the number of passengers being carried, will be the main focus as the fuselage is being designed to hold a large number of passengers. With these design parameters and missions considered, the final design for the aircraft will be lightweight to take off within the runway constraint but also be stable enough to ensure a safe flight for the necessary cargo for each flight mission.

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I. Executive Summary

This report details the design, fabrication, and testing of the University of Memphis M-Town Flyers' aircraft for this year's American Institute of Aeronautics and Astronautics (AIAA) Design Build Fly competition. The team's objective is to manufacture an unmanned, electric powered, radio-controlled aircraft that successfully demonstrates Urban Air Mobility by medical transport and urban taxi missions. The M-Town Flyers designed an aircraft capable of achieving all objectives and requirements detailed by the DBF flight missions and rule book. To maximize the team's mission scores the design efficiently maximizes payload weight, minimizes aircraft assembly time, and maximizes thrust for the three air missions and singular ground mission. The team carefully researched and determined the design that would most optimize the aircraft's capabilities.

The aircraft design is modeled after short take-off and landing (STOL) aircraft due to their light yet durable structure and short runway take-off and landing capabilities. To achieve this model, the aircraft consists of a dual motor driven aircraft with a rectangular high wing design and a Clark Y airfoil with a tail dragger landing gear. These components will be fitted around a hinged balsa and plywood fuselage construction to fit within the 30-inch parking configuration. The hinged fuselage will allow for an increase in stability and durability compared to a hinged wing. The dual motors were chosen to create enough thrust for the shortest possible take-off. The thrust for a single motor is around five pounds, therefore the two motors combined give 10 pounds of thrust. The Clark Y airfoil was chosen for its high lift coefficient of around 0.95 for the represented angle of attack. The tail dragger landing gear will increase the angle of attack by 3-5 degrees. The aircraft will be made up of mostly plywood and maple wood with carbon fiber to help support the wing's structure.

II. Management Summary

The University of Memphis *M-Town Flyers* Design / Build / Fly team is made up entirely of members of the university AIAA student branch and advisors. The team consists of 4 senior members, 2 underclassmen members, a mechanical engineering faculty advisor, and an alumnus engineering mentor with experience in the model aircraft field. The faculty advisor oversees the AIAA organization, offers project management advice, and interfaces directly with the mechanical engineering department. The team leader oversees and approves all actions including, but not limited to, overall design of the aircraft, team organization, research plans, and project budget. The remainder of the organizational structure consists of a design lead, a propulsion/manufacturing lead, an avionics/mechanisms lead, an aerodynamics lead, and a simulations lead. Major milestones yet to be completed include Flight Tests, final competition flight mission checks, and the Design/Build/Fly (DBF) competition.

III. Conceptual Design

A. Mission Requirements

When selecting design configurations, the general requirements and mission scoring rules were analyzed and broken down into sub-system requirements. A sensitivity analysis was performed to determine the design characteristics that would have the greatest effect on mission scoring. A decision matrix analysis was performed for key design configurations to select optimal configurations.

For the 2023-2024 competition, the aircraft theme was urban air mobility. There are a total of four missions that must be completed, with three of the missions being flight missions and one being a ground mission. The flight missions are as follows: one flight to show the capability to complete 3 laps around the designated track while the crew payload is inserted (M1); one flight to simulate patient and medical supply transport with a crew, patient, gurney, EMTs, and medical supply cabinet payload (M2); and one flight to simulate general passenger transport with a crew and passenger payload (M3). The ground mission is to demonstrate ease of access of the passenger and crew compartments as well as the speed at which the aircraft can be changed from parking to flight configuration.

Before each mission begins, the airplane must enter the staging box in the parking configuration with the propulsion battery removed. Afterwards, the ground crew assembly team member will then have 5 minutes to change the plane into its flight configuration and install the propulsion battery, crew, and payload that will pertain to the mission that is about to be performed. Each mission will also be performed with a varying number and type of wooden peg dolls to simulate crew, EMTs, a patient, and passengers.

B. Scoring Sensitivity Analysis

A sensitivity analysis was performed for the 2 missions that the overall design will attribute to the most, those being M2 and M3. From this it is determined that more focus will be put on M3 as it attributes to a higher overall performance score compared to M2. A parameter sensitivity analysis was then performed and for the 2 main parameters in M3 being the number of laps flown and the number of passengers, to see which would lead to a higher score as these parameters are increased compared to the other staying the same. From this it is concluded that a focus in laps flown would be more beneficial to increase the mission score. Through ecalc propellor calculations, it is observed that the overall change in weight as the number of passengers increases to capacity max will not affect flight speed as much as it will affect how fast the airplane will need to go to take off. This should be accounted for given the 20 feet take off that is required.

C. Considered Concepts and Configurations

Numerous design parameters were considered between key configuration considerations. These parameters were specific to the configuration being considered and were weighted based on its importance for mission performance and were graded from 1-5. The total score of each parameter based on weighting times score were then compared where the highest score becoming the selected configuration. The manufacturability of each configuration was a parameter considered for each configuration since it would not be valuable to attempt to manufacture a configuration with the risk of making it improperly for minimal gains in performance.

A rectangular wing and delta wing configuration were considered. The two main parameters to be considered were the lift and drag from these two wing configurations. These two were weighed the highest due to the flight mission requirements to take off within 20 feet calling for a high lift for a faster take off and needing to make a 360 degree turn in the middle of the flight path calls for drag to be minimized so that the maneuverability of the plane is not compromised. Weight was considered since a lower weight airplane weight will help improve flight mission performance. The conventional rectangular wing configuration was chosen due to it having lower drag than the delta wing when making sharper turns and it being much easier to manufacture by the team.

A single and twin-engine configuration was considered for propulsion. The two key parameters being considered were how it affects flight stability and flight speed. Flight stability is a key consideration due to the payload for M2 and M3 being EMTs, a patient, and passengers that need to remain relatively unbothered during flight. Flight speed was also a key consideration since faster flight speeds will help mission score. A twin-engine configuration was selected due to its superior flight stability as the payloads within the passenger compartment need to have minimal movement to avoid any mission failures.

The team considered two airfoils: the Clark-Y and the NACA 23012. The parameters considered were the airfoils' lift and drag coefficients. Lift and drag need to be weighed to make sure that we can maximize weight carried on M2 while remaining maneuverable during flight to complete each lap as fast as possible. A high lift to drag ratio at desired angles of attack for launch angles was looked at to make sure the airplane could achieve a short take off. The Clark-Y airfoil was chosen due to its superior lift to drag coefficient ratio at the desired angles of attack during launch.

The team considered a tricycle and tail dragger landing gear configuration. The parameters considered were the drag caused by a fixed landing gear, the takeoff speed, and the weight. Drag was considered to ensure that the landing gear would not hinder flight performance. Takeoff speed considered the loss in speed while moving along the ground and the launch angle that could be achieved more easily by each configuration. Weight was also considered while considering the launch angle desired from the landing gear and how much added weight it would be to achieve those angles. A tail dragger configuration was chosen due to it weighing less while trying to achieve higher launch angles for a shorter take off. The final conceptual design for the *Flying Tiger* is a rectangular wing, twin engine airplane with a tail dragger landing gear and a Clark-Y airfoil.

IV. Preliminary Design

A. Design and Analysis Methodology

The design methodology was heavily influenced by last year's University of Memphis competition, other colleges, mentors, and faculty. The AIAA rulebook and requirements were first thoroughly investigated and noted. Once this was completed, the team discussed ideas presented by the team's mentor. Similarly built models, computer aided design (CAD and Fusion 360) 3D drawing, and blueprints showed the design's look. The propulsion estimation tool in eCalc was used in weighing and narrowing down the team's decision. During this process expected performance was analyzed to give a better judgement on our final preliminary design. Upon further analysis, large and slight changes were made to help overall performance. Figure 4.1 shows the preliminary design process the team undertook.

B. Trade-offs in Design and Sizing

The fuselage size was mainly dependent on the payload dimensions. The competition rules dictated the layout of the cargo and payloads that vary between missions. This held us to a set minimum dimension for not only the width of the entire fuselage, but also the forward half of the fuselage that holds this cargo area. This cargo section had to be wide enough to hold the entire payload without any component touching the walls of the aircraft. We constructed the fuselage have straight edges, which would make this easier to assemble, cover, and fit all of our payload in correctly in the most efficient layout.

We were not limited to our materials because there were no set thicknesses or types of materials required. With this in mind, we were able to strengthen a few points in the fuselage by using a thicker material in places that would be directly concentrated to the area of the payload placements and were able to use thinner materials to help reduce weight at other areas to ensure proper balance of the aircraft both on the ground and in flight. In doing so, another point of conflict we had a challenge to fight was the parking space configuration. The rulebook stated that while in its parking configuration on its own landing gear in the upright orientation, the aircraft must fit within a parking space that is 2 ½ feet wide. We had several ideas on how to approach this challenge, our first design choice was to fold the wing upward to meet this requirement. However, after further study, stress tests and models that more support would have to be inserted into the hinge joint that was now a high stress point for our aircraft. Our second design choice was to not fold the wing but instead, pivot the wing. The pivot would reside on the top side of the fuselage and the wing would be held down for flight with 4 rubber bands, allowing 2 on each side of the fuselage to secure the wing to fuselage. Unfortunately, after one of the Q&A sessions in regard to this competition, we learned that rubber bands were no longer allowed. We opted to try a threaded bolt alternative to the hold and support the wing. This idea too didn't last long in our brainstorm because we were unsure of the safety of the pivot joint.
On our final design, in order to meet our parking configuration, we decided to hinge the aircraft but in a different approach than most will. We decided to hinge the fuselage directly behind the cargo area so the aircraft will essentially fold onto itself. **Figure 1** shows a very basic understanding of how the aircraft will rest in the parking configuration. This allows the aircraft to meet this specification along with reducing any high stress points in the wing if we were to fold the wing. The fuselage pivot will be held together with a series of thread nylon bolts for ease of access in and out of the parking configuration.

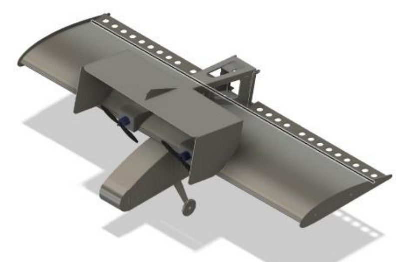

Figure 1. Aircraft Parking Configuration

In the competition rules, it stated a maximum wingspan of five feet. We decided to keep as close as possible to ensure we had enough surface area on our wings to ensure takeoff at the specified short takeoff distance. We used the maximum wingspan as our goal to maintain and focused on adjusting with the size of the rear tail to ensure balance, a proper flight path, and needed surface area to takeoff in the specified distance. More consideration was taken in regard to the proper airfoil choice to set the highest lift and attack angle we could with our current configuration.

V. Detail Design

A. Dimensional Parameters of the Final Design

Because the requirement is a sixty-inch wingspan maximum and parking space requirement of thirty inches wide, our team decided to approach our design with a simple hinged fuselage. Our aircraft has a wingspan of 58" and length of 54". Because of the parking space limitations, we had to have fuselage be able to hinge before the thirty-inch length or width requirement. To accommodate this, we decided to hinge the aircraft directly behind the cargo hold and split the fuselage into two main sections. The forward section would hold the majority of the weight and structure integrity because it is to house all of the cargo, battery, and majority of the electrical wiring and other electrical equipment needed for flight of our aircraft.

B. Structural Characteristics and Capabilities of the Final Design

Because the fuselage is meant to be split in half via a hinge, we designed a spar joiner to hold the two halves together, while providing torsional strength. Using a plywood spar joiner, fastened by 8 nylon bolts, washers, and nylon nuts, the fuselage sections are held together by the grip of that hinge. The rectangular spar joiner acts as an extension of the normal wing spar but is not connected to the lower web of the I-beam on either side. We determined this to be an acceptable tradeoff, as this portion of the fuselage does not experience a great deal of stress. This plywood hinge which serves to prevent rotation of the wing sections and hold the fuselage sections together should be strong enough to withstand any shear stress we may encounter in flight. Carbon fiber was chosen elsewhere, due to its stiffness and light weight construction in the wing to also prevent shear stress pr torsional stress in our flights.

The main spar for the aircraft is an I-beam with a balsa web and basswood flanges. Because the web does not encounter as much stress as the flanges, it can be made of lighter material, such as balsa. To improve the strength of the ribs, the spar webs are cut between each gap. The shear and moment calculations for the wing spar based on a 5lb airplane weight distributed over a 58" beam, plus a 2.5lb point load at mid span are shown in ***Figure 2*** and ***Figure 3*** below.

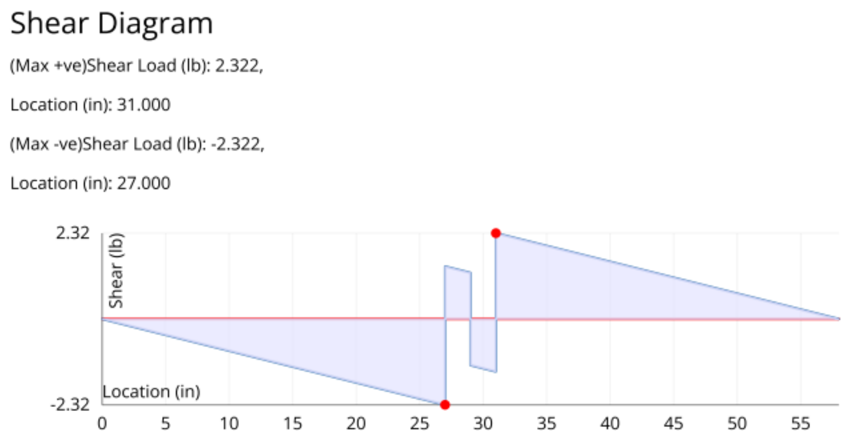

Figure 2: Shear Diagram

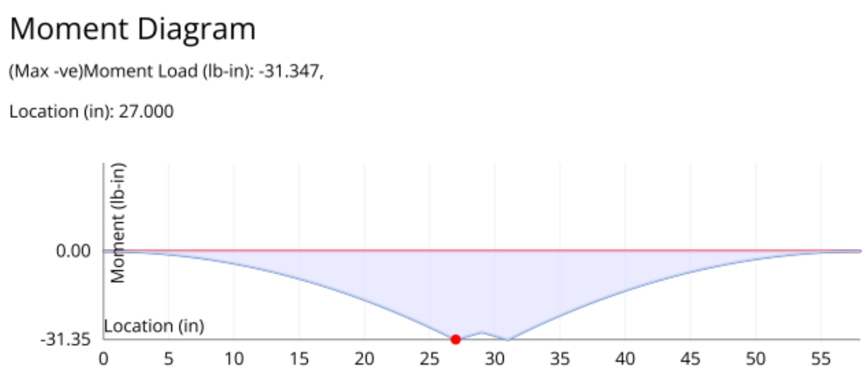

Figure 3: Moment Diagram

To get a better understanding of the stresses and deformation that will take place with the wings at max loading, finite element analysis is done using NX. The cross section of the wing is taken and extended to half the length of the total wingspan. From this, we utilize the predicted load of the cargo chosen for each mission and a calculated air resistance force with the known mechanical properties of balsa wood to find the deformation and stress. The mechanical properties used for the model are density, 130 pounds per cubic inch, and the modulus of elasticity, at 538 kpsi. The displacement diagram is shown in ***Figure 4*** and the Von Mises stress diagram is shown in ***Figure 5***.

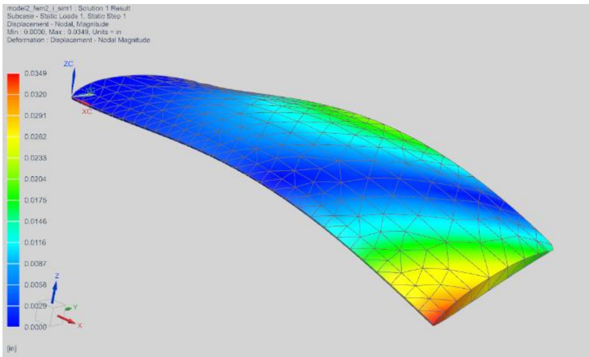

Figure 4. Displacement

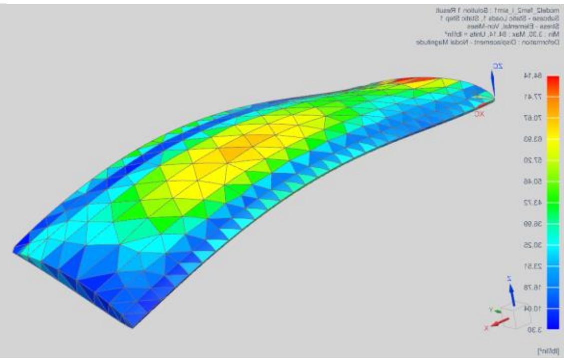

Figure 5. Von Mises Stress

According to our data, the max displacement in which the wing can take is .03 inches, with weak spots at spot of PVC placement and the back of the airfoil where air resistance will be greatest with the loads prescribed. The value at which the material will yield, Von Mises stress, is shown to be 84 psi. The spots at which the wing will yield are at the spar joints and in the middle of the wing closer to the PVC load.

VI. Manufacturing Plan

The *Flying Tiger* consists of maple, balsawood, and plywood, which was determined to be the most cost-effective and accessible resource to use for aircraft buildup. The maple wood and plywood, while sparsely used contributed to strengthening the aircraft while the balsawood makes up majority of the aircraft buildup. With the missions having varying payloads, the wooden construction allowed the aircraft to minimize weight and maximize payload capacity for the competition.   CNC Machining was used for creating each component made from Balsawood and Plywood. This method of cutting out the parts proved to be more accurate than cutting parts by hand. Hand cutting parts took more time consuming and deemed to be less accurate than using 2D drawings to cut parts in the CNC Machine. The CAM for the CNC was created using SolidWorks provided by a member of the team with experience in the software.

Once the wooden parts were cut and sanded, we used extra foam board cutouts from the prototyping phase to align and glue the parts. This method of joining the components of each part of the aircraft proved to be much better than without. Attempting to freehand build the aircraft and holding parts in place while trying to glue and clamp led to wasted materials and was more time consuming. Allowing the parts to remain in the foam board allowed the team to let the glue dry while being able to work on other components of the plane build.

The wings components were cut using the CNC machine, containing Plywood, Balsawood, and 2 carbon fiber rods purchased to improve the rigidity of the wing. After cutting out each component, we sanded the inner holes and edges of each component to ensure servos, wiring, and other internal parts would fit flush and snug. We started this process by first attaching and glueing the shear webs using Cyanoacrylate glue and Wood glue to the leading and trailing edge. Next, the team began to place the spar caps and shear web caps along the top and bottom portions of the wing using glue and clamps. Then, using 1/16th inch plywood to sheet the top and bottom portions of the wing while keeping the middle portion open to allow for wiring of the batteries and servos. We assembled the wing in 3 parts, being the left, middle, and right portion of the wing and joined them with glue and the carbon fiber rods inserted through each.

For the Fuselage and Tail of the aircraft, a CNC machine was used to cut Plywood and Balsawood, like the wing. However, the fuselage also contains pieces of Maple wood in the front and back for added strength and rigidity. We began by using the creating the fuselage and “snapping” all the parts together in the corresponding holes created in the pieces. We joined most pieces of the fuselage using Cyanoacrylate with a few being joined by Wood Glue to create a stronger bond for the back and top joints attached to the tail and wing. We created a hinge for joining portion of the tail and fuselage for the aircraft to meet competition standards of the parking configuration size.

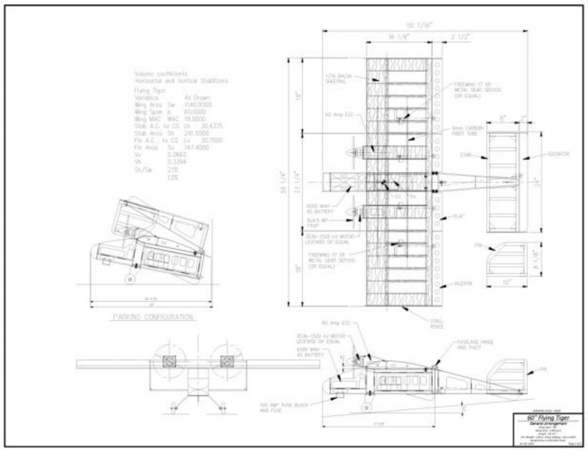

Figure 6. Aircraft Dimensions

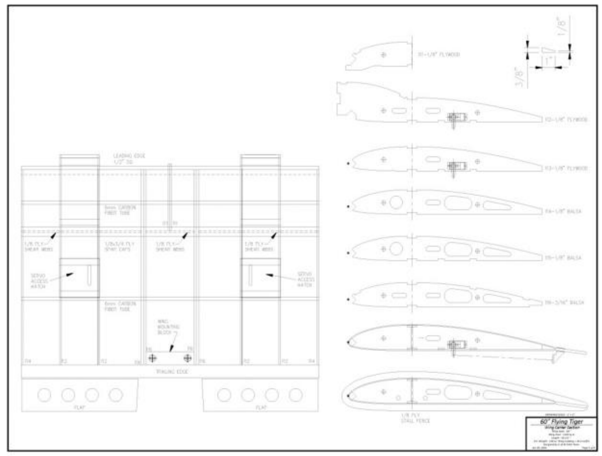

Figure 7. Wing Cross Sections

VII. Testing Plan

A variety of tests were conducted on the aircraft's materials and components throughout the period of prototyping and during final building phases. The goal for testing was to validate predicted performance and evaluate design decisions through analysis of acquired data.

The testing phase of the aircraft components and performance is designed to ensure that all aspects of competition missions and rules are within calculated specifications. The testing objectives for the *Flying Tiger* are defined in by different phases of testing as follows: structural testing, performance testing with a testing checklist for each phase.

To perform structural testing for the *Flying Tiger's* wing, we used blocks to elevate the wing at the wing tips. Then, began to add weight to the middle of the wing to determine how much weight the wing would withstand before deflecting enough to crack the wood. This test was performed by placing a concentrated load in the center of the wing. We also tested the wing for overall stiffness by placing weight along the entire span of the wing.

Using motor stands, placing our Leopard 3536-5T 1520 Kv motor and connecting to the battery, we were able to confirm and evaluate performance on take-off, in-air, and the effect of different payloads on the premise of having two identical motors attached to the top of the wing.

To manage all testing throughout the year, the timeline was developed to keep track of progress. The checklist was utilized during all applicable testing of the aircraft during the final build construction phases. These checklists ensured safety, reliability of the aircraft, and compliance with the competition requirements.

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