SAE Aero Micro Design

Preliminary Proposal

Team 19F11: The Prop Dogs

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2019-2020

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DISCLAIMER

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1 BACKGROUND

1.1 Introduction

The SAE Aero Design competition is composed of three classes Regular, Advanced, and Micro. The SAE Aero Micro Class is a design competition tasking the team with designing and constructing a small unmanned aerial vehicle (SUAV). The SUAV is controlled from the ground by one of the team members via wireless remote controller. The objectives of this class include making trades between carrying the highest payload fraction possible, while at the same time trying for the lowest empty weight possible. There are various other constraints to the design including a limited gross weight of ten pounds, being able to fit within a cardboard box with dimensions of 12.125 inches X 3.625 inches X 13.875 inches, and being hand launched [1]. This competition is highly renowned and has been around since 1986. This year there will be 85 teams attending at Fort Worth Texas from April 3-5 of 2020 for the west division [1]. The teams gracious sponsor W.L. Gore will be represented by our SUAV which is why it is crucial that the team is successful. This competition addresses issues in engineering design, professionalism in presentations, prototyping, and manufacturing products.

1.2 Project Description

The following is SAE's original project description.

> The SAE Aero Design competition is intended to provide undergraduate and graduate engineering students with a real-world design challenge. These rules were developed and designed by industry professionals with the focus on educational value and hands-on experience through exposure to today's technical and technology advancement. These rules were designed to compress a typical aircraft development program into one calendar year, taking participants through the system engineering process of breaking down requirements. It will expose participants to the nuances of conceptual design, manufacturing, system integration/test, and sell-off through demonstration [1].

1.3 Original System

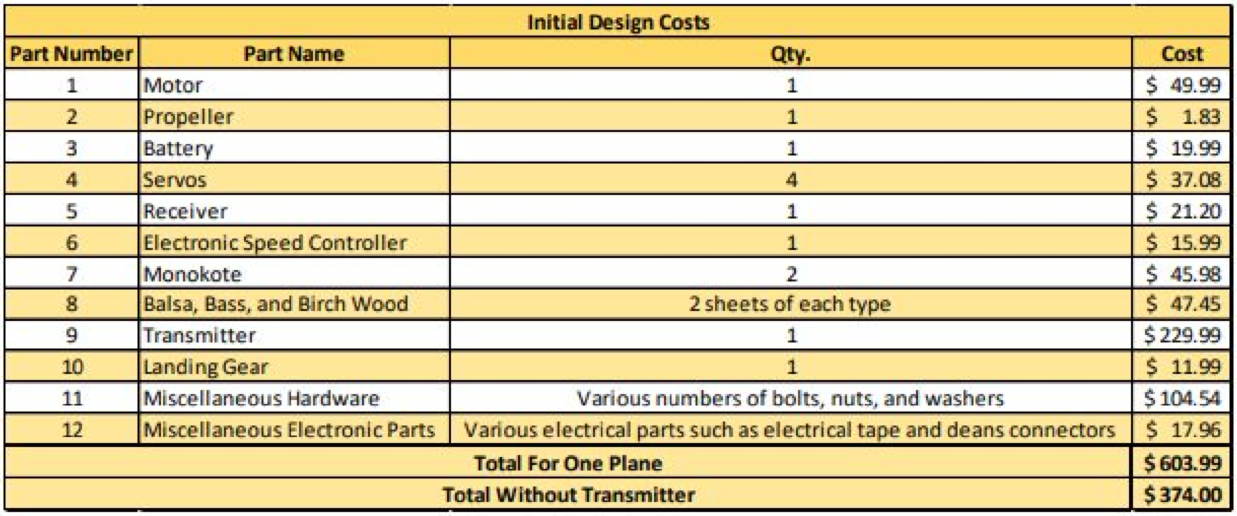
1.3.1 Original System Structure

The physical structure of the original design which is that of the NAU 2019 Aero Micro class design is an ugly stick design composed of mostly balsa wood for the wings and the shaft connecting the fuselage to the tail. Dacron foam was used for the tail end of the plane which reduced the weight in the tail significantly. The landing gear is in a taildragger orientation which is connected to a square fuselage. The previous team used dual ailerons, a single elevator and a single rudder [2]. Shown below is the assembly view of the SUAV.

Figure 1: Assembly view of 2019 NAU Aero Micro design [2]

The bill of materials with all components of the aircraft is shown in the table below.

Table 1: Bill of material of 2019 NAU Aero Micro design [2]



Initial Design Costs			
Part Number	**Part Name**	**Qty.**	**Cost**
1	Motor	1	$ 49.99
2	Propeller	1	$ 1.83
3	Battery	1	$ 19.99
4	Servos	4	$ 37.08
5	Receiver	1	$ 21.20
6	Electronic Speed Controller	1	$ 15.99
7	Monokote	2	$ 45.98
8	Balsa, Bass, and Birch Wood	2 sheets of each type	$ 47.45
9	Transmitter	1	$ 229.99
10	Landing Gear	1	$ 11.99
11	Miscellaneous Hardware	Various numbers of bolts, nuts, and washers	$ 104.54
12	Miscellaneous Electronic Parts	Various electrical parts such as electrical tape and deans connectors	$ 17.96
Total For One Plane			**$ 603.99**
Total Without Transmitter			**$ 374.00**

With the previous teams design crashing four times from the hand launch design crashing four times after being hand launched this years team has deemed last years data not useful for collecting data on operation and performance. In the deficiencies section of the original system there are too many deficiencies to even consider because the plane did not even get the chance to fly.

2 REQUIREMENTS

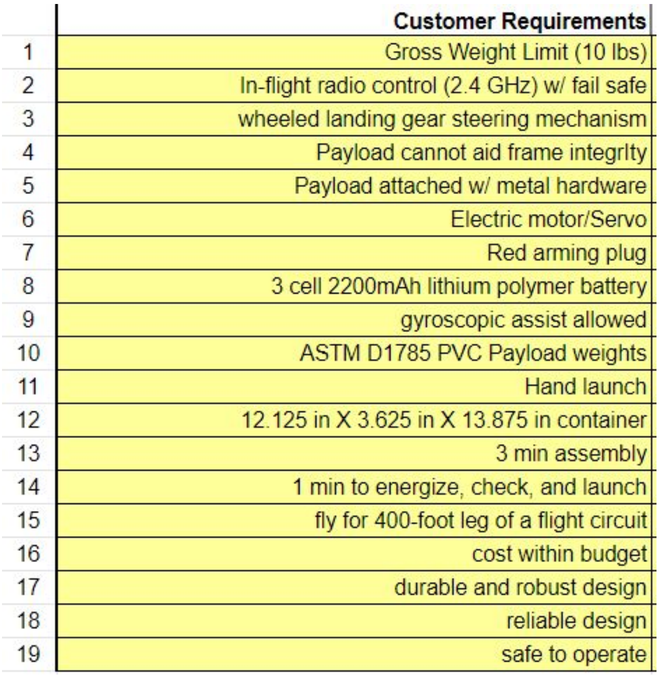
Following the original system breakdown for the SAE Aero Micro fixed-wing plane, the next step in the design process is developing design requirements. The purpose of design requirements is to provide necessary data for concept generation and selection. This section presents the customer requirements, engineering requirements, and house of quality developed for the aero micro design.

2.1 Customer Requirements (CRs)

Customer requirements (CRs) are necessary to fully define a complete list of design requirements. CRs are provided by customers/stakeholders to describe what the design needs to accomplish, while also not arriving at a solution for said requirements. These CRs were generated through NAU faculty advisor interviews, the SAE Aero Micro Design competition rulebook, and instructor requirements.

First, when interviewing the faculty advisor , Dr. John Tester, the team was provided with the following insight: follow all the rules exactly as stated, or the design will automatically fail. Consequently, the meeting with Dr. Tester yielded no direct CRs, but rather encouraged the team to reference the rulebook. So, in reading the 2019-2020 SAE Aero Design competition rulebook, the team developed the first 15 CRs, shown below in Table 2. Each CR in Table 2 directly corresponds to at least one competition rule. Descriptions of each rule and subsequent CR are provided within Table 2 for reference [1].

Table 2: Customer Requirements



	Customer Requirements
1	Gross Weight Limit (10 lbs)
2	In-flight radio control (2.4 GHz) w/ fail safe
3	wheeled landing gear steering mechanism
4	Payload cannot aid frame integrlty
5	Payload attached w/ metal hardware
6	Electric motor/Servo
7	Red arming plug
8	3 cell 2200mAh lithium polymer battery
9	gyroscopic assist allowed
10	ASTM D1785 PVC Payload weights
11	Hand launch
12	12.125 in X 3.625 in X 13.875 in container
13	3 min assembly
14	1 min to energize, check, and launch
15	fly for 400-foot leg of a flight circuit
16	cost within budget
17	durable and robust design
18	reliable design
19	safe to operate

The final method of gathering CRs was through implementing mandatory instructor requirements. These requirements (CR's 16-19) are seen above in Table 2. The design must be manufactured within budget to ensure no monetary loss, while subsequently using project funds to develop a durable and robust design. Finally, the design must operate reliably by functioning predictably and not dangering people upon malfunction.

2.2 Engineering Requirements (ERs)

Given the CRs generated above, the next step in the design process was to translate CRs into engineering requirements (ERs). While customer requirements define what the plane must do, the purpose of ERs are to define how the plane will fulfill those requirements. So, each ER was generated by relating a measurement characteristic to at least one of the CRs. In general, the title of each ER describes which component of design or CR is being measured. The complete list of ERs is shown below in Table 3.

Table 3: Engineering Requirements

Engineering Requirements	**Target**	**Tolerance (+-)**	**Target and Tolerance Rationale**
Control Frequency (GHz)	2.4	0.1	Exact competition requirement
Motor Power (Watts)	350	50	Power limited by 2200 mAh battery
Total Weight (lbs)	5	1.5	Benchmarked weights approx. 4-5 pounds [2,3]
Assembly Time (min)	2	0.5	Competition requires assembly under 3 minutes
Battery Capacity (mAh)	1000	250	Optimize weight, max battery capacity 2200 mAh
Storage Volume (in^3)	72.3	20	Calculated for 2-lb payload given PVC density
Storage Length (inch)	16.3	5	Calculated for 2-lb payload given PVC volume
Current (Amperes)	15	5	Benchmarked value for aero micro planes [2,3]
Launch Angle (deg)	5	1.5	Benchmarked value [2,3]
Launch Acceleration (ft/s^2)	1.3	0.3	Benchmarked average overhand acceleration [2,3]
Propeller Velocity (m/sec)	variable	variable	Variable motor rpm
Motor Speed (rpm)	variable	variable	Variable motor rpm
Lift (lb)	2	0.5	Benchmarked value [2,3]
Thrust (lb)	3	0.5	Benchmarked value [2,3]
Cost ($)	550	100	Calculated given budget and prototype materials
Frame Yield Strength (psi)	145	15	Known yield strength of balsa wood

It is important to note the target and tolerance rationale provided in Table 3. The rationale describes how each value was determined. Prior to conducting testing on components such as propellers and airfoils, many of the target and tolerance values originate from benchmarked values. Other target values are derived by calculations, known values, and competition requirements.

2.3 House of Quality (HoQ)

After defining both the CRs and ERs for the project, the next step was to compare CRs and ERs to each other using a quality function deployment (QFD) system. The purpose of the QFD was to determine the relative importance of each ER and compare how each ER affects other ERs. The relative importance of each ER was determined by how well the ERs satisfied each CR. In this system, CRs are given a customer weight (1-5), and each ER is scored (1,3, or 9) on the relationship with all CRs. Then, the sum of the scoring for each ER is added and compared to yield to relative technical importance. Next, ERs are compared to ERs to determine the design relationships when changing variables. The results for the relative technical importance of ERs and relationships between ERs are shown in the QFD in Appendix

Table A.1.

Upon completing the QFD, the ranked importance of each ER and the relationships between ERs were defined. As shown in Appendix Table A.1, the top 5 most important ERs were weight, power, thrust, payload storage length, and lift, respectively. The reason the top 5 ERs scored so high is they are crucial measurements to determine flight characteristics. Nearly the entire success of flight is dependent upon the weight, power, thrust, storage length, and lift of the aircraft. Understanding the importance of these engineering requirements provided the team with the necessary knowledge to research and generate concept designs that fulfill such requirements. Furthermore, the QFD shows that weight, power, thrust, and lift are all interconnected. So, if the team considered a smaller motor or battery to conserve weight, this will drastically affect the thrust and lift characteristics of the plane. Realizing this, future iterative designs must account for interrelated variables such as weight, power, thrust, and lift.

3 DESIGN SPACE RESEARCH

The contents within chapter 3 includes; a literature review from each member of the group, benchmarking from previous designs, with multiple subsections, and a functional decomposition including a black box model and a functional model.

3.1 Literature Review

3.1.1 Student 1 (Corbin Miller)

Source 1: RC Basics: Introduction to how a RC radio system works [4]

This video gave clear definitions of the components of the radio control system which include the radio controller, radio receiver, binding tool, servo motors, and electric motors. Along with the components there are also different mode variations of the controller which outline the analog sticks axis to the outputs of the SUAV. There is also information on how to bind the human inputs of the controller to the outputs of the SUAV using the binding tool.

Source 2: Online marketplace for Radio Controller/Receiver [5]

This online marketplace gave the team a general understanding of remote controller/receiver prices to use for optimizing our budget. The review sections for each product is extremely useful to understand what consumers thought of different products which will help the team to weed out what is unreliable products.

Source 3: Understanding Radio control gear [6]

This resource is key in the teams design to understand the channels of a remote controller. Channels are the connection between inputs to the code within the controller and the outputs of the SUAV. Each channel has a distinct output including actuation of the propellor, ailerons, elevators and rudder.

Source 4: How to land your R/C model airplane [7]

This informational website gives explicit instructions on the landing of an SUAV. A useful tip learned was about adjusting power rather than the ailerons to increase/decrease the altitude of the vehicle. Another tip mentioned was to make the landing as gradual and flat as possible to ensure that all wheels come into contact simultaneously as possible following a guide slope.

Source 5: Fox and McDonald's Introduction to Fluid Mechanics, 8th ed [8]

The fluid mechanics textbook is a very essential tool in the calculations to be used for concepts such as lift and drag. Boundary conditions and airfoils for the teams design will be referenced through this book as well. When comparing the prototypes to the final design a non dimensionalized analysis approach will be using references from the text book.

3.1.2 Student 2 (Eli Perleberg)

Source 1: CORENGR-V012200 [9]

A technical aspect that is beneficial to our overall design is a Computational Fluid Dynamics or CFD. This is important because we can simulate and view the flow vectors, the lift, and the overall airfoil. This foreshadows how our overall design of the fuselage and the wing will look like. The ANSYS Fluent software performs these tasks with ease. After setting up the boundaries of the airfoil and creating a C-Mesh domain the user can design a model of what airflow they want simulated.

Source 2: CORENGR-V012800 [10]

In ANSYS Fluent the user can start plotting the streamline function, which is very similar to plotting velocity vectors. After creating a mesh grid and clicking on the Stream Function tab in ANSYS Fluent and put in desired values. By changing the minimum mass flow rate, the maximum flow rate, and the levels, Fluent will create a graph shown in (Figure 2).

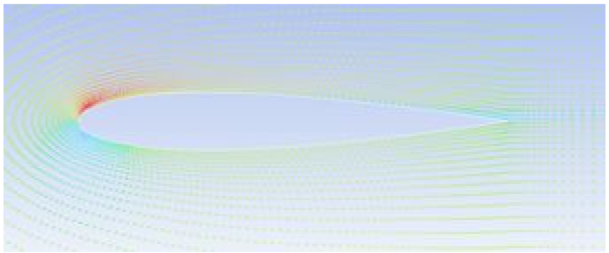


Figure 2: Streamline of Airfoil

In Figure 3, the fluid that the airfoil is submersed in at a certain angle of attack. It shows how the fluid (air in this case) molds around the airfoil at its' desired angle of attack. Without the use of CFD it would be possible to compute the velocity vectors, but in order to achieve the desired accuracy of an actual experiment, CFD is the ideal method.

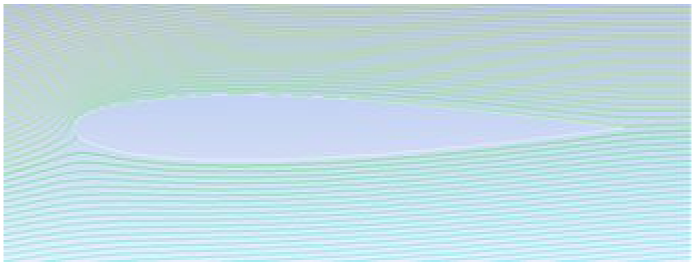


Figure 3: Flow of the Fluid around Airfoil

Source 3: Introduction to Aircraft and Stability Control [11]

This resource explains the importance of lift and drag of airfoils and how it dictates how well the aircraft will fly. The back of the envelope calculations introduced in the Academic text describe how to calculate the desired life and thrust in order for the aircraft to be successful. The most important criteria that this project details is that that aircraft must fly. Throwing an aircraft and letting it glide will not be efficient enough. The pilot of the aircraft must be able to control the design during the duration of the flight.

Source 4: How Ducting a Propeller Increases Efficiency and Thrust [12]

One of the important components of an aircraft and the flight. The propulsion of the aircraft is one of the deciding factors whether or not the aircraft will take flight. The use of a shroud or ducts will increase the thrust and efficiency of the aircraft.

Source 5: Cornell University Learning Modules [13]

This website that Cornell University created details the importance of modules; such as Matlab, ANSYS Aim, and Bladed learning modules. All of these modules are integrated with fluid mechanics, with each module has their own distinct advantages when dealing with fluid mechanics. ANSYS will plot the vectors a lot more efficiently than Matlab, but Matlab will calculate the drag and lift values more accurately.

Student 3 (Zach Simmons)

One of the most important aspects of designing the plane is conducting structural analyses on various parts. For instance, the wing frame and foil must be able to support the lift that is being generated, and the fuselage must support the landing and payload. For these structural analyses, the team decided to use finite element analysis (FEA). Five sources of literature were identified to aid in FEA implementation.

Source 1: “What is FEA: Finite Element Analysis” [14]

The purpose of analyzing this source was to understand the basic fundamentals of FEA and the types of software that are used in FEA. This resource explained that ANSYS and SolidWorks are among the leading software used in FEA [14]. From this, the team decided to use SolidWorks for future FEA endeavors.

Source 2: “Learn SolidWorks Simulation Tutorial” [15]

After identifying SolidWorks as the preferred (and free) method of FEA, the next step was to learn how to analyze a part or assembly using SolidWorks simulation. From this source, the team learned of the various inputs in SolidWorks, which include the geometry, material, connections, fixtures, external loads, and mesh [15]. Furthermore, the tutorial explains how SolidWorks simulations can analyze stress, strain, fatigue, and other metrics using said inputs.

Source 3: “FEA Explained for Beginners” [16]

Although the previous tutorial explained how SolidWorks FEA operates, it did not explain the theory behind how mesh and geometry interact. Basically, the overall geometry is broken into thousands of individual elements. Given boundary conditions, known material properties, and element-to-element interactions, the overall stress and strain can be solved for throughout the geometry [16].

Source 4: “Finite Element Analysis: Easy Explanation (YouTube)” [17]

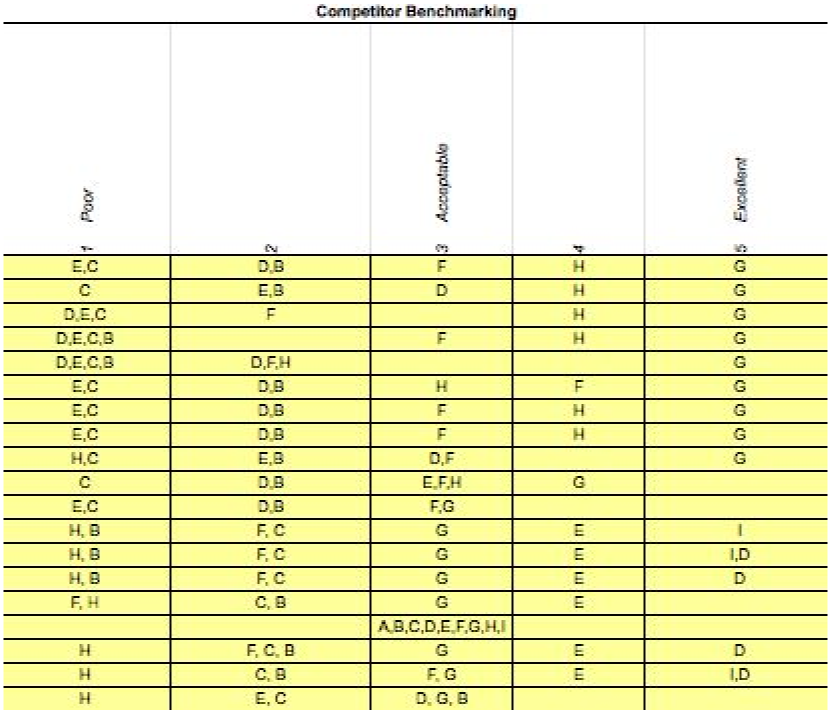
This source served as supplemental information to the previous source, while also providing a video of SolidWorks FEA. The structure analyzed was a plane wing, where the user input various conditions and calculated the stress across the geometry [17].

Source 5: “Solidworks Simulation Tutorial: Steel Structure in Solidworks (YoutTube)” [18]
The final source analyzed was a SolidWorks FEA simulation video, very similar to the previous video. However, this video explained ways of creating different meshes and fixtures for a simple beam [18]. This video was extremely valuable because taught the team how to properly analyze loading within a beam, which will be used in both the wing and fuselage frame analyses.

3.2 Benchmarking

Table 4: Benchmarking

Legend		
A	SAE Aero Micro 2014-2015 NAU	
B	SAE Aero Micro 2016-2017 NAU	
C	SAE Aero Micro 2018-2019 NAU	
D	SAE Aero Micro 2018 Puerto Rico Results	
E	SAE Aero Micro 2019 University of Minnesota	
F	SAE Aero Micro 2015 Montana State University	
G	SAE Aero Micro 2019 Xi'an Jiaotong Univ First Place	
H	SAE Aero Micro 2019 Acharya Institute of Technology	
I	SAE Aero Micro 2019 Wright State Univ 6	



Competitor Benchmarking

1 Poor	2	3 Acceptable	4	5 Excellent
E,C	D,B	F	H	G
C	E,B	D	H	G
D,E,C	F		H	G
D,E,C,B		F	H	G
D,E,C,B	D,F,H			G
E,C	D,B	H	F	G
E,C	D,B	F	H	G
E,C	D,B	F	H	G
H,C	E,B	D,F		G
C	D,B	E,F,H	G	
E,C	D,B	F,G		
H, B	F, C	G	E	I
H, B	F, C	G	E	I,D
H, B	F, C	G	E	D
F, H	C, B	G	E	
		A,B,C,D,E,F,G,H,I		
H	F, C, B	G	E	D
H	C, B	F, G	E	I,D
H	E, C	D, G, B		

In order to design, manufacture, and operate a functional prototype Engineers must compare their initial design to previous models that have been made; this is called benchmarking. The purpose of benchmarking is to create a more efficient and functional design than previous iterations. Observing why systems fail is part of being an engineer, so this process is designed to address the failure that occurred and then expand and improve upon the design. The best possible way to benchmark in a competition based Capstone, where each year there are various designs of the same criteria, was to look at previous competitors.

The three designs that will be benchmarked are the SAE Aero Micro 2014-2015 NAU, the SAE Aero Micro 2016-2017 NAU, and the SAE Aero Micro 2018-2019 NAU. The group found the most information regarding these designs, so this will make the benchmarking more precise and exact. The issues with benchmarking these specific designs are that none of these designs won the competition. They are average designs, but the main problems with these designs was not the design itself. It was that the members did not abide by the criteria that was set by SAE, i.e. not throwing the aircraft, not landing intact, or creating a invalid storage unit. Another problem that can occur with benchmarking is not reviewing all the information that is presented because some models are designed for a specific materials, etc.

3.2.1 System Level Benchmarking

In our project we are abiding by the competition rules, which are also the customer requirements. The payload cannot aid frame integrity, gross weight limit, and a wheeled landing gear steering mechanism must be about of the assembly; these are a few examples of the criteria of the competition.

3.2.1.1 Existing Design #1: SAE Aero Micro 2014-2015 NAU

The first design that we benchmarked was the SAE Aero Micro 2014-2015 NAU [19]. The customer requirements for the SAE 2014-2015 Design competition were quite different, in that they had a 24 inch tube to place their components into. Their would then limit the team in their wingspan and total aircraft chord length.

3.2.1.2 Existing Design #2: SAE Aero Micro 2016-2017 NAU

The second design that was benchmarked was the 2016-2017 NAU design. The customer requirements of their design are similar to the customer requirement of the 2020 competition. The design components like the aircraft must fit in a box like container, must land, and be controlled through hand launch still apply.

3.2.1.3 Existing Design #3: SAE Aero Micro 2018-2019 NAU

The final design that was selected for the benchmarking process is the SAE Aero Micro 2018-2019 NAU. The storage unit for this competition is very similar to the 2019-2020 Micro Aero competition 12x13.8x3.6 inches in volume.

3.2.2 Subsystem Level Benchmarking

The wing design, landing mechanism, and propulsion system will heavily decide on the effectiveness of the aircraft as a whole. Every year the design criteria will change, which will determine the effectiveness of the benchmarking process as a whole, but it still is relevant researching former teams designs. It will describe what are the positives and negatives of the design that will be implemented accordingly.

3.2.2.1 Subsystem #1: Propulsion

The propulsion of the aircraft is determined by the propeller, motor, and the force of drag. The increase of propeller blades will decrease the aerodynamic efficiency of the aircraft. The motor will determine how the angular velocity of the propeller blades.

3.2.2.1.1 Existing Design #1: Basic Two Blade Propellor with No Shroud

The 2014-2015 NAU team were not limited in the battery power nor the size of the motor, but they did use a propeller with a width of 9.95 inches. This will generate enough thrust to continue the desired flight path. There was no shroud with the design, which would have increased the thrust, but it would have increased the weight.

3.2.2.1.2 Existing Design #2: Angled blades that have differential thrust

The propulsion concept of the 2014-2015 NAU's team revolved around the blade angle and number of blades on the propeller. The team decided that even though the more number of blades in the propeller efficiency will decrease, but they combatted since a Micro aircraft needs more surface area because the aircraft's velocity is not too high. The thrust generation is decided upon the angle at which the blades are formed. The outer edge of the blades have a greater velocity than the inner edges, so there will be a difference in thrust.

3.2.2.1.3 Existing Design #3: Scorpion SII servo motor

The motor that was selected by this team was the Scorpion SII-2212-1850, which then created a 2.28:1

thrust ratio, along with a 4.66:1 weight ratio. The design team decided the 7x4 APC Electric E propeller would be the best cost/thrust ratio. [20]

3.2.2.2 Subsystem #2: Wing Design

The wing design is based upon the airfoil that is selected. Every airfoil will calculate difference coefficients of lift and drag, and based on the design/materials of the prototype design will dictate what airfoil is selected. In general the wings should have a high aspect ratio (AR). The aspect ratio is the ratio of the wingspan to the chord length. This creates a lot of efficient surface area, which in turn creates lift.

3.2.2.2.1 Existing Design #1: 54 Inch Wingspan

The 2014-2015 NAU team [19] created an aircraft that focused more on the AR than anything else. Shown below in Figure 4, the total wingspan is 54.00 inches or 4.5 feet long. In their customer requirements they were limited in their chord length. The maximum limit for the chord length is 5 inches, so their AR is 11.9.

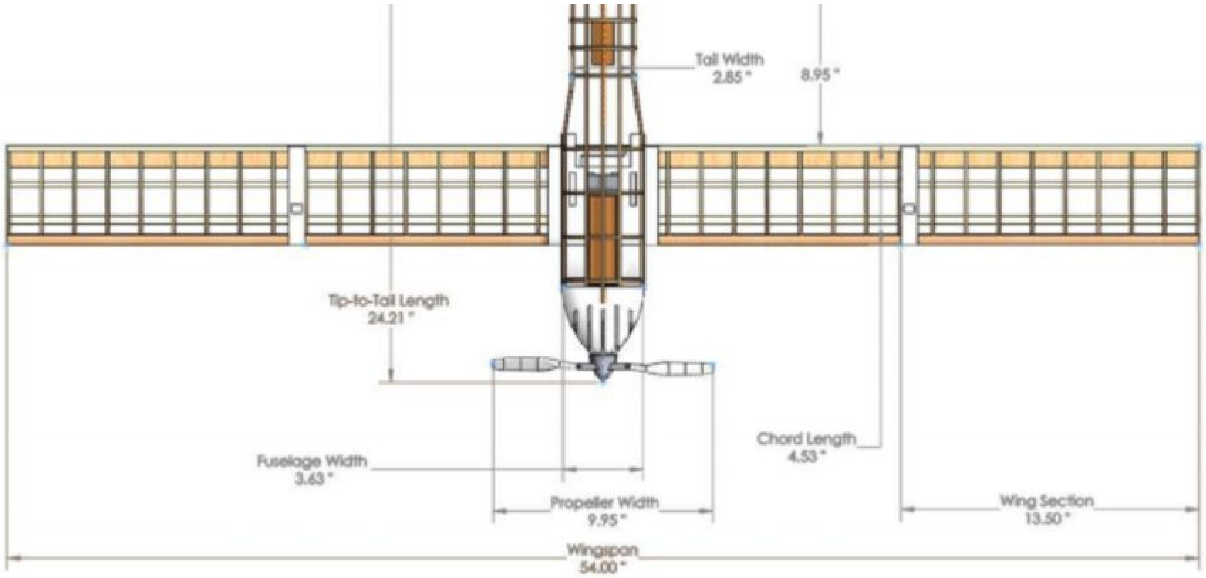


Figure 4: 2014-2015 Design model

3.2.2.2.2 Existing Design #2: Light Material with a higher Surface Area

The aspect ratio of the 2016-2017 NAU design is 8.4 [21]. The wingspan is 42 inches and the chord length is 5 inches. The material of the wing is housing insulation pink foam, which is light but unit volume.

3.2.2.2.3 Existing Design #3: Short wingspan with a low weight ratio and aspect ratio

The 2018-2019 NAU Design team constructed a plane with an aspect ratio of 7.5 with the wingspan being 30 inches and then the wing chord length of 4 inches. This is the smallest AR that was researched, so overall observing the flight of the aircraft determines how well the AR contributes to the flight of the aircraft. The more surface area increasing the lift, but it can also create drag and induced drag.

3.2.2.3 Subsystem #3: Landing Mechanism

The only requirement for the landing mechanism is that it lands. There are no limitations in the amount of wheels it has to be or if there even needs wheels. The updated customer requirements are that the landing mechanism has to be steered landing mechanism.

3.2.2.3.1 Existing Design #1: Aircraft with little to no landing gear

The 2014-2015 NAU team did not focus heavily on the landing mechanism. They implemented small landing gear components that were calculated to have a high enough modulus of elasticity to handle the load of landing.

3.2.2.3.2 Existing Design #2: Tricycle Tail Dragger

This Micro team decided to use the reverse tricycle landing mechanism, which is two wheels in the front, connected to the mid-chord length of the wing, and a single wheel that balances the front and the back of the aircraft. This design shows the static representation of the aircraft which sits at a two degree angle from horizontal.

3.2.2.3.3 Existing Design #3: Two wheels in the front, One wheel in the back with Rudder Servo

The landing mechanism for the 2018-2019 NAU team was the same as the previous design. A reverse tricycle wheeled system with two wheels in the front to stabilize the tipping/rolling effect.

3.3 Functional Decomposition

The Functional Decomposition for the SAE Aero Micro is quite simple. The overall function of our design must fly under the certain criteria. There are other guidelines in the SAE Aero Micro rules, but in order to receive any half-way decent result, the aircraft must fly. Some of the important components of the design are the fuselage/payload design, wing design, and propulsion mechanics. In order to carry the desired payload, the design of the fuselage and payload mechanism must be placed in such a way that is aerodynamic and able to be thrown by a human hand. The wing design is strictly based on the airfoil decided, which determines the amount of lift and drag on the aircraft. Finally, the propulsion is based upon the motor and propeller efficiency, which in turn creates thrust. Thrust determines how much weight the aircraft can carry because it is dependent on velocity of the aircraft.

3.3.1 Black Box Model

Figure 5 is the Block Box Model that simplifies the Functional Decomposition. The ‘material inputs’ are components of the actual design: motor, battery, wing, radio controller, and propeller. The airflow is a material component because it is something that is tangible. These ‘material inputs’ are the ‘material outputs’ because they do not change. The ‘energy inputs’ are electrical energy and kinetic energy. The aircraft is wired and is controlled by an RC device, so electrical energy will be the ‘energy output’ as well. On the other hand the kinetic energy from throwing the aircraft initially is converted into mechanical energy. The ‘input signals’ are wind direction, radio frequency, aim, and on/off. All of the previous signals will become ‘output signals’ besides wind direction because while the device is in the air it will be adjusted to the airflow, so it turn be flight direction.

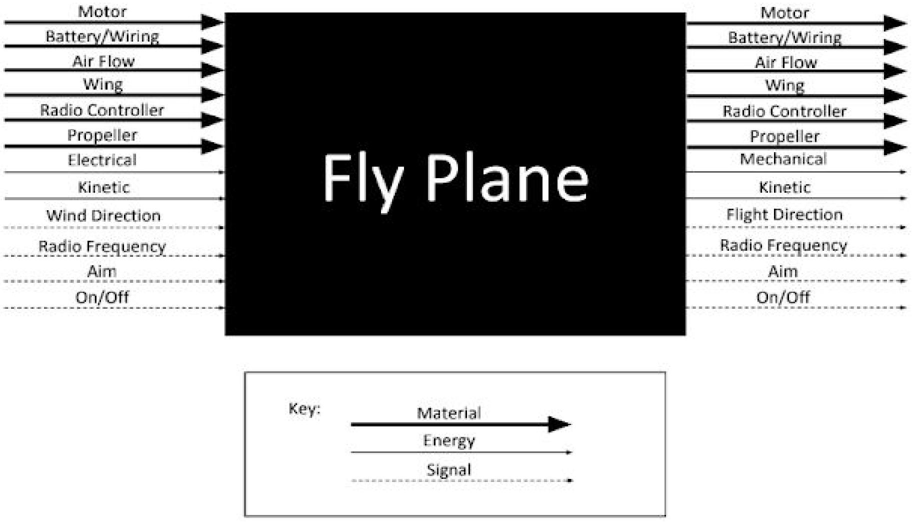


Figure 5: Black Box Model

3.3.2 Functional Model/Work-Process Diagram/Hierarchical Task Analysis

The Functional Model is shown below (Figure 6). The flow chart directs all the inputs of the Black Box Model (Figure 6) and describes what they do physically. All the ‘material inputs’ when they are imported they will then direct the airflow; this will create flight (signal) and lift, thrust, and drag (material). All the remaining inputs are then needed to drive the electricity component of the aircraft. The RC Controller provides an input and integrated with electricity and controller frequency actuates the motor, which converts electrical energy to rotational energy. This then determines the thrust and flight path. All of the following inputs are needed to create a successful flight.

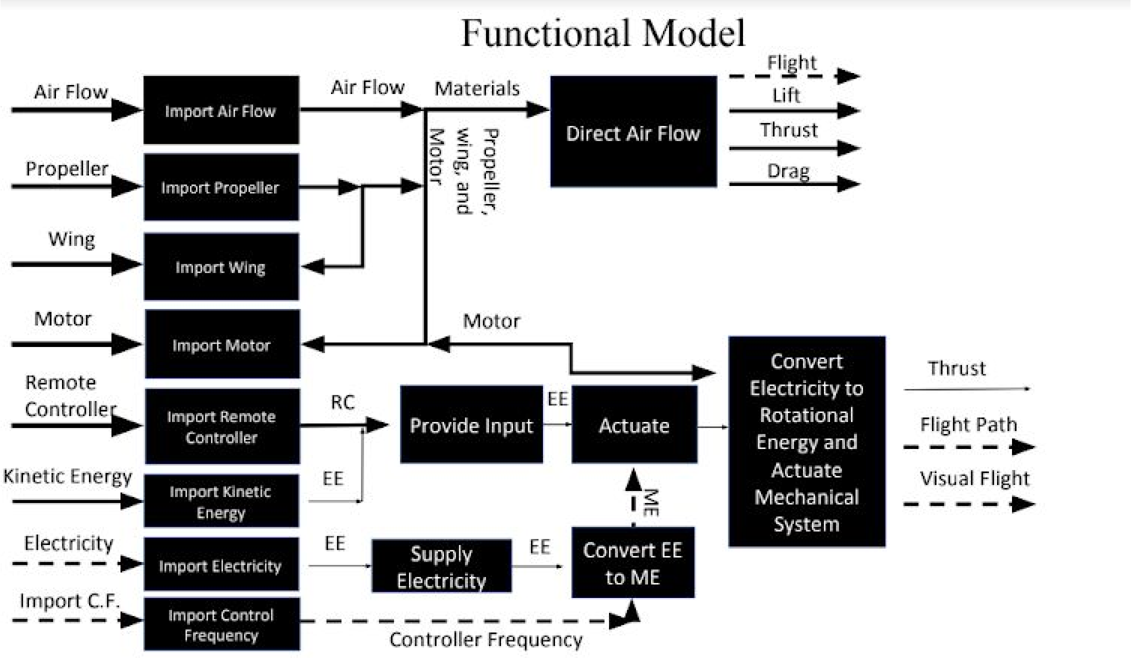


Figure 6: Functional Model

4 CONCEPT GENERATION

4.1 Full System Concepts

Below in sections 4.1.1-3 are 3 different concepts created with each sub system with various pros and cons of each design listed.

4.1.1 Full System Design #1: Single wing, full maneuvering devices, rear steer, single motor, and elliptical taper fuselage with payload snaps

Pros:

- Lightweight with single wing and single motor
- Higher maneuverability
- Longer wheelbase of landing gear
- Increased aerodynamics with elliptical taper
- Faster set up time with snaps

Cons:

- Less surface area compared to dual wing
- More difficult manufacturing with increase of moving parts
- Posible rollover
- Decreased aerodynamics with payload outside of system

4.1.2 Full System Design #2: Single wing, dual aileron with rudder, front steer, single motor, and elliptical taper fuselage with internal storage

Pros:

- Lightweight with single wing and single motor
- Easier manufacturing with less moving parts
- Decrease of rollover possibility with front steer
- Increased aerodynamics with elliptical taper and internal storage

Cons:

- Less surface area compared to dual wing
- Angle of attack when landing is more flat

4.1.3 Full System Design #3: Dual wing, dual elevator with rudder, rear steer, single motor, and elliptical taper fuselage with payload snaps.

Pros:

- Increased lift with dual wings
- Greater lift from rear
- Easier manufacturing with less moving parts
- Faster set up time with snaps
- Increased aerodynamics with elliptical taper

Cons:

- Increased weight with two wings
- Possible rollover
- Less control from wings
- Decreased aerodynamics with payload outside of system

4.2 Subsystem Concepts

To arrive at the full system designs from above the team had to break down the SUAV into five subsystems each having three different designs within the subsystems. Each design is described through short descriptions and figures.

4.2.1 Subsystem #1: Wing Design

4.2.1.1 Design #1: Bi-Plane

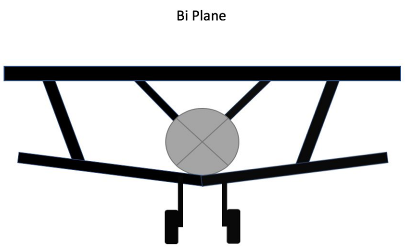


Figure 7: Bi-plane design

A wing above and below the fuselage.

Pros:

- Greater lift

Cons:

- Greater weight

4.2.1.2 Design #2: Single Wing

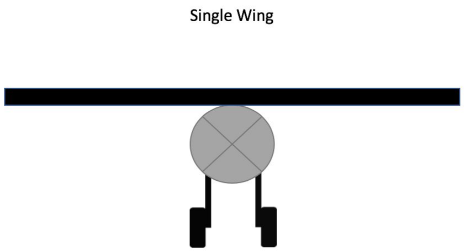


Figure 8: Single Wing design

Single wing

Pros:

- Less weight

Cons:

- Less lift

4.2.1.3 Design #3: Airfoil design

The airfoil design will be implemented on either the biplane or single wing the set NACA design just has not been decided.

Pros:

- Greater lift

Cons:

- Manufacturing

4.2.2 Subsystem #2: Maneuvering Devices

4.2.2.1 Design #1: Dual aileron, dual elevator, rudder

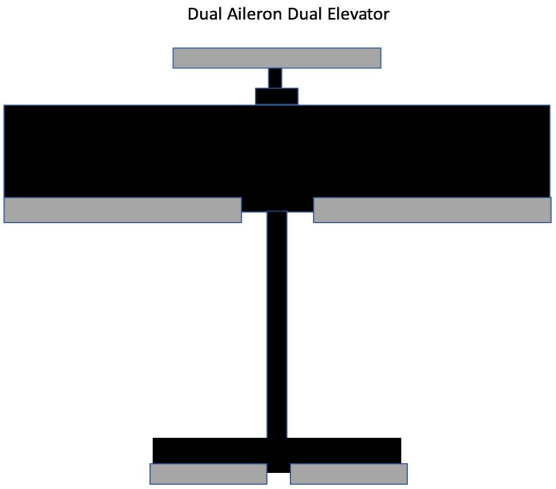


Figure 9: Dual aileron, dual elevator

Having both elevators and ailerons allows for drag and lift to be better controlled in the wings and tail end of the plane however the increase in moving parts will increase the difficulty in manufacturing.

Pros:

- Greater maneuverability

Cons:

- Greater difficulty for manufacturing

4.2.2.2 Design #2: No aileron, dual elevator, rudder

With this design there is only lift generated from the tail and turing is based from the rudder.
Pros:

- Easier manufacturing with less moving parts

Cons:

- Less Maneuverability

4.2.2.3 Design #3: Dual aileron, no elevator, rudder

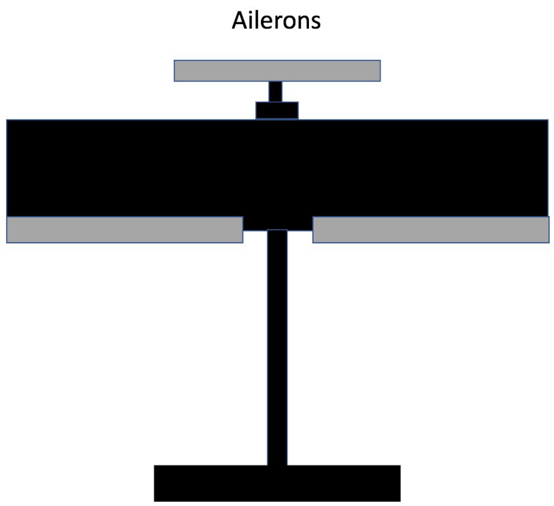


Figure 10: Dual aileron, no elevator

This design will be able to steer from both the ailerons and the rudder and the reduction in moving parts is beneficial for manufacturing purposes.

Pros:

- Greater lift from wings

Cons:

- No lift from tailend

4.2.3 Subsystem #3: Landing Gear

4.2.3.1 Design #1: Skids

This design does not have any wheels attached to the plane and reduces weight but the lack of being able to roll may cause the planes propellor to hit the ground and break.

Pros:

- Lightweight

Cons:

- Landing difficulty increased

4.2.3.2 Design #2: Tricycle front steer

Figure 11: Tricycle landing gear [22]

The tricycle design has a much more flat angle of attack for taking off but this is not relevant for the Aero Micro competition because the SUAV is hand launched.

Pros:

- Less rollover possibility

Cons:

- Angle of attack for landing more flat

4.2.3.3 Design #3: Two front wheels rear steer

Figure 12: Two front wheels, rear steer [23]

Having two wheels in the front and one in the back allows the two wheels to make contact first then the tail will drop after reducing power to the propellor.

Pros:

- Longer wheelbase

Cons:

- Potential risk of rollover

4.2.4 Subsystem #4: Propulsion

4.2.4.1 Design #1: Twin motor

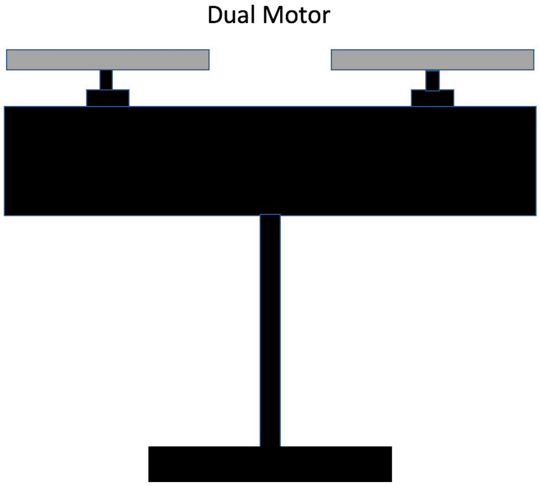


Figure 13: Twin motor

The twin motor design is very simple in that there are two motor simultaneously rotating and generating twice as much thrust.

Pros:

- Greater thrust

Cons:

- Greater weight

4.2.4.2 Design #2: Single motor

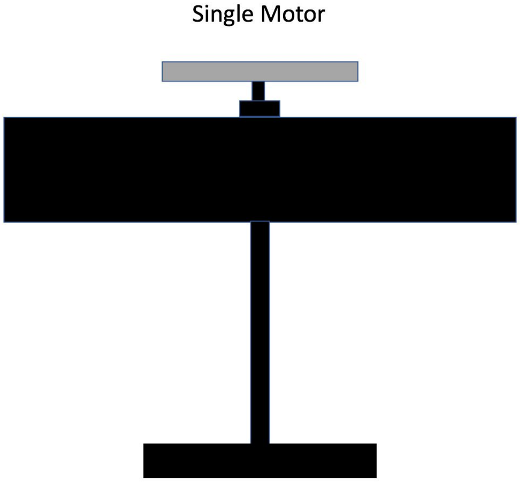


Figure 14: Single motor

The single motor will be placed at the front of the fuselage and adds less weight compared to the dual motors.

Pros:

- Lighter weight

Cons:

- Less thrust

4.2.4.3 Design #3: Singe motor with shroud

A shroud is a cylindrical tube that surrounds the propellor to guide more air into the propellor increasing thrust

Pros:

- Increased thrust

Cons:

- Increased weight

4.2.5 Subsystem #5: Fuselage/Payload

4.2.5.1 Design #1: Tapered cylinder with internal storage

The cylinder of the fuselage will gradually taper to the tail and the internal storage is used to hold the payload which is 2 inch diameter pvc piping which will in turn decrease drag.

Pros:

- Less drag

Cons:

- Placing payload internally may reduce structural integrity

4.2.5.2 Design #2: Elliptical taper with fuselage snaps

The elliptical taper starts larger at the front of the plane and tapers down for the purpose of increasing aerodynamics. The payload is intended to be snapped into the fuselage with an undetermined fastening system but will in turn cause more drag.

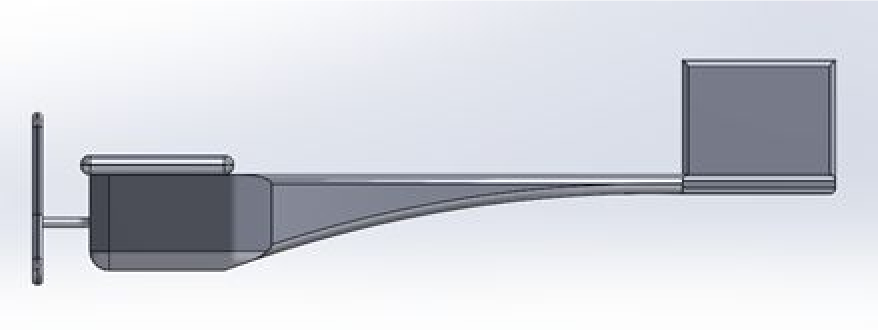


Figure 15: Elliptical taper

Pros:

- Faster set up time

Cons:

- Greater drag

4.2.5.3 Design #3: Elliptical taper with wing snaps

The elliptical taper as shown in Figure 15 starts larger at the front of the plane and tapers down for the purpose of increasing aerodynamics. The payload is intended to be snapped into the wings with an undetermined fastening system.

Pros:

- Faster set up time

Cons:

- Greater drag

5 DESIGNS SELECTED – First Semester

The final product of concept generation yielded three full-system or full-design variants. Each full-design variant contained unique combinations of subsystem variants. So, the manner in which subsystem variants are combined dictates the overall performance of the plane. The goal of chapter 5 is to compare each design variant and select the design that performs best given a unique subsystem combination. Designs are first compared using a pugh chart, where the selection criteria are CRs. Next, the designs are compared using a decision matrix, where the selection criteria are ERs. The result of this chapter is the final concept design selection for the project.

5.1 Technical Selection Criteria

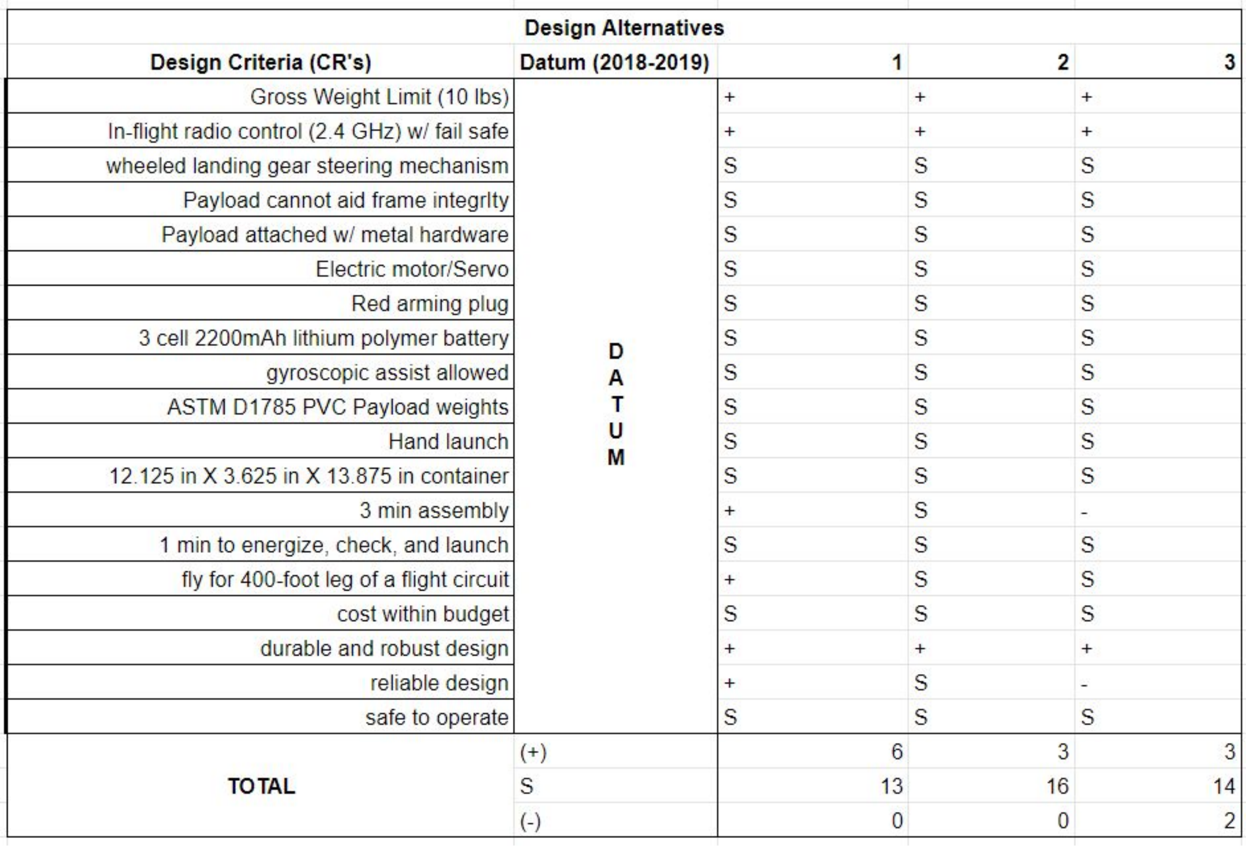
When comparing each of the three full-design alternatives, two forms of selection criteria are used. First, customer requirements are used when qualitatively comparing designs via a Pugh chart. The Pugh chart operates using a datum and CRs, where the datum is the SAE Aero Micro Plane from 2019 [2]. With the datum and CRs in place, each design is qualitatively compared as better, same, or worse than the datum in regards to fulfilling CRs. Most importantly, the CRs used as selection criteria in the Pugh chart are not quantifiable. Thus, the advantage of the Pugh chart selection criteria is a fast and conceptual comparison. However, the disadvantage is that this method yields a qualitative design comparison that lacks calculations to justify scoring.

The next form of selection criteria are engineering requirements used to quantitatively compare designs within a decision matrix. In this method, there is no datum, but rather the three designs. Each ER is given a weight percentage in terms of importance. Then, the full-design alternatives are scored based on how well each design fulfills each ER. Most importantly, the ERs are quantifiable, so calculations are used to compare how each design achieves each ER. So, the advantage of using the decision matrix is a quantifiable means of comparing designs based on calculations.

5.2 Rationale for Design Selection

After establishing the technical selection criteria in section 5.1, the next step in the design selection process was to evaluate designs 1, 2, and 3 using a Pugh chart and decision matrix. First, each design was evaluated using the Pugh chart, seen below in Table 5.

Table 5: Pugh Chart



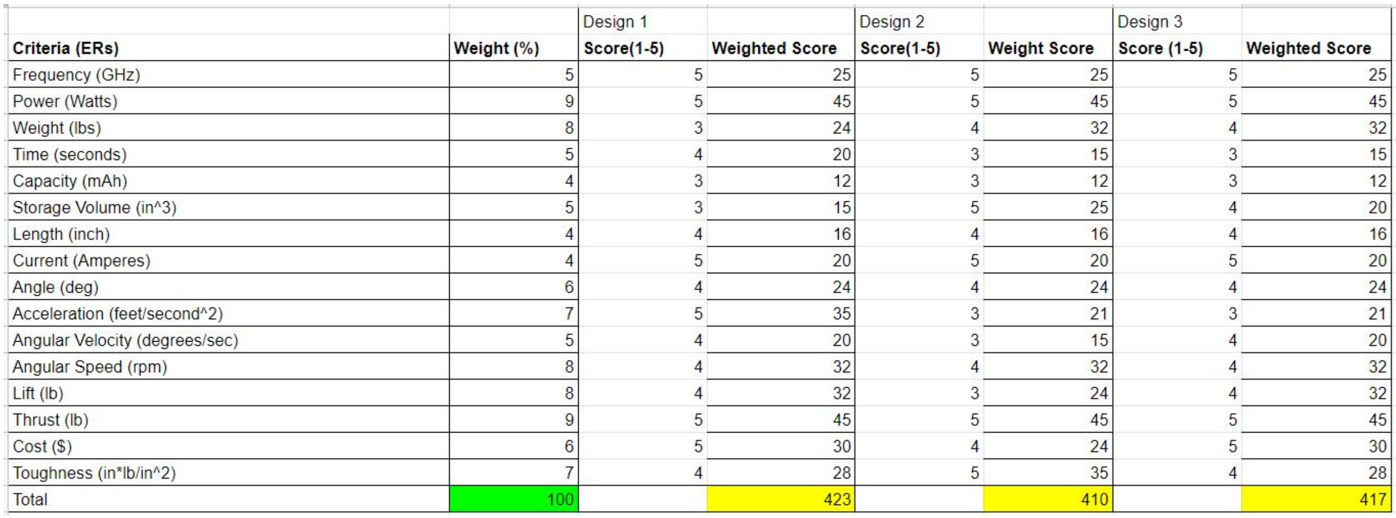
	Design Alternatives			
Design Criteria (CR's)	**Datum (2018-2019)**	**1**	**2**	**3**
Gross Weight Limit (10 lbs)	**DATUM**	+	+	+
In-flight radio control (2.4 GHz) w/ fail safe		+	+	+
wheeled landing gear steering mechanism		S	S	S
Payload cannot aid frame integrlty		S	S	S
Payload attached w/ metal hardware		S	S	S
Electric motor/Servo		S	S	S
Red arming plug		S	S	S
3 cell 2200mAh lithium polymer battery		S	S	S
gyroscopic assist allowed		S	S	S
ASTM D1785 PVC Payload weights		S	S	S
Hand launch		S	S	S
12.125 in X 3.625 in X 13.875 in container		S	S	S
3 min assembly		+	S	-
1 min to energize, check, and launch		S	S	S
fly for 400-foot leg of a flight circuit		+	S	S
cost within budget		S	S	S
durable and robust design		+	+	+
reliable design		+	S	-
safe to operate		S	S	S
TOTAL	(+)	6	3	3
	S	13	16	14
	(-)	0	0	2

As shown in the Pugh chart, all three designs scored the same as the datum when compared to most competition requirements. However, design 1 (described in section 4.1.1) had the highest positive score compared to the datum. The subsystem design concepts that make design 1 superior to the datum are the front wheels with rear steering mechanism and the elliptical tapered fuselage with payload fasteners. The rear steering mechanism allows for greater control upon landing, so the radio control and reliability CRs scored higher with design 1. Next, the elliptical tapered fuselage with external fasteners allows for payload storage on the fuselage rather than wings, providing more area to store weight and greater durability. Thus, design 1 also scored higher in durability, flight characteristics, assembly time, and weight CRs.

Design 2 (described in section 4.2.2) scored the second highest in the Pugh chart evaluation. The subsystem concepts that make design 2 superior to the datum are the tricycle front steer and the elimination of elevators. The tricycle front steer prevents rollover landings, making design 2 more durable and robust. The deletion of elevators simplifies the control system while also limiting the weight of actuators, so design 2 also scored higher in weight and control CRs. Thus, from the Pugh chart comparison, designs 1 and 2 scored highest.

The final step in design evaluation is the decision matrix, shown below in Table 6. Each design is evaluated on how well it satisfies each ER, and the highest score is considered the most promising design.

Table 6: Decision Matrix



		Design 1		Design 2		Design 3	
Criteria (ERs)	**Weight (%)**	**Score(1-5)**	**Weighted Score**	**Score(1-5)**	**Weight Score**	**Score (1-5)**	**Weighted Score**
Frequency (GHz)	5	5	25	5	25	5	25
Power (Watts)	9	5	45	5	45	5	45
Weight (lbs)	8	3	24	4	32	4	32
Time (seconds)	5	4	20	3	15	3	15
Capacity (mAh)	4	3	12	3	12	3	12
Storage Volume (in^3)	5	3	15	5	25	4	20
Length (inch)	4	4	16	4	16	4	16
Current (Amperes)	4	5	20	5	20	5	20
Angle (deg)	6	4	24	4	24	4	24
Acceleration (feet/second^2)	7	5	35	3	21	3	21
Angular Velocity (degrees/sec)	5	4	20	3	15	4	20
Angular Speed (rpm)	8	4	32	4	32	4	32
Lift (lb)	8	4	32	3	24	4	32
Thrust (lb)	9	5	45	5	45	5	45
Cost ($)	6	5	30	4	24	5	30
Toughness (in*lb/in^2)	7	4	28	5	35	4	28
Total	100		423		410		417

Much like the Pugh chart, design 1 was evaluated as the superior design within the decision matrix. However, design 3 scored in second place in the decision matrix. Due to design 2 scoring above design 3 in the Pugh chart, along with the bi-plane wing design in design 3, designs 1 and 2 were selected as the top two designs.

First, the main differences between designs 1 and 2 were the fuselage and landing gear designs. Design 1 features external payload storage with a rear wheel steering mechanism. This allows for decreased assembly time, increased landing capability, increased payload capacity, and less drag. The most important considerations are the decreased assembly time and decreased drag. Equations for payload assembly time and drag are shown in equations 1 and 2, respectively.

$$t_{assembly} = C_{fastener}N$$

$$Drag = C_D(0.5\rho v^2 A)$$

In equation 1, the assembly time is dependent on the fastener coefficient and the number of fasteners. Design 1 features external payload snap-on fasteners while design 2 features internal payload storage. Therefore, design 1 has a lower assembly coefficient and the same number of fasteners as design 2. Thus, the assembly time for design 1 is lower than design 2.

Finally, the drag equation is dependent on the coefficient of drag and the cross-sectional area. Design 1 features a smaller fuselage with external storage, resulting in a smaller area and drag coefficient than design 2. Therefore, design 1 has a lower drag force than design 1.

In conclusion, designs 1 and 2 were selected as the top two designs upon evaluation. While design 1 currently features external payload storage and a rear-steering design, these two concepts are still in flux. Before prototyping begins, the airfoil, motor, propellor, and the battery must be tested and selected. After selection, then the design components will stand confirmed. Until then, the team plans to design and manufacture design 1.

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7 APPENDICES

7.1 Appendix A: QFD

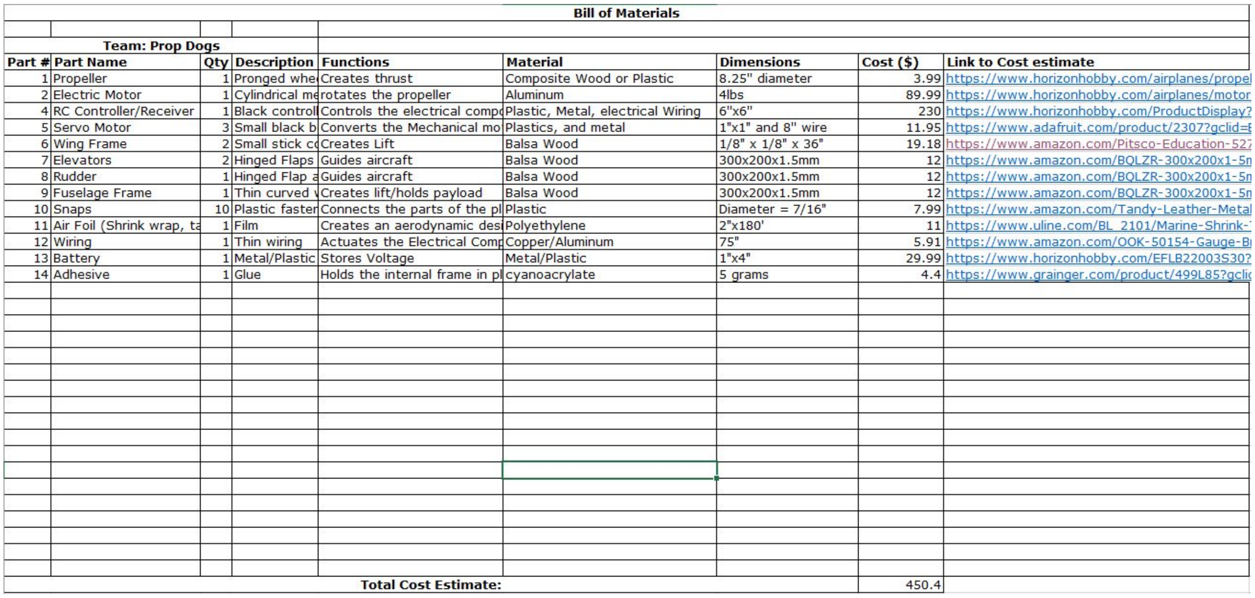
Table A.1: QFD System

Control Frequency (GHz)															
Motor Power (Watts)	1														
Total Weight (lbs)	1	9													
Assembly Time (min)	1	3	1												
Battery Capacity (mAh)	1	3	1	3											
Storage Volume (in^3)	1	1	3	1	3										
Storage Length (inch)	1	1	3	1	1	9									
Current (Amperes)	1	3	1	1	9	1	1								
Launch Angle (deg)	1	1	1	1	1	1	1	1							
Launch Acceleration (ft/s^2)	3	9	9	3	1	9	3	3	1						
Motor Velocity (degrees/sec)	1	1	3	3	1	3	3	1	3	1					
Motor Speed (rpm)	3	9	1	3	3	1	1	3	1	1	1				
Lift (lb)	1	9	3	1	1	3	3	1	9	9	1	1			
Thrust (lb)	1	9	9	1	1	3	9	1	9	9	1	3	9		
Cost ($)	1	3	9	3	9	1	1	1	1	3	1	1	1	1	
Yield Strength (psi)	1	1	9	1	1	3	3	1	1	9	1	1	1	1	3

Customer Requirements	Customer Weights	Control Frequency (GHz)	Motor Power (Watts)	Total Weight (lbs)	Assembly Time (min)	Battery Capacity (mAh)	Storage Volume (in^3)	Storage Length (inch)	Current (Amperes)	Launch Angle (deg)	Launch Acceleration (ft/s^2)	Motor Velocity (degrees/sec)	Motor Speed (rpm)	Lift (lb)	Thrust (lb)	Cost ($)	Yield Strength (psi)
Gross Weight Limit (10 lbs)	5	1	3	9	1	1	3	3	1	1	1	1	1	1	9	3	3
In-flight radio control (2.4 GHz) w/ fail safe	5	9	1	1	3	1	1	1	3	1	1	3	1	1	1	3	1
wheeled landing gear steering mechanism	4	1	1	1	1	1	1	9	1	3	1	1	1	1	1	3	3
Payload cannot aid frame integrlty	3	1	1	9	1	1	9	3	1	1	1	1	1	1	3	1	9
Payload attached w/ metal hardware	3	1	1	9	1	1	3	3	1	1	1	1	1	1	3	1	1
Electric motor/Servo	4	3	9	9	1	9	1	1	9	1	9	9	9	9	9	3	3
Red arming plug	5	1	9	1	1	1	1	1	9	1	1	1	1	9	9	1	1
3 cell 2200mAh lithium polymer battery	5	1	9	9	1	9	9	3	9	1	1	1	1	3	3	3	1
gyroscopic assist allowed	2	1	1	3	1	1	3	3	1	9	1	9	1	1	1	3	3
2" dia schedule 40 ASTM D1785 PVC Payload	4	1	1	9	1	1	9	9	1	1	1	1	1	1	9	1	3
Hand launch	4	1	9	9	3	1	1	9	1	9	9	9	9	9	9	1	3
12.125 in X 3.625 in X 13.875 in container	5	1	1	3	9	1	9	9	1	1	1	1	1	3	3	1	3
3 min assembly	4	1	1	3	9	1	3	3	1	1	1	1	1	1	1	1	9
1 min to energize, check, and launch	4	1	1	3	9	1	1	3	9	1	1	1	1	1	1	1	3
fly for 400-foot leg of a flight circuit	3	1	9	9	3	3	9	9	1	9	3	3	9	3	3	1	1
cost within budget	3	3	9	9	1	3	1	3	1	1	9	1	3	9	9	9	3
durable and robust design	4	1	3	9	1	1	3	3	1	1	3	1	1	3	1	9	9
reliable design	5	9	9	3	3	9	3	9	9	9	9	3	3	9	9	1	3
safe to operate	5	9	9	1	1	9	1	3	3	1	3	1	1	3	3	1	1
Absolute Technical Importance		211	367	421	215	241	283	353	281	197	229	183	181	289	365	183	245
Relative Technical Importance		12	2	1	11	9	6	4	7	13	10	15	16	5	3	14	8
Target Value		2.4	350	5	2	1000	72.3	16.3	15	5	1.3	N/A	N/A	2	3	550	145
Tolerance(+-)		0.1	50	1.5	0.5	250	20	5	5	1.5	0.3	N/A	N/A	0.5	0.5	100	15

7.2 Appendix B: Budget and Bill of Materials

Table B.1: Bill of Materials



Bill of Materials

Team: Prop Dogs

Part #	Part Name	Qty	Description	Functions	Material	Dimensions	Cost ($)	Link to Cost estimate
1	Propeller	1	Pronged whe	Creates thrust	Composite Wood or Plastic	8.25" diameter	3.99	https://www.horizonhobby.com/airplanes/propel
2	Electric Motor	1	Cylindrical me	rotates the propeller	Aluminum	4lbs	89.99	https://www.horizonhobby.com/airplanes/motor
4	RC Controller/Receiver	1	Black controll	Controls the electrical compo	Plastic, Metal, electrical Wiring	6"x6"	230	https://www.horizonhobby.com/ProductDisplay?
5	Servo Motor	3	Small black b	Converts the Mechanical mo	Plastics, and metal	1"x1" and 8" wire	11.95	https://www.adafruit.com/product/2307?gclid=
6	Wing Frame	2	Small stick co	Creates Lift	Balsa Wood	1/8" x 1/8" x 36"	19.18	https://www.amazon.com/Pitsco-Education-527
7	Elevators	2	Hinged Flaps	Guides aircraft	Balsa Wood	300x200x1.5mm	12	https://www.amazon.com/BQLZR-300x200x1-5m
8	Rudder	1	Hinged Flap a	Guides aircraft	Balsa Wood	300x200x1.5mm	12	https://www.amazon.com/BQLZR-300x200x1-5m
9	Fuselage Frame	1	Thin curved w	Creates lift/holds payload	Balsa Wood	300x200x1.5mm	12	https://www.amazon.com/BQLZR-300x200x1-5m
10	Snaps	10	Plastic faster	Connects the parts of the pl	Plastic	Diameter = 7/16"	7.99	https://www.amazon.com/Tandy-Leather-Metal
11	Air Foil (Shrink wrap, ta	1	Film	Creates an aerodynamic desi	Polyethylene	2"x180'	11	https://www.uline.com/BL_2101/Marine-Shrink-
12	Wiring	1	Thin wiring	Actuates the Electrical Comp	Copper/Aluminum	75"	5.91	https://www.amazon.com/OOK-50154-Gauge-B
13	Battery	1	Metal/Plastic	Stores Voltage	Metal/Plastic	1"x4"	29.99	https://www.horizonhobby.com/EFLB22003S30?
14	Adhesive	1	Glue	Holds the internal frame in pl	cyanoacrylate	5 grams	4.4	https://www.grainger.com/product/499L85?gcli
				Total Cost Estimate:			450.4	