Kent State University

Design • Build • Fly

Nomenclature

a	=	Acceleration Constant
AIAA	=	American Institute of Aeronautics and Astronautics
AR	=	Aspect Ratio
c	=	Chord length
C_L	=	Coefficient of Lift
C_{LMax}	=	Maximum Coefficient of Lift
c_d	=	Parasite Drag Coefficient
C_D	=	Coefficient of Drag
$C_{D,i}$	=	Induced Drag
$C_{D,0}$	=	Skin Friction Drag
C_{fe}	=	Average Coefficient of Friction
CFD	=	Computational Fluid Dynamics
D	=	*Drag*
DBF	=	Design Build Fly
D_{total}	=	Total Distance
D_{turn}	=	Distance of Turn
Ft	=	Feet
FOM	=	Figure of Merit
g	=	Acceleration due to Gravity`
GM	=	Ground Mission
KSU	=	Kent State University
L	=	Lift
Lbs	=	Pounds
L/D	=	Lift to Drag Ratio
M1	=	Mission 1
M2	=	Mission 2
M3	=	Mission 3
P_{M1}	=	Power Required Mission 1
P_{M2}	=	Power Required Mission 2
P_{M3}	=	Power Required Mission 3
q	=	Dynamic Pressure
S	=	Wing Area
S_n	=	Takeoff Distance
S_{ref}	=	Reference Area
S_{wet}	=	Wetted Area
STOL	=	Short Take-off and Landing
T	=	Static Thrust
t	=	Time (seconds)
t_{min}	=	Time (minutes)
t_{total}	=	Total Time (seconds)
t_{turn}	=	Time for Turn
TBD	=	To Be Determined
TOFL	=	Take off Field Length
UAS	=	Unmanned Aerial Systems
V	=	Velocity
v_{avg}	=	Average Velocity
V_c/V_{Cruise}	=	Cruise Speed
V_{Stall}	=	Stall Speed
V_t	=	Take off speed
W	=	Weight
W_{M1}	=	Weight Mission 1
W_{M2}	=	Weight Mission 2
W_{M3}	=	Weight Mission 3
α	=	Angle of Attack
ρ	=	Density
μ	=	Coefficient of Friction
θ	=	Bank Angle

Table of Contents

I. Executive Summary

This Design Report is the detailed description of the design, fabrication, and testing of Kent State University's AIAA DBF Team's aircraft that has been developed for the 2019-2020 AIAA DBF Competition. We developed a remotely controlled bush plane, per competition requirements, that can complete all four of the missions: (1) ground control mission, (2) empty weight mission, (3) charter mission, and (4) banner towing mission.

A. Description of Selected Design

The Kent State team worked to manufacture a lightweight aircraft that could maximize scores for the two payload missions. As first-time competitors, we began by analyzing the competition rules extensively as well as the previous winning design reports to determine what elements of the mission are the most critical to the design. Our team began with a completely new design and was not able to recycle previous aircraft components. The three most important competition necessities were (1) the ability to carry many passengers, (2) the ability to fly at a high speed, and (3) the ability to take off in 20 feet or less. The final design is a traditional bush plane with conventional tail and tricycle landing gear, see **Table 1** for Design Parameters. To maximize our payload capacity, we designed a cargo box in the fuselage that is 20" in length with a range of 3" to 5" in width to better allow more passengers and luggage to be securely placed inside. The T-Motor F1000 electric motor, was selected because of its high power to weight ratio allowed for maximizing flight speed and minimize take off field length. To further minimize the take-off field length, the wingspan was maximized at five feet; the empty weight was minimized by manufacturing most components out of carbon fiber; and flaperons were installed.

Table 1: Design Parameters

NACA 4414	**C_{LMax}**: 1.305	**$C_{LMax,Flaps}$**: 1.600	
W_{M1} (lbs)	7.54	**$V_{stall,M1}$ (ft/s)**	38.464
W_{M2} (lbs)	13.79	**$V_{stall,M2}$ (ft/s)**	52.018
W_{31} (lbs)	7.58	**$V_{stall,M3}$ (ft/s)**	38.566
P_{M1} (Watts)	51.995	**AR**	7.36
P_{M2} (Watts)	109.303	**S (in_2)**	489
P_{M3} (Watts)	54.007	**c (in)**	8.15

B. Performance and Capabilities

The maximization of our aircraft's performance and the final score can be summarized by the capabilities below:

- Empty weight of 7.54 lbs. and maximum weight of 13.79 lbs.
- Wingspan of 5 feet and area of 3.396 ft_2
- Ability to carry up to 20 passengers and luggage

II. Management Summary

A. Team Organization

The Kent State Team consists of 12 active student members, 8 of which are senior capstone design students who bring a wealth of knowledge from military experience, internships, jobs, course work, and other student lead design projects. The faculty advisor is Dr. Blake Stringer and the RC pilot instructor is Dr. Richard Hassler of Kent State. This is a student led organization, see **Figure 1** for the team management structure, with a Project Manager and Assistant Project Manager who oversee the overall project, assist on other sub-teams when necessary, and keep the project on time and on budget. Every other senior member was assigned a technical lead position and creates goals and timelines for their team. Although the team is divided into several sub-teams, there is an understanding that everyone shares knowledge across all the sub-teams and support teams with heavier workloads in order to keep the project on track.

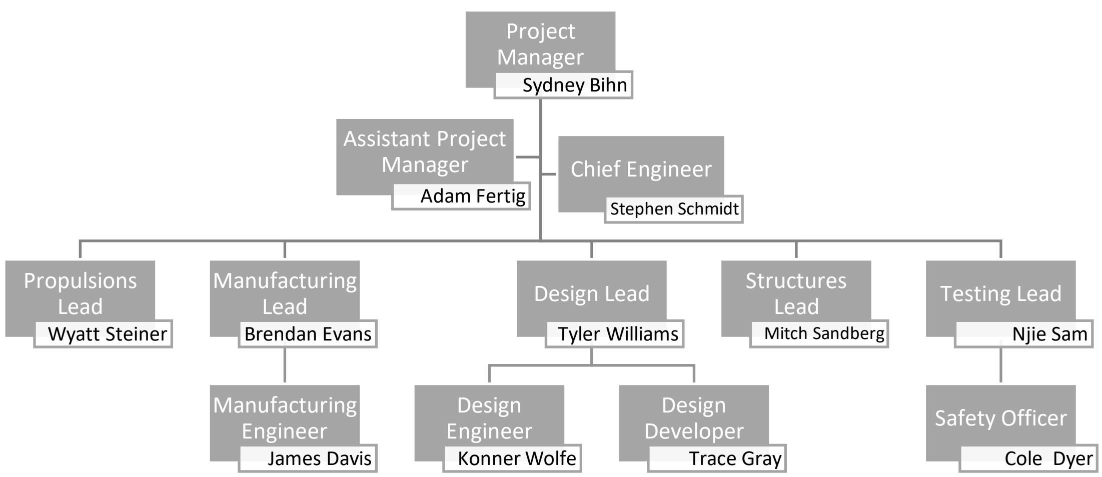


Figure 1: Team Organization

B. Milestones

A Gantt chart was created at the beginning of the design process. It has been updated along the way to reflect schedule changes as more information became available. The Gantt chart representing important milestones is shown in **Figure 2**. The first major milestone achieved was the design of the aircraft and that was completed by then end of December 2019. After that the manufacturing of major components was completed mid-February followed by component testing being concluded. Tests flights have yet to be conducted but will begin in the first week of March, weather permitting.

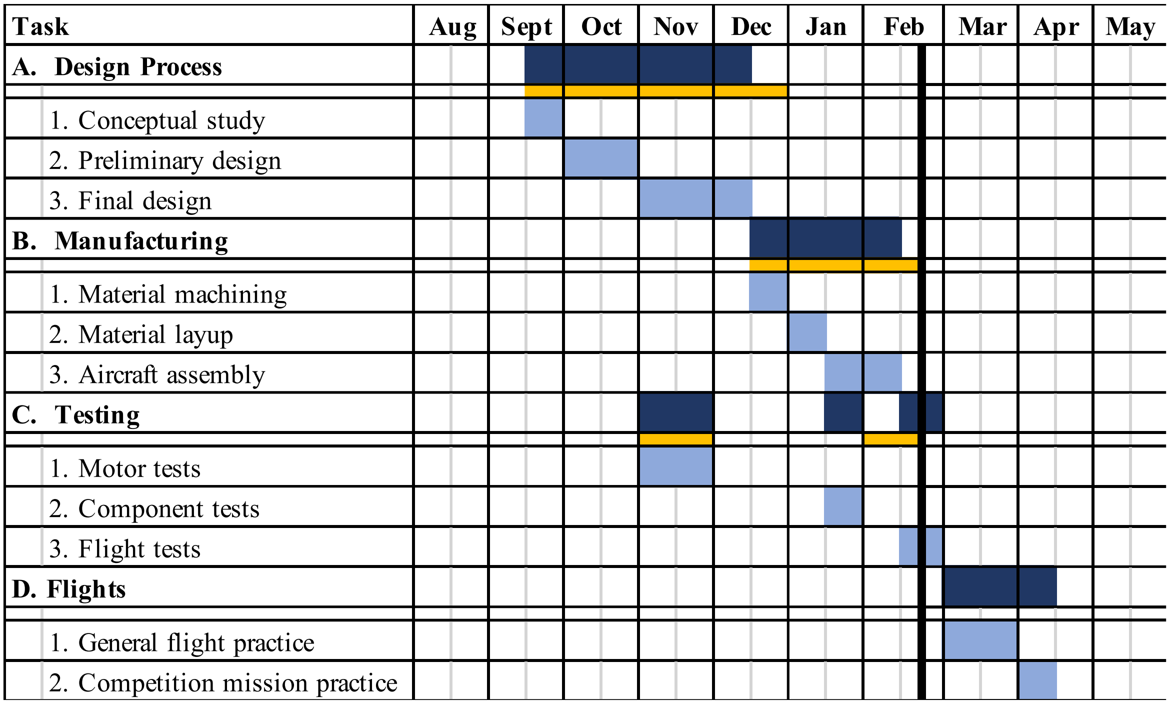


Figure 2: Gantt Chart

III. Conceptual Design

The team's initial conceptual design phase began with analyzing competition requirements and scoring formulas to set a specific baseline of necessities for the aircraft. Then historical bush plane data was researched to further develop the aircraft's characteristics. The final conceptual design decisions were made based off of a series of Figure of Merit analysis of various structural options.

A. Problem Statement

The 2020 AIAA Design Build Fly competition challenges competing teams to design, fabricate, and fly a bush plane that can not only hold subscale people but also remotely deploy a banner. There are four stages to the competition; three flight missions and a ground mission. Our aircraft was designed to maximize mission scores while also remaining safe and realistically achievable in the timeframe. The final score for the competition is calculated with **Eq (1).** [1]

$$SCORE = Wrtiten\ Report\ Score\ \cdot Total\ Mission\ Score \tag{1}$$

The Total Mission Score is calculated by summing each of the team's mission scores, see **Eq (2)** [1].

$$Total\ Mission\ Score = M1 + M2 + M3 + GM \tag{2}$$

Each mission is flown on the same stadium shaped course with flight requirements varying slightly with each mission, see **Figure 3** [1]. The course begins with a takeoff at the center line of one of the straight lengths, followed by 500 feet of straight flight, a 180_{o} turn, 1000 feet of straight flight including a 360_{o} turn, another 180_{o} turn, and lastly 500 feet of straight flight that may include landing space depending on the number of laps previously completed [1].

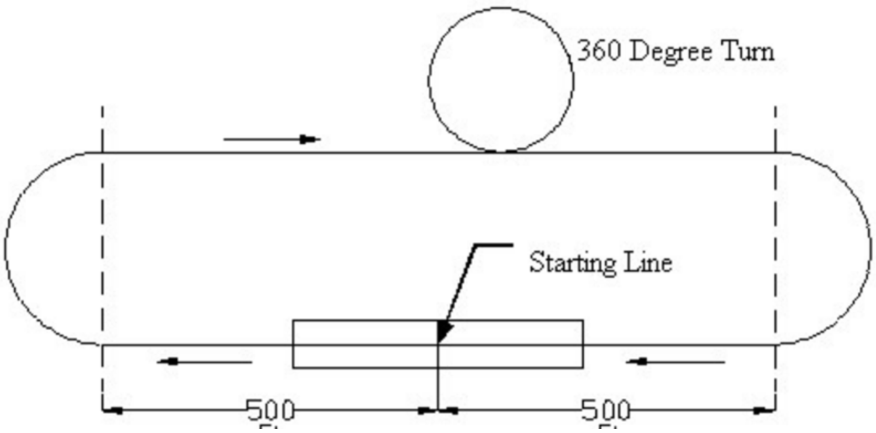


Figure 3: Course Layout

B. Mission Requirements

There are several basic constraints for the aircraft designated by the competition rules, those requirements are listed in **Table 2** [1].

Table 2: General Aircraft Constraints	
Design	Any aircraft configuration is permissible besides rotary wing or lighter than air.
	Aircraft must be less than 55-lbs.
	The aircraft must be able to be assembled in a 10’ x 10’ box.
	Wingspan must be under 5 feet.
Propulsions	On-board battery packs can be the only energy used for take-off.
	Aircraft must be propeller driven by a commercially purchased electric motor.
	Motors must be brushed or brushless.
	NiCad/NiMH or LiPo batteries may be used with provisions.
Safety	No components may be dropped from the aircraft other than the banner.
	Aircraft must pass tech inspection that involved wing tip load test, banner deployment test, and other safety verifications.

i. Mission 1: Test Flight

The first mission is the test flight. There is no payload or banner on board during this flight. The plane must take off within 20 and fly three laps within the five-minute flight window. Time starts when the throttle is advanced and stops when the plane passes the finish line. Lastly, the plane must make a successful landing on the runway without bouncing off. The scoring for this mission is pass or fail with one point being awarded to successful teams, **Eq (3).** [1]

$$M1 = 1 \tag{3}$$

ii. Mission 2: Charter Flight

The second flight mission is a charter flight with passengers and luggage as the payload. Teams are able to design their aircraft to carry as many passengers as they choose and are given five minutes to fly three course laps with their loaded aircraft. A successful mission includes landing without the aircraft bouncing off the runway. Each passenger must weigh at least four ounces and must have a single piece of luggage weighing at least one ounce. Every passenger must be restrained in the vertical position in a single passenger compartment. Luggage must be stored either in front of or behind the passengers and must also be restrained. The score for mission two is calculated using **Eq. (4).** [1]

$$M2 = 1 + \frac{KSU_{\#passengers/time}}{Max_{\#passengers/time}} \tag{4}$$

iii. Mission 3: Banner Flight

The third flight mission requires a banner payload that is remotely deployed and released. The banner must be deployed during the first upwind turn and released after crossing the finish line of the last lap. The team is given ten minutes to fly as many laps as possible. A successful mission includes taking off in twenty feet and successfully landing without the aircraft bouncing off the runway. The banner is required to be at least 10 inches long with an aspect ratio of no greater than 5. The banner must be safely secured to the outside of the aircraft, remain in the vertical position during flight, and not sustain any damage during flight. The score for mission three is calculated using **Eq. (5).** [1]

$$M3 = 2 + \frac{KSU_{\#Laps \cdot BannerLength}}{Max_{\#Laps \cdot BannerLength}} \tag{5}$$

iv. Ground Mission: Operational Demonstration

The ground mission consists of an operational demonstration by the assembly crew member and the pilot. While being timed, this pair will first load the passengers and luggage into the aircraft. Following this, the assembly crew will unload the passengers and luggage and install the banner and banner devices. After this, time will be stopped. The pilot will then demonstrate that the controls are active and remotely deploy the banner while the assembly crew member is holding the aircraft in the vertical position. The score for the ground mission is calculated using **Eq. (6).** [1]

$$GM = \frac{t_{min}}{t_{KSU}} \tag{6}$$

v. Scoring Sensitivity

A sensitivity analysis of the scoring for missions 2 and 3 can be seen in **Figure 4.** Several assumptions were made in order to calculate an estimated score for all four missions: (1) sea level density, (2) coefficient of lift of 1.3, (3) wing area of 3.5 ft^2, (4) distance for one lap is 3500 feet, (5) score for mission 1 is 1, (6) the best ratio of passengers to time in mission 2 is 10, (7) the best multiplied banner length and number of laps in mission 3 is 400, and (8) the ground mission ratio is 3:10. An obvious trend was established where the total competition mission score increased as both the number of passengers increased and the length of the banner increased.

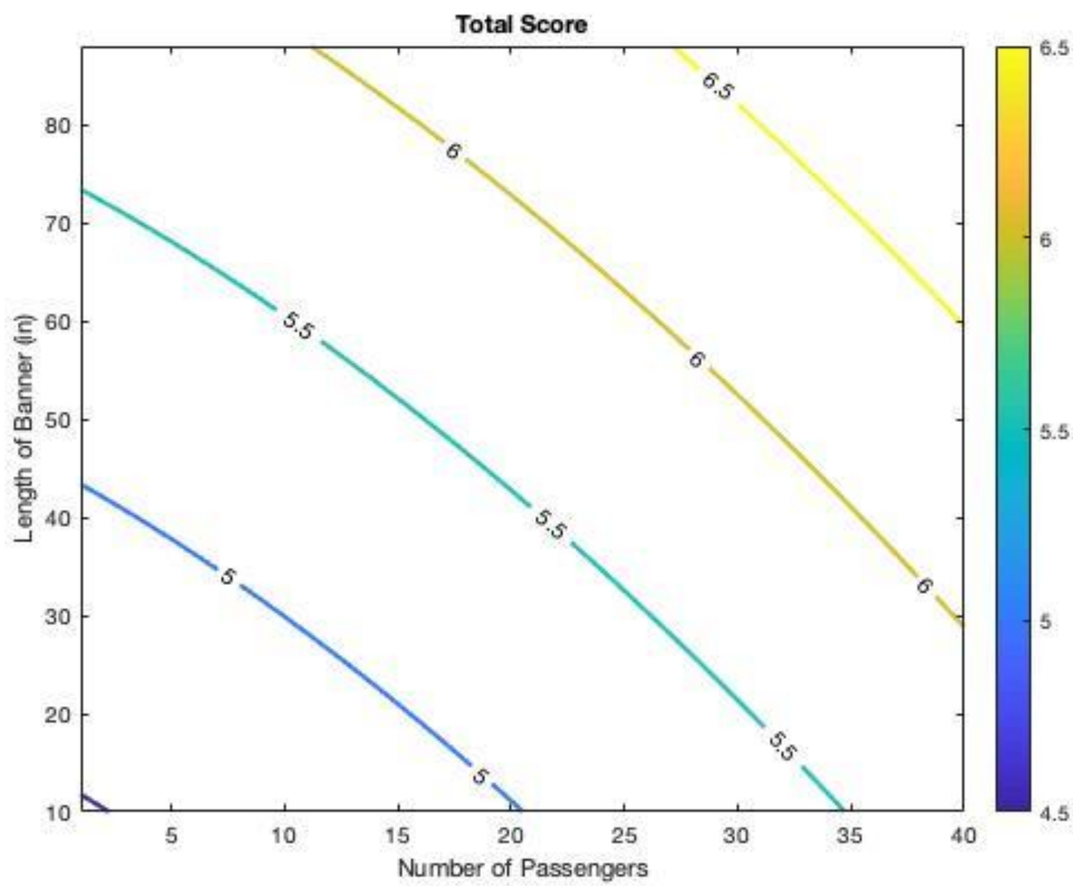


Figure 4: Score Sensitivity Study

C. Translation of Mission Requirements into Sub-System Design Requirements

Table 3: Sub-System Requirements

	Requirements	Sub-System Requirements
Ground	• Assemble in 10' by 10' box • Quickly load passengers • Demonstrate banner deployment	• Easily accessible storage for banner/payload • Efficient remote deployment/release mechanism for banner
Mission 1	• TOFL 20 feet • 3 laps in 5 mins • Successful landing	• Fuselage with best aerodynamic properties
Mission 2	• 3 laps in 5 mins • Passenger payload • Successful landing	• Adaquate fuselage storage • Maximizing power and efficiency of propulsion system
Mission 3	• Max flight time of 10 mins • TOFL 20 feet • Banner payload • Banner deployment and release • Successful landing	• External banner storage capabilities • Servos to deploy and release the banner during flight • Lightweight banner

i. Sensitivity of Design Parameters

A sensitivity analysis was conducted to determine how various design parameters interact with each other and affect the estimated weight of the aircraft. **Figure 5** illustrates several parameters as they affect the predicted weight in pounds, including, lift to drag ratio, specific energy of the battery, total efficiency of the propulsion system, endurance, and wing loading. The weights listed in **Table 1** were calculated by adding the weights of the components on the aircraft, whereas the estimated weight in **Figure 5** is determined using statistical methods.

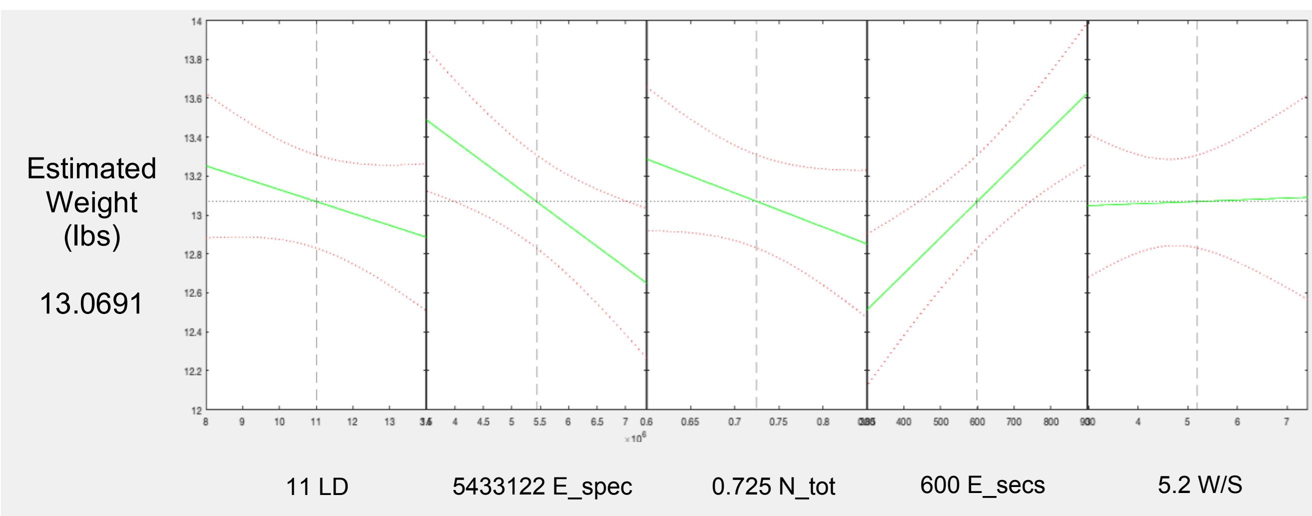


Figure 5: Design Sensitivity Study

D. Selection Process

Throughout the selection process several different configurations of the aircraft were considered, **Figure 6**. The initial phase focused on the critical design features of historical bush planes, see **Table 4**. These data points allowed the team to determine the critical attributes of a bush plane while also providing a jumping off point for design considerations.

Table 4: Historical Aircraft Data

Aircraft	Cessna 172 Skyhawk	Piper PA-18 Super Cub	Aviat Husky A-1	Zenith STOL CH 750
Wing Position	High with struts [2]	Low [2]	High	High
Length (ft)	23.62 [2]	22.503 [2]	22.58 [3]	22.00 [4]
Wing Ares (ft$_2$)	174.00 [4]	178.50 [3]	183.00 [3]	162.00 [4]
Wingspan (ft)	35.76 [2]	35.30 [3]	35.50 [3]	33.42 [4]
Landing Gear	Tricycle [2]	Tricycle [2]	Taildragger	Tricycle
Tail	Regular, mid set [2]	Regular, mid set [2]	Conventional	Conventional
Wing Loading (lbs/ ft$_2$)	13.2 [5]	9.80 [3]	9.80 [3]	11.73 [4]
Stall Speed (ft/s)	84.39 [5]	101.27 [5]	61.6 [3]	49.87 [4]
Power Loading (lbs/hp)	15.9 [5]	11.70 [5]	10.0 [3]	9.27 [4]
Aspect Ratio	7.35	6.98	6.89	6.89
Number of Passengers	4 [2]	4 [2]	2 [3]	2 [4]

Figure 6: Design Inspiration Aircrafts [10][11][12][13]

Following traditional bush plane research, the team began brainstorming various aircraft configurations. The team formed a matrix of component configurations to be considered, see **Table 5**. In order to access each configuration, a Figure of Merit (FOM) was created, see **Table 6.** Each of the key components were ranked on a scale from 0 to 5, with 5 being the highest level of importance. For each component option we designated a rating and that rating was multiplied by the FOM score related to each factor. Then the component with the highest score was selected for the final design.

Table 5: Component Variations			
Components	Options Considered		
Wing Configuration	Straight	Dihedral	Biplane
Wing Location	High	Low	Mid
Landing Gear	Taildragger	Tricycle	-
Tail Configuration	Conventional	V	-
Fuselage	Lifting Body	Traditional Single Compartment Monocoque	-
Engine location	Pusher	Tractor	-

Table 6: Figure of Merit	
Factor	**Importance**
Weight	5
Payload Capacity	4
Simplicity	3
Take off Distance	4
Payload Accessibility	2
Stability	2

i. Wing Configuration

The team deliberated over three wing configurations: (1) straight, (2) dihedral, or (3) biplane. The conventional straight wing offers easy accessibility to the payload and the simplicity of the design allows for easier manufacturability and assembly than the other two designs, **Table 7.**

		Table 7: Wing Configuration		
FOM	**Value**	**Straight**	**Dihedral**	**Biplane**
Weight	5	4	4	2
Payload Capacity	4	3	3	2
Simplicity	3	4	2	2
Take off Distance	4	3	3	4
Payload Accessibility	2	4	4	1
Stability	2	2	4	3
Result		68	66	48

ii. Wing Location

Three different wing placement configurations were considered by the team: (1) high, (2) low, or (3) mid. The team selected a high wing configuration as it provides more stability, better payload accessibility, and simpler assembly, **Table 8.**

		Table 8: Wing Location		
FOM	**Value**	**Low**	**High**	**Mid**
Weight	5	3	3	3
Payload Capacity	4	3	3	3
Simplicity	3	3	4	3
Take off Distance	4	4	3	3
Payload Accessibility	2	3	4	3
Stability	2	4	5	3
Result		66	69	61

iii. Landing Gear

Two landing gear assemblies were considered by our team: (1) tail dragger or (2) tricycle. Tricycle landing gear was selected for its inherent stability and control as successful landings are a critical part of the missions, **Table 9.**

		Table 9: Landing Gear	
FOM	**Value**	**Tail Dragger**	**Tricycle**
Weight	5	4	3
Payload Capacity	4	3	3
Simplicity	3	3	3
Take off Distance	4	2	4
Payload Accessibility	2	3	3
Stability	2	2	4
Result		59	66

iv. Tail Configuration

Two tail configurations were considered by our team: (1) V or (2) conventional. A conventional tail was selected because of its design simplicity and stability while still providing minimal drag and improving lift, **Table 10**.

		Table 10: Tail Configurations	
FOM	**Value**	**V**	**Conventional**
Weight	5	2	2
Payload Capacity	4	1	1
Simplicity	3	3	4
Take off Distance	4	4	3
Payload Accessibility	2	1	1
Stability	2	3	4
Result		47	48

v. Fuselage

Two fuselage configurations were considered: (1) lifting body or (2) traditional single compartment monocoque. A traditional single compartment monocoque fuselage design was selected for its lightweight and simple design, **Table 11**.

		Table 11: Fuselage	
FOM	**Value**	**Lifting Body**	**Traditional**
Weight	5	2	5
Payload Capacity	4	3	4
Simplicity	3	3	4
Take off Distance	4	4	3
Payload Accessibility	2	3	3
Stability	2	4	3
Result		61	80

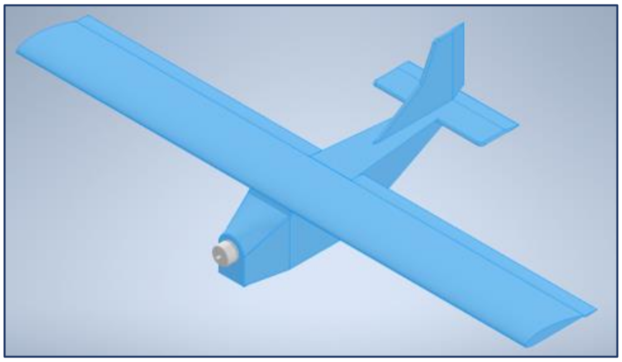
vi. Engine Placement

During the initial research phase, the team considered two traditional engine placements: (1) pusher or (2) tractor. The tractor style was selected as it is a more traditional bush plane configuration and benefits the simplicity of the design, **Table 12**.

		Table 12: Engine Placement	
FOM	**Value**	**Pusher**	**Tractor**
Weight	5	3	3
Payload Capacity	4	3	3
Simplicity	3	3	4
Take off Distance	4	3	4
Payload Accessibility	2	3	3
Stability	2	4	3
Result		62	67

E. Final Conceptual Design Configuration

The final conceptual design configuration, see **Figure 7**, is a high straight wing bush plane with a rectangular fuselage that allows for a maximum of twenty passengers. The aircraft will include a conventional tail configuration and steerable tricycle landing gear. The predicted scores for flight scores for this conceptual aircraft are included in **Table 13**.



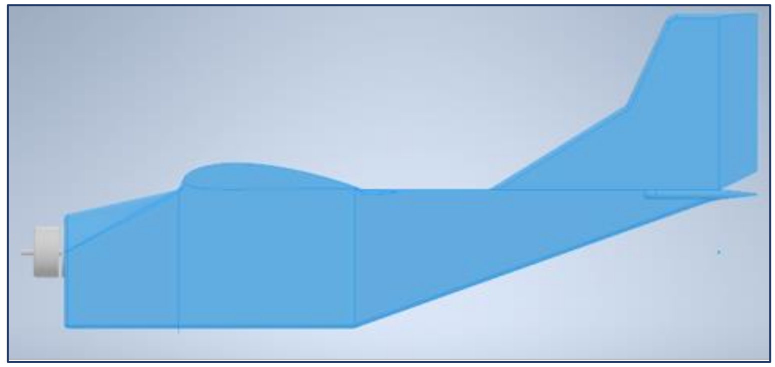


Figure 7: Conceptual Design Configuration

Table 13: Predicted Conceptual Design Scores			
Estimations	Mission 1	Mission 2	Mission 3
Weight (lbs)	9.75	16	10
Stall Speed (ft/s)	39.891	51.101	40.309
Max time per lap (s)	62.67	48.92	62.02
Performance	1	14.8	64
Assumed Best	1	25	80
Score	1	1.592	1.8

IV. Preliminary Design

The objective of the preliminary design phase was to further develop our conceptual design. Using information obtained through conceptual design and research, estimations for various parameters were found. These parameters include; power required, wingspan estimations, weight estimations, fuselage volume and others. Once parameters were estimated, trade studies were conducted, and our final design was approached and refined. During this phase of the design, testing was also conducted to determine our propulsion system and from that testing much of the design was derived. The team constructed mission profiles for all competition requirements and weighed those against attainable deliverables for the team to further refine and develop the final product.

A. Design Methodology

Once the preliminary design phase was nearing completion, a design methodology was developed. The design methodology used was an iterative approach featuring key stages in development which would feed back into themselves until the design was deemed efficient and effective enough to be built. The first stage in the design methodology was to use estimated values for some parameters obtained both in the design methodology stage and the preliminary design phase. From that point the power requirements were estimated, and experimentation was performed, which in turn led to new estimations. This process continued until the results were sufficient to go to the design layup stage and be made into a physical model which was tested and re-evaluated several times. The visual representation of our design methodology can be seen in **Figure 8**.

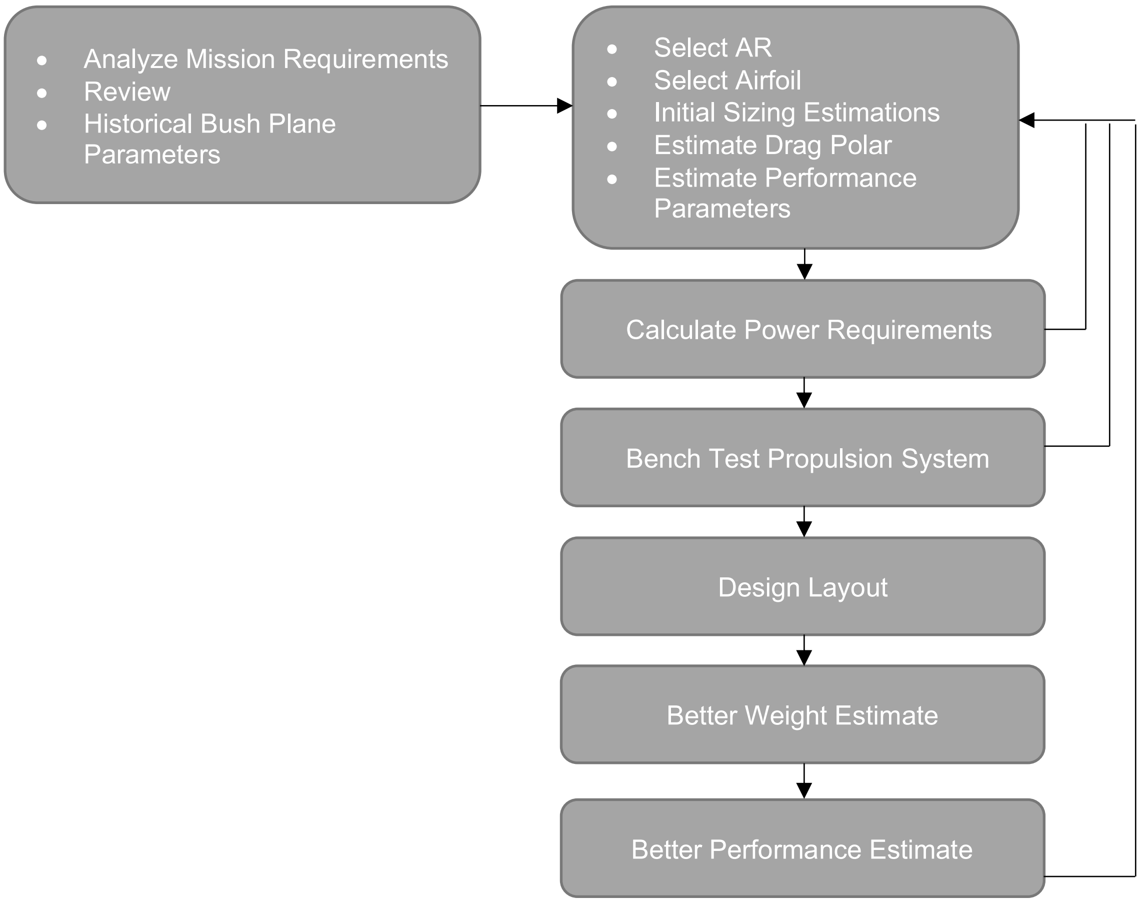


Figure 8: Design Methodology

B. Design Trades

i. Wingspan

During the iterative process of designing our aircraft, the team chose an optimal wingspan that would help the performance of the aircraft. Due to the aircraft's weight and its mission requirements, a shorter wingspan of 36 inches proved to be insufficient because of the lack of necessary lift generation and increased stall speed. In order to optimize the performance of the aircraft, the team decided to design the wing with the maximum allowable wingspan of 60 inches. The **Figure 9** shows that the increase in wingspan provides a significant increase in lift with only a minor increase in drag.

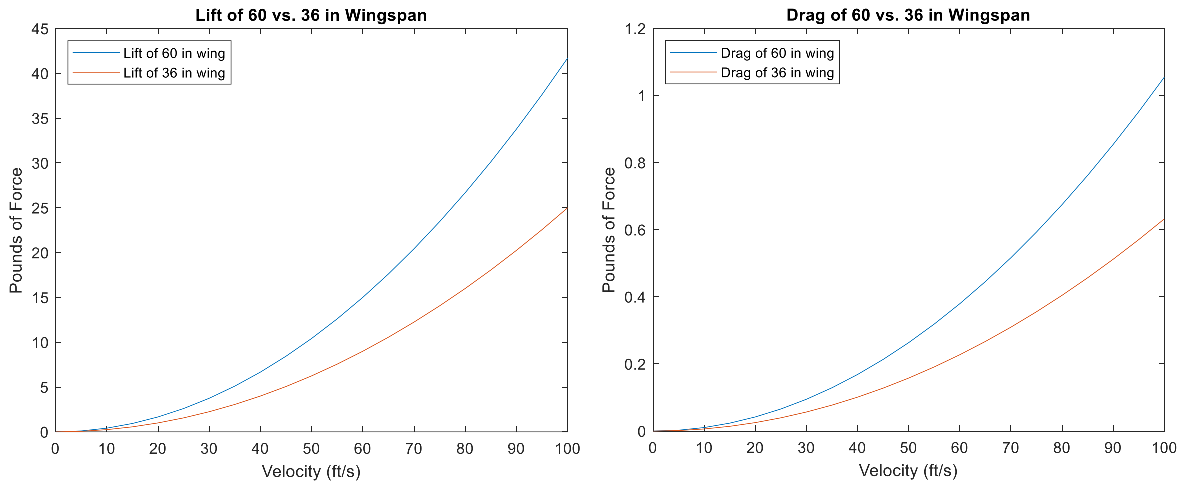


Figure 9: Lift and Drag Curves

ii. Fuselage

The team designed the fuselage so that the aircraft can easily fit twenty passengers, servos that control the primary flight controls and banner deployment mechanism, and batteries that power the motor and servos. **Figure 10** details the additional weight in the fuselage due to the passengers and their luggage. Maximizing our mission 2 score is dependent on balancing the number of passengers and the cruise speed of the aircraft. Below is a chart that compares the number of passengers with the required cruise speed. As the number of passengers increases, the weight of the passengers and their luggage increases which requires a higher cruise speed.

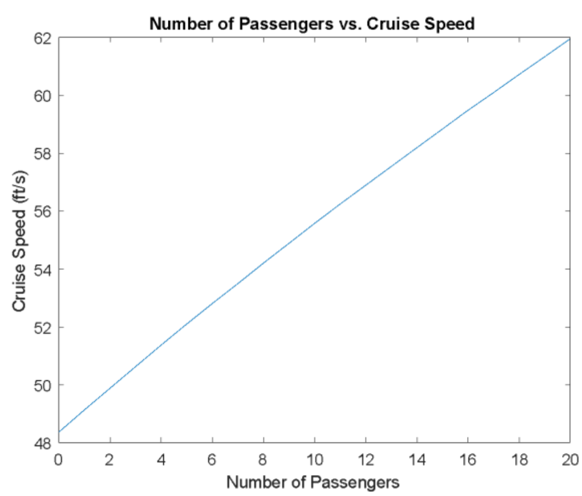


Figure 10: Passengers and Cruise Speed

iii. Propulsions

Two different motors were tested on the Kent State University Static Thrust Bench, **Figure 11**: (1) the KDE4215XF-465 and the (2) T-motor F1000. Each motor was paired with three different propellers: (1) 3-blade 12x7", (2) 2-blade 14x5.5", and (3) 3-blade 10.5x7" on each of them. Data was collected on thrust, electric power, voltage, current, RPM, and efficiency of each of the motor-propeller combinations, see **Table 14** and **Figures 12-16**.

Figure 11: KSU Static Thrust Bench

Table 14: Motor and Propeller Combinations

Motor	Propeller	Thrust (lbf)	Current (A)
KDE4215XF-465	3-blade 12x7	7.5	42.5
	3-blade 10.5x7	5.5	32.5
	2-blade 14x5.5	8	43.2
T-Motor F1000	3-blade 12x7	10.12	83
	3-blade 10.5x7	8.1	60
	2-blade 14x5.5	8.7	47.5

Figure 12: 3 blade 12 x 7

Figure 13: 3 blade 10.5 x 7

Figure 14: 2 blade 14 x 5.5

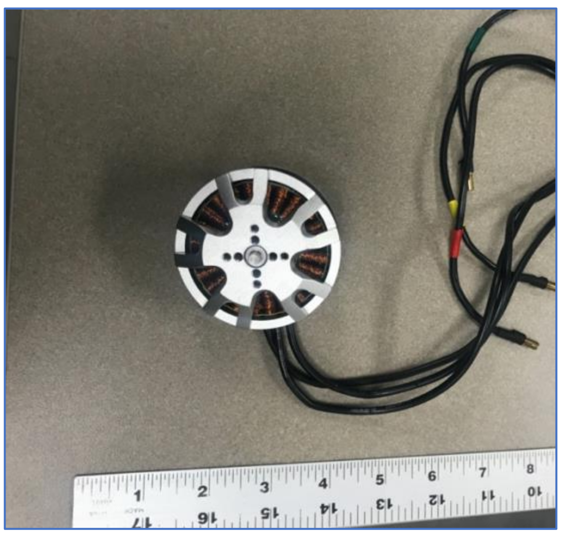


Figure 15: KDE4215XF-465

Figure 16: T-Motor F1000

The overlying purpose of these tests was to find the combination of motor and propeller that gave the aircraft the optimal balance of thrust and current draw. **Figure 17-23** were built from the motor and propeller test data clearly showed unique values and trends for each combination. The individual graphs show the thrust (left side) and current draw (right side) versus the throttle setting. The graphs that depict the T-Motor motor with a 7-inch propeller showed that as the throttle setting increased to 100%, the thrust curve began to flatten. This suggests that the tip speed of the propeller approached Mach 1 where it began to lose efficiency. The solution to this would be to increase the propeller size, pitch, or number of blades. At the end of the tests, the T-Motor F1000 and 3 bladed 12x7 propeller were shown to give the best performance, but future testing with a larger, more aggressive propeller is planned to lower the tip speed to a more efficient speed.

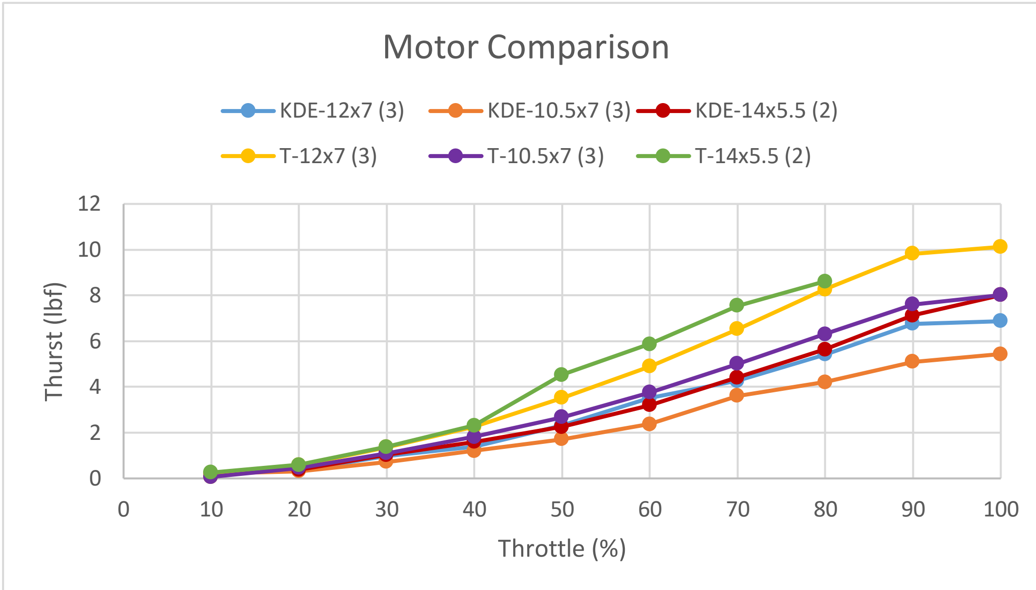


Figure 17: Motor Comparisons

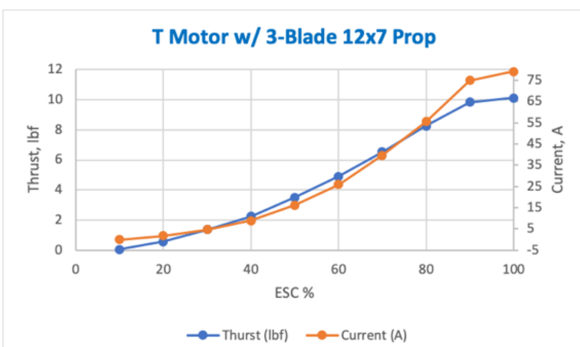


Figure 18: T-Motor 3 Blade 12x7

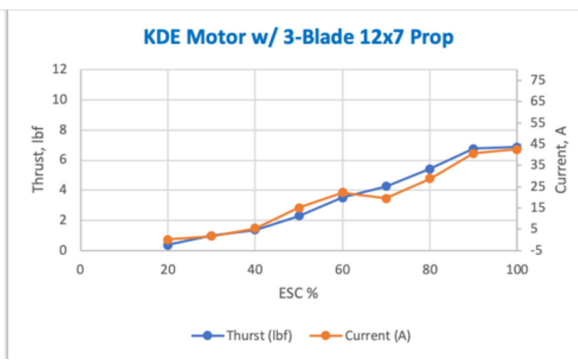


Figure 19: KDE Motor 3 Blade 12x7

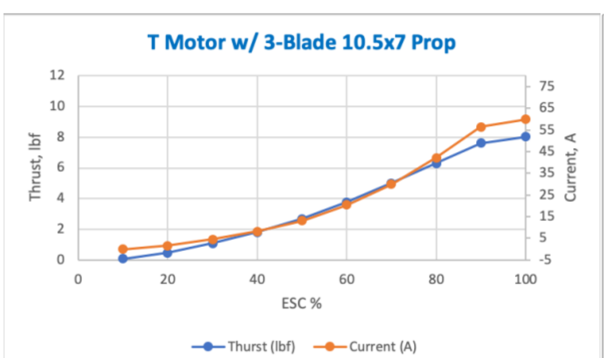


Figure 20: T-Motor 3 Blade 10.5x7

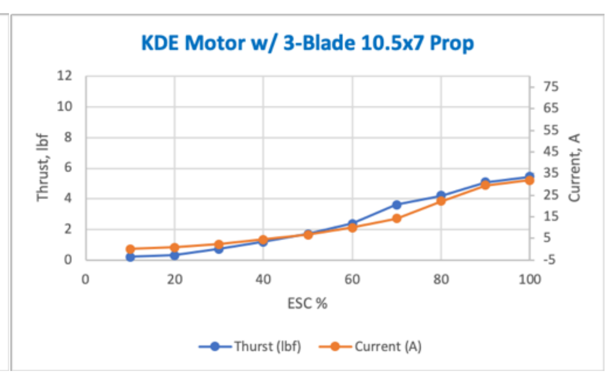
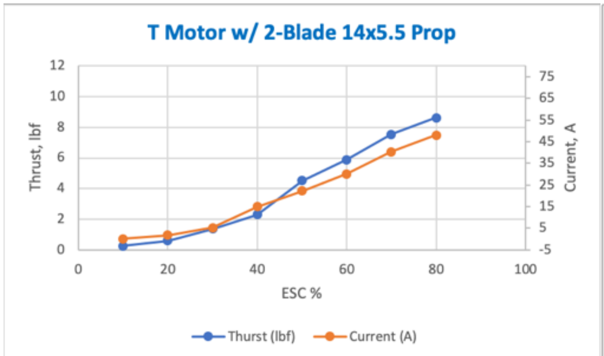


Figure 21: KDE Motor 3 Blade 10.5x7



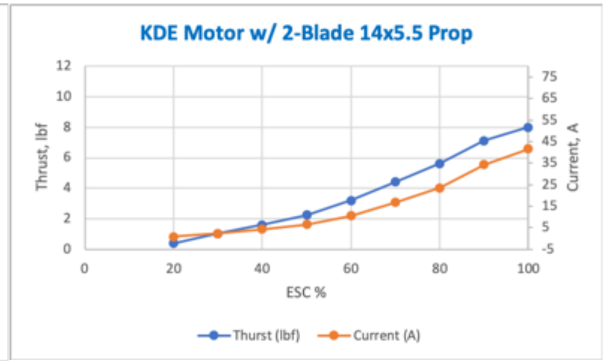


Figure 22: T-Motor 2 Blade 14x5.5

Figure 23: KDE Motor 2 Blade 14x5.5

iv. Take off Distance

A study was performed to determine theoretical take-off distance lengths for varying power to weight ratios and wing loading combinations, **Figure 24.** This provided general guidelines for design and helped to steer decisions surrounding propulsion systems and material selection.

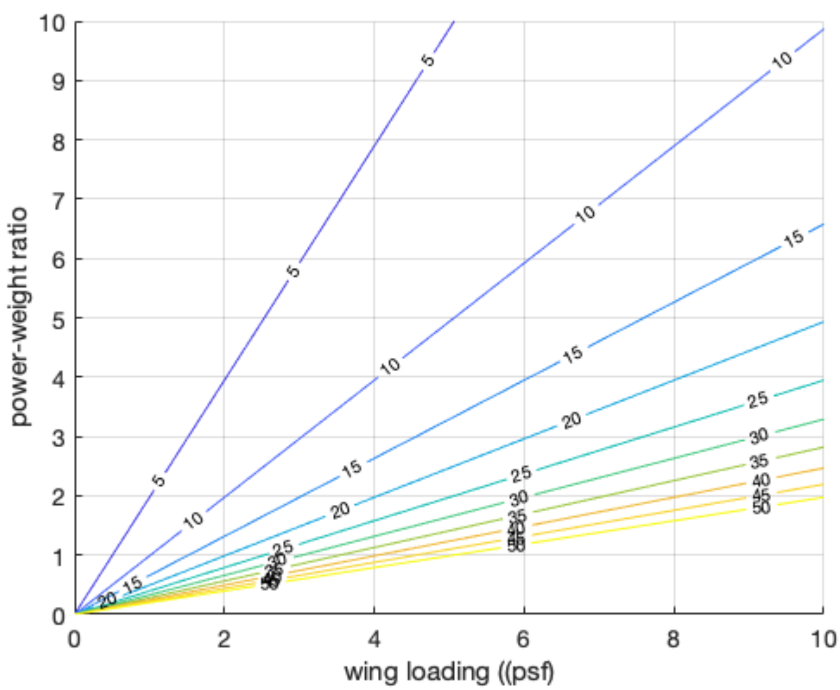


Figure 24: Take off Distance Study

C. Mission Model

Each aspect of the mission was modeled in order to predict the performance of the aircraft throughout different stages of the missions, **Figure 25** depicts the general mission model for the competition track. The calculations utilized the predicted weight from the conceptual design.

Take-off: Take-off was estimated to be performed at full throttle while flaperons where engaged.

Climb: The aircraft was estimated to climb to an altitude of 60 feet with a steady rate of climb.

Straight and Level Flight: The straight flight was assumed to be steady and level with constant speed. The thrust varied for each mission to account for the change in weight and the speed need to compensate.

Turns: The two 180o turns, and one 360o turn for each lap were assumed to be taken at a constant speed and with an estimated radius.

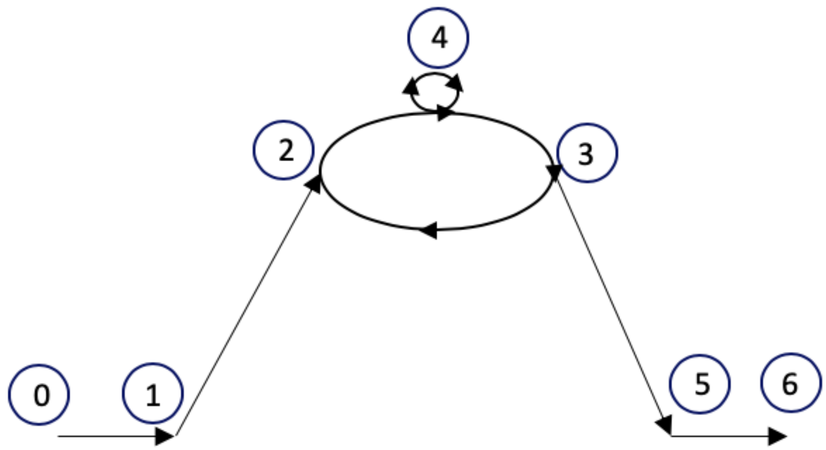
Calculated Lap Times: To calculate lap times the cruise velocity was assumed to be 20% greater than the calculated stall speed for that mission, see **Eq (7-10).** The turns were assumed to be made at a 45o bank angle. A two-second buffer was added to each lap to account for steering corrections and imperfections. One lap was calculated to be two 1000-foot straightaways with four 180o turns, where the 360o turn was calculated using two 180o turns. The calculated lap times for each mission are as follows: (1) 82.248 seconds per lap, (2) 64.644 seconds per lap, and (3) 81.238 seconds per lap.

$$D_{turn} = \frac{\pi\, v_{avg}^2}{19.005 tan\theta} \tag{7}$$

$$t_{turn} = \frac{1841.4 tan\theta}{v_{avg}} \tag{8}$$

$$D_{total} = 2000 + 4D_{turn} \tag{9}$$

$$t_{total} = \frac{2000}{v_{avg}} + t_{turn} \tag{10}$$



Mission Profile Key	
0	Starting Position
0-1	Take off
1-2	Climb
2-3	Cruise
4	360$_{o}$ Turn
3-5	Decent
5-6	Landing

Figure 25: Mission Profile

i. Design for Uncertainties

This mission model neglects several variable elements of the flight. First, it assumes the pilot flies a perfect lap, meaning the ideal course is flown with turns being taken immediately following the 1000-foot straight portion of the lap, along with no other flying errors being made. Secondly, the model used accounts for the distance traveled during the take-off and landing portions of the flight, but not the change in altitude. The lack of vertical dimension in the model leaves out the change in aerodynamic properties during the take-off and landing cruise, and also the change in potential energy. Lastly, the model assumes steady and calm wind conditions. Also, all calculations were done using the tested thrust of the T-motor F1000, along with the estimated drag and weight. The uncertainties in these values would lead to uncertainties in the mission model.

D. Aircraft Lift and Drag Analysis

i. STOL Capabilities

Weight and power are the biggest factors in determining the minimum take off distance. The aircraft has been designed to have performance capabilities well above what is required in order to provide safety precautions and account for any uncertainties. The following equations were utilized by the team to determine estimated take-off distances, **Eq (11-13).** Using these formulas and the take-off distance design trade, the take-off distance of 35.68 feet was calculated when considering the T-motor F1000 with the 12-inch three blade propeller. This is not a short enough estimated take-off distance, so the team plans to fly the aircraft to determine the actual take-off distance and make minor adjustments to improve performance such as increasing the propeller length and pitch.

$$S = \frac{V_t^2}{2a} \tag{11}$$

$$a = \frac{g}{W}(T - \mu W) \tag{12}$$

$$V_c = 1.2(V_{Stall}) \tag{13}$$

ii. Range and Endurance

The components selected allow the aircraft to be able to fly longer and farther than it will be required to ensure mission success. The aircraft can achieve an endurance of at least 12 minutes based on the capacity of the batteries and the current and voltage drawn by our motor during test stand experimentation**.**

iii. Airfoil

The NACA 4415 airfoil was selected for ease of manufacturability as well as its ability to create more lift at higher angles of attack. The thickness of the airfoil also allows for more strength reinforcement in the wing. The estimated maximum coefficient of lift is 1.305 but increases to 1.6 with the addition of flaperons. The comparison of the lift with and without flaperons is observed in **Figure 26**. The higher Cl_{max} is essential in meeting the need for a short take-off distance. The 2-Dimensional shape of our airfoil in **Figure 30**, the coefficient of lift vs. angle of attack chart in **Figure 27**, the C_L vs. C_D chart in **Figure 28**, and the C_L/C_D vs alpha chart in **Figure 29** are on the following page and readily available from airfoiltools.com [6]. These charts are instrumental in determining the optimal performance of the aircraft and in what areas it will perform well.

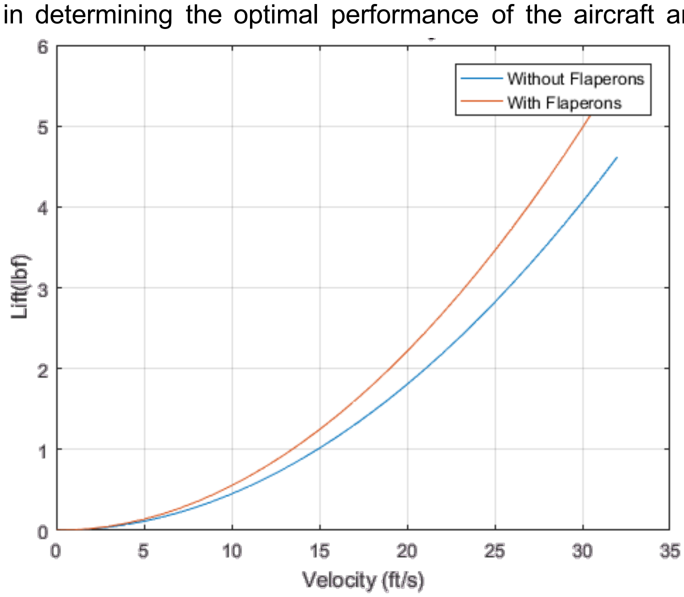


Figure 26: Flaperon Lift Comparison

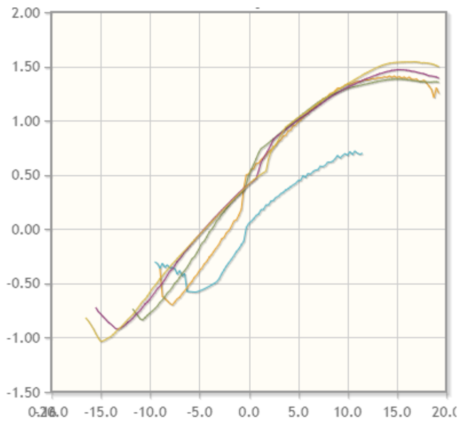


Figure 27: C_L v Alpha

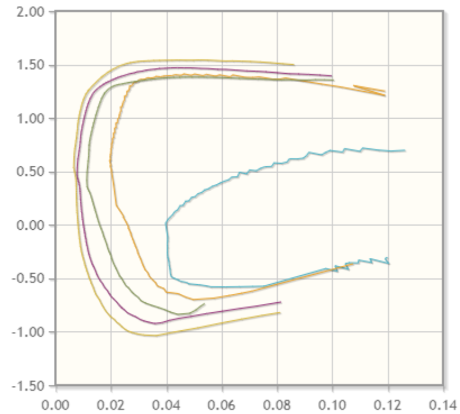


Figure 28: C_L v C_D

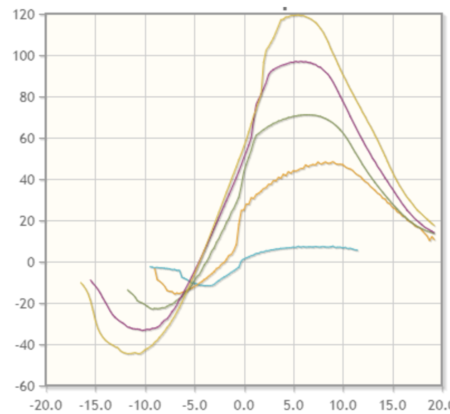


Figure 29: C_L/C_D v Alpha

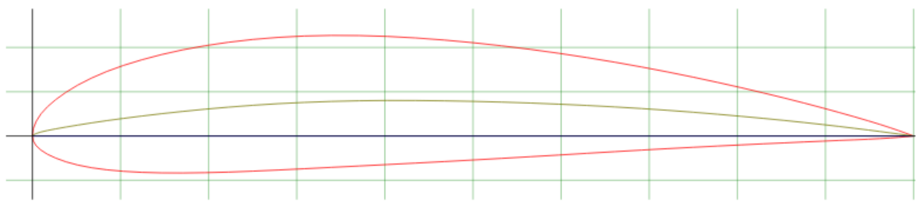


Figure 30: Flaperon Lift Comparison

iv. Aerodynamic Properties

The aircraft has an aspect ratio of 7.36. This value will give the aircraft slightly less induced drag than a lower AR and results in less power required. An additional effect of our high AR is increased stability but at the cost of maneuverability. The wing loading is 4.06 lbs/sq.ft for Mission 2, the heaviest mission. The maximum lift to drag ratio is 1.97. Our estimated cruise speed is 47.869 ft/s in mission 1, 61.321 ft/s in mission 2, and 48.479 ft/s in mission 3**,** and at about those speeds our aircraft is projected to generate about 12 lbs. of thrust with a 0 degree angle of attack obtained through **Eq. (14)** [7] Our estimated stall speed is found to be 39.89 ft/s for mission 1, 51.10 ft/s for mission 2 and 40.31 ft/s for mission 3, as calculated in **Eq. (15)** [7].

$$L = qSC_L \tag{14}$$

$$V_{Stall} = 2\frac{W}{S}C_{L_{Max}} \tag{15}$$

$$q = \frac{1}{2}\rho V^2 \tag{16}$$

v. Drag Estimations

The initial estimation of drag was found through **Eq. (20).** The different components of the aircraft were broken down and the drag imposed by each component was found with the banner in mission 3 contributing the most while other surfaces such as landing gear and antennas contributing the least. The method for breaking down the drag modeled after the textbooks written by Leland M. Nicolai and Grant E. Carichner's *Fundamentals of Aircraft and Airship Design Volume I - Aircraft Design* and Anderson's *Introduction to Flight* using **Eq. (17-22)** [8] [7] . The individual component contributions on the total drag can be observed in **Table 15** based on percentage of total drag for mission 3. The coefficient of drag vs. angle of attack for the NACA 4415, from Airfoiltools.com is depicted in **Figure 32** [6].

$$c_d = \frac{D}{q^s} \tag{17}$$

$$C_{D,i} = \frac{C_L^2}{eAR} \tag{18}$$

$$C_D = c_d + C_{D,i} \tag{19}$$

$$D = qSC_D \tag{20}$$

$$C_{D,0} = C_{fe}\frac{S_{wet}}{S_{ref}} \tag{21}$$

$$C_D = 0.561AR^{-0.480} \tag{22}$$

Table 15: Drag Distribution	
Drag Contributions	**(%)**
Induced Drag on Wings	12.20%
Banner	70%
Body Friction	9.10%
Other Sources	8.75%

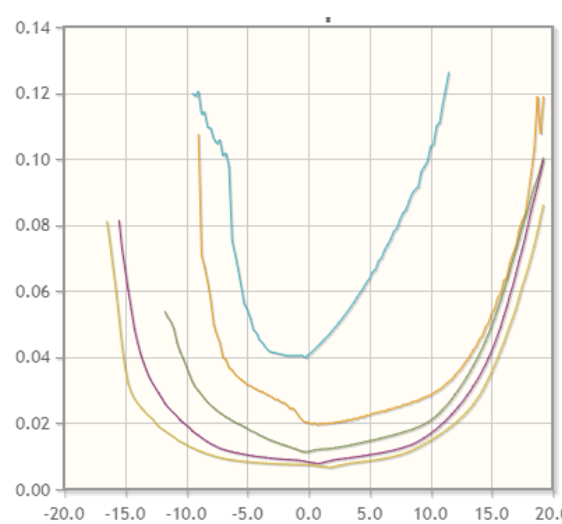


Figure 31: Cd v Alpha

E. Stability Analysis

The stability and control testing posed a major problem for the team. A large amount of effort was put into finding and learning how to use AVL software, but in the end, the team accepted that it was not a possible task to accomplish in the time remaining due to a lack of experience using the software. The team briefly looked into performing the stability calculations without the use of AVL software, but to quote Raymer, "Dynamic-stability analysis is complex and requires computer programs for any degree of accuracy" [9]. To counteract the lack of stability testing, a very traditional airframe design was chosen for its easily predictable stability characteristics. A high wing configuration was also selected because of its inherent stability about the longitudinal and lateral axis. Original avionics designs included an active gyro stabilizer to be wired between the receiver and the servos to automatically correct unwanted pitching, rolling, and yawing moments encountered. Unfortunately, an amendment to the competition rules specifically forbade the use of active gyro stabilization, so the pilot will now be in full control of the aircraft without the benefit of having active stabilization. As the team progresses though flight testing, particular attention will be payed to the aircraft's stability characteristics. If an instability is found, the team will have to decide if it is controllable enough to simply contend with, or if warrants a minor amendment to the design of the aircraft.

F. Estimated Mission Performance

Performance of several flight characteristics were estimated and are listed in **Table 16.**

Table 16: Mission Performance			
Performance Parameter	Mission 1	Mission 2	Mission 3
$C_{L,Max}$	1.305 (1.6 w/ flaps)	1.305 (1.6 w/ flaps)	1.305 (1.6 w/ flaps)
Cd_0	0.02	0.02	0.02
L/D_{cruise}	1.077	1.970	1.080
V_{cruise} [ft/s]	47.869	61.321	48.479
V_{stall} [ft/s]	39.891	51.101	40.399
Power [watts]	51.995	109.303	54.007
Aircraft Weight [lbs]	9.75	16	10
Wing Loading [lbs/ft^2]	3.508	5.757	3.598
Max Time [min]	5	5	10
Number of Laps	3	3	8
Payload	None	20 passengers/ luggage	Banner (48 in)
Mission Score	1	1 + 6.8/TBD	2 + 388/ TBD

V. Final Design

The detail design phase combines aspects of the conceptual design phase and the preliminary design phase with more detailed testing and analysis of all the components of the aircraft. The design team considered and analyzed the structural characteristics, weight, avionics systems, propulsion system, and specific mission requirements in order to refine the dimensions of the aircraft to maximize the potential scoring of the missions in the competition.

A. Design Parameters

The aircraft's dimensional properties are listed in **Table 17**.

Table 17: Aircraft's Dimensional Properties

Fuselage	Length (in)	27.5
	Width (in)	5
	Height (in)	5.5
Wing	Span (in)	60
	Chord (in)	6.98
	Maximum Thickness (in)	1.09
Nose	Length (in)	4.5
	Width (in)	3-5
Horizontal Stabilizer	Chord (in)	4.5
	Thickness (in)	0.38
Vertical Stabilizer	Length (in)	10.8
	Width (in)	0.38
	Height (in)	7
Flaperons	Chord (in)	1.51
	Span (in)	27.5
Rudder	Length (in)	1.5
	Width (in)	0-0.38
	Height (in)	7
Elevator	Length (in)	1.5
	Span (in)	13

B. Structural Characteristics

The structural composition of the aircraft was created to make sure that all the loads that the aircraft is subjected to have a load path that leads to the major load bearing components. There are three categories of loads to which the aircraft will be subjected to: (1) thrust loads, (2) aerodynamic loads, and (3) ground loads.

- Thrust loads: This includes thrust, torque, and vibrations. The load path of the thrust load leads to the motor mount. The motor mount is made of 1/8-inch plywood which provides more than enough strength to combat the thrust, torque, and vibrations caused by the motor and propeller.
- Aerodynamic loads: This includes lift created by the wing and control surfaces, drag, and moment. The load path of the aerodynamic loads leads to the wing nut-plates.
    - Wing nut-plates: In order to ensure structural integrity of the aircraft due to aerodynamic loads, the structural team decided to fasten the wing to the fuselage with bolts that are connected to wing nut-plates that are epoxied to the interior of the fuselage. There are four bolts that go through the wing, one bolt in each corner of the wing and fuselage intersection. The strength that the bolts and nut-plates provide is strong enough to avoid the use of spars, which simplified the manufacturing process. Because of the high aspect ratio of the wings, there is a much greater moment produced compared to a low aspect ratio wing, and the bolts and nut-plates ensures structural integrity.
- Ground loads: This includes the aircraft weight when on the ground, and landing impact. The load path of the ground loads primarily lead to the landing gear struts while on the ground, but on landing impact, the loads will be transferred to the landing gear struts, and the wing bolts and nut-plates.
    - Landing gear struts: The landing gear struts need to be able to handle the landing impact of the aircraft. The struts will be made of metal, so they are able to bend and not brake when the aircraft is landing. In addition to the struts, the tires on the landing gear will also absorb some of the shock.

i. Monocoque Structure

In addition to the primary load bearing components of the aircraft, the skin of the aircraft also provides a great deal of structural strength. The design team has chosen to construct a monocoque aircraft with a combination of fiberglass and carbon fiber as the skin of all surfaces, including control surfaces. The wings, empennage, and control surfaces will have a foam interior and a carbon fiber exterior. The fuselage will be a carbon fiber and fiberglass shell. The advantage of a monocoque design is that it is much easier to manufacture. Although monocoque designs have less strength than semi-monocoque designs, the team's use of carbon fiber makes up for the lost strength. In fact, the carbon fiber-monocoque design provides more strength than a semi-monocoque design made of other materials that were being considered. Carbon fiber is a very strong material and combined with the primary load bearing components, the structural integrity of the aircraft is very sound.

C. System and Subsystem Selection, Integration, and Architecture

i. Fuselage

The fuselage was designed to maximize usable space in order to fit as many passengers and their luggage while making them easily accessible. In order to account for the full 20 passengers, most of the bottom of the aircraft removable. This allows for easy access to both the required payload as well as the batteries; which are located at the top of the fuselage and secured using Velcro, **Figure 32-33**.

Figure 32: Fuselage

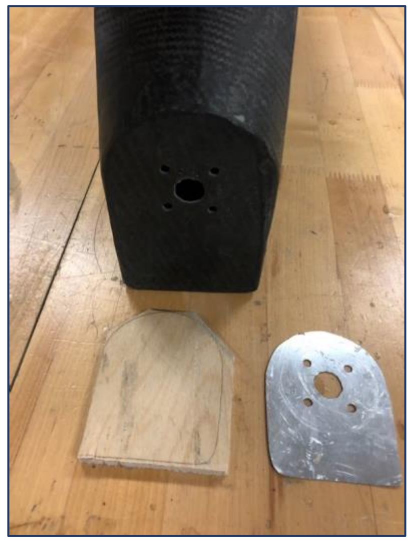


Figure 33: Motor Mount

ii. Payloads: People and Banner Mechanisms

The passengers were bought but did not meet the required weight that is acceptable by the competition, **Figure 34**. A hole was drilled out from the bottom of each passenger and filled with lead in order to get them to the specified weight. The luggage for each of the passengers were cut from pine and were also underweight, so they had to be drilled out and filled with lead as well.

For the retaining of the passengers and their respective luggage, there will be a foam piece that will have drilled slots big enough to hold each passenger separately. To account for more force into being able to hold the passengers in place, elastic bands will be strategically placed to sufficiently hold all the passengers. The luggage will be held in by netting behind the passengers.

Figure 34: People and Luggage

iii. Propulsion

The motor chosen is T-motor F1000 which allows for enough power to handle all three missions with ease. The motor is mounted to the front of the fuselage. The mount for the motor is made of aluminum sheeting, as seen in **Figure 33** in order to create more support for the carbon fiber fuselage. The motor was initially paired with a three-blade propeller with a radius of 12 inches. Upon further testing, a different propeller may be selected in order to improve take-off distance. A three-blade propeller allows for enough thrust with a smaller radius while allowing for shorter landing gear, resulting in less drag.

iv. Control Surfaces and Banner Mechanism

We will be using servos to control a multitude of aspects on our aircraft. For our banner mechanism, two servos will be used in order to hold, deploy, and release the banner during flight. One servo will be mounted under the plane and the banner will be folded so the arm of the servo can put enough pressure between the folded banner and the plane to keep the banner from prematurely deploying. The servo used to release the banner will be located outside of the fuselage towards the tail section of the aircraft, pinning the line of the banner down so that it does not release when the banner is initially deployed. Attached to the banner will be monofilament line, which provides enough strength as well as stretch to keep the banner from tearing during deployment and flight. The banner size selected is 10 inches in width and 48 inches long. Servos will also be utilized on all four control surfaces: (1) rudder, (2) elevator, (3) left flaperon, and (4) right flaperon, **Figure 35.**

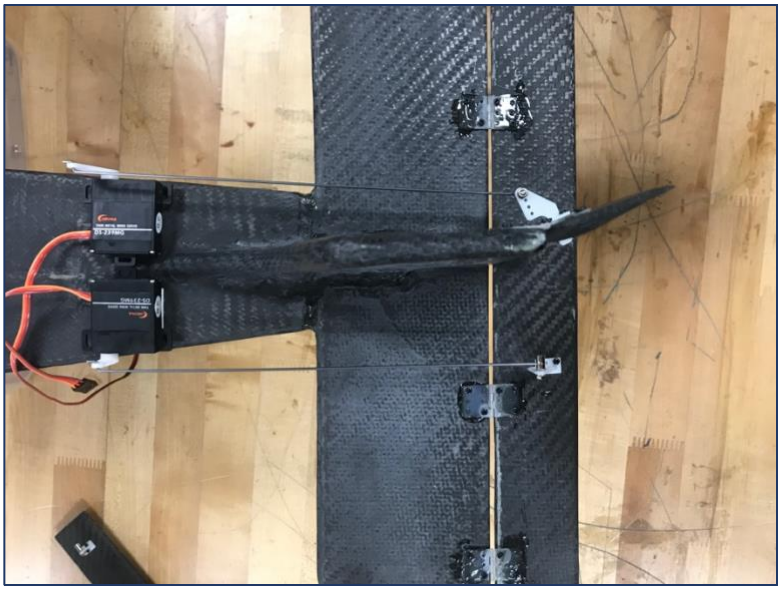


Figure 35: Elevator and Rudder Servos

v. Flaperons

Flaperons were chosen over typical flaps in order to help with takeoff and flight stability, **Figure 36**. The flaperons are 27.5 inches in length each and are constructed with the NACA 0012 airfoil. They are held onto the empennage by hinges that are screwed in place.

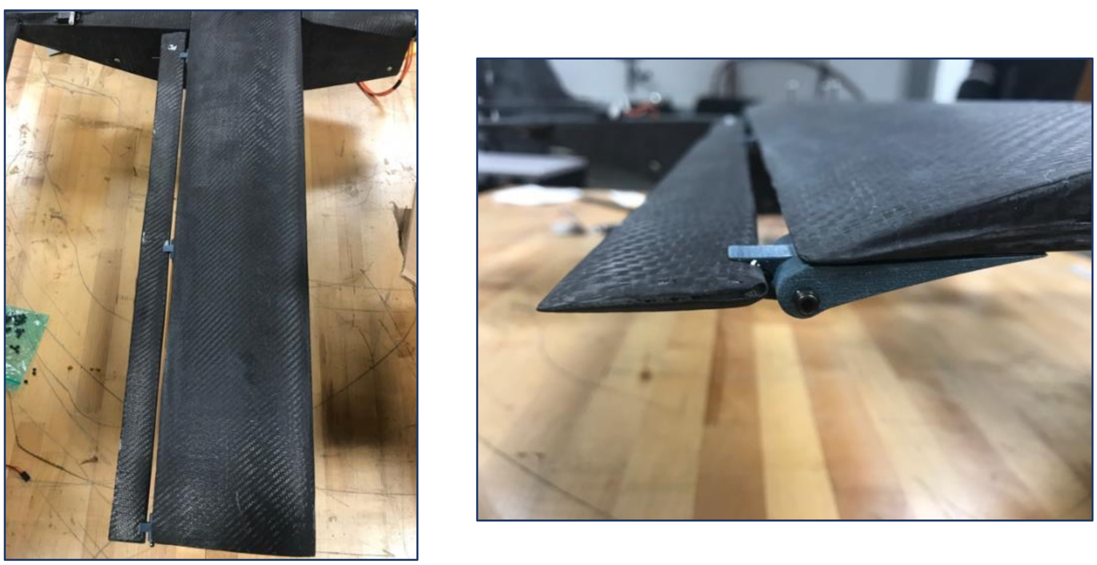


Figure 36: Flaperon and Hinge

vi. Empennage

The empennage will be a typical T-tail construction, **Figure 37.** A portion of the vertical stabilizer will be used for the rudder and a portion of horizontal stabilizer will rotate and function as the elevator.

Figure 37: Empennage

vii. Landing Gear

The rear wheels have a diameter of 3 inches and the landing gear has a base that is 3-5/8 inches, a landing length of 4-1/2 inches, and a width of 14 inches. This allows for enough clearance for the propeller during landing. The wheels and the elasticity of the landing gear itself ensure that landings can be done without bouncing off the runway.

The nose landing gear is steerable and can absorb shock to help with runway positioning during takeoff and landing. The diameter of the wheel for the nose gear is also 3 inches. Smaller wheels for the front landing gear will also be ordered in order to see whether or not the plane is capable of using a smaller tire to properly control the aircraft on takeoff and landing. Using a smaller tire for the front landing gear would result in less drag.

D. Weight and Balance

Table 18 shows the weight of our aircraft for each mission. Our empty weight for the aircraft is 7.54 lbs. The maximum amount of people/luggage to which we can carry on the aircraft during mission 2 will be determined on competition day; therefore, three different configurations were used to analyze weight: (1) the minimum number of passengers we plan to have, (2) the median number of passengers, and (3) the max number of passengers. The variations include two, eleven, and twenty passengers with the same amount of luggage for each.

The internal components of the aircraft have been designed in a fashion that will allow critical flight components to be moved around so the ideal center of gravity can be achieved, **Figure 38**. Particularly the batteries will be able to be relocated depending on the weight of the payload during a particular mission in order to allow for changes in center of gravity.

Table 18: Weight (lbs)

		Payload	Batteries	Propulsion	Landing Gear	Fuselage/ Wings	Avionics/ Misc	TOTAL
Mission 1 (Empty)		0	2.53	0.81	0.63	2.92	0.65	7.54
Mission 2 (# of Passenger)	2	0.63	2.53	0.81	0.63	2.92	0.65	8.17
	10	3.13	2.53	0.81	0.63	2.92	0.65	10.67
	20	6.25	2.53	0.81	0.63	2.92	0.65	13.79
Mission 3 (Banner)		0.04	2.53	0.81	0.63	2.92	0.65	7.58

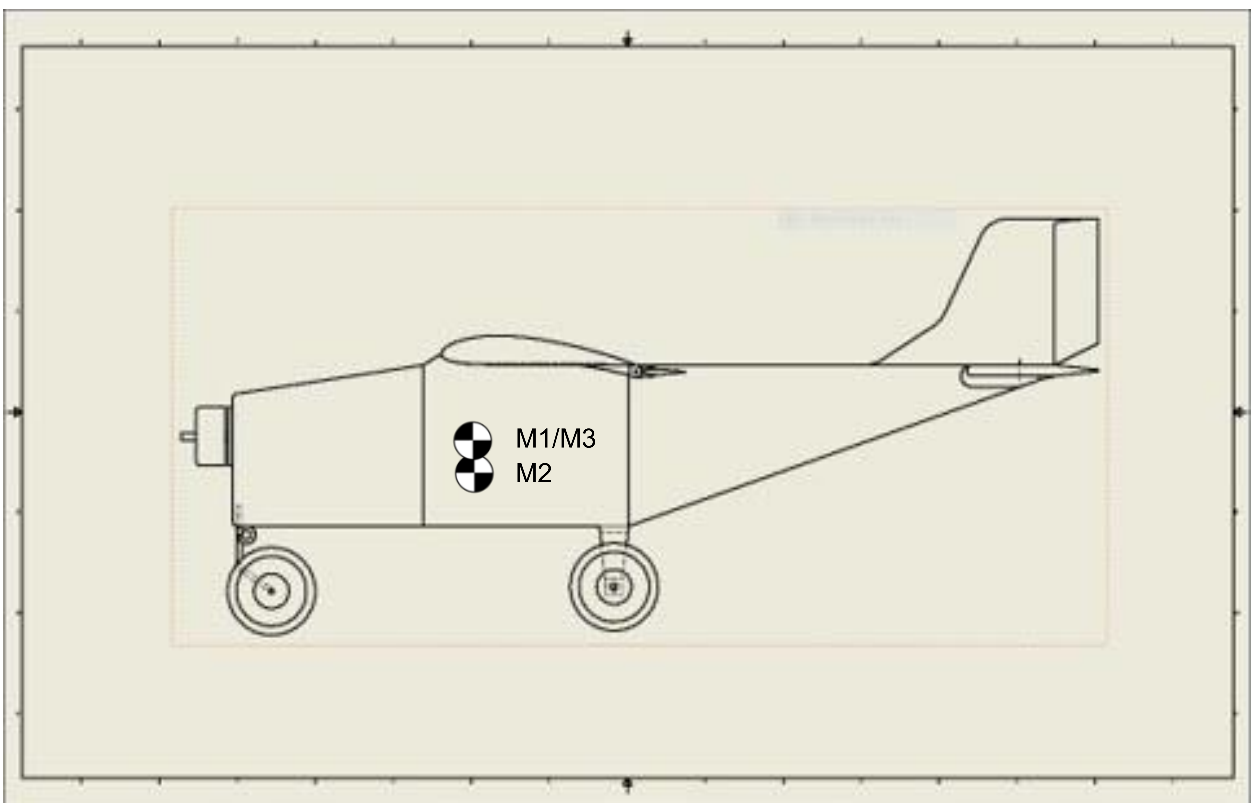


Figure 38: Center of Gravity

E. Flight Performance Parameters and Mission Performance

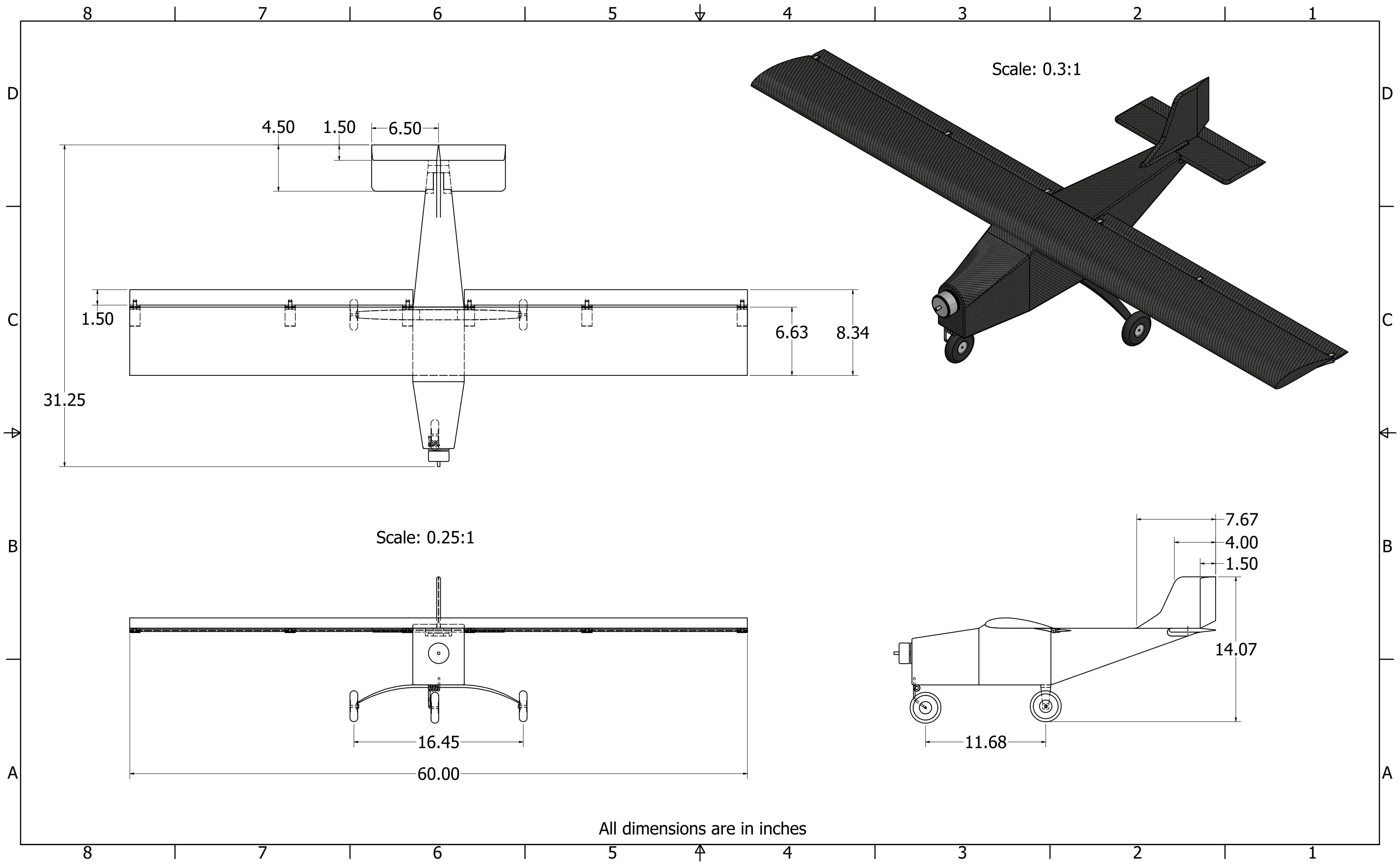
Performance of several flight characteristics were estimated and are listed in **Table 19**.

Table 19: Flight Performance Parameters

Performance Parameter	Mission 1	Mission 2	Mission 3
V_{stall} [ft/s]	38.464	52.018	38.566
V_{cruise} [ft/s]	46.157	62.422	46.279
Aircraft Weight [lbs]	7.54	13.79	7.58
Wing Loading [lbs/ft^2]	2.22	4.06	2.23
Time [min]	4.161	3.077	10
Number of Laps	3	3	7
Payload	None	20 passengers & luggage	Banner (48 inches)
Score	1	1 + 6.50/TBD	2 + 336/TBD

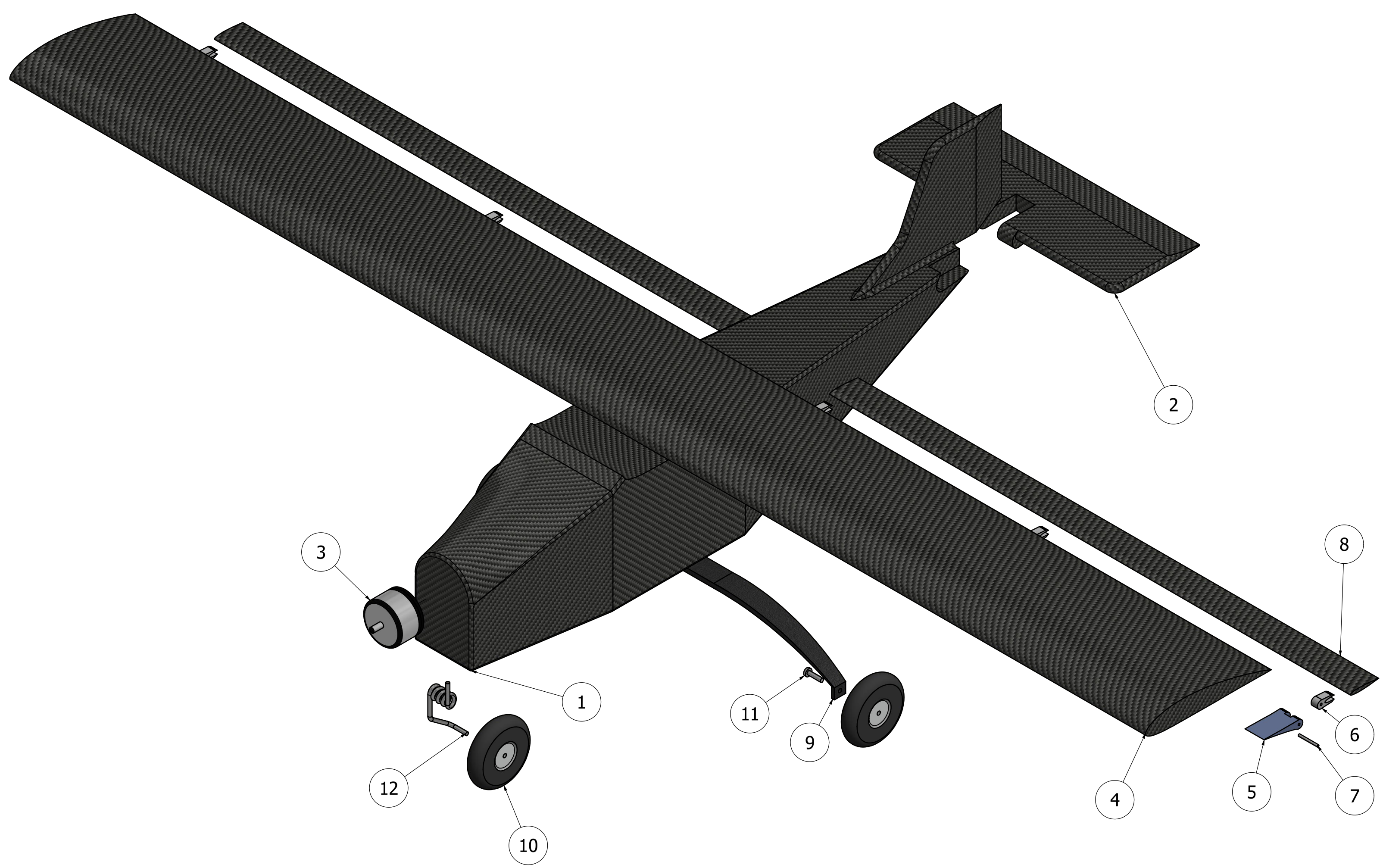
F. Drawing Package

This section contains the 3-view drawing with dimensions and the exploded view drawing with parts list.



Scale: 0.3:1
4.50
1.50
6.50
1.50
31.25
6.63
8.34
Scale: 0.25:1
16.45
60.00
7.67
4.00
1.50
14.07
11.68
All dimensions are in inches

PARTS LIST		
ITEM	QTY	PART NUMBER
1	1	Fuselage Redesign 3 - with partial assembly
2	1	Fuselage Redesign 3 - Horizontal stab
3	1	Motor
4	1	NACA4415-scaled-6.65x60 CF
5	6	Flaperon Hinge Mk 4 - Wing
6	6	Flaperon Hinge Mk 4 - Flaperon
7	6	Hinge pin
8	2	Aileron-1.5x27.5
9	1	MLG
10	3	Wheel and Tire 3 in
11	2	MLG Axel
12	1	NLG



VI. Manufacturing

Various manufacturing processes and materials were investigated for each of the components our team chose to manufacture wing, fuselage, flaperons, hinges, control surfaces, and empennage. The ideal process and materials were selected for each component.

A. Manufacturing Processes Investigated

CNC: A CNC router uses a computer model created within AutoCAD to cut materials to shape with routing bits. The cuts begin with large rough passes to take out the bulk of material, then passes become shorter and slower to create the fine shape of the final component required.

Composite Layups: Composites are lighter than metals while retaining the same strengths. While they are heavier than wood, they are also more resilient, providing a more robust structure.

Foam: Foam is easily molded to shapes required for uses such as airfoils. While the foam itself would provide next to no material strength itself, when put together with composite materials it can provide great benefit for component manufacturing by providing a light mold in which to seal the composites.

Balsa Wood: Balsa wood works well for creating underlying structures within aircraft. Wood is lighter than composite materials and, while not being as strong of a material, still provides material strength that works very well for non-intensive applications.

3-D Printing: 3-D printers use AutoCAD models to create a plastic structure with varying accuracy based upon the system and material used. The system and material investigated were the Stratasys™ printer with Vero™ plastic. This combination ensures accurate printing of material with enough tensile strength for use in light mechanical systems.

Hot wire cutters: Hot wire cutters rely on current running through a wire between two rods to create heat. The wire is then used to run across foam to cut the material to shape. The system works well for rough cuts but does not work well for fine shaping.

Laser Cutter: Laser cutters use AutoCAD models to recreate the shape of the model onto a material. The process can be used for burning fine designs onto materials or can be used in cutting materials to size with relative accuracy.

B. Selection Process

Several materials were considered, and final decisions were made using a FOM system where each FOM was ranked from zero to five, with five being the most important. See **Table 20**.

Availability: Use of available materials from our lab allowed for more of the budget to be used on costs such as travel for the team and team uniforms.

Weight: allows the best performance from our aircraft, to include takeoff distance, acceleration, endurance, and landing. With too much weight, we wouldn't be able to perform our given missions correctly.

Cost: Opens possibility of spending funds on travel and lodging during competition, along with extra funds for replacement materials if required

Durability: Creates a robust airframe to handle possible impacts, G forces in flight, and weight of extra passengers.

Manufacturability: Shortens time required to build components along with the cost required to manufacture the products.

Table 20: Figure of Merit

FOM		Materials				
	Importance	Carbon Fiber	Fiberglass	Balsa Wood	Aluminum	Foam
Availability	4	5	4	3	3	5
Weight	4	3	2	4	2	5
Cost	3	1	2	3	2	5
Durability	5	5	4	1	4	1
Manufacturability	3	3	3	4	3	3
Total		**69**	**59**	**54**	**55**	**69**

C. Manufacturing of Parts

i. Wings, Fuselage, and Tail

Wings, Fuselage, and tail were created by starting with a foam mold. This mold was CNC routed, then sanded smooth. The foam mold was then layered in two layers of fiberglass, a layer of carbon fiber, and vacuum bagged. After being entirely cured, the vacuum bag was removed, and excess carbon material was cut away using a Dremel away to form the final shape. The components were then finished by being sanded and sealed. The wing was completed by being attached to the fuselage with four screws and four nut plates. In the fuselage, the bottom plate was cut out to create an access panel for all passengers and cargo. The panel was connected to the rest of the fuselage by eight screws and nut plates. The majority of the foam mold within the fuselage was then cut out to create the cargo space. The tail was completed after being glued to the rest of the fuselage using two-part epoxy. Gaps between the two were then covered by patches of carbon fiber and refinished.

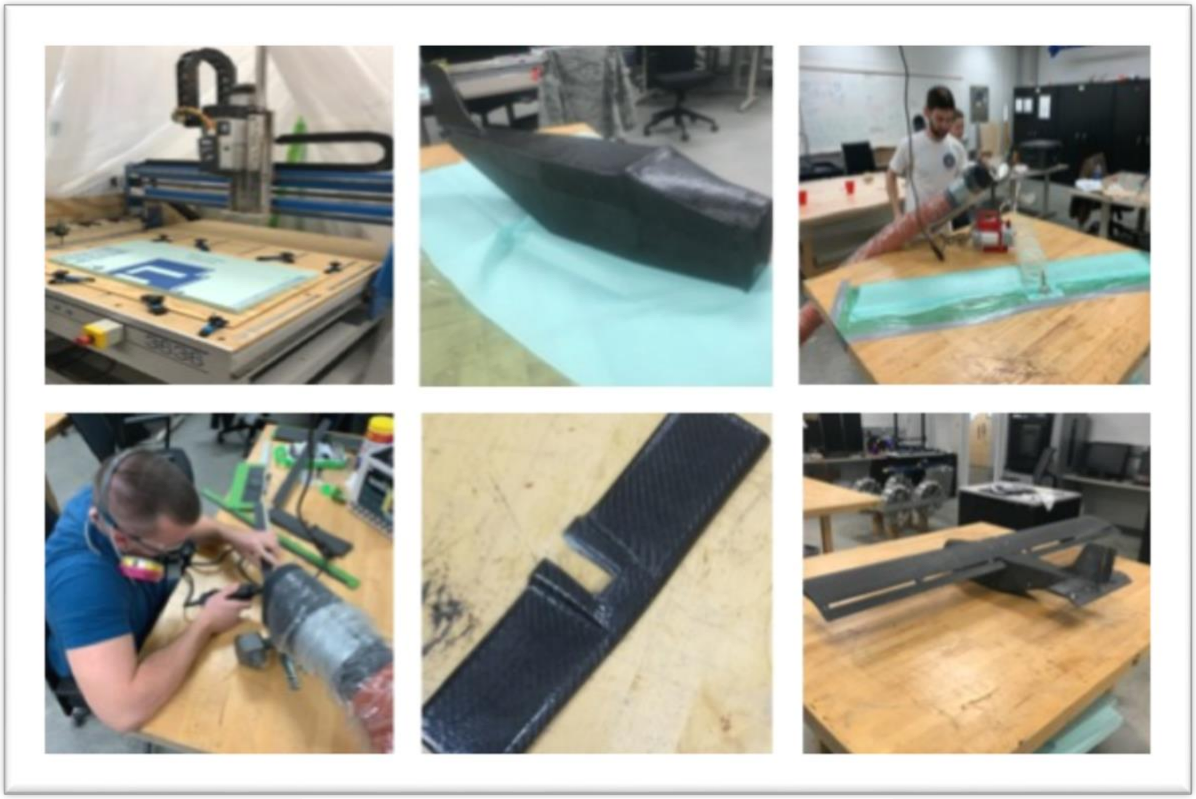


Figure 39: Manufacturing Process

ii. Control Surfaces

All control surfaces were created through a similar vacuum bagging process to the wing. Surfaces were then connected through the use of one servo per control surface. Four servos were used in total for two flaperons, the elevator, and the rudder.

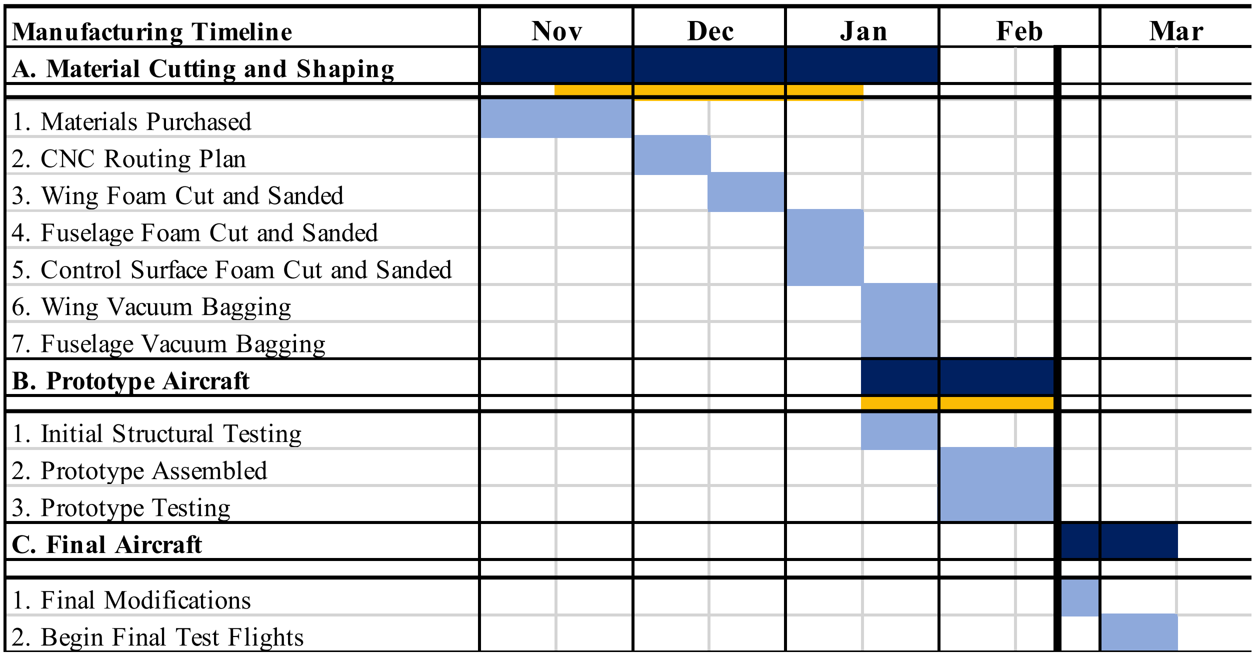
iii. Control Surface Hinges

Hinges were 3-D printed in a Stratasys printer using VeroTM plastic, a proprietary material used for models, prototyping, and lightweight functionality. The tabs of the hinges were then sanded down to fit within each other before being attached between the wings and control surfaces.

D. Timeline

A timeline was strictly followed for the manufacturing of this aircraft, **Table 21**. Deadlines were set based on past experiences when creating similar projects.

Table 21: Manufacturing Gantt Chart



VII. Testing Plan

It is necessary to conduct extensive and redundant testing to ensure that the theoretical assumptions and calculations made during the initial design phase are representative of the final product. It's critical to validate the functionality to ensure the safety of the aircraft prior to initial flight test.

A. Objective

Tests were divided into four categories: propulsion, avionic, structures, and flights. The purpose of the tests is to validate the strength, power, functionality, and endurance of the critical flight components. The propulsion system is tested to ensure the relationship between motor, propellers, and batteries, and validate the thrust, voltage, current, and electric power produced. The structure testing is to ensure that the airframe, wings, fuselage, and center of gravity structure can withstand bending, torsion load in flight and shear. Finally, flight performance was tested with a flight test to validate all systems were successfully integrated.

B. Propulsion Testing

The teams plan for testing possible motors and propellers center around the KSU electronics test bench. The test bench allows the accurate testing and recording of propulsion data from any motor/propeller/power source combination. Thrust, RPM, temperature, amperage, voltage, and wattage draw can all be measured using the sensors in the test bench. This method of data collection was invaluable in the testing of our propulsion sources as it allowed us to build graphs, compare data, and more accurately calculate flight performance.

C. Wing Tip Testing

To ensure the wing would withstand ultimate load without collapsing, wing tip tests were conducted and will continue to be conducted prior to test flights. The test was conducted as follows: the wing tips were suspended by two tables. A spring scale is inversely used to pull down on the fuselage. The scale is pulled until the maximum predicted weight is achieved.

D. Aerodynamic Testing

i. Banner

Potential banner material has been tested in KSU wing tunnel lab to verify integrity of the material. The test was announced successful if the banner is not deteriorated. The next portion of the banner testing will be directed during flight testing.

ii. Fuselage

The fuselage did not undergo aerodynamic testing due to limited space in the KSU wind tunnel and Autodesk CFD not being compatible with computers available, but testing is not required for it to be assumed this design will produce substantial drag; however, the propulsion system selected is powerful enough to allow the aircraft to fly successfully and complete the missions in the required amount of time.

E. Flight Testing

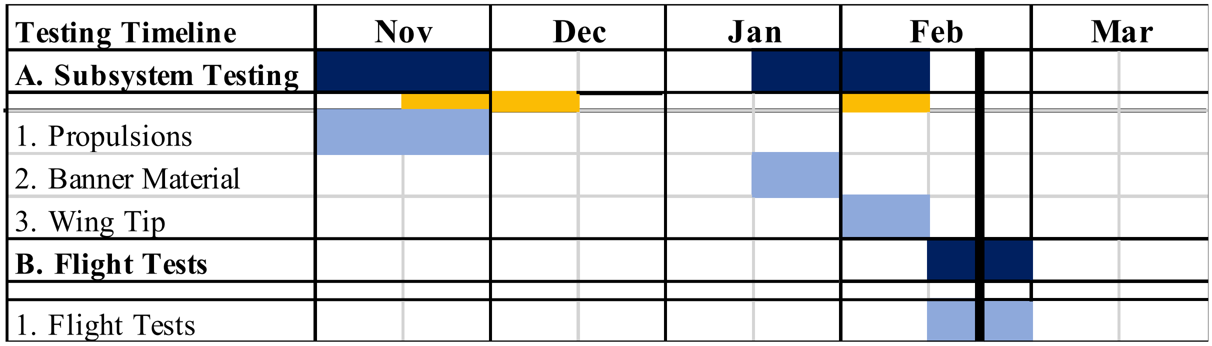
Flight testing is the final stage of the testing after all other components have been assigned, built, tested, and integrated. The results of these tests provide critical information about performance of the aircraft while offering areas of improvement.

Although the team has not flown this aircraft prior to the deadline of this report, the team is confident from the extensive analysis methods that the model will fly, and only minor design changes will be necessary to improve mission scoring. Test flights will begin in March and the design will continue to be tweaked, redundancies with be developed, and finishing touches will be applied to the aircraft up until the competition.

F. Schedule

A testing schedule was developed to ensure the success of all aspects of the aircraft, **Table 22**. All testing was and will be supervised by the testing team lead and assistant project manager to ensure that all tests were completed in the designated time frame and safely.

Table 22: Testing Gantt Chart



G. Checklists

A checklist was designed to ensure safety during flight missions. The checklist has three major sections: (1) Structural, (2) Avionics and Controls, and (3) After Flight.

Pre Flight Check List	
Date	
Time	
Location	
Pilot	
Safety Officer	
Weather Conditions	
Additional Notes	

Before Flight	Initials
Structural	
Apply Loctite and Verify fasteners are tightened	
Verify all components are adequately secured to the vehicle:	
Verify propeller structure and attachment integrity	
Verify motor mount is secure	
Verify control surfaces are free and correct	
Verify all batteries are secure and charged	
Avionics and Controls	
Visual inspect all wiring and connectors	
Verify controls	
Verify failsafe	
Final	
Runway Clear	
Pilot Ready	
Visual Observer Ready	
After Flight	
Throttle put into idle	
Batter disconnected	

VIII. Results

A. Component Performance

Tests were performed on multiple components to test their reliability before they were integrated into the system. These tests were performed to help make design decisions.

i. Propulsions

Testing on various motor-propeller combinations were performed to see what combination produced the optimum amount of thrust needed for the aircraft. Kent State's UAS Static Thrust Bench, **Figure 11**, was utilized to conduct these tests. Two motors were already on hand from pervious UAS competitions, and to keep costs low, tests were conducted on these first to see if one would satisfy the needs for this year's competition. A very basic test was written, where the motor was walked through throttle settings from 0% to 100% in 10% increments. The T-Motor F1000 with a 12-inch propeller produced the most thrust. The test stand utilizes automotive batteries for its power supply, based on voltage use and amperage draw the batteries were selected from this data.

ii. Wing

A wing tip test was performed to ensure the wing could handle the load of the fuselage and payload, **Figure 40**. The aircraft was setup in its current configuration, then the wing tips were suspended by two tables. A spring scale was inversely used to pull down on the fuselage. The scale was pulled until the maximum predicted weight, 16 lbs. was achieved. The aircraft showed no signs of stress when this weight was held for a reasonable amount of time.

Figure 40: Wing Tip Test

iii. Paint

A clear coat is planned to be applied to the carbon fiber structure. In order to test the effects of the added material, a test piece was painted. The spare horizontal stabilizer was selected for the test piece, **Figure 42**. Prior to being painted the weight of the piece was taken and drag force on the piece was tested in

Kent State's Subsonic Wind Tunnel, **Figure 41**. The test piece was then sanded and sprayed with clear coat at Steiner Aviation with aerospace grade paint products. The same tests were performed after the paint system had been built up with 4 coats of clear coat, **Figure 43**. The weight increased from 0.095 lbs to 0.097 lbs for a piece with a surface area of 86.4 in2, so an overall increase of 2.11%. The drag tests did indicate a slight increase in overall drag. These results are believed to be caused by imperfections in the setup of the experiment. Since the wind tunnel measures overall drag and skin friction drag plays a small part of overall drag, the change in drag could have been caused by calibration issues or placement of the piece in the wind tunnel.

Figure 41: KSU Subsonic Wind Tunnel

Figure 42: Horizontal Stabilizer

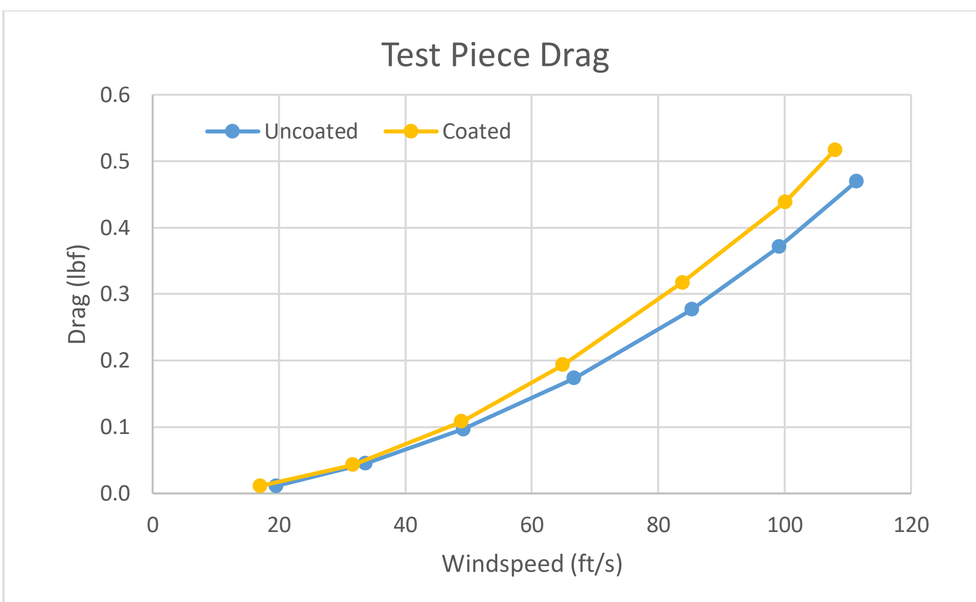


Figure 43: Drag Comparison

iv. Banner

The banner material was tested using Kent State's Subsonic Wind Tunnel. The test was conducted to compare the durability of two materials. Both Mylar and Ripstop was cut into a 1:4 scale piece of the banner size. The pieces were mounted in the wind tunnel and ran up to 110 ft/s, a speed over the max speed of the aircraft. The Ripstop held up better than the Mylar, so the decision was made to use Ripstop as our final material, **Figure 44-46**.

Figure 44: Mylar

Figure 45: Ripstop

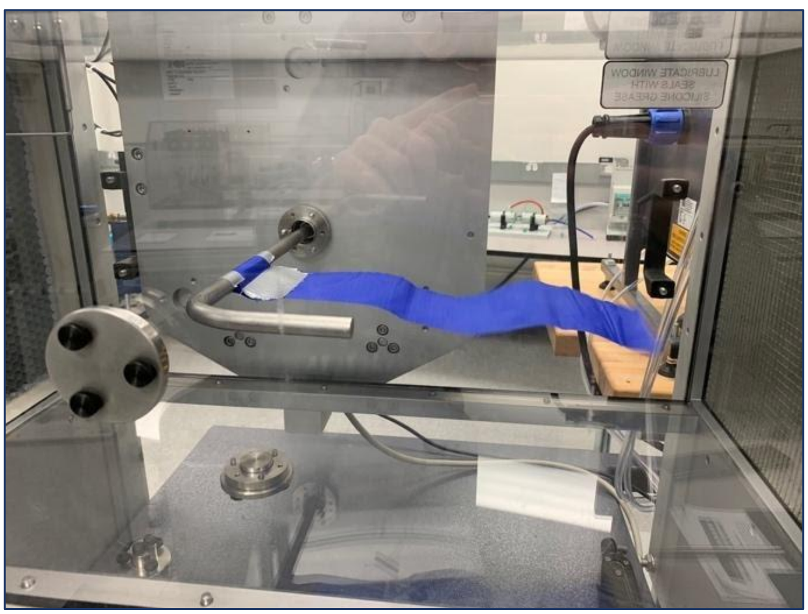


Figure 46: Wind Tunnel Test

B. System Results

The team was unable to finish aircraft assembly and test fly before this report's deadline due to ongoing issues with parts not being ordered on time by university faculty, 3D printed hinges cracking, and other integration errors. Although the team is unable to write the results from a test flight, the utmost care will be taken to provide a safe and effective aircraft for the competition.

C. Improvements

From these tests adaptive changes were made. The propulsion system performed well on the test stand, but after considering battery options and wiring patterns the possibility of a bigger propeller is being considered to produce more power at lower throttle settings. A steeper pitch of blade is also being considered for shorter take-off distance. One thing that is needed to keep in mind with these adjustments is the propeller tip speed. A larger prop will also lower the RPM the motor needs to run at keeping power consummation lower. Minor improvements will be made as flight testing is conducted with the aircraft.

IX. References

[1] Rules, D. B. F. "Summary :" 2019, pp. 1–29.

[2] Aircraft Performance Database > C172. https://contentzone.eurocontrol.int/aircraftperformance/details.aspx?ICAO=C172&ICAOFilter=C172. Accessed Jan. 30, 2020.

[3] Scott Erickson Aviation - Husky Specs (Aircraft Shopper Online, Aircraft Sales, Aircraft for Sale). https://www.aso.com/seller/6810/huskcomp.htm. Accessed Jan. 30, 2020.

[4] Cessna 172 Skyhawk - Specifications - Technical Data / Description. http://www.flugzeuginfo.net/acdata_php/acdata_cessna172_en.php. Accessed Jan. 30, 2020.

[5] Cessna 172 - AOPA. https://www.aopa.org/go-fly/aircraft-and-ownership/aircraft-fact-sheets/cessna-172. Accessed Jan. 30, 2020.

[6] NACA 4415 (Naca4415-Il). http://airfoiltools.com/airfoil/details?airfoil=naca4415-il. Accessed Feb. 11, 2020.

[7] Anderson, J. D. *Fundamentals of Aerodynamics Sixth Edition*. McGraw-Hill Education, New York, NY, 2018.

[8] Nicolai, L. M., and Carichner, G. E. *Fundamentals of Aircraft and Airship Design*. 2010.

[9] Raymer, D. *Aircraft Design: A Conceptual Approach, Fifth Edition*. 2012.

[10] F-HATZ | Cessna 172S Skyhawk SP | Private | Echelon01 | JetPhotos. https://www.jetphotos.com/photo/6817606. Accessed Feb. 19, 2020.

[11] Piper_Super_Cub_1_1998-07-07.Jpg (4848×3096). https://upload.wikimedia.org/wikipedia/commons/9/98/Piper_Super_Cub_1_1998-07-07.jpg. Accessed Feb. 19, 2020.

[12] File:AviatA-1BHuskyC-GTHY01.Jpg - Wikimedia Commons. https://commons.wikimedia.org/wiki/File:AviatA-1BHuskyC-GTHY01.jpg. Accessed Feb. 19, 2020.

[13] File:Zenair STOL CH750 C-IKIM 1716.JPG - Wikimedia Commons. https://commons.wikimedia.org/wiki/File:Zenair_STOL_CH750_C-IKIM_1716.JPG. Accessed Feb. 19, 2020.