BYU

BRIGHAM YOUNG UNIVERSITY

AIAA Design/Build/Fly Competition 2020-2021 Aircraft Design Report

Contents

I Executive Summary

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Table 1 Summary of major system performance factors.

Metric	
	[Performance (units)]
	[Performance (units)]

II Management Summary

II.A Team Organization

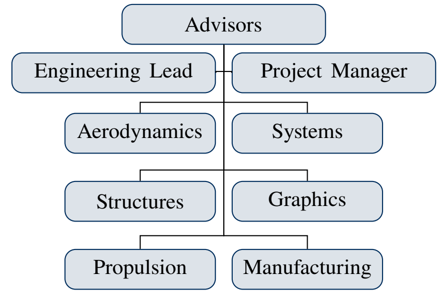

Figure 1 Here we show the structure of, and assignment areas within, our team organization.

Figure 1 depicts the overall organization of our team structure. Each of the teams is lead by an individual who answers to the Engineering Lead and Project Manager. The skills required for each position/team are as follows.

Engineering Lead As with the team leads, the Engineering Lead primarily requires good decision making and leadership skills, qualities the BYU Aero Club seeks to develop in all of its members. In addition the Engineering Lead has a well rounded understanding of the various systems and both design and testing expertise.

Project Manager The Project Manager has excellent organizational skills and oversees the logistical side of the project: heading up report writing, budgeting tasks, scheduling, etc.

Aerodynamics The Aerodyanmics team members have expertise in aerodynamic analysis and testing, including skills in hand calculations, computational analysis tools, wind tunnel and glide testing.

Structures The Structures team members focus on skills in structural analysis and testing, employing hand calculations, computational tools, and various structural testing methods.

Propulsion The Propulsion team focuses on analyzing and testing the propulsion system effectiveness and efficiency, but also has skills in electronics related to the propulsion system.

Systems The Systems team works very closely with the Engineering Lead, as they oversee all systems interfacing, avionics, etc. There is a sub-group of the Systems team that is assigned to work on the mission specific payload and related components, as well as related testing.

Manufacturing The Manufacturing team oversees the manufacturing of all prototypes and testing apparatus.

Graphics The Graphics team has skills in CAD design as well as graphical marketing for the team.

II.B Schedule

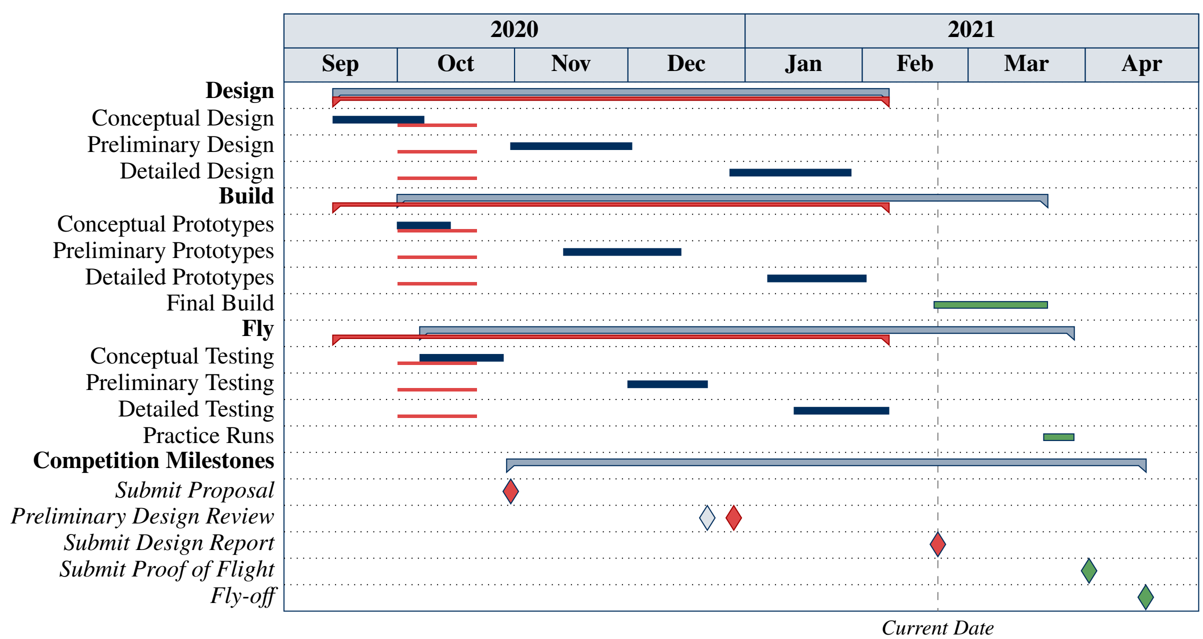

Figure 2 This milestone chart reveals our original plan for major elements of our design process compared to the actual timing of these events. Note that we submitted the proposal on time, as well as this report. We anticipate remaining on schedule for the future elements of this chart.

Figure 2 depicts our planned vs. actual timeline for the year. Nam dui ligula, fringilla a, euismod sodales, sollicitudin vel, wisi. Morbi auctor lorem non justo. Nam lacus libero, pretium at, lobortis vitae, ultricies et, tellus. Donec aliquet, tortor sed accumsan bibendum, erat ligula aliquet magna, vitae ornare odio metus a mi. Morbi ac orci et nisl hendrerit mollis. Suspendisse ut massa. Cras nec ante. Pellentesque a nulla. Cum sociis natoque penatibus et magnis dis parturient montes, nascetur ridiculus mus. Aliquam tincidunt urna. Nulla ullamcorper vestibulum turpis. Pellentesque cursus luctus mauris.

III Conceptual Design

III.A Mission Requirements

The mission requirements for this year's competition are as follows:

III.A.1 Airframe and Operational Constraints:

- Safety Requirements:
  - [THIS YEAR'S REQUIREMENT(S).]
- Airframe Requirements:
  - [THIS YEAR'S REQUIREMENT(S).]
- Payload Requirements:
  - [THIS YEAR'S REQUIREMENT(S).]
- [THIS YEAR'S SPECIAL REQUIREMENT(S)]:
  - [THIS YEAR'S REQUIREMENT(S).]

III.A.2 Flight Mission Scoring:

Flight Mission 1:

Flight Mission 2:

Flight Mission 3:

III.A.3 Total Score Summary:

$$TS = M_1 + M_2 + M_3 + GM + DR$$

where TS is total score, M_i is the score associated with the mission number subscript, GM is the ground mission score, and DR is the design report score.

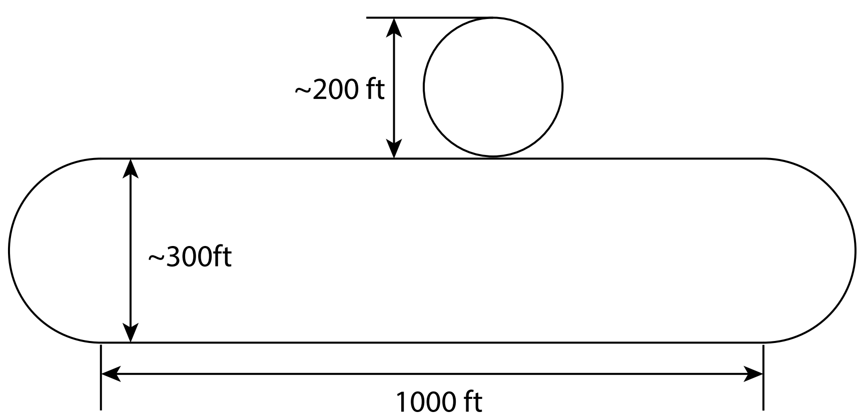

Figure 3 This plot breaks down the estimated lengths of the course based on the scale drawing from the mission requirements.

III.B Sub-system Design Requirements

We have organized our sub-system requirements into aerodynamics, structure, propulsion, and specialty requirements explained below.

III.B.1 Aerodynamics Requirements

Some of the major requirements for the aerodynamics sub-system are: Maximize aerodynamic efficiency in order to use less energy to overcome drag for all flight missions. Design wing loading to be able to take off and fly with design max payload weight. Keep the wingspan within the maximum of [MAX SPAN CONSTRAINT THIS YEAR]. Choose airfoil(s) and configuration that will make take off feasible in the [THIS YEAR'S TAKE-OFF REQUIREMENT]

III.B.2 Structural Requirements

The breakdown of mission requirements for the structures sub-system include: Minimize the structural weight while maintaining sufficient rigidity to keep the aerodynamics as designed, especially when full payload weight is in use. Make sure the structure is sufficiently rigid to avoid aerodynamic flutter within the flight envelope. [OTHER MISC. STRUCTURES REQUIREMENTS THIS YEAR (E.G. FOLDING WINGS.)]

III.B.3 Propulsion Requirements

The propulsion sub-system requirements are to: Have sufficient system efficiency and battery capacity to enable completion of the flight missions and maximizing speed with sufficient endurance while also providing sufficient thrust for [THIS YEAR'S TAKE-OFF REQUIREMENT]

III.B.4 Specialty Requirements

[REQUIREMENTS FOR THIS YEAR'S SPECIAL STUFF.] Nam dui ligula, fringilla a, euismod sodales, sollicitudin vel, wisi. Morbi auctor lorem non justo. Nam lacus libero, pretium at, lobortis vitae, ultricies et, tellus. Donec aliquet, tortor sed accumsan bibendum, erat ligula aliquet magna, vitae ornare odio metus a mi. Morbi ac orci et nisl hendrerit mollis. Suspendisse ut massa. Cras nec ante. Pellentesque a nulla. Cum sociis natoque penatibus et magnis dis parturient montes, nascetur ridiculus mus. Aliquam tincidunt urna. Nulla ullamcorper vestibulum turpis. Pellentesque cursus luctus mauris.

III.C Scoring Sensitivity Analysis

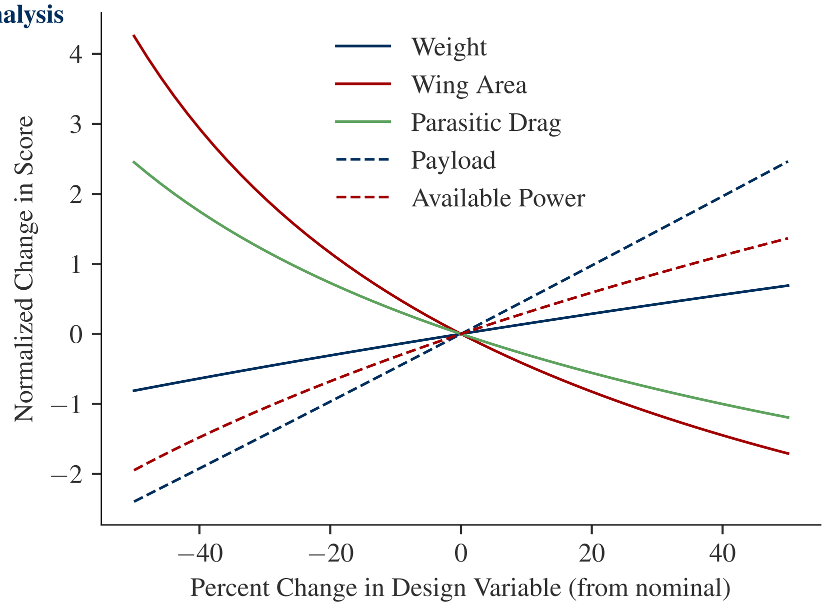

Figure 4 This plot shows the effects of those design parameters that directly affect the increase/decrease in mission scoring beyond simple completion.

For our sensitivity study, we first differentiated between design variables that could increase/decrease our score and those that were only related to the minimum constraints. Furthermore, some aspects of the score are insensitive by design parameters, such as the design report score, the ground mission score, and the Flight Mission 1 score. Our total, design-sensitive score is simply the sum of scores from Flight Mission 2 and 3.

[BREAKDOWN OF THE MATHS USED TO PERFORM THE SENSITIVITY STUDY.]

In order to normalize the scores as they are in the competition, we ran the analysis first without normalization, from which we saved the maximum scores like they are in competition. We then used those maxima as the normalization factors and re-ran the analysis. This way we could simulate the competition normalizations for the scoring and one mission would not dominate another unrealistically.

In our analysis (results shown in figure 4), we found that the wing area and parasitic drag coefficient induced negative sensitivities, thus we want to minimize drag and maximize wing loading (while still being able to take off). The available power was also important, and can be affected by increasing battery capacity, discharge rate, or voltage, or increasing propulsive efficiency. [TAKE AWAYS FROM PAYLOAD STUFF]. We should also note that the aircraft weight had the lowest effect on the overall sensitivity, but is incredibly important to meeting the fixed constraints of the competition.

III.D Concept Review, Weighting, and Selection Process

Informed by our sensitivity study, table 2 shows our general figures of merit for our conceptual design choices. In addition to the primary mission sensitive parameters, we added some practical figures of merit as well. In addition, rather than having multiple figures of the same value, we chose to make each figure a distinct value, thereby requiring a true prioritization and less change of ambiguity during the selection process.

We chose weight as the most important factor because it not only relates to the mission objectives, but also concerns the take-off/landing constraints. Drag was our next highest factor, as speed is important for maximizing flight mission scores. We placed simplicity next, as we must be able to actually produce our chosen design with our current and realistic potential abilities. We found stability to be important as well, since our aircraft needs to be controllable if we are to compete, but stability is relatively easy to achieve for most designs, so it was given a relatively lower value to match. Finally [TALK ABOUT THE YEAR SPECIFIC METRIC IF THERE IS ONE.] Each of the decision matrices has additional figures of merit associated with sub-system specific requirements. Note also, that parameters associated with available power were not included in the general list of figures of merit, but are included in propulsion specific decision matrices.

Table 2 Figures of Merit

Factor	Scale (1-5)
Weight	10
Drag	8
Simplicity	6
Stability	4
[YEAR SPECIFIC ITEM]	2

III.D.1 Wing Configuration Selection

For our wing configuration, we needed to take overall potential lift into account, due to the take-off/landing requirements. Table 3 shows our scoring for single wing, tandem wing, and bi/tri-wing configurations. Note that we eliminated flying wing/blended wing body configurations up front based on our previous experience with that concept.

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III.D.2 Wing Placement Selection

For the wing placement, we compared high, mid, and low wing placement. An addition figure of merit here is the accessibility, that is, the accessibility of the payload and electronics. This is important not only for the ground mission, but also for setting up the aircraft for flight.

Table 3 Weighted decision matrix for wing configuration.

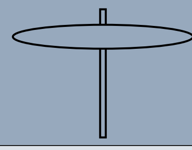
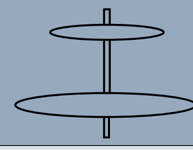
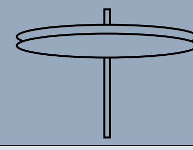
Factor	Scale	Single Wing 	Tandem Wing 	Bi/Tri-wing 
Weight	10	3	2	1
Drag	8	3	2	1
Simplicity	6	3	1	2
Lift	5	2	2	3
Stability	4	3	2	3
[YEAR SPECIFIC ITEM]	2			
Totals				

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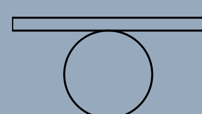
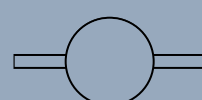
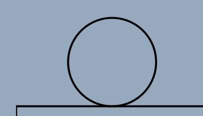
Table 4 Weighted decision matrix for wing placement.

Factor	Scale	High Wing 	Mid Wing 	Low Wing 
Weight	10	3	2	3
Drag	8	2	3	2
Simplicity	6	3	1	2
Accessibility	5	1	2	3
Stability	4	3	2	1
[YEAR SPECIFIC ITEM]	2			
Totals				

III.D.3 Empennage Configuration Selection

For the tail configuration selection, we did not see the need for any further figures of merit. We compared three families of configuration: T-tail family, including conventional, cruciform, and T-tail designs; V-tail family, including V- and inverted V-tail designs; and H-tail family, including U-, H-, and inverted U-tail designs.

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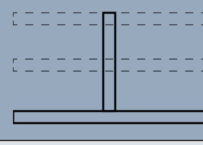
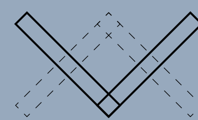
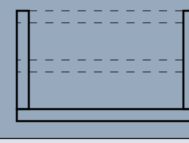
Table 5 Weighted decision matrix for tail configuration.

Factor	Scale	T-Tail Variations 	V-Tail Variations 	H-Tail Variations 
Weight	10	2	3	1
Drag	8	2	3	2
Simplicity	6	3	2	1
Stability	4	2	1	3
[YEAR SPECIFIC ITEM]	2			
Totals				

III.D.4 Propulsion Configuration Selection

For the propulsion configuration, drag did not make sense as a figure of merit, since the system is in direct opposition to drag. Therefore we exchanged drag for efficiency, since efficiency directly affects available power (which we found to be important in section 3.3). We also included lift as a figure of merit for the propulsion system, because blown wing configurations can experience increased lift (due to higher induced velocities over the wing).

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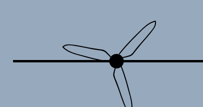
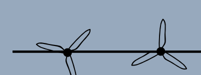
Table 6 Weighted decision matrix for propulsion configuration.

Factor	Scale	Single Prop 	Dual Prop 	Distributed Prop 
Weight	10	3	2	1
Propulsive Efficiency	8	1	2	3
Lift	7	1	2	3
Simplicity	6	3	2	1
Stability	4	3	2	3
[YEAR SPECIFIC ITEM]	2			
Totals				

III.D.5 Propulsion Placement Selection

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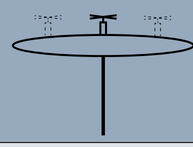
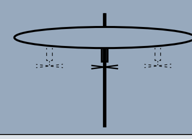
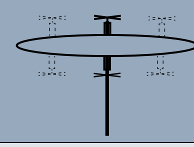
Table 7 Weighted decision matrix for propulsion placement.

Factor	Scale	Pull Variations 	Push Variations 	Combinations 
Weight	10	3	3	3
Lift	4	3	1	2
Simplicity	6	3	2	1
Propulsive Efficiency	4	3	1	2
[YEAR SPECIFIC ITEM]	2			
Totals				

III.D.6 Payload

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Table 8 Weighted decision matrix for [SPECIFY THIS YEAR'S PAYLOAD DESIGN].

Factor	Scale	[OPTION] *Figure Placeholder* Aspect ratio = 4:3	[OPTION] *Figure Placeholder* Aspect ratio = 4:3	[OPTION] *Figure Placeholder* Aspect ratio = 4:3
Weight	10			
Strength	8			
Simplicity	6			
Durability	4			
[YEAR SPECIFIC ITEM]	2			
Totals				

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III.D.7 Final Concept

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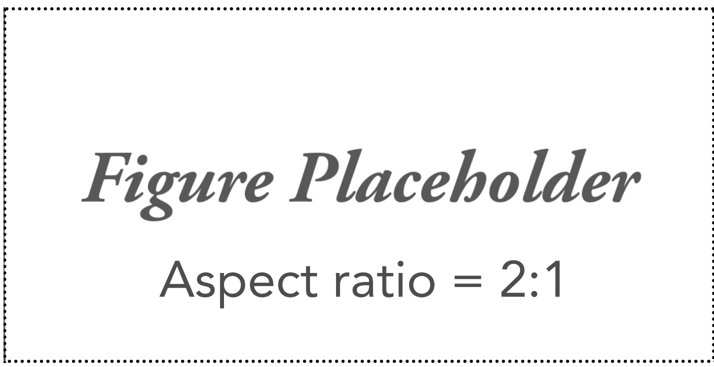
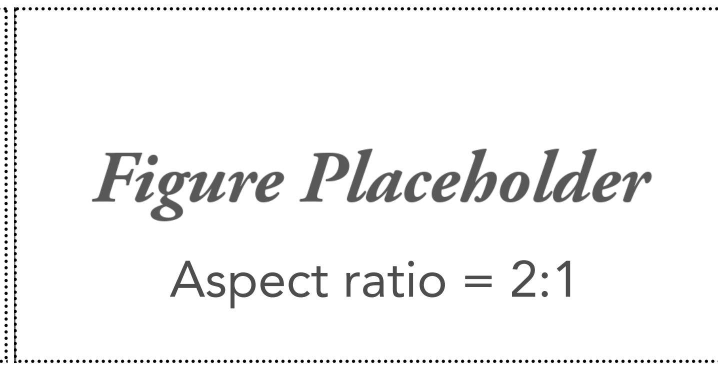
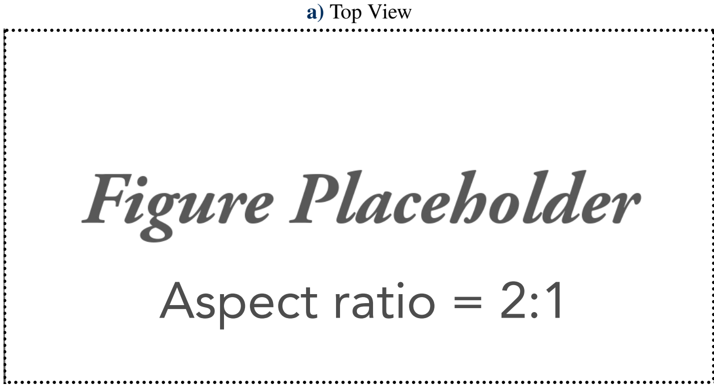


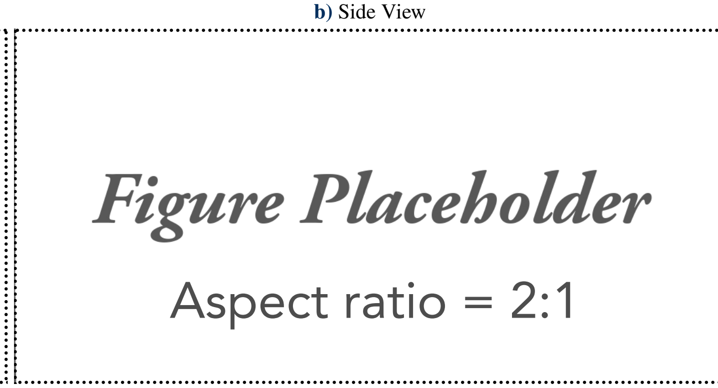
a) Top View



b) Side View



c) Front View



d) Rendered View

Figure 5 Drawings and rendering of our conceptual aircraft design.

IV Preliminary Design

IV.A Methodology

IV.A.1 Quantify Basic Constraints

The sensitivity study presented in section 3.3 did not include any constraints, but rather simple sensitivities that informed our conceptual design choices. To begin a preliminary design, we first needed to translate the given constraints (listed in section 3.2) into mathematical formulas for rapid comparison and trade studies. Aside from the obvious constraints (such as the wing span constraint), we determined the following to be important expressions.

Stall Speed

$$V_{\text{stall}} = \left[\frac{2W}{\rho S_{\text{ref}} C_{L_{\max}}}\right]^{1/2}$$

Where V_{stall} is the stall speed, W is the total aircraft weight, ρ is the ambient air density, S_{ref} is the reference wing area, and $C_{L_{\max}}$ is the maximum aircraft lift coefficient.

Take-off Distance

$$d_{LO} = \frac{W^{5/2}}{\left(\rho S_{\text{ref}} C_{L_{\max}}\right)^{3/2} P_{\text{net}}}$$

Where d_{LO} is the distance to lift-off, P_{net} is the net power, that is, the power accounting for both thrust and drag, and the other variables are as defined previously.

Maximum Speed

$$V_{\max} = \left[\frac{\frac{T_a}{S_{\text{ref}}} + \frac{W}{S_{\text{ref}}}\sqrt{\left(\frac{T_a}{W}\right)^2 - 4C_{D_0}K}}{\rho C_{D_0}}\right]^{1/2}$$

Where $V_{\max}$ is the maximum velocity, T_a is the available thrust, C_{D_0} is the zero-lift drag coefficient of the aircraft, and K is an empirical constant assumed here to be 0.38.

Maximum Range

$$R = \frac{e_b}{g}\eta\frac{L}{D}\frac{m_b}{m_{\text{tot}}}$$

Where R is the total range; e_b is the battery energy per unit mass; g is the gravitational constant; η is the combination of efficiency factors from the battery, motor, and propeller ($\eta = \eta_b\eta_m\eta_p$); L/D is the aircraft lift to drag ratio, and m_b/m_{tot} is ratio of the battery mass to total aircraft mass.

C_L for Maximum Efficiency (and Range)

$$C_{L_{\text{max L/D}}} = \left[C_{D_p}\pi S_{\text{ref}} Re\right]^{1/2}$$

Where C_{D_p} is the parasitic drag coefficient for the aircraft, Re is the Reynolds number, and other variables are defined previously.

Climb Rate

$$v_z = \frac{V_\infty (T - D)}{W}$$

Where v_z is the vertical climb rate, V_∞ is the flight velocity of the aircraft, T is the thrust force magnitude, and D is the drag force magnitude.

Coordinated Turn Radius

$$r_{\text{turn}} = \frac{V^2}{g\tan\phi}$$

Where r_{turn} is the turn radius, V is the aircraft speed, and ϕ is the bank angle of the aircraft.

Coordinated Turn Load Factor

$$n = \frac{1}{\cos\phi}$$

Where n is the load factor.

IV.A.2 Analysis Models

Weight Estimation

Propulsion Model

Vortex Lattice Method (XFLR5, AVL, or VLM.jl)

Structures Stuff (Beams, composites, etc.)

Code

IV.B Trade Studies

$$\begin{aligned} \text{maximize :}\ & M2 + M3 \\ \text{with respect to :}\ & W, S_{\text{ref}}, C_{D_0}, \text{[PAYLOAD STUFF]}, P_a \\ \text{subject to :}\ & V_{\text{stall}}, V_{\text{maneuver}}, d_{LO}, R, r_{\text{turn}} \end{aligned} \tag{1}$$

where V_{maneuver} is the maximum velocity boundary associated with structural failure due to maneuver acceleration.

IV.B.1 Wing Design

Airfoil(s)

IV.B.2 Wing/Tail Design

IV.B.3 Fuselage

IV.B.4 Payload

IV.B.5 [DESIGN TRADE STUDIES TO FIND THE ANSWER TO THE OPTIMIZATION PROBLEM.]

IV.C Estimated Aircraft Performance

IV.C.1 Performance Prediction Methodologies and Uncertainties

IV.C.2 Lift and Drag

IV.C.3 Stability

IV.C.4 Mission Performance

Figure 6 V-n diagram for our preliminary aircraft design.

V Detail Design

V.A Sizing

V.B Structures

V.C Systems and Sub-system Selection, Integration, and Architecture

V.D Weights and Balance

Table 9 Weight and Balance table including empty aircraft and each possible configuration.

Configuration	Weight (grams)	CG Location (mm)
Mission 1 (Empty)		
Mission 2		
Mission 3		

V.E Expected Flight Performance Parameters

V.F Expected Mission Performance

V.G Drawing Package

The following are drawings including a 3-View drawing with dimensions of all configurations, a structural arrangement drawing, a systems layout/location drawing, and payload accommodation drawings.

Figure Placeholder

Figure Placeholder

Figure Placeholder

Figure Placeholder

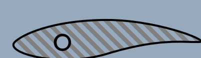
VI Manufacturing Plan

Table 10 shows our figures of merit for our manufacturing technique decision matrices. Note that we prioritized in a similar fashion to our design figures with some changes to more applicable figures. First, again, is weight. The lower the aircraft weight, the more points can be had through [YEAR SPECIFIC ITEM]. After weight, we prioritized strength, as our structures need to be able to carry the loads required. Third is simplicity; we need to be able to actually manufacture something with a given technique. Note that simplicity is relative to our team's expertise at the time of our decisions and feasible future abilities within the time frame of the competition. We next chose to include durability. It is not very high on our list since we would hope to be able to design an aircraft that has no unscheduled landings, however, one cannot predict the future enough to know whether or not durability will be required, and experience shows that it most likely will. Finally, [TALK ABOUT THE YEAR SPECIFIC METRIC IF THERE IS ONE.] Because many of these factors depend on intelligent design (e.g. a built-up balsa wing could be heavier than a foam core wing, depending on how it is designed), as well as manufacturer skill, we did some prototyping and testing of representative models before completing our decision factor calculations.

Table 10 Figures of Merit

Factor	Relative Importance (1-5)
Weight	10
Strength	8
Simplicity	6
Durability	4
[YEAR SPECIFIC ITEM]	2

Table 11 Weighted decision matrix for wing manufacturing technique. Factors here come from our initial testing of balsa and fiber reinforced polymer (FRP) techniques.

Factor	Scale	Foam Core FRP 	Hollow Core FRP 	Built-up/Balsa 
Weight	10			
Strength	8			
Simplicity	6			
Durability	4			
[YEAR SPECIFIC ITEM]	2			
Totals				

VII Testing Plan

VII.A Completed Testing

Ground Testing

Flight Testing

VII.B Planned Testing

VII.C Test and Flight Checklists

VIII Performance Results

Table 12 Weighted decision matrix for tail manufacturing technique.

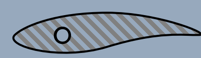
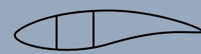
Factor	Scale	Foam Core FRP 	Hollow Core FRP 	Built-up/Balsa 
Weight	10			
Strength	8			
Simplicity	6			
Durability	4			
[YEAR SPECIFIC ITEM]	2			
Totals				

Table 13 Weighted decision matrix for fuselage manufacturing technique.

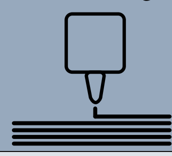
Factor	Scale	3D Printing 	Hollow Core FRP 	Built-up/Balsa 
Weight	10			
Strength	8			
Simplicity	6			
Durability	4			
[YEAR SPECIFIC ITEM]	2			
Totals				

Table 14 Weighted decision matrix for [SPECIFY THIS YEAR'S PAYLOAD DESIGN].

Factor	Scale	[OPTION] *Figure Placeholder* Aspect ratio = 4:3	[OPTION] *Figure Placeholder* Aspect ratio = 4:3	[OPTION] *Figure Placeholder* Aspect ratio = 4:3
Weight	10			
Strength	8			
Simplicity	6			
Durability	4			
[YEAR SPECIFIC ITEM]	2			
Totals				

Figure 7 This milestone chart reveals our original plan for major elements of our manufacturing process compared to the actual timing of these events.