Design Report 1 - Introduction and Background Research

Engi 7926 - Mechanical Design Project I

Group M10 - FICE
"*Flying In Control Engineering*"

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Abstract

As part of the design process to determine the optimal aircraft design, extensive background research and project planning must be performed. The first design report created by Flying in Control Engineering (FICE) will cover the design introduction, project management plan, and background research conducted for the remote control (RC) airplane project. This report is the first in a series of four reports which will be completed throughout the aircraft design, building and testing process.

Before the final design path can be decided, the appropriate constraints of the competition and the desired objectives must be determined. A section of this report summarizes the design planning, including objectives, constraints and specifications. The information included summarizes the restrictions the team must follow to adhere to the competition guidelines and also outlines some objectives and specifications which will be considered to achieve the optimal design.

Along with the design planning, this report includes the team design structure, project plan and scheduling. A project management plan was formed with each member of the team being given a specific position and set of tasks to complete, along with a preliminary timeline on a GANTT Chart, for the completion of various tasks. Throughout the 10 week project process the team aims to develop the optimal RC airplane design to compete at Memorial University's RC Competition in July of 2018.

Finally, this report includes background research from similar SAE Aero projects. Some of the information from these projects being considered in our design includes; payload ratios, typical materials, wing loading, power loading, airfoil design, testing procedures and fabrication methods. The team will analyze the research information and make educated selections on parameters the team will aim to achieve during the design, building and testing phase of the project.

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1. Introduction

Designing a model airplane serves as a way to allow students to obtain hands on experience with project management as well as complex design problems.

At Flying in Control Engineering (FICE), a dedicated group of four mechanical engineering students share a common goal: design, build and test the highest payload airplane using aircraft design fundamentals, past experience, and engineering intuition.

The first report, in a series of four design reports, will serve as the basis to document the project management model, background research and give insight into design parameters. Using the contents of this report, FICE will proceed to generate preliminary designs in order to start the design process and then move further into design work, analysis optimization, and testing.

FICE aims to further develop skills in project management and engineering design during this aircraft design project, which will enhance the team members early career skill development.

2. Design Planning

Design planning is a major component in the beginning of any project. The design objective, constraints and specifications must be fully defined before creating the initial design.

2.1 Design Objective

To successfully complete the project, a detailed aircraft design must be completed as well as detailed technical analysis of materials, stress loading, and aircraft parameters. The materials used in the design will be borrowed from Memorial University or purchased by FICE such that an optimal design is achieved.

The design objective for FICE is to achieve the highest payload percentage for the model airplane when compared with other teams competing in the Memorial University competition. To achieve this, FICE requires that the model airplane be able to successfully takeoff, complete a lap of the Techniplex, and then land without destroying crucial components. The maximum score will be awarded to the team that completes these objectives and optimizes the payload percentage to the highest value.

2.2 Design Constraints

The following constraints will be considered throughout the design of the model aircraft:

- Materials purchased by FICE must remain under $250.
- The final design must be capable of navigating in a 300x200 ft area.
- The design must be capable of landing without destroying components.
- The design can only use one motor which can produce a set torque and batteries which can provide a set amount of power.
- The design must carry the weight of the motor, motor electronic speed controller and battery configuration.
- The final design when disassembled must be able to fit in a box with dimensions of 36.25in x 21in x 10.5in.
- The design must contain a fully enclosed payload bay with dimensions 1.5x1.5x5 inches.
- A propeller must be chosen from a supplied propeller list.

2.3 Design Specifications

During the design process, many factors are important to consider such that performance is optimized. At FICE, the specifications of the model airplane that the team is focused on achieving are as follows:

Table I: Desired Aircraft Specifications

Stall Speed	< 8 ft/s
Cruise Speed	10 - 20 ft/s
Wing Loading	0.3-2.5 lb/ft^2
Power Loading	2 - 18 lb/hp
Payload Percentage	35 - 55%
Wing Semi-Span Length	30 - 36”

Due to the limited space to maneuver, it is important to consider appropriate maneuverability and lift forces to allow the pilot to control the plane with ease. Along with aiming for the best design specifications, durability of the plane and its components will be considered during manufacturing to ensure multiple test flights can be completed without incurring significant damage. Some components which will be expected to take the majority of damages during landing will be considered to have a modular design with spare parts for easy repair after potential damage.

3. Project Management Plan

3.1 Team Structure

FICE's design team is made up of four Term 7 Mechanical Engineering students. Each member has a variety of different internship experiences which includes project management, engineering analysis, as well as mechanical and electrical design. This variety allows a contribution of unique perspectives and skill sets creating a dynamic ecosystem within the company. Additionally, each member is assigned a role that best suits their individual skill sets in order to maximize company productivity.

Table II: Team Roles

Joshua Kearney	Team Lead / Electronic Systems
Matthew Butt	Manufacturing Lead
Alex Keating	Simulation Lead
Michael Duguay	Design & CAD Lead

3.2 Project Schedule

To guide the project, a project management plan was created in the form of a Gantt chart. This chart tracks all critical project milestones as well as tracks the design and manufacturing process.

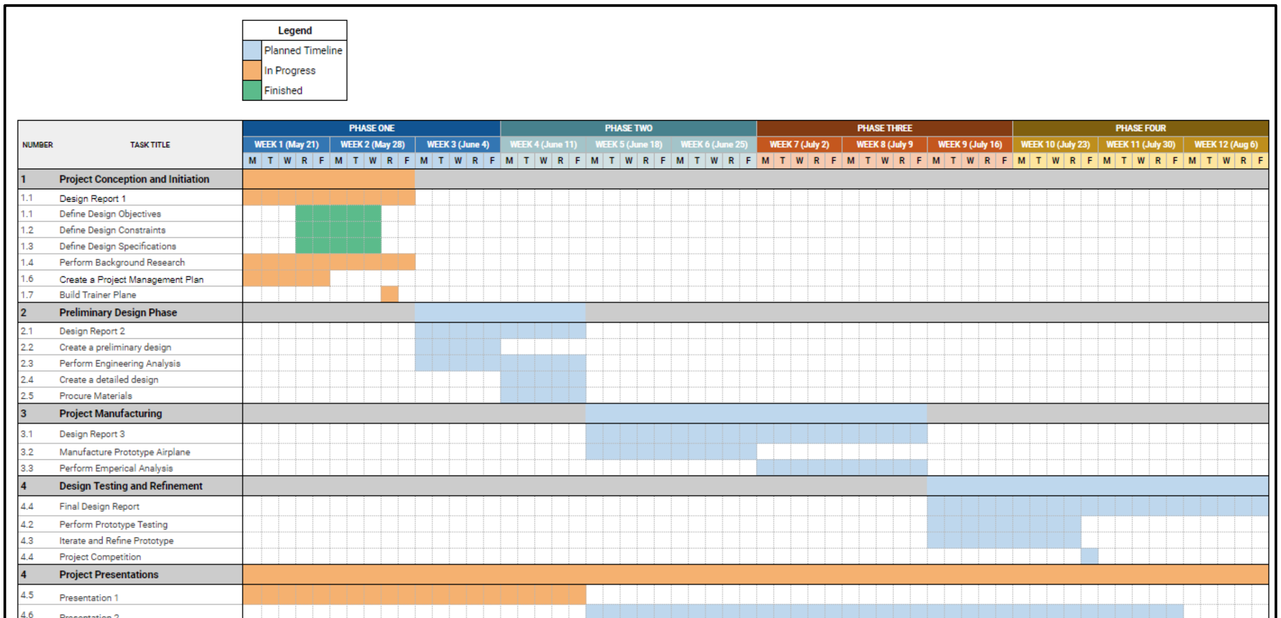

Figure 1: GANTT Chart

4. Background Research

Main design components which must be researched to optimize the aircraft include; airfoil, wing planform, wing position, fuselage, and tail. The background research aims to find information relevant to render the optimal design for each major component to maximize the payload ratio while maintaining ease of fabrication, construction and durability.

4.1 Range of Payload Ratios

Payload Ratio is the ratio of payload weight to total system weight as shown in **Equation 1**.

$$\boldsymbol{Payload\ Fraction} = \frac{\boldsymbol{W_{Payload}}}{\boldsymbol{W_{Total}}} \quad \textbf{(1)}$$

To optimize payload ratio, the capacity that the plane is able to carry in flight should be as high as possible, while maintaining the lowest possible airplane empty weight. To gain a better understanding of what a realistic payload ratio should be, it is necessary to review past designs. During the SAE Aero competitions that took place in 2017, the range of payload ratios was from 14-87% with the majority of teams placing around the 50-60% as shown in **Appendix A1**. The winning payload ratio of 87% was designed by the University of Warsaw. Such values in the upper range of the SEA Aero competition are higher than the expected values for the Memorial competition as they were achieved by teams that have optimized their designs over multiple years. Another competitive team competing in a similar competition conducted by the Society of Automotive Engineers conducted in 2016 reported payload ratios of approximately 48% as shown in **Appendix A1.** This team followed a similar time constraint to that provided in this course and provides an appropriate value that FICE can strive for. By analyzing the previous competition results it was determined that for FICE to remain competitive, the team is aiming to achieve above a 45% payload ratio, which the majority of teams have been unable to accomplish in previous Memorial competitions.

4.2 Typical Construction Materials

Upon reviewing past designs, it was noted that there is a multitude of various materials that teams have used during the fabrication of their models. To adequately choose a material a few major properties need to be considered. Firstly, it must be lightweight, as mentioned in the discussion on payload ratios the airplane needs to remain as light as possible to help the payload ratio and also the planes overall performance. Secondly, it needs to be durable, this is so that if there is a failure the main structure of the plane will not be damaged during testing and competition flights. Lastly, it needs to be cost effective, although a material such as carbon fibre may be an obvious choice to meet the other criteria it would not be affordable.

In addition to the above mentioned criterium, it should also be noted that the chosen material should be relatively easy to handle and be simple to use in manufacturing processes.

Construction materials commonly used by design teams include the following[1]:

- Foam
- Foam Boards
- Corrugated Plastic Sheets
- Carbon Fibre Rods
- ABS Polymer
- Balsa Wood

4.3 Typical Wing Loading (lb/ft^2)

Wing loading is the ratio of the aircraft weight over the total wing area. Choosing an appropriate wing loading value is essential to generate the desired amount of maneuverability in the aircraft.

Andy Lennon, the author of “Basics of RC Model Aircraft Design”, summarized typical wing loading values that are commonly used in different types of aircrafts with varying ranges of maneuverability. Typical values for different types of model airplanes are summarized below[2]:

Table III: Wing Loading

Model Type	Wing Loading (lb/ft^2)
Pattern Models	1.44 - 1.63
Sport Models	0.94 - 1.25
Trainer Models	0.75 - 1
Glider Models	0.5 - 0.875

A higher wing loading value typically results in a smaller, faster, and stronger aircraft but sacrifices maneuverability resulting in higher stall and landing speeds[2]. The goal of most SAE Aero projects is to fly at a moderate speed and maneuverability to accommodate the limited space in many competition venues. From research, it was determined that a wing loading of approximately 1.25 lb/ft^s was a common choice to accommodate the flight requirements of the SAE ariel circuit**[3]**. This value was chosen by many teams to excel at the competition because it requires the strength and speed that higher wing loading offers, but also requires relatively low landing and stall speeds with moderate maneuverability. To obtain the optimal value that fills all requirements it was determined by these teams that a value in the range of sport models is most appropriate.

4.4 Typical Power Loading (lb/hp)

Power loading or weight-to-power ratio is a ratio compiled of the model's full weight (model, cargo, fuel etc..) in lbs over the horsepower (hp) scaled up in proportions to 1 hp. As can be expected, a plane with a lot of horsepower and a small overall weight will perform much better than its counterpart with low horsepower and a high overall weight. However, thrust is also critical to the model's performance and depends not solely on horsepower.

Table IV: Power Loading[4]

Model Type	**Power Loading (lb/hp)**
Very lightweight/low wing loading slow flyer	14.91
Light powered gliders, trainers	14.91-9.32
General sport flying and basic/intermediate aerobatics	9.32-6.21
Serious aerobatics, pattern flying	6.21-4.14
Faster jets (flies in clouds)	4.14+

With FICE's design being restricted to a certain motor the only design factor affecting this ratio will be the overall weight of the model with payload. FICE classifies their model as a light powered glider or trainer model and will have a design goal for a power loading of 14.91-9.32 (lb/hp).

4.5 Airfoil Design and Parameters

Airfoils are objects that have a cross-sectional shape that when moved through a fluid such as air, creates an aerodynamic force. Airfoils are frequently used on aircrafts as wings to produce lift or as propeller blades to produce thrust. In the case of this report, airfoils will be focused on in the context of being used as wings for an aircraft[5].

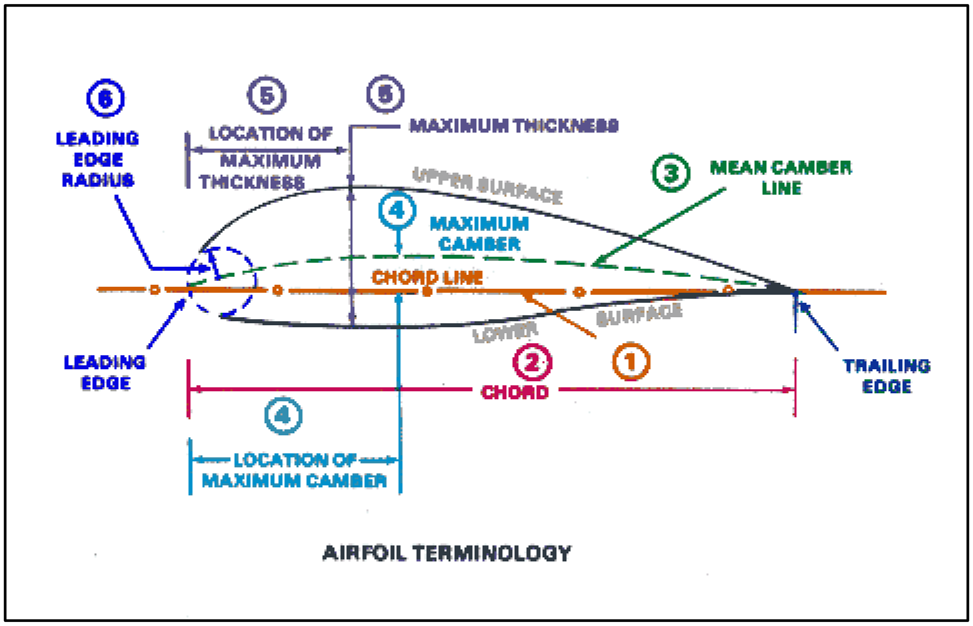

Figure 2 - Airfoil Terminology[5]

There are two main categories of airfoils, non-symmetrical and symmetrical. Non-symmetrical airfoils are characterized by a different upper surface from the bottom surface with the majority of the airfoil residing above the chamber line. This type of airfoil allows high lift generation even with zero angle of attack. Symmetrical airfoils have the same surface above and below the chamber line and are unable to generate lift without a non-zero angle of attack. Non-symmetrical airfoils are generally superior for the purpose of aircraft wings and, thus, will be the wing type focused on by FICE[6].

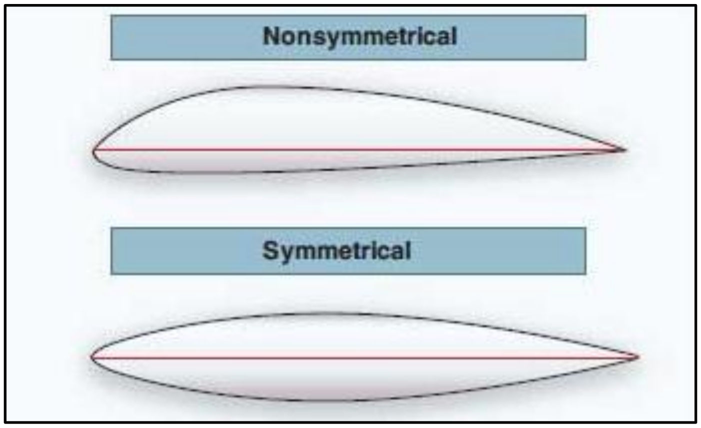

Figure 3 - Appearance of Different Types of Airfoils[6]

In the past a common non-symmetrical airfoil used in the design of model airplanes was the Eppler 423. Theoretically at a reynolds number value of 200,000, this airfoil can achieve a lift to drag ratio of 73.7 at an angle of attack of 9.25 degrees, with CL_{max} equal to 2.00[7].

However, more recently, the S1223 airfoil has been used for designing model airplanes. Again, theoretically at a reynolds number value of 200,000, this airfoil can achieve a lift to drag ratio of 73.6 at an angle of attack of 3.75 degrees, with CL_{max} equal to 2.25. A design team from Northern Arizona University was able to configure the S1223 airfoil such that it achieved a zero lift drag coefficient of 0.24, with an aspect ratio of 7.17 and an oswald efficiency factor of 0.935[8].

While the theoretical values for the lift to drag ratio are similar, the CL_{max} value clearly shows that the S1223 airfoil is the superior airfoil. Experimental data acquired by Northern Arizona University from XFOIL can be seen in Figure 4 and it shows that the S1223 outperforms the Eppler 423 by 18% in the lift to drag ratio and can produce about 10-20% more lift.

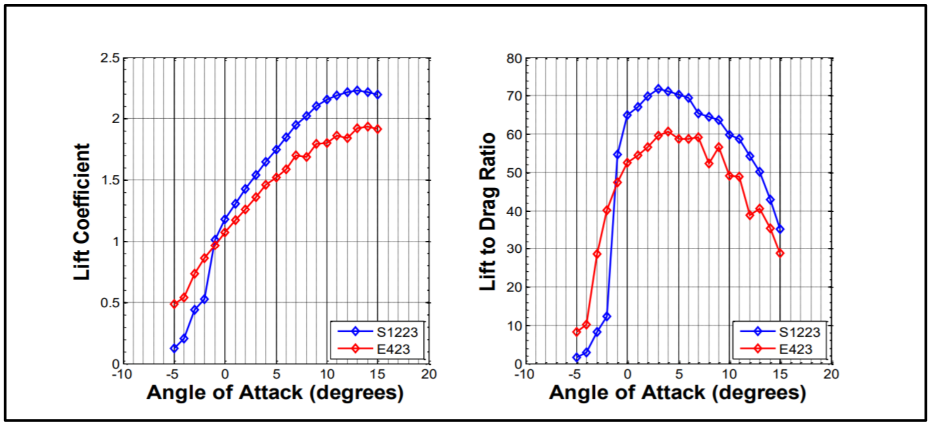

Figure 4 - S1223 and Eppler 423 Lift Vs. Angle of Attack Comparison (Left)
S1223 and Eppler 423 Lift to Drag Ratio Vs. Angle of Attack Comparison (Right)[9]

Remote controlled aircrafts have also used airfoils such as the Clark Y, E197, and NACA 2412. These airfoils display fine lift characteristics, capable of reaching CLmax values close to 1.5, but, as shown in the figures below, the S1223 outperforms each of these airfoils when set to its optimal angle of attack.

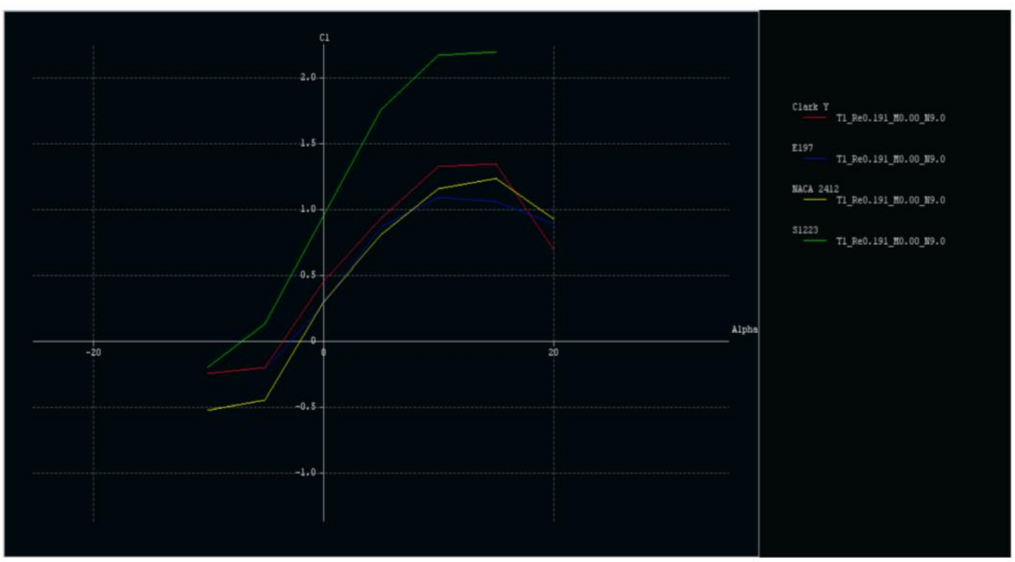

Figure 5 - CL vs Angle of Attack for Various Airfoils[3]

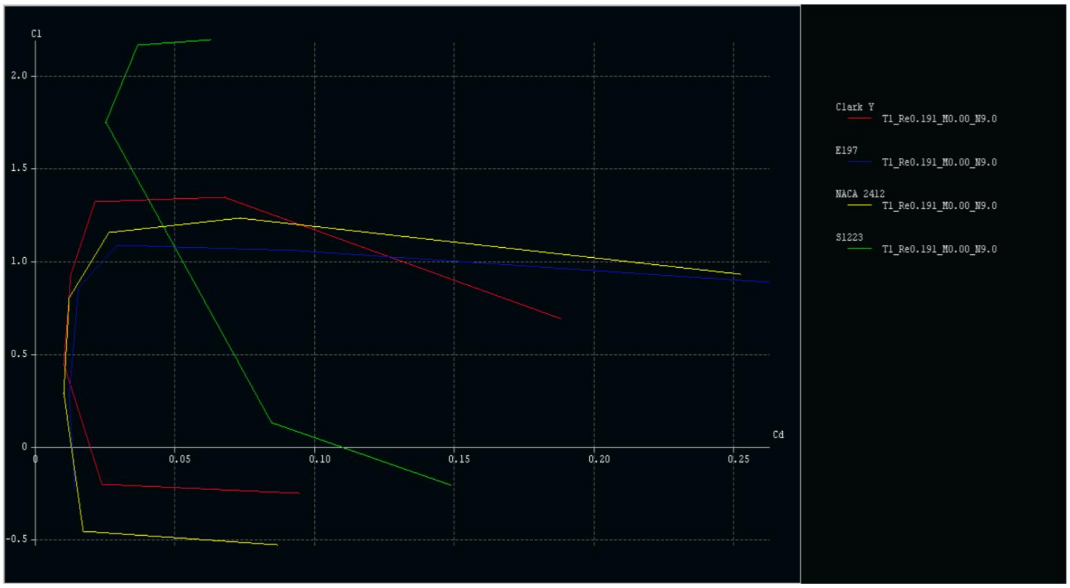

Figure 6 - CL vs CD for Various Airfoils[3]

From the research conducted by FICE, the S1223 is the standout airfoil and is currently FICE's first choice, provided that the airfoil can be proven to be structurally sound within the conditions that FICE plans to operate within.

4.6 Proposed System Testing Methods

The following tests can be used to assist with the design process of the model airplane:

- **Thrust Testing** - Operate a motor with an attached propeller on a scale such that the thrust can be calculated.
- **Tensile/Compression/Torsion Testing** - Samples of the materials to be used in the design can be subjected to tension, compression, and torsion. While subjected to these forces, they can be monitored such that the materials performance characteristics are known.
- **Impact and Flight Testing** - The model can be flown before the competition date to ensure it flies as expected and then crashed to ensure that no components are destroyed in the crash.

Simulations using programs such as SolidWorks or ANSYS can also be performed to reduce the amount of required testing and to also obtain parameters which are more difficult to test.

4.7 Material Fabrication Methodologies

Generally, when building a model airplane the majority of the fabrication processes involved are cutting materials to create desired shapes. For example, many model airplane design teams use foam which can be cut using a hot wire CNC[10]. Corrugated plastic is also a commonly used material which can be cut using a BK Series Cutting Machine or a laser cutter[11].

Design teams often need additional support in sections of their models and look to using carbon fibre rods to achieve this. These rods can be cut with any bladed tool as long as the rod is properly supported and the cut is made slowly. Proper dust collection is also very important as these particles are hazardous once in the lungs[12].

Recently, some design teams have taken to 3D printing components of their models with materials such as ABS polymer. This allows the teams to obtain the exact geometry they desire but they may not be able to use the optimal material[9].

5. Conclusion

This preliminary report prepared by FICE outlines the design constraints and specifications of the project, the project management plan, and background research conducted by the team. At this time FICE has completed Phase 1 of its RC Airplane and will be moving forward into Phase 2. Phase 1 concluded the team's research into past designs and outlined their specific design criteria and specifications. Phase 2 will proceed into a more detailed engineering phase including CAD models, calculations, simulations and design iterations. FICE is confident that their team will be able to execute the design plan thoroughly and accurately, yielding the winning aircraft design.

6. References

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7. Appendix A

Best Payload Fraction Results

Micro Class Best Payload Fractiopn Results
2017 Aero Design East

Rank	Team #	University	Country	Best Payload Fraction
1	318	Warsaw University of Technology	Poland	86.9118%
2	302	Xian Jiaotong Univ	China	85.1158%
3	325	Anadolu Universitesi	Turkey	78.7718%
4	315	Univ of Puerto Rico-Mayaquez	United States	74.0066%
5	324	Florida International Univ	United States	71.8031%
6	331	Union College	United States	66.6314%
7	326	Brigham Young Univ - Idaho	United States	64.9892%
8	310	Sahyadri College of Engineering & Mgmt	India	63.4925%
9	306	Wright State Univ	United States	60.1819%
10	314	Saint Louis Univ	United States	49.9517%
11	320	Polytechnic Univ of Puerto Rico	United States	48.2274%
12	317	Universidad Metropolitana	Venezuela	45.4465%
13	322	Univ of Wisconsin - Platteville	United States	42.6506%
14	316	Queens Univ - Ontario Canada	Canada	34.6824%
15	328	BMS College of Engineering	India	14.1274%
-	329	Vellore Institute of Technology	India	0.0000%
-	311	Universidade Federal de Sao Joao del Rei	Brazil	0.0000%
-	312	Louisiana State Univ	United States	0.0000%
-	319	Dayananda Sagar College of Engineering	India	0.0000%
-	323	SRM Engineering College	India	0.0000%

Figure A1 - 2017 SEA Aero East Payload Results[13]

APPENDIX IV

Above ground level (feet)	Temperature (°R)	Pressure (lb/ft^2)	P (mm of hg)	Density of Air (slugs/ft^3)	Density Altitude (feet)	Lift (lb)	Payload fraction
200	543.1568	2101.659769	29.81555	0.002250593	1747.744901	7.384618	0.477549164
300	542.8002	2094.412123	29.71273	0.002242832	1864.287769	7.359152	0.47574124
400	542.4436	2087.184733	29.61019	0.002235092	1980.812563	7.333757	0.473925865
500	542.087	2079.977554	29.50795	0.002227375	2097.319271	7.308433	0.472103004
600	541.7304	2072.790545	29.40599	0.002219678	2213.807886	7.28318	0.470272621
700	541.3738	2065.62366	29.30431	0.002212003	2330.278399	7.257998	0.46843468
800	541.0172	2058.476859	29.20293	0.00220435	2446.730799	7.232886	0.466589144
900	540.6606	2051.350096	29.10182	0.002196718	2563.165079	7.207845	0.464735978
1000	540.304	2044.24333	29.001	0.002189108	2679.581228	7.182874	0.462875145
1100	539.9474	2037.156517	28.90046	0.002181519	2795.979238	7.157973	0.461006607
1200	539.5908	2030.089615	28.8002	0.002173951	2912.3591	7.133142	0.459130329
1300	539.2342	2023.04258	28.70023	0.002166405	3028.720804	7.10838	0.457246272
1400	538.8776	2016.015369	28.60054	0.00215888	3145.064342	7.083689	0.455354399
1500	538.521	2009.007941	28.50113	0.002151376	3261.389704	7.059067	0.453454673
1600	538.1644	2002.020253	28.40199	0.002143893	3377.69688	7.034514	0.451547055
1700	537.8078	1995.052261	28.30314	0.002136431	3493.985863	7.010031	0.449631509
1800	537.4512	1988.103923	28.20457	0.00212899	3610.256642	6.985616	0.447707995
1900	537.0946	1981.175197	28.10627	0.002121571	3726.509208	6.961271	0.445776475
2000	536.738	1974.266041	28.00825	0.002114172	3842.743552	6.936994	0.44383691

Figure A2 - Payload Fractions at Various Operating Conditions[2]

8. Appendix B

FICE has started building the trainer model aircraft. The team took dimensions of a prebuilt version and calculated critical performance factors. The values obtained by FICE are shown on the following pages.

ENGI 7926 - Aero Design - General Sizing Sheet

Weights			lbm	N	Notes/Equations Used
Airframe (W_e)	0.436	kg	0.9612	4.2772	Airframe Only
Batteries and Instruments (W_f)	0.327	kg	0.7209	3.2079	
Payload (W_pl)	0	kg	0	0	No Payload Assumed
Total (W_o)	0.763	kg	1.6821	7.485	

Aircraft Aerodynamics			Notes/Equations Used
			Calculate using the provided drag polar
Max Lift Coefficient (C_lmax)	0.9	-	From graph
Max Lift to Drag Ratio (L/D_max)	18	-	From graph
Zero Lift Drag Coefficient (C_do)	0.0153	-	
K	0.0548	-	
Oswald Efficiency (e)	80.73%	-	

Environmental Conditions			Notes/Equations Used
Air Density (ρ)	1.225	kg/m^3	Assume Sea Level
Gravity (g)	9.81	m/s^2	
Air Speed (V _cruise)	12	m/s	

Propulsion					Notes/Equations Used
Motor Power (P_max)	336	W	0.4506	HP	
Battery Voltage (V_bat)	11.1	V			
Battery Capacity (E_bat)	2200	mAh			
Propeller Diameter (Φ_prop)	204	mm			
Propeller Pitch (p_prop)	101.6	mm			
Propulsion Efficiency (η_p)		-			(takeoff) omit for now
Max Thrust (T_max)		N			(takeoff) omit for now

Coordinate System Origin: y wing tip x pointing forward (nose) and z pointing

Main Wing			Ft	m
Airfoil	Flat Bottom			
Aspect Ratio (AR)	7.2	-		
Taper Ratio	1	-		
Wing Area (S)	2851	cm^2	3.0688	0.2851
Wingspan (b)	144	cm	4.7244	1.44
Semispan (b/2)	72	cm	2.3622	0.72
Root Chord (c_root)	19.8	cm	0.6496	0.198
Tip Chord (c_tip)	19.8	cm	0.6496	0.198
Average Chord (c)	19.8	cm	0.6496	0.198
Sweep	0	deg		
Wing Rise	9.5	cm	0.3117	0.095
Dihedral	8	deg		

Horizontal Stabilizer			Ft	m	
Airfoil	Over/Under Cambered				
Aspect Ratio (AR)	3.1543	-			
Taper Ratio	0.5294	-			
Wing Area (S)	520	cm^2	0.5597	0.052	
Wingspan (b)	40.5	cm	1.3287	0.405	
Semispan (b/2)	20.25	cm	0.6644	0.2025	
Root Chord (c_root)	17	cm	0.5577	0.17	
Tip Chord (c_tip)	9	cm	0.2953	0.09	
Average Chord (c)	12.9	cm	0.4232	0.129	
Sweep (this is an angle)	25.4	deg			
Volume Ratio	0.6347	-			
Lever Arm (x)	68.9	cm			
Vertical Offset (z)	11.5	cm			

Vertical Stabilizer			Ft	m	
Airfoil	Over/Under Cambered				
Aspect Ratio (AR)	4.2516	-			
Taper Ratio	0.7097	-			
Wing Area (S)	288.13	cm^2	0.3101	0.0288	Total Height of the Wing
Semispan (b/2)	17.5	cm	0.5741	0.175	
Root Chord (c_root)	15.5	cm	0.5085	0.155	
Tip Chord (c_tip)	11	cm	0.3609	0.11	
Average Chord (c)	13.25	cm	0.4347	0.1325	
Sweep	58	deg			
Volume Ratio	0.0484	-			(Surface area of the stabilizer *lever arm)/(main wing area *main wingspan)
Lever Arm (x)	68.9	cm			
Vertical Offset (z)	5	cm			

Performance			Notes/Equations Used
Wing Loading (W/S)	0.548140013	lb/ft^2	
Power Loading (max)	3.733220039	lb/hp	
Payload Fraction	0	-	
Lift Coefficient	0.29766498	-	
Drag Coefficient	0.020101979	-	
Lift to Drag Ratio	14.80774493	-	
Thrust Required	0.505480749	N	
Power Required	6.06576899	W	
Current Draw (Cruise)	0.546465675	A	
Stall Speed	6.901188068	m/s	
Max Range Air Speed		m/s	omit for now
Max Endurance Air Speed		m/s	omit for now
Rate of Climb		m/s	omit for now
Estimated Flight Time		s	omit for now
Estimated Range		m	omit for now