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Systems Engineering in Zips Aero Design

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SYSTEMS ENGINEERING IN ZIPS AERO DESIGN

By

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Final Report for 4600:001 Senior/Honor Design, Spring 2024

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Abstract

This project entails the implementation of systems engineering to the Zips Aero Design team at the general member level. This project demonstrates the skills obtained through the University of Akron along with co-op experience which are applied to a large-scale team for streamlining the process for design and manufacturing. Documentation, organization, and communication were important factors for the success of this project and to be able to qualify for the 2024 AIAA DBF competition. By implementing systems engineering to the team, this will help to design a new aircraft per AIAA rules and allow for the development of design and manufacturing methods.

Overall, the project was able to create a new design and manufacturing methodology for the team. The team demonstrated efficiency and was able to complete all tasks before the competition in a timely fashion. The aircraft was successful at competition and ranked 4th out of 106 schools that competed. Unique mechanisms such as the wing locking device were developed under the management of systems engineering along with new manufacturing methods such as composite layup for the buildup of the aircraft's fuselage. The implementation also organized all the data for the aircraft which was used by the team at a general member level.

Contents

1. Introduction

This report outlines the design, manufacture, and test methodology of *the final design aircraft*: The University of Akron's aircraft entry for the 2023-2024 American Institute of Aeronautics and Astronautics (AIAA) Design/Build/Fly (DBF) Competition. The Zips Aero Design Team developed the final design in accordance with the requirements set out by this year's series of missions focused on showcasing Urban Air Mobility (UAM). An iterative design process was employed to optimize the aircraft's performance and configurability for each of the three Flight Missions in addition to Ground Mission. Prior to each flight, the aircraft will enter the staging box in parking configuration. From this state, the aircraft must be reconfigured for its flight mission in five minutes. Mission 1 (*M1*), a Delivery Flight with only the Crew present, will demonstrate the aircraft's flight worthiness by completing three laps and a successful landing within five minutes. In Mission 2 (*M2*), a Medical Transport Flight, the Crew, EMTs, Patient on Gurney, and Medical Supply Cabinet will be installed into the aircraft and three laps will be flown in as little time as possible, thereby showcasing the optimization of payload weight and speed. Mission 3 (*M3*), an Urban Taxi Flight, will further exhibit *the final design*'s payload interchangeability and endurance with Crew and Passengers loaded. The aircraft will balance speed and payload volumetric capacity to complete as many laps as possible within five minutes. Successful completion of all flight missions requires the aircraft to takeoff within 20 feet and land successfully. Lastly, Ground Mission (*GM*) consists of the assembly crew member quickly changing between mission configurations in as little time as possible, beginning and ending with the aircraft in parking configuration.

As shown in Figure 1, *the final design's* semi-monocoque fuselage maximizes the volume of the passenger compartment and electronics bay. A single motor provides adequate thrust for all flight missions and weighs less than a multi-motor configuration. A 5-feet low-mounted folding rectangular wing provides ease of payload loading and fulfills parking requirements. A tricycle landing gear was selected to reduce takeoff distance, and a V-tail was chosen to prevent tail-strikes. *The final design* was constructed using a wide array of materials, including balsa wood, carbon fiber, fiberglass, and low-density polystyrene foam - many of which were paired to create various composite structures to achieve a higher strength-to-weight ratio and a more robust airframe. Manufacturing processes included laser cutting, foam cutting, 3D printing, composite layups, and metalworking.

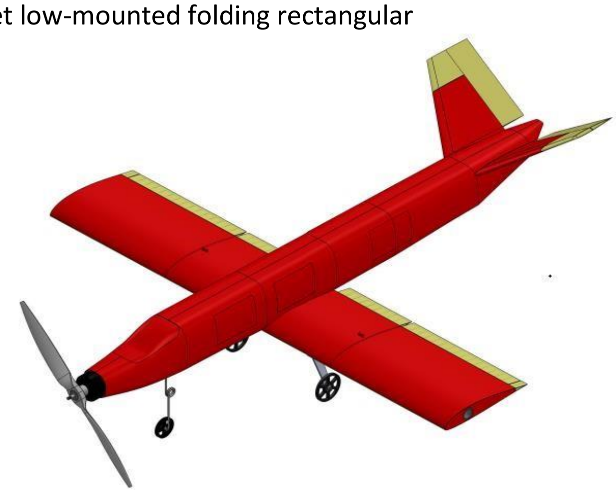


Figure 1 Model of the final design

1.1 Organization of the Team

The top level of student management are the *officers*, consisting of 3 *co-captains* and a *treasurer*. *Officers* guide team decisions, facilitate communications between members, and oversee travel planning and other expenditures. Next on the leadership tree is the ***Systems Engineering Team***, which is composed of two *Systems Engineers* (Mathieu K. and Benjamin S.). In addition to breaking down competition rules, deriving requirements, and organizing design reviews, this team plays a crucial role in uniting discussions amongst subsections to verify proper aircraft systems integration. Though it is an integral part of team dynamics and occurs persistently, Systems Engineering efforts are reviewed weekly as part of Integrations Meetings led by the *Integrations Manager.* Another level of leadership, *subsection leads*, includes the following: *wing*, *fuselage*, *avionics*, *tail*, *landing gear*, *payload*, and *math*. Each lead is responsible for assigning tasks to interested *general members* and working alongside them to meet scheduled design milestones, testing plans, and manufacturing goals for their respective subsection. The table below summarizes the skills and requirements for each position on the team which was developed by the systems engineers.

Role	Skills	Role Requirement
Captains	Leadership, Organization, Communication, Teamwork, Technical Writing	Organize meetings and ensure tasks are completed in a timely manner. Oversee major tasks and support sections that need help.
Treasurer	Organization, Microsoft Suite, Technical Writing, Communication	Manage finances with the team and communicate with the University of Akron pertaining any purchases.
Systems Engineering Team	Analysis, Model-Based Engineering, Technical Knowledge, Technical Writing, Organization, Communication	Organize meetings while communcating with section leads to assure the project integrates together seemlessy. Prioritize tasks for each section and support any sub-section.
Section Leads	3D Modeling, Technical Knowledge, Leadership, Analysis	Distribute tasks and guide support members to create models and manufacture parts of the aircraft. Find solutions to problems and communicate them to systems engineers or captains.
Support Members	Multi-tasking, Research	Support section leads in creating 3D models and in any manufacturing task. Support members may switch to different sections where support is needed.

Figure 2 Table of skills and roles require for each position on the Zips Aero Design team

2 Design

The design of the aircraft will be optimized to obtain the maximum number of points for each mission. Mission 1 is the verification flight for the aircraft where it needs to be able to fly without payload and be able to take-off and land successfully. Mission 2 is the heavy payload application where the aircraft needs to be able to carry as much weight as possible while maintaining velocity and stability. Mission 3 the aircraft must optimize its space inside the fuselage to carry the most amount of wooden figurine passengers with the smallest possible battery in order maximize the mission's score. The systems engineers developed a series of matrices to support members in the decision-making process for each component of the aircraft. Below is the decision matrix for the type of wing mounting for the aircraft.

Wing Mounting Considerations				
Characteristics	Merit	Low	Mid	High
				
Maneuverability	3	5	4	3
Payload Capacity	4	5	1	5
Structural Integrity	4	4	3	1
Assembly	2	4	1	4
Stability	2	1	3	5
Total Merit	-	61	36	51

Figure 3 Decision matrix for wing mounting

A low-mounted wing was selected primarily due to its benefits in maneuverability and structural integrity. High and mid mounted wings are less favorable in this competition, due to the volumetric *M3* payload and Medical Supply Cabinet occupying space where structure would need to be. The low-mounted wing is the least stable, but it performed better in other aspects regarding mission-specific conditions. Tip dihedral was implemented to mitigate adverse effects associated with the inherent instability of the low mounted wing. The next matrix was used to decide the shape of the wing, and which one would be optimal for all the missions.

Planform Shape				
Characteristics	Merit	 Elliptical	 Tapered	 Rectangular
Aerodynamic efficiency	3	5	3	1
Manufacturability	5	1	3	4
Stall characteristics	3	1	3	5
Effective area	3	5	3	1
Total Merit	-	38	42	41

Figure 4 Planform decision matrix table

Multiple parameters were evaluated in wing planform selection, such as aerodynamic efficiency, manufacturability, stall characteristics, and effective area. All planform shapes are depicted in Table 4. After analysis, a partially tapered wing was chosen due to its increased efficiency and similar stall characteristics to a rectangular wing, while not drastically increasing the difficulty in manufacturing. Then material for the fuselage was considered in terms of weight versus strength, which the table below shows.

Fuselage Considerations				
Characteristics	Merit	Built Up	Plywood Skin	Composite Skin
Weight	3	3	1	2
Structure	4	1	2	3
Ease of Access	2	1	2	3
Complex Geometries	1	1	2	3
Total Merit	-	16	17	27

Figure 5 Fuselage material decision matrix table

Upon inspection of the fuselage decision matrix, it was decided that the most efficient fuselage design would be made through a composite skin layup with internal bulkheads and stringers. With the design being moderately light, the fuselage would provide structure from the significant weight of the Passengers used in *M3*. This design would also allow for ease of access for Ground Mission, as well as the 5-minute assembly time. Next the landing gear configuration was considered to carry all the payload and allow for smooth take-off and landing.

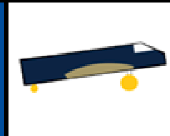
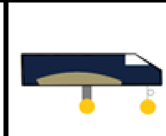
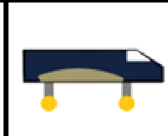
Landing Gear Configuration				
Characteristics	Merit	 Taildragger	 Tricycle	 Quadricycle
Weight	4	3	2	1
Taxi Control	3	3	4	2
Takeoff Performance	5	2	4	3
Manufacturability	1	2	4	3
Prop Clearance	3	4	2	2
Drag	2	3	2	1
Total	-	51	54	36

Figure 6 Landing gear configuration decision matrix table

Based on the decision matrix, a tricycle configuration was selected. The tricycle was selected because of its superior takeoff rotation, landing flare, taxi control performance, and comparatively low weight. Different tail configurations were also considered for each mission case.

Tail Configuration					
Parameter	Merit	 Conventional	 V-Tail	 H-Tail	 T-Tail
Weight	5	3	4	2	1
Complexity/ Manufacturability	2	3	4	2	1
Drag	3	4	3	3	3
Yaw Maneuverability	1	4	2	4	4
Pitch Maneuverability	4	4	4	4	4
Structural Integrity	6	4	4	3	1
Total Merit	-	77	79	61	42

Figure 7 Tail configuration decision matrix table

Based on the table, a V-tail was chosen because it offers excellent pitch control at a light weight. Despite its shortcomings compared to a conventional tail on the figures of yaw control and drag, the weight and ease of manufacturing outweighs these shortcomings. In terms of avionics, the number of motors was considered for efficiency and static thrust.

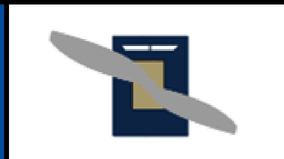
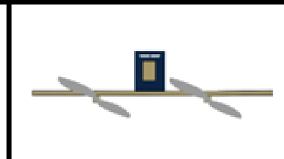
Motor Configuration			
Characteristics	Merit	 One Motor	 Two Motors
Weight	4	4	2
Static Thrust	5	2	4
Drag	2	3	2
Integration	3	4	1
Efficiency	2	3	4
Cost	2	4	3
Total Merit	-	58	49

Figure 8 Motor configuration decision matrix table

The single motor configuration was selected because of its simplicity, low weight, and ease of integration into the fuselage. A tractor configuration of the motor was selected from previous competition experience and simplicity in integration. A lithium polymer (LiPo) battery was chosen for its superior energy density and discharge rate. Maximizing the thrust overshadowed the weight increase from a larger motor and battery. A high cell count battery was selected to lower the current draw while producing peak thrust. For the wing, an airfoil needs to be selected that will suit all three mission requirements, which will have a balance between heavy lifting and minimal drag.

Airfoil Selection			
Parameters	 SD-7062	 ARA-D 10%	 Clark-Z
t_{MAX}	14%	10%	11.80%
$C_{l_{MAX}}$	1.61	1.70	1.58
$C_{d_{MIN}}$	.015	.015	.017
$MAX\left[\frac{C_l}{C_d}\right]$	100	82	102
α_o	-4	-4	-4

Figure 9 Decision matrix table for different airfoils

The initial phase of airfoil selection involved researching different airfoils and their characteristics. The conceptual design results showed that the most optimal aircraft must be capable of high speed, high efficiency, high payload capacity, and structurally sound to excel in all missions. The desired maximum lift coefficient was 1.55 due to the need for high lift to attain the short 20 feet takeoff requirement. The L/D vs α plot needed to have a wide range of efficient α values, as the aircraft is anticipated to fly at a wide range of AOA. Though a thicker airfoil is less energy efficient, it allows room for adequate structure in the wing and a hinging mechanism. For each airfoil, MATLAB and XFoil were used to perform calculations using the text file from Airfoil Tools. Once all configurations have been determined, then the design process for the aircraft begins in terms of integrate each part and assuring that the aircraft is qualified for competition.

2.1 Preliminary Design

2.1.1 V-Tail Preliminary Design

The planform area for the V-Tail configuration was determined using the volume ratio method. The intention of the tail design is to allow the aircraft to remain stable at a very wide range of speeds. This allows for very strong pitch maneuverability and high resistance to crosswinds. The horizontal and vertical volume ratios were found to be .65 and .1 respectively using the equations below.

$$V_v = \frac{S_v * l_v}{S_w * b} \qquad V_h = \frac{S_h * h}{S_w * c_{MAC}}$$

For weight and balance reasons, the $MACwing$ to $MACTail$ distance is 3 feet for a CG location of 28% wing chord. Solving for horizontal planform area yields 1.0775 square feet, providing sufficient pitch stability in the wide range of speeds flown. With proper CG location, the aircraft will maintain stability in each flight mission. The vertical planform area is .7957 square feet for directional stability, due to the length of the fuselage. The length of the fuselage was the deciding factor in vertical tail size as there is a very high cross-sectional area susceptible to cross winds and directional stability is required. The sizing for the tail was done as if it were a conventional tail and then was converted to a V-Tail using trigonometry as detailed in the figure below. The control surfaces compose 50% of the area of the tail to allow for rapid changes in direction while also maintaining directional and pitch stability.

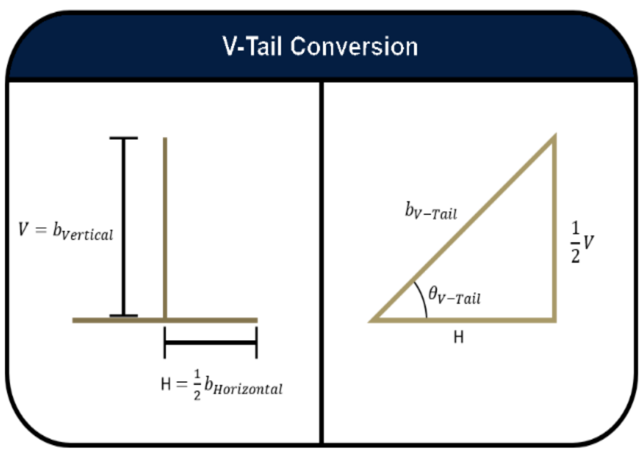


Figure 10 Calculations for the V-tail design

Figure 11 Prototype tail design

2.1.2 Landing Gear Preliminary Design

Landing gear sizing was based on four constraints: height, width, tail strike prevention, and taxi control. The landing gear must be tall enough to provide propeller clearance, and to avoid a tail strike on takeoff and landing. During takeoff, the wheelbase must be wide enough to prevent torque rolls. For taxi control, the percentage of aircraft weight borne by the nose wheel should be between 8-15%, in accordance with Raymer. *The prototype's* landing gear is 9 inches tall, providing 1⁄2-inch propeller clearance with the maximum anticipated propeller diameter of 22 inches. The tail strike and tip back angles were 19° and 9°, respectively. The main landing gear (MLG) wheels were spaced 15 inches apart, and 2.1 inches back from the CG, and the nose wheel was 21 inches forward of the CG. The MLG is mounted with bolts passing through the wing into the fuselage, and the nose gear is mounted on the front solid bulkhead via commercially available Du-bro hardware. A view of the mounting system as implemented on the prototype. The figures below show the prototype design of the landing gear and the incorporation of the nose gear servo into the fuselage.

Figure 12 Prototype landing gear mounted to the prototype wing

Figure 13 Nose Gear Servo

2.1.3 Fuselage Preliminary Design

To give as much of the 5 feet limit to the wingspan, the goal of the fuselage was to be constructed as narrowly as possible, all while still being structurally sound and holding a competitive amount of Passengers for *M3*. Along with this design constraint, the Flight Crew must reside forward of the Passenger compartment, meaning the fuselage must be created so the front is tapered down and sectioned off from the other Passengers. An additional height was needed to route avionics beneath the floor because the wires cannot pass through the bulkhead separating the Passenger compartment from the Pilots. Due to a narrow width in mind and wanting to carry a sizable number of Passengers, the fuselage was also designed to be long, as depicted in the figure below. Extra length was needed at the rear of the aircraft to have space for the tail to mount. The preliminary dimensions for *the prototype* were 6 feet by 5 inches by 6 inches.

Figure 14 Prototype fuselage design

2.1.4 Wing Preliminary Design

The aircraft will have a wing planform area of 4.74 square feet and the wing control surfaces were sized to 20% of the root chord to allow for greater maneuverability of the aircraft. The taper provides an effective dihedral of 5˚. The wing will be foam core to aid in manufacturability and to reduce weight. The wing will be sheeted in 1/32" balsa and covered to provide torsional rigidity while aiding in repairability for the intense wind conditions anticipated in Wichita. A carbon fiber tube was selected to serve as the spar in the prototype wing's center section. The spar was sized to have a factor of safety greater than 5 when at maximum loading. The bending stress in the spar was determined analytically using the maximum anticipated wing loading. An in-house layup was performed for the wingtip spars due to the commercial unavailability of a tapered rod, as seen in the figure below. To find the strength of the tapered section spars, tests were performed. A factor of safety of two was obtained in the tip spars.

Figure 15 Carbon fiber spar layup design

2.2 Detailed Design

The final aircraft was optimized during the detail design phase by using the parameters specified in the preliminary design. Based on mission scoring and past competitions, the most successful aircraft are the ones that complete and optimize for all four missions efficiently. To achieve this, the final aircraft design will focus on weight-reduction, structural integrity, reliability, functionality, and performance. All the final aircraft parameters are outlined in the table below.

Parameters	Wing	Tail - R/L Stabilizers
Airfoil	SD7062	NACA0008
Span	59.50 in	10.68 in
Area	671.875 in²	96.12 in²
Taper	0.00%	50.00%
MAC	12.50 in	9.00 in
Mount Angle	0.00 deg	36.45 deg

Fuselage	Length	Width	Height	Weight
	67.00 in	5.75 in	6.00 in	2 lb 9.3 oz

Electronics	Receiver	Servos	Battery M1	Transmitter
	Spektrum AR8360T	HiTec HS-85MG	MaxAmps 2375 mAh 10S 87.87 Wh	Spektrum

Source Information	Propeller	Motor	ESC
Manufacturer	APC	T-Motor	Castle Creations
Model	24x12E	AT7215KV245	Phoenix Edge Lite HV 120

Figure 16 Table of final aircraft parameters

2.2.1 Detailed Wing Design

This aircraft's wing has been improved from the prototype to improve rigidity, accuracy, and assembly time. The design matrix for the wing planform was redone and concluded with the use of a rectangular wing instead of a wing tip taper. This decision was made due to issues with manufacturing the tapered section of the wing for *the prototype*. The slight decrease in aerodynamic efficiency due to this design change allowed for a simpler design. Switching to a rectangular planform area allowed for quicker and easier manufacturing. The design also included a straightforward hinging mechanism, allowing for a better Ground Mission score. Foam core carbon fiber ribs have been utilized to mount press-fit locking mechanisms in the wing. The carbon fiber ribs resist fatigue when assembling and manufacturing the wing. G-code aided in manufacturing many of these parts with high accuracy. The foam for the wings

was cut using a CNC foam cutter. 1⁄32-inch balsa was bent along a 3D printed mold of the wing's shape for more precise gluing. Ribs were cut out of the carbon fiber sandwich panel on the CNC router.
The team has spent many hours developing a mechanism that is lightweight, mostly hidden, and simple to allow for quick assembly and disassembly times. The system consists of a 3D printed slot that allows the wing to move on a rail-like mechanism. A mechanical locking mechanism prevents the wing from sliding off in flight. The load on the locking mechanism is transferred because the spar in the outer section slides into the center section. This simple mechanism is quick and repeatable, allowing quicker mission assembly time. Below are figures of the wing hinging mechanism that was introduced to be able to fit in a 2.5 feet parking space.

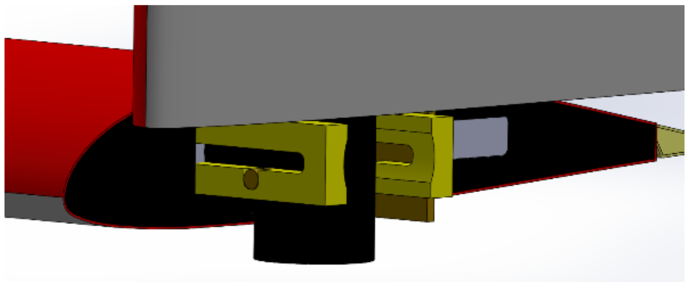


Figure 17 Wing hinging mechanism

Figure 18 Wing hinging device

Two 3D printed PETG blocks are integrated into the aircraft's wing. These blocks allow bolts to pass through them and into the internal structure of the fuselage. The fuselage sits flush on the wing's upper surface, allowing for repeatable mounting. The 3D printed blocks are mounted around the main spar and provide a flat location for the landing gear to mount to, which is shown in the figure below.

Figure 19 3D printed block for winging mounting to the fuselage

2.2.2 Detailed Fuselage Design

The fuselage was designed to be semi-monocoque, keeping the skin lightweight and sustaining a sound structure. The composite skin is comprised of balsa wood, fiberglass, and epoxy, adding carbon fiber to the nose of the fuselage. The stringers running down the length of the fuselage are made from 1⁄2-inch balsa in a carbon fiber sleeve. The bulkheads are made of Divinycell H80 PVC foam, sheeted with a twill carbon weave on both sides. The tail was adhered to the rear of the fuselage using skewers and epoxy. This adhesion method was utilized to create a simple, lightweight, and effective joint. The preliminary design allowed the team to create a baseline for the fuselage, and all interior components. Once completed, this design was iterated upon to help create the detailed design. This year, the dimensions of the aircraft's fuselage are 67 inches in length, 5.75 inches in width, and 6 inches in height. The internal structure consists of carbon fiber stringers, bulkheads, and the floor. The stringers are placed on the sides of the skin, with the floor 1⁄64-inch birch plywood and 1⁄8-inch balsa placed on top of them. Payload is supported by the floor and stringers. Additionally, the stringers are used as structure for the wing mount. All components were adhered to the fuselage composite skin using epoxy, except for the wing mount which used T-Nuts. Hatches were cut out of the composite skin for placing avionics, Flight Crew, and mission-specific payload in the aircraft.

2.2.3 Detailed Tail Design

The tail was designed for maneuverability and structure at high speeds. It was determined that a V-tail would best fulfill these goals without adding a large amount of weight. The control surface on each structure is 50% of the total surface area, allowing the aircraft to make tight turns and quickly change direction, without sacrificing much structure. The counterbalance comprises 25% of the total surface to reduce loading on the control servo and to prevent aerodynamic flutter. The stabilizer and the control surface were sheeted in 1⁄32-inch balsa sheeting and covered in Monokote covering to reduce drag. Below shows the figure for the final CAD design of the tail.

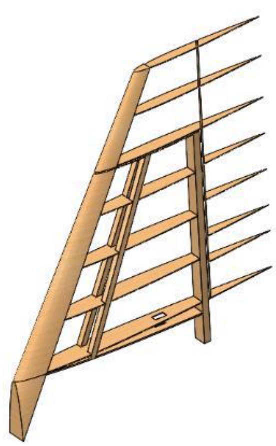


Figure 20 CAD model of the tail

2.2.4 Detailed Landing Gear

Several iterations of landing gear sizes were considered when transitioning from prototype to final design. The main landing gear is cut from .16-inch Al-7075 and then bent to shape, followed by heat treatment to achieve a T6 temper. The landing gear wheels are machined from high-impact ABS plastic and covered to reduce the drag from the cutouts. Using ANSYS Structural, a FEA of the main gear was created and shown is seen in the figure below. The figure represents the von-Mises stress at a 5-g loading. The stress is expected to be below yield. The nose gear pictured in the figure below is bent from a 3/16-inch 1065 spring steel wire. A torsion spring is placed halfway down the steering shaft to absorb shock from landing. Steering will be controlled by a HITEC HS-85 MG+ Mighty Micro Servo. Below shows the main landing gear FEA analysis which several iterations of it were performed along with the CAD model of the nose gear.

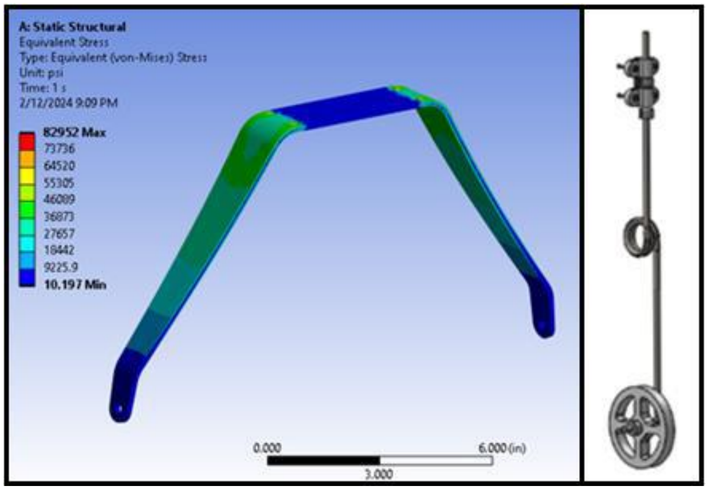


Figure 21 FEA analysis of the main landing gear with the CAD model of the nose gear

The mounting structure of the main landing gear was also used as the mount structure for the wing. Two nylon and two aluminum bolts were used to secure the MLG through the wing block into the fuselage. Each 1⁄4-20 bolt passes through a 3D printed PETG block into T-nuts mounted in the fuselage. A detailed assembly is depicted in the figure below. The Nose Gear was mounted to the front solid fuselage bulkhead below the Flight Crew. The nose gear material was made of commercially available Du-Bro mounting hardware as shown in the figures below.

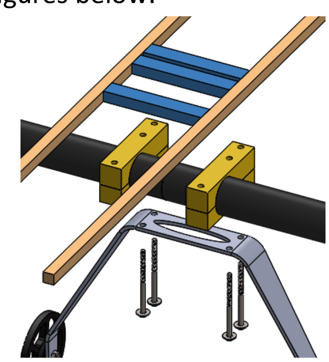


Figure 22 Landing gear integration

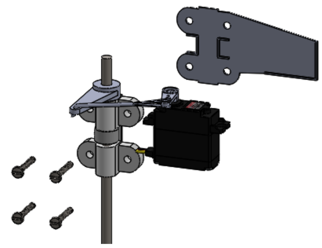


Figure 23 Nose gear integration

2.2.5 Detailed Avionics Design

It was also important for us the systems engineers to implement a chart and design for how the avionics would be placed inside the aircraft. This would help to make the payload integration more efficient and allow for more passengers to be carried. Each servo has an independent ground, power, and signal line for redundant operation if a single servo malfunctions. 26 AWG wire is connected from each factory servo lead to the receiver for power, signal, and ground. Standard 3-slot universal servo connectors are used to interface between wire leads and the receiver. 10 AWG wire is supplied from Max Amps as standard on the 10S Li-Po battery and is used to wire from the EC5 battery connector to the Castle ESC and from the ESC to the AT7215 motor. Below is the wiring diagram and schematic of the avionics for the aircraft.

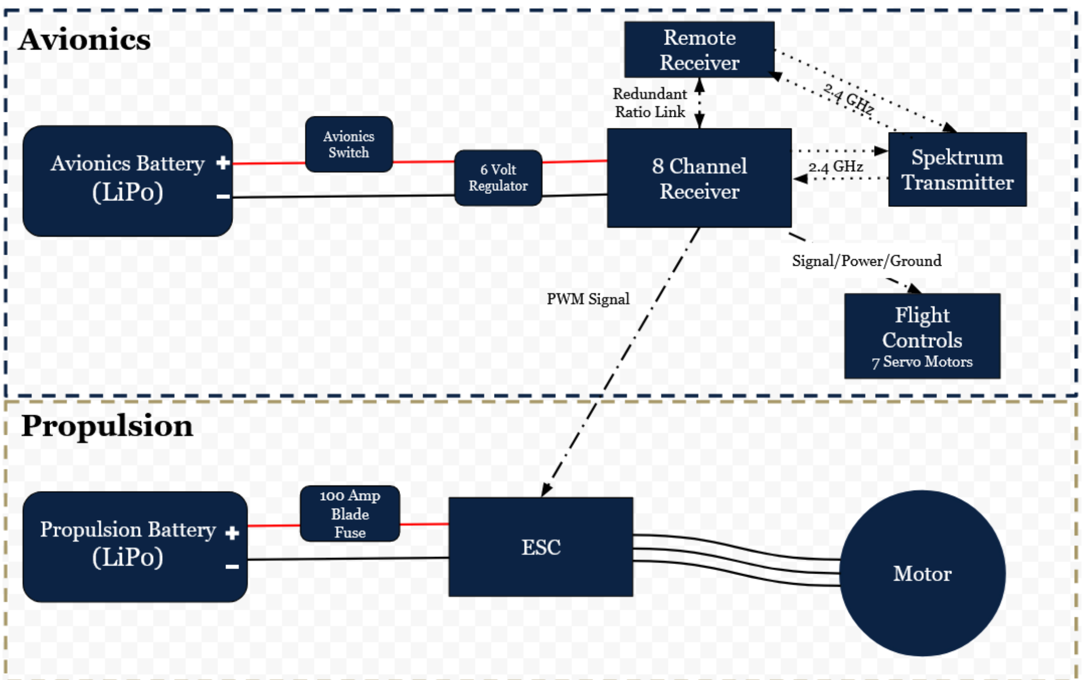


Figure 24 Avionics schematic for the aircraft

2.3 Manufacturing

Once all the components were designed and verified the manufacturing of these components began. As mentioned before, new manufacturing methods were developed by the systems engineers to ensure efficiency and that all tasks are completed before competition. Integration is also a key factor for the success of the aircraft, so communication is important to maintain between each section lead. A manufacturing milestone chart was developed to monitor the progress of the team and to keep track of which components need to be manufactured.

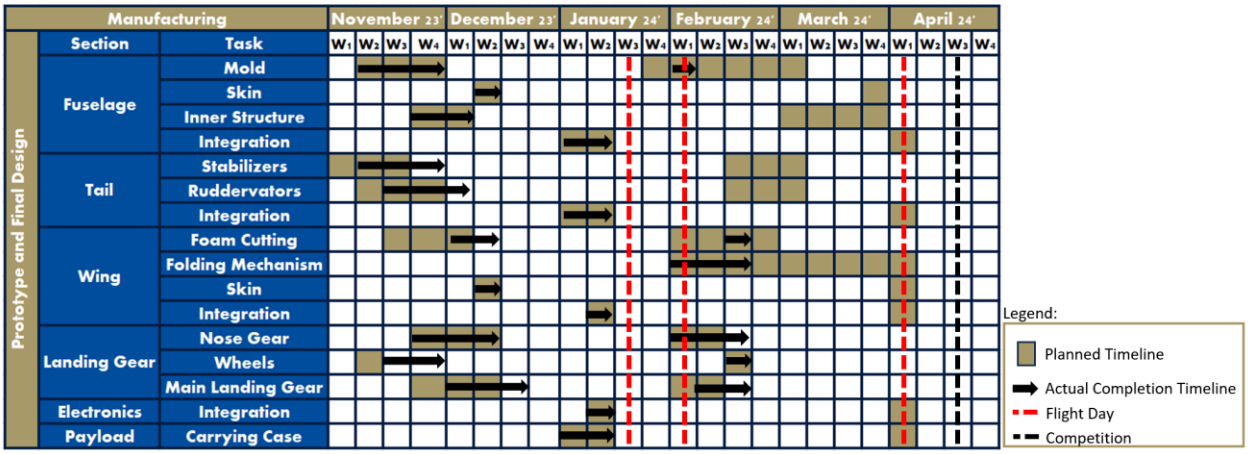


Figure 25 Manufacturing milestone chart

2.3.1 Laser Cutting

The team's 80-watt laser cutter was used to manufacture thin parts from sheet stock. Models created in SolidWorks were converted to a DXF (Drawing Exchange Format) file. Excess burns off from the laser cutter were accounted for by a calibration and offset process that achieves a correct final dimension. An example of the laser cutting process can be seen in the figure below. Applications of the laser cutter to this year's aircraft include balsa ribs for control surfaces, the plywood battery tray, and plywood firewall. Below is an image example of laser cutting balsa wood for fuselage pieces.

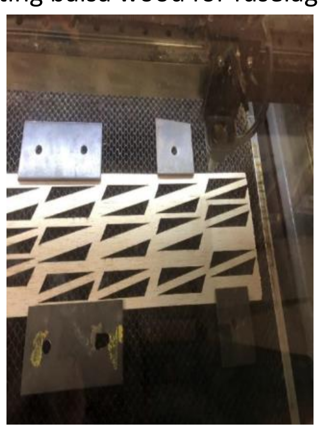


Figure 26 Laser cutting example

2.3.2 Foam Cutting

The team's 4-axis hotwire foam cutter can be used to cut both straight and tapered profiles. DXF files created from SolidWorks models were imported into a program called DevFoam 3D 2, which generates g-code to run the foam cutter. Often, the foam cutter is used to create cores for wings and to hollow out space for additional structures such as carbon fiber spars. Foam cutting can also be used to create a wing table to assist in the manufacturing of wings and their storage. The foam cutter in action can be seen in the image below.

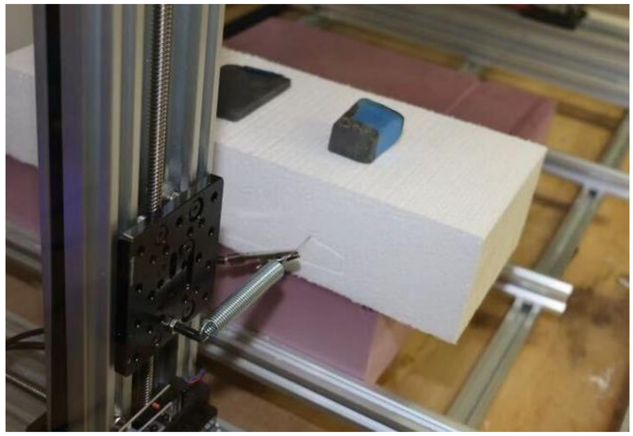


Figure 27 Foam cutter

2.3.3 3D Printing

The additive manufacturing process allows the team to create complex structures with incredible accuracy in a short time, which is helpful for rapid prototyping. Molds are a common use of 3D printing and have been used to create the fuselage skin in previous years. 3D printing has also been used to contain payload weights and create lightweight hatch structures. Depending on the required strength, there are different material options for 3D-printed components. PLA is typically used for large parts like molds, Lightweight PLA is used for on-aircraft components not requiring high strength, and PETG is used for components requiring high strength, toughness, and thermal resistance. Some pictures of 3D-printed components can be seen in the figures below.

Figure 28 3D printed fuselage mold

Figure 29 3D printed leading edge mold

2.3.4 Composite Layups

Composites have an excellent strength-to-weight strength but can be challenging to design and manufacture. The team commonly manufactures simple composite structures, such as sandwich paneling, however complex structures such as carbon fiber tubes are purchased commercially instead of manufactured. Developing composite manufacturing techniques has been a focus of the team in recent years. One of these developments was the use of fiberglass and balsa to create sandwich panels. This material was tested on the prototype aircraft. A variety of materials are used in composites, including carbon fiber, fiberglass, and a variety of foams and woods. Composite structures give the aircraft strength while minimizing weight and are thus used for the fuselage skin.

Figure 30 Composite layup process

2.3.5 Foam-Core Method

The foam core method uses a core of type XI polystyrene foam as the basis for a wing. The Styrofoam core was cut on the foam cutter, and any additional structure, such as carbon fiber spars and balsa hinge blocks, were added. Then the wing was sheeted with balsa wood and covered in Monokote. The foam core method for wing manufacturing is much simpler and more accurate than a built-up wing. The image below shows a foam core blank ready for additional structure.

Figure 31 Foam core wing cutout

2.3.6 Wing Manufacturing

This wing is constructed with the foam-cored method. The center section of the wing is constructed first because it is used as a reference for the outer sections. First, Cores are cut from Low-density type XI polystyrene foam. The carbon fiber spars are glued into the wing, followed by ribs made from carbon fiber sandwich panels at the hinge point and wingtip. The hinging mechanism is mounted flush on the center section and protrudes out to mate with the outer section. The 3D printed PETG blocks for landing gear and wing integration are mounted in the center section using a specialty fixture for alignment. accuracy. Channels are cut in the wing foam sections so servos can be glued into the wing with 3D printed mounts. The 3D printed mounts allow the servos to be removed, if necessary, as shown in the image below.

Figure 32 3D printed servo mounts

Control surfaces and trailing edges are constructed using the built-up method. Control horns are bolted to the control surface in line with the servo arms in the main body of the wing. This allows for actuation without binding. The wing is then completely sheeted in 1⁄32 " balsa and covered with Monokote covering. CA hinges are embedded to connect the main wing to the control surfaces. Finally, linkages are created so servos can actuate control surfaces as shown in the image below.

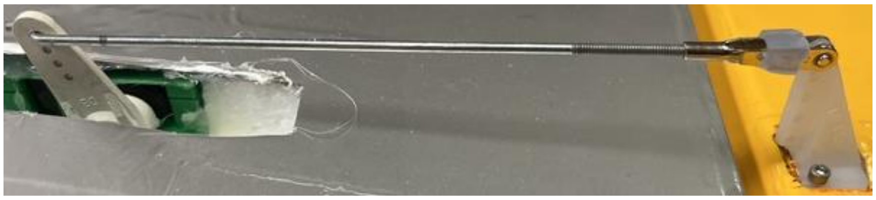


Figure 33 Servo and linkage assembly

2.3.7 Landing Gear Manufacturing

The main landing gear started as a sheet of .16’’ thick aluminum 7075-T6 sheet metal. A DXF of the unfolded model was generated in SolidWorks and sent to a machine shop sponsor to be waterjet cut.

The cut-out blanks were heated with an oxy-acetylene torch to prevent shattering during bending. A brake press was used to complete the bends. The bent main landing gear is shown in the image below.

Figure 34 Main landing gear

The landing gear was tempered back to a T6 temper. To do this, the aluminum was solution heat treated at 900 degrees Fahrenheit for 55 minutes, quenched in room temperature water, then artificially aged by heating the aluminum at 250 degrees Fahrenheit for 24 hours as per *ASM 1967 Standards.* The nose gear started as a 3 ⁄16 " spring steel wire and was bent to shape using a custom-made fixture. A MAPP gas torch was used to assist the bend for the axle. The images below show the fixture used to bend the nose gear and the nose gear.

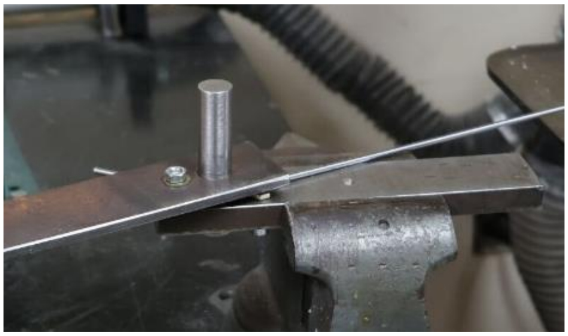


Figure 35 Nose gear bending

Figure 36 Bent nose gear

Wheels were machined on a CNC lathe from high-impact ABS plastic stock. Weight Savings cutouts in the wheels were patched with Monokote covering to reduce drag. The image below shows the covered (right) and uncovered (left) wheel.

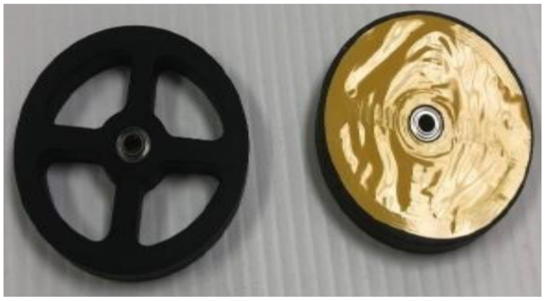


Figure 37 Landing gear wheels

2.3.8 Tail Manufacturing

The tail was constructed using the built-up method. The laser cutter was used to create balsa ribs and spars, and templates for sanding leading edges out of solid balsa. CA glue was then used to assemble the ribs onto the spars and leading edge, followed by balsa sheeting to provide a rigid skin. Servos are mounted internally to actuate control surfaces. The tail components are then covered in Monokote and mounted to the fuselage. The tail partway through the built-up process is pictured in the image below.

Figure 38 Tail manufacturing

3. Design Verification

Various tests were performed to better understand the aircraft's capabilities. The tests range from internal structural components to performing an overall test flight. A list of tests was generated to set dates for when they would be performed and to keep all other tasks on time. Each section was responsible for performing their own tests to verify that it can be used in flight. The image below shows the different types of tests performed and when they were completed.

Testing Schedule			
Test	**Description**	**Date of Completion**	**Completed?**
Composite Testing	Testing different materials such as balsa, 3lb divinycell foam, and 5lb divinycell for the fuselages' core skin material.	11/23/2023	Yes
Wing Structure Testing	Will use different spar diameters and materials to test for the spar that shows the most strength. A cantilever test will be performed until failure.	11/5/2023	Yes
Landing Gear Testing	A jig will be setup to add weight to the landing gear configuration and then it will be drop tested to see how much force the landing gear could handle.	12/3/2023	Yes
Motor Testing	Testing the motor on a motor test stand to measure static thrust and will use the wind tunnel to measure for dynamic thrust.	11/15/2023	Yes
Mold Release Testing	Different types of applications will be used on 3D printed parts to test which would allow the mold to release without damages.	10/29/2023	Yes
Payload Time Study	Performing different methods of installing the payload into McQueen and evaluate different payload containers.	3/15/2024	No
Bluey Flight Test 1	Testing the overall performance of the aircraft and ensuring that the structural components can withstand aerodynamic forces.	1/23/2024	Yes
Bluey Flight Test 2	Collecting data from Pixhawk to add improvements to the final design.	2/16/2024	Yes
McQueen Flight Test	Testing all improvements and modifications from the prototype applied to McQueen.	3/28/2024	No
Mission 1 Testing	Evaluating McQueen's capabilities to fly 3 laps within 5 minutes and with crew members as payload.	4/3/2024	No
Mission 2 Testing	Adding mission 2 payload to McQueen and flying 3 laps as fast as possible.	4/3/2024	No
Mission 3 Testing	Installing mission 3 payload and testing McQueen's capability of flying with maximum payload while flying as many laps as possible.	4/3/2024	No

Figure 39 Testing schedule

3.1 Ground Tests

3.1.1 Composite Testing

Qualitative testing was employed to select a core material for the fuselage skin. Three test coupons of sandwich panel skin were created using 3-ounce style 120 E-glass on each side. Core materials tested were 1⁄16-inch balsa, 3-pound Divinycell foam, and 5-pound Divinycell foam. The image below shows the laid-up coupons.

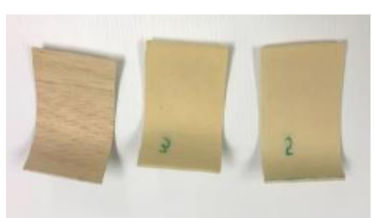


Figure 40 Laid-Up Coupons

3.1.2 Motor Testing

The T-Motor AT7215 was installed on the motor test stand as seen in the image below. Both static and dynamic motor testing is performed using the team's motor test stand. Dynamic thrust data is taken in ten mile per hour increments up to the wind tunnel's maximum airspeed of 40 miles per hour. Throttle input can also be varied. The motor is situated on linear rails connected to a spring scale for recording of data points. The thrust value in pounds is recorded at each airspeed to allow for dynamic thrust curve calculations.

Figure 41 Motor Test Stand

3.1.3 Landing Gear Testing

Landing gear testing involved simulating the maximum expected landing load of five g's by performing a 1-feet drop test. A fixture was constructed using scrap wood to simulate the geometry, balance, and weight of the fuselage as seen in the image below. Tests using this fixture included multipurpose 4140 steel vs 1065 spring steel for the nose wire and annealed versus heat treated 7075 aluminum for the MLG.

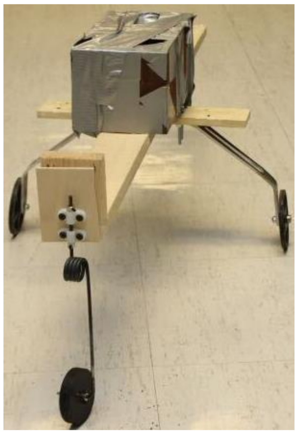


Figure 42 Landing gear test fixture

3.1.4 Wing Structure Testing

Custom foam core carbon fiber tube tip spars were used in the prototype aircraft. To gauge their strength, a cantilever test was performed. The spar was fixed securely in a vice, and the free end was loaded until failure. The final load weight was then compared with the expected wing loading at the highest predicted speed and angle of attack. A factor of safety of three to four is desired. Two tests were performed, one with two layers of carbon fiber sock around a core of XPS Formular 250 pink foam, and another with five layers of carbon fiber. The test setup can be seen in the image below.

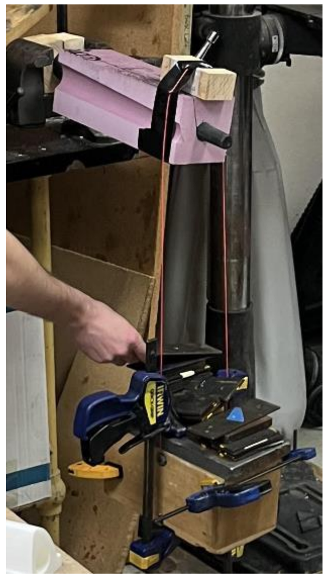


Figure 43 Wing Structural Testing

3.2 Flight Tests

Upon completion of the prototype aircraft, several flights were conducted to test key aircraft performance parameters, including takeoff distance, *M2* and *M3* payload capacity, and top speed. These tests revealed areas of improvement relating to aircraft structure and payload weight distribution.

3.2.1 Mission 1 Testing

Multiple parameters were tested for *M1*. The runway was marked at the 20-feet mark to determine if the prototype was capable of takeoff within competition limits. A camera was lined up parallel to the 20-feet mark to allow for review post flight. *M1* tests were performed on a day with a density altitude of -3,500 feet as the measured air temperature was 25°F. There was no headwind during the test flight allowing for a baseline takeoff distance to be determined. The prototype was trimmed for level flight at 60% throttle and three laps were flown successfully. The landing performance was measured through cameras positioned further down the runway to capture the approach, flare, touchdown, and rollout. After the aircraft was verified as operational and within standards, the next flight involved payload added in the form of lead weights. The video of takeoff was reviewed thoroughly to determine approximate takeoff angles and to check for bending of the main landing gear. The video of the landing rollout was reviewed to check for the reaction of the nose gear upon touchdown.

3.2.2 Mission 2 Testing

Testing for *M3* occurred on a day with no headwind and a density altitude of -1,000 feet. The runway was marked out to include the 10-feet and 20-feet mark. Cameras were set up to record each takeoff marking for insight into the different stages of the takeoff phase. Four pounds of weight were inserted into the fuselage to simulate the *M2* payload configuration. The Pixhawk was used throughout the flight to record a plethora of flight data. Testing consisted of top speed runs to determine the fastest M2 time.

The maximum g-loading encountered in any portion of the flight was recorded by the Pixhawk in every axis. A 3-dimensional flight path recording for the *M2* test flight was created through GPS data and provided the team with the ability to look at all forces and angles of the aircraft for any portion of the flight.

3.2.3 Mission 3 Testing

Testing for M3 took place on the same day as M1 testing. The weather remained nearly identical to the prior flight. A total of 3.125-pound payload was added in the form of lead weights to simulate the weight of 36 Passengers. After takeoff, the number of laps the aircraft could fly was recorded to determine maximum endurance. After completing as many laps as possible, the landing performance of the *M3* configuration was recorded to allow for analysis. The results of *M3* testing were adjusted to truncate any laps flown after the 5-minute mission limitation. The additional laps are considered factors of safety to allow for multiple go-arounds in the event of a non-stable approach. The videos for takeoff and landing were reviewed to gain an understanding of areas of improvement.

4. Costs

Costs are covered by the University of Akron funding, which means that the costs did not affect the project.

4.1 Parts

Below is a table of costs that the team spends on materials and electronics for the aircraft.

Estimated Budget Chart	Description	Cost
Materials	Balsa Wood	$ 500.00
	Foam	$ 800.00
	Plywood	$ 100.00
	Aluminum	$ 150.00
	Carbon Fiber	$ 1,250.00
	Covering	$ 125.00
	Glue	$ 500.00
	Props	$ 200.00
	3D Printer Filament	$ 300.00
Electronics	Receiver	$ 80.00
	ESC & BEC	$ 300.00
	Wiring	$ 100.00
	Motor	$ 600.00
	Propulsion Batteries	$ 500.00
	Receiver Batteries	$ 80.00
	Transmitter	$ 2,000.00
	Servos	$ 500.00
Total Cost:		$ 8,085.00

Figure 44 Cost table

5. Conclusion

The Zips Aero Design Team thoroughly evaluated each mission parameter to simplify the competition rules to the most basic level. For rapid prototyping, the scope of the prototype aircraft was limited to determine if the flight performance of the airframe was satisfactory. The prototype aircraft had adequate performance for optimal flight mission performance. The very high-top speed and static thrust allows for great performance in *M2***.** While the static thrust and efficiency of the airframe allow for optimal *M3* performance. The limited number of flights showed the absolute limits of the aircraft at its current state in terms of top speed, maximum payload, and maximum G-loading. The failure to perform high-g maneuvers due to structural limitations shows there is insufficient resistance to failure when attempting to maximize *M2* and *M3* scores. These shortcomings will be fixed in the competition aircraft through changes in how the tail, wing, and fuselage are manufactured and the limited scope will be broadened to meet every requirement. Due to the great flight performance from the prototype, *the final design* will be able to compete at the top level in the 2024 Design Build Fly Competition in Wichita, Kansas.

5.1 Accomplishments

The Zips Aero Design team was able to design an airplane that would place 6th overall out of 106 schools that participated in the competition. The implementation of systems engineering to the team at a general member level was a success overall. The new design and manufacturing methods helped the team create standards and increase overall team performance and efficiency.

5.2 Future work

With all the new implementations made by the systems engineers, the team can have material and content to pass down to incoming freshmen and provide a standard method for designing and manufacturing RC airplanes for each new set rules that AIAA generates. The Matlab code developed will also significantly increase efficiency to provide calculations in a shorter amount of time. This project can be served as an example for companies that want to implement systems engineering into their ecosystem to improve their project workflows and quality.

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