

# **Final Design Report**

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## NOMENCLATURE

### Aircraft Design Coefficients and Parameters

$C_l$  : Airfoil Lift Coefficient  
 $C_L$  : Wing Lift Coefficient  
 $C_d$  : Airfoil Drag Coefficient  
 $C_D$ : Wing Drag Coefficient  
 $C_{l, \alpha}$ : Wing Lift Coefficient at specific angle of attack  
 $C_{m, \alpha}$ : Change in Pitching Moment with Angle of Incidence  
 $C_{m, \delta e}$  : Change in Pitching Moment with Elevator Deflection Angle  
 $C_n$ : Lateral Force Coefficient at Sideslip Angle  
 $C_{l_s}$ : Lift Coefficient at Sideslip Angle  
 $\epsilon_a$ : Downwash Angle  
 $e$ : Oswald's efficiency factor

### Abbreviations and Acronyms

AIAA: American Institute of Aeronautics and Astronautics  
ANOPP: Aircraft Noise Prediction Program  
AVL: Athena Vortex Lattice  
BRS: Ballistic Recovery Systems  
BSFC: Brake Specific Fuel Consumption  
CAD: Computer Aided Design  
CFR: Code of Federal Regulations  
CMI: Champaign IL USA Airport  
CG: Center of Gravity  
DAPCA IV: Development and Procurement Costs of Aircraft Model 4  
DATCOM: Data Compendium  
DRR: Design Readiness Report  
EAA: Experimental Aircraft Association  
EASA: European Aviation Safety Administration  
ECU: Engine Control Unit  
FAA: Federal Aviation Administration  
FADEC: Full Authority Digital Engine Control  
FEA: Finite Element Analysis  
OEW: Operating Empty Weight  
EW: Empty Weight  
IA: Iota Air  
ISA: International Standard Atmosphere  
KTAS: Knots True Airspeed  
LFL: Landing Field Length  
LUK: Lunken Airport, Cincinnati, USA  
MAC: Mean Aerodynamic Chord  
MTOW: Maximum Take-Off Weight  
NACA: National Advisory Committee for Aeronautics  
ORD: Chicago O'Hare International Airport, USA  
PCU: Power Control Unit

PDR: Preliminary Design Report  
PSFC: Power-Specific Fuel Consumption  
RAND: Research and Development Corporation  
RDT&E: Research, Development, Test and Evaluation  
RFP: Request for Proposal  
RPM: Revolutions per Minute  
SFC: Specific Fuel Consumption  
TOFL: Takeoff Field Length  
VDC: Volt Direct Current

## COMPLIANCE CHECKLIST<sup>1</sup>

Description	Aircraft Requirement	IA Mark 2 Compliance	Section
Planned Certification	14 CFR Part 23	14 CFR Part 23	Section II
Certification / Performance Level	Level 2/Low Speed	Level 2/Low Speed	Section II
Usage of single reciprocating engine	Installed full aircraft parachute	Iota Air - Airframe Parachute System	Section VI, VII and XI
Single engine noise limits per Part 36 Sec. G36.301(c)	Meet single engine noise limit	Acoustics Certification met as per Part 36 Sec. G36.301(c)	Section XIII
Certification / entry into service	Year 2025	Year 2025	Section II
Payload	4 passengers (800 lb)	6 passengers (1,200 lb)	Section II
Crew	Single pilot (180 lb)	1 pilot (180 lb)	Section II
Aircraft Operating Cost	Achieve low direct operating costs that maximize profits for operators	Estimated \$375 per flight hour in operating costs	Section XII
<b>Reference Mission</b>			
Takeoff Distance	≤ 2500 ft	2,348 ft	Section VII
Landing Distance	≤ 2500 ft	1,920 ft	Section VII
Range	≥ 135 nmi	436 nmi	Section VII
Flight Time	≤ 45 min	41 minutes	Section VII
Reserve	Fuel/energy remaining for: Climb to 3,000 ft and Loiter for 45 minutes	Reserve requirements met according to the RFP. Maximum loiter time is 72 minutes.	Section VII
<b>Sizing Mission</b>			
Payload	Full payload	6 passengers (1,200 lb)	Section II
Range	≥ 250 nmi	436 nmi	Section VII
Flight Time	No requirement	No requirement	Section II



## I. INTRODUCTION

The IA Mark 2 will be a profitable new design that will provide thin haul transportation for routes such as CMI to ORD. Customers will soon be able to travel with on-demand flights that have accelerated boarding and egress times with multiple destination points. Iota Air focused on designing a seven-seat aircraft to hold up to six passengers. The IA Mark 2 will have the capability of traveling a maximum range of 250 nmi at speeds up to 210 KTAS. With an average of 20 flights per week, the IA Mark 2 will be able to maximize profits for potential operators. Utilizing the Lycoming IO-720 piston engine will reduce operating costs due to lower maintenance requirements and cost effective fuel selection. Safety is another important aspect of Iota Air's design process. The IA Mark 2 will utilize one of the best safety features for any reciprocating engine aircraft, an airframe parachute system. Using parachutes, like the one designed for IA Mark 2, have led to almost 400 lives saved since August 2017<sup>2</sup>. The IA Mark 2 is designed for companies looking to expand their services and offer on-demand travel to the skies. It will be a competitive option compared to similar aircraft such as the Piper PA-46 or Cirrus SR22. The IA Mark 2 will feature state of the art composite materials that will help reduce the overall weight of the aircraft while adding to the airframe strength. The following sections describe Iota Air's design process, for the IA Mark 2.



**Figure 1.1: IA Mark 2**

## II. CONCEPT OF OPERATIONS

### A. Design Requirements

The AIAA has described mission requirements and constraints that must be met in order to complete the primary design objective. The primary objective, as stated in the RFP, is to design an aircraft that “minimizes operating costs while maximizing the profit for operators<sup>1</sup>”. Since Iota Air chose a single piston engine, the aircraft will include a full-aircraft parachute.

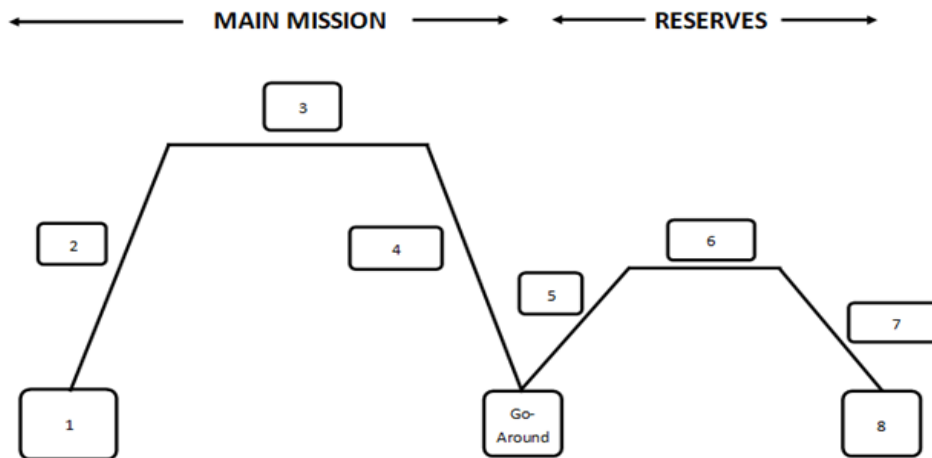
**Table 2.1: Design Requirements<sup>1</sup>**

Description	Requirement
Certification	14 CFR Part 23
Noise Limit	Part 36 Sec. G36.301 (c)
Crew / Passengers	1/4
Payload	800 lb
Takeoff / Landing Field Length	$\leq 2,500$ ft
Takeoff / Landing Obstacle Clearance	$\geq 50$ ft
Entry into Service	2025
Reference Mission	
Range	$\geq 135$ nmi
Flight Time	$\leq 45$ min
Payload	50% Payload
Fuel / Energy Reserves for	<ul style="list-style-type: none"> <li>● Climb to 3,000 ft</li> <li>● Loiter for 45 mins</li> <li>● Descend to sea level and land</li> </ul>
Sizing Mission	
Range	$\geq 250$ nmi
Flight Time	No Requirement
Payload	Full Payload

## B. Mission Profiles

### 1. Reference Mission

The reference mission provided by the RFP is the expected day to day operational mission for the IA Mark 2. This mission will be flown an average of twenty times per week with a 50% passenger capacity. This mission requires the IA Mark 2 to travel a minimum of 135 nmi in 45 minutes. In order to meet the remaining fuel/energy requirement, Iota Air added a reserves section to the mission profile. The reserves component allows the IA Mark 2 to prove that it will have enough fuel remaining when the main mission is complete. A detailed mission profile can be seen in Figure 2.1. A detailed description of each mission segment can be seen in Table 2.2.



**Figure 2.1: Reference Mission Profile**

**Table 2.2: Reference Mission Description**

Mission Segment	Description	Altitude	Velocity	Range	Endurance
1	Warmup and Takeoff	0 ft	70 KTAS	2,348 ft	-
2	Climb	-	-	-	-
3	Cruise	10,000 ft	195 KTAS	135 nmi	-
4	Descend	-	-	-	-
5	Go-Around, Climb	-	-	-	-
6	Loiter	3,000 ft	105 KTAS	-	45 min
7	Descend	-	-	-	-
8	Land	0 ft	65 KTAS	2,381 ft	-

*2. Sizing Mission*

The RFP also requires a long range sizing mission to be considered for the aircraft design. This mission will require the IA Mark 2 to fly with a full payload for a minimum range of 250 nmi. There is no speed/flight time requirement for the sizing mission. Iota Air created a new mission profile for the sizing mission which can be seen in Figure 2.2. A detailed description of each mission segment can be seen in Table 2.3.



**Figure 2.2: Sizing Mission Profile**

**Table 2.3: Sizing Mission Description**

<b>Mission Segment</b>	<b>Description</b>	<b>Altitude</b>	<b>Velocity</b>	<b>Range</b>
1	Warmup and Takeoff	0 ft	70 kts	2,348 ft
2	Climb	-	-	-
3	Cruise	10,000 ft	195 kts	250 nmi
4	Descend	-	-	-
5	Land	0 ft	58 kts	2,064 ft

### **C. Fielding and Maintenance**

The expected operations for the IA Mark 2 consist of an average of twenty flights per week averaging about 45 minutes per flight. Based on the designated operation the IA Mark 2 will have to operate about 780 hours per year. Flights can range from 135 nmi to 250 nmi depending on the type of mission being flown. The IA Mark 2 will be able to take off and land on runways with concrete or grass at a distance shorter than the required 2,500 ft. This aircraft was designed for quick boarding and egress procedures. The aircraft will also be able to be refueled quickly and returned to the sky in order to keep up with the on-demand services that operators are looking for. All systems and propulsion equipment will be able to be maintained and inspected as required by the CFR Part 23 regulations. The engine system will have a 1,800 flight hour time before overhaul. At the end of the cycle operators will need to follow the Lycoming overhaul manual before the IA Mark 2 propulsion system is ready to fly again.

Due to the on-demand nature of flights for the IA Mark 2, maintenance checks before each flight will be required. The airframe parachute system will need to be checked for each flight to ensure the best safety for passengers and crew. Airframe, fuel tanks landing gear and control surfaces will all be inspected before takeoff to ensure safe flying. Storage and routine maintenance checks are recommended for operators to keep the airplane clean and allow for regular engine inspection.

### III. SIZING ANALYSIS

#### A. Similarity Analysis

When designing an aircraft to maximize profits, it is important to look at similar aircraft and compare their specifications with IA Mark 2's specifications. The RFP suggested looking at aircraft such as the Piper PA-46 and Cirrus SR22. Along with those aircraft, Iota Air gathered information on other similar aircraft which can be seen in Table 3.1. Based on the IA Mark 2's crew to passenger ratio the Diamond DA-62 and Piper PA-34 are the closest aircraft to this design. A comprehensive list of similar aircraft can be seen in Table 3.1.

**Table 3.1: Similar Aircraft Comparison**

Aircraft	Crew/Passenger #	Wingspan (ft)	Length (ft)	Engine # /Type	Power (hp)	Cruise Speed (KTAS)	MTOW (lb)
Beechcraft Bonanza <sup>3</sup>	1/5	33.5	27.5	2/Piston	300	176	3,650
Cirrus SR-20 <sup>4</sup>	1/4	38.3	26.0	1/Piston	200	155	3,050
Cirrus SR22 <sup>5</sup>	1/4	38.3	26.0	1/Piston	310	183	3,600
Cessna 172 <sup>6</sup>	1/3	36.1	27.2	1/Piston	160	122	2,450
Cessna 182 <sup>7</sup>	1/3	36.0	29.0	1/Piston	230	145	3,100
Diamond DA-62 <sup>8</sup>	1/6	48.3	30.2	2/Piston	180	175	5,071
Piper PA-34 <sup>9</sup>	1/6	38.9	28.6	2/Piston	220	188	4,750
Piper PA-46 M600 <sup>10</sup>	1/5	43.2	29.7	1/Turboprop	600	274	6,000
<b>IA Mark 2</b>	<b>1/6</b>	<b>38.58</b>	<b>31.0</b>	<b>1/Piston</b>	<b>400</b>	<b>195</b>	<b>4,273</b>

#### B. Initial Sizing

Using refined sizing methods from Raymer<sup>11</sup>, Iota Air completed an initial sizing analysis with more accurate equations and key parameters. One important design consideration to notice is Iota Air's decision

to allocate for 6 total passengers. Iota Air decided to add the extra passenger seating in order to allow for more tickets to be sold per flight which will increase the maximum profit for operators.

Another important design feature for the IA Mark 2 was the engine selection. Initially, Iota Air chose the Continental TSIO-550-B for its low cost and weight. After completing the preliminary design for the IA Mark 1, Iota Air discovered that the power from the TSIO-550-B was insufficient for the required speed in the reference mission. In order to meet the requirement a new engine was chosen. The engine chosen was the Lycoming IO-720. This engine gave a power output of 400 hp which was sufficient to meet the RFP requirements. A detailed trade study on the two engines can be found in section V. Due to the selected Lycoming IO-720, Iota Air does not need to consider electric or hybrid propulsion systems. This decision was made due to large weight accommodation that would be necessary for the batteries modeled in the RFP.

A complete list of the parameters used in the initial sizing analysis can be seen in Table 3.2. The initial sizing parameters were chosen based on the RFP mission descriptions. Some parameters were required by the RFP but others were chosen based on the IA Mark 2's CONOPs. The rest of the parameters were estimated using Raymer or historical trends for general aviation aircraft.

**Table 3.2: IA Mark 2 Initial Sizing Parameters**

<b>Key Parameters</b>	<b>Value</b>	<b>Units</b>	<b>Source</b>
L/D max	17	-	Estimated
Cruise Range	250	nmi	Allowed RFP Excursion
Cruise Altitude	10,000	ft	Estimated
Cruise Velocity	180	KTAS	Required by the RFP
Takeoff Velocity	91	KTAS	Estimated
Landing Velocity	82	KTAS	Estimated
Loiter Velocity	100	KTAS	Estimated
Number of Engines	1	-	Estimated
Payload Weight	1,380	lb	Required by the RFP

Iota Air also created a Pugh matrix to narrow down specific aircraft design considerations. A Pugh matrix<sup>12</sup> is a useful tool for concept generation and selection based on a predetermined weighting method. Iota Air chose to look at five design considerations; weight, manufacturability, operating costs, project costs and aesthetics. These were decided as most important based on the RFP project description. After weighing each choice the sum of each component was calculated giving a score on which would be the best option out of all categories. Iota Air used a total weighting of 1 and broke the five design considerations into percentages based on their importance. Weight was chosen as the most important and given a 0.25 weighting. It was chosen because the goal of the IA Mark 2's design is to reduce the cost of the aircraft. The design components looked at were the empennage, landing gear, engine, number of engines and engine location. Using the weighting method described Iota Air decided that a fuselage mounted tail, tricycle landing gear and a single piston engine mounted on the nose would be the best design choice in order to keep aircraft costs low. The Pugh matrix used by Iota Air and can be seen in Table 3.3 with the chosen design configurations in bold.



**Table 3.3: Pugh Matrix**

Pugh Decision Matrix		Weight	Manufacturability	Operating Costs	Project Cost	Aesthetics	Total Score
<b>Component</b>	<b>Configuration</b>	<b>0.25</b>	<b>0.2</b>	<b>0.175</b>	<b>0.225</b>	<b>0.15</b>	
Empennage	T-Tail	4	8	7	5	5	5.7
	<b>Fuselage Mounted</b>	<b>7</b>	<b>9</b>	<b>8</b>	<b>5</b>	<b>5</b>	<b>6.825</b>
	Cruciform	6	5	3	5	4	4.75
	V-Tail	8	3	5	2	7	4.975
Landing Gear	<b>Tricycle</b>	<b>6</b>	<b>5</b>	<b>5</b>	<b>5</b>	<b>8</b>	<b>5.7</b>
	Tail-Wheel	7	5	6	5	5	5.675
Engine	Turbo-Prop	5	6	6	7	5	5.825
	<b>Piston</b>	<b>8</b>	<b>8</b>	<b>8</b>	<b>8</b>	<b>5</b>	<b>7.55</b>
	Hybrid	6	4	7	3	5	4.95
Number of Engines	<b>1</b>	<b>8</b>	<b>8</b>	<b>8</b>	<b>9</b>	<b>5</b>	<b>7.775</b>
	2	4	4	6	5	5	4.725
Engine Location	<b>Nose</b>	<b>8</b>	<b>9</b>	<b>8</b>	<b>8</b>	<b>8</b>	<b>8.2</b>
	Wing Mounted	4	7	6	6	7	5.85

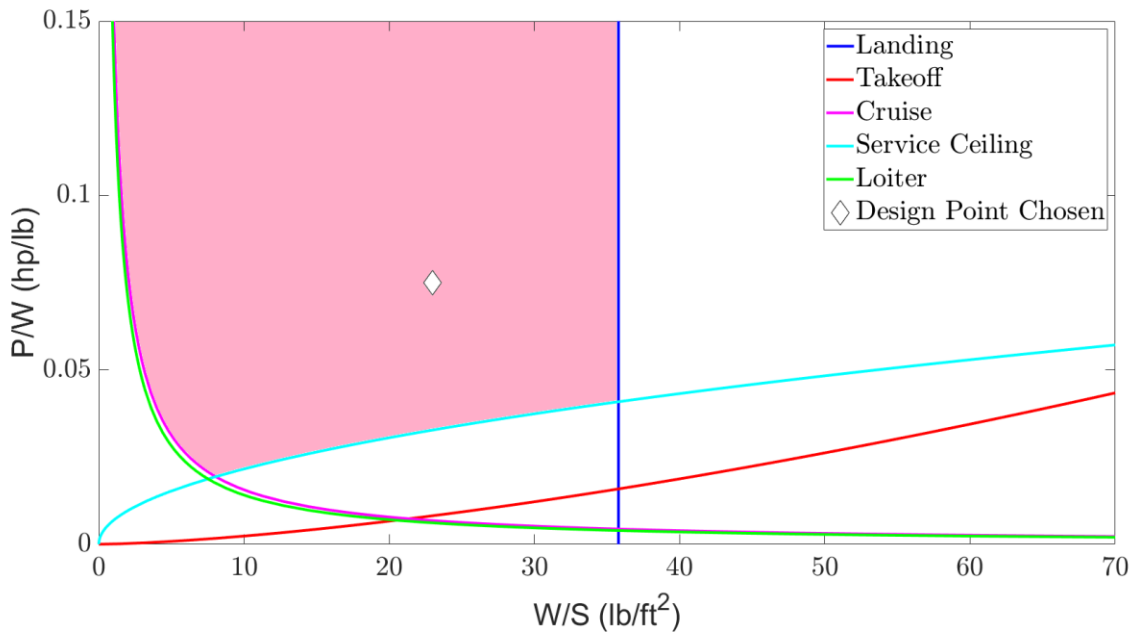
After completing the Pugh matrix and initial sizing, estimated design weights were calculated and compared to the mass properties calculations. The final mass properties calculations provided a larger weight than the initial sizing values. A comparison of IA Mark 2's estimated weights can be seen in Table 3.4.

**Table 3.4: IA Mark 2 Estimated Weights**

Description	Initial Sizing Value (lb)	Mass Properties Value (lb)
Maximum Takeoff Weight	4,102	4,273
Standard Empty Weight	2,386	2,714

### C. Constraint Analysis

With the maximum takeoff weight obtained in the refined sizing process, a constraint analysis was completed to find the required power loading in the valid design region. The result of the constraint diagram is shown in Figure 3.1. The design point we chose for the IA Mark 2 is shown in the plot within the shaded valid design region. This point corresponds to a power loading of 0.075 hp/lb and a wing loading of 22.97 lb/sq-ft. These values were calculated based on the MTOW of 4,273 lb, available power 320 hp and wing reference area of 186 sq-ft.



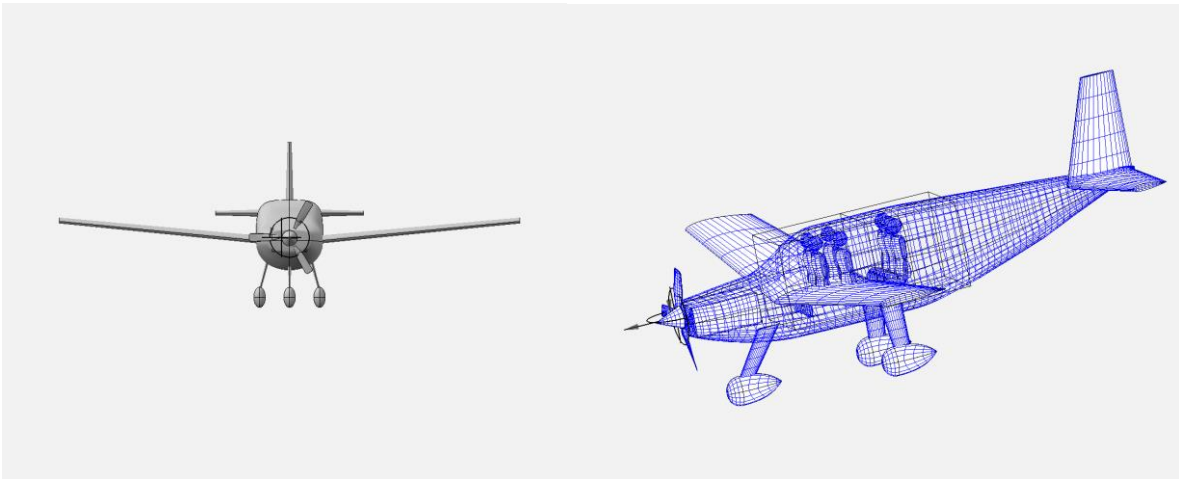
**Figure 3.1: Constraint Diagram**

## IV. CONFIGURATION

### A. Design Morphology

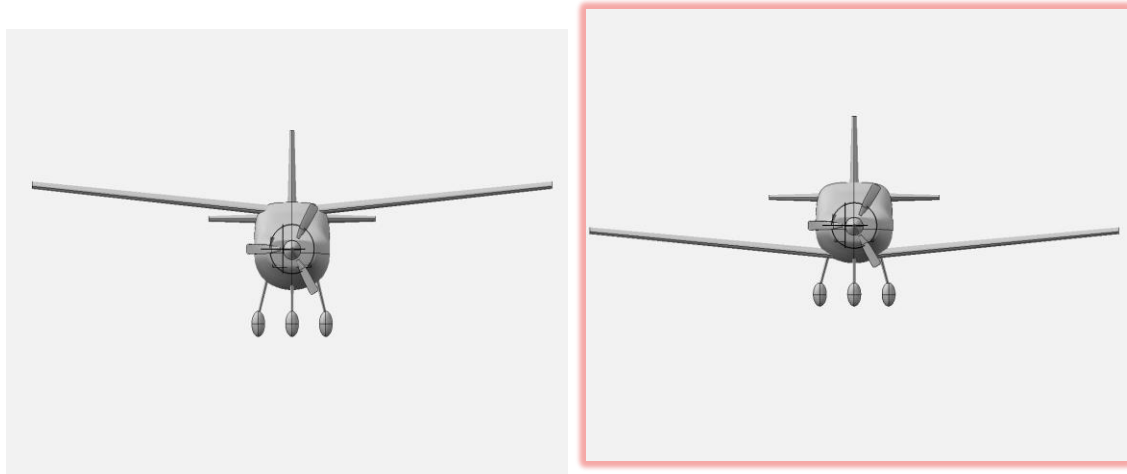
During the initial sizing process, Iota Air considered multiple design alternatives in order to maximize customer appeal while minimizing overall costs. The Pugh Matrix, found in Table 3.3, highlights the major design alternatives. The two main external geometry alternatives for the IA Mark 2 were placement of the wing and tail.

Table 3.3 features the three possible wing configurations for the IA Mark 2. High wings were considered for their ease of boarding and stability at low speeds. Mid wings were also considered for their balance and maneuverability. Finally, low wings were considered for their stability and maneuverability. It became evident very quickly during the design process that a mid-wing configuration would not be beneficial for the IA Mark 2. Using a mid-wing configuration would require cutting through the fuselage and cabin. Figure 4.1 presents the complications from using a mid-wing configuration.



**Figure 4.1: Mid Wing Visualization and Cabin Complications**

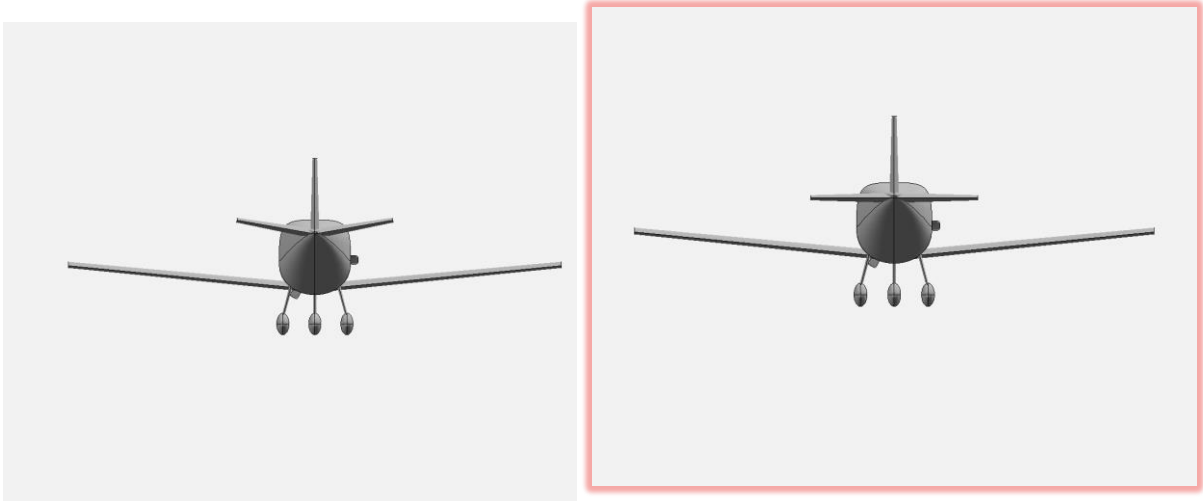
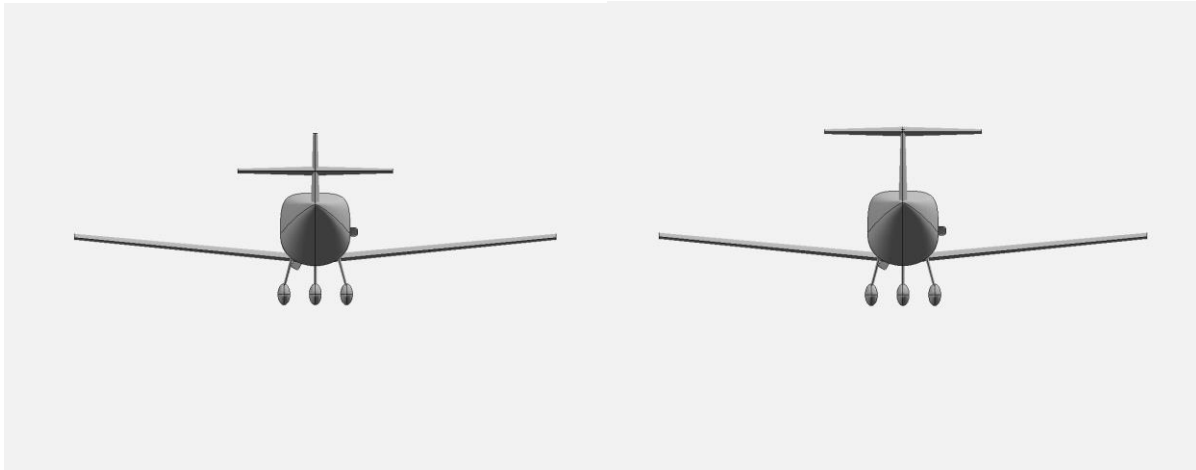
Once the mid wing configuration was ruled out, the only two alternatives left were either a high wing or a low wing. Low wings typically have better maneuverability than high wings, but high wings are usually more stable than their low wing counterparts. Figure 4.2 illustrates the high and low wing alternatives for the IA Mark 2.



**Figure 4.2: High Wing vs Low Wing Visualizations**

Ultimately, Iota Air chose to move forward with a low wing placement, highlighted in red in Figure 4.2, for the IA Mark 2 due to its increased maneuverability and lower operating and maintenance costs.

Iota Air also conducted a study for the tail placement of the IA Mark 2. Since maneuverability won out over stability when it came to the IA Mark 2's wing configuration, it was crucial to make up for it with the tail configuration. The four alternative tail configurations considered for the IA Mark 2 were a cruciform, T-tail, V-tail, or conventional tail. Figure 4.3 demonstrates the various tail placement considerations.



**Figure 4.3: Cruciform, T-tail, V-tail, and Conventional Tail Alternatives**

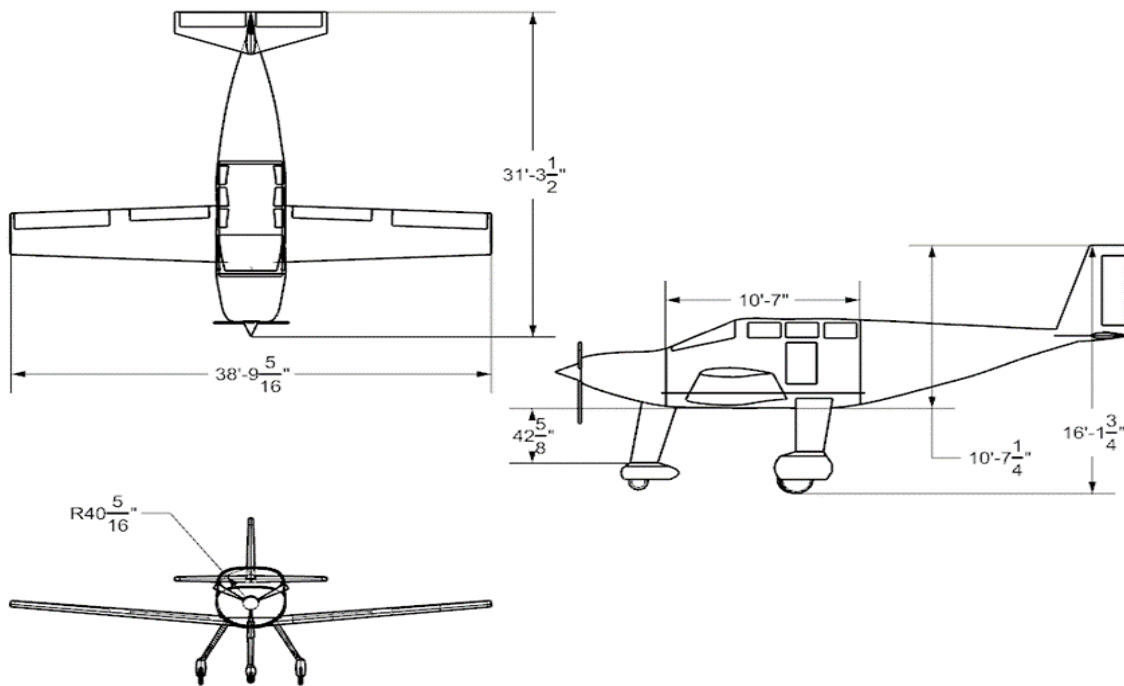
Iota Air chose the fuselage-mounted tail for the IA Mark 2, highlighted in red in Figure 4.3. The conventional tail was chosen for its stabilizing effects and the lower operating and maintenance costs.

## B. External Configuration

The final design for the IA Mark 2 is included in Figure 4.4. The dimensions of the IA Mark 2 are included in Figure 4.5.



**Figure 4.4: Final Design**



**Figure 4.5: Final Design Dimensions**

Major design parameters of the IA Mark 2 include a three-blade composite propeller with a single piston engine integrated into the nose of the aircraft. The aircraft has fixed tricycle landing gear and a low wing with a fuselage-mounted tail. The cabin is capable of comfortably seating up to six passengers. Table 4.1 highlights all of the major dimensions for the IA Mark 2.

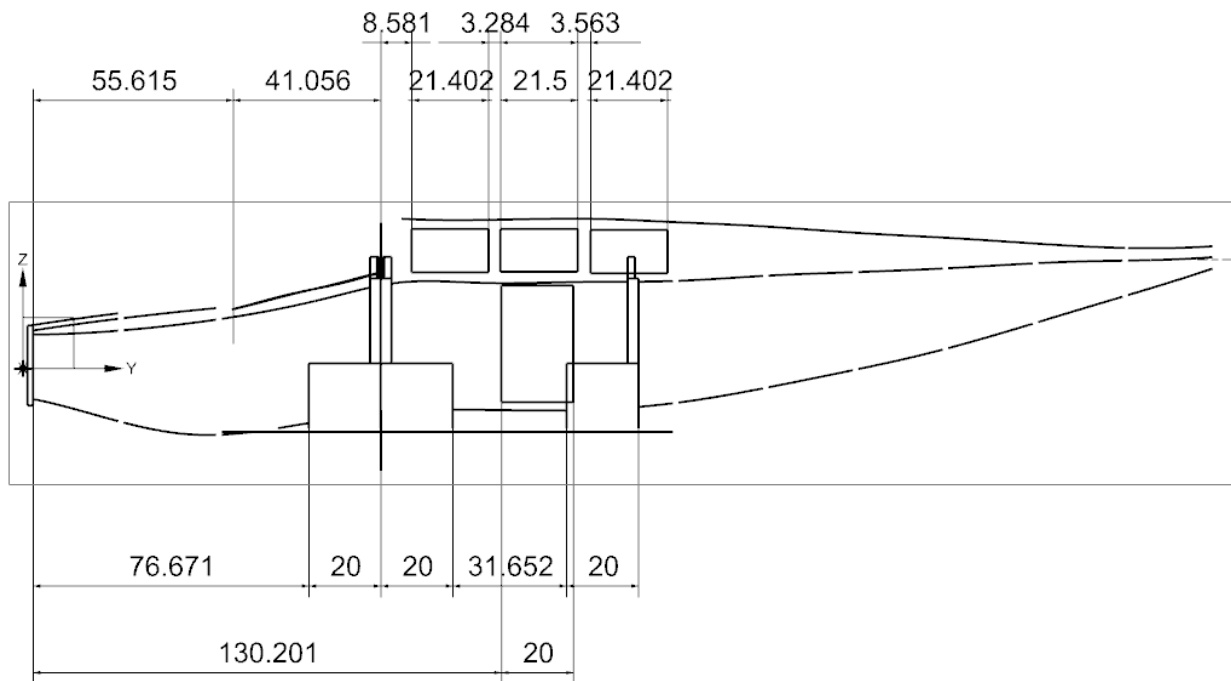
**Table 4.1: Major External Configuration Dimensions**

<b>Parameter</b>	<b>Dimension [ft]</b>
Neutral Point	11.8
Center of Gravity	11.5
Wing Area	186.0 sq ft
Wing Root Chord	5.67
Wing Tip Chord	3.97
Vertical Tail Root Chord	3.92
Vertical Tail Tip Chord	1.96
Horizontal Tail Span	12.31
Fuselage Length	27.62
Fuselage Width	6.0
Fuselage Height	4.92
Landing Gear Height	4.36

### **C. Interior Design**

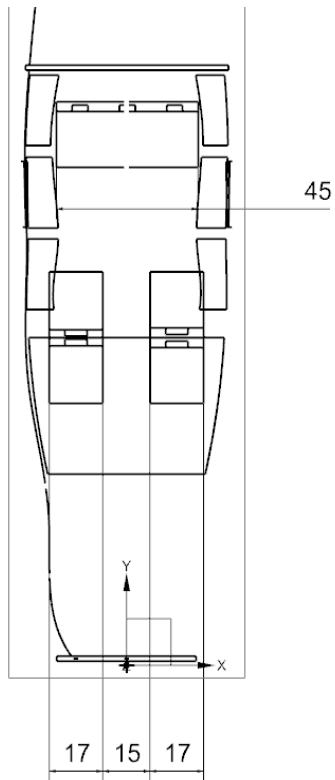
The IA Mark 2 was designed for thin haul transport and air taxi for routes less than or equal to 250 nmi. To maximize the profits for operators, Iota Air designed three rows of seats with a 2-2-3 configuration in the cabin. The IA Mark 2 can take up to six passengers and one pilot. The cabin interior has a height of 4.9 ft, width of 5.2 ft and length of 10.6 ft. Four 17 inch wide seats will be implemented in the first and second rows while three 15 inches wide seats make up the third row. The width of the seats is similar to jetliner economy class such as those on an A330-300<sup>13</sup>. The seats in the second row face the rear of the aircraft to

create extra legroom for passengers in the second and third row. Across-the-shoulder seat belts are employed for the IA Mark 2 to ensure the safety of passengers. The aisle between the two seats in second row allows the pilot and first row passenger to enter and exit the cockpit easily. There will be one door located on the port side of the cabin to make boarding convenient. The luggage compartment is located behind the third row with a width of 3.75 ft, length of 0.8 ft and height of 4 ft. The size of the luggage compartment can accommodate up to 6 bags with a size of 22x14x9 inches. It is approximately the same size as the carry-on luggage allowed by mainstream airlines. The third row seats can be folded forward to allow access to the luggage compartment. The detailed seat configuration dimensions for the IA Mark 2 are illustrated in Figures 4.6 and 4.7. The IA Mark 2 has a panorama forward window to provide good vision for the pilot. The pilot view angles are shown in Figure 4.8. In Figure 4.9, a furnished cabin rendering is shown. Composite plastic, a transparent material that is lightweight and malleable, makes up the windows for the IA Mark 2. The window material was picked to prevent foreign object debris from damaging the aircraft such as bird strikes.

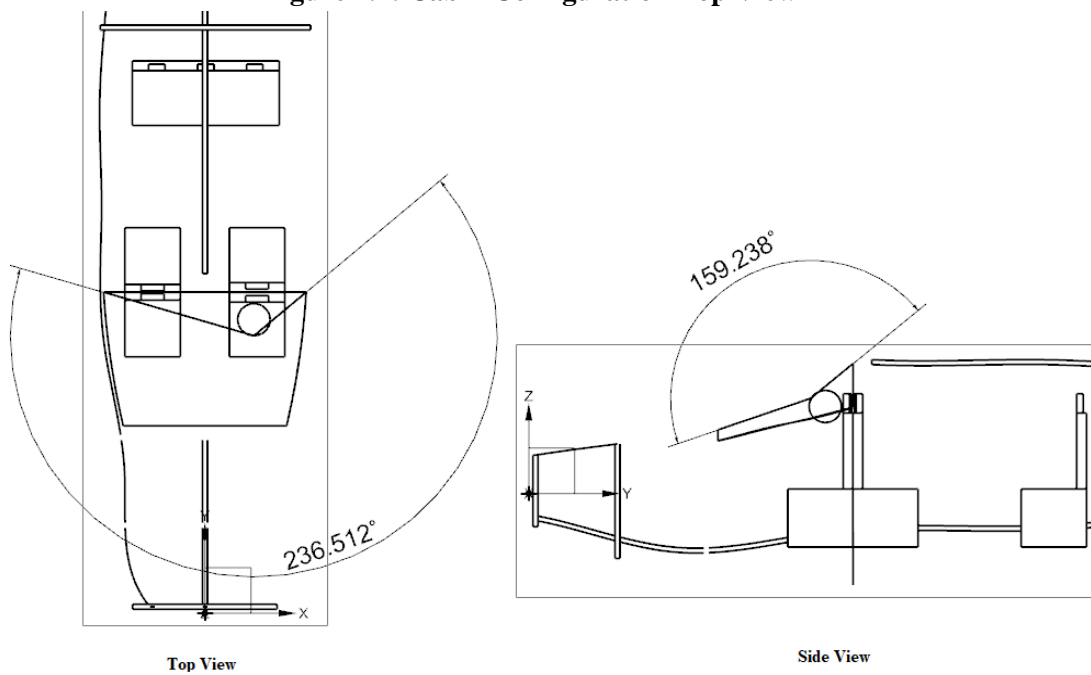


**Figure 4.6: Cabin Configuration Side View**





**Figure 4.7: Cabin Configuration Top View**



**Figure 4.8: Pilot Viewing Angles**



**Figure 4.9: Cabin Design Rendering**

#### **D. Trade Study**

One of the major decisions for the external configuration of the IA Mark 2 was the wing placement. Historically, for propeller-driven aircraft of a similar size, the wings are either high or low. For comparison, the Cirrus SR22 has a low wing, whereas the Cessna 172 has a high wing. Both aircraft have tricycle landing gear, single piston engines mounted in the nose, and fuselage-mounted tails. The only major external configuration difference between the two are the wings.

Table 4.2 highlights the major performance differences between the two aircraft. Iota Air looked extensively into both the Cessna 172 and the Cirrus SR22 when conducting the initial similarity analysis. After completing the similarity analysis, Iota Air determined what type of external configuration would work best for the IA Mark 2.

**Table 4.2: Cessna 172<sup>6</sup> and Cirrus SR22<sup>5</sup> Comparison**

<b>Aircraft:</b>	<b>Cessna 172</b>	<b>Cirrus SR22</b>
Wing Placement	High	Low
Crew/Passenger Number	1/3	1/4
Fuselage Length	27.2 ft	26.0 ft
Wingspan	36.1 ft	38.3 ft
Standard Empty Weight	1,691 lb	2,269 lb
MTOW	2,450 lb	3,600 lb
Total Flight Range	696 nmi	1,050 nmi

The fuselage length and wingspan of the two aircraft are very similar. The maximum takeoff weights and maximum range varied drastically. The Cirrus SR22 has a standard empty weight and maximum takeoff weight similar to the weight estimates of the IA Mark 2. High wings have a greater stabilizing factor than low wings, but the Cirrus SR22, which is a larger and heavier aircraft than the Cessna 172, performs just as well if not better with its low wings. Low wings are more maneuverable than high wings, but the lighter Cessna 172 needs the stability of a high wing more than the maneuverability of a low wing. The IA Mark 2, which is even heavier than the Cirrus SR22, will benefit more from the increased maneuverability from low wings than the increase in stability a high wing would offer. Based on that comparison, Iota Air made the decision to have the IA Mark 2's wing placement similar to the Cirrus SR22.

## V. PROPULSION

### A. Overall Propulsion System

#### 1. Engine Requirements

During initial sizing, preliminary calculations concluded that the maximum power required for the reference mission was 250 hp. Based on initial sizing calculations and keeping cost minimization in mind, Iota Air chose a reciprocating engine as the main power plant for the IA Mark 2. Piston engines are more than capable of achieving the power requirements, and they are significantly more cost effective than their turboprop or turbofan counterparts. From there, an engine similarity analysis was performed, and Table 5.1 highlights the significant findings of possible engines for the IA Mark 2.

**Table 5.1: Initial Reciprocating Engine Comparison**

Engine	Dry Weight [lb]	Power Output [hp]	P/W [hp/lb]
Continental IO-550 <sup>14</sup>	430	300	0.7
Lycoming TIO-540 <sup>15</sup>	438	300	0.68

Based on the similarity analysis, Iota Air initially adopted the Continental TSIO-550 piston propeller engine for the IA Mark 2. It had a maximum available power of 350 hp, so it could easily achieve the 250 hp power requirement from the initial sizing calculations.

As progress continued on the design of the aircraft, it was soon apparent that the maximum horsepower the Continental TSIO-550 could achieve was just shy of the power required to meet the cruise requirement of 180 KTAS. The IA Mark 2 would need a power allowance of 400 hp to meet the RFP requirement.

Based on this new information, Iota Air scrapped the Continental TSIO-550 and conducted a new similarity analysis based on the new engine requirements. 400 hp was on the higher end but still in the realm of possibilities for reciprocating engines, so the analysis was still focused on piston engines in order to minimize both production costs and project costs. Table 5.2 highlights the findings of that secondary comparison.

**Table 5.2: Secondary Reciprocating Engine Comparison**

<b>Engine</b>	<b>Dry Weight [lb]</b>	<b>Power Output [hp]</b>	<b>P/W [hp/lb]</b>
Continental IO-550 <sup>14</sup>	430	300	0.7
<b>Lycoming IO-720<sup>16</sup></b>	<b>593</b>	<b>400</b>	<b>0.67</b>

After the second similarity analysis, Iota Air determined that the Lycoming IO-720 reciprocating engine would be the engine of choice for the IA Mark 2. Its available 400 hp covered the performance power requirements, and its similar size to the Continental TSIO-550 meant no major dimensions needed to change to fit the new power plant.

## *2. Configuration*

Due to the fact that the IA Mark 2 runs on a reciprocating engine and is a propeller-driven aircraft, the two alternatives for engine placement were either a pusher or a tractor. For a pusher, the engine and propeller are mounted at the back of the aircraft, whereas for a tractor, they are mounted at the front. The industry standard for most commercial aircraft is a tractor configuration. In order to minimize operating costs, Iota Air opted to follow suit with the tractor configuration.

## *3. Safety Considerations*

Keeping in compliance with the Code of Federal Regulations Part 23.1191, the IA Mark 2 will have a firewall protecting the cockpit and the cabin from the engine block. In the case of a fire or an engine emergency, the cabin will be protected and, “resist flame penetration for at least 15 minutes,” as the regulations require.

In the case of an emergency engine out situation, if the aircraft has not left the ground yet and still has enough leeway to do so, the engine should be manually shut off immediately and the brakes applied to come to a safe stop. If the aircraft is already in flight, then one of two possibilities remain: restart the engine or deploy the emergency parachute. If time and altitude permits, and if the engine is not damaged or in any type of emergency state, then an engine restart should be attempted. The aircraft should be pitched nose-down so the propeller can start accelerating and ‘windmilling’ to coax the engine to restart. If the engine is

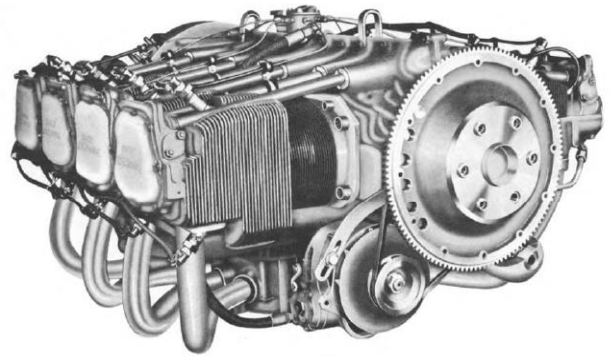
damaged or an inflight restart is otherwise not possible, then the emergency airframe parachute system should deploy and the pilot should initiate emergency landing procedures.

## B. Power Plant Selection and Features

Once it was concluded that Iota Air would be moving forward with the Lycoming IO-720 for the IA Mark 2, the next step was to rerun the performance data for the new engine. As aforementioned, the Lycoming IO-720 is a piston-propeller engine, and the specifications provided by Lycoming for the IO-720 are included in Table 5.3.

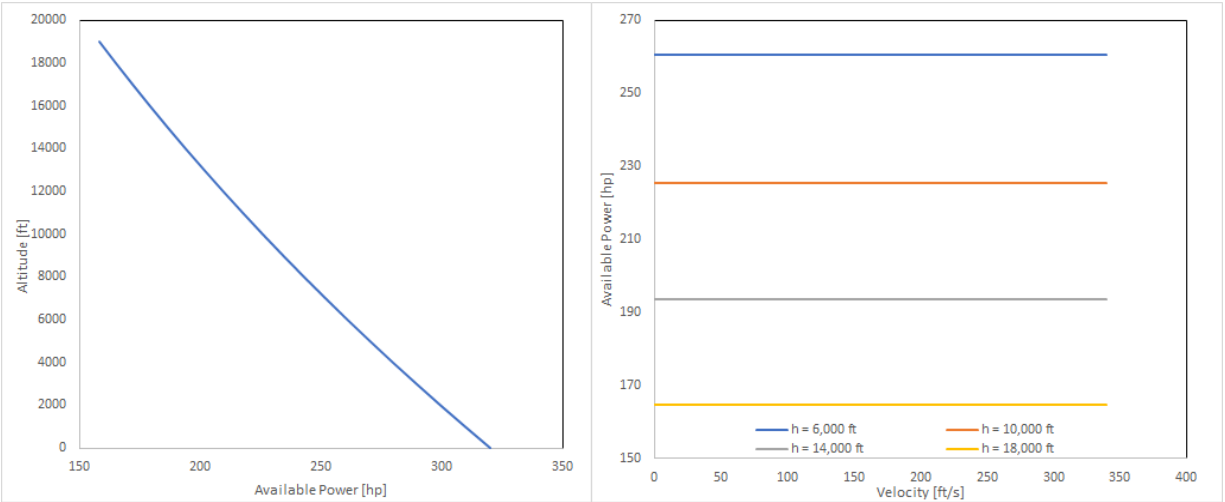
**Table 5.3: Lycoming IO-720<sup>17</sup> Specifications**

Engine Parameter	Value
Shaft Power	400 hp
Maximum Thrust Available	1,800 lb
Maximum Power Available	320 hp
Dry Weight	597 lb
Length	46.47 inches
Width	34.25 inches
Height	20.63 inches



**Figure 5.1. Lycoming IO-720 Engine<sup>16</sup>.**

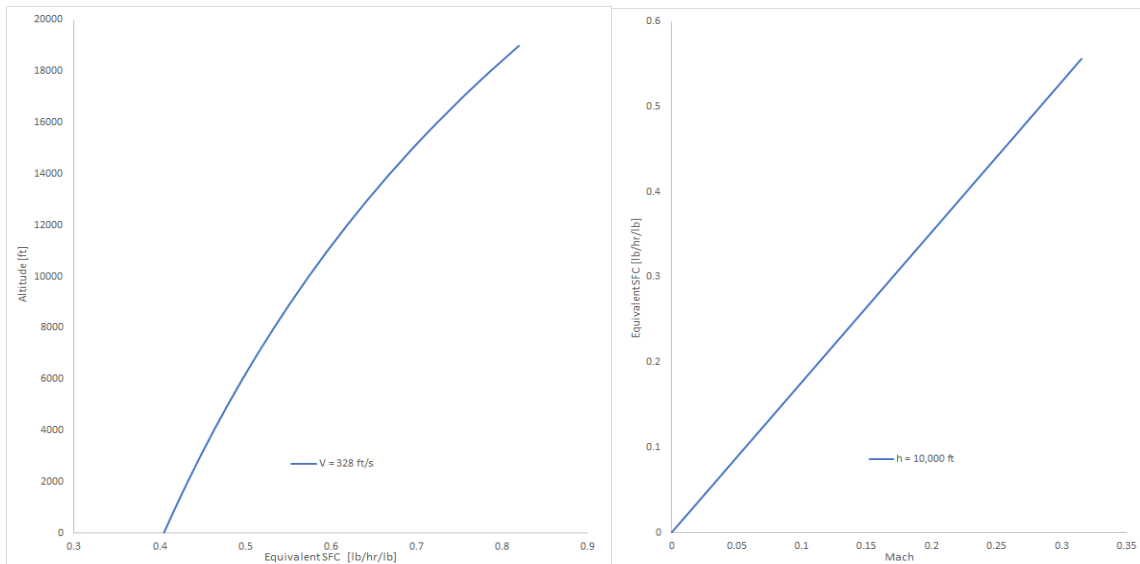
Performance data for the engine, obtained from the Type Certification Data Sheet for the Lycoming IO-720<sup>17</sup> and Lycoming's Operating Manual<sup>16</sup>, are included in Figures 5.2 and 5.3.



**Figure 5.2: Available Power vs Altitude and Velocity**

The available power versus altitude was calculated using equations from Raymer<sup>11</sup> and McCormick<sup>18</sup>. The equation for brake horsepower as a function of altitude was given by Raymer<sup>14</sup>. The power available as a function of altitude was the brake horsepower multiplied by the propeller efficiency.

McCormick<sup>18</sup> states that the available power for propeller-driven aircraft remains about constant with respect to velocity as altitude remains constant. The thrust available would decrease as velocity increased, but the power available remains constant. Figure 5.3 demonstrates how the power available remains constant at constant altitudes over a range of velocities and therefore Mach numbers, but it decreases as altitude increases.



**Figure 5.3: SFC vs Altitude and Mach Number**

SFC is normally a parameter used to define jet engines, but Raymer<sup>14</sup> gives the relationship between brake specific fuel consumption and equivalent specific fuel consumption. The brake specific fuel consumption is defined as the rate at which the engine is consuming fuel over the brake horsepower being delivered by the engine. Lycoming<sup>16</sup> cites the IO-720's fuel consumption as a function of the rated horsepower, and the calculated BSFC values are included in Table 5.4. Once the BSFC values are known, equivalent SFC is then the BSFC multiplied by the velocity and a conversion factor. BSFC is altitude dependent and not velocity dependent, while equivalent SFC is dependent on both altitude and velocity.

**Table 5.4: Lycoming IO-720 Fuel Consumption**

<b>Power Level</b>	<b>BHP [hp]</b>	<b>Fuel Consumption [gal/hr]</b>	<b>Fuel Consumption [lb/hr]</b>	<b>BSFC [lb/hr/hp]</b>
<b>Rated, 100%</b>	<b>400</b>	<b>33.9</b>	<b>217</b>	<b>0.543</b>
Cruise, 75%	300	23.3	149	0.497
Cruise, 65%	240	16	102	0.425

For the equivalent SFC calculations, the assumed BSFC was at maximum rated power. Figure 5.3 demonstrates how, when velocity is held constant at cruise speed, the equivalent SFC varies with altitude, and how, when the altitude and therefore the brake specific fuel consumption is held constant at maximum rated power, the equivalent SFC varies with speed at an altitude of 10,000 ft.

### *1. Exhaust Design*

Similar to the Cirrus SR22<sup>5</sup>, the IA Mark 2 will have two exhaust exit pipes, one on either side of the leading landing gear. This configuration allows for minimal exhaust and fuel line contact; the exhaust leaves the system from the bottom of the engine, and the fuel enters at the rear of the engine. That way, in the case of an emergency, the hot exhaust air is nowhere near the fuel. The exhaust will also exit in front of the fire wall, so again, in the case of an engine emergency, the hot exhaust will not be able to penetrate the cabin or the cockpit. The exhaust will exit at the underside of the aircraft as to not disturb the airflow over the wings.



## C. Propeller Selection

After extensive research on the topic, it was found that in order for a propeller to work well and efficiently, it has to be engineered to fit well with and complement the engine of the aircraft. For that reason, Iota Air chose to match the Lycoming IO-720 engine with a propeller that has already been demonstrated to work well with it; the Hartzell HC-A3VK-2A<sup>19</sup> propeller. The sizing, specifications, and performance of that propeller are in Table 5.5.

**Table 5.5: Sizing, Specifications, and Performance of HC-A3VK-2A Propeller<sup>19</sup>**

Propeller Design Parameter	Value
Propeller Selection	HC-A3VK-2A
Number of Blades	3
Blade Diameter	80.6 inches
Hub Diameter	15.5 inches
Propeller Weight	94 lb
Propeller Efficiency	0.8
Maximum Rotation Speed	2,650 RPM

### 1. Cone Design

The hub that mounts the propeller and allows for air intake, also known as the nose cone, is another parameter that is incredibly specific to each propeller and engine combination. For the Lycoming IO-720 engine and the HC-A3VK-2A propeller, the dimensions for the hub are included in Table 5.6. The IA Mark 2 was modeled following the prescribed dimensions.

**Table 5.6: Propeller Hub Dimensions<sup>20</sup>**

Part	Dimension [inches]
Hub Length	18.18
Hub Diameter	15.5

## **D. Battery and Electric Motor Discussion**

During the initial sizing analysis for the IA Mark 2, an electric propulsion system was briefly considered. Given the specifications for the requirements of the battery by the RFP<sup>1</sup>, it was quickly realized to be largely less efficient than the reciprocating engine.

The RFP<sup>1</sup> cites the maximum allowance for specific energy to be 285 W-hr/kg, with the pack specific power being defined as  $P \times 85 \text{ s}$ . Using the same power available as the Lycoming IO-720 engine, 400 hp, the entire weight of the electric propulsion system would be approximately 3,268 lb. The maximum weight of the reciprocating engine system, including both the engine and the maximum fuel capacity, was calculated to be 1,093 lb. The electric propulsion system would have been about three times heavier than the reciprocating engine system, and given the minimum RFP costs for the system, it would have also been much more costly than the piston engine. The goal of the IA Mark 2 was to largely decrease the overall cost, and at this time with the current technology available, an electric propulsion system would not aid in that effort.

## **E. Fuel System**

The first consideration for the fuel system of the IA Mark 2 was placement of the fuel tanks. Since the IA Mark 2 was designed to be a comparatively small aircraft to other general aviation vehicles, the two main alternatives for types of fuel tanks were either discrete tanks or integrated tanks. The estimated fuel weight for the IA Mark 2 was calculated to be about 500 lb. This would be a very large, concentrated mass at the nose of the aircraft. If Iota Air chose to implement discrete tanks, it would also shift the center of gravity too far aft. For those reasons, Iota Air decided to move forward with the decision to have the fuel weight split between two fuel tanks, one in either wing, otherwise known as a wet wing. Since the volume allowed for it, bladders will be used within the wing to store the fuel. Bladders are removable rubber bags stored within a cavity of the aircraft; for the IA Mark 2, they will be stored in cavities within either wing. Bladders only offer about 90% of their total volume to fuel storage, but they are preferable to an integrated tank due to their removability and their self-sealing properties. The bladders will act as another safety

precaution; during the event of an emergency when the wings and therefore the fuel tanks are struck and severed, the self-sealing properties of the bladders would prevent large fuel losses and fire hazards.

Since the fuel will be stored a distance away from the engine in the wings, fuel lines will have to run underneath the cabin of the fuselage to reach the nose of the aircraft. Similarly, exhaust lines from the engine will run under the nose, within the skin of the aircraft, through exhaust pipes to exit near the front wheel of the landing gear. These two separate line systems will have to be spaced fairly far apart and parallel to one another so as to not allow the high temperature exhaust to affect the fuel temperature before it reaches the engine.

The IA Mark 2's engine is a reciprocating engine integrated into the nose of the aircraft, therefore, no nacelle will be used and no resulting inlet pressure losses or inlet area designs need be considered. The propeller and engine combination specifications already take into consideration air inlet routing and installation.

## **F. Trade Study**

The Piper PA-24 Comanche family, which the Lycoming IO-720 was specifically built for, also had a number of other engine and propeller configurations. The Comanche 400<sup>21</sup> debuted the IO-720, but its predecessors flew with other Lycoming engines, as well. For instance, the Comanche 260<sup>22</sup> flew with the Lycoming O-540. The two planes were advertised as similar aircraft to a similar customer base, but the 400 was advertised as an upgrade to the 260. Table 5.7 highlights the various upgrades and how the bigger, higher powered engine affected the Piper Comanche.

**Table 5.7: Piper Comanche 260<sup>22</sup> vs Piper Comanche 400<sup>21</sup>**

<b>Aircraft:</b>	<b>Piper Comanche 260</b>	<b>Piper Comanche 400</b>
<b>Engine</b>	Lycoming O-540	Lycoming IO-720
<b>Maximum Power Output</b>	260 hp	400 hp
<b>MTOW</b>	2,900 lb	3,600 lb
<b>Standard Empty Weight</b>	1,700 lb	2,110 lb
<b>Crew/Passenger Capacity</b>	1/3	1/3
<b>Cruise Speed</b>	142 KTAS	185 KTAS
<b>Range</b>	950 nmi	1,200 nmi

The only structural change from the Piper Comanche 260 to the Piper Comanche 400 was a stronger tail; the rest of the planform and the exterior are identical between the two Comanches. Therefore, it is a safe comparison to make between the two planes how a different engine with more available horsepower can truly affect the performance of the Comanche.

With the Lycoming IO-720 engine instead of the Lycoming O-540, the range increased as well as the cruise speed; Comanches could fly farther distances in less time with the more powerful engine. Similar to the Comanche 400, Iota Air focused on designing the IA Mark 2 to fly longer distances in a shorter flight time, which is why the Lycoming IO-720 was chosen.

## VI. AERODYNAMICS

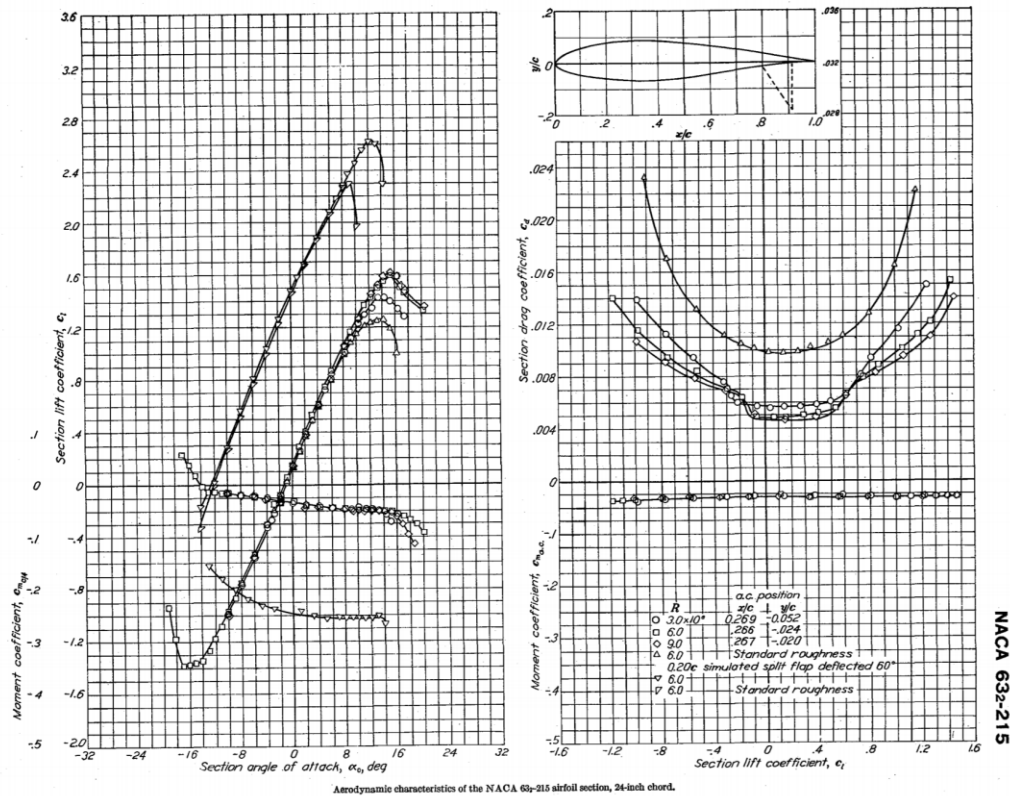
### A. Airfoil Selection

With a MTOW of 4,273 lb and a wing Reynolds number of  $8 \times 10^6$  at cruising conditions, the total required lift coefficient to maintain steady level flight is 0.24. Airfoil selection to achieve this goal began with studies of the earliest regularly categorized airfoils developed by NACA in their first studies of airfoil shapes. For the IA Mark 2, the NACA 2412 is the benchmark against which other airfoils can be compared to evaluate lift, drag, and moment characteristics. The other airfoils taken into consideration included a range of NACA 5 and 6 series airfoils, several NASA natural laminar flow airfoils and the Wortmann FX 63137. The 6 series was considered because it was the result of NACA's initial attempts into designing airfoils with as much laminar airflow over the chord as possible. The laminar airflow would seek to provide lower drag at a range of desired lift coefficients and has found success in general aviation aircraft such as the Bellanca Skyrocket II, an aircraft with a design similar to the IA Mark 2. More advanced techniques were employed to develop the Natural Laminar Flow airfoils also considered in airfoil selection. Although they were not as popular, they sought to improve upon the NACA 6 series airfoils.

Though the 4 digit NACA airfoils were largely a result of well-informed trial and error, the performance of the NACA 2412, a cambered, twelve percent thick member of the family, still provided sufficient lift for the IA Mark 2 at an angle of attack within 0 to 2 degrees at cruise. As such it serves as a good comparison to later airfoils.

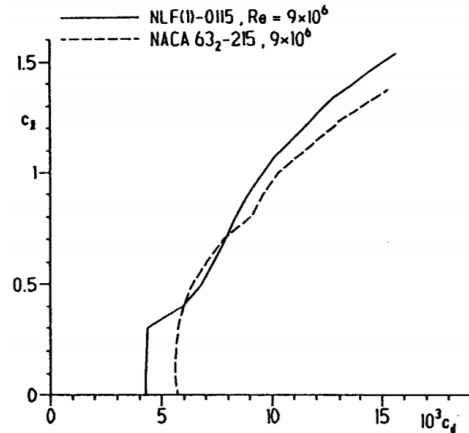
The 6 digit NACA airfoil of similar capabilities is represented by the NACA 63215. Moving on from heavily empirical design methods of the 4 digit airfoils, the 6 series aimed to design the shape of the airfoil based on desirable pressure curves and characteristics. With 60 counts of wing drag at a lift coefficient of 0.3 there is an improvement over the NACA 2412 of 20 counts of drag which translates to 31 lb of reduced drag force at cruise conditions. Though the airfoil has a much lower drag in the laminar design range, the range itself is limited and these earlier airfoils were particularly susceptible to contamination or

manufacturing limitations. Attempts to address these issues were later made in the design of NASA's Natural Laminar Flow airfoils.



**Figure 6.1: Empirical Data of NACA 63-215** <sup>23</sup>

The NASA NLF 0115 was chosen due to its similarity in performance with the NACA 63215 and the NACA 23015 that served as design goals in terms of lift characteristics and drag. Though other airfoils were designed for higher lift coefficients like the NLF 0215, 0414, and 0416, the NLF 0115 best fits the lift needs of the IA Mark 2 while maintaining a low drag. According to the report on the NLF0115<sup>24</sup>, the airfoil was designed for a cruise Reynolds number of  $9 \times 10^6$  and a landing at  $4 \times 10^6$  which matches the design criteria of the IA Mark 2. Although the design of this airfoil sought to preserve the low drag characteristics of earlier NACA airfoils, the Cl range of laminar flow has been extended while preserving the low drag and pitch characteristics of the NACA airfoils it was based upon. Even with contamination, the airfoil is predicted to lose only 11% of its Clmax as opposed to the NACA 23015's 14% loss which would mean the wing could remain effective even in adverse conditions.



**Figure 6.2: Theoretical Comparison of NLF 0115 and NACA 63-215<sup>24</sup>**

Also available to choose based on usage in the similar Diamond aircraft was the Wortmann FX 63137. The highly cambered Wortmann airfoil however provided far too much lift at 0 degrees angle of attack as well as nearly 4 times the moment coefficient of the other airfoils which requires more trim to balance which would result in penalties in drag.

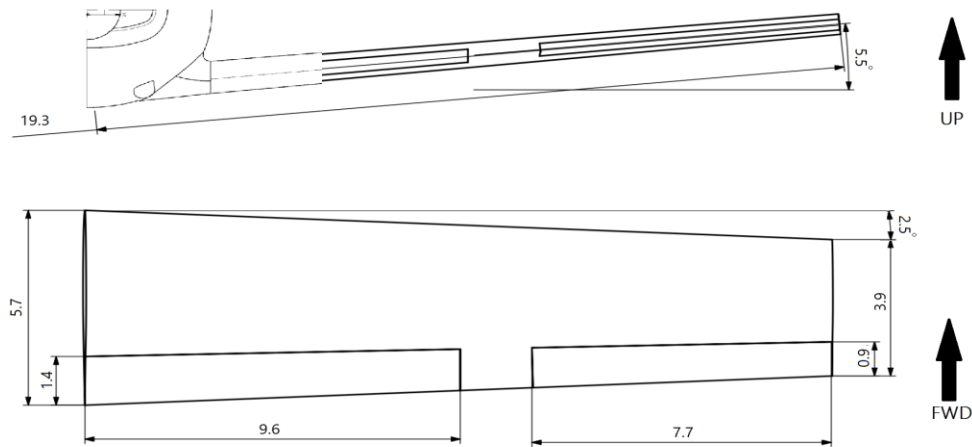
## **B. Wing Design**

Based on constraint analysis of takeoff, landing, and cruise, the wing planform area was determined to be 186 ft<sup>2</sup> which sets a wing loading of 23 lb/ft<sup>2</sup>. This places the design point close to the far edge of the design space while maintaining extra room for unexpected additional loads. Increasing the wing loading in this manner ensures that there is not an excess in wing area that would need to be supported by excess structural weight which would be detrimental to the overall range efficiency of the aircraft.

With the area of the wing determined, the best aspect ratio for the wing had to be determined weighing the benefits of efficiency with the structural demands an increased aspect ratio would imply. The best aspect ratio was then found to be 8 as the potential gain in induced drag performance does not diminish through an aspect ratio of 10. Structural weight, however, increases with aspect ratio and as such becomes a limiting factor to the benefits of an increased aspect ratio.

Beyond adjustments to the aspect ratios, modifications to the taper ratio may also seek to reduce the lift induced drag by approximating an elliptical lift distribution across the span of the wing. A drawback to this

modification, however, is an increasing tendency for the wing tips to reach their  $C_{L,Max}$  and stalling before the root does. This reduces the controllability of the aircraft during stall conditions which can be dangerous. Based on these tradeoffs, a taper ratio of 0.7 was found to be the best option. At a taper ratio of 0.7, the span wise position of the peak  $C_l$  occurs near the middle of the wing which would not cause the tip to stall before the rest of the wing. This reduces the need for modification of the wing sections beyond chord length which could reduce manufacturing complexity.

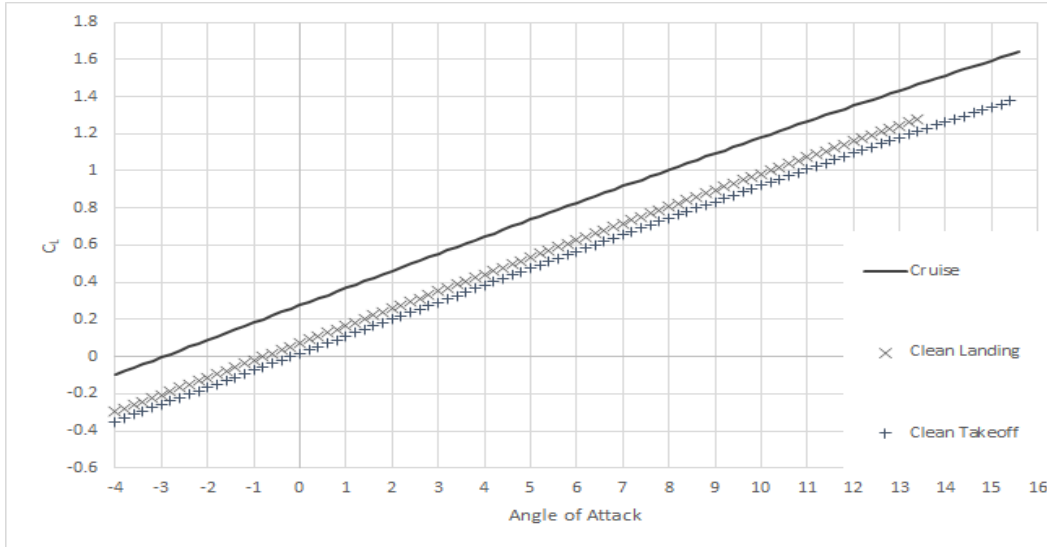


**Figure 6.3: Wing Planform Design with Control Surfaces (ft)**

### C. High-lift System

In order to safely land and takeoff within the RFP requirements<sup>1</sup>, the performance of the IA Mark 2 dictates a required  $C_{L,max}$  of at least 1.3. Due to the elevator deflection necessary for a stable and controlled landing, however,  $C_L$  during a landing Reynolds number of 3 million would decrease to 1.0 just before stall at an angle of attack of 10 degrees. An increase in  $C_L$  of 0.3 is necessary then to maintain the aircraft landing required by performance. Hamburg<sup>25</sup> shows that plain flaps would be able to provide a  $C_{l,max}$  increase of up to 0.8 which exceeds the requirements of the IA Mark 2. A 2D analysis in Javafoil verifies that a plain flap spanning 25% of the chord deflected by 30 degrees provides a  $C_l$  max increase of almost 0.9. Given this information, a flap of the same dimensions covering 50% of the wing span should be sufficient for performance while allowing room for the ailerons.





**Figure 6.4: Cl Alpha Plots**

## D. Drag Buildup

A major contribution to the total drag of the aircraft, parasitic drag ( $C_{d0}$ ), describes the drag without contributions from either lifting or trimming forces. The components under consideration include the wing, fuselage, tail, cooling and landing gears.

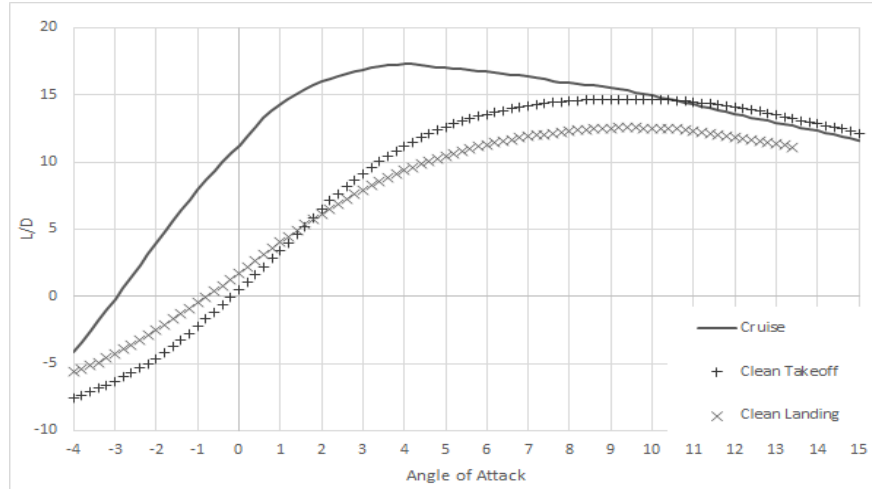
**Table 6.1: Parasitic Drag Build Up**

Component	$C_{d0}$	Swet	FF equation	FF	Reynolds ( $10^7$ )	Q	$L_{ref}$	%Total
Wing	0.01026	31.38	DATCOM	1.36	0.79	1.1	1.458	35.7
Fuselage	0.00757	35.66	Torenbeek	1.26	4.52	1	8.451	26.4
Horizontal Tail	0.00245	6.32	DATCOM	1.58	0.52	1.05	0.971	8.5
Vertical Tail	0.00119	3.04	DATCOM	1.58	0.5	1.05	0.929	4.1
Landing Struts (x3)	0.00131	0.93	DATCOM	1.68	0.18	1	0.345	4.5
Landing Pants (x3)	0.00121	1	Torenbeek	1.73	0.54	1	1.001	4.2
Cooling	0.00381	NA	McCormick	-	-	-	-	13.7
Total	0.02779	78.33	-	-	-	-	-	-

The wetted surface areas which were given by OpenVSP exclude the surface areas of intersecting bodies which ensures some level of accuracy in the following calculations. The form factors calculations were based on equations available in OpenVSP<sup>26</sup> that erred towards conservative higher drag predictions with the landing gear struts represented as wing sections. Reference lengths that defined the Reynolds numbers were defined as mean area weighted chords for wings and tip to tip lengths for pod shapes. Laminar flow has been assumed to be nonexistent on all surfaces. Addition of the 70% chord section of laminar flow to the main wing reduces the drag coefficient by around 8 counts. The laminar flow contribution, however, has not been included in the table for the most conservative estimate as factors that may disturb the laminar flow such as wing contamination is not reliably predictable. Interference values (Q) were all gathered from Raymer<sup>11</sup>. Efforts were made to smoothly fillet the wing body intersection and that has been reflected in the chosen interference factor of the wing of 1.1. Cooling drag has also been approximated in Raymer<sup>11</sup> as taking 10% of the power which given the cruise conditions gave 3.8 counts of drag.

The different drag values for different flight conditions, however, depend on the efficiency of the wing often quantified by the Oswald's efficiency factor. According to Hamburg<sup>27</sup> a conservative estimate of  $e$  based on aircraft with similar taper and aspect ratio gives an average total aircraft value of 0.8. This would mean that the total induced drag during cruise would add an additional 28.6 counts of drag giving the total cruise drag to be conservatively estimated at 306.6 counts. This value is 57 counts above the estimation given by Raymer's equivalent skin friction method<sup>11</sup> that is based on historic averages.

## E. Aerodynamic Performance



**Figure 6.5: L/D vs Angle of Attack of Three Flight Segments**

Three distinct segments of the flight plan are shown above with cruise at a Reynolds number of 8 million while takeoff and landing occurs at 3 million. The cruise condition accounts for a wing with no flap deflection and a horizontal tail elevator deflection to maintain trim flying at 10,000 ft. Landing and takeoff both consider the elevators deflection fully to achieve rotation while varying only the flap deflection of the main wing.

## F. Key Aerodynamic Information

**Table 6.2: Key Aerodynamic Parameters**

Aerodynamic Parameter	Value
Angle of Incidence	1.4 degrees
L/D during Cruise	10.6
Cl during Cruise	0.24
Cd during Cruise	0.03066

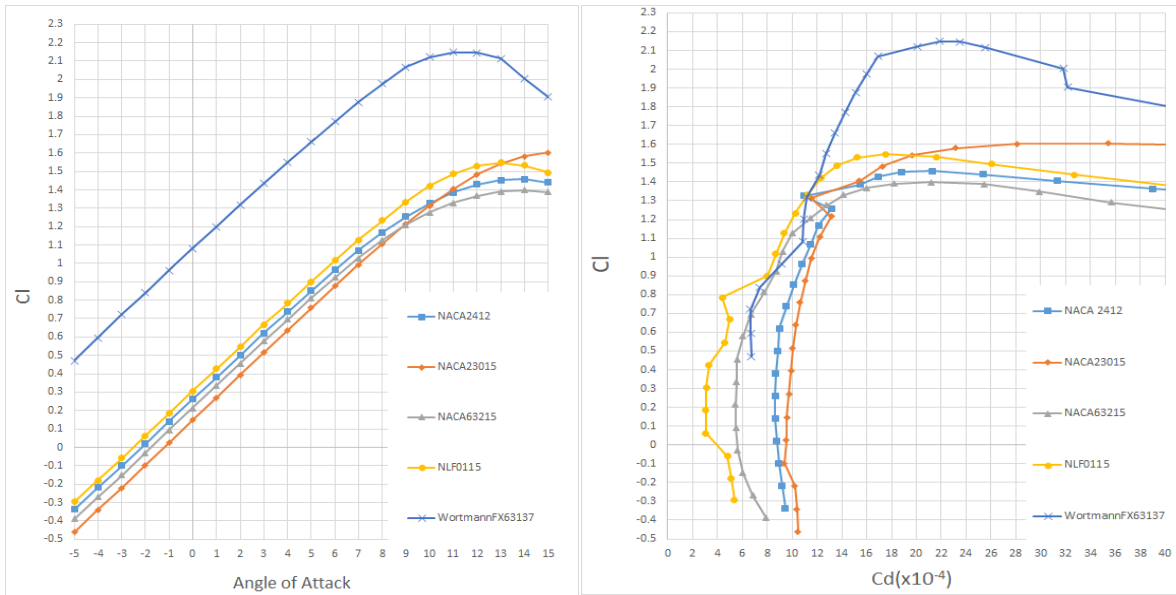
## G. Iota Air - Airframe Parachute System

Iota Air will be installing a full aircraft parachute as per the RFP requirements. There currently exists similar systems from BRS Aerospace that are available for Cessna 182 and Cirrus SR22 models<sup>28</sup> along

with other aircraft of similar takeoff weights. The parachute installed on the IA MKII will need to deploy in two major stages. The first major stage aims to reduce the horizontal velocity as quickly as possible without using excessive force which can be achieved with a deceleration of 1.05g that the structure and passengers can safely tolerate. This is achieved by limiting the parachute to initially only deploy to 24 ft<sup>2</sup>. From there, the reefing allows the parachute area to increase with decreasing speed to maintain the horizontal deceleration until has begun a completely vertical descent. Based on data gathered, the vertical descent rate at sea level with a fully deployed parachute is estimated at around 17 mph<sup>29</sup>. Deployment should typically occur at a high enough altitude to allow full vertical deceleration such that the vertical impact at that speed would be relatively safe for both the occupants and the aircraft. The BRS system lists an official altitude to be at least 400 ft<sup>28</sup>. By making the assumption that drag coefficients of all the parachutes can be predicted to be 1.4<sup>30</sup> with the projected area as the reference area, the predicted projected surface area of the parachute for the IA Mark 2 is 3,937 ft<sup>2</sup>. The distance of 100 ft from the canopy to the aircraft can be assumed based off of other BRS systems such that there is no interference between the descending aircraft and the parachute.

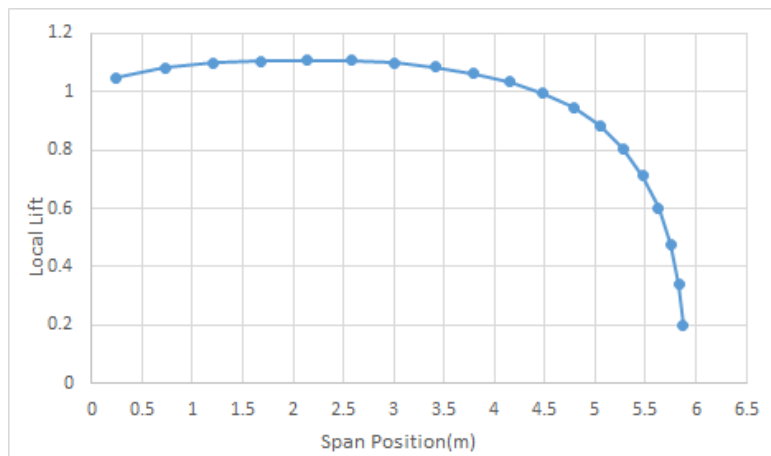
## **H. Trade Study**

The initial airfoils under consideration were the 4 digit, 5 digit, and 6 series airfoils developed by NACA. Representatives from each family of airfoils were compared and the 6 series airfoil showed the most promise with a laminar bucket reaching well below 50 counts of drag at the desired Cl value NASA Natural Laminar Flow airfoils, successors to the NACA airfoils, were then compared to determine whether or not there was a justification to choosing the newer airfoil. According to the figure below, The NLF 0115 displays drag characteristics that were better, if not the same as a comparable NACA airfoil and as such, the choice of airfoil remained the NLF 0115. Other NLF Airfoils were also considered but the useful range of Cl's were above what was required for the IA MK2 and the drag at the operating Cl's were higher than that of the NLF 0115 and as such the other NLF airfoils were not considered any further.



**Figure 6.6: Airfoil Cl/Cd Diagram**

One of the more important parameters to study was determining the appropriate taper ratio. The taper ratio was varied from 0.4 to 1.0 and at a taper of 0.7 peak Cl values began to near the inner edge of the aileron that begins at 3.5 m which limited further tapering of the airfoil.



**Figure 6.7: Span CL Diagram**

## VII. PERFORMANCE

### A. Takeoff and Landing Analysis

The AIAA RFP requirements for takeoff and landing distances are take off and land over a 50 ft obstacle in less than 2,500 ft at  $\Delta ISA+0$ , zero wind and sea level on a dry concrete runway. The methods Iota Air employed to calculate takeoff and landing field length are discussed in Roskam<sup>31</sup> Chapter 10. The results are listed in Tables 7.1 and 7.2 below. After takeoff, the IA Mark 2 will climb at a rate of 1,440 ft/min to the cruise altitude of 10,000 ft. The takeoff and landing performance of IA Mark 2 meets and exceeds the requirements for a dry concrete runway. The landing field length on icy concrete, soft turf and wet grass exceeds 2,500 ft by about 200 to 400 ft. However, as all TOFLs and most LFLs are within 2,500 ft, IA Mark 2 still has the ability to operate at most airports including those with short runways and various runway conditions.

**Table 7.1: Takeoff Ground Roll and Field Length**

Runway Condition	Coefficient of Friction <sup>11</sup>	Takeoff Ground Roll	Takeoff Field Length
Concrete	0.04	1,468 ft	2,348 ft
Wet Concrete	0.05	1,487 ft	2,379 ft
Icy Concrete	0.02	1,430 ft	2,288 ft
Hard Turf	0.05	1,487 ft	2,379 ft
Firm Turf	0.04	1,468 ft	2,348 ft
Soft Turf	0.07	1,528 ft	2,444 ft
Wet Grass	0.08	1,549 ft	2,478 ft

**Table 7.2: Landing Ground Roll and Field Length**

<b>Runway Condition</b>	<b>Coefficient of Friction<sup>11</sup></b>	<b>Landing Ground Roll</b>	<b>Landing Field Length</b>
Dry Concrete	0.5	991 ft	1,920 ft
Wet Concrete	0.3	1,252 ft	2,426 ft
Icy Concrete	0.1	1,512 ft	2,930 ft
Hard Turf	0.4	1,121 ft	2,172 ft
Firm Turf	0.3	1,252 ft	2,426 ft
Soft Turf	0.2	1,383 ft	2,680 ft
Wet Grass	0.2	1,383 ft	2,680 ft

## **B. Fuel Requirements**

The mission segment fuel requirements were calculated based on the weight fraction values. The weight fractions were calculated using a MTOW of 4,273 lb. Tables 7.3 and 7.4 show the fuel requirement per mission segment for both the reference mission and sizing mission. Combined, the reference mission requires 456 lb of fuel and the sizing mission requires 284 lb of fuel. The fuel tanks for the IA Mark 2 should hold up to 500 lb of fuel, which meets the requirements and grants at least 44 lb of reserve fuel for safety.

For the reference mission, the IA Mark 2 can fly a 135 nmi route in 41 minutes and loiter for another 72 minutes, which fulfills and outperforms the RFP requirements. The long loiter ability can make the IA Mark 2 safer than the RFP requirement. Moreover, the IA Mark 2 requires less fuel to complete the reference mission.

**Table 7.3: Fuel Requirement per Mission Segment for Reference mission**

<b>Mission Segment</b>	<b>Fuel Requirement</b>	<b>Weight Fraction</b>
Warmup, Taxi, Takeoff	128 lb	0.970
Climb Phase 1	29 lb	0.993
Cruise	56 lb	0.986
Descent Phase 1	41 lb	0.990
Climb Phase 2	5 lb	0.998
Loiter	129 lb	0.968
Descent Phase 2	39 lb	0.990
Land	31 lb	0.992
Total	456 lb	0.893

**Table 7.4: Fuel Requirement per Mission Segment for Sizing mission**

<b>Mission Segment</b>	<b>Fuel Requirement</b>	<b>Weight Fraction</b>
Warmup, Taxi, Takeoff	128 lb	0.970
Climb	29 lb	0.993
Cruise	56 lb	0.986
Descent	41 lb	0.990
Land	31 lb	0.992
Total	284 lb	0.933

### **C. Drag Calculations**

Drag force in flight constitutes two major parts. The parasite drag generally stays constant throughout the mission and the induced drag due to lift varies at different segments according to the flight path angle. Tables 7.5 and 7.6 show the drag values calculated for the IA Mark 2 under different missions. The takeoff and landing calculation was based on the  $\Delta$ ISA+0 sea level conditions and the climb calculation was



performed at  $\Delta ISA+0$  5,000 ft, which is halfway from sea level to cruise altitude. The differences between the values on the two tables are due to various weights in mission segments.

**Table 7.5: Drag per Mission Segment for Reference Mission**

Mission Segment	Drag Value
Takeoff	303 lb
Climb Phase 1	345 lb
Cruise	250 lb
Descent Phase 1	343 lb
Climb Phase 2	340 lb
Loiter	207 lb
Descent Phase 2	338 lb
Land	470 lb

**Table 7.6: Drag per Mission Segment for Sizing Mission**

Mission Segment	Drag Value
Takeoff	303 lb
Climb	346 lb
Cruise	250 lb
Descent	340 lb
Land	471 lb

#### **D. Cruise and Loiter Analysis**

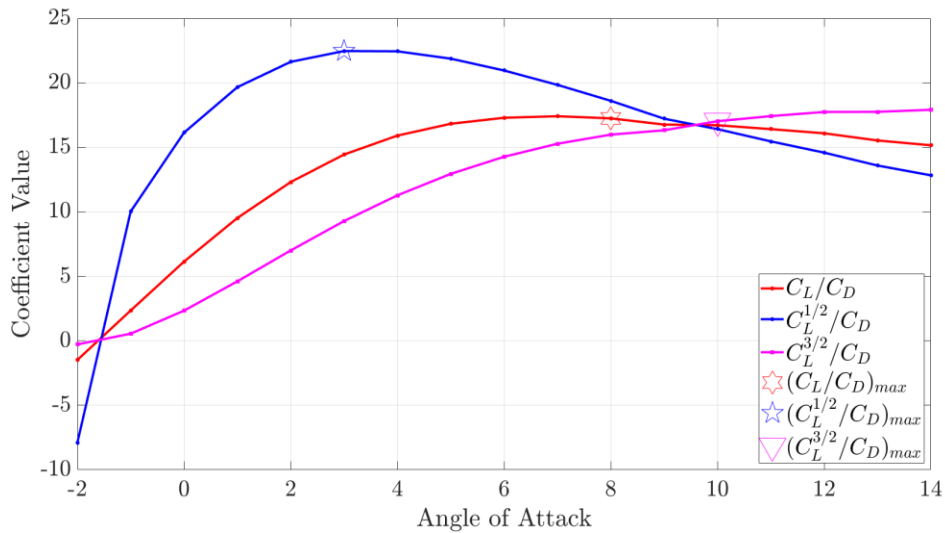
The minimum average cruise speed required by the RFP is 180 KTAS. During the initial sizing phase, Iota Air compared the IA Mark 2 with similar aircraft including Cirrus SR22, Piper PA-46, Beechcraft Bonanza and Cessna 172R. Given the propulsion system chosen, the cruise speed of the IA Mark 2 will be 195 KTAS. The cruise speed was designed for a cruise altitude of 10,000 ft. The IA Mark 2 was designed as a thin haul transport so the cruise altitude was chosen to not include a pressurized cabin. The cost for IA

Mark 2 can be lowered with this design in order to obtain a competitive advantage in the market. The low cruise altitude also decreases the duration of high-drag climbing and descending segments and increases low-drag cruise segment. A high fuel efficiency can be reached with these cruise parameters. With the ability to reach 31,000 ft, IA Mark 2 has an oxygen system to keep crew and passengers safe.

The aircraft performance coefficients are plotted in Figure 7.1. The maximum points of each plot are marked in Figure 7.1. The value and significance of those values are shown in Table 7.7.

**Table 7.7: Performance Coefficients Table**

Coefficient	Value	Significance
$\left(\frac{C_L}{C_D}\right)_{max}$	17.5	Minimum gliding flight path angle
$\left(\frac{C_L^{1/2}}{C_D}\right)_{max}$	22.5	Longest range flight path angle
$\left(\frac{C_L^{3/2}}{C_D}\right)_{max}$	17	Maximum rate of climb flight path angle



**Figure 7.1: Performance Coefficients Plot**

## E. Payload Range

The IA Mark 2 meets the range requirements set by the RFP to complete a typical reference mission. Using the Breguet range equation specified in Roskam<sup>31</sup>, the payload-range diagram was plotted as shown in Figure 7.2. When the IA Mark 2 takes off at MTOW with full payload of 1,280 lb, it can carry 279 lb of fuel. In this case, the maximum range with full payload is 436 nmi as the first segment of the plot shows. The range performance of the IA Mark 2 fulfills and outperforms the RFP requirements.

With the maximum fuel capacity at 500 lb, some payload can be reduced and substituted with extra fuel to fly longer routes. The aircraft can take off with a 1,059 lb payload and a 500 lb fuel and can fly a range of 804 nmi. Anything in between is shown in the second segment of the plot. Moreover, payload can be reduced with full fuel tank at takeoff. The ultimate range of 1,092 nmi is achieved when the aircraft takes off with zero payload and 500 lb of fuel.

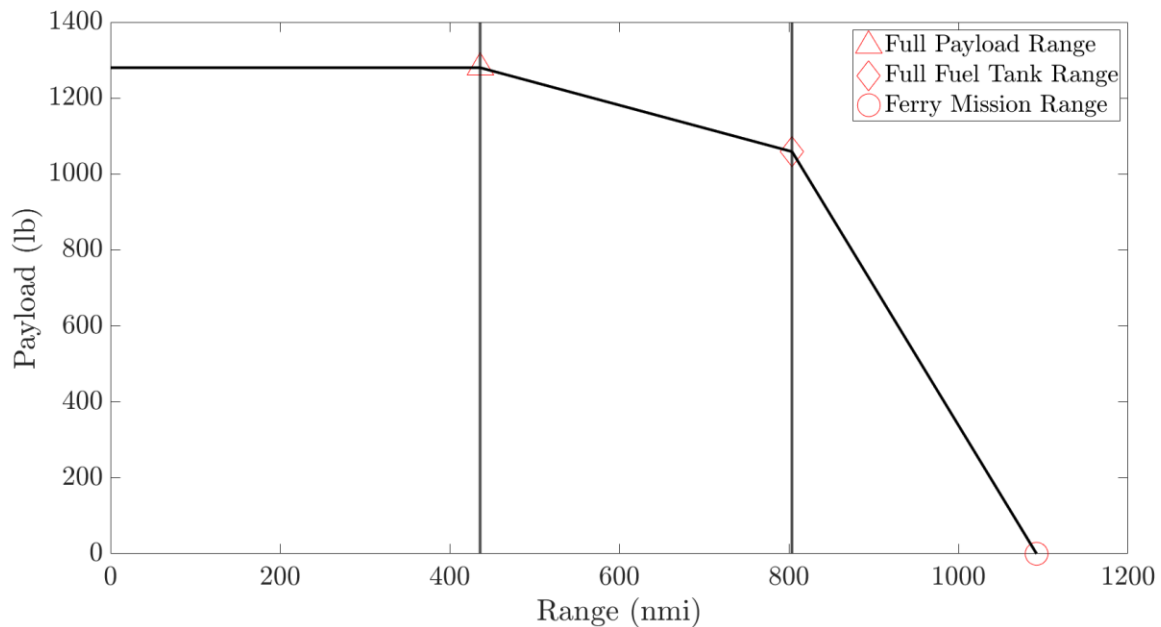
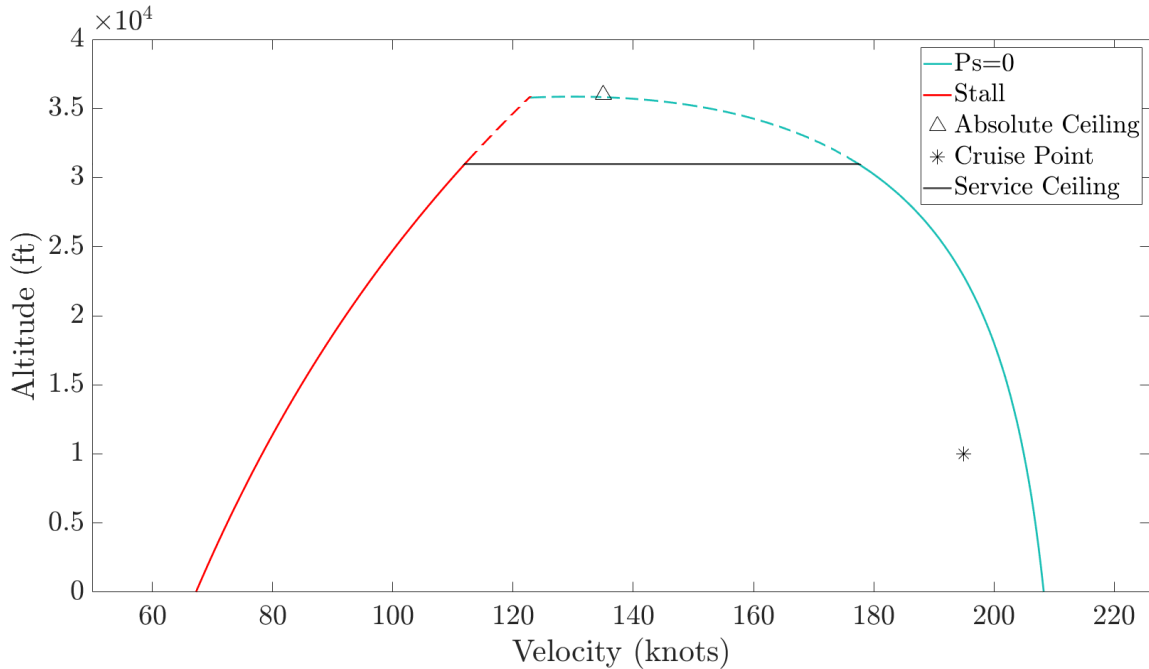


Figure 7.2: Payload-Range Diagram

## F. Flight Envelope

The flight envelope for the IA Mark 2 is shown in Figure 7.3. The flight envelope illustrates the speed/altitude constraints for the aircraft. The segment of the plot to the left of the triangle marker shows

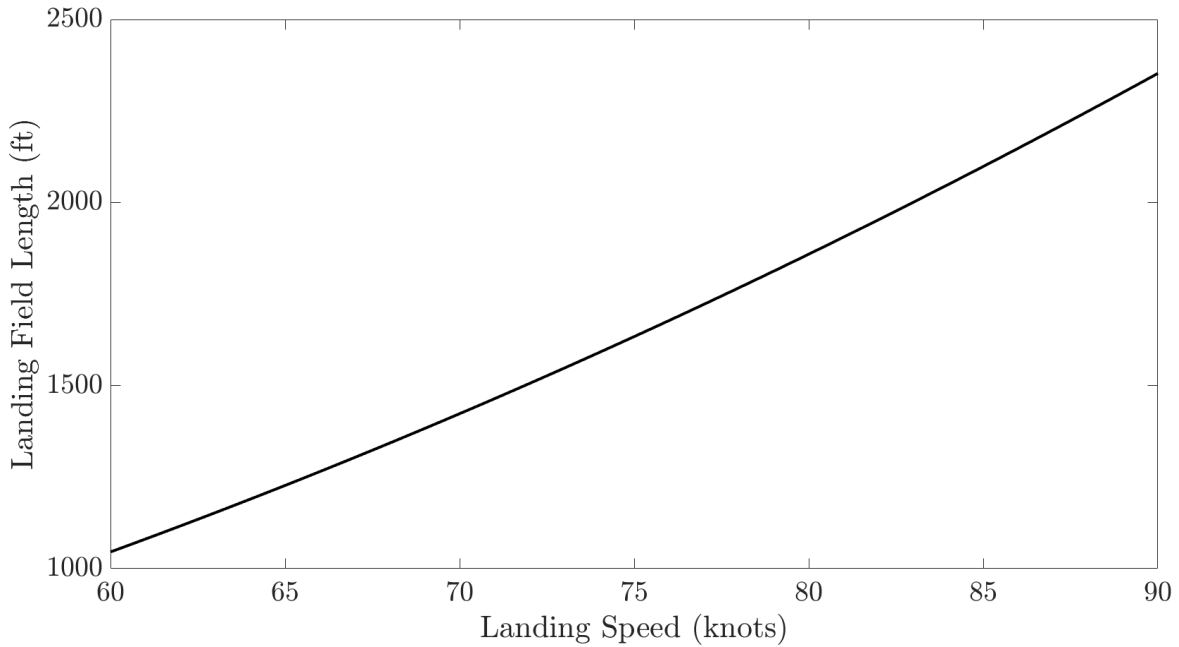
the minimum speed at any altitude while the right segment shows the maximum speed. The triangle marker shows the absolute ceiling of the IA Mark 2, which is 36,000 ft. The service ceiling of 31,000 ft is also shown in the plot. At this altitude, the IA Mark 2 can climb at a maximum rate of 100 ft/min<sup>32</sup>. The IA Mark 2 is able to fly the reference mission at an altitude of 10,000 ft with a cruise speed of at least 195 KTAS. The cruise condition is marked by the star marker.



**Figure 7.3: Flight Envelope**

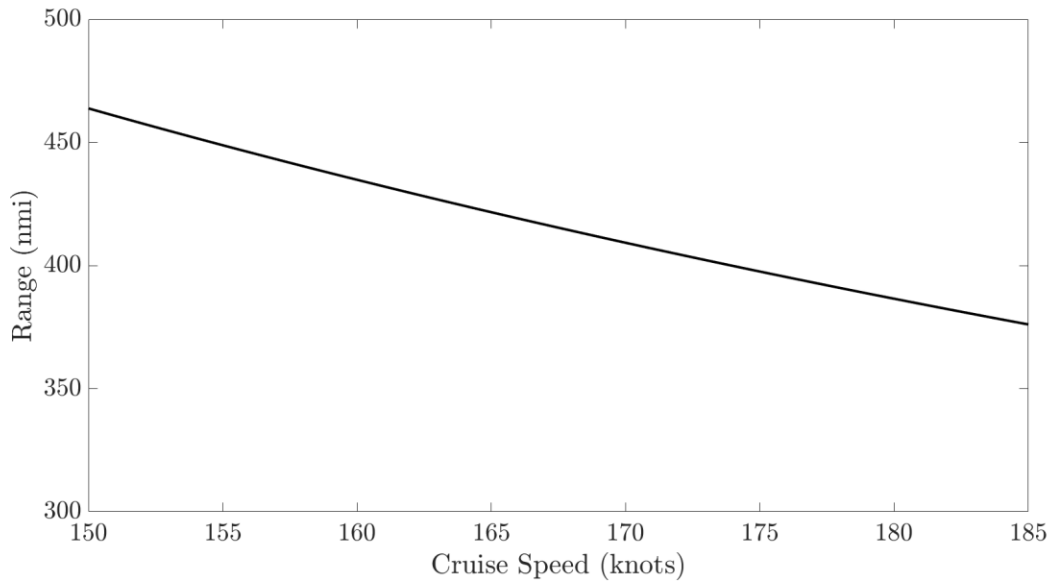
## G. Trade Study

A significant flight parameter to be studied is the landing field length, which determines the number of airports the aircraft can serve. Figure 7.4 shows the effect of varying landing speeds at a  $\Delta$ ISA+0 sea level dry concrete runway on the landing field length. As shown in the plot, landing field length grows as the landing speed increases. To achieve a short landing distance while preventing stall, Iota Air chose 65 KTAS as the landing speed for the IA Mark 2.



**Figure 7.4: Landing Speed vs Landing Field Length Trade Study**

Another important flight parameter to be studied is the cruise speed. Figure 7.5 shows the effect of varying cruise speed at a constant altitude on the maximum range. As shown in the plot, maximum range is higher at lower cruise speed as the engine works at a higher fuel efficiency.



**Figure 7.5: Cruise Speed vs Maximum Range Trade Study Plot**

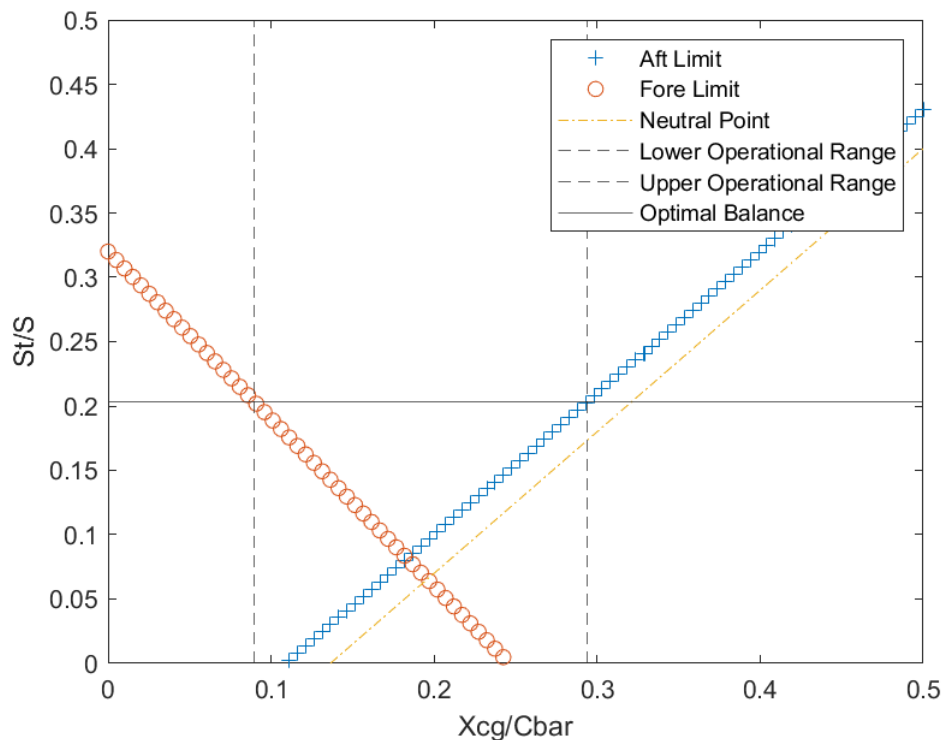
## VIII. STABILITY AND CONTROL

### A. Stabilizer Configuration

The IA Mark 2 utilizes a conventional tail configuration. The configuration was chosen to reduce the weight of the structure. By having a conventional tail, the stabilizer does not need heavier and stronger structures compared to a T-tail or crucifix tail. The stabilizers are positioned to be above the wing to reduce the downwash effect.

### B. Stabilizer Design Methodology

The sizing process of the stabilizers follows the methodology outlined in Raymer<sup>11</sup>. First, a scissor diagram is created to provide a general design restriction for the stabilizers. The scissor diagram is shown in Figure 8.1.



**Figure 8.1: Scissor Diagram**

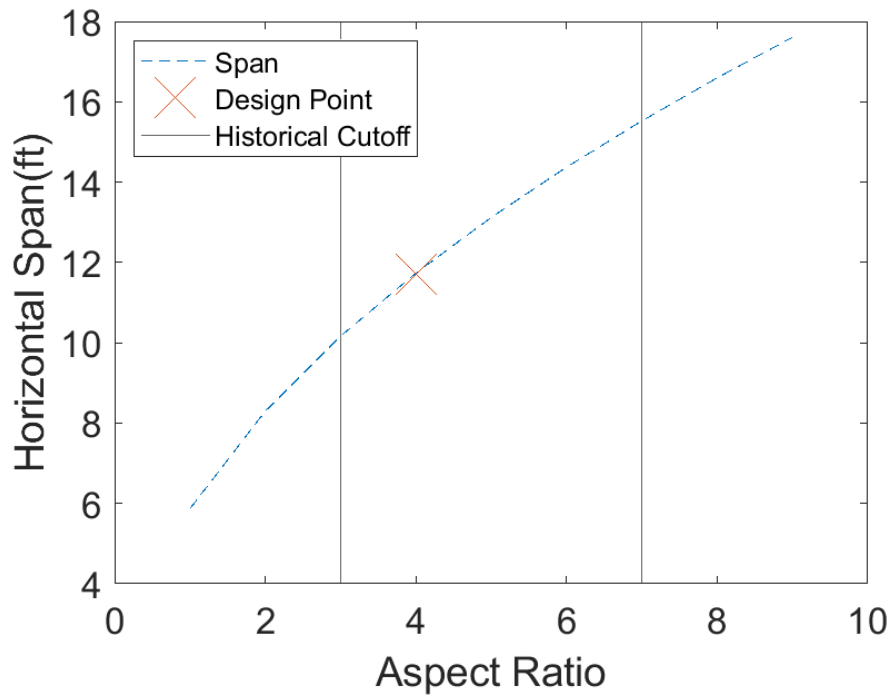
Both vertical and horizontal stabilizers utilize the same airfoil. This is done to maintain symmetry between the stabilizers. Both stabilizers use a symmetric airfoil. The main reason for this decision is to have

no lift force on the stabilizer during cruise. The stabilizers will also behave the same with positive and negative angles of attack. Further consideration for selecting the airfoil was the drag created by the stabilizer. A trade study was done to investigate the effect of the selected airfoil on the drag of the stabilizer. The results are shown in Table 8.1. Therefore, the NACA 0018 was chosen because it has the lowest drag coefficient.

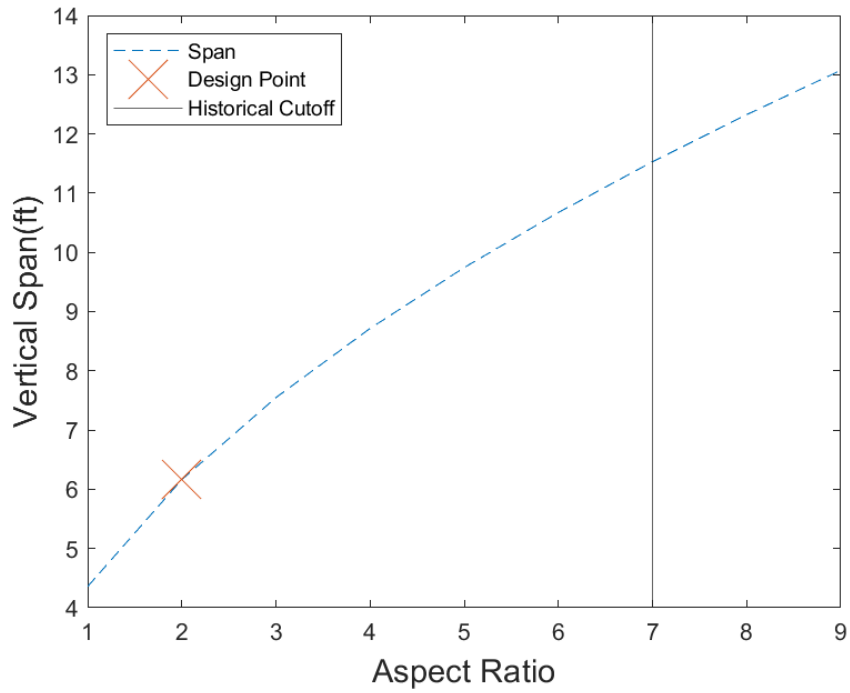
**Table 8.1: Airfoil Trade Study**

Airfoil	$C_d$ at $\alpha=0$
NACA 0012	0.009
NACA 0018	0.008
NACA 0021	0.009
NACA 0024	0.01

The only parameter calculated numerically was the reference area of both horizontal and vertical stabilizers. The other parameters were chosen from the historical data given by Raymer<sup>11</sup>. The specific values of the parameters were chosen based on several design criteria such as the center of gravity location, length of the moment arm and aesthetics. The parameters that were chosen are aspect ratio, taper ratio and quarter chord sweep angle. A trade study was done to quantify the change aspect ratios have on the designated design criteria. The result of the study is shown in Figures 8.2 and 8.3. An aspect ratio of 4 and 2 was selected for the horizontal and vertical stabilizer, respectively.



**Figure 8.2: Horizontal Stabilizer Sizing Trade Study**



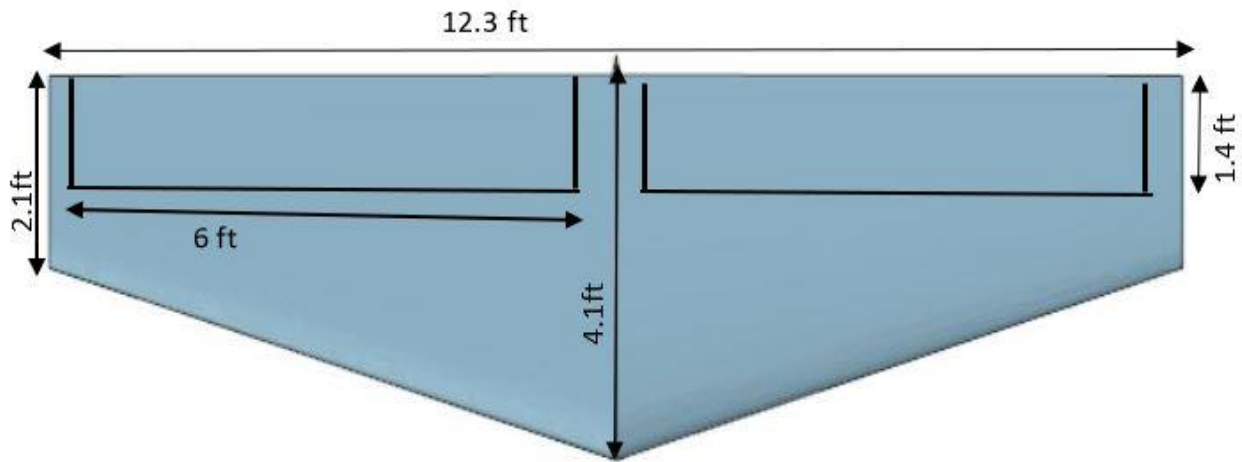
**Figure 8.3: Vertical Stabilizer Sizing Trade Study**



Additionally, the tail volume coefficient and quarter chord location (moment arm length) were determined from historical data stated in Raymer<sup>11</sup>. The geometrical parameters for the horizontal and vertical stabilizer are shown in Tables 8.2 and 8.3 respectively. The geometry of the stabilizers are shown in the Figures 8.4 and 8.5.

**Table 8.2: Horizontal Stabilizer Parameters**

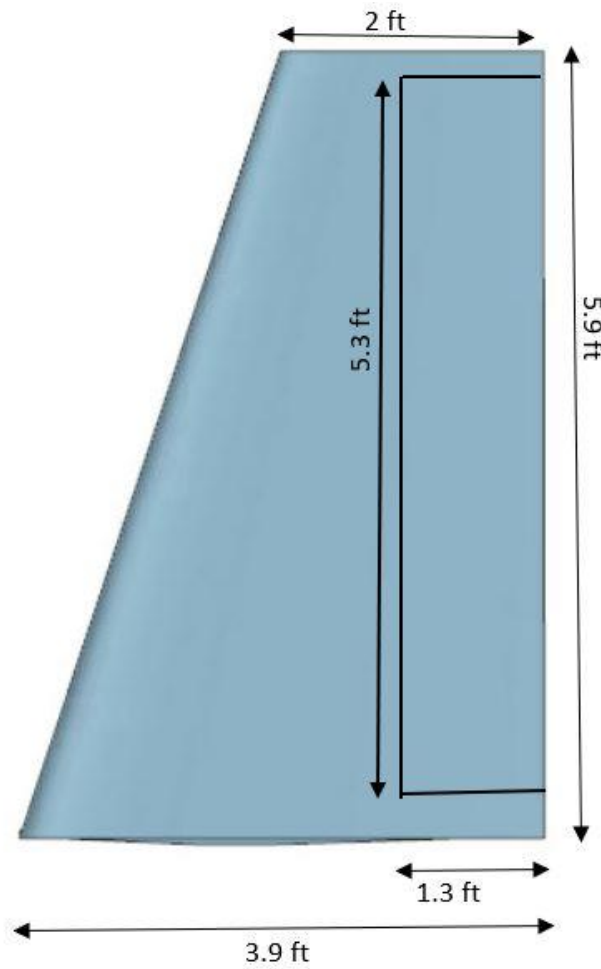
Horizontal Stabilizer Parameters	Value
Horizontal Stabilizer Span	12.3 ft
Root Chord	4.1 ft
Tip Chord	2.1 ft
Quarter Chord Sweep	18.4°
Reference Area	37.8 sq ft
Leading Edge Location From Nose of the Aircraft	23.7 ft
Volume Coefficient	0.7



**Figure 8.4. Horizontal Tail Geometry**

**Table 8.3: Vertical Stabilizer Parameters**

Parameters	Value
Vertical Stabilizer Span	5.9 ft
Root Chord	3.9 ft
Tip Chord	2.0 ft
Quarter Chord Sweep	18.4°
Reference Area	17.3 sq ft
Leading Edge Location From Nose of the Aircraft	23.7 ft
Volume Coefficient	0.04



**Figure 8.5. Vertical Tail Geometry**

### C. Control Surface Design Methodology

The sizing process for the control surfaces follows the methodology outlined in Raymer<sup>11</sup>. Ailerons, elevators and rudders were sized using historical data of span and chord ratio given by Raymer<sup>11</sup> and Sadraey<sup>33</sup>. The deflection angle of all control surfaces was determined to be 25° in both directions to ensure the aircraft is controllable in all situations. The geometry of the control surfaces is shown in Table 8.4.

**Table 8.4: Control Surface Geometry**

Control Surfaces	Chord Ratio	Chord [ft]	Span Ratio	Span [ft]	Deflection Range
Elevator	0.44	1.4	0.99	12.2	-25° to 25°
Ailerons	0.23	1.3	0.4	15.4	-25° to 25°
Rudder	0.44	1.3	0.9	5.3	-25° to 25°

### D. Incidence Values

The angle of incidence for both the wing and horizontal stabilizers were set to be zero degrees. The incidence angle for the wing was chosen because the lift coefficient during cruise can be achieved without additional incidence angle alterations. The angle of incidence for the horizontal stabilizer was chosen to maintain symmetry with the wing, maintaining stability of the aircraft.

### E. Stability and Control Derivatives

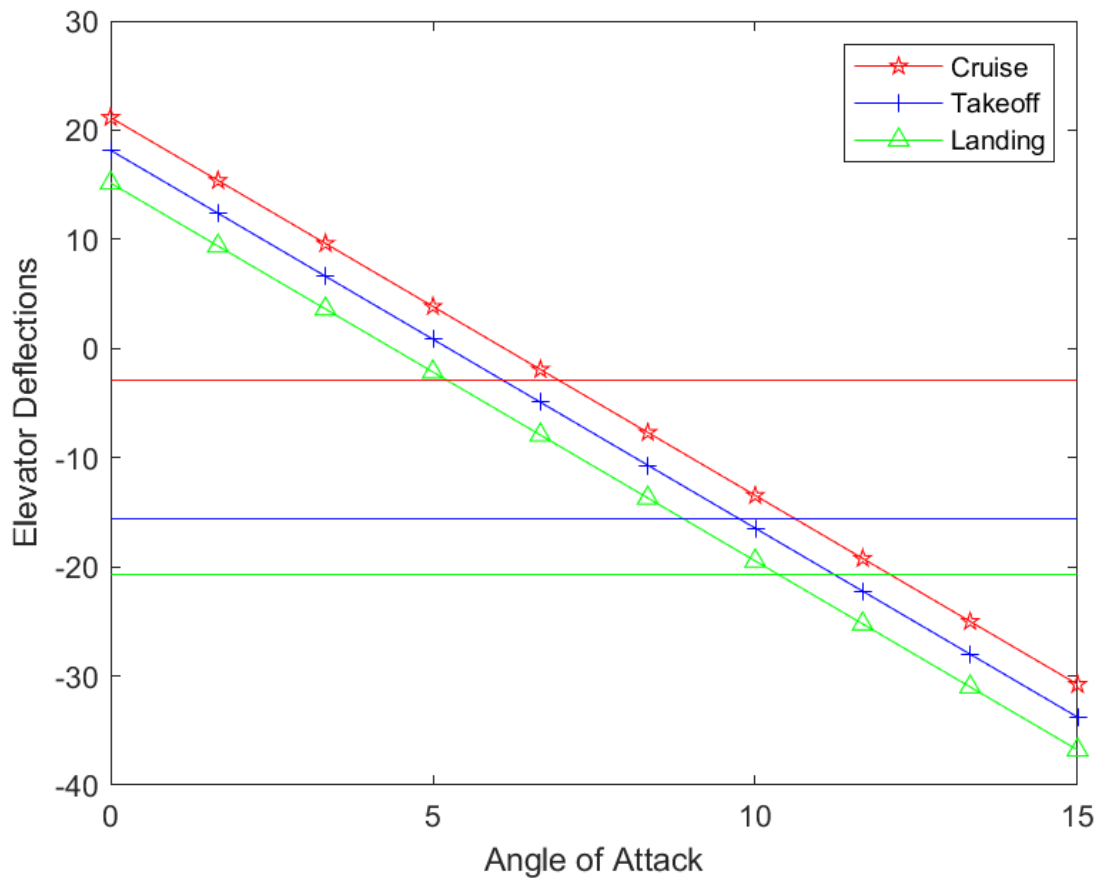
Stability and control derivatives of the IA Mark 2 was determined using AVL. Geometry of the aircraft was used to calculate the derivatives. The resulting values of the stability and control derivatives are shown in Table 8.5. With the given derivatives, stability is guaranteed.

**Table 8.5: Stability Derivatives**

Flight Conditions	$C_{l,\alpha}$	$C_{m,\alpha}$	$C_{m,\delta e}$	$\epsilon_\alpha$	$C_{l,B}$	$C_{n,B}$
Takeoff	3.8	-1.2	-0.067	0.1	-0.14	0.09
Cruise	4.4	-0.7	-0.07	0.1	-0.07	0.08
Landing	3.5	-0.9	-0.063	0.1	-0.18	0.11

## F. Longitudinal Trim Analysis

Trim analysis of the aircraft follows the equations outlined in Raymer<sup>11</sup>. Three different parts of the mission segment were considered, cruise, takeoff and landing. Different stability derivatives were used to differentiate the three mission segments. Trim points take place when the elevator deflection angle creates a zero moment for the aircraft, hence providing stability. The trim diagram for the IA Mark 2 is shown in Figure 8.6.



**Figure 8.6: Trim Diagram**

The longitudinal static stability is measured by the static margin range and neutral point of the aircraft. The calculations follow the equations outlined in Raymer<sup>11</sup>. For static margin range calculations, two center of gravity locations were used. The fore and aft center of gravity is located at 10.3 ft and 11.7 ft from the front of the aircraft, respectively. The two center of gravity locations used are based on mass properties

calculations. The static margin range was calculated to be between 6% and 36%. Furthermore, the neutral point of the aircraft was calculated to be 11.8 ft from the front of the aircraft.

### G. Directional Stability

Directional stability of the aircraft is demonstrated by showing the aircraft’s performance with the effect of crosswind. The necessary rudder deflections, for takeoff and landing with crosswind, were calculated. The crosswind is defined as 20% of the aircraft speed with 11.3° sideslip. The stability derivative values used are tabulated in Table 8.5. The procedure for calculating the rudder deflection can be seen in equations given by Sadrey<sup>33</sup>. The necessary rudder deflections are shown in Table 8.6. The IA Mark 2’s rudder is capable to reaching the necessary rudder deflection. Hence, stability is achieved.

**Table 8.6: Rudder Deflections with Crosswind**

Mission Segment	Rudder Deflection (°)
Takeoff	23.3
Landing	23.1

### H. Lateral Dynamic Stability

Lateral dynamic stability of the aircraft was determined by the roll rate of the aircraft. CFR Part 23 Section 23.157 provides the required time needed by the aircraft to roll through 60 degrees [CFR]. Using the process outlined in Raymer<sup>11</sup>, the roll time of the IA Mark 2 was calculated. The roll time and required time are shown in Table 8.7.

**Table 8.7: Aircraft Roll Time**

Mission Segment	Aircraft Roll Time (s)	Required Roll Time (s)
Takeoff	2.5	5
Landing	2.9	4

## I. Longitudinal and Lateral Flight Qualities

Longitudinal flight qualities of the IA Mark 2 was analyzed using equations from Cook<sup>34</sup>. Stability derivatives used in the analysis are tabulated in Table 8.5. The Cooper-Harper scale was used to determine the flight quality of the aircraft<sup>34</sup>. The goal for the IA Mark 2 is to achieve level 1 flight qualities which means the pilot will have more control of the aircraft. Therefore, requirements are set to fulfill this goal. From the given formula and derivatives, the matrix A was created. By evaluating eigenvalues of matrix A, the damping ratio and natural frequency for both short-period and phugoid modes were found. The Matrix A is given in Figure 8.7.

$$A = \begin{bmatrix} -0.06 & 18.7 & 0 & -32.2 \\ -0.02 & -2.5 & 0.1 & 0 \\ 0 & -4.5 & -3.5 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}$$

**Figure 8.7: Longitudinal Flight Qualities Matrix**

The resulting damping ratio and natural frequency for both short-period and phugoid mode are shown in Table 8.8. Since, the calculated values are well within the requirement, level 1 flight quality is achieved.

**Table 8.8. Longitudinal Flight Quality Values**

Parameters	$\zeta_{sp}$	$\omega_{sp}$ (rad/s)	$\zeta_{phug}$	$\omega_{phug}$ (rad/s)
Calculated Value	0.98	3.1	0.0147	0.48
Requirement	$0.5 < \zeta_{sp} < 1.1$	$2.5 < \omega_{sp} < 3.5$	-	-

For lateral flight qualities of the IA Mark 2, equations from Cook<sup>34</sup> were used for the analysis. Stability derivatives used in the analysis are tabulated in Table 8.5. The Cooper-Harper scale was used to determine the flight quality of the aircraft<sup>34</sup>. Similar to the longitudinal flight qualities, the goal for the IA Mark 2 is to achieve level 1 flight qualities. Matrix A was created from the given formula and derivatives. By

evaluating the eigenvalues of Matrix A, the frequency and damping ratio for Dutch roll, time constant for roll, and doubling time for spiral modes were found. Matrix A can be seen in Figure 8.8

$$A = \begin{bmatrix} -0.15 & -0.0001 & -0.99 & 0.014 \\ -38.7 & -2.4 & 0.23 & 0 \\ 2.1 & -0.094 & -1.3 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix}$$

**Figure 8.8: Lateral Flight Qualities Matrix**

The resulting flight quality values are shown in Table 8.9. Since, the calculated values are well within the requirement, level 1 flight quality is achieved.

**Table 8.9: Lateral Flight Quality Values**

Parameter	$\zeta_{\text{Dutch}}$	$\omega_{\text{Dutch}}$ (rad/s)	$\tau_{\text{roll}}$	$t_{1/2}$ (s)
Calculated Value	0.21	1.8	0.23	13.9
Requirement	$\zeta_{\text{Dutch}} > 0.19$	$\omega_{\text{Dutch}} > 1$	$\tau_{\text{roll}} < 1$	$t_{1/2} > 12$ s

## J. Iota Air - Airframe Parachute System

The IA Mark 2 incorporates an airframe parachute system as one of its emergency systems. In regards to the aircraft stability, the parachute was designed to reach level floor as quickly as possible. The cables connecting the parachute to the aircraft are placed such that, the center of gravity is under the center of the parachute. Hence, the aircraft will be stable during descent.

## IX. STRUCTURES AND LOADS

### A. Load Cases of Interest

To help visualize the loading that the IA Mark 2 will undergo at various speeds, a V-N diagram was created as shown in Figure 9.1 using performance equations provided by Roskam<sup>35</sup>. The positive lifting load,  $n_{lim-pos}$ , and negative lifting load,  $n_{lim-neg}$ , were determined to be 3.78 and -1.51, respectively. As per CFR part 23.2215, the V-N Diagram must also incorporate gusts loads up to 25 fps and 50 fps which can redefine the loads felt at higher velocities. In the case of the IA Mark 2, the positive limit load is increase to 4.18 and the negative limit load decreases to -2.98 at the cruise velocity.

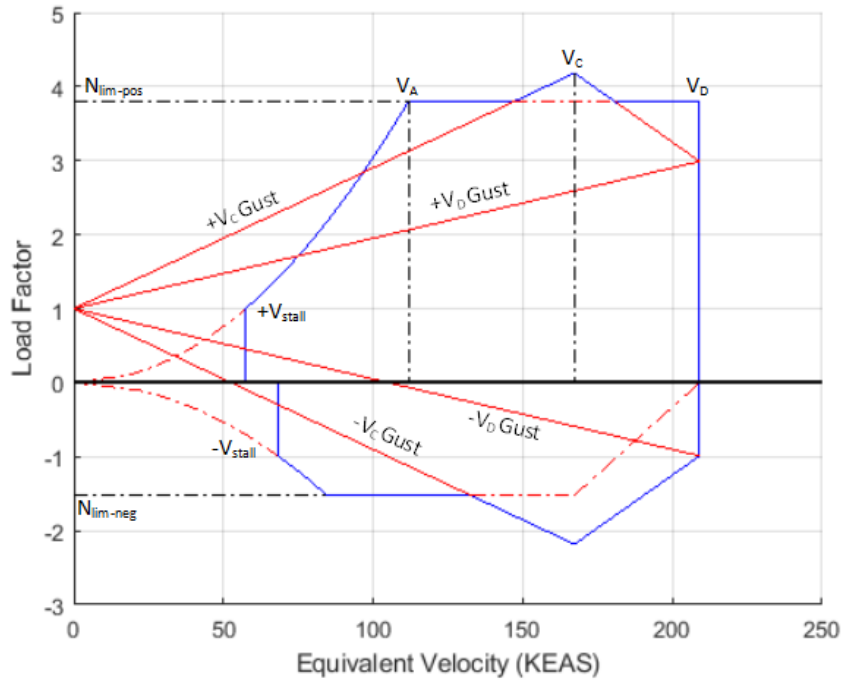
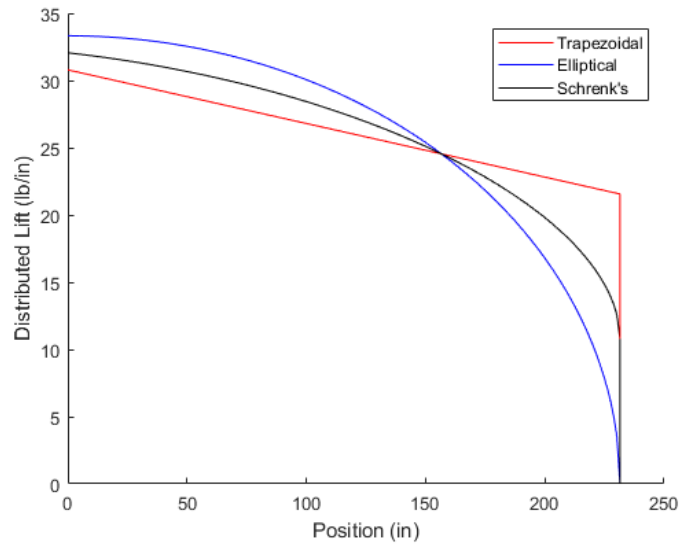


Figure 9.1: V-N Diagram at Sea Level

#### 1. Wing Loading Analysis

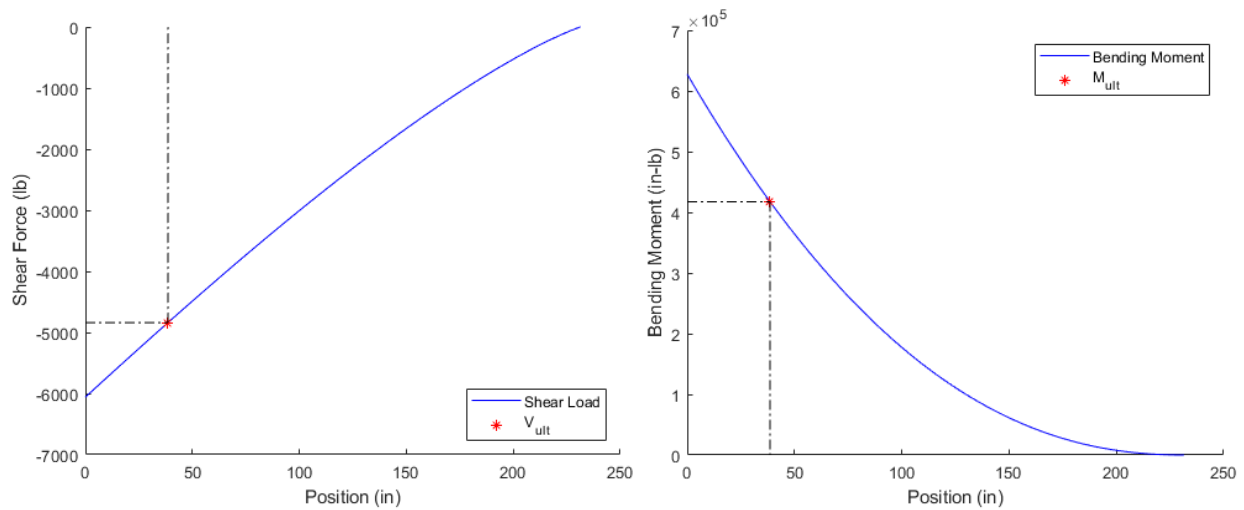
Using the positive lifting load factor found from the V-N Diagram, a lift distribution along the length of the port side wing was determined using three separate approximations as seen in Figure 9.2.





**Figure 9.2: Lift Distribution Approximation**

Using Schrenk's lift approximation, the shear loads and bending moments across the span of the wing are seen in Figure 9.3. A safety factor of 1.5 was used to ensure that the design of structural elements would be able to handle these loads.



**Figure 9.3: Shear Force and Bending Moment Diagrams**

Based on Figure 9.3, the shear force and bending moment at the root of the wing are -4,919.35 lb and 430,014.66 inch-lb, respectively.

## 2. Parachute Loads

Due to the requirements of the RFP, the IA Mark 2 must contain an airframe parachute system in case of engine failure<sup>1</sup>. The parachute designed by aerodynamics will initially decelerate the aircraft at 1.02 times the acceleration of gravity. This will cause a maximum loading of 4,296.22 lb.

## 3. Pressurization

CFR part 23.2545 requires aircraft cruising above 12,500 ft. to be pressurized. The IA Mark 2 cruises below that limit at 10,000ft; therefore, the effects of pressurization was not included in structural considerations.

## B. Material Selection

Historically, similar aircraft such as the Beechcraft Bonanza<sup>3</sup> and the Piper PA-46<sup>10</sup> were built using metal and metal alloys while the Cirrus SR22<sup>5</sup>, a more modern aircraft, utilizes composites to increase the overall performance of the aircraft. Due to their low densities and high tensile strengths, the IA Mark 2 will consist of an all-composite skin with aluminum alloy structural elements. A trade study was completed to determine which composites and aluminum alloys will be best for the aircraft.

**Table 9.1: Material Trade Study**

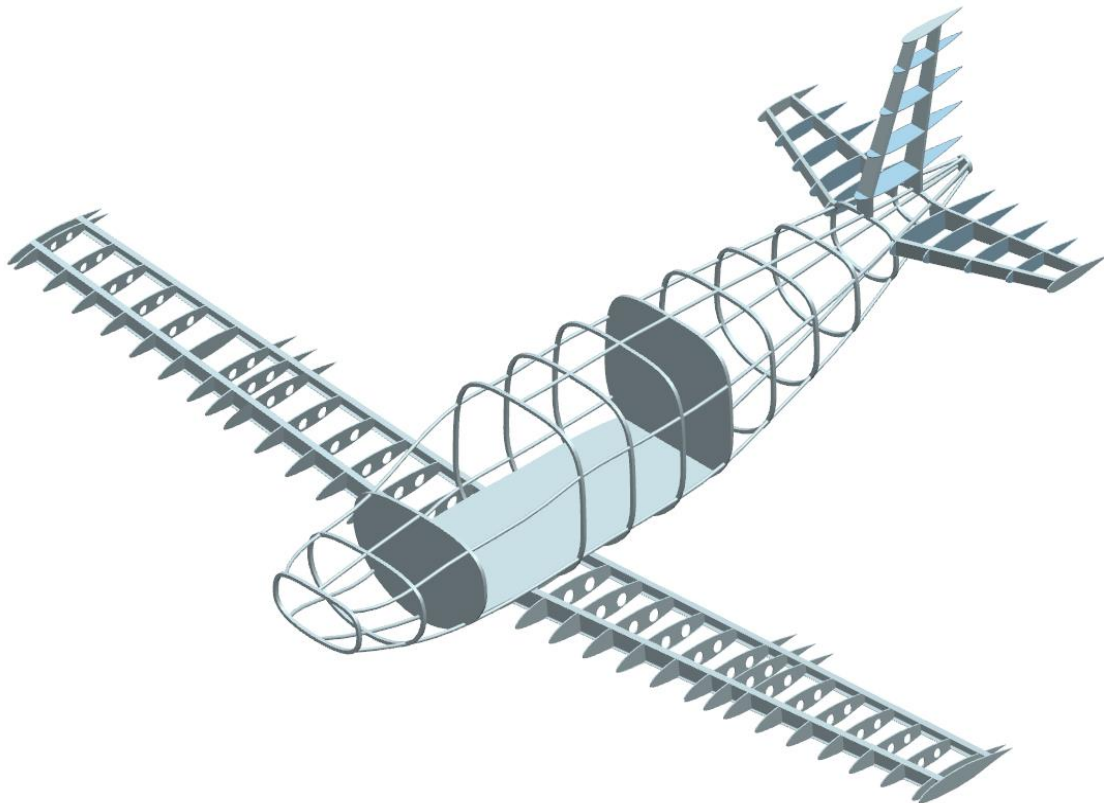
Material	$\overline{F1}$ ( $\frac{lb \cdot inch}{slug}$ )	$\overline{E1}$ ( $\frac{lb \cdot inch}{slug}$ )	$\overline{E2}$ ( $\frac{lb \cdot inch}{slug}$ )
AS4-12k/938 <sup>36</sup>	$1.681 \times 10^8$	$1.243 \times 10^{10}$	$7.156 \times 10^8$
T-300 3k/934 Plain Weave <sup>36</sup>	$5.228 \times 10^7$	$5.228 \times 10^9$	$5.171 \times 10^9$
T-500 12k/976 Unidirectional <sup>36</sup>	$1.665 \times 10^8$	$1.236 \times 10^{10}$	$7.338 \times 10^8$
Aluminum 2024 <sup>37</sup>	$2.188 \times 10^7$	$3.410 \times 10^9$	-
Aluminum 6061 <sup>37</sup>	$1.477 \times 10^7$	$3.250 \times 10^9$	-
Aluminum 7075 <sup>37</sup>	$1.644 \times 10^7$	$3.313 \times 10^9$	-

Based on the trade study in Table 9.1 and some material research, the IA Mark 2 will consist of an all composite skin using the AS4-12k/938 in a quasi-isotropic layup due to its high specific strength and

modulus. The internal structure will be comprised of aluminum 6061 since it provides enough strength and is the cheaper of the other two aluminum alloys.

One area of concern is the contraction of the aluminum elements due to the drop in temperature as the aircraft increases in altitude. This will cause a certain amount of strain that can cause the composite layers of the skin to fail. However, the coefficient of thermal expansion for aluminum 6061 is about  $13.1 \mu\text{inch}/\text{inch}\text{-}^\circ\text{F}$ <sup>37</sup> and the typical coefficient of thermal expansion for carbon fiber reinforced polymers is around  $1.19 \mu\text{inch}/\text{inch}\text{-}^\circ\text{F}$ <sup>38</sup>. From sea level to cruise altitude, the temperature will drop  $39.66^\circ\text{F}$  causing the aluminum to contract  $467.15 \mu\text{in}/\text{in}$  and the skin to contract  $47.2 \mu\text{inch}/\text{inch}$  causing an overall strain of  $-419.95 \mu\text{inch}/\text{inch}$  on the skin. Based on the mission profile, the flight duration will not be long enough for this contraction to cause any significant damage to the overall structure of the aircraft.

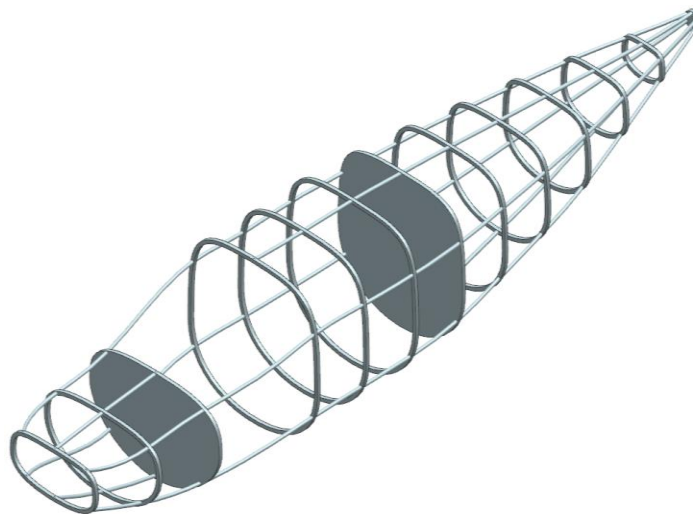
### C. Structural Arrangement



**Figure 9.4: Full Structural Layout of IA Mark 2**

## 1. Fuselage

The fuselage of the IA Mark 2 is a semi-monocoque structure consisting of six longerons, ten frames, two bulkheads, and a keel beam. The first bulkhead, located at 108.47 inches aft of the nose, contains a firewall to protect the pilot from the heat of the engine. The second bulkhead is located behind the cabin at 235.47 inches aft of the nose. Frames are evenly spaced around the bulkheads so as not to exceed a maximum spacing of 28 inches. The six longerons extend the length of the fuselage to help prevent the buckling of the fuselage skin. They are located at 60° intervals around the perimeter of each cross section. The keel beam is situated at the bottom of the fuselage and spans between the two bulkheads to sustain the loads within the cabin. Attached to the keel beam is the carry through section of the wing which will serve as the main source for load transfer between the wing and the fuselage.

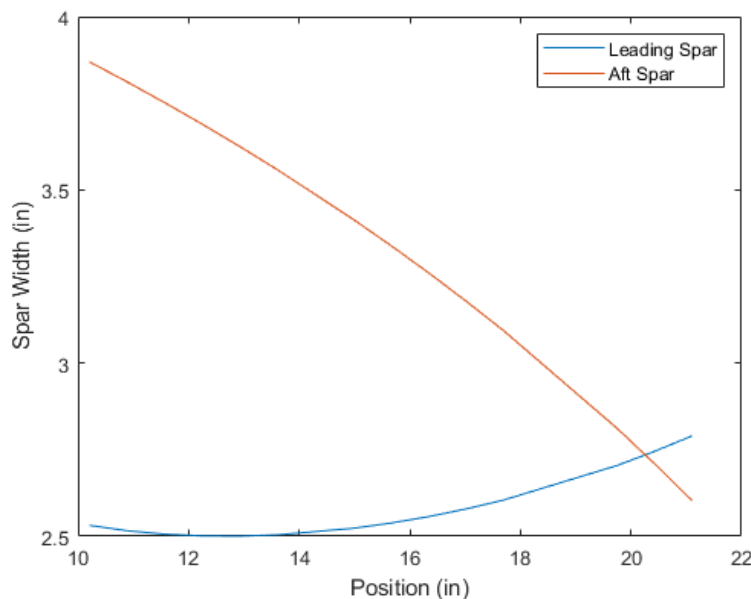


**Figure 9.5: Fuselage Structure**

The parachute is located directly behind the second bulkhead. There are 2 attachment points bolted on either side of each bulkhead to ensure the load is distributed throughout the internal structure of the fuselage. Assuming all but one connection point fails, the bolt must have a minimum diameter of 0.43 inch to endure the shear load applied by the parachute.

## 2. Wing

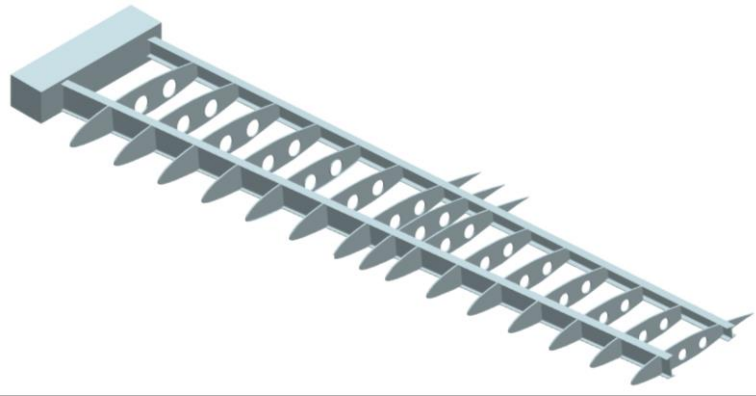
The wing will consist of two spars with an I-beam cross section connected by a series of ribs. The aft spar is located at 72% chord to leave room for control systems. As suggested by Roskam<sup>35</sup>, the location of the leading spar was initially estimated to be in the range of 15-30% chord. By applying bending and shear formulas, the dimensions for the spar flanges and web can be estimated to ensure that the loads felt are below the yield stress (40,000 psi) and shear strength (30,000 psi) of aluminum 6061<sup>36</sup> with a 10% margin of safety. With the center of pressure located at 46% chord, as determined by aerodynamics, the total load felt by both spars was statically resolved. Using these resolved loads, a trade study was conducted to determine which location of the leading spar would minimize the flange width necessary to sustain the bending loads thus reducing the structural mass of the wing. As shown in Figure 9.6, the flange width is minimized at 30% chord giving a total width of 2.75 inches for each spar. At this location, the width of each spar web is 0.5 inch. The height of each spar is constrained by the thickness of the airfoil at each location.



**Figure 9.6: Trade Study - Leading Spar Location**

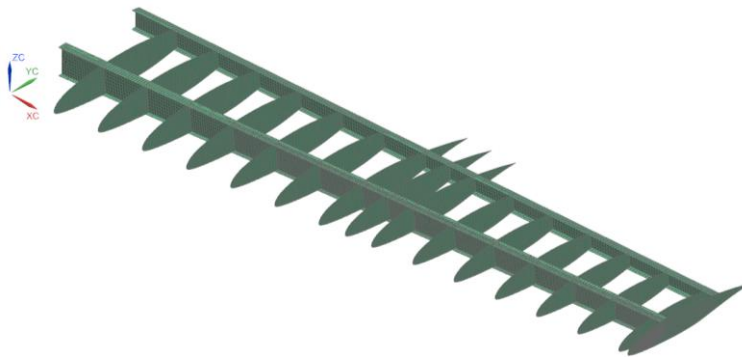
Using plate buckling theory with the assumption of fixed boundary conditions<sup>39</sup>, the spacing between the ribs was determined to be no longer than 18.14 inches. However, to ensure structural rigidity, ribs will

be placed at the start and end locations of the flaps and ailerons. Finally, to ensure the loads sustained from the wing are transferred to the airframe, the wing will be attached via carry through section which will attach to the keel beam of the fuselage. The entire structure of the wing can be seen in Figure 9.7.



**Figure 9.7: Wing Structure**

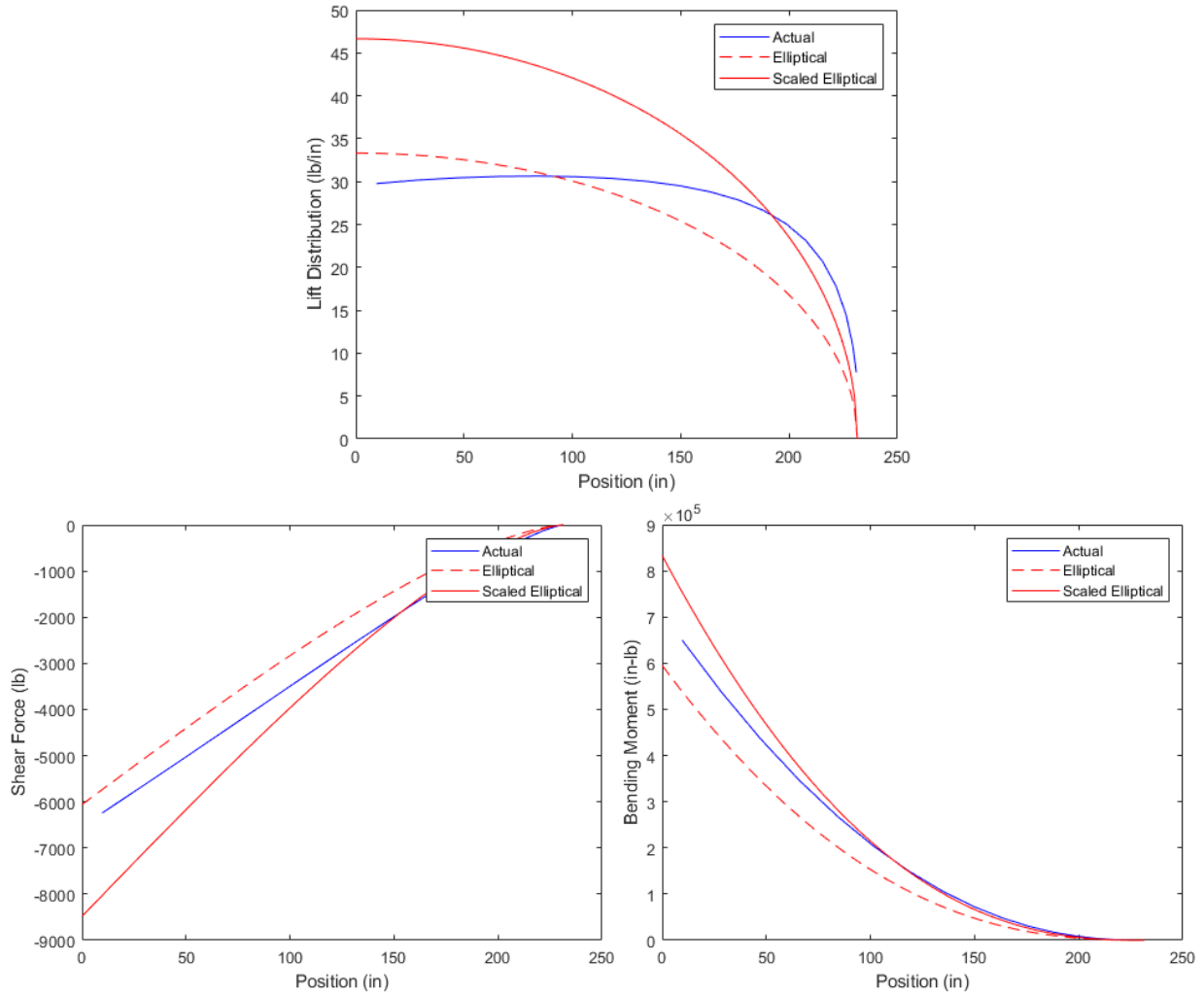
A finite element model of the wing was created using NX NASTRAN to validate that the structural design can withstand the loads applied. The skin and internal structures were modeled using the mechanical properties of a quasi-isotropic layup of AS4-12k/938 and aluminum 6061, respectively with a 0.5-inch element CQUAD4 mesh. The complete finite element model can be seen in Figure 9.8.



**Figure 9.8: FEA Wing Model**

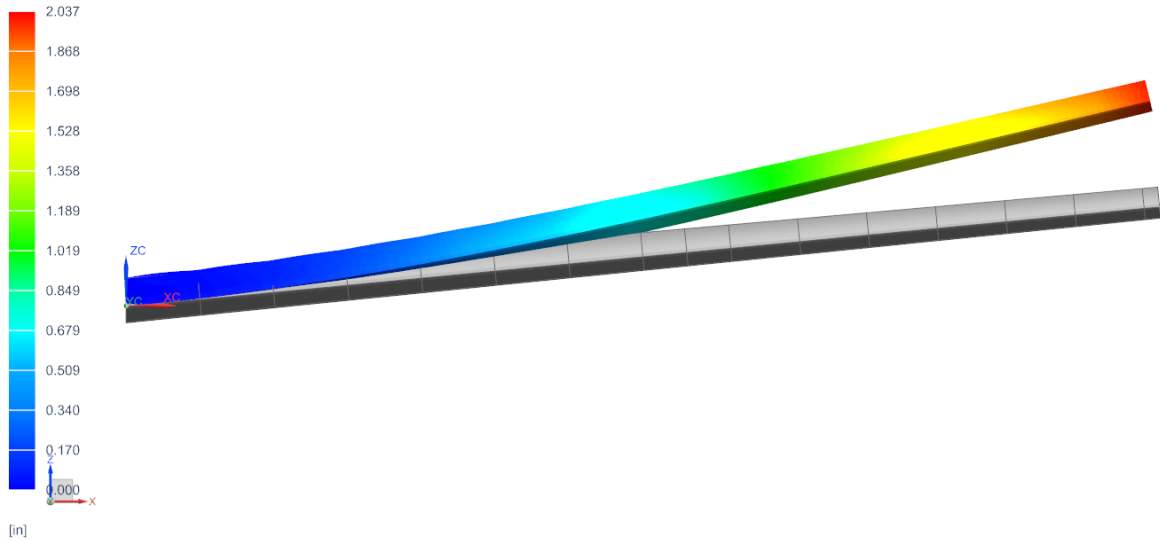
The root of the wing model represents the attachment point to the carry through section and thus was modeled using a fixed boundary condition. Using the worst case loading condition for the IA Mark 2, an elliptical lifting load was applied over the top surface of the wing. However, as can be seen in Figure 9.9, the original elliptical distribution was not conservative relative to the lift distribution determined by

aerodynamics. Thus, the elliptical distribution was scaled to create a more conservative lift distribution across the wing. Other forces such as the weight of the fuel tanks and the structural components were neglected since these forces counteract the lift.



**Figure 9.9: Plots Comparing the Lift Distribution, Shear Force, and Bending Moments**

The displacement results of the finite element analysis can be seen in Figure 9.9. To validate the results of the finite element analysis, an Euler Bernoulli analysis was done on the leading spar. Applying the same elliptical lift distribution across the top of the spar, the maximum deflection was 10 inches. Although this deflection is much larger than that determined from the finite element analysis, the wing also includes ribs, skin, and an additional spar which increases its overall stiffness.



**Figure 9.10: Wing Displacement - Elliptical Loading**

### 3. *Empennage*

The empennage of the aircraft will consist of fuselage mounted vertical and horizontal stabilizers. Both stabilizers are attached to the frames of the fuselage to allow for load transfer from the empennage structure. The leading spar will be located at 15% and the rear spar 56% for the vertical and horizontal stabilizers. Ribs are spaced up to 15 inches apart for both the vertical and horizontal stabilizers. These design decisions were based on the recommendations given by Roskam<sup>35</sup>.



**Figure 9.11: Empennage Structure**



## D. Landing Gear

### 1. Sizing Analysis

The IA Mark 2 uses tricycle configuration for its landing gear. The tricycle configuration was chosen to provide a level cabin floor during taxi, therefore adding comfortability for the passengers. The size of the landing gear was determined from the load applied on the landing gear by the aircraft. The nose gear takes 10% of the overall weight of the aircraft. The two aft gear each take 45% of the aircraft weight. The sizing of the landing gear follows the process outlined in Raymer<sup>11</sup>. A factor of 1.5 was added in the sizing process to account for safety and additional loads during emergency landings. The maximum loads of each gear were calculated using methods outlined in Currey<sup>40</sup>. The geometry of the landing gear is shown in Table 9.2.

**Table 9.2: Landing Gear Geometry**

Parameters	Main Gear	Nose Gear
Number of Gear	2	1
Max Load per Gear	1952.3 lb	987.3 lb
Min Load per Gear	1642.6 lb	367.85 lb
Diameter	21.3 inches	12.6 inches
Width	9.4 inches	5.9 inches
Longitudinal Location From Nose	13.1 ft	3.2 ft
Lateral Location From Centerline	3.8 ft	0 ft

The landing gear was placed to ensure the requirement for longitudinal tip over. The tip back angle of the aircraft is  $15.9^\circ$ , which is above the limit of  $15^\circ$ . Therefore, the aircraft will not tip over in any condition. The overturn angle of the aircraft is  $40^\circ$ , which fulfills the requirement of under  $63^\circ$ . Furthermore, the height of the landing gear was chosen to be 4.4 ft from the ground to the undercarriage of the fuselage. This height was chosen to ensure propeller and tail strike clearance given in CFR Part 23 Section 23.2400. The

landing gear height for the IA Mark 2 is higher compared to similar aircrafts. Since, the current configuration satisfies all requirements, no further modification is necessary.

## 2. Tire Selection

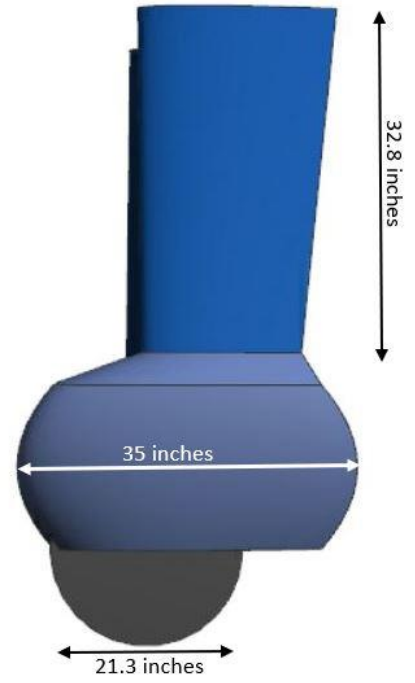
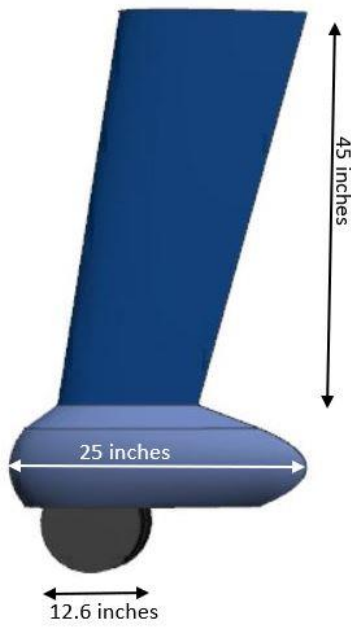
The tires of the aircraft were chosen based on the diameter, width and maximum expected load on each gear. The nose gear uses the Type III 7.00-8 tire and the main gear uses Type III 9.50-16. The parameters of the chosen tires are shown in Table 9.3.

**Table 9.3: Tire Parameters<sup>11</sup>**

	<b>Tire Selection</b>	<b>Size</b>	<b>Load</b>	<b>Diameter</b>	<b>Width</b>	<b>Rated Inflation</b>
Main Gear	Type III	9.50-16	9250 lb	26.6 inches	10.34 inches	90 psi
Nose Gear	Type III	7.00-8	2400 lb	15.8 inches	6.5 inches	46 psi

## 3. Retraction System

The IA Mark 2 implements fixed (non-retractable) landing gear. This configuration was chosen to reduce the weight of the aircraft, due to no retraction systems needed. Furthermore, additional space is available for fuel tanks in the wings. Fixed landing gear creates drag during flights. Therefore, fairings were placed around the landing gear to reduce the drag. In order to reduce the drag, the trailing flow from the fairings must be unseparated. Hence, the shape of the fairings used in the aircraft were based on the NACA 0024 airfoil. The symmetrical shape is chosen so that no lift is created during flight. The maximum thickness of 24% is chosen to ensure the tire fits inside the fairings. The geometry of the landing gear is shown in Figure 9.12.



**Figure 9.12: Landing Gear**

## X. MASS PROPERTIES

### A. Aircraft Components List

A comprehensive list of the aircraft components that were taken into consideration are listed in Tables 10.1, 10.2, and 10.3. The structure component weights were verified and obtained from NX while the rest of the component weights were calculated using equations and estimation from Roskam<sup>35</sup>, except for the installed engine weight, which was calculated using an approximation from Raymer<sup>11</sup>. The weights of the subsystems were estimated according to Roskam<sup>35</sup>. The corresponding center of gravity locations for each component was determined relative to the nose of the aircraft. Due to the fact that both the weights of the flight control system and electrical system are distributed throughout the aircraft body, they were excluded from the overall CG calculation process. The CG location of the fuel system was obtained by including the fuel weight. An iteration algorithm with a tolerance of 1% was adopted to determine the aircraft takeoff weight. All of the weights of the aircraft components were calculated using a MTOW of 4,102 lb from the initial sizing analysis.

Assumptions were made that a restricted number of subsystems were implemented and the payload included six passengers and one crew member. The aircraft was assumed to be symmetric about the centerline of the aircraft, so that the CG location of any component was measured along the centerline of the aircraft. All the CG locations in the following tables were measured from the nose of the aircraft.

**Table 10.1: Structure Component Weights**

<b>Component Name</b>	<b>Weight (lb)</b>	<b>CG location (ft)</b>
Wing	506	14.56
Horizontal Tail	62	30.19
Vertical Tail	33	29.88
Fuselage	521	15.09
Nose Landing Gear	26	3.35
Main Landing Gear	123	13.68

**Table 10.2: Power Plant Component Weights**

Component Name	Weight (lb)	CG location (ft)
Engine	593	4.47
Propeller	72	1.51
Fuel System	556	14.52

**Table 10.3: Fixed Equipment Weights**

Component Name	Weight (lb)	CG location (ft)
Flight Control	61	N/A
Electrical	101	N/A
Avionics	231	7.26

**B. Total Weight and CG Locations**

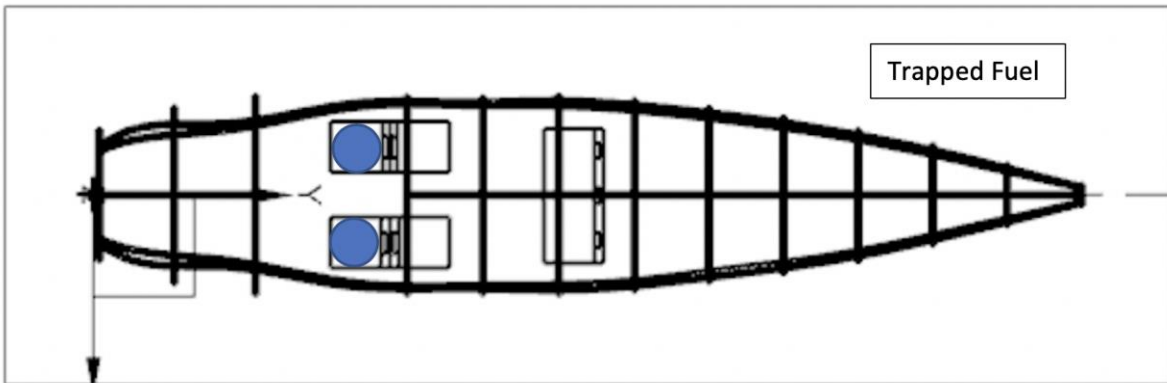
The IA Mark 2 has an extreme fore CG of 10.31 ft determined by assuming only a single pilot and passenger in the cabin with trapped fuel as suggested in Figure 10.1. An extreme aft CG of 11.77 ft was calculated under the assumption that there was a single pilot and three passengers in the last row of the cabin with both fuel tanks full as shown in Figure 10.2. Both extreme CG results are shown in Tables 10.4 and 10.5.

**Table 10.4: Total Weight**

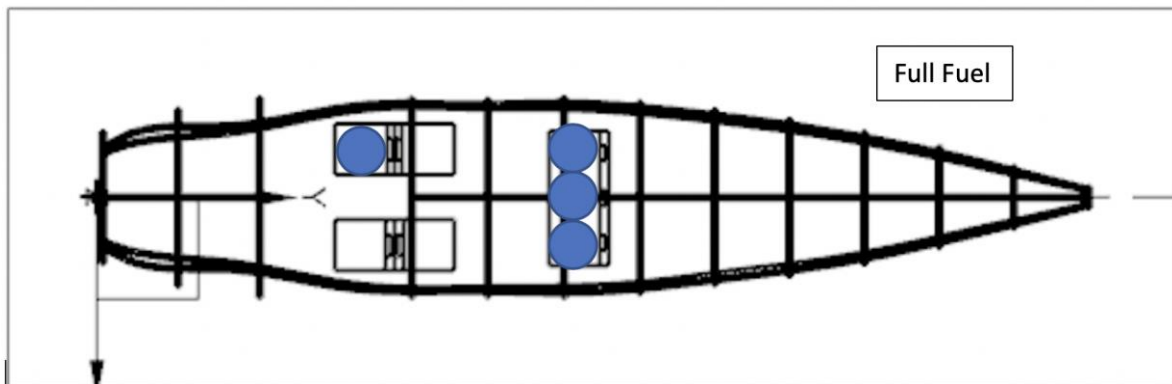
Weight	Value (lb)
MTOW	4,272
EOW	2,714

**Table 10.5: Extreme CG**

Extreme CG Location (ft)	Value (ft)
Extreme fore CG	10.31
Extreme Aft CG	11.77



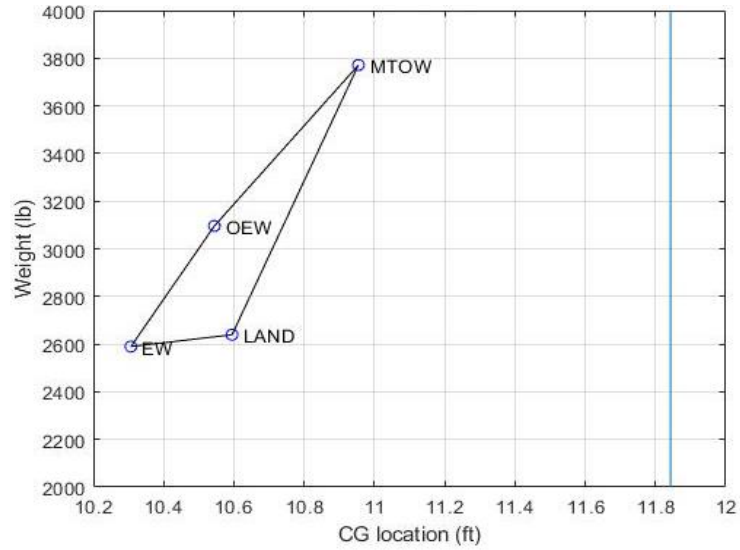
**Figure 10.1: Extreme Fore CG Loading Condition**



**Figure 10.2: Extreme Aft CG Loading Condition**

### C. CG Envelope

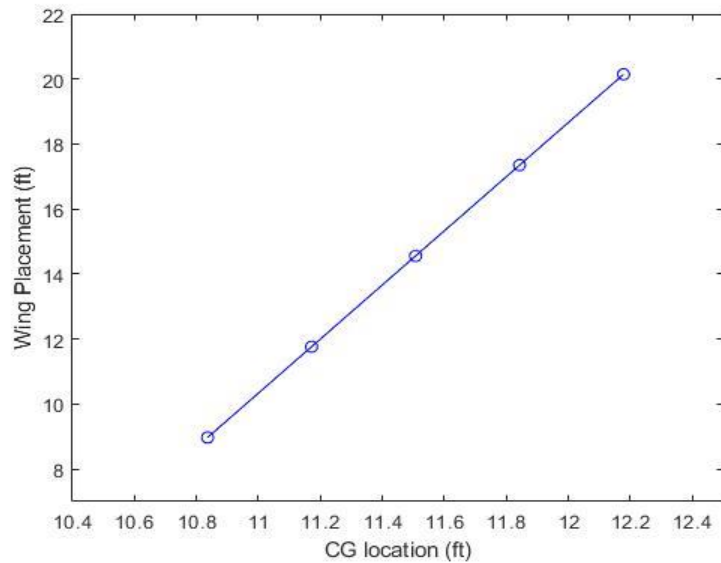
During the sizing mission profile, the CG location will change with each segment. The following Figure 10.1 shows the shift in CG locations from the nose of the aircraft during a complete flight. The standard empty weight is 2,714 lb which includes weights of the structure and installed systems of the aircraft. Operating empty weight suggests the weight of the aircraft with full fuel tanks and one pilot, while the MTOW includes a full payload and maximum allowable fuel. The landing weight represents the final weight when mission fuel is burned with a full payload. All the CG locations are between the nose of the aircraft and the neural point, 11.84 ft from the nose of the aircraft, ensuring stability. As shown in Figure 10.3 the location of the neutral point was plotted as a vertical straight line.



**Figure 10.3: CG Envelope under Sizing Mission**

#### D. Trade Study

Figure 10.2 shows the trade study of the wing placement with an increment of 2.79 ft. Five data points were collected where the mean of which was the actual design location of the wing. The graph shows a linear relationship between CG location and wing placement.

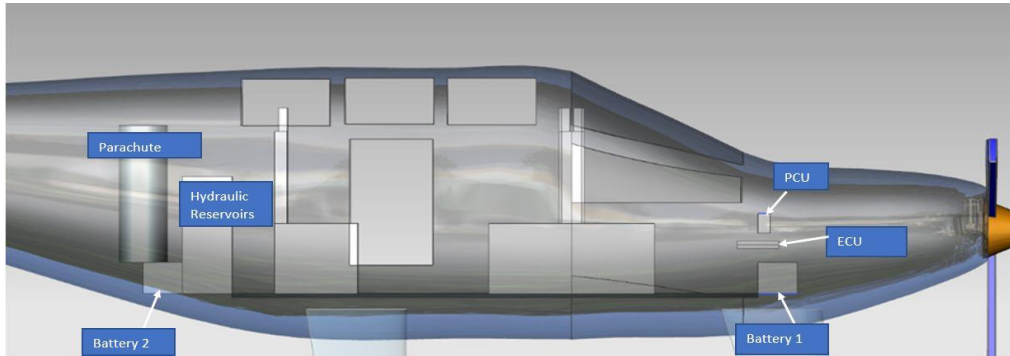


**Figure 10.4: CG Location vs. Wing Placement**

## XI. AUXILIARY SYSTEMS

### A. Overall System Configuration

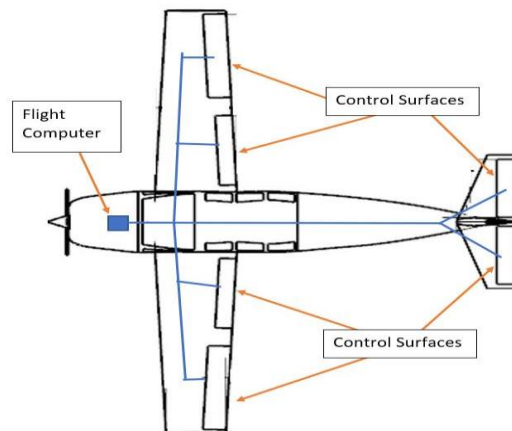
The IA Mark 2 incorporates all the necessary systems to make the aircraft functional, safe and comfortable. The systems were configured to not interfere with each other. The overall configuration of all the auxiliary systems are shown in the Figure 11.1.



**Figure 11.1. Overall System Configuration**

### B. Flight Controls

The IA Mark 2 will incorporate a fly-by-wire system for the aircraft's flight control. Fly-by-wire system replaces the cables, pulleys and hydraulics with wires and actuators. A flight computer was incorporated with the avionics to control the movement of control surfaces. The fly-by-wire system was chosen to reduce the weight of the aircraft, due to wires being used instead of hydraulic cables and pulleys. The detailed configurations of the flight controls can be seen in Figure 11.2.

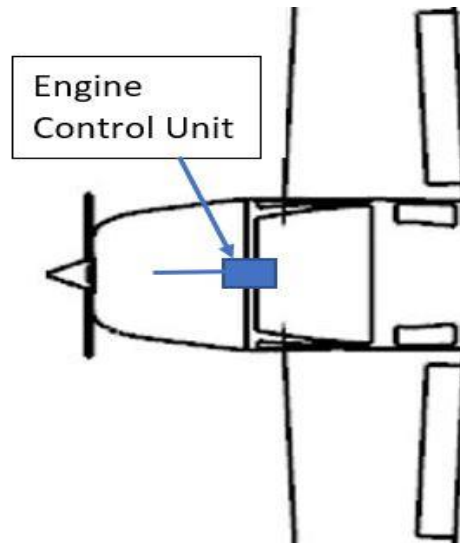


**Figure 11.2: Flight Control Systems Overview**



### C. Engine Controls

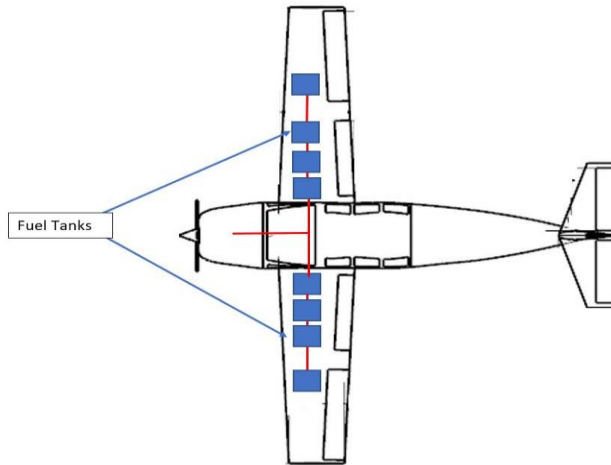
The IA Mark 2 incorporates Full Authority Digital Engine Control system attached to the engine. The FADEC system is connected to an Engine Control Unit and the avionics systems. The FADEC system is used to control the fuel flow and air flow of the engine. The ECU is placed behind the engine. The IA Mark 2 chose the FADEC system for a better fuel efficiency and safer flight. A detailed configuration of the engine control system can be seen in Figure 11.3.



**Figure 11.3: Engine Control Systems Overview**

### D. Fuel System

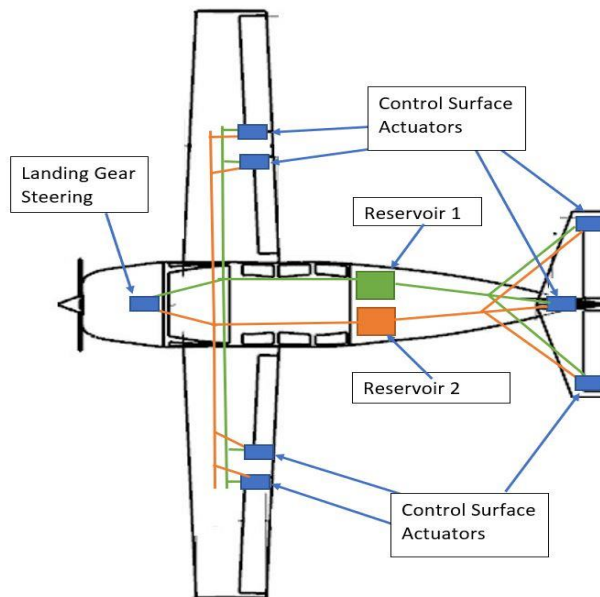
The IA Mark 2's fuel tanks are placed in the wing. Fuel lines are placed under the cabin leading to the engine. The fuel lines configuration can be seen in Figure 11.4. Additional details regarding the fuel system of the IA Mark 2 are given in Section V.



**Figure 11.4: Fuel Lines Overview**

### **E. Hydraulic System**

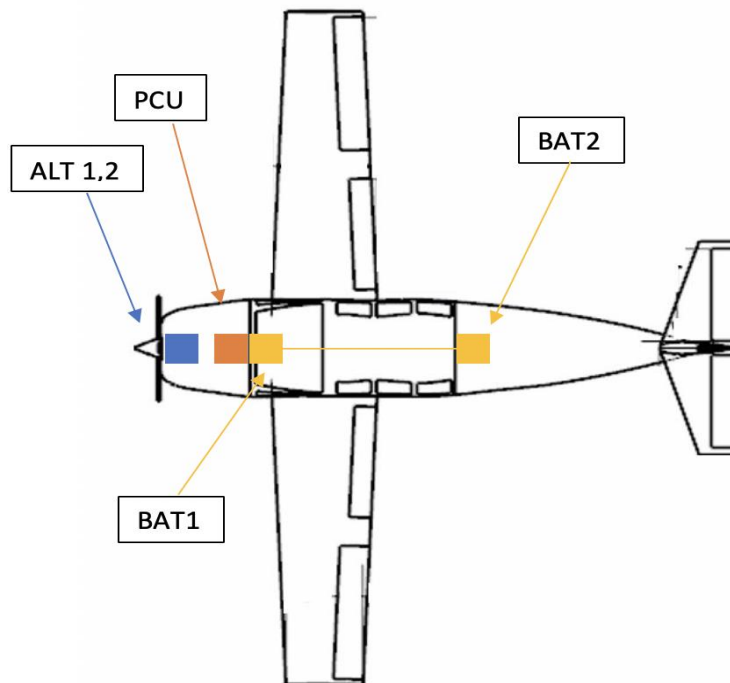
The IA Mark 2 incorporates hydraulic systems for control surface actuators, landing gear brakes and steering. The IA Mark 2 uses a fly-by-wire system, therefore hydraulics will only be required for the control surfaces. Hydraulics are used on the nose landing gear for steering and on all landing gear for braking. Two separate reservoirs and lines were placed to create redundancy. Therefore, if malfunction occurs on one line, the aircraft can operate as intended. The overview of the hydraulic systems can be seen in Figure 11.5.



**Figure 11.5: Hydraulic Systems Overview**

## F. Electrical System

The IA Mark 2 will be equipped with an electrical system including a 28-volt direct current for both main and backup power generator, two batteries, and two alternators. The generator will be installed in the engine of the aircraft. Battery 1 (BAT1) will be placed on the firewall, and Battery 2 (BAT2) will be placed at the rear pressure bulkhead in the consideration of system safety and equipment check. A Power Control Unit that regulates both batteries will be placed on the fire wall. The electrical system will provide electrical power at all times for flight instrumentation, avionics, passenger services and other electrically-powered systems during operation. The electrical system layout is demonstrated in Figure 11.6.



**Figure 11.6. Electrical Systems Overview**

## G. Pneumatic System and Environmental Control System

The IA Mark 2 will have an environmental control system to provide air conditioning and temperature control to ensure a comfortable cabin environment. The IA Mark 2 will not have a pneumatic system since no pressurization is needed due to the chosen cruise altitude.

## H. Emergency System

The IA Mark 2 will have seven oxygen masks stored in the compartments above passenger and crew seats. A smoke detector will be installed in the cabin between the pilot seat and second row seat. A fire extinguisher will be placed in the cabin. An airframe parachute system will be included in consideration of increasing safety. Cockpit windows are designed to serve as emergency exits and can be removed under emergency conditions.

## I. Avionics

**Table 11.1: Avionics<sup>42</sup>**

Component	Model
Navigation	GR 225
Flight Deck Display	G500 TXi
Autopilot	GFC 500
Weather	GDL 39
Air Traffic System	GTS 800

The avionics systems listed in Table 11.1 was chosen specifically to meet the requirements stated in the CFR Part 23. Given these requirements, it was the goal of Iota Air to choose systems that not only met these conditions but also minimized the cost of the project. The Garmin G500 is compatible with most avionic systems and has the ability to interface with autopilots which offers the customers the option of having a semi-autonomous aircraft during cruise.

The IA Mark 2 does not have any plans to incorporate fully autonomous capabilities. This is due to the RFP requiring the aircraft to be certifiable by 2025. Most experts believe that the technology, industry, and certification requirements will not be ready by that time.

## **XII. COST ANALYSIS**

### **A. DAPCA IV Cost Model**

A cost model was completed for the IA Mark 2 using the DAPCA IV cost model from Gudmundsson<sup>41</sup> and Raymer<sup>11</sup>. This model was first introduced by RAND in 1987. It is an acceptable model for estimating the RDT&E, flyaway and operating costs from an initial aircraft design. The DAPCA IV cost model was last updated in 2012. In order to compute values in 2019 dollars, Iota Air used the Bureau of Labor Statistics inflation calculator to correctly estimate the costs for the IA Mark 2 in 2019 dollars. All dollar amounts shown in the cost analysis section are based on 2019 dollars. The DAPCA IV model calculates cost estimates based on a five year production basis. According to the RFP, the amount of aircraft produced should be 500, 1000 and 2000 units.

#### *1. Research and Development*

Research and development consists of the cost of engineering, tooling, quality control, development support and flight testing. Following the DAPCA IV process requires looking at multiple design aspects that can increase or decrease cost. Since a major design requirement is to design an aircraft that maximizes profits for operators, Iota Air focused on reducing the cost of the IA Mark 2 through many design considerations. For example, Iota Air chose to utilize fixed landing gear because it will save on the overall cost of the aircraft due to less systems that would normally be required for retractable landing gear. Iota Air also chose to use one engine because it will cost less than two engines in installation and maintenance fees. These are just a few examples of design considerations that were made in order to reduce aircraft costs. A complete list of all RDT&E costs can be found in Table 12.1.

**Table 12.1: Total RDT&E Cost for 5 Year Production (in millions)**

<b>Cost Parameter</b>	<b>500 Units Produced</b>	<b>1000 Units Produced</b>	<b>2000 Units Produced</b>
Engineering	\$95	\$108	\$122
Tooling	\$78	\$92	\$109
Quality Control	\$70	\$100	\$144
Manufacturing	\$411	\$592	\$851
Development Support Cost	\$2.85	\$2.85	\$2.85
Flight Test Cost	\$0.38	\$0.38	\$0.38
<b>RDT&amp;E Project Cost</b>	<b>\$245</b>	<b>\$303</b>	<b>\$378</b>
<b>RDT&amp;E Cost per Aircraft</b>	<b>\$0.49</b>	<b>\$0.30</b>	<b>\$0.19</b>

## 2. *Flyaway Cost*

Flyaway costs include the avionics, airframe and engine cost. Iota Air chose to use a single piston engine instead of a turbine engine because it will reduce the cost of the propulsion system. Most piston engines cost between \$40,000-\$80,000 while turbine engines can cost anywhere between \$100,000-\$200,000. This is a significant cost and Iota Air believes that using a piston engine is the most cost effective option for the mission parameters specified by the AIAA. Another important part of the flyaway cost is the avionics package. Iota Air chose a cost effective avionics package that met the CFR Part 23 requirements. Table 12.2 provides the chosen avionics component cost with the total avionics cost. Table 12.3 gives a detailed look at the flyaway cost for the IA Mark 2.

**Table 12.2: IA Mark 2 Avionics Cost** <sup>42</sup>

Component Name	Component Model	Cost
Navigation	GR 225	\$2,095
Flight Deck Display	G500 TXi	\$11,995
Autopilot	GFC 500	\$6,995
Weather	GDL 39	\$539
Air Traffic System	GTS 800	\$10,395
Total	-	\$32,019

**Table 12.3: Total Flyaway Cost for 5 Year Production (in millions)**

Cost Parameter	500 Units Produced	1000 Units Produced	2000 Units Produced
Flyaway Project Cost	\$657	\$895	\$1229
Flyaway Cost per Aircraft	\$1.31	\$0.895	\$0.615

### 3. Unit Cost Comparison

After completing the RDT&E and flyaway cost an estimation for the IA Mark 2 unit cost can be determined. Table 12.4 provides an estimated range of prices for the IA Mark 2 based on various profit margins. Overall the base price of the IA Mark 2 is \$755,000.

**Table 12.4: IA Mark 2 Unit Cost (2019 Dollars)**

Cost Parameter per Aircraft	500 Units Produced	1000 Units Produced	2000 Units Produced
Base Cost (0% Profit)	\$1,467,000	\$1,041,000	\$755,000
10% Profit Margin	\$1,614,000	\$1,146,000	\$831,000
15% Profit Margin	\$1,687,000	\$1,198,000	\$869,000

Another requirement from the RFP is that the IA Mark 2 is cost competitive to similar aircraft such as the Piper PA-46 and Cirrus SR22. Iota Air performed a cost comparison on similar aircraft that compared unit cost, passenger number and cruise speed. The results of the cost comparison are in Table 12.5.

**Table 12.5: Similar Aircraft Comparison**

<b>Aircraft</b>	<b>MTOW (lb)</b>	<b>Passenger Number</b>	<b>Cruise Speed (KTAS)</b>	<b>Unit Price (2019 Dollars)</b>
Cirrus SR22 <sup>5</sup>	3,600	4	183	\$640,000
<b>Iota Air IA Mark 2</b>	<b>4,273</b>	<b>6</b>	<b>195</b>	<b>\$831,000</b>
Beechcraft Bonanza <sup>3</sup>	3,650	5	176	\$845,000
Diamond DA-62 <sup>8</sup>	5,071	6	198	\$1,080,000
Piper PA-46 M600 <sup>10</sup>	6,000	6	274	\$2,040,000

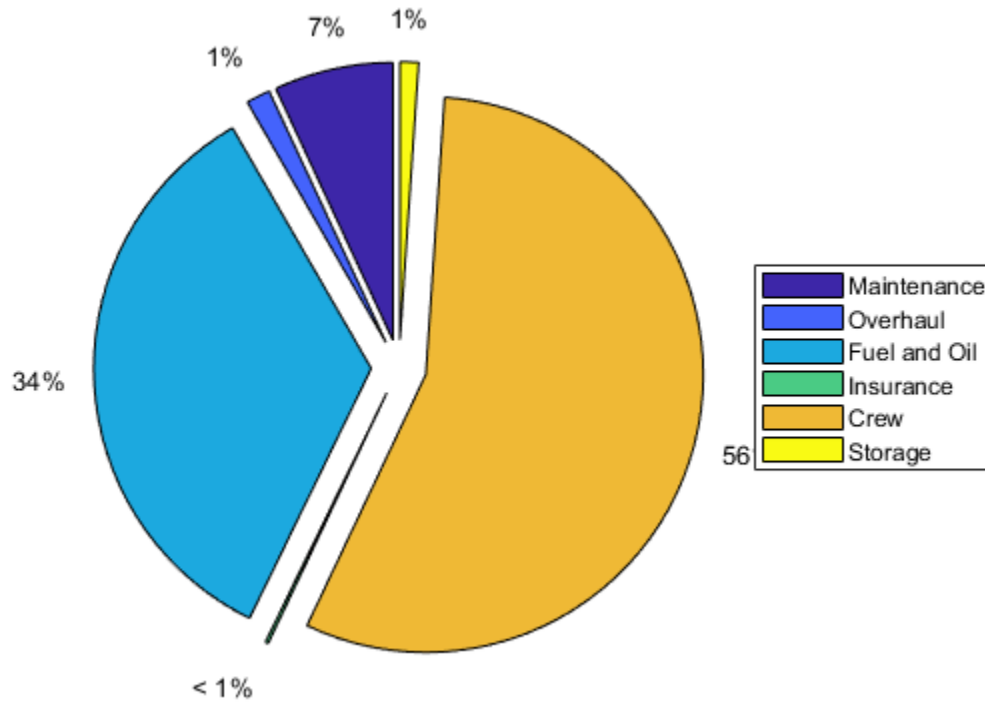
The IA Mark 2 will be a cost competitive when compared to similar aircraft. Allowing up to six passengers gives operator an added bonus that they can charge more per ticket and still be competitive with other airlines. The RFP requested an aircraft that will be cost competitive and maximize profit for future operators and Iota Air believes that the IA Mark 2 will meet that request.

## **B. Operating Costs**

Operating cost components for the IA Mark 2 include everything after the aircraft is in service such as fuel, crew salaries and maintenance. Using the DAPCA IV model, Iota Air calculated the total operating cost based on flight hours per year. According to the RFP the IA Mark 2 should be expected to fly an average of 20 times per week with a total flight time less than or equal to 45 minutes. An expected yearly flight hour total of 780 hours was calculated based in the RFP mission description. Iota Air also estimated the yearly operating cost for 520 and 1,560 flight hours. 520 hours represents a 30 minute average flight time and 1,560 represents a 90 minute average flight time. Iota Air chose to look at a range of flight hours due the IA Mark 2 being designed for both the reference mission and sizing mission. A pie chart giving a percentage difference for each operating cost component can be seen in Figure 12.1. This pie chart is a



representation of the operating costs specific to the reference mission. A detailed list of each operating cost component can be found in Table 12.6. The reference mission operating costs are bolded in column three.



**Figure 12.1: Reference Mission Operating Cost Pie Chart**

**Table 12.6: IA Mark 2 Operating Costs**

Operating Cost Component	520 FH per Year	780 FH per Year	1,560 FH per Year	Cost per FH
Maintenance Cost	\$12,890	<b>\$19,336</b>	\$38,672	\$25.00
Overhaul Cost	\$2,600	<b>\$3,900</b>	\$7,800	\$5.00
Storage Cost	\$3,000	<b>\$3,000</b>	\$3,000	Fixed Rate
Fuel and Oil Cost	\$64,000	<b>\$96,000</b>	\$192,000	\$123.00
Insurance Cost	\$13,535	<b>\$13,535</b>	\$13,535	Fixed Rate
Crew Cost	\$104,000	<b>\$156,000</b>	\$312,000	\$200.00
Total Cost	\$200,525	<b>\$292,271</b>	\$567,507	\$375.00

## C. Ticket Pricing

### 1. Reference Mission

According to the RFP, the reference mission requires a 50% passenger payload for a 45 minute flight. At a 50% passenger payload the IA Mark 2 can hold 3 passengers. Iota Air researched similar airline ticket prices for flights of similar lengths and completed a cost comparison. Ticket prices are based on individual passenger flights. Overall Iota Air's IA Mark 2 can have ticket prices as low as \$47 to break even with hourly operating costs per flight.

**Table 12.7: Reference Mission Ticket Pricing**

Airline Company	Flight Time	Individual Passenger Ticket Price
<b>Iota Air</b>	<b>45 minutes</b>	<b>\$47</b>
Skyway Air Taxi	46 minutes	\$1,236
Cape Air	53 minutes	\$89
Mokulele Airlines	45 minutes	\$154

### 2. Sizing Mission

According to the RFP, the sizing mission requires a full passenger payload for a 250 nmi flight. The IA Mark 2 can hold a total of 6 passengers for the sizing mission. Iota Air estimated that the flight time will be about 90 minutes for the sizing mission flights. Iota Air researched similar airline ticket prices for flights of similar lengths and completed a cost comparison.

**Table 12.8: Sizing Mission Ticket Pricing (90 min Flight Time)**

Airline Company	Flight Time	Individual Passenger Ticket Price
<b>Iota Air</b>	<b>90 minutes</b>	<b>\$94</b>
Skyway Air Taxi	90 minutes	\$2,049
Cape Air	75 minutes	\$119
Mokulele Airlines	90 minutes	\$132

Overall, the IA Mark 2 will allow operators to provide low cost air fare to their customers. Many private air taxi companies are located in specific regions or operate as private airline organizations. The IA Mark 2 is designed for companies looking to expand their operations into thin haul transport and air taxi services. With low ticket prices that cover the operating cost of the aircraft, the IA Mark 2 will be an excellent choice for the rising market of on-demand air travelers.

#### **D. Methods for Reducing Aircraft Cost**

There are many ways to decrease the cost of the IA Mark 2. One way to decrease the IA Mark 2's cost is to reduce the overall size and structure of the aircraft. Iota Air chose to design a larger aircraft that could accommodate up to six passengers. The RFP requires an aircraft that design that can hold up to four passengers. Reducing the number of passengers will reduce the weight of the aircraft. It will also reduce the size of the aircraft. Designing and manufacturing an aircraft that is smaller than the current IA Mark 2 design will reduce the cost of the aircraft.

Another method for reducing the cost of an aircraft is to reduce the cruise speed and therefore select an engine that has a lower power output. In order to meet the flight time requirement Iota Air had to choose an engine that could provide enough power to meet that requirement. If the flight time requirement was not a part of the RFP, Iota Air could have selected a smaller engine that would have reduced the cost of the aircraft. Choosing a smaller engine would also reduce the overall propulsion weight of the aircraft. Reducing the weight of an aircraft almost always reduced the total cost.

Material selection is an important part of any aircraft design. Iota Air chose to use a composite skin on the IA Mark 2. The drawback of using composite material is that the manufacturing cost will increase. Using composite materials does allow for a smaller weight as compared to using all aluminum airframes. There is a tradeoff when looking at materials for aircraft design. When the material selection is optimized for the cost it will consist of multiple materials, composite and metal. This will help reduce the cost of the aircraft.

## **E. Uncertainty and Accuracy**

The DAPCA IV Cost Analysis method was developed in 1987. Some corrections have been made over the years but the method used in Raymer was updated as of 2012<sup>11</sup>. This method also takes into account different types of aircraft. This reduces the accuracy because cost analysis methods should be different based on the type of aircraft design. In order to correct for the uncertainty of equations used in Raymer, Iota Air used an additional cost analysis method from Gudmundsson. The Gudmundsson cost analysis method was derived specifically for general aviation aircraft. Using both methods allowed for a more accurate cost analysis<sup>41</sup>.

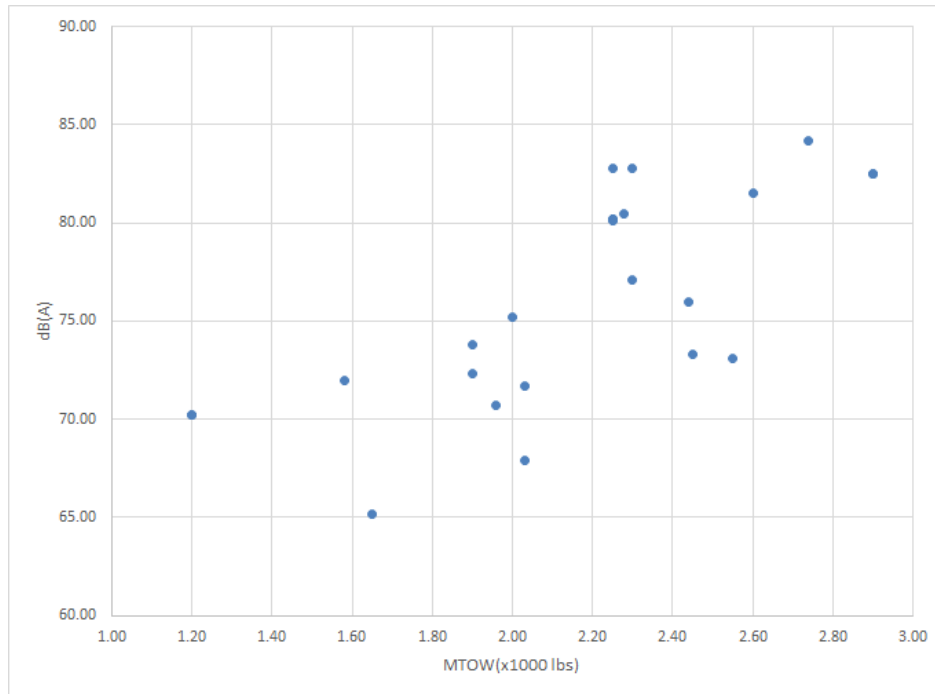
### **XIII. ACOUSTICS**

#### **A. Acoustic Requirements**

According to the parameters of the mission, noise is limited to the single-engine limits set in place by FAA 14 CFR Part 36 Appendix G Part D (G36.301)<sup>43</sup>. During takeoff, the noise of the aircraft as measured from the runway is restricted according to a noise level versus weight curve described as starting from 1,257 lb and 70 dB(A). From that point, the limit increases with the logarithm of the weight at a rate of 10.75 dB(A) doubling the weight until reaching an 85 dB(A) limit at 3,307 lb. From this limit until 19,000 lb, the noise limit is constant at 85 dB(A). According to this rule, the noise limit of the IA Mark 2 is set to be 85 dB(A) due to its max takeoff weight being above 3,307 lb while still being under 19,000 lbs.

#### **B. Acoustic Estimation**

Lycoming engines have been used on certified aircraft as recently as 2012<sup>44</sup> and the engine used on the IAMK2 is an 8 cylinder Lycoming IO 720. The figure below, however, describes certification data of 4 cylinder engines from not only Lycoming but also Continental and Rotax engine. Assuming a proportionally halved MTOW, the IAMK2 should fall between 70 and 75 dB(A). If there was a 3 dB(A) buffer that represents doubling the amount of engines and another 3 dB(A) to account for airframe noise, the maximum noise level would still be 4 dB(A) below the 85dB(A) limit. Based on those certification figures, noise will not be an issue. Based on this data, there will not be any special considerations that need to be taken to reduce the noise produced by the engine or its propeller.



**Figure 13.1: US Certified Propeller Driven Small Airplanes<sup>44</sup>**

### C. Model Uncertainty and Accuracy

These estimations represent preliminary estimations to the noise that will be produced by the IAMK2 and as such is limited in the accuracy it represents. Despite this however, the predictions still fall well below the noise limits prescribed by the RFP and as such, models with greater accuracy such as the NASA ANOPP would be beneficial but not be necessary.

#### **XIV. CONCLUSION**

The need for on demand cheap transportation has grown with the introduction of companies like Uber and Lyft. Airlines are exploring options to provide thin haul transport and air taxi services for customers around the world. Iota Air has completed the final design for the IA Mark 2. This single piston engine general aviation aircraft will meet the requirements set by the AIAA and exceed the requirements for a long range sizing mission. The IA Mark 2 will have an estimated MTOW of 4,273 lb. It will be able to travel as speeds up to 210 knots and maximum ferry mission range of 1,092 nmi. Based on these key performance metrics the IA Mark 2 meets all RFP requirements. The main objective for the IA Mark 2 was to create a cost competitive aircraft that is profitable for future operators. After completing a cost analysis Iota Air estimated that the unit cost of the IA Mark 2 will be \$831,000. This is cheaper than similar aircraft like the Beechcraft Bonanza and Piper PA-46 making the IA Mark 2 a more profitable option for thin haul transport and air taxi services.

## REFERENCES

- <sup>1</sup> AIAA, “2018-2019 Undergraduate Team Aircraft – Thin Haul Transport and Air Taxi”, URL: <https://www.aiaa.org/2018-2019-Undergrad-Team-Engine-Design-Competition>
- <sup>2</sup> BRS Aerospace “FAQs” [online database], URL: <https://brsaerospace.com/questions/>
- <sup>2</sup> “Beechcraft Bonanza.” Beechcraft Aircraft, <https://beechcraft.txtav.com/en/bonanza-g36>
- <sup>4</sup> Cirrus Aircraft. “SR20.” Cirrus Aircraft, <https://cirrusaircraft.com/aircraft/sr20/>
- <sup>5</sup> Cirrus Aircraft. “SR22.” Cirrus Aircraft, <https://cirrusaircraft.com/aircraft/sr22/>
- <sup>6</sup> Cessna. Textron Aviation. “Cessna Skyhawk.” Cessna, <https://cessna.txtav.com/en/piston/cessna-skyhawk>
- <sup>7</sup> Cessna. Textron Aviation. “Cessna Skylane.” Cessna, <https://cessna.txtav.com/en/piston/cessna-skylane>
- <sup>8</sup> Diamond Aircraft. “DA62.” Diamond Aircraft, <https://www.diamondaircraft.com/aircraft/da62/>
- <sup>9</sup> Piper. “Seneca.” Piper, <https://www.piper.com/aircraft/trainer-class/seneca-v/>
- <sup>10</sup> Piper. “Welcome to the M600.” Piper, <https://www.piper.com/aircraft/m-class/m600/>
- <sup>11</sup> Raymer, D. P., *Aircraft Design: A Conceptual Approach*, AIAA Education Series, AIAA, Washington, DC. 1992
- <sup>12</sup> ISIXSIGMA. “PUGH MATRIX.” <https://www.isixsigma.com/dictionary/pugh-matrix/>
- <sup>13</sup> “Airbus A330-300 (333).” *Seat Guru*, [www.seatguru.com/airlines/AirAsia\\_X/AirAsia\\_X\\_Airbus\\_A330-300.php](http://www.seatguru.com/airlines/AirAsia_X/AirAsia_X_Airbus_A330-300.php).
- <sup>14</sup> European Aviation Safety Agency. “Type-Certificate Data Sheet for Continental-IO 550 Engines.” EASA, 2017.
- <sup>15</sup> European Aviation Safety Agency, “Type-Certificate Data Sheet for Lycoming TIO-540 Engine Series.” EASA, [https://www.easa.europa.eu/sites/default/files/dfu/TCDS%20IM.E.119%20Lycoming%20TEO\\_540\\_Initial%20Issue\\_20181212.pdf](https://www.easa.europa.eu/sites/default/files/dfu/TCDS%20IM.E.119%20Lycoming%20TEO_540_Initial%20Issue_20181212.pdf)
- <sup>16</sup> Lycoming Engines. “Operator’s Manual; Lycoming; IO 720 Series.” Lycoming, Fourth Edition, Williamsport, PA, 2006.



- <sup>17</sup> Department of Transportation. "Type Certificate Data Sheet No. 1E15 for Texatron Lycoming IO-720," Federal Aviation Administration, 1988.
- <sup>18</sup> McCormick, B.W., *Aerodynamics, Aeronautics, and Flight Mechanics*, Wiley, Second Edition, 1995.
- <sup>19</sup> Department of Transportation. "Type Certificate Data Sheet No. P6EA for Hartzell Propeller Inc." Federal Aviation Administration, 2002.
- <sup>20</sup> Hartzell Propeller Inc. "Metal Spinner Maintenance Manual." Hartzell, Piqua, OH, 2014.
- <sup>21</sup> Comanche Flyer. "Comanche 400 (PA-24-400) 1964-1965." Comanche Flyer, <http://www.comancheflyer.com/PA24-400.htm>
- <sup>22</sup> Comanche Flyer. "Comanche 260 series." Comanche Flyer, <http://www.comancheflyer.com/PA24-260.htm>
- <sup>23</sup> NACA Airfoil Experimental Data  
<https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19930090976.pdf>
- <sup>24</sup> NLF0115 paper  
<https://m-selig.ae.illinois.edu/pubs/SeligMaughmerSomers-1995-JofAC-NLF-Airfoil-Design.pdf>  
<https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19910003259.pdf>
- <sup>25</sup> High Lift devices  
[https://www.fzt.haw-hamburg.de/pers/Scholz/HOOU/AircraftDesign\\_5\\_PreliminarySizing.pdf](https://www.fzt.haw-hamburg.de/pers/Scholz/HOOU/AircraftDesign_5_PreliminarySizing.pdf)
- <sup>26</sup> VSP Parasitic Drag  
<http://openvsp.org/wiki/doku.php?id=parasitedrag>
- <sup>27</sup> OSwalds Hamburg  
[https://www.fzt.haw-hamburg.de/pers/Scholz/OPerA/OPerA\\_PUB\\_DLRK\\_12-09-10.pdf](https://www.fzt.haw-hamburg.de/pers/Scholz/OPerA/OPerA_PUB_DLRK_12-09-10.pdf)
- <sup>28</sup> BRS White paper  
[https://www.brsaerospace.com/pdf/BRS\\_Cessna\\_182\\_White\\_paper.pdf](https://www.brsaerospace.com/pdf/BRS_Cessna_182_White_paper.pdf)
- <sup>29</sup> BRS Deployment Video  
<https://www.youtube.com/watch?v=gBCUQIF3MMU&t=47s>
- <sup>30</sup> Parachute CD A.J. Smits, "A Physical Introduction to Fluid Mechanics," John Wiley & Sons, ISBN 0-471-25349-9 (2nd Printing May, 2000).
- <sup>31</sup> Roskam, Jan, and Chuan-Tau Edward Lan. *Airplane Aerodynamics and Performance*. DARcorporation, 2008.
- <sup>32</sup> Pilot's handbook of aeronautical knowledge. (2008). [Washington, D.C.]: U.S. Dept. of Transportation, Federal Aviation Administration, pp.11-7.
- <sup>33</sup> Sadraey, M.H., *Aircraft Design A Systems Engineering Approach*, Wiley, New Hampshire, 2013.
- <sup>34</sup> Cook, M.V., *Flight Dynamics Principles*, Elsevier, Burlington, MA. 2007

- <sup>35</sup> Roskam, J. *Airplane Design - Part 3: Layout Design of Cockpit, Fuselage, Wing and Empennage: Cutaways and Inboard Profiles*, DARcorporation, Ottawa, Kansas, 1986.
- <sup>36</sup> Department of Defense, *Composite Materials Handbook*, Vol. 2, June 2002.
- <sup>37</sup> ASM Aerospace Specification Metals Inc. *Aluminum - Technical Data Sheets*.  
<http://www.aerospacemetals.com/aluminum-distributor.html>
- <sup>38</sup> Performance Composites Ltd. *Mechanical Properties of Carbon Fibre Composite Materials*.  
[http://www.performance-composites.com/carbonfibre/mechanicalproperties\\_2.asp](http://www.performance-composites.com/carbonfibre/mechanicalproperties_2.asp)
- <sup>39</sup> "Plates," John Hopkins University [Lecture].  
<http://www.ce.jhu.edu/cfs/cfslibrary/SSRC%20Guide%202009%20Ch%204%20plates%20Schafer%20version.pdf>
- <sup>40</sup> Currey, N., *Aircraft Landing Gear Design: Principles and Practices*. American Institute of Aeronautics and Astronautics, Inc., Washington D.C., 1988.
- <sup>41</sup> Gudmundsson Snorri, *General Aviation Aircraft Design: Chapter 2 - Aircraft Cost Analysis*, Elsevier, 2014
- <sup>42</sup> Garmin. "General Aviation Solution" <https://buy.garmin.com/en-US/US/in-the-air/general-aviation/cInTheAir-c582-p0.html>
- <sup>43</sup> Noise Requirements  
[https://www.law.cornell.edu/cfr/text/14/appendix-G\\_to\\_part\\_36](https://www.law.cornell.edu/cfr/text/14/appendix-G_to_part_36)
- <sup>44</sup> Noise Estimation data  
[https://www.faa.gov/about/office\\_org/headquarters\\_offices/apl/noise\\_emissions/aircraft\\_noise\\_levels/](https://www.faa.gov/about/office_org/headquarters_offices/apl/noise_emissions/aircraft_noise_levels/)
- <sup>45</sup> 14 Code of Federal Regulations Part 23-Airworthiness Standards: Normal Category Airplane  
<https://www.law.cornell.edu/cfr/text/14/part-23>

**APPENDIX A: CFR Part 23 Certification Requirements<sup>45</sup>**

<b>Designation Number</b>	<b>Description</b>	<b>Section</b>
23.1191	Firewalls	V, IX
23.1457	Cockpit voice recorders	XI
23.1459	Flight data recorders	XI
23.2100	Weight and center of gravity	X
23.2105	Performance data	VII
23.2110	Stall speed	VII
23.2115	Takeoff performance	VII
23.2120	Climb requirements	VII
23.2125	Climb information	VII
23.2130	Landing	VII
23.2135	Controllability	VIII
23.2140	Trim	VIII
23.2145	Stability	VIII
23.2150	Stall characteristics, stall warning, and spins	VII
23.2165	Performance and flight characteristics requirements for flight icing conditions	VII
23.2200	Structural design envelope	IX
23.2210	Structural design loads	IX
23.2215	Flight load conditions	IX
23.2225	Component loading conditions	IX
23.2230	Limit and ultimate loads	IX
23.2235	Structural strength	IX
23.2240	Structural durability	IX
23.2260	Materials and processes	IX
23.2270	Emergency conditions	XI

23.2300	Flight control systems	XI
23.2305	Landing gear systems	IX
23.2315	Means of egress and emergency exits	XI
23.2320	Occupant physical environment	IV
23.2325	Fire protection	XI
23.2330	Fire protection in designated fire zones and adjacent areas	XI
23.2400	Power plant installation	V
23.2405	Automatic power or thrust control systems	XI
23.2410	Power plant installation hazard assessment	V
23.2415	Power plant ice protection	V
23.2425	Power plant operational characteristics	V
23.2430	Fuel systems	XI
23.2435	Power plant induction and exhaust systems	V
23.2440	Power plant fire protection	V
23.2505	Function and installation	XI
23.2510	Equipment, systems and installations	XI
23.2525	System power generation, storage and distribution	XI
23.2530	External and cockpit lighting	XI
23.2535	Safety equipment	XI
23.2545	Pressurized systems elements	XI
23.2550	Equipment containing high-energy rotors	V
23.2615	Flight, navigation and power plant instruments	XI
23.2620	Airplane flight manual	II