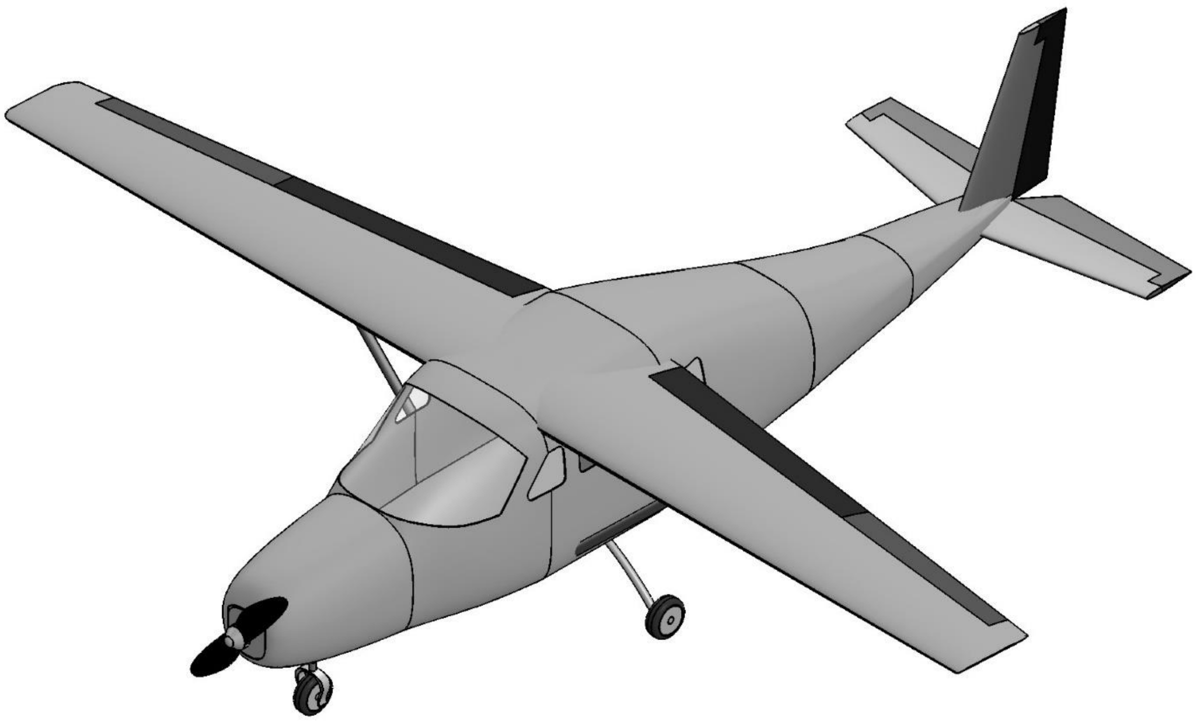
Roll Control *presents* EFA-1



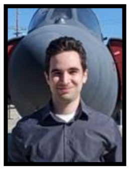
In response to the 2018-2019 AIAA Thin Haul Transport and Air Taxi Design Competition

Presented by California State Polytechnic University Pomona

Aerospace Engineering Department

Aircraft Design 2018–2019

Roll Control's Organizational Chart



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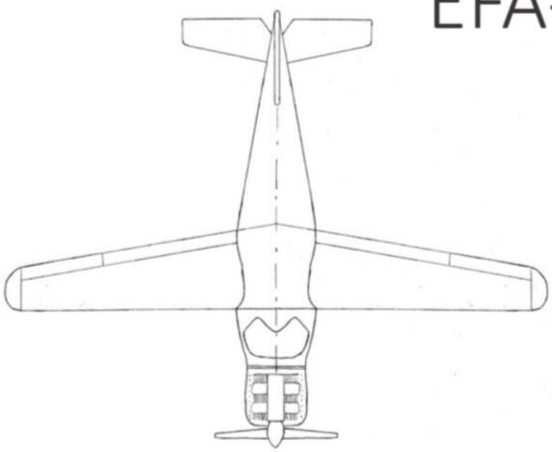
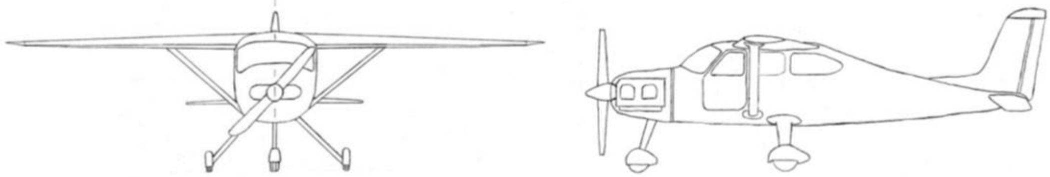
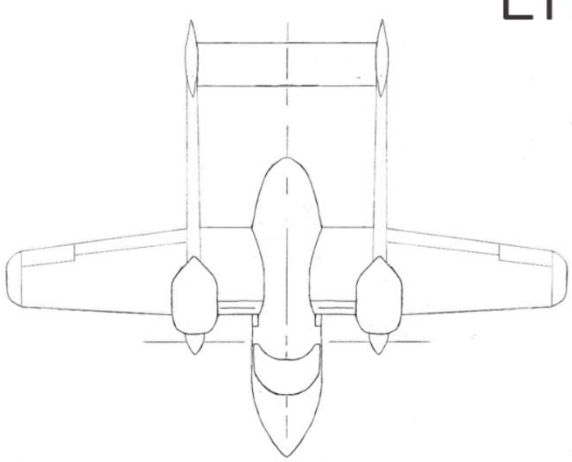
EFA-1



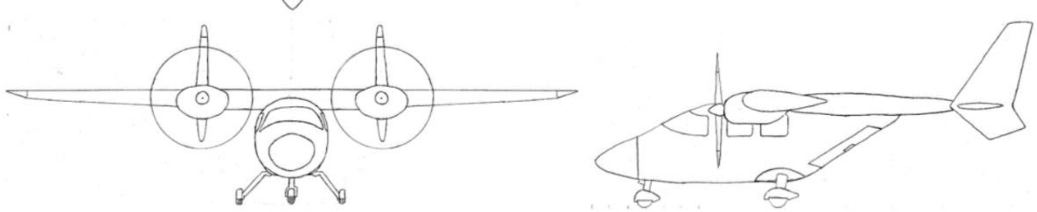
$MGTOW = 3010\ lb$	$W_{TO}/S = 22\ psf$
$S_{REF} = 137\ ft^2$	$P/W = 0.12\ hp/lb$
$MAC = 4.3\ ft$	$Length = 26\ ft$
$Span = 33\ ft$	$AR = 8$
Engine = TIO-540-J2B [350 hp]	



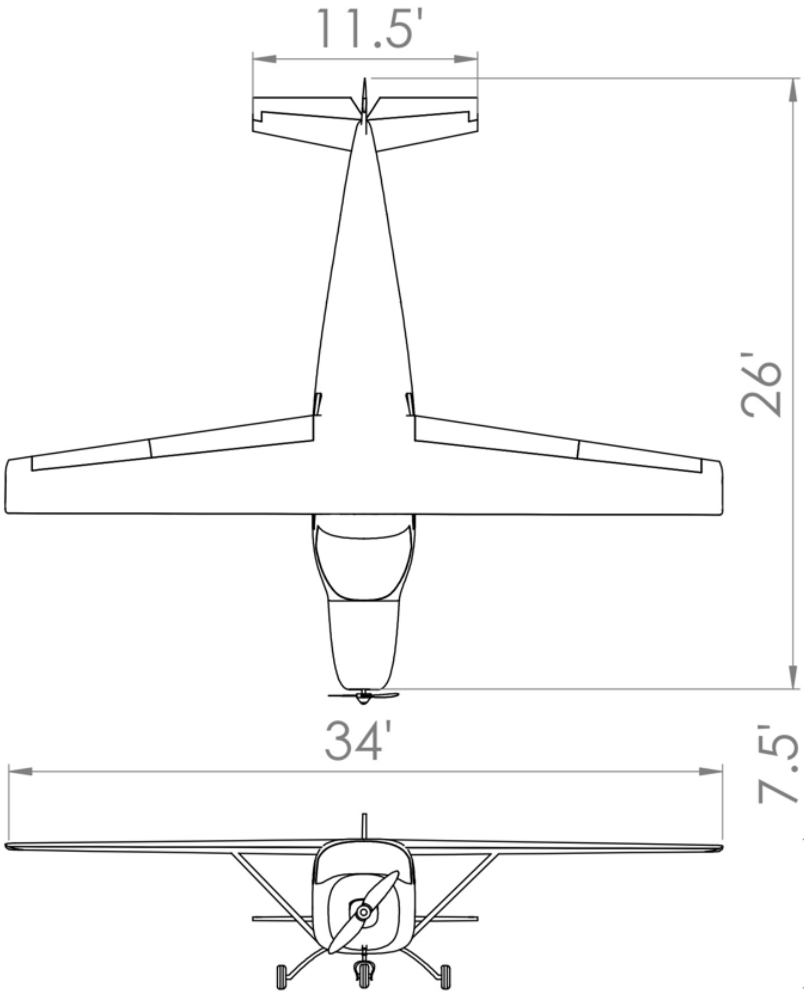
EFA-2



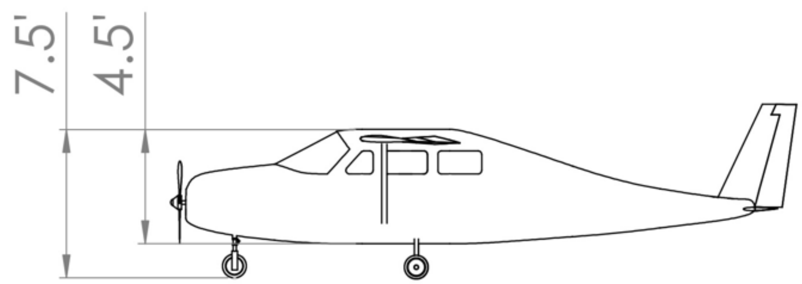
$MGTOW = 3500\ lb$	$W_{TO}/S = 22\ psf$
$S_{REF} = 155\ ft^2$	$P/W = 0.12\ hp/lb$
$MAC = 4.88\ ft$	$Length = 25\ ft$
$Span = 33\ ft$	$AR = 7$
Engine = Lycoming TSIO-360-HB [210 hp]	



EFA-1 Optimized



$MGTOW = 2940\ lb$	$W_{TO}/S = 22.5\ psf$
$S_{REF} = 129 ft^2$	$P/W = 0.105\ hp/lb$
$MAC = 4.3\ ft$	$Length = 26\ ft$
$Span = 34\ ft$	$AR = 9$
$S_{VT} = 12.96\ ft^2$	$S_{HT} = 26.5\ ft^2$
Engine = TSIO−390−C3B6 [310 hp]	



EXECUTIVE SUMMARY

In response to the 2018-2019 American Institute of Aeronautics and Astronautics (AIAA) Undergraduate Team Aircraft Design Competition Request for Proposal, Roll Control presents the EFA-1. The Request for Proposal (RFP) states that it is not economically feasible for airlines operating large aircrafts to serve majority of the airports in the United States. Instead, an alternative would be to use smaller airports with aircrafts with higher frequency scheduled flights. Thus, the objective is to design an economically feasible aircraft capable of servicing small airports and short routes at a higher frequency.

The EFA-1 and EFA-2 were designed with the goal of creating an aircraft considered economically feasible when compared to current competition. In order to accomplish this task, the aircrafts were designed to have low direct operating costs. Electric propulsion was compared with conventional combustion engines to find which configuration yields the lowest cost over a span of 20 years. Following the comparison, it was found that due to the current state of batteries and associated costs, electric propulsion costs approximately 3 times more than the conventional combustion engines. Therefore, conventional combustion engines were selected for both designs.

In order to down select between the two designs, direct operating costs based on 20 flights per week of each design was calculated to be $5,085 and $6,598, respectively. Therefore, in order to reduce the overall direct operating cost, the EFA-1 was selected.

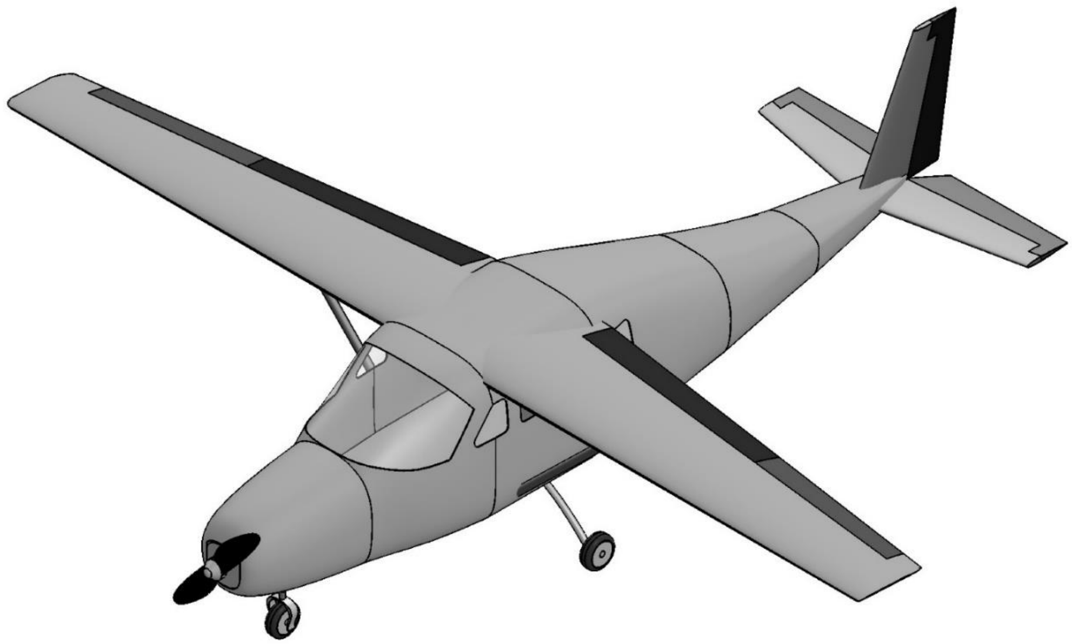


Figure 1: EFA-1 Isometric View

A baseline design of the EFA-1 was created using the RFP requirements along with historical data utilized as a reference point to optimize the design for a low direct operating cost. Using the baseline design, 25 aircraft configurations were analyzed to determine the optimal aspect ratio and maximum thickness ratio. The taper ratio was selected to be 0.5 in order to provide a good balance between elliptical lift distribution and reduced wing tip chord size. In order to counteract the negative effects of wing taper, a 3-degree aerodynamic twist (washout) was implemented to reduce tip stall and loads. Using historical wind tunnel data, it was found that NACA 2415 yields the lowest drag at the cruise lift coefficient. Therefore, NACA 2415 was selected at the root and NACA 2412 was used at the tip to reduce drag. Using these selected parameters, a refined 4-variable analysis was constructed to find the final max gross takeoff weight, power-to-weight ratio and wing loading as shown in Figure 2. The main driving constraints of the analysis were the 180 kt average ground speed RFP requirement and the FAR 23 stall speed requirements. These parameters were used to create the wing planform.

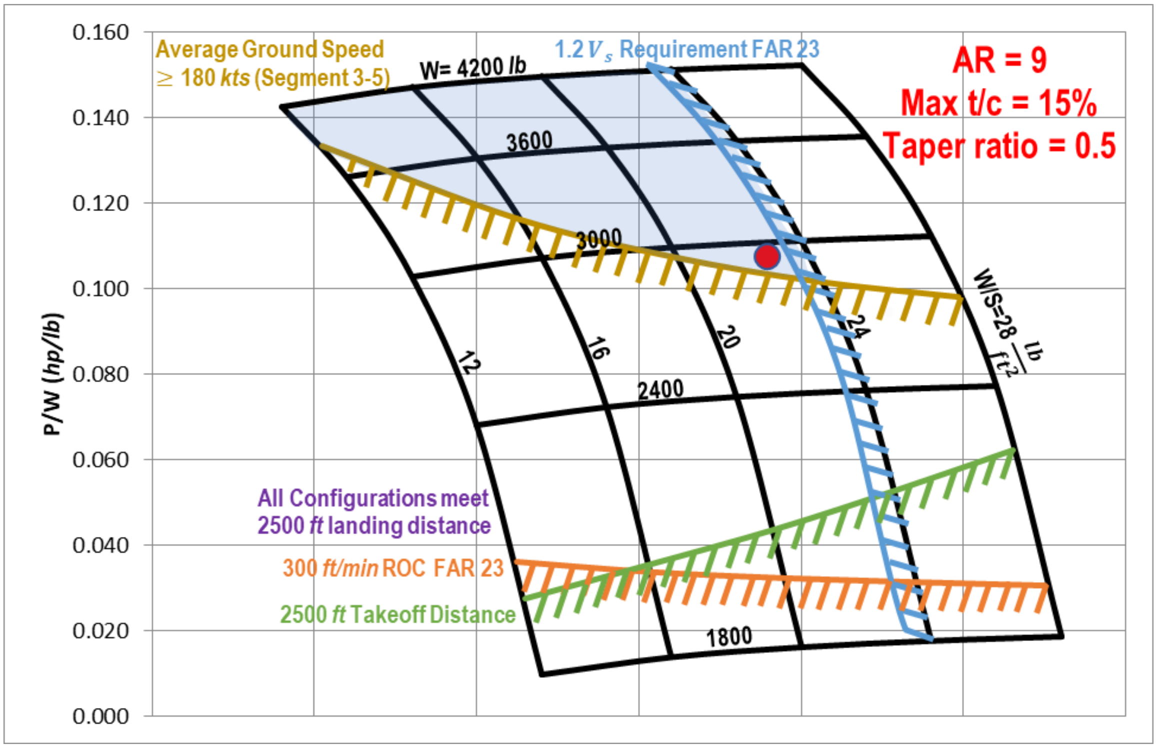


Figure 2: Refined 4-Variable Analysis

A high-wing configuration was selected to address the RFP consideration for ease of boarding and egress, as well as overall passenger experience. The horizontal and vertical tails were initially sized using volume coefficients from previous similar general aviation aircraft. The fuselage layout was configured to fit 4 passengers and 1 pilot with a total payload of 980 lb, per the requirements set forth in the RFP. Centering the rear seat allowed for greater fuselage tapering from the cabin to tail, not only reducing drag and weight, but also overall cost. The single piston engine was selected by comparing several engines that met the 310 HP requirement. It was found that the Lycoming-580-B1A had a higher purchase price but had the lowest operating cost over a span of 20 years. The engine has a noise level of 79 dB(A), which is lower than the required limit of 85 dB(A) set by Part 36 Sec. G36.301(c). Since the aircraft uses a single reciprocating engine, a 57 ft diameter full aircraft parachute was added using a 1700 fpm terminal velocity and a parachute coefficient of drag of 1.2 in accordance with the RFP.

A fixed tricycle-type landing gear was selected due to lower overall operating costs. The rear landing gear was positioned to have a tip back angle of 15 degrees, a C.G. to rear landing gear of 16 degrees and a turnover angle of 35 degrees. Using the mission segments, the total mission fuel fraction was computed and used to determine the required fuel of 38 gal. Using an integral tank packing factor along with worst-case fuel density in accordance to FAR 23.2430 Fuel Systems, the total tank volume was found to be 7.09 ft^3. The fuel was split into two wing integral tanks of 3.55 ft^3 each.

The primary material for the EFA-1 was 2024 T-3 aluminum, since it provides a good balance between a low manufacturing cost and high strength properties. Weight and balance were used to adjust the location of items and redesign as necessary to obtain a static margin of 8%. Further analysis into the longitudinal stability of the EFA-1 was conducted using information on the landing flare, rear stability limit, nosewheel liftoff and C.G. travel in order to find the required volume coefficient of 0.71 for the horizontal tail. To ensure that the EFA-1 has adequate lateral stability, a historically stable value for the yaw moment derivative of 0.07 was selected and used to size the vertical tail.

The MGTOW and parasite drag buildup of the EFA-1 was lowered by 6% and 2.3%, respectively, in comparison to the baseline design. The reduction in both weight and parasite drag directly reduces the overall direct operating cost of the EFA-1. The EFA-1 cruise altitude was selected by considering the 45-minute time limit, fuel burn and the horsepower required. Several iterations were performed to find the optimal cruise altitude of 6000 ft, since this yields the lowest direct operating cost. The maximum lift-to-drag ratio for the EFA-1 was found to be 15. Due to the lower cruise altitude, the EFA-1 cruises at a lower than normal lift-to-drag ratio of 11. The EFA-1 has an average ground speed of 180 kt (Cruise speed of 210 kt), takeoff distance of 1354 ft and landing distance of 1164 ft, all of which satisfies the main requirements proposed by the RFP.

The flyaway cost and yearly direct operating cost of the EFA-1 is $234,300 and $412,500 respectively. Comparing these values to a similar aircraft, such as the Cirrus SR22, it was found that the EFA-1 has a 4.5% lower flyaway cost and a 2.1% lower direct operating cost. The yearly direct operating cost of the EFA-1 and similar aircraft is shown in Figure 3. Considering the higher cruise speed of the EFA-1 as well as its ability to service small airports with a frequent and regular schedule, it is a competitive alternative with its lower flyaway and operating costs. Therefore, the EFA-1 is a viable candidate for future configurations with similar requirements.

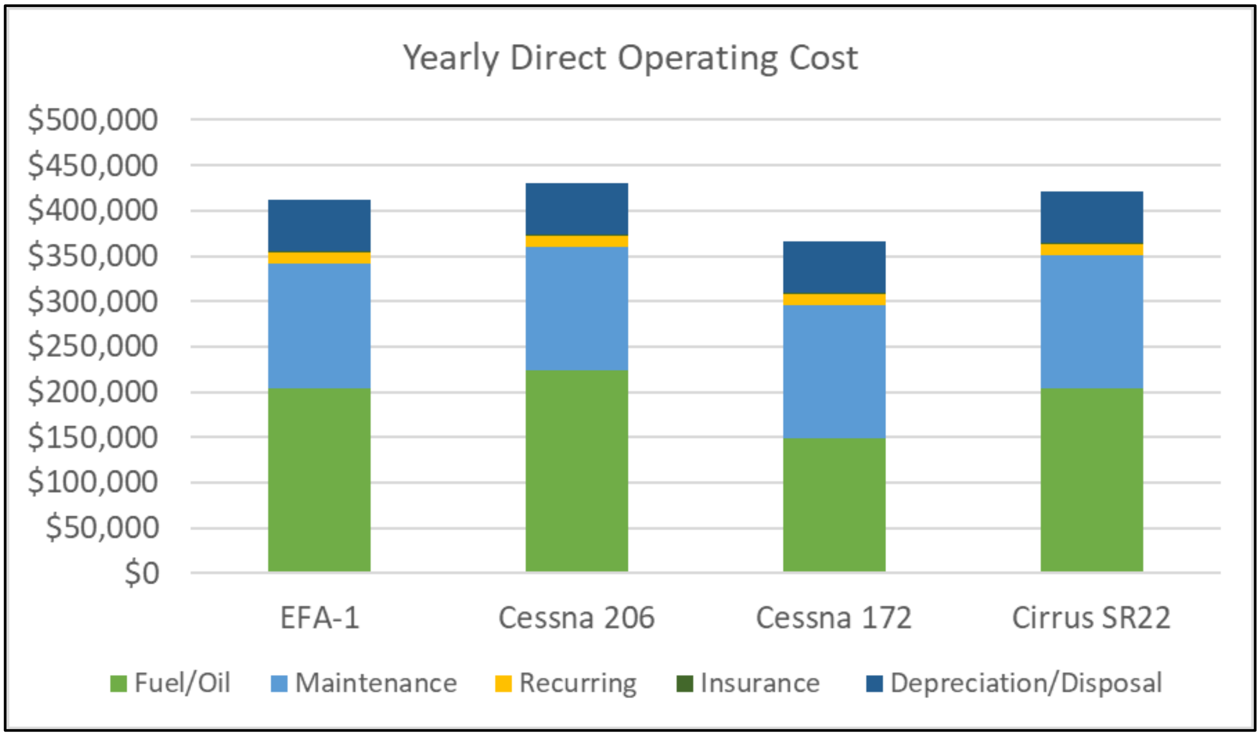


Figure 3: Yearly Direct Operating Cost

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List of Acronyms

Symbol	Definition
14 CFR	Title 14 Code of Federal Regulations
AR	Aspect Ratio
b	Wingspan (ft)
b_E	Span of Elevator (ft)
C.G	Center Gravity (ft)
C	Chord Length (ft)
C_D	Coefficient of Drag
C_E	Chord of Elevator (ft)
C_{HT}	Horizontal Tail Volume Coefficient
C_L	Coefficient of Lift
C_m	Coefficient of moment
C_m	Directional Stability Derivative
C_{VT}	Vertical Tail Volume Coefficient
CFR	Code of Federal Regulations
D	Drag (lb)
DOC	Direct Operating Cost
EFA-1	Economically Feasible Aircraft – 1
EFA-2	Economically Feasible Aircraft – 2
FAR	Federal Aviation Regulations
fpm	Feet Per Minute
HT	Horizontal Tail
IFR	Instrument Flight Rules
L	Lift (lb)
LE	Leading Edge
L/D	Lift-to-Drag ratio
MAC	Mean Aerodynamic Chord (ft)

MGTOW	Max Gross Takeoff Weight
MSL	Mean Sea Level
M_z	Lateral Moment (ft-lb)
Mz	Longitudinal Moment (ft-lb)
NACA	National Advisory Committee for Aeronautics
nmi	Nautical Miles
P/W	Power to Weight Ratio (HP/lb)
q	Dynamic Pressure (lb/ft)
S	Wing Area (ft)
S_{HT}	Horizontal Tail Area (ft)
S_V	Vertical Tail Area (ft)
TE	Trailing Edge
t/c	Thickness Ratio
VFR	Visual Flight Rules
VT	Vertical Tail
Vz	Shear Force
W/S	Wing Loading (psf)

1 REQUIREMENTS OVERVIEW

The aircraft will enter service in 2025 certified in Title 14 Code of Federal Regulations Part 23 (14 CFR Part 23) under certification level 2 and low speed performance. Pursuant to 14 CFR Part 23, level 2 certification is required for airplanes with max seating configuration of 2 to 6. Since 4 passengers are the minimum requirement from the RFP, a 4-passenger seating configuration is chosen to save unnecessary costs and weight. Additionally, only one pilot is required pursuant the RFP. The requirement by the RFP and CFR Part 23 are shown in Table 1 below.

Table 1: Performance Characteristic Requirements

Performance Characteristics	Requirements	Units
Average ground speed	≥ 180	*ktas*
Takeoff distance	≤ 2500	*ft*
Landing distance	≤ 2500	*ft*
Stall speed FAR 23	≤ 61	*kts*
Rate of Climb FAR 23	≥ 300	*ft/min*
Payload – Four Passengers	800	*lb*
Crew – Single pilot	180	*lb*
Total range of flight (See Ref. 2.1 Reference Mission)	≥ 135	*nmi*
Total range of flight (See Ref. 2.2 Sizing Mission)	≥ 250	*nmi*

The purpose of the RFP is to design an "economically feasible" aircraft capable of servicing small airports and short routes. Consideration is taken in improving passenger experience and overcoming barriers associated with traveling in small aircrafts.

2 MISSION PROFILES

Since the objective of the RFP is to design a domestic transport aircraft for small airports and short routes, the mission profiles were based on these conditions.

2.1 REFERENCE MISSION

The reference mission is expected to be flown an average of 20 times per week with 50% passenger capacity. Figure 4 shows the requirements that must be met for the aircraft to complete the reference mission. Segments 2 and 6 require a takeoff and landing distance of less than 2500 ft, while being able to clear a 50 ft obstacle. For segment 3 and 7, the climb requirement is 300 ft/min from CFR Part 23.65 Climb: All Operating Engines. The 45 minutes loiter time requirement also meets CFR Part 91.151 Fuel Requirements for Flight in VFR conditions and CFR Part 91.167 Fuel Requirements for Flight in IFR conditions, if segment 6 was a missed approached. Segments 3 to 5 must have an average ground speed of 180 ktas to meet the 135 nmi range requirement within 45 minutes.

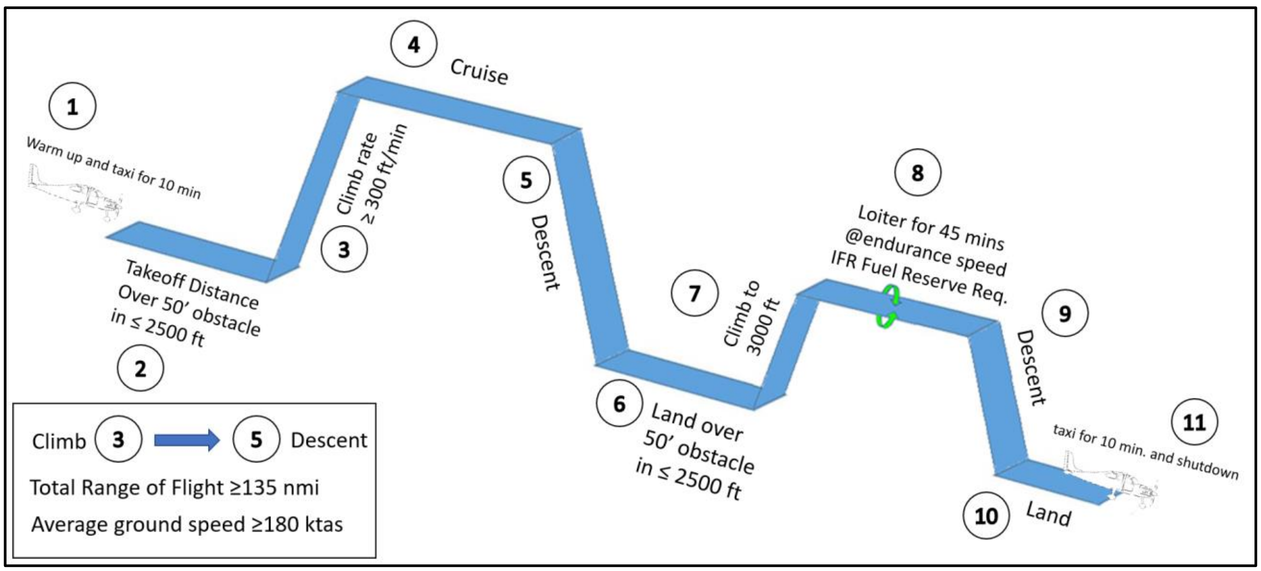


Figure 4: Reference Mission Profile

2.2 SIZING MISSION

From the RFP, the required range is 250 nmi for the long-range sizing mission. With no speed and flight time requirement, a speed lower than cruise speed from Figure 5 will be chosen in order to cover the range most efficiently. Segment 2 requires a takeoff distance of less than 2500 ft while being able to takeoff over a 50 ft obstacle. Segment 6, like segment 2, also needs to be able to have a landing distance less than 2500 ft over a 50 ft obstacle. Segment 3 contains the same 300 ft/min climb requirement under CFR Part 23.

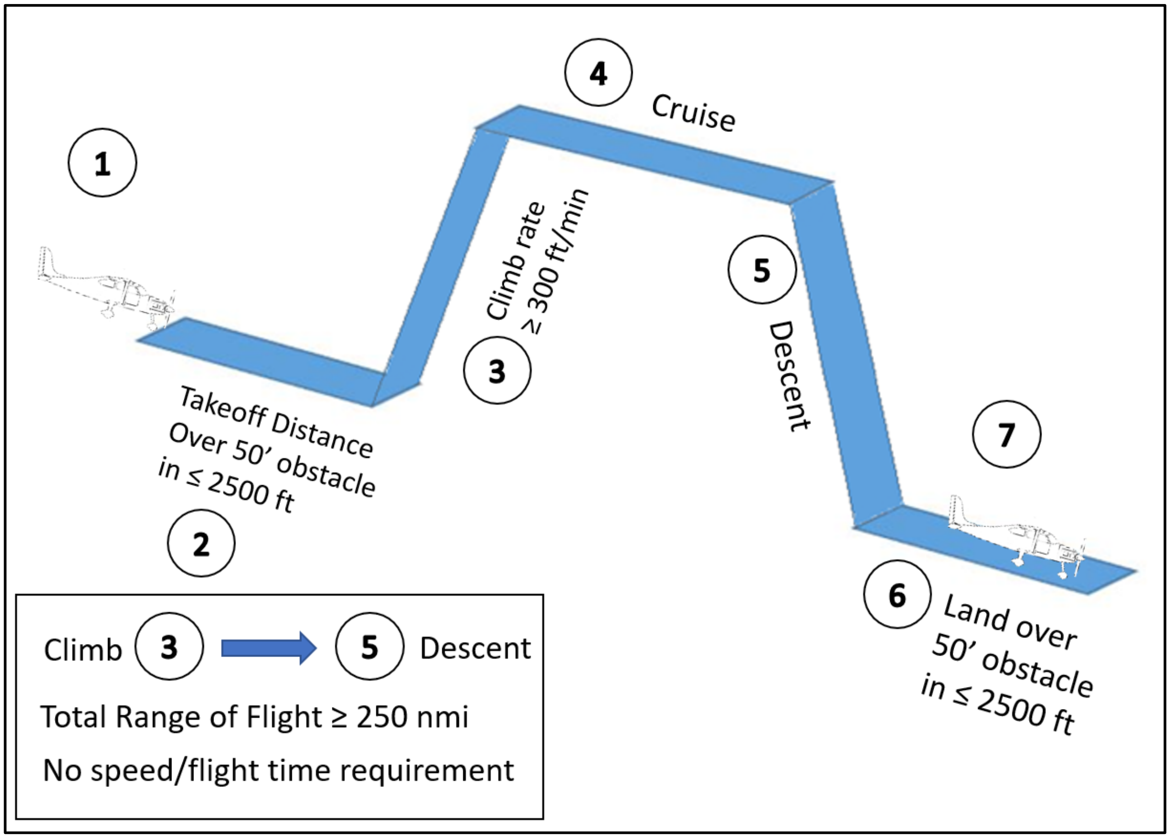


Figure 5: Sizing Mission

3 DESIGN APPROACH

The key designing factors in the design approach are shown in Figure 6. Operating cost was the driving figure of merit, which was used in choosing key design parameters and characteristics. RFP and FAR requirements were further broken down and translated to performance characteristics. In order to meet these performance characteristics, a methodology of key figures of merit was used. This gave guidance to the decisions made in both the selection and design process. With operating cost as the driving factor, decisions for the overall design were based on the aircraft's ability to meet requirements while simultaneously being economically practical and viable.

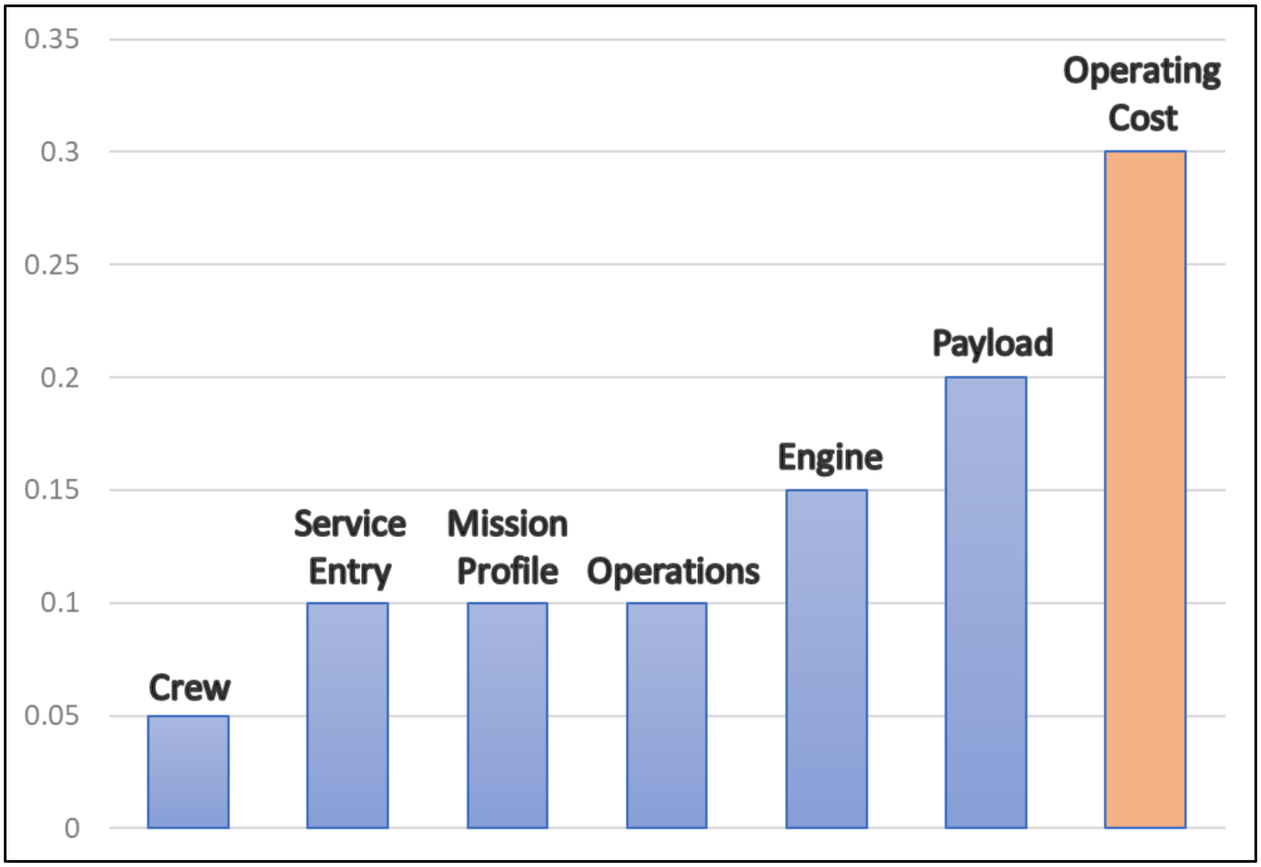


Figure 6: Defining the Key Figures of Merit

Figure 7 illustrates the breakdown of functional cost. Between direct operating costs, ground operations costs, and system operating costs, the key design driver for the aircraft was direct operating cost. Direct operating costs accounts for 50% of the overall cost of an aircraft. Therefore, the aircraft was designed with an emphasis on low direct operating cost.

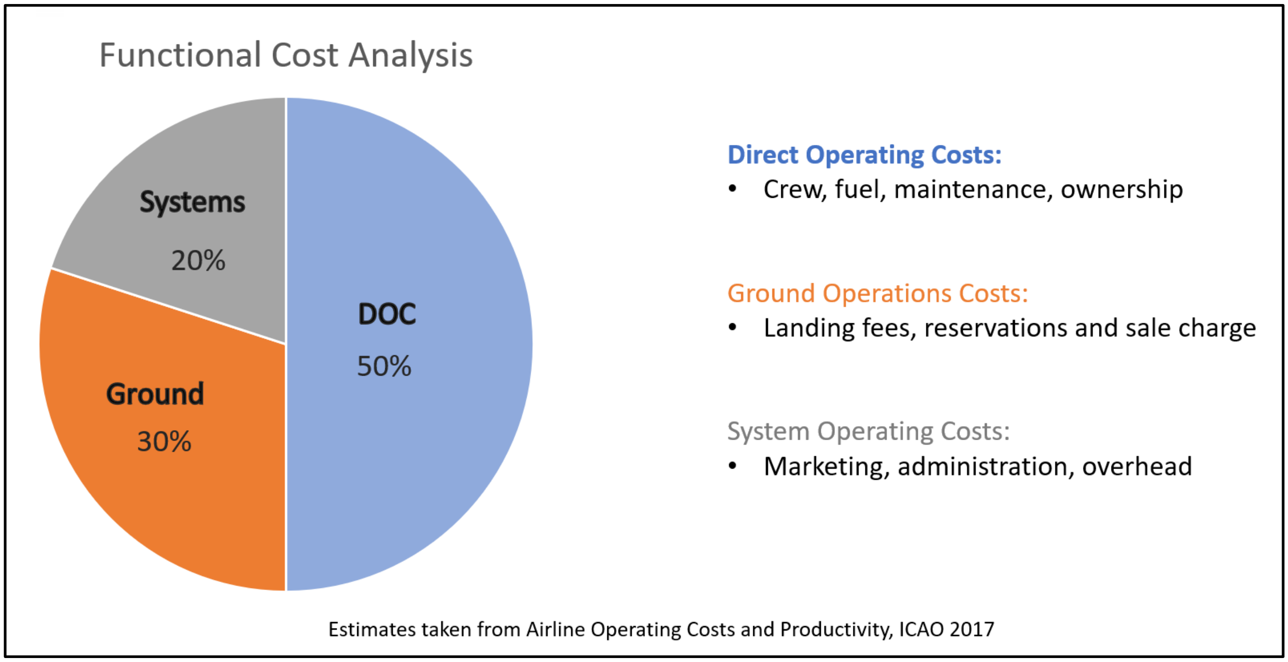


Figure 7: Total Operating Cost Analysis

4 ELECTRIC PROPULSION ANALYSIS

When investigating whether electric propulsion was a viable option, various factors were evaluated, i.e., engine power, battery power required, and battery weight. Table 2 shows the calculated results needed to complete the mission outlined by the RFP. From an electric aircraft with similar payload capacity, cruise speed and mission duration, 750 hp was assumed to be sufficient for our design architecture. In order to meet the 1000 cycle battery life requirement listed in the RFP, the battery capacity was doubled.

Table 2: Electric Propulsion Characteristics

Electric Propulsion Characteristics	Value	Units
Engine Power Output	750	hp
Engine Efficiency	93.8	%
Battery Pack Density	0.285	kWh/lb
Battery power required	597	kW
Battery power required (for 50% discharge)	1194	kW
Battery power required w/ Total Mission time (1.5 hours)	1791	kWh
Weight of Batteries	6284	lb

To decide if electric propulsion was a viable option, it was compared to a conventional gasoline engine. Using direct operating cost as a main driving factor, Figure 8 shows how affordable a combustion engine is compared to the electric propulsion during a span of 20 years. Although recharging the batteries is more cost effective than filling it up with Avgas, yearly battery replacement is financially detrimental to the success of electric propulsion. Therefore, the combustion engine is selected.

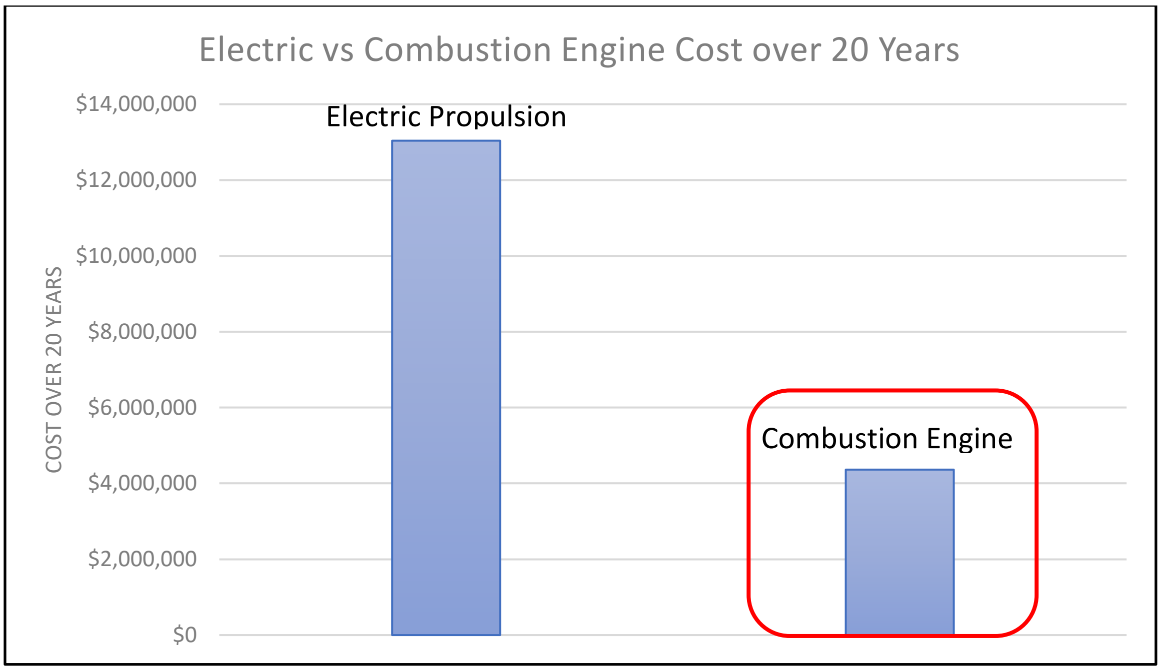


Figure 8: Electric Engine vs Combustion Engine Cost over 20 years

5 CONFIGURATION/DOWN-SELECT

The main driving factor that was used to down select between the two configurations was direct operating cost. To compute an initial estimate of the operating cost of both configurations, the parasite drag buildup was computed as shown in Figure 9 & Figure 10. The EFA-1 and EFA-2 had a parasite drag buildup of 0.0259 and 0.0260, respectively.

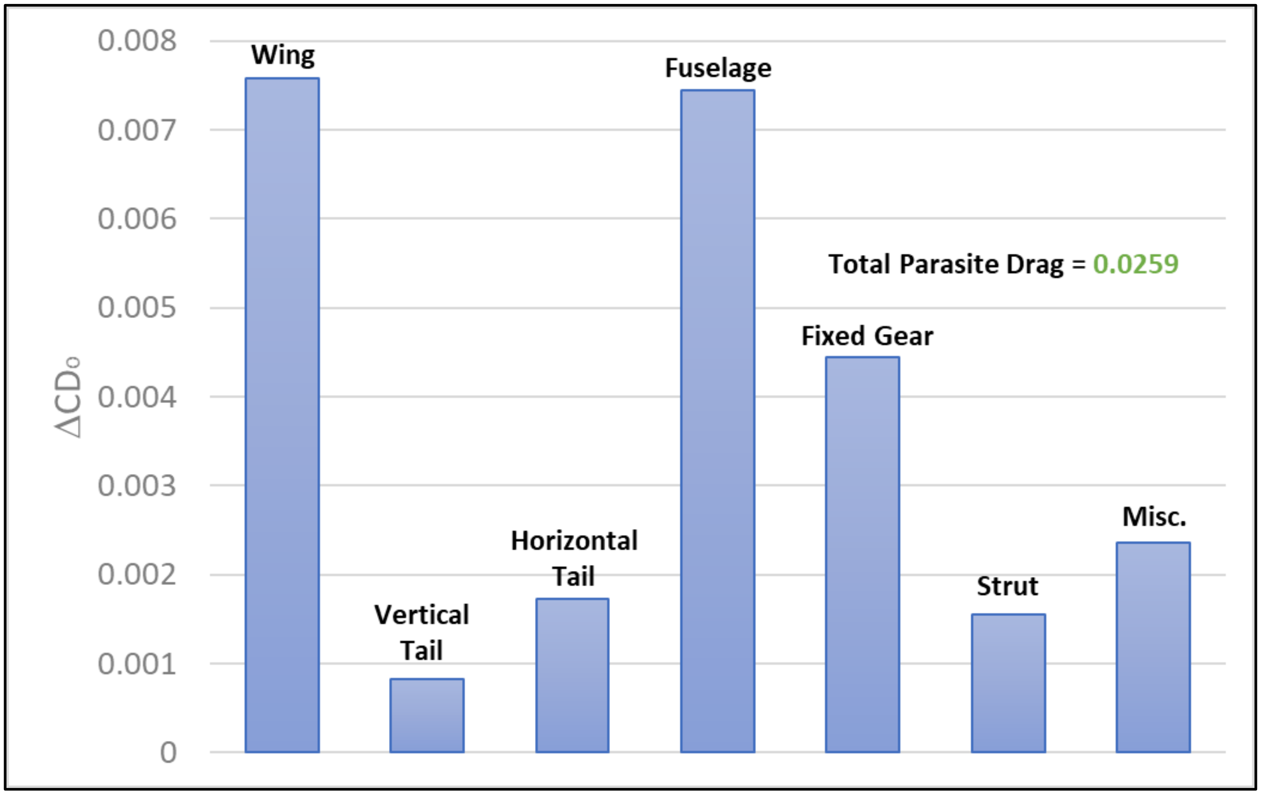


Figure 9: EFA-1 – Parasite Drag Buildup [Cruise Condition]

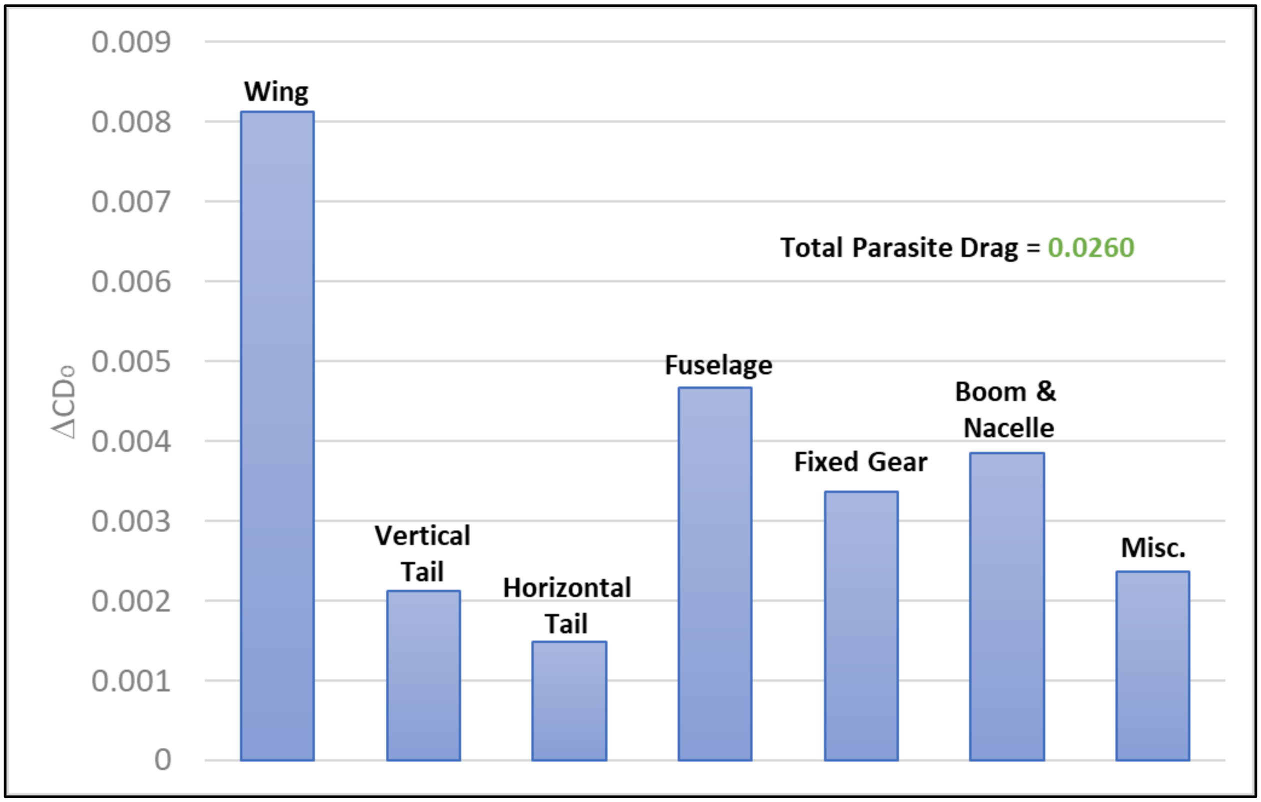


Figure 10: EFA-2 – Parasite Drag Buildup [Cruise Condition]

The parasite drag buildup and the induced drag for each configuration was used to estimate the total drag and the corresponding cost of fuel consumption for 20 flights per week, as shown in Figure 11 and Figure 12. That, along with the maintenance cost for each aircraft, was used to estimate the total weekly operating cost, as shown in Table 3. It was found that the EFA-1 and EFA-2 had a total weekly operating cost of $5,085 and $6,598, respectively. It is important to note that the EFA-2, being a twin-engine design, had a higher maintenance cost than the single-engine EFA-1. Thus, EFA-1 was selected due to its overall lower weekly direct operating cost.

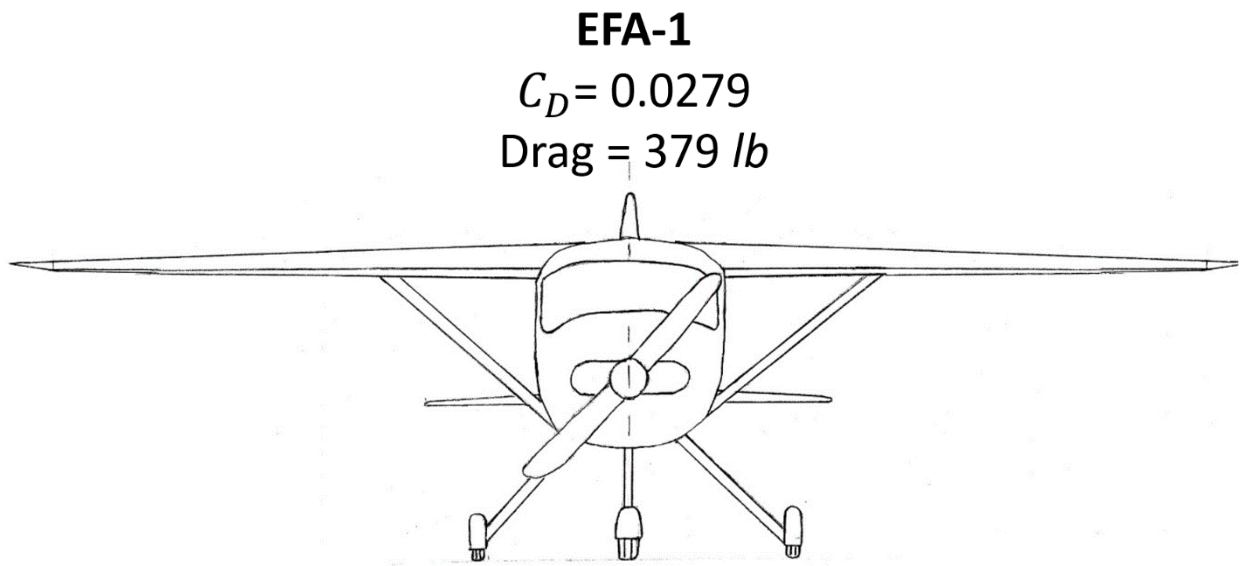


Figure 11: EFA-1 Drag

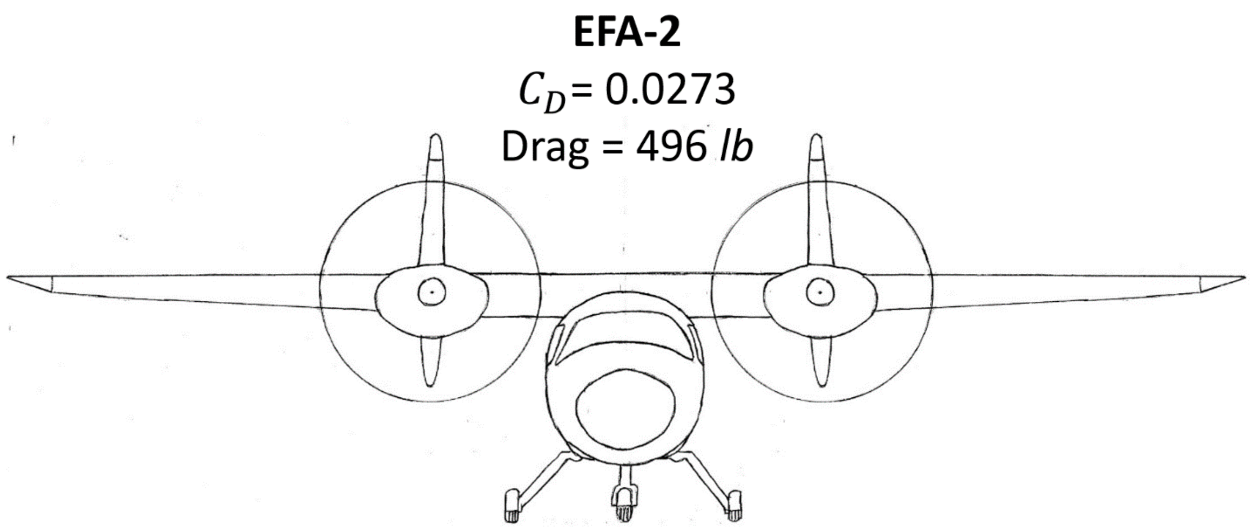


Figure 12: EFA-2 Drag

Table 3: Down Selection [Total Weekly Cost]

Operating Cost (20 Flights/Week)	EFA-1	EFA-2
Fuel	$2301	$2567
Maintenance	$2760	$4031
Total Weekly Cost	**$5085**	**$6598**

6 INITIAL SIZING

The constraint diagram, as shown in Figure 13, was constructed using the requirements presented in the RFP. The resulting design point gave an initial estimate of the wing loading at 22 psf and a power-to-weight ratio of 0.12 hp/lb.

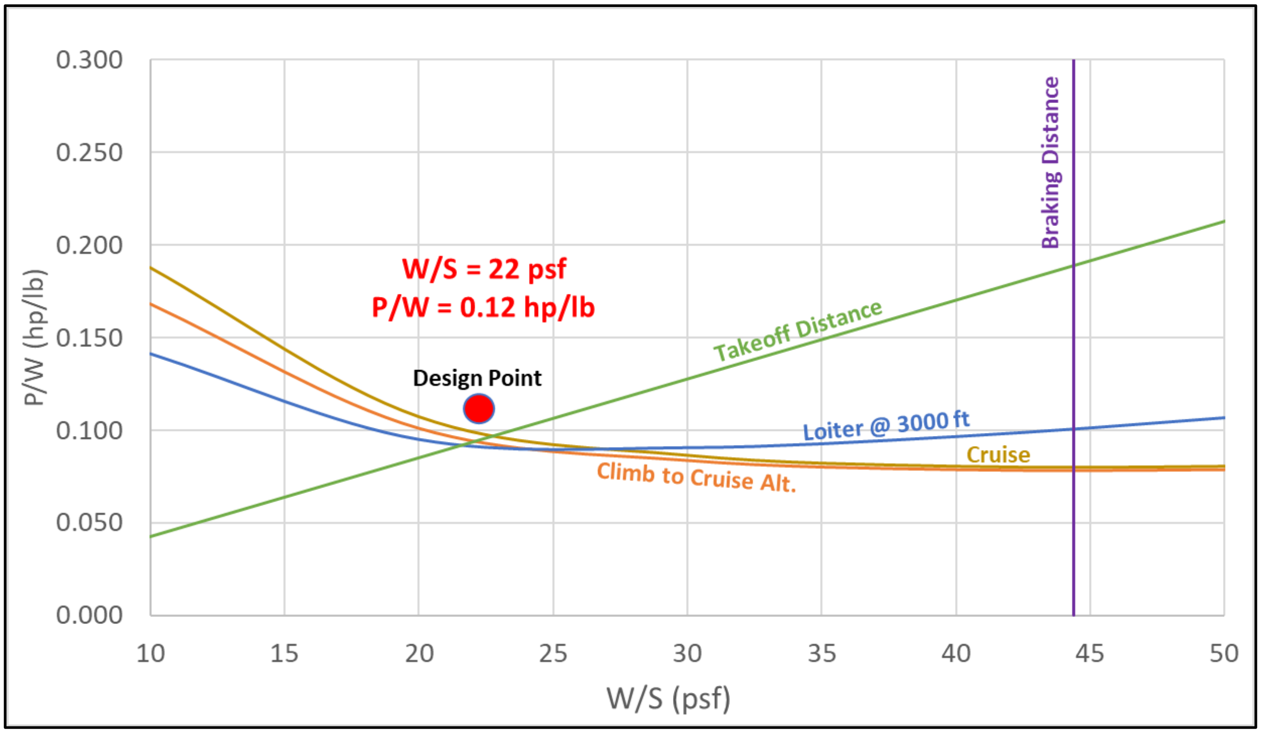


Figure 13: Constraint Diagram

The mission weight fraction for each segment was calculated as shown in Table 4. From the individual weight fractions, the total mission weight and fuel fraction was calculated as shown in Table 5. Using the total weight and fuel fractions, along with a trendline equation for statistical general aviation aircraft from Nicolai & Carichner [4], the initial estimated MGTOW for the aircraft was 3010 lb.

Table 4: Mission Segment Weight Fractions

Mission Segment Weight Fraction		
Fraction	**Condition**	**Value**
W2/W1	Takeoff	0.975
W3/W2	Climb	1.000
W4/W3	Cruise	0.977
W5/W4	Loiter	0.968
W6/W5	Descent	1.000
W7/W6	Land	1.000

Table 5: Total Mission Weight & Fuel Fraction

General Fuel Fraction Calculation		
Calculation	**Fraction**	**Value**
Total Mission Weight Fraction	W7/W1	0.922
Mission Fuel Fraction (Wf/W_GTOW)	1-W7/W1	0.078

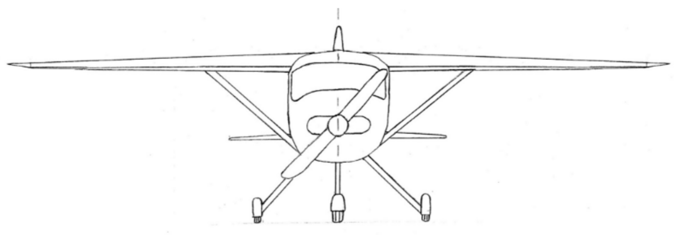
Table 6: MGTOW Initial Estimate

MGTOW Calculation (Using We/Wto = 0.911*Wto^-0.53)				
-	**Wcrew**	**Wpayload**	**MGTOW**	**EMPTY**
Units	*lb*	*lb*	*lb*	*lb*
Value	180	800	3010	1794

7 BASELINE DESIGN

The baseline design in Figure 14 was constructed using the constraint diagram, initial sizing of the MGTOW and historical data for general aviation aircraft from Nicolai & Carichner [4] and Raymer [8]. The baseline design was used as a reference point to optimize the design by reducing the direct operating cost. Before the baseline design was used as a reference point, the requirements from the RFP and FAR 23 were checked to ensure that requirements were met.

Characteristics	Value
Max Takeoff Weight (*lb*)	3010
Length (*ft*)	26
Wing Span (*ft*)	33
Wing Area (*ft²*)	138
Wing Loading (*lb/ft²*)	22
Wing Airfoil	NACA 23015
Aspect Ratio	8
Max Thickness (%Chord)	15
Power Loading (*hp/lb*)	0.12
Propeller	3 blade/64" diam.
Engine	TIO-540-J2B



Performance Characteristics	Baseline Design	Requirements	Satisfied
Avg. Ground Speed (Seg 3-5) (*kts*)	185	≥ 180	√
Takeoff Distance (*ft*)	1290	≤ 2500	√
Landing Distance (*ft*)	1258	≤ 2500	√
Stall Speed FAR 23 (*kts*)	60	≤ 61	√
Rate of Climb FAR 23 (*ft/min*)	2002	≥ 300	√

Figure 14: EFA-1 Baseline Design

8 Wing Selection

8.1 Wing Location

A trade study was conducted to find the optimal wing location as shown in Figure 15. Interference drag, passenger visibility, dihedral effect and loading/unloading of passengers were considered and weighed accordingly. Since ease of boarding, means of egress and passenger experience is highly valued in the RFP, those areas were weighed higher than the resultant drag increase from having a higher wing configuration. Using the results from Figure 15, the high wing configuration was selected.

Wing Location			High	Mid	Low
Criteria	Weight	Scale	Scores		
Interference Drag	0.15	10 = Least Drag 1 = Most Drag	2	5	9
Passenger Visibility	0.35	10 = Best 1 = Poor	10	5	3
Dihedral Effect	0.1	10 = Most Stable 1 = Least Stable	5	5	10
Loading & Unloading	0.4	10 = Least Difficult 1 =Most Difficult	10	8	4
WEIGHTED TOTALS in %	1.0	High Wing Selected →	8.3	6.2	5

Figure 15: Wing Location Trade Study

8.2 ASPECT RATIO

Using the baseline design as a reference point, 25 configurations were evaluated. The following four variables were evaluated to determine the optimal aspect ratio of the EFA-1:

- Power-to-Weight Ratio
- Max Gross Takeoff Weight
- Wing Loading
- Aspect Ratio

In order to find which configurations met the requirements from the RFP and FAR 23 regulations, the following constraints were used:

- Average Ground Speed ≥ 180 *kt* (Segments 3-5)
- 2500 *ft* Landing Distance with 50 *ft* obstacle
- 2500 *ft* Takeoff Distance with 50 *ft* obstacle
- 1.2 V_s Takeoff Stall Speed Requirement FAR 23
- 300 *ft/min* Rate of Climb FAR 23

An aspect ratio of 6,7,8,9 and 10 were evaluated as shown in Figure 16-20.

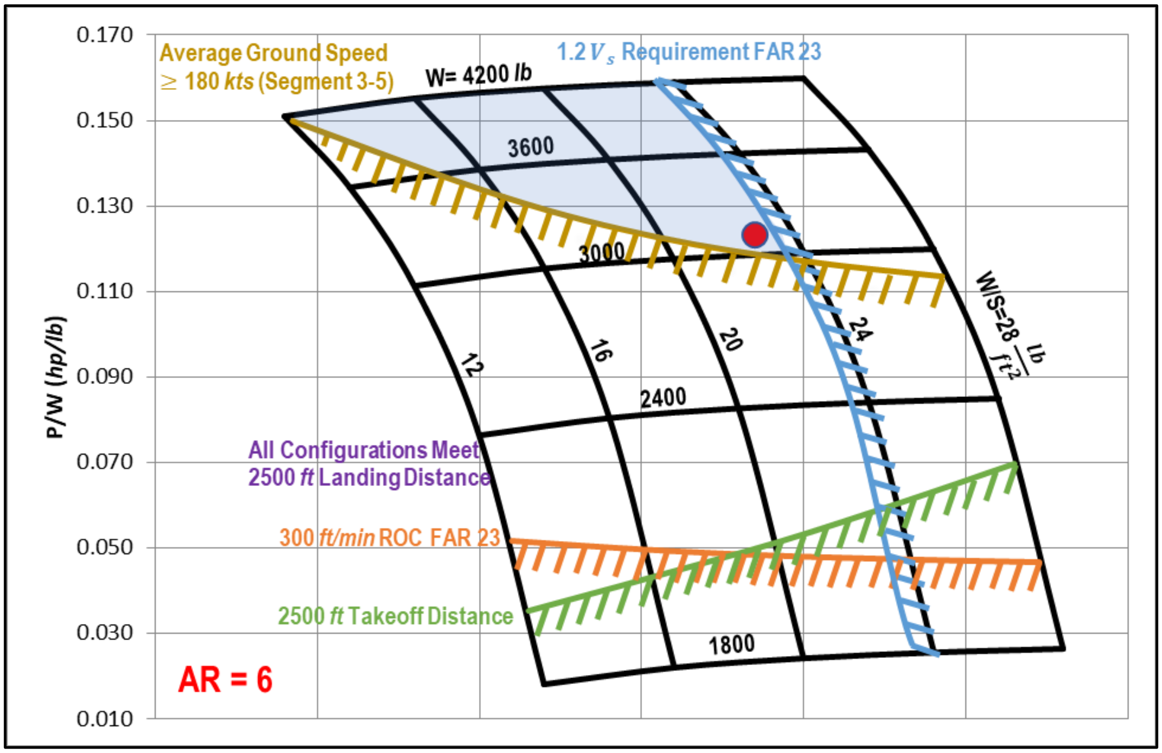


Figure 16: Aspect Ratio Optimization [AR = 6]

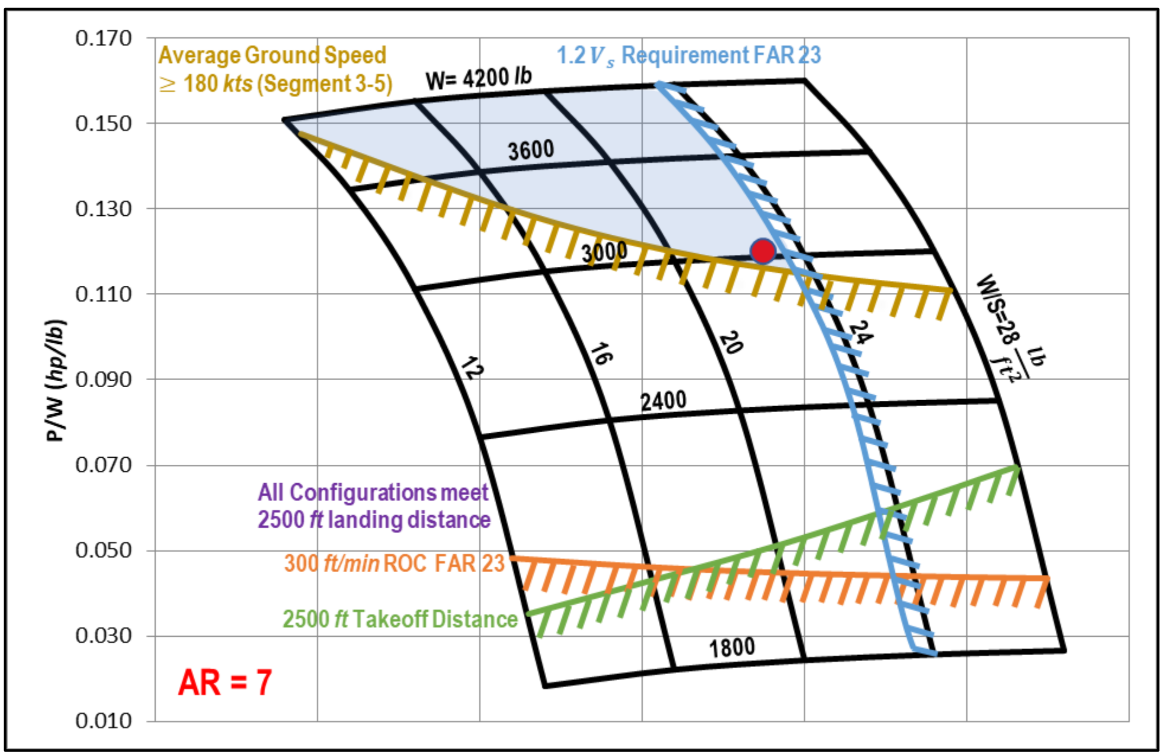


Figure 17: Aspect Ratio Optimization [AR = 7]

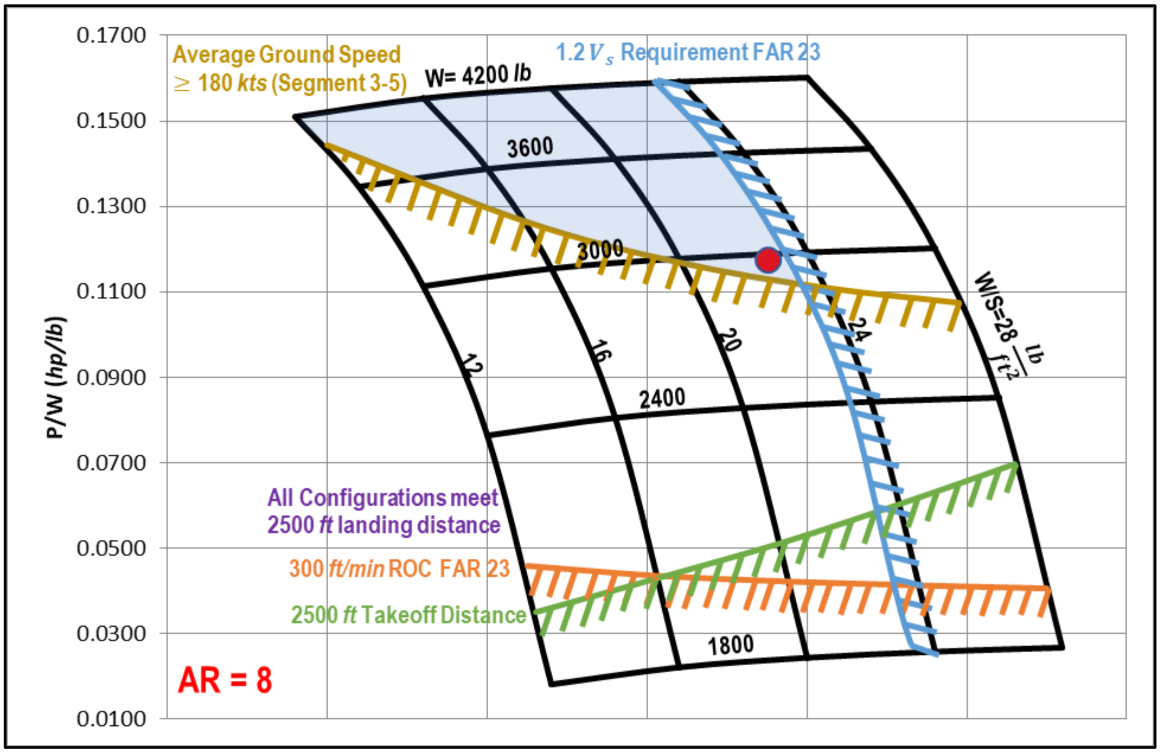


Figure 18: Aspect Ratio Optimization [AR = 8]

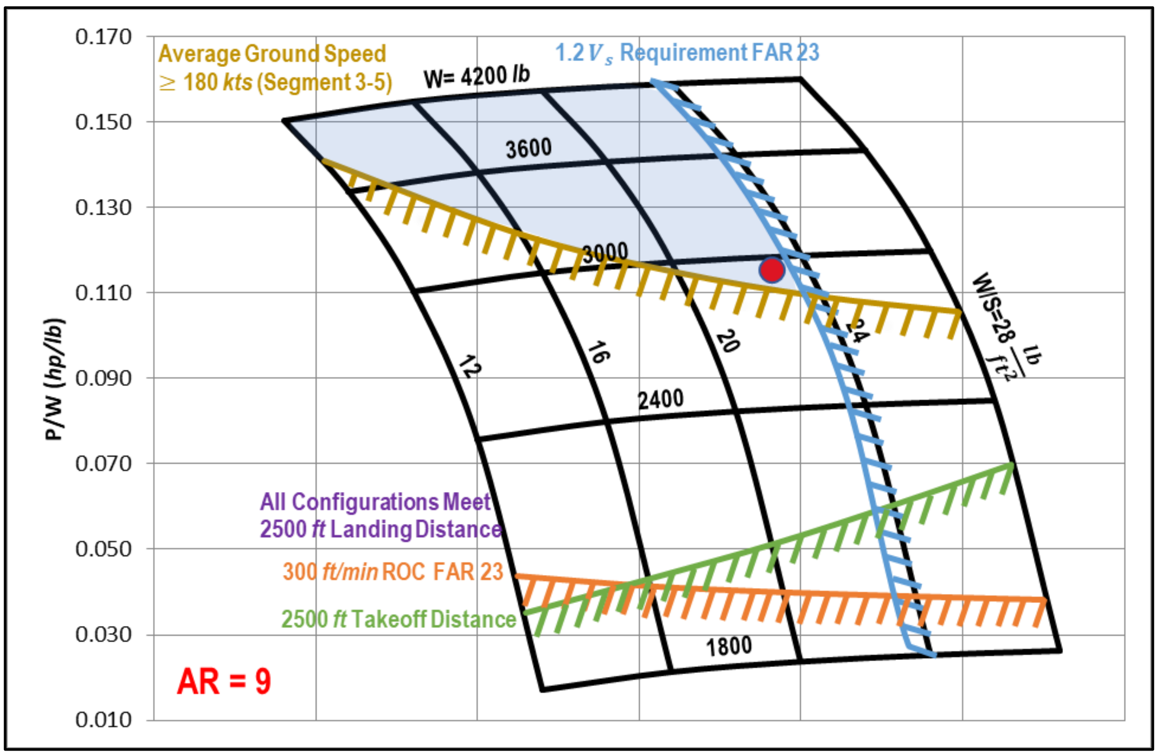


Figure 19: Aspect Ratio Optimization [AR = 9]

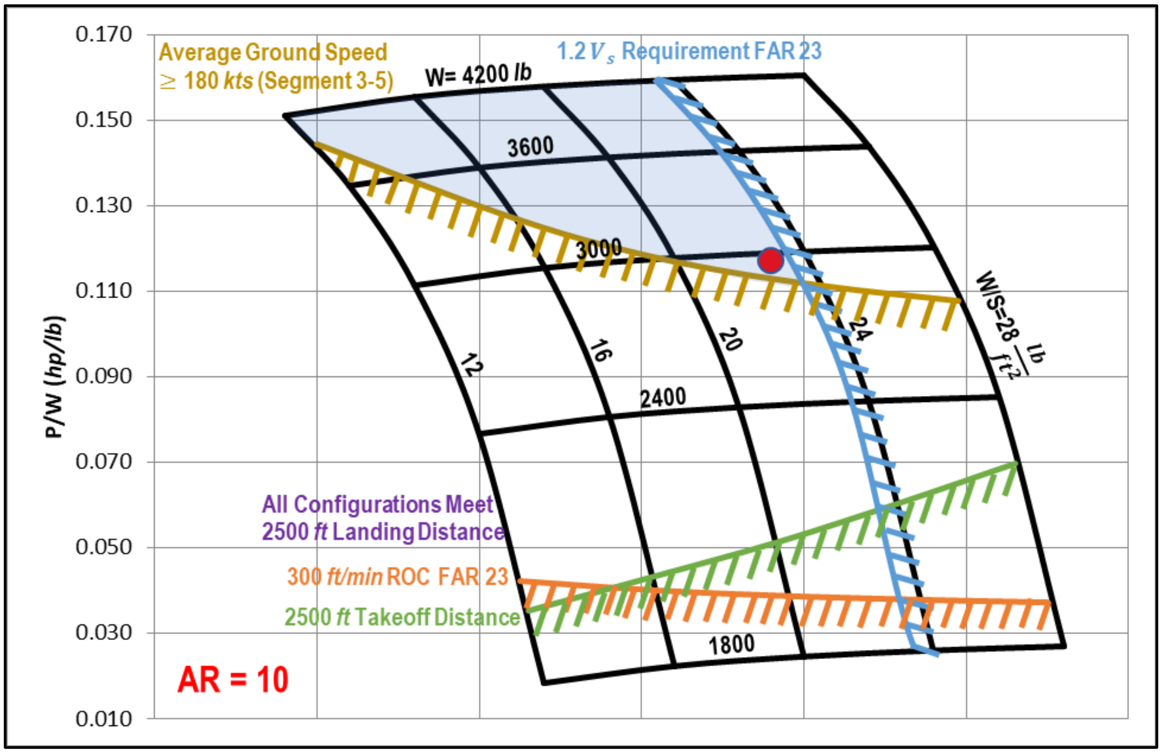


Figure 20: Aspect Ratio Optimization [AR = 10]

Plotting each design point from Figure 16-20, with respect to aspect ratio and MGTOW yields Figure 21**.** Thus, the optimal aspect ratio was selected to be 9, since is gives the lowest MGTOW, which is directly correlated with lowering direct operating costs.

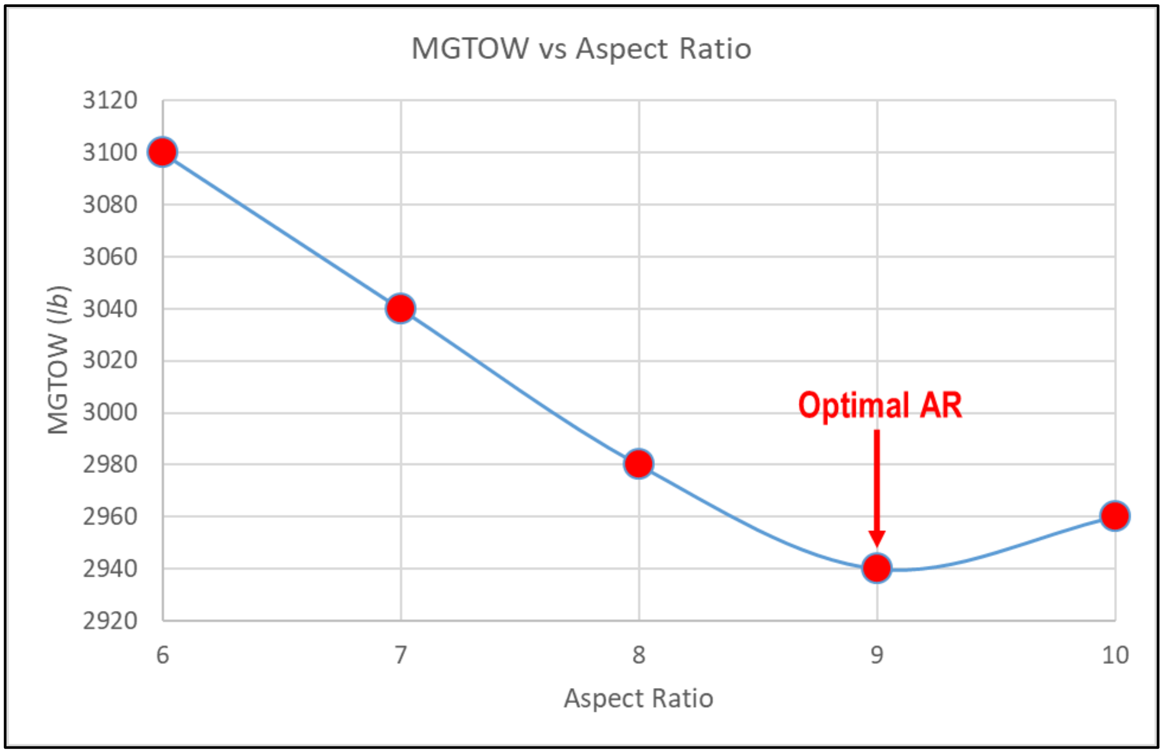


Figure 21: MGTOW vs. Aspect Ratio

8.3 MAXIMUM THICKNESS RATIO

A similar approach was used to find the optimal maximum thickness ratio for the wing. Instead of varying the aspect ratio, the maximum thickness ratio was varied. Thickness ratios of 12%, 15% and 18% chord were evaluated as shown in Figure 22-24.

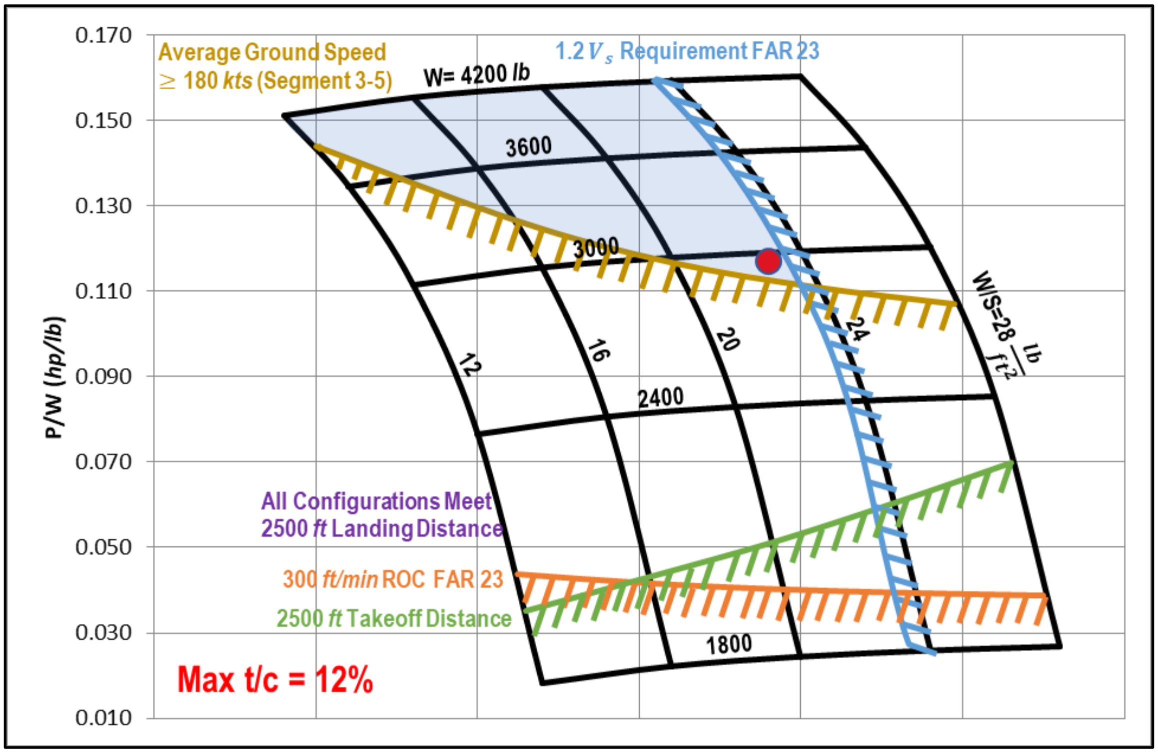


Figure 22: Maximum Thickness Ratio Optimization [Max t/c = 12%]

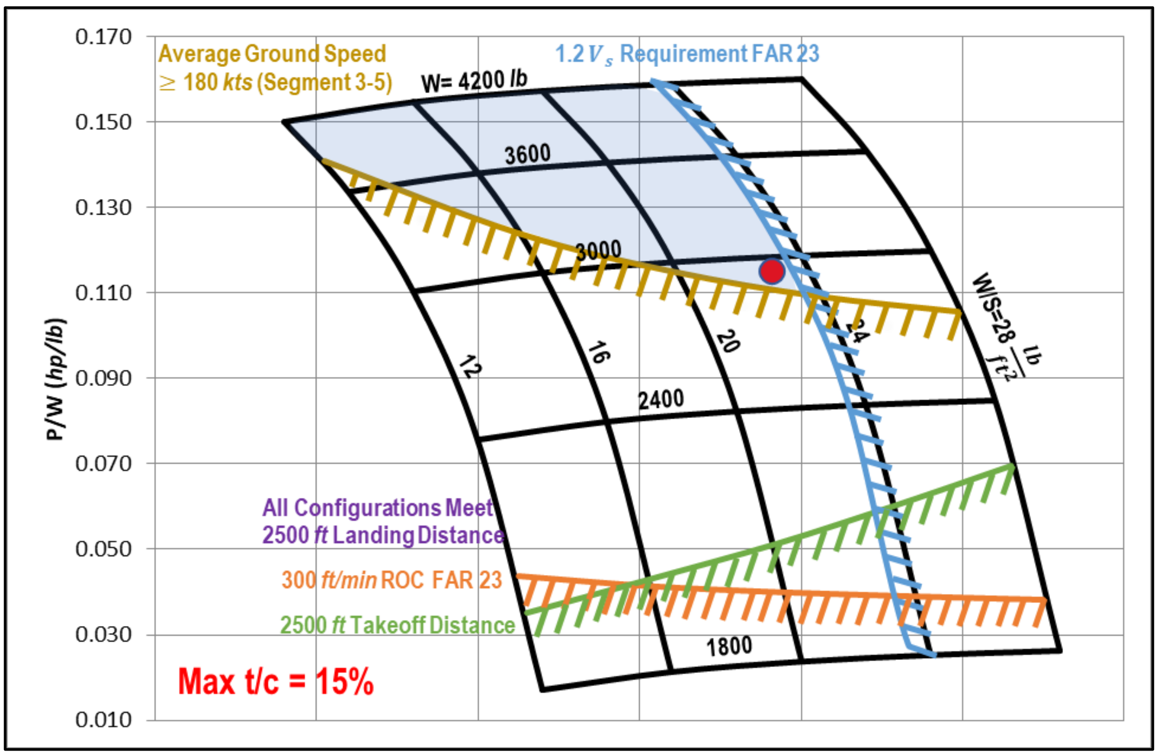


Figure 23: Maximum Thickness Ratio Optimization [Max t/c = 15%]

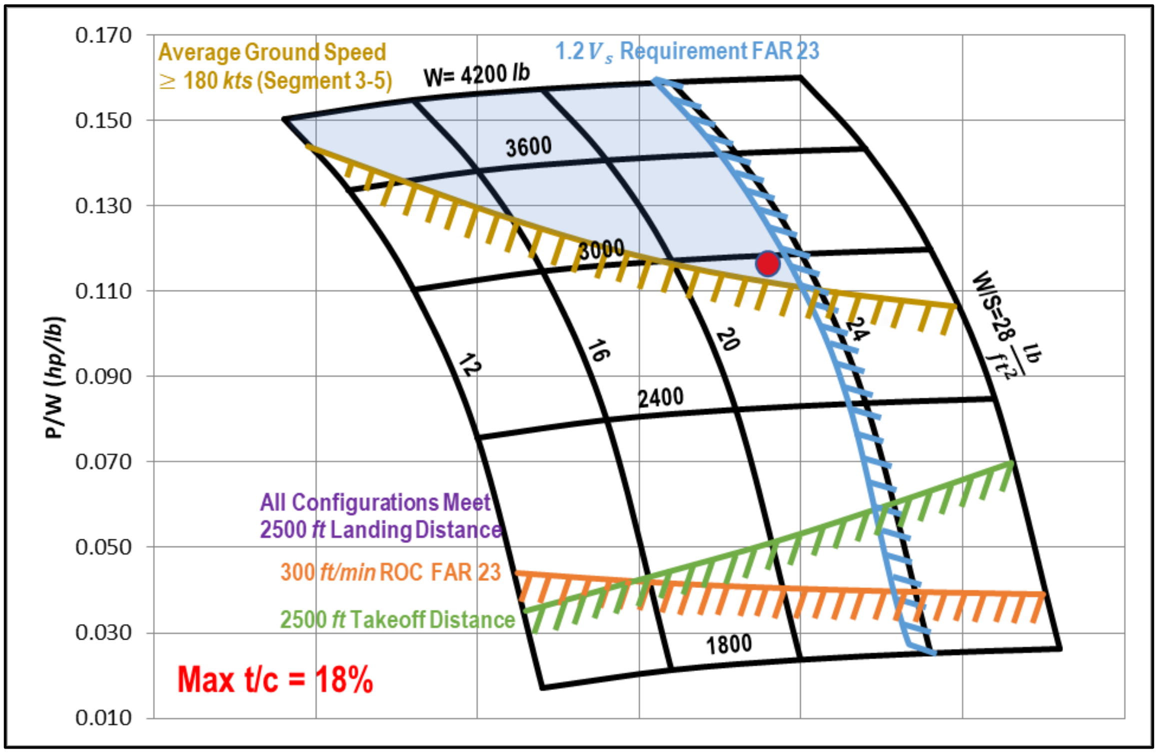


Figure 24: Maximum Thickness Ratio Optimization [Max t/c = 18%]

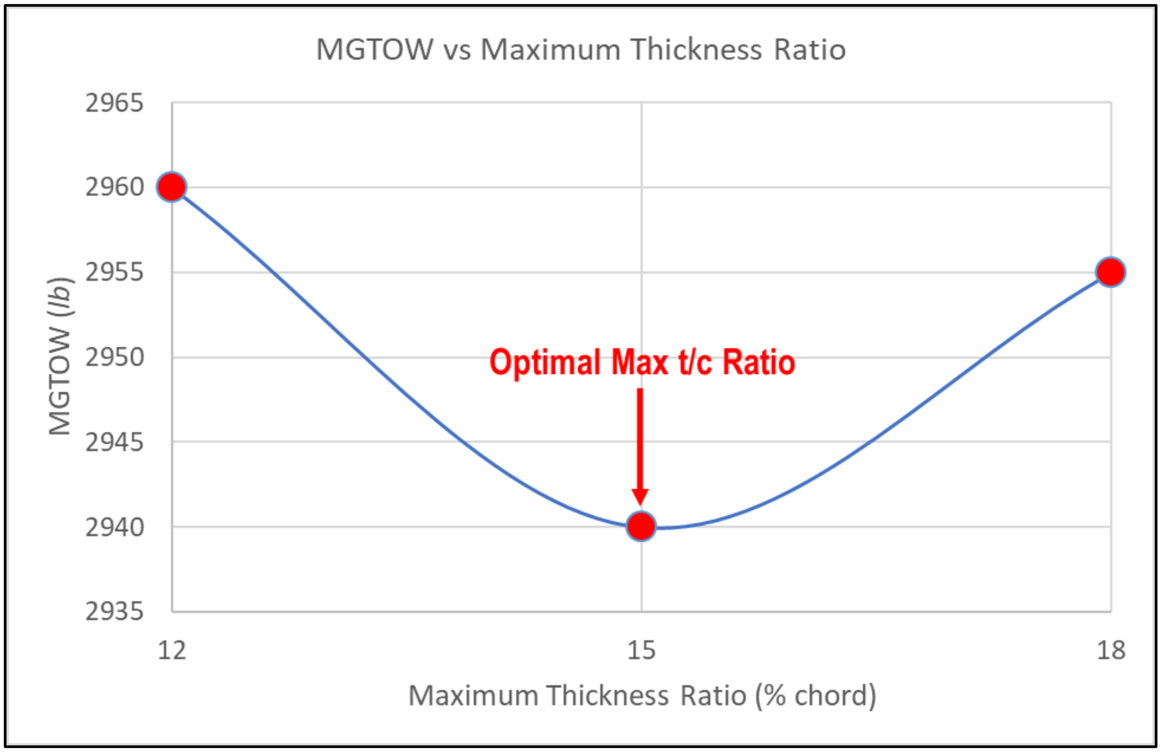


Figure 25: MGTOW vs. Maximum Thickness Ratio

Plotting each design point from Figure 22-24, with respect to maximum thickness ratio and MGTOW yields Figure 25Figure 25. Thus, the optimal maximum thickness ratio was selected to be 15% chord, as is gives the lowest MGTOW, which is directly correlated with lowering direct operating cost.

8.4 TAPER RATIO & WING TWIST

Using historical wind tunnel data from Abbott [1], the non-dimensional lift distribution was analyzed for a taper ratio of 0, 0.5 and 1. From Figure 26, it was found that a taper ratio of 0.5 gives a good balance between elliptical lift distribution and reduced wing tip chord size. In order to counteract the negative effects of wing taper, a 3-degree aerodynamic twist was implemented to reduce tip stall and loads.

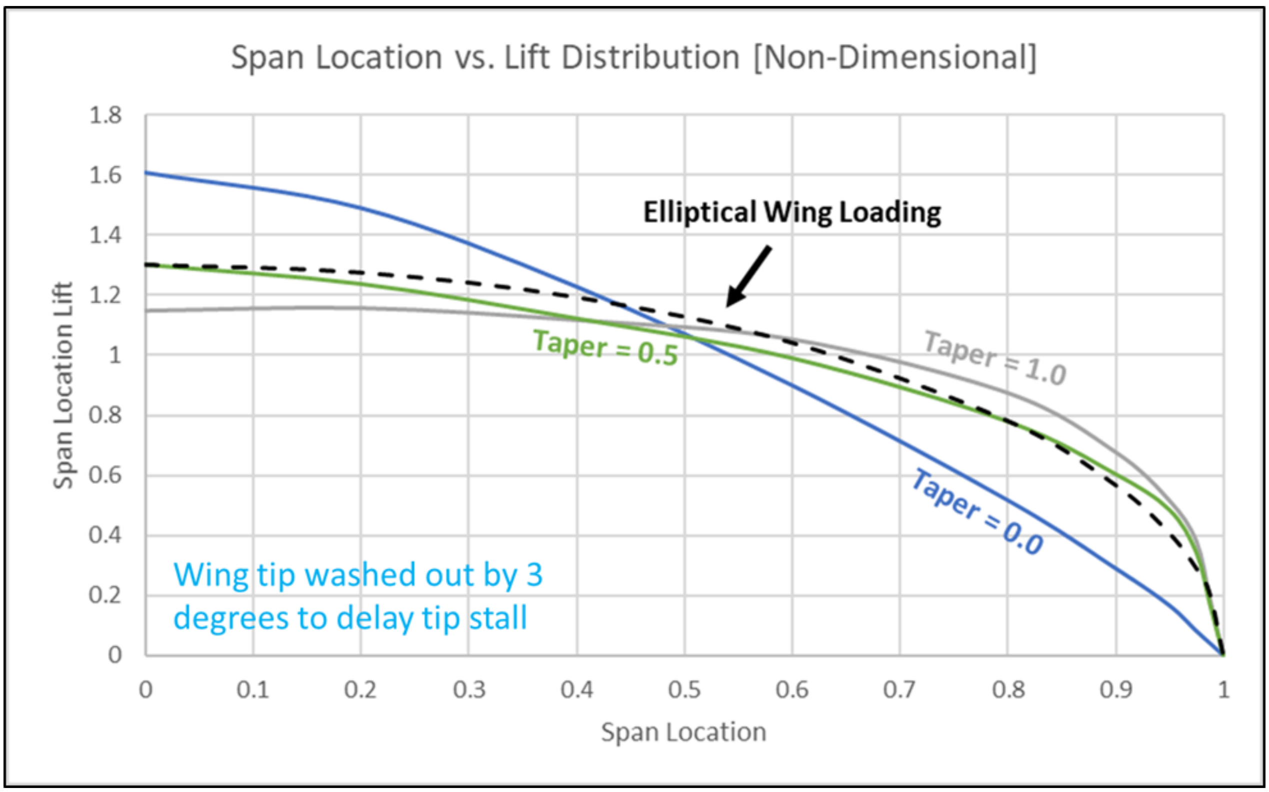


Figure 26: Span Location vs. Lift Distribution [Non-Dimensional]

8.5 Airfoil Selection

Various NACA airfoils that have been used in subsonic transportation flight such as, NACA 2415, NACA 4415, and NACA 23015 were compared in Figure 27 using wind tunnel data from Abbott [1]. NACA 2415 had the lowest coefficient of drag at the design lift coefficient. Therefore, NACA 2415 was selected.

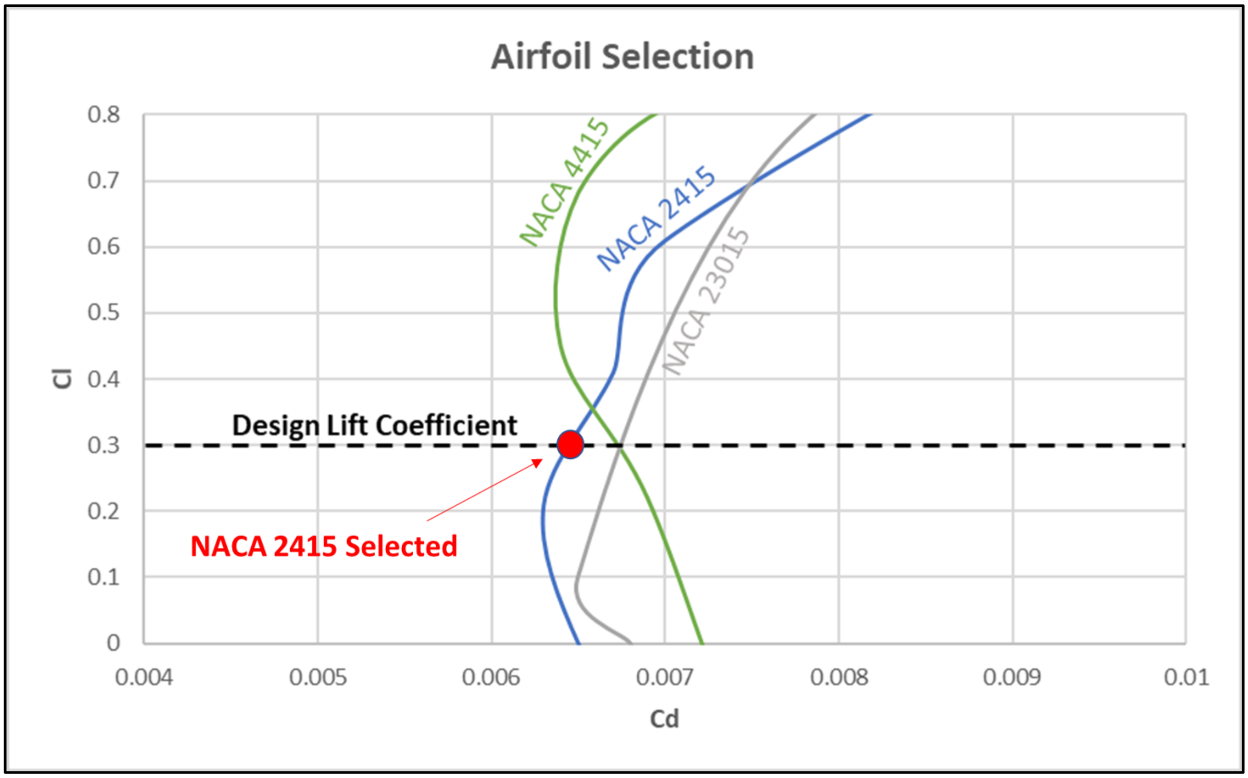


Figure 27: Airfoil Selection

Figure 28 shows the characteristics of the NACA 2415 airfoil used at the root of the wing.

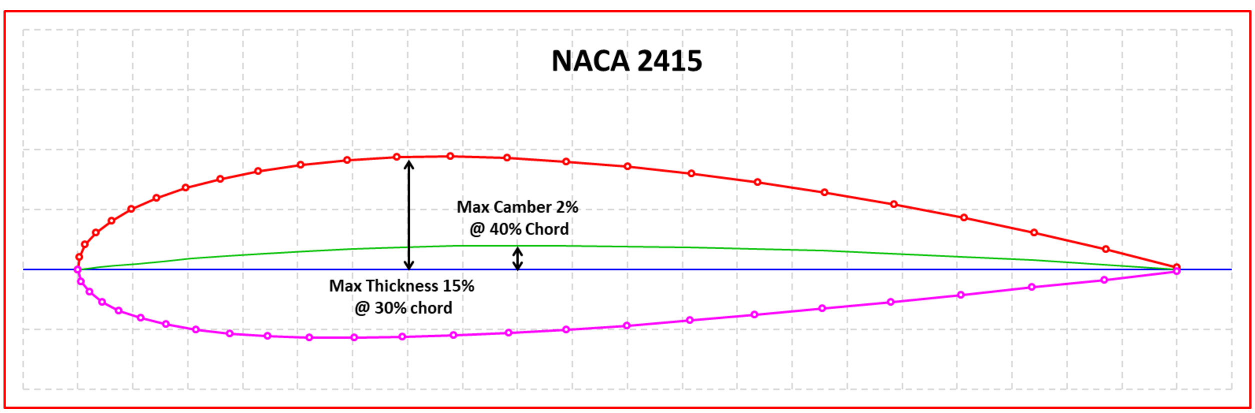


Figure 28: Root – NACA 2415 Airfoil

Figure 29 shows the characteristics of the NACA 2412 airfoil used at the tip of the wing. A lower thickness ratio at the wing tip is used to lower the overall drag of the EFA-1. Even though a lower maximum thickness ratio results in a higher wing weight, the tip has very low bending moments and reacting loads. Therefore, it does not need to be very thick for structural considerations.

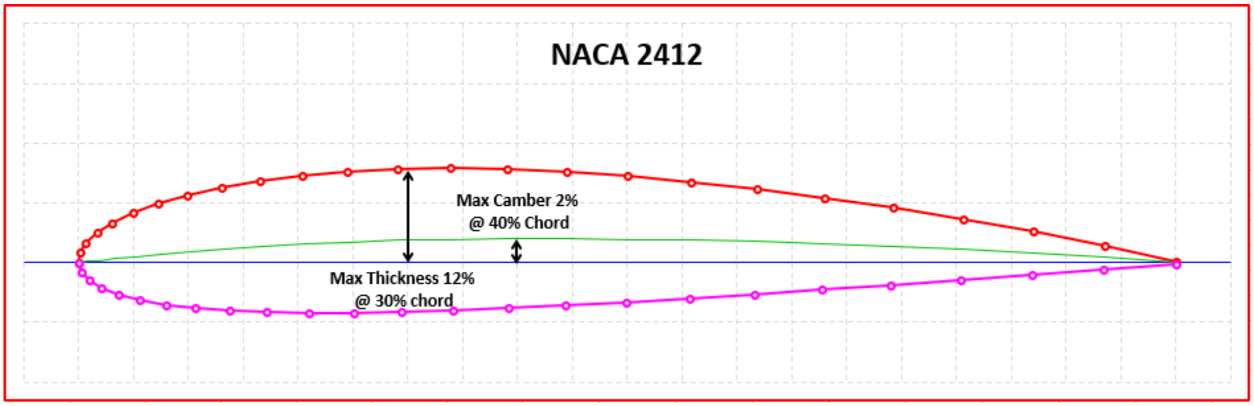


Figure 29: Tip – NACA 2412 Airfoil

8.6 WING PLANFORM

Using the selected maximum thickness ratio, aspect ratio and taper a refined 4-variable analysis was created to find the final MGTOW, power-to-weight ratio and wing loading. From Figure 30 the MGTOW = 2940 lb, power-to-weight ratio = 0.105 hp/lb and wing loading = 22.5 psf.

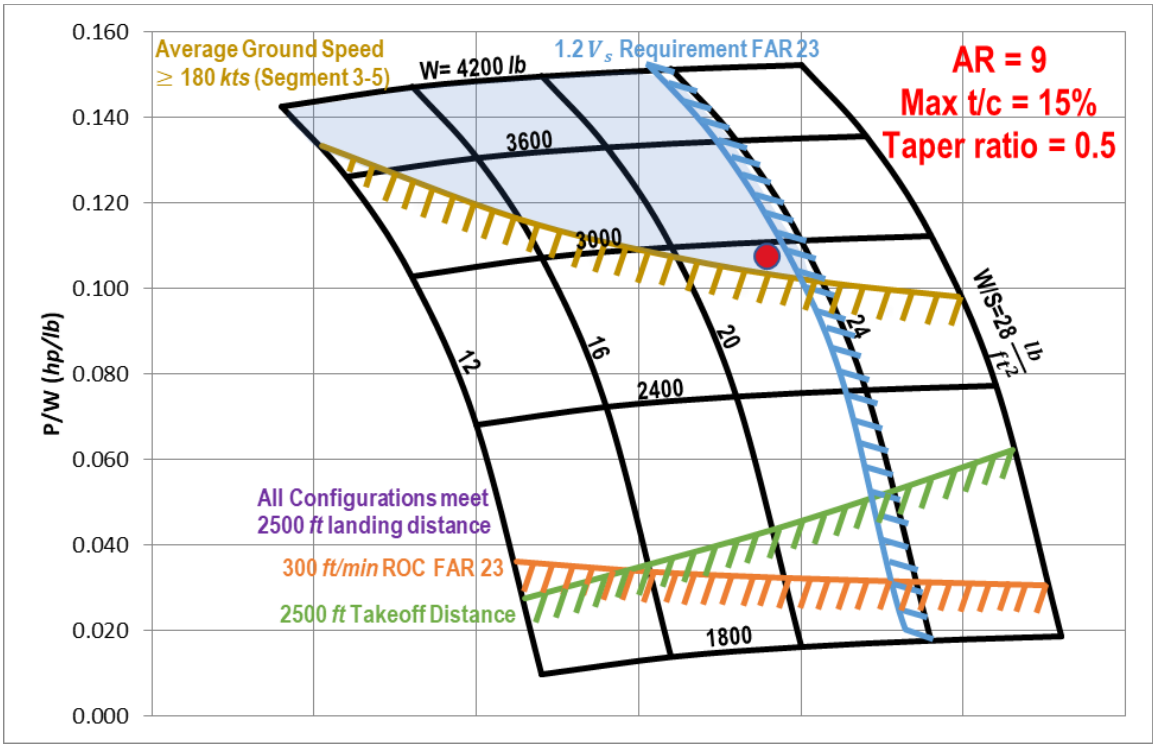


Figure 30: Refined 4-Variable Analysis

Using these values, the calculated wing parameters and wing planform is shown in Figure 31.

Wng Parameters	
Name	**Value**
Aspect Ratio	9
Taper Ratio	0.5
t/c Ratio	0.15
Root Chord (ft)	5.05
Tip Chord (ft)	2.52
MAC (ft)	3.93
Area (ft^2)	129.0
Span/2 (ft)	17.04

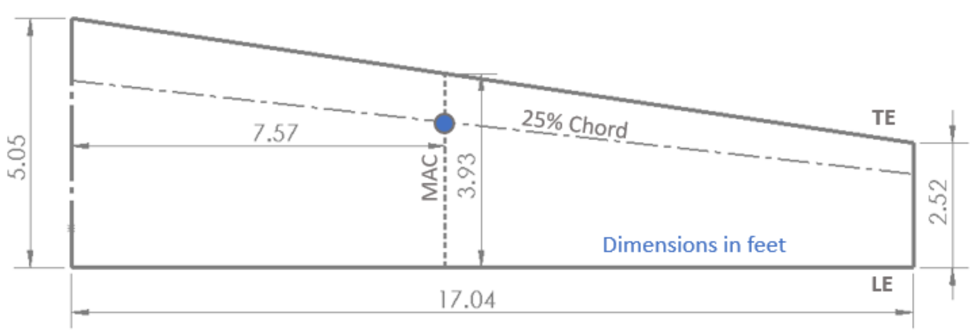


Figure 31: Wing Planform

9 HORIZONTAL & VERTICAL TAIL INITIAL SIZING

The horizontal and vertical tails were initially sized using historical tail volume coefficients of similar general aviation aircraft from Nicolai & Carichner [4], as shown in Table 7 & 9. The aspect ratio, taper, and maximum thickness ratio was determined using statistical data for general aviation aircraft from Raymer [8]. Figure 32 & 33 show the horizontal and vertical tail planform, respectively. For both the horizontal and vertical tails, the airfoil selection chosen was NACA 0012 and NACA 0009, respectively. Airfoil selection was based on selecting a symmetrical airfoil profile for both the horizontal and vertical tail stabilizers in order to provide better stability and control. Theoretical equations were then used to calculate the root chord, tip chord, MAC location, area, and span dimensions of the airfoil from Raymer [8].

9.1 HORIZONTAL TAIL INITIAL SIZING

Table 7: Horizontal Tail Volume Coefficient Initial Sizing

Similar Aircraft Initial Sizing			
-	EFA-1	Piper Cherokee	Cessna Cardinal
C_{HT}	0.61	0.61	0.60

Horizontal Tail Parameters	
Name	Value
Aspect Ratio	5
Taper Ratio	0.6
Maximum t/c Ratio	0.12
Root Chord (ft)	2.67
Tip Chord (ft)	1.6
MAC (ft)	2.18
Area (ft^2)	22.8
Span/2 (ft)	5.34

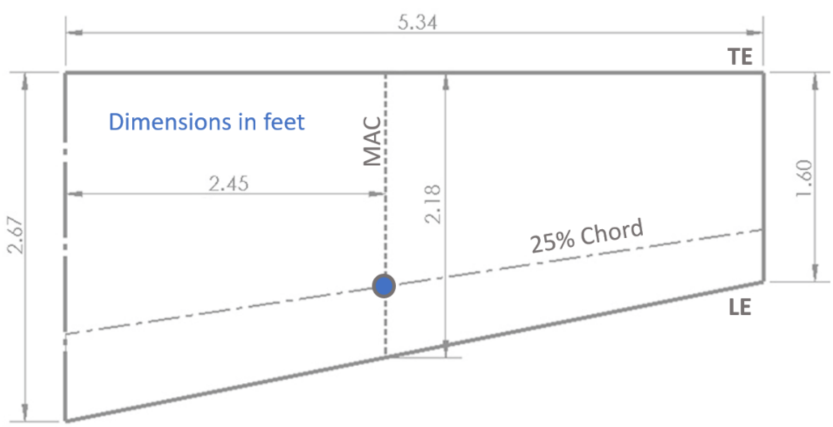


Figure 32: Horizontal Tail Planform

9.1.1 Initial Elevator Sizing

The elevator was sized by using similar general aviation aircraft statistical data from Nicholai & Carichner [4] and is fixed along the trailing edge of the horizontal stabilizer. The elevator parameters are shown in Table 8.

Table 8: Elevator Initial Sizing Parameters

Elevator Parameters	
Name	**Value**
Span of Elevator (ft.)	9.18
Chord of Elevator (ft.)	1.5

9.2 VERTICAL TAIL INITIAL SIZING

Table 9: Vertical Tail Volume Coefficient Initial Sizing

Similar Aircraft Initial Sizing			
-	EFA-1	Piper Cherokee	Cessna Cardinal
C_{VT}	0.037	0.037	0.038

Vertical Tail Parameters	
Name	**Value**
Aspect Ratio	2
Taper Ratio	0.5
Maximum t/c Ratio	0.09
Root Chord (ft)	3.26
Tip Chord (ft)	1.63
MAC (ft)	2.54
Area (ft^2)	12.0
Span (ft)	4.90
LE Sweep ($Degrees$)	25

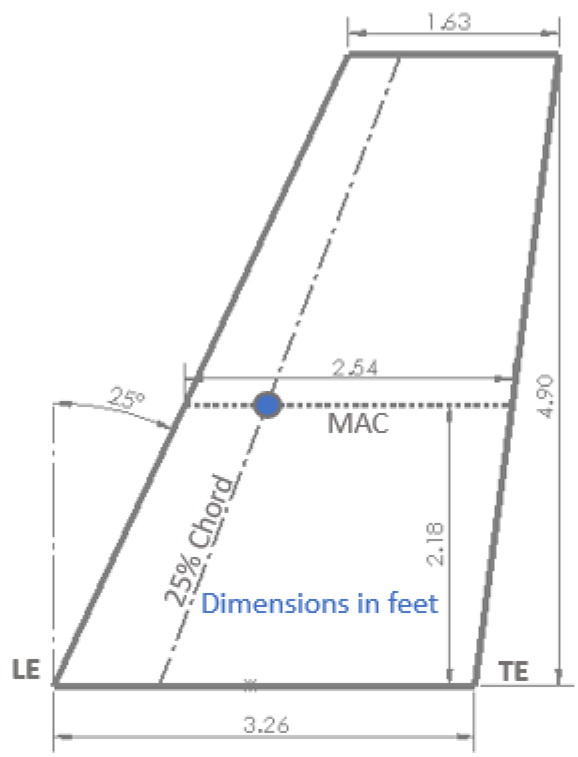


Figure 33: Vertical Tail Planform

9.2.1 Initial Rudder Sizing

The rudder was sized by using similar general aviation aircraft statistical data from Nicholai & Carichner [4] and is fixed along the trailing edge of the vertical stabilizer. The elevator parameters are shown in Table 10.

Table 10: Rudder Initial Sizing Parameters

Rudder Parameters	
Name	**Value**
Span of Rudder (ft.)	3.9
Chord of Rudder (ft.)	1.7

10 FUSELAGE LAYOUT

For initial sizing of the fuselage, the length was determined using statistical data based on general aviation-single engine aircraft estimates from Raymer [8]. The initial length of the fuselage was estimated to be 27.5 ft. After constructing a top-view layout of the required systems and seating arrangements, it was found that the necessary length of the aircraft could be reduced to 26 ft, allowing the shorter body to lower the weight and cost. The maximum height was determined to be 4.5 ft, in order to minimize drag while maintaining reasonable passenger comfort. The fuselage sizing of EFA-1 results in a fineness ratio of 5.77, which is comparable to similar aircraft. Figure 34 shows sizing comparisons to a Cessna 206, which is also a high-wing, single-engine aircraft with a fineness ratio of 7.

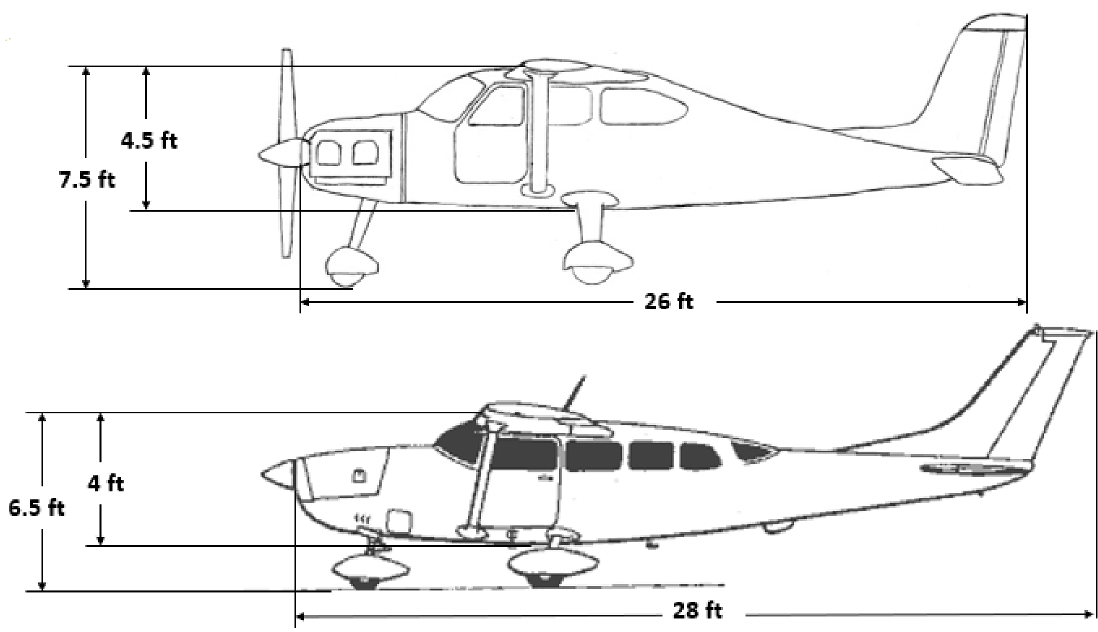


Figure 34: EFA-1 Fuselage sizing comparison to Cessna 206

Figure 34 shows the seating arrangement for the EFA-1. There is one pilot seat and 4 passengers with a cargo area behind the rear seat. Centering the rear seat allows for greater fuselage tapering from the cabin to the tail, reducing weight and cost. Figure 35 provides details of the seat and aisle dimensions, which allow for passenger comfort and accessibility. Figure 36 shows the location of the installed parachute in the ceiling of the cabin area with sufficient head room for passenger comfort.

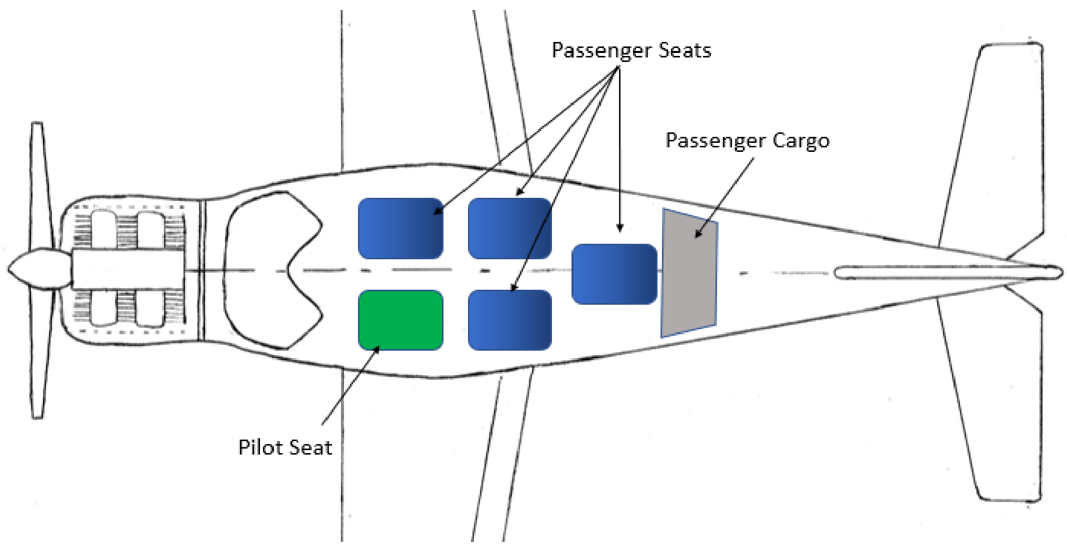


Figure 35: EFA-1 seating arrangement

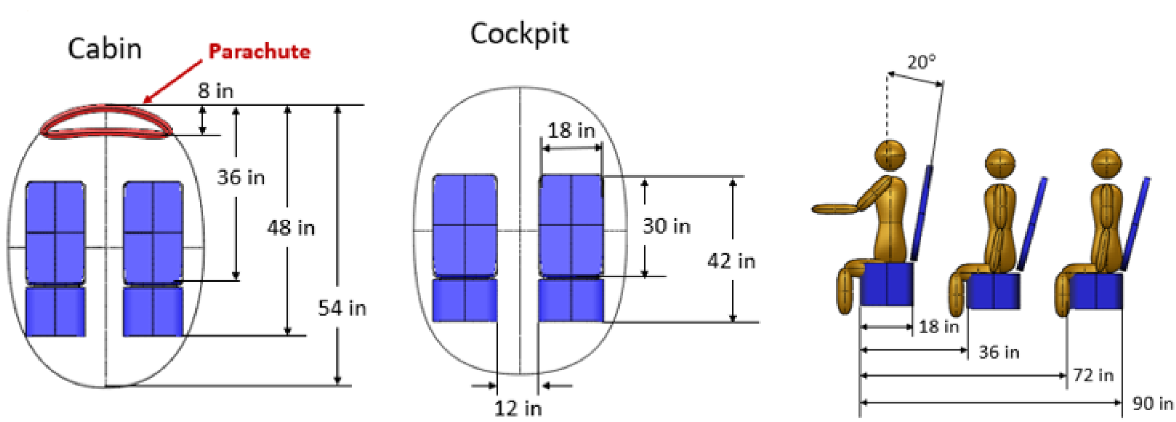


Figure 36: Seat and isle dimensions

Based on the RFP, a full body parachute must be installed for a single engine aircraft. The parachute deploys above the C.G. and has a diameter of 57 ft, based on a parachute drag coefficient of 1.2 and 1700 fpm terminal velocity [5]. Figure 36 shows the location of the deployed parachute.

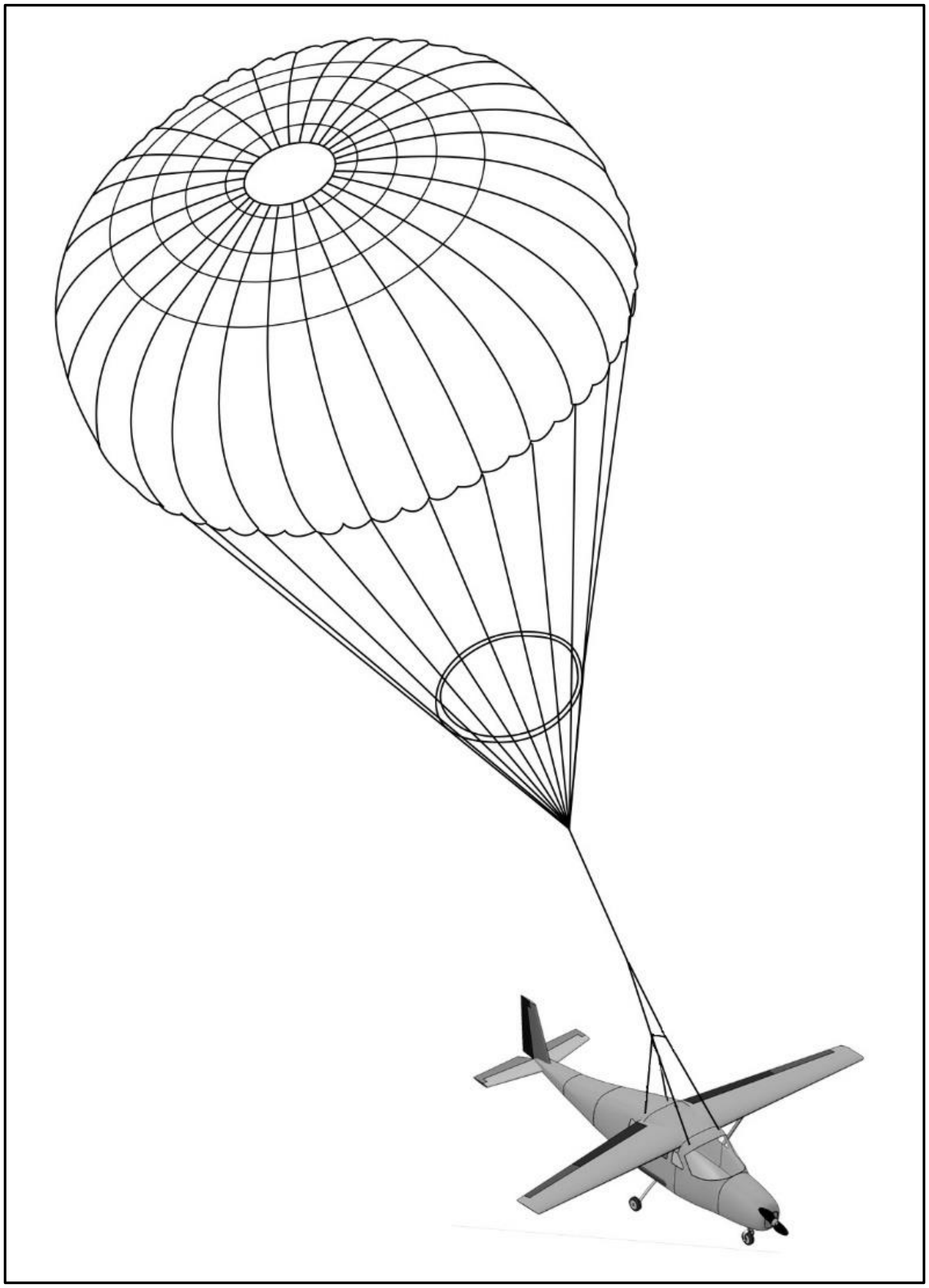


Figure 37: EFA-1 Deployed Parachute

11 ENGINE SELECTION

Four engines that meet the minimum power requirement of 310 hp were compared against each other using specific fuel consumption, time before overhaul, overhaul cost, price, and weight as seen in Table 11. Figure 38 shows the total cost of each engine after 20 years of service. The Lycoming IO-580-B1A was chosen because it will save over $200,000 per plane. With a production plan of at least 200 units, this would amount to a $40 million savings.

Power Requirement:	310hp

Table 11: Engine Trade Study Parameters

Engine:	SFC: (lbm/hour/hp)	TBO:	Overhaul Cost:	Price:	Weight: (lb)
Continental TSIO-520-M	0.54	2000 hours	$39,500	$77,637	454
Continental IO-550-N	0.52	2400 hours	$29,500	$55,301	496
Lycoming IO-580-B1A	0.47	2000 hours	$31,000	$89,174	434
Lycoming TIO-541-A1A	0.52	1300 hours	$40,000	$68,684	449

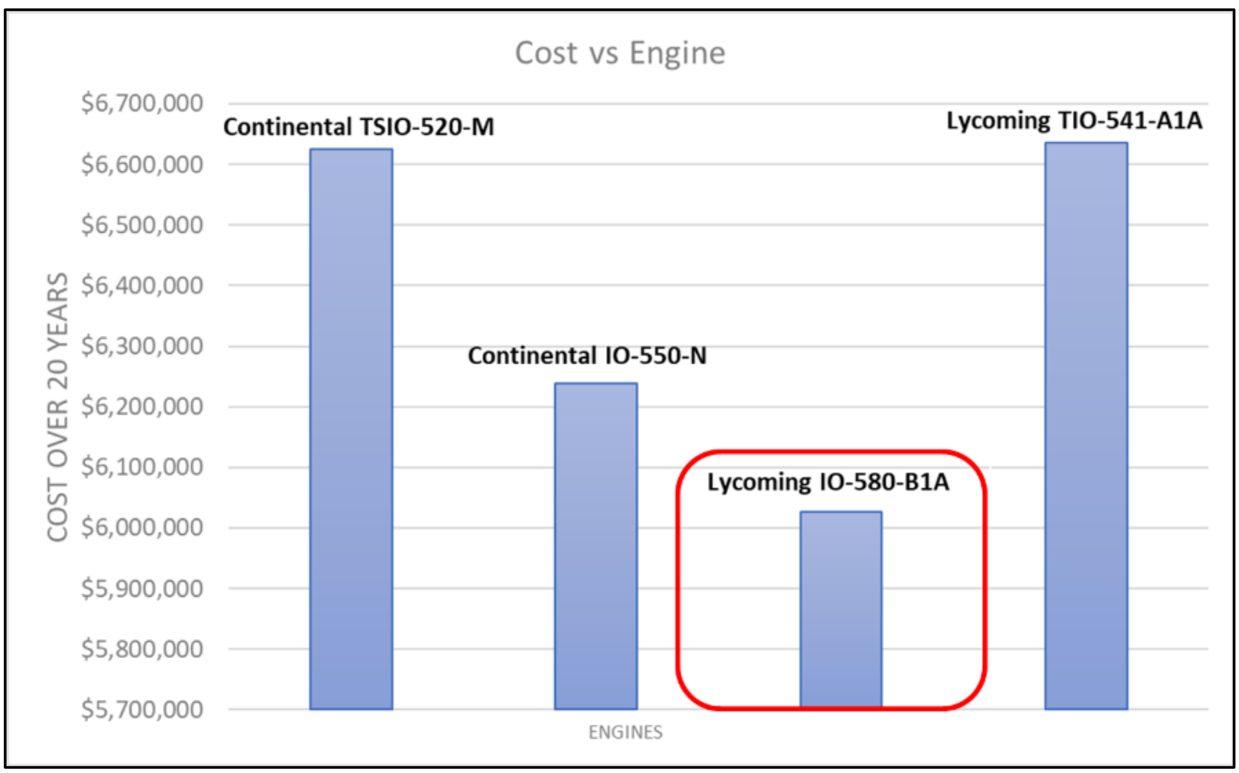


Figure 38: Cost of Engine over 20 years

12 Material Selection

The selection of material for the EFA-1 aircraft is one of the most important decisions made from both the structural and cost aspects. When selecting the material for the aircraft, the top three parameters considered included cost, weight and durability. The results of the trade study comparing four types of materials can be seen in Figure 39. The four types of materials included aluminum, carbon steel 4130, composite, and titanium 6A1-4V. These materials were analyzed with a higher weight factor in cost, fracture toughness, and specific strength. The results of the material trade study determined that aluminum was the best material for our design.

Material Selection			Aluminum	Carbon Steel 4130	Composite	Titanium 6A1-4V
Criteria	**Weight**	**Scale**	**Scores**			
Specific Strength	0.15	10 = High Specific Strength 1 = Low Specific Strength	9	7	8	10
Specific Stiffness	0.2	10 = High Specific Stiffness 1 = Low Specific Stiffness	10	9	8	7
Fracture Toughness	0.15	10 = High Resistance to Crack Growth 1 = Low Resistance to Crack Growth	6	8	5	10
Cost	0.15	10 = Low Cost 1 = High Cost	9	9	7	4
Minimum Gage Limitations	0.2	10 = Least Thick 1 = Most Thick	9	8	10	7
Availability	0.15	10 = Takes Less Time 1 = Takes More Time	10	4	8	5
Weighted Total	**1.00**	**Selection →**	8.90	7.60	7.80	7.15

Figure 39: Material Selection Trade Study

From there, a more in-depth trade study on three aluminum alloy properties was conducted for 2024-T3, 6061-T6, and 7075-T6. These three aluminum alloys are commonly used for airframe material in the aerospace industry. Figure 40 shows the trade study on the three materials with fracture toughness, specific strength and cost. Even though 2024-T3 cost per cubic foot is higher than 6061-T6, this specific alloy provides an increased specific and yield strength at a fraction of the cost. Aluminum 2024-T3 was chosen as the material for our aircraft design due to the material's lightweight properties as well as long-lasting durability.

Material Properties	Selection	Aluminum Alloy		
	Units	2024-T3	6061-T6	7075-T6
Fracture Toughness	Mpa - $\sqrt{m}$	25	29	25
Specific Strength	in	7.00E+05	4.60E+05	8.00E+04
Elastic Modulus	Msi	10.6	10	10.44
Yield Strength	ksi	50	39.9	13.8
Cost per cubic foot	USD	$16.75	$11.95	$27.80

Figure 40: Aluminum Alloy Properties

13 DETAILED WEIGHT BREAKDOWN

Figure 41 shows the detailed weight breakdown of the EFA-1, which results in a 2.3% decrease in weight from our initial weight estimations. As stated previously, weight reductions were accomplished by centering the rear seat and tapering the fuselage. Further weight reductions were made through the optimization of the aspect ratio and maximum thickness ratio.

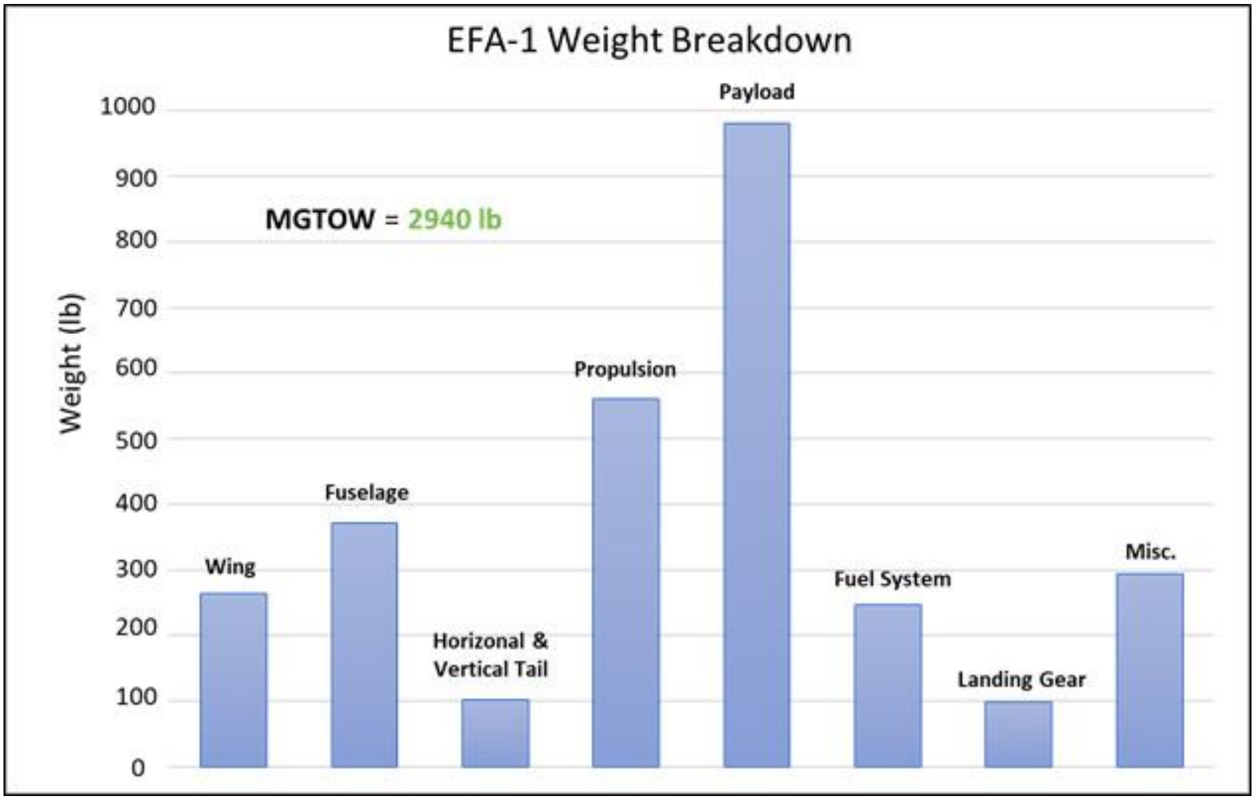


Figure 41: Detailed Weight Breakdown of EFA-1

13.1 C.G Travel & Static Margin

Weight and balance information in Table 12 determines the C.G. location for the takeoff weight.

The C.G. locations of the main components is shown in Figure 42.

Table 12: Weight and Balance for Takeoff

Component	Weight (lb)	Moment Arm (ft)	Moment (ft-lb)
Fuselage	371	10	3344
Wing	263	7.5	1975
H.T. + V.T.	102	24.5	1710
Landing Gear	100	5.6	582
Propulsion	550	1.25	687
Fuel System	247	7.5	1792
Flight Controls	76	11	844
Parachute	30	13	390
Electrical System	64	9	582
Avionics	23	5.5	126
Furnishings	110	11.5	1268
Crew/Payload	980	7	6800
Misc.	24	-	-
Total	2940	-	22162

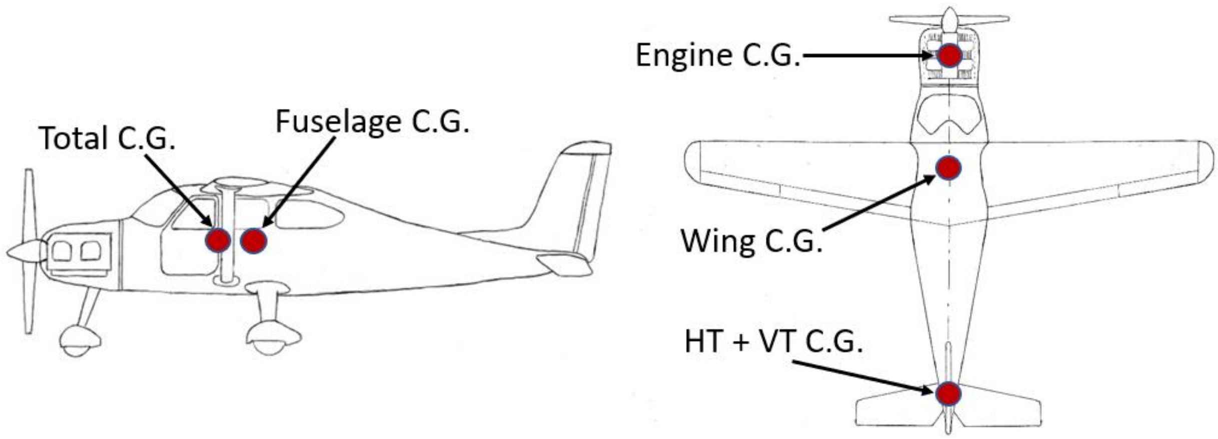


Figure 42: C.G. location breakdown

The C.G. travel graph shows the C.G. location of the takeoff weight, zero fuel, zero payload and empty weight configurations, as shown in Figure 43. These values result in a C.G. travel of 8.3% and a static margin of 8.0%.

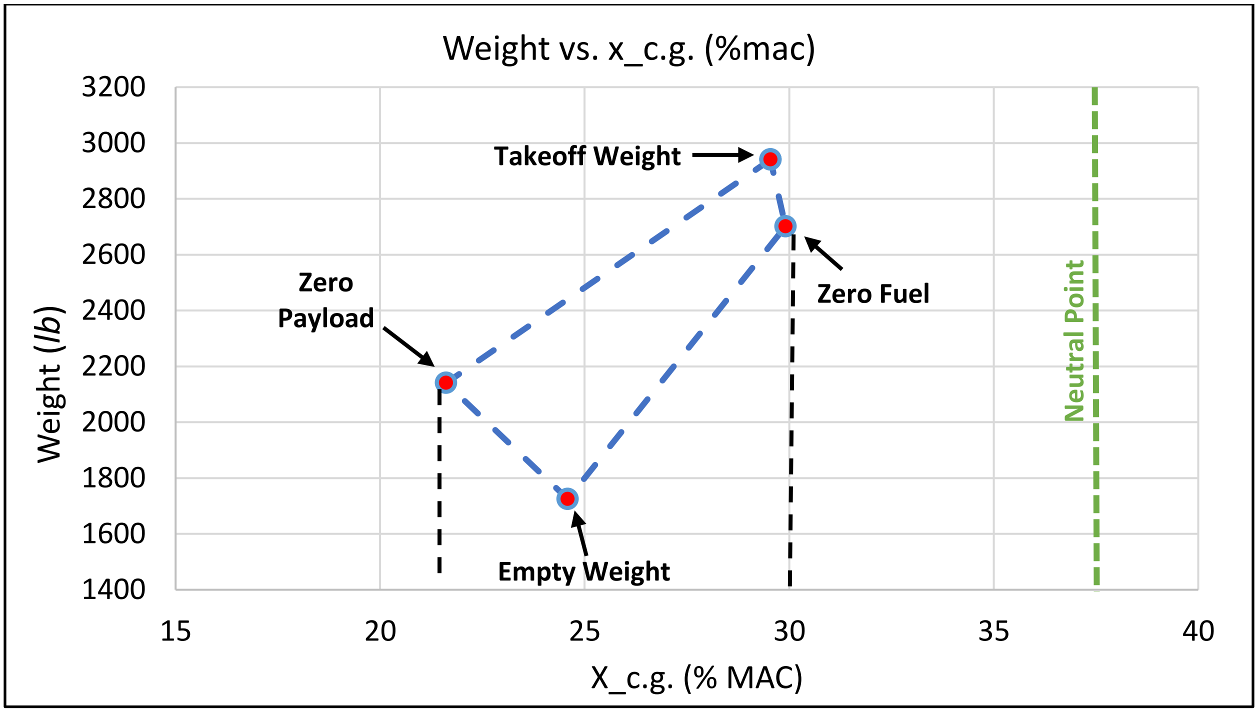


Figure 43: C.G. Travel Graph

14 FUEL TANK INTEGRATION

Using the mission fuel fraction of 0.078 calculated in Table 5 (Section 6) and the MGTOW of 2940 lb, the required fuel was found to be 230 lb, as shown in Table 13. The tank volume was calculated by using an integral tank packing factor of 0.75 from Carichner & Nicolai [4] and a worst-case fuel density at 50 Celsius in accordance to FAR 23.2430 Fuel Systems. The resulting total tank volume to hold the necessary fuel is 7.09 ft^3.

Table 13: Fuel & Tank Volume Sizing

Tank Volume & Fuel (Using AvGAS)						
-	**Fuel**	**Fuel**	**Density @ 15 C**	**Density @ 50 C**	**Package Factor**	**Tank Volume**
Units	*lb*	*gal*	*lb/gal*	*lb/gal*	-	ft^3
Value	230	38	6.01	5.78	0.75	7.09

Figure 44 shows the location of the wing integral tank. Each wing integral tank must hold at least 3.55 $ft^3$of fuel to complete the mission.

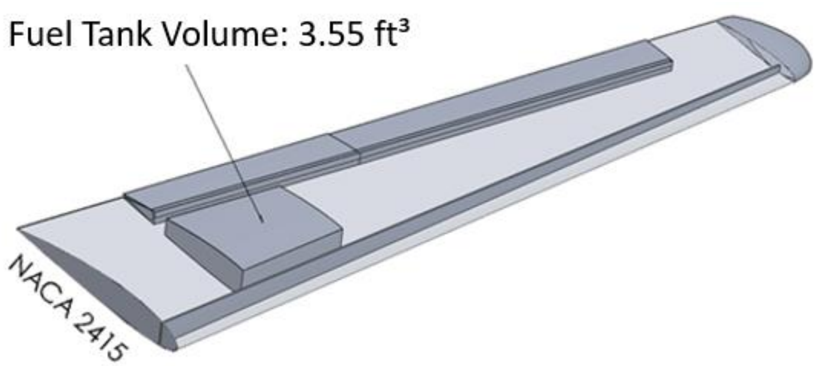


Figure 44: Wing Integral Tank

15 Landing Gear

Fixed, tricycle-type landing gear was selected as shown in Figure 45. Even with an increase in drag, the fixed gear is more beneficial for the aircraft in all other areas, including weight, cost, and maintenance. Having fixed gear also reduces the possibility of gear malfunctions, which increases the factor of safety.

Fixed Gear vs Retractable			Fixed Gear	Retractable Gear
Criteria	**Weight**	**Scale**	**Scores**	
Weight:	0.05	10 = Lightest 1 = Heaviest	9	5
Cost:	0.25	10 = Low Cost 1 = High Cost	9	2
Maintenance:	0.3	10 = Low Cost 1 = High Cost	8	3
Drag	0.4	10 = Less Drag 1 = More Drag	4	9
WEIGHTED TOTALS:	1.0	Fixed Gear Selected →	6.7	5.3

Figure 45: Landing Gear Trade Study

15.1 Landing Gear Placement

The main landing gear will take 85% of the total aircraft weight and will be placed behind the CG, as shown in Figure 46. The tip-back angle of 15 degrees is enough to ensure that the aircraft does not require a large deflection of the elevator during rotation, and thus will not collide with the horizontal stabilizer. The angle from the C.G. to the main landing gear should be greater than the tip-back angle of 15 degrees, resulting in a design angle of 16 degrees.

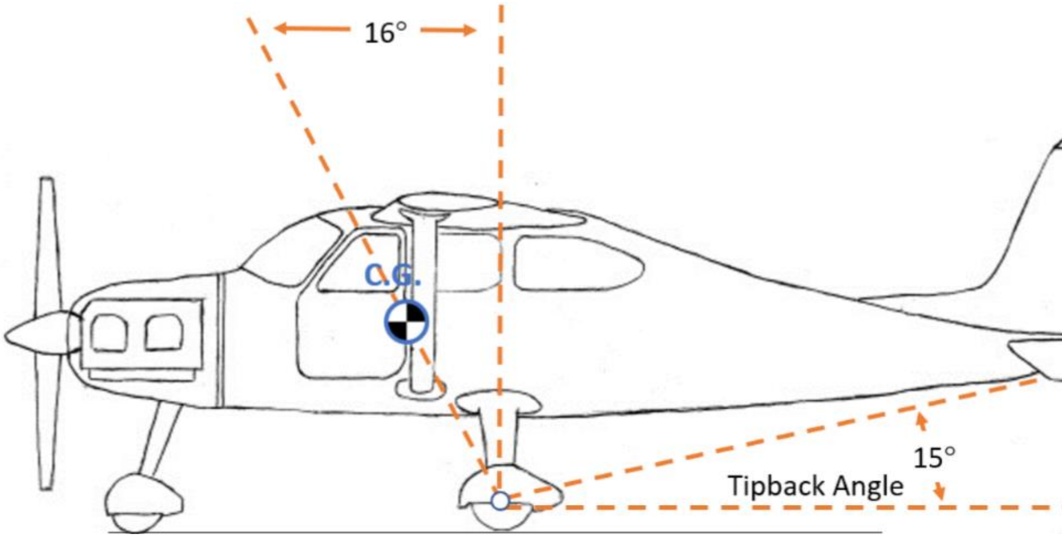


Figure 46: Landing Gear Placement

The overturn angle, seen in Figure 47, was calculated to be 35 degrees, which is between the optimum range of 25-60 degrees. This angle ensures that the aircraft does not overturn when going around a sharp corner.

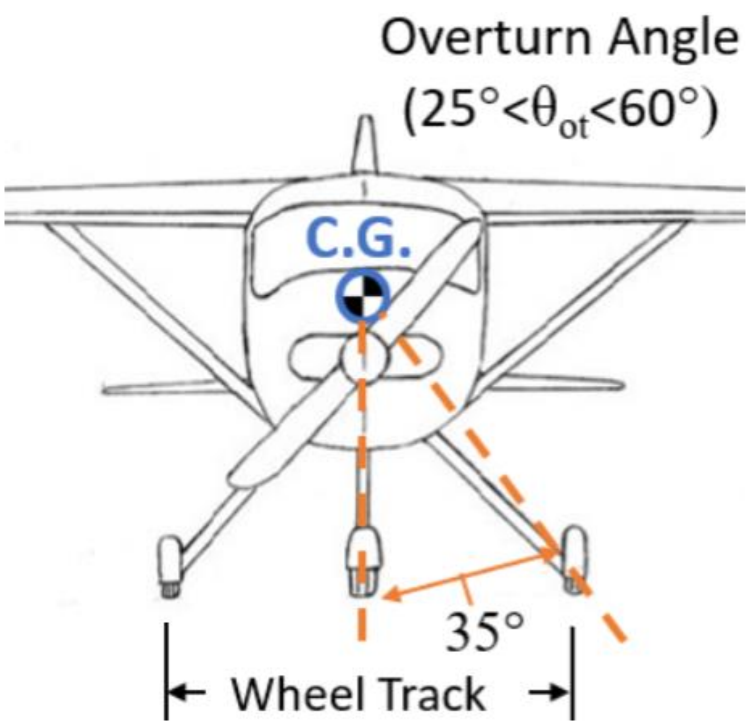


Figure 47: Landing Gear Overturn Angle

16 ALTITUDE OPTIMIZATION

Due to FAR regulations 14 CFR 91.159 - VFR cruising altitude or flight level, the flight altitudes vary from even to odd altitudes depending on direction plus 500 ft MSL. EFA-1 cruise altitude ranges from 5,500 ft-6,500 ft. For simplicity, 6,000 ft cruise altitude is used as an average to account for the variation. Cruise altitude was determined through a series of iterations considering a 45-minute timeframe as well as an optimal fuel burn. The change in horsepower during climb was monitored, while selecting the cruise altitude with the lowest fuel burn. As the altitude increases, cruise fuel burn decreases. Since the mission profile range is 135 nautical miles, having a short time-to-climb would be a better choice than having a higher altitude fuel burn. Therefore, a cruise altitude of 6,000 ft is selected where fuel burn and time to climb would be minimal. Also considering the oxygen requirements of FAR 91.211 Supplemental Oxygen, which the required altitude for supplemental oxygen is at 12,500 MSL and above. Operating below this altitude will remove the need for oxygen and pressurization. A max service ceiling of 12,500 ft was selected for EFA-1 because supplemental oxygen equipment would further drive up operating costs.

17 OPERATING ENVELOPE

An operational envelope was constructed for the EFA-1 to determine the operating parameters and capabilities. The boundary limits consist of stall velocity, max ceiling, and thrust equals drag. As shown in Figure 48, the EFA-1 has a max ceiling at an altitude of 30,000 ft. Although, EFA-1 can reach an altitude of 30,000 ft, FAR 91.211 requirement must be met. The FAR 91.211 requirement states that no person can operate a civil aircraft of U.S. registry at a cabin pressure above a max ceiling altitude of 12,500 ft. In order to consider this altitude FAR requirement, an altitude optimization analysis was conducted in order to determine the cruise point. Upon completion of the analysis, the cruise velocity was determined to be 210 kts, with an optimal cruise altitude of 6,000 ft.

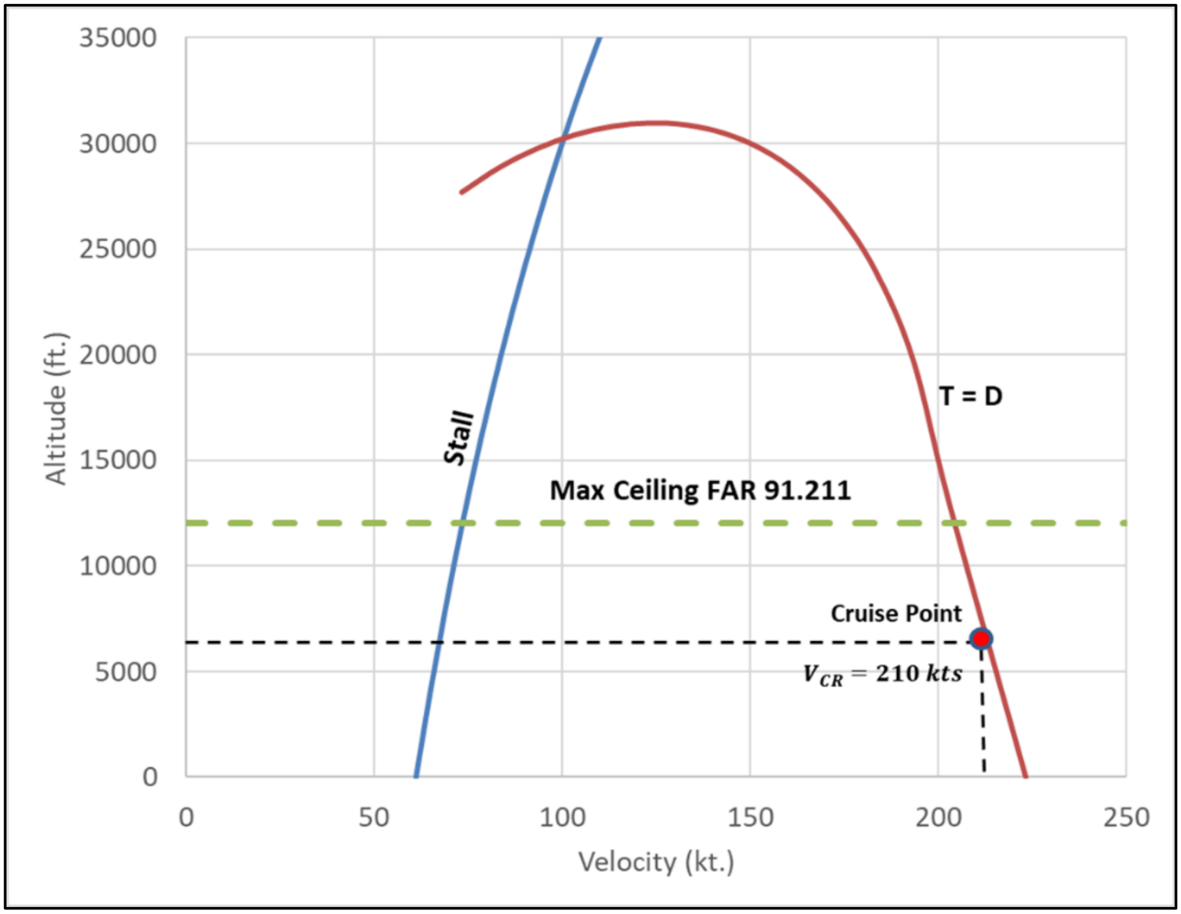


Figure 48: Operational Envelope for EFA-1

18 AERODYNAMICS

18.1 PARASITE DRAG BUILDUP

Figure 49 shows the parasite drag buildup of the optimized EFA-1 of 0.0244. The optimization of the aircraft through the various trade studies lowered the parasite drag buildup by 6% from the baseline design, which reduces the direct operating cost.

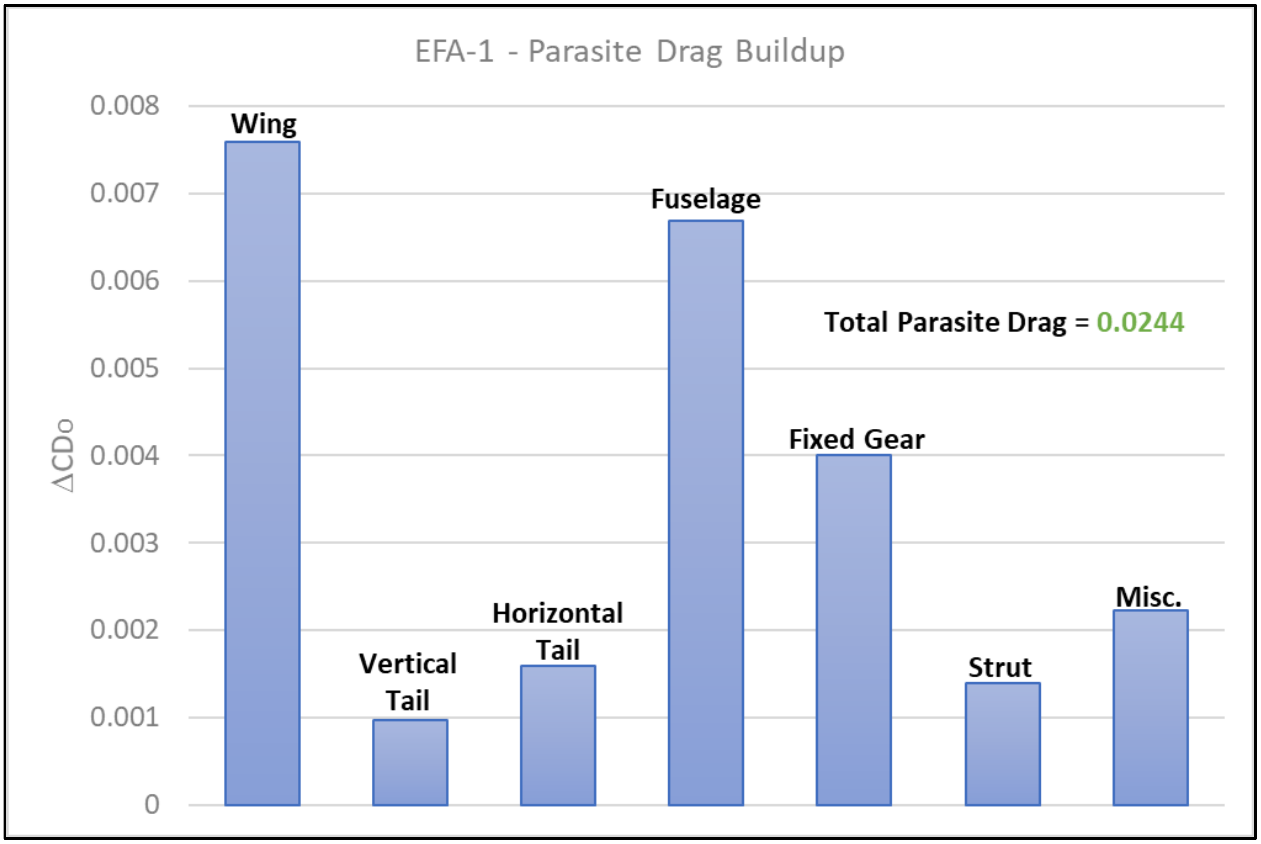


Figure 49: EFA-1 Optimized Parasite Drag Buildup

18.2 Drag Polar & L/D Max

From the Drag Polar, the maximum lift-to-drag ratio was found to be 15, as shown in Figure 50. The EFA-1 cruises at a L/D of 11. This is due to the cruise optimization calculations and selection of a lower altitude of 6,000 ft. With a lower altitude than the calculated maximum L/D, there is less time to climb and less fuel burn. Thus, cruising at 6,000 ft yields a lower direct operating cost.

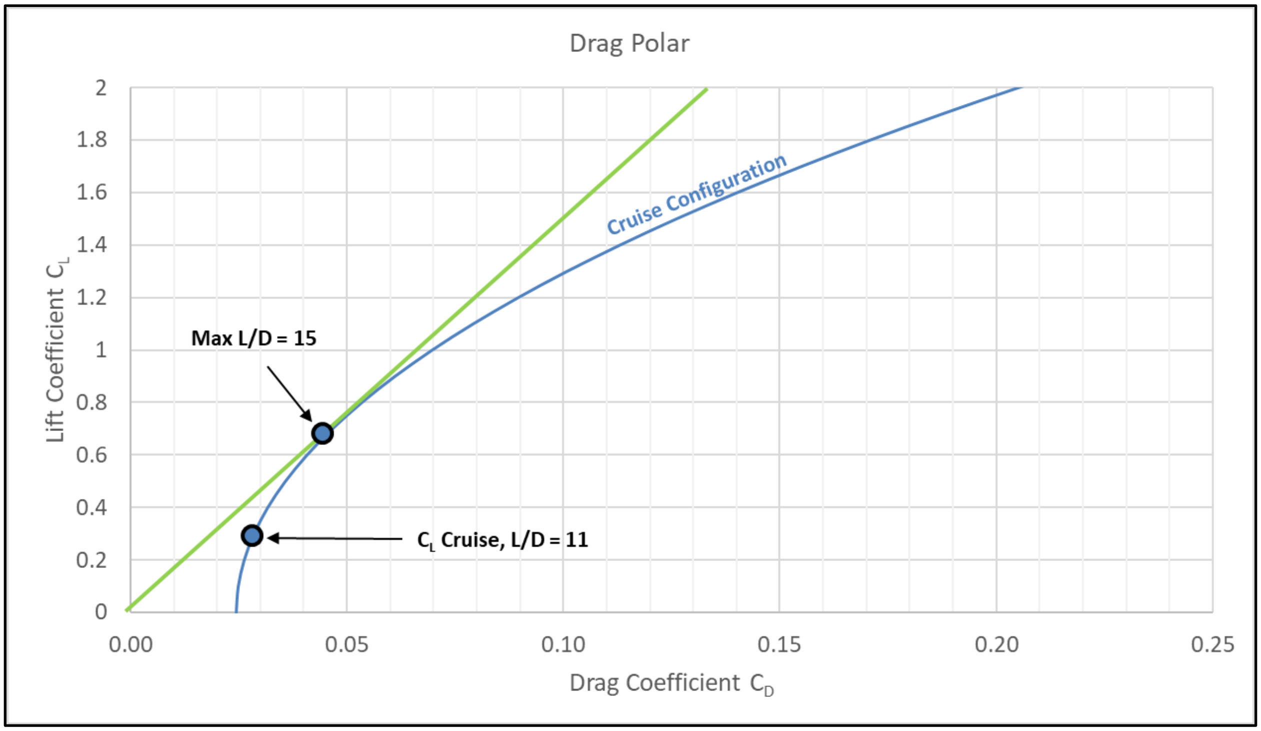


Figure 50: Drag Polar

19 Takeoff and Landing Analysis

The takeoff and landing analyses were calculated based on sea level and standard day conditions. The takeoff distance was calculated based on a typical takeoff configuration 10-degree flap deflection, as shown in Figure 51, with a distance of 1353 ft. Based on a typical landing configuration of 40-degree flap deflection, as shown in Figure 52, landing distance was calculated to be 1164 ft. The EFA-1 meets the requirement of landing distance and takeoff distance of less than 2500 ft over a 50 ft obstacle.

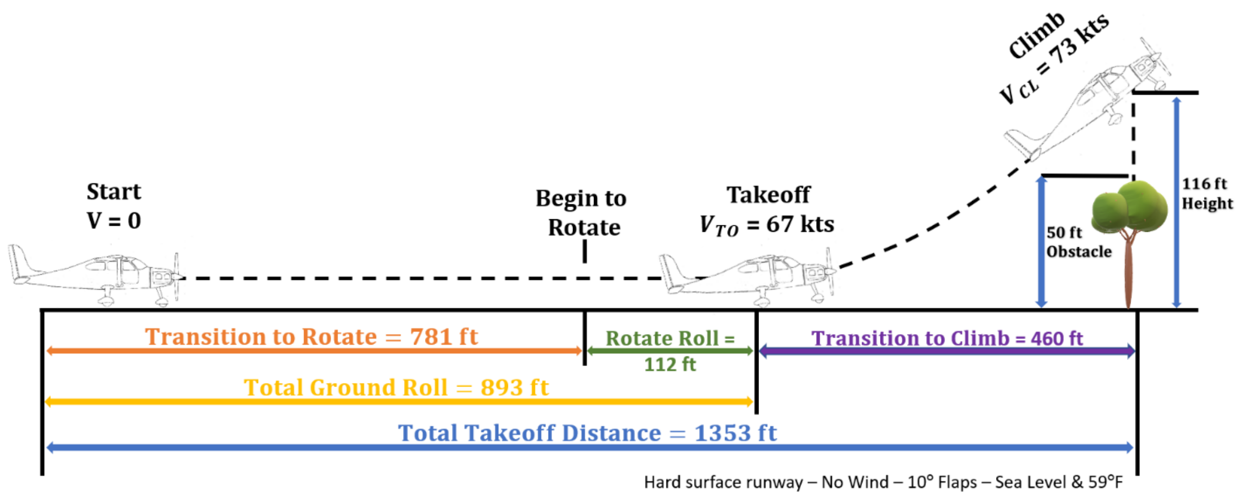


Figure 51: Takeoff Analysis

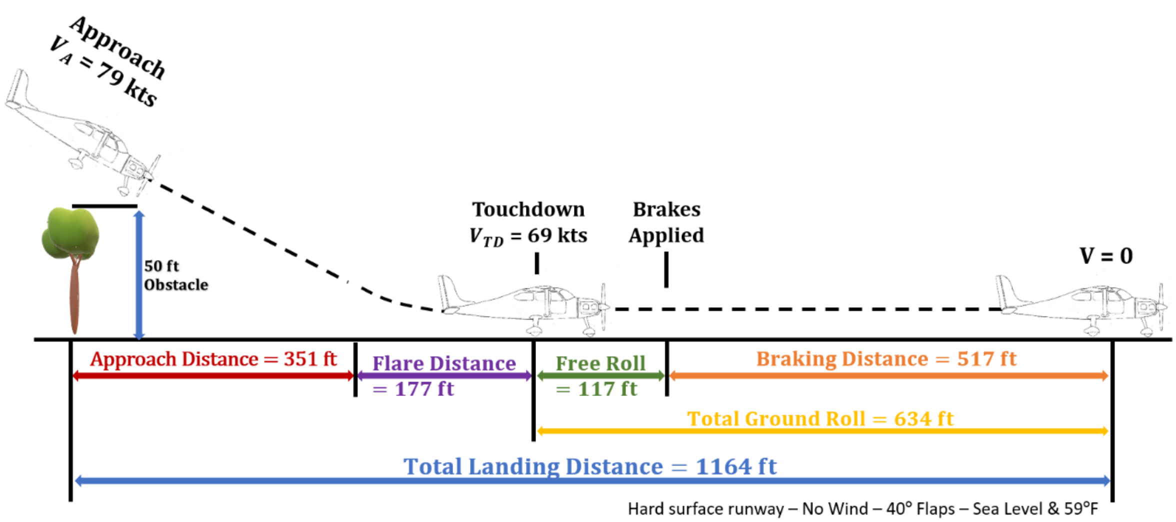


Figure 52: Landing Analysis

20 STABILITY AND CONTROL

At this stage of the design, longitudinal and lateral stability of EFA-1 was evaluated. In analyzing both longitudinal and lateral stability, a more accurate design for the horizontal and vertical tails were determined.

20.1 LONGITUDINAL STABILITY

Figure 53 was used to determine the horizontal tail volume coefficient. As shown in the graph, the horizontal tail is sized based on the following four requirements:

- Static Margin with the C.G. at the rearmost location.
- Control in pitch with full flaps at landing approach speed with the C.G. at the forward-most location. (Landing Flare)
- Takeoff rotation with the C.G. at the forward most location. (Nosewheel Liftoff)
- Maximum C.G. travel.

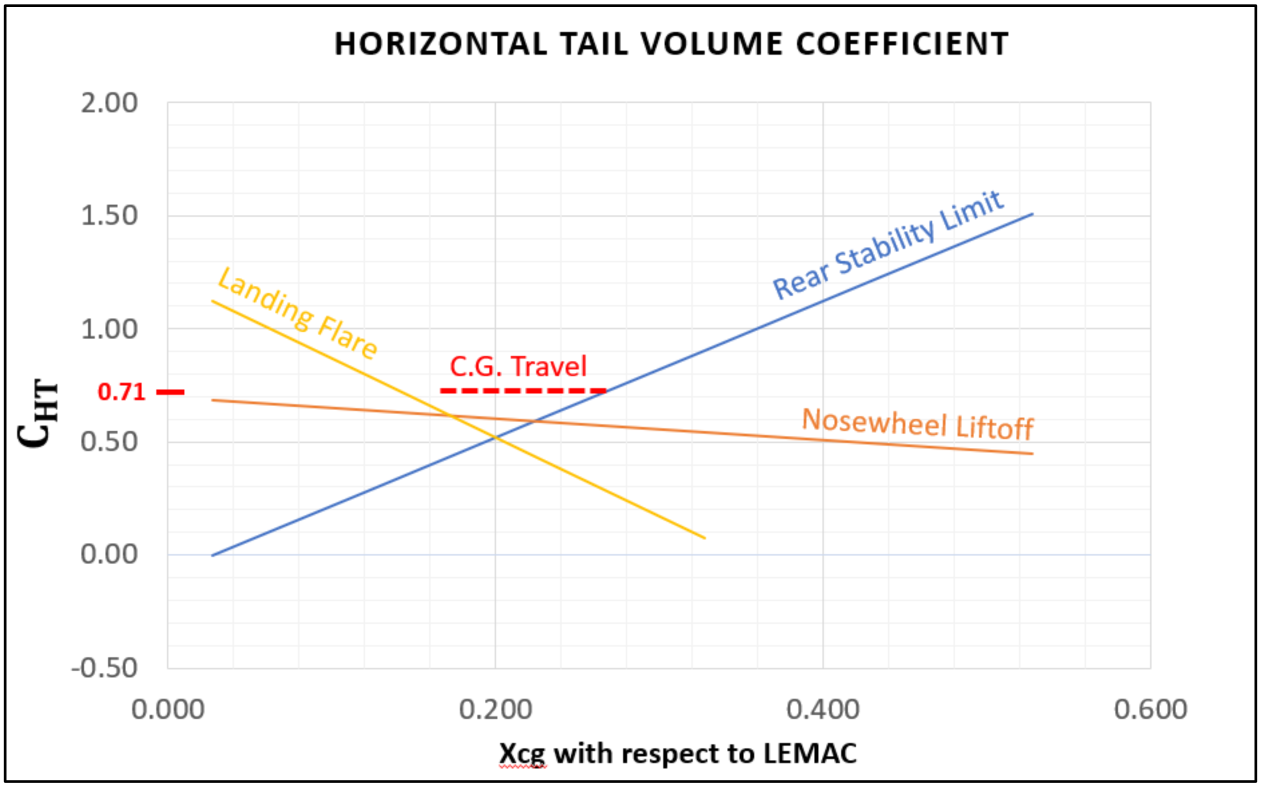


Figure 53: Notch Chart

From the chart C_{HT} was found to be 0.71 which gave a horizontal tail area (S_{HT}) of 26.5 ft^2. Table 14 shows C_{HT} values of similar aircrafts.

Table 14: C_{HT} Comparison with Similar Aircrafts

-	EFA-1	Piper Cherokee	Cessna Cardinal
C_{HT}	0.71	0.61	0.6

20.2 Lateral Stability

Figure 54 was used to determine Yaw Moment Derivative for the EFA-1. The optimal point was chosen with the consideration of the required Mach Number for EFA-1 and historical data on similar aircrafts from Raymer [8]. The estimated Yawing Moment Stability Derivative was then used to calculate the C_{VT} and the vertical tail area (S_{VT}), as shown in Table 15. Table 16 shows C_{VT} values of similar aircrafts.

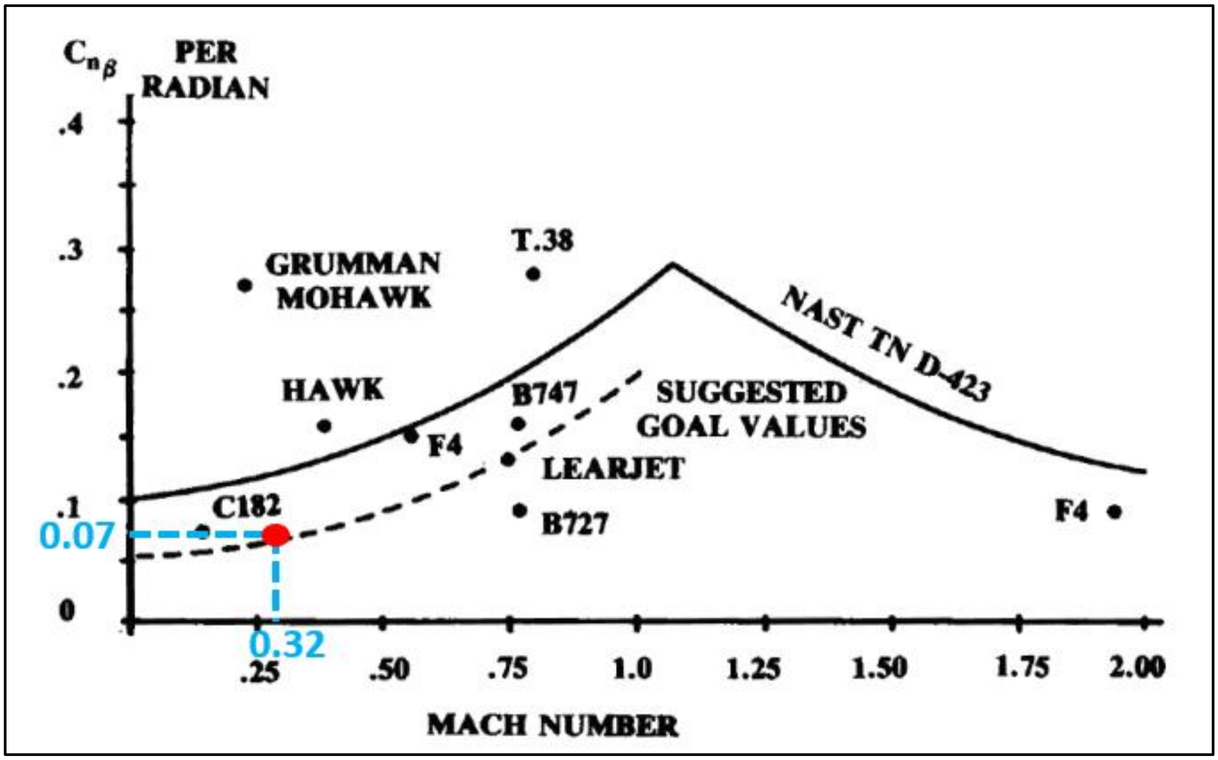


Figure 54: Typical Yaw Moment Derivative Values

Table 15: Vertical Tail Stability Parameters

C_{nB} (per rad)	0.07
S_V (ft^2)	12.96
C_{VT}	0.04

Table 16: C_{VT} Comparison with Similar Aircrafts

-	EFA-1	Piper Cherokee	Cessna Cardinal
C_{VT}	0.04	0.037	0.038

21 Structural Analysis

21.1 V-n Diagram

In order to determine the operational limits for the aircraft, a V-n diagram was constructed as shown in Figure 55. From FAR 23.2215 Flight Load Condition, gust velocities of 25, 50, and 66 feet per second were evaluated to further define the operational limits at various velocities. A maximum load factor of +3.8 and -1.0 was used in accordance with FAR 23.337 Limit Maneuvering Load Factors.

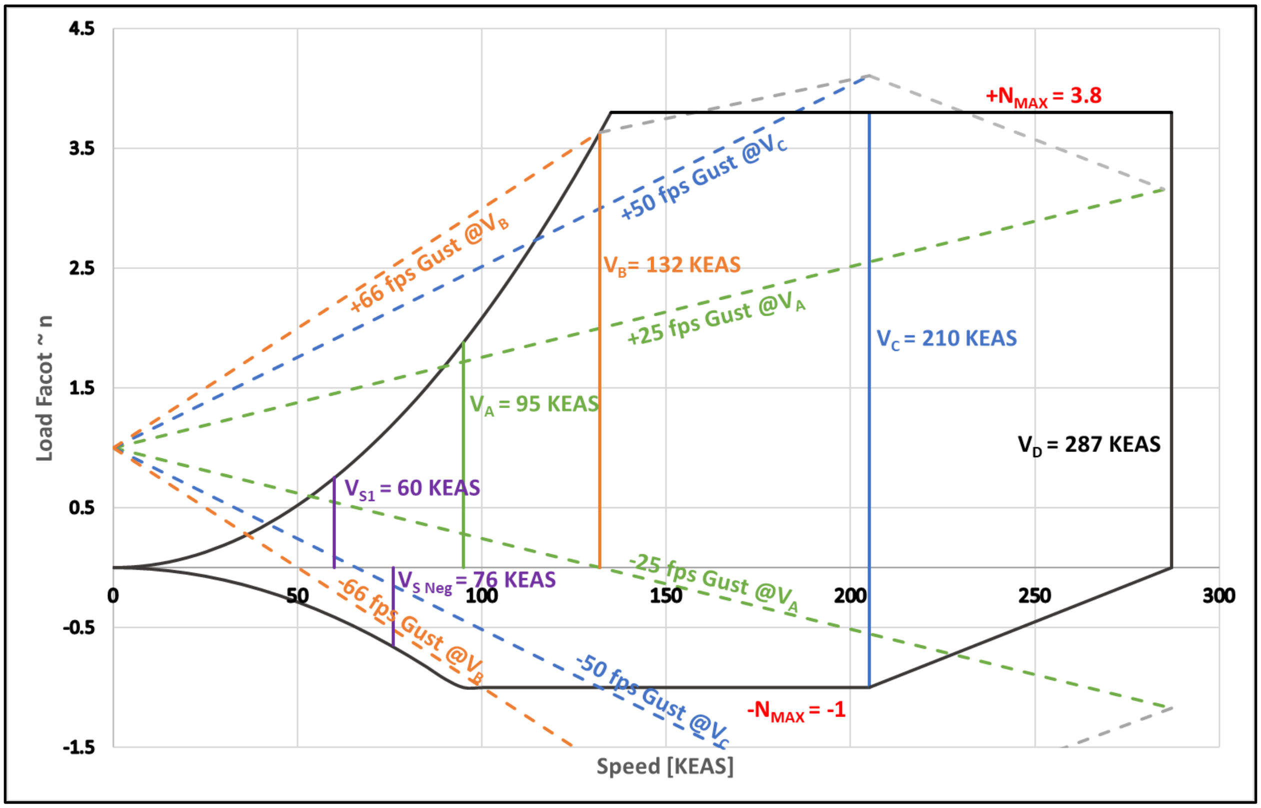


Figure 55: V-n Diagram

21.2 Spar and Rib Sizing

Using the assumption of elliptic load distribution, the bending moment in the lateral (M_x) and the longitudinal (M_z) and the shear force (V_z) was calculated for the EFA-1 using Bruhn [3].

Table 17: Maximum Bending Moment and Shear force

Mx (Kips-ft)	5.9
Mz (Mips-ft)	1.908
Vz (Mips)	1.35

Using the bending moments and shear force, several iterations were conducted to find the optimal spar sizing, rib sizing, and locations for the EFA-1. Two spars were selected in the front and rear of the airfoil as shown in Figure 56 and Figure 57, respectively. The front spar will take approximately 75% of the loading and the rear spar will take the remaining 25%. As a result, a total of 12 ribs with 0.24-inch thickness located 17.04 inches apart from the root chord to the tip chord was selected as shown in Figure 58. One rib was removed to allow room for the fuel tank.

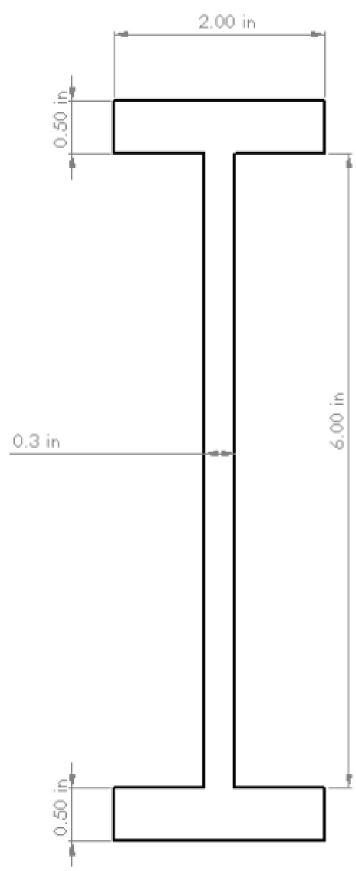


Figure 56: Front Spar Size (Cross-Section View)

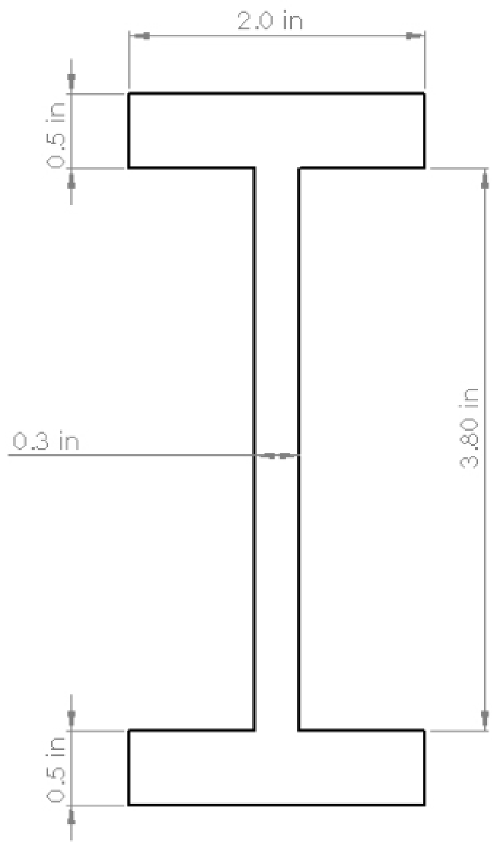


Figure 57: Rear Spar Size (Cross-Section View)

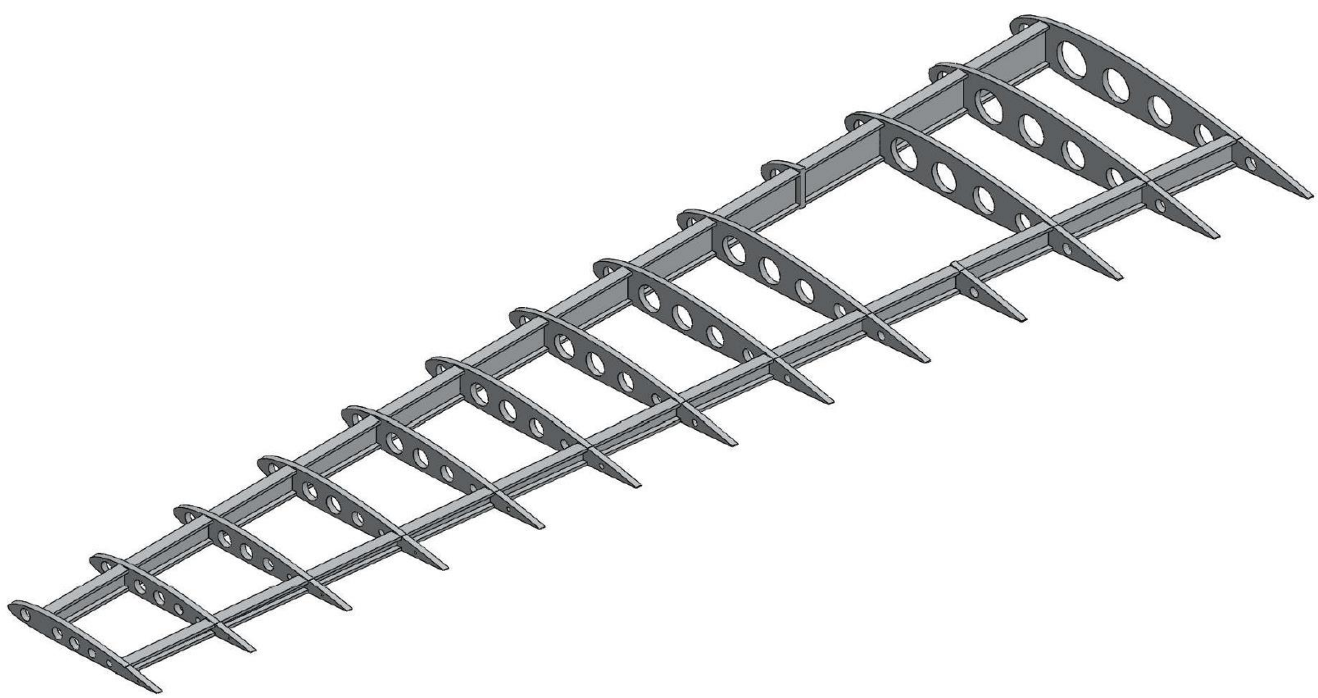


Figure 58: Rib and Spar Placement

An I-beam was used because it is stiff enough to counteract bending caused by lift, while reducing overall weight. Both the front and the rear spars are sized to fit in the front and rear positions of the airfoil.

Table 18: Maximum Stress Limit for Front and Rear Spar

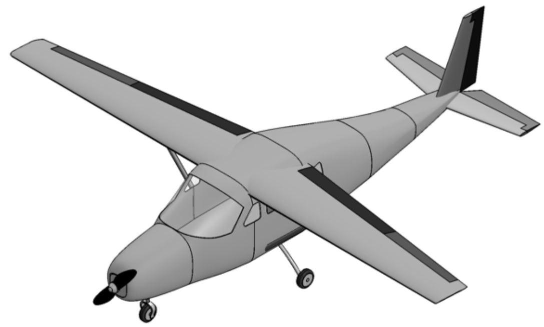
Front Spar (KSI)	33.8
Rear Spar (KSI)	15.9
Total Stress (KSI)	49.7
Bending Allowable (KSI) of Al 2024-T3	64.0

From Table 18, the total maximum stress is 49.7 KSI, using a maximum load factor of 3.8 per FAR 23.337 Limit Maneuvering Load Factors and a factor of safety of 1.5 to the applied loads per FAR 23.2230 Limit and Ultimate Loads. The corresponding Margin of Safety for the spars is 0.287.

22 OPTIMIZED DESIGN

The final characteristics of the EFA-1 is shown in Figure 59.

Characteristics	Value
Max Takeoff Weight (lb)	2940
Length (*ft*)	26
Wing Loading (lb/ft²)	22.5
Wing Span (ft)	34
Wing Area (ft²)	129
Wing Airfoil - Root	NACA 2415
Wing Airfoil - Tip	NACA 2412
Aspect Ratio	9
Taper Ratio	0.5
Power Loading (hp/lb)	0.105
Propeller	3 blade/74" diam.
Engine	IO-580-B1A



Performance Characteristics	Optimzed Design	Requirements	Satisfied
Avg. Ground Speed (Seg 3-5) (*kts*)	180	≥ 180	√
Takeoff Distance (*ft*)	1354	≤ 2500	√
Landing Distance (*ft*)	1164	≤ 2500	√
Stall Speed FAR 23 (*kts*)	60	≤ 61	√
Rate of Climb FAR 23 (*ft/min*)	1952	≥ 300	√

Figure 59: EFA-1 Optimized Design

A 3-view drawing of the optimized EFA-1 aircraft along with key parameters and dimensions is shown in Figure 60.

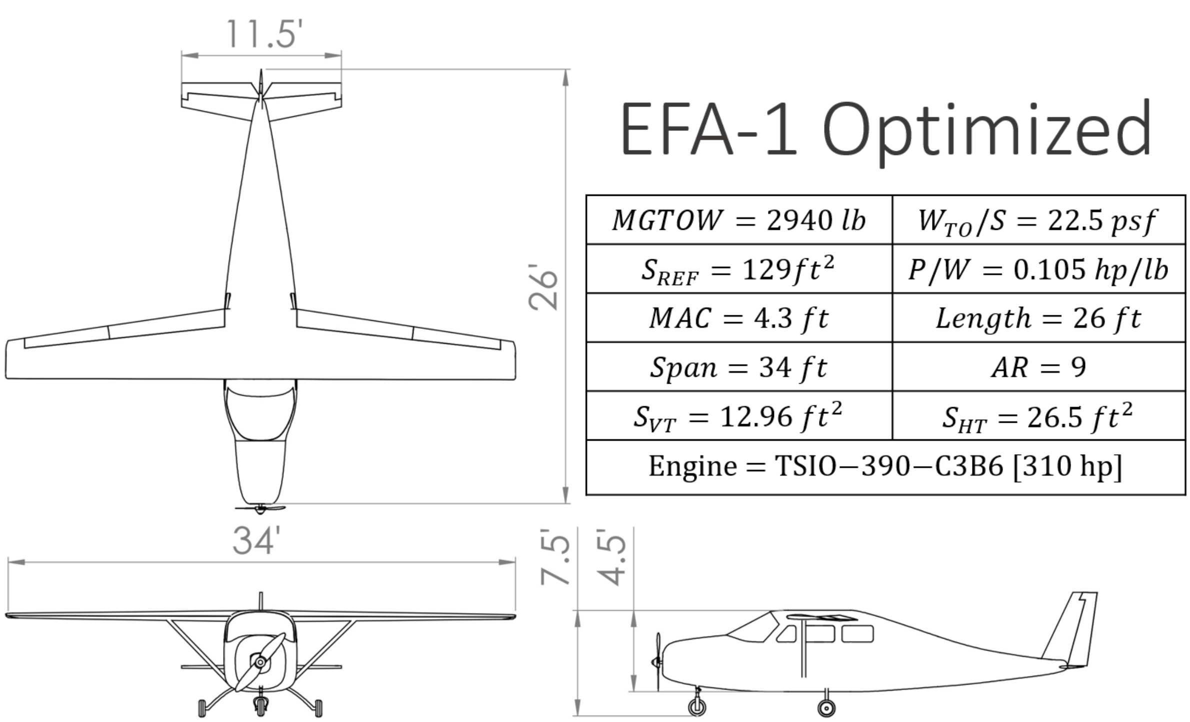


Figure 60: EFA-1 Optimized 3-view Drawing

23 EFA-1 Mission Profiles

23.1 EFA-1 Reference Mission

In order to obtain an average ground speed of 180 kt, the cruise speed would need to be higher than 180 kt to meet this criterion. Segment 4 cruise speed and cruise altitude were 210 kt at 6,000 ft MSL. From segment 2, EFA-1 takeoff distance over 50 ft obstacle was 1354 ft. For segment 6 and 10, the landing distance over the 50 ft obstacle was 1164 ft. For EFA-1, the power produced and fuel flow rate are proportionally related. To achieve best endurance, the minimum power and minimum fuel flow rate are selected. The optimal loiter speed for the 45 minutes was determined to be 79 kt. As shown in Figure 61, EFA-1 meets or exceeds all requirements for the Reference Mission.

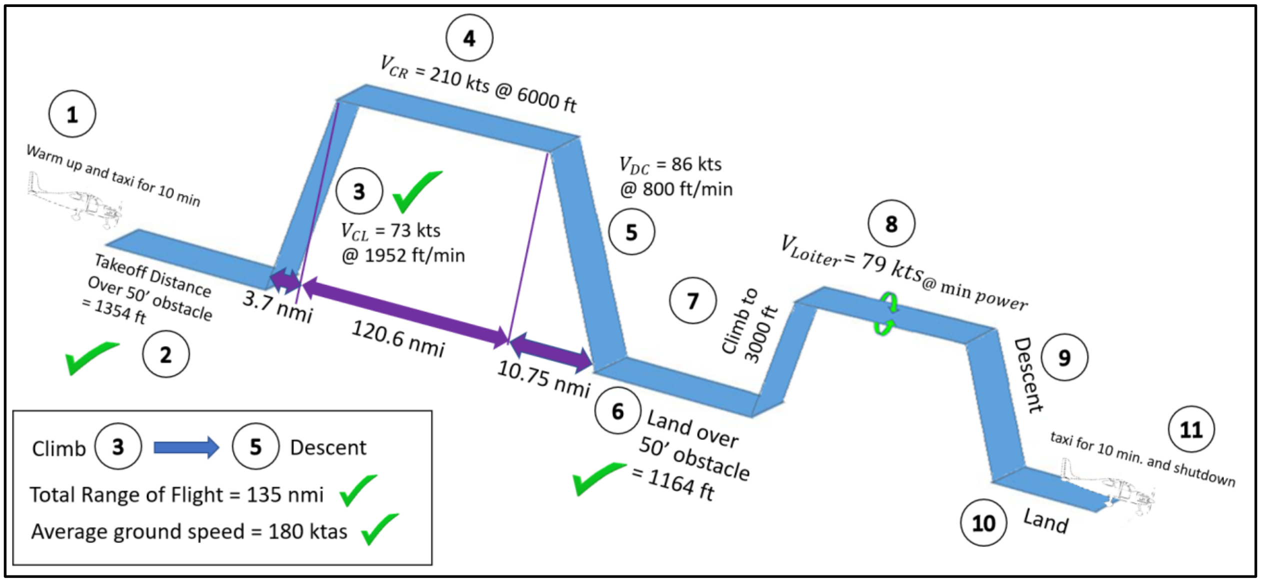


Figure 61: EFA-1 Reference Mission

23.2 EFA-1 SIZING MISSION

EFA-1 meets the total range of flight requirement of 250 nmi with no time or speed requirement. For segment 2 & 3, EFA-1 takeoff distance of 1354 ft and a climb rate of 1952 ft/min, meet both the takeoff distance and climb requirement in Figure 62. EFA-1 cruises at 180 kt for the majority of the long-range sizing mission. Segment 6 landing distance was 1164 ft over a 50 ft obstacle, which was below the 2500 ft landing distance requirement.

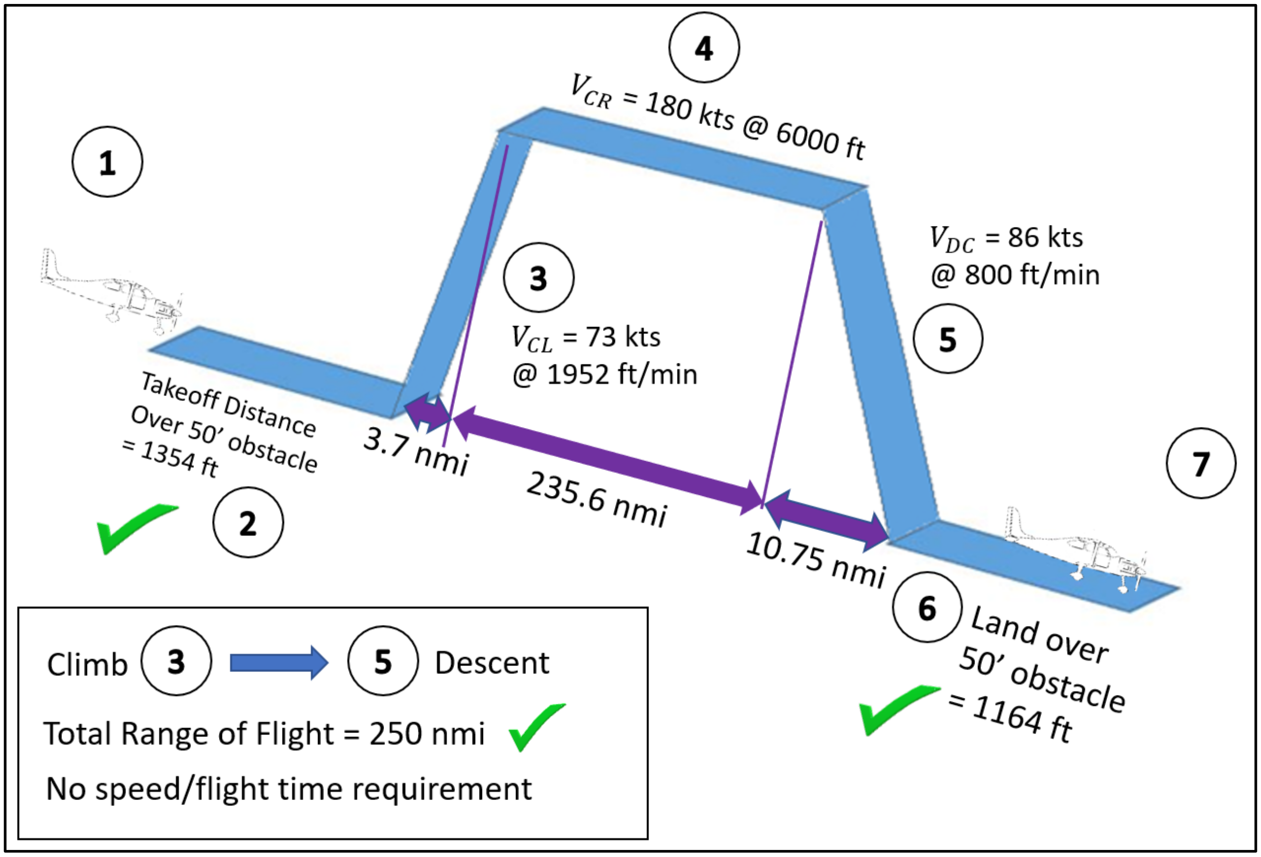


Figure 62: EFA-1 Sizing Mission

24 COST ANALYSIS

The cost analysis was based off equations from Nicolai and Carichner [4] coupled with the added cost of inflation. The following sections breakdown our flyaway cost, operations & maintenance cost, direct-operating cost and production break-even point.

24.1 FLYAWAY COST

Based on the analysis, EFA-1 will cost $245,300 to produce, with the cost comparable to a similar aircraft. The aircraft will be a cost-efficient aircraft for the outlined mission profiles, as shown in Figure 63.

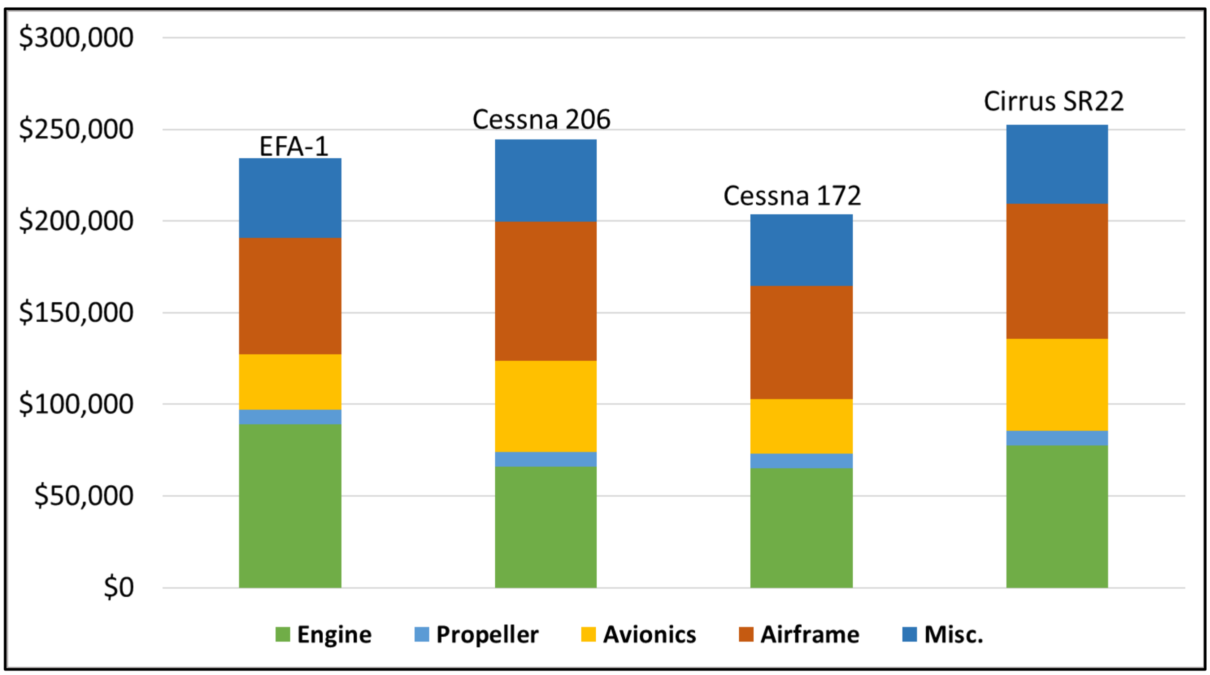


Figure 63: Flyaway Cost analysis. EFA-1 total cost = $245,300 per aircraft

24.2 Operations & Maintenance Cost

Figure 64 shows a breakdown of the operation cost and maintenance cost for EFA-1. The fuel, oil and maintenance costs were determined based on the operating and owner's manuals for the chosen Lycoming IO-580-BIA engine [2]. The airframe and propeller maintenance requirements were determined based off similar aircraft. A salary of $60,000 was assumed for the crew personnel based on average pay for flight instructors.

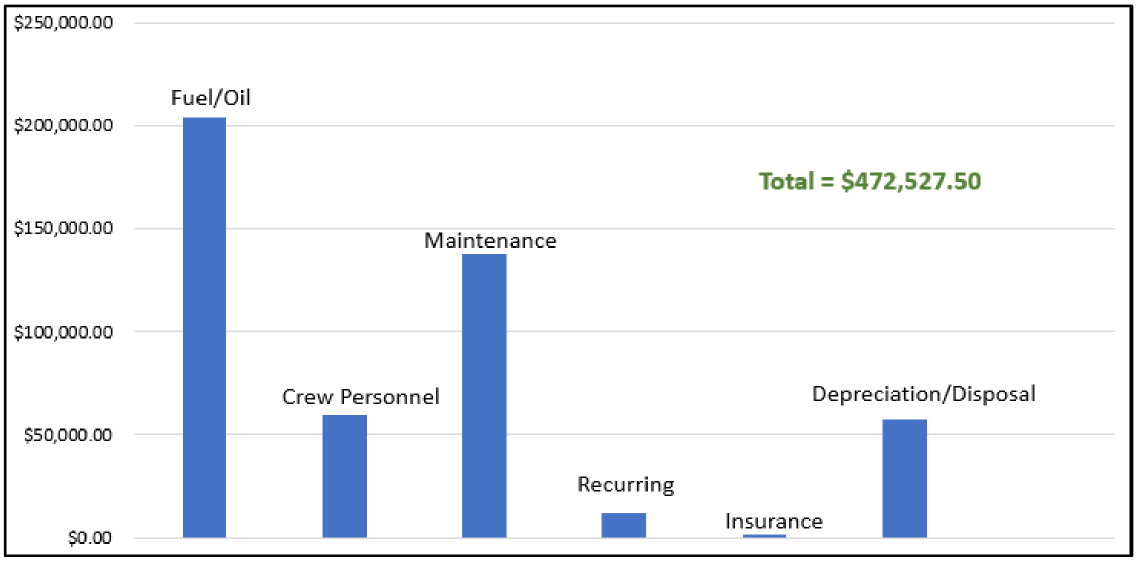


Figure 64: Operations and Maintenance Cost Analysis

24.3 Direct-Operating Cost

Figure 65 compares the yearly direct operating cost with similar aircraft including the Cessna 206, Cessna 172 and Cirrus SR22. The DOC for EFA-1 is lower than the Cessna 206 and the Cirrus SR22 and higher than the Cessna 172. The Cessna 172 seats four people total, which is less than what the EFA-1 accommodates, demonstrating the difference in cost. Therefore, EFA-1 is a cost-efficient aircraft to purchase and own.

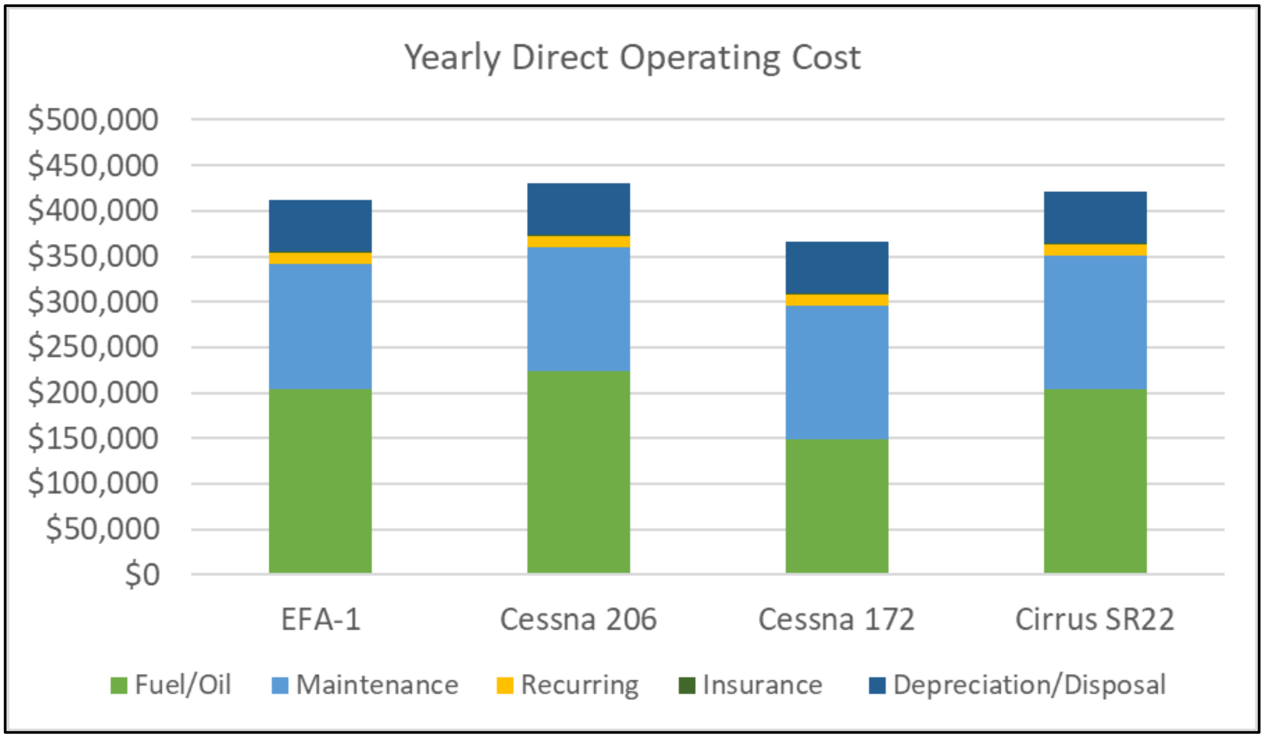


Figure 65: Comparison of Yearly Direct Operating Cost

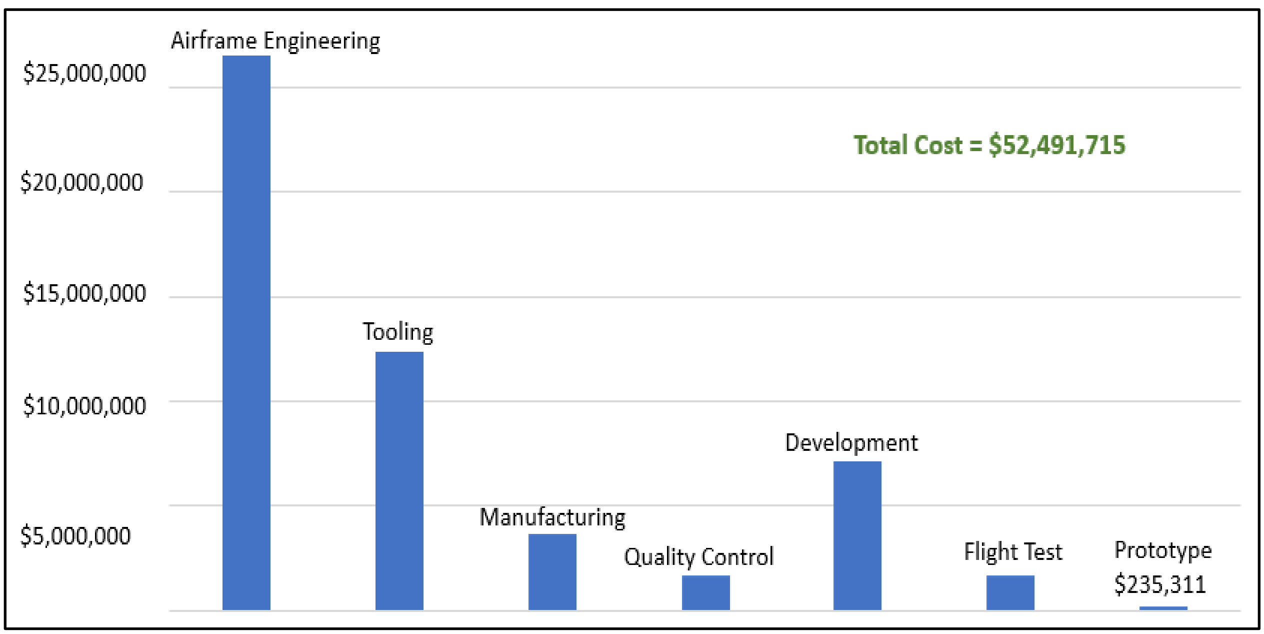


Figure 66: Research, Direct-Operating and Engineering cost

24.4 Production Break-Even Point

Figure 67 shows that based on a 500-unit production plan, the cost break-even point is 380 units if sold at $256,000 per aircraft.

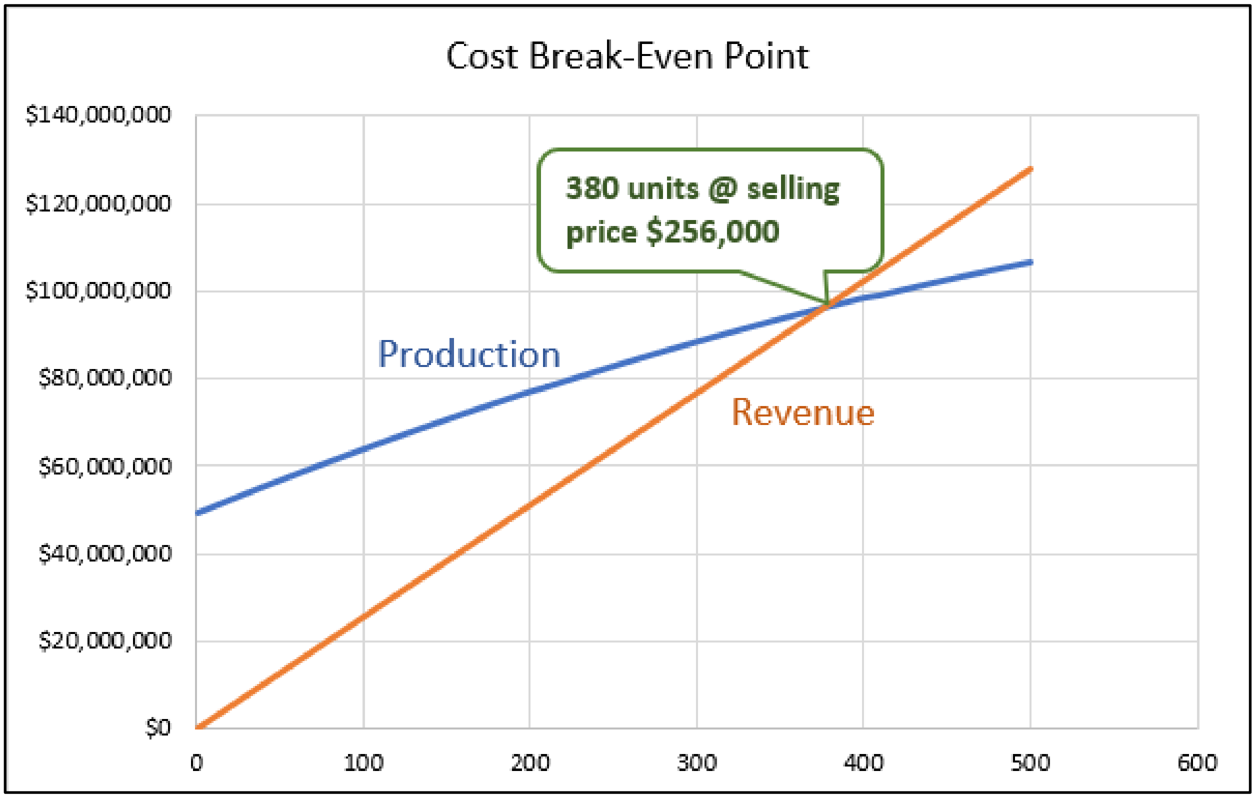


Figure 67: EFA-1 Break-Even Point

25 MANUFACTURING

EFA-1 will be manufactured in Chandler, Arizona near the Chandler Municipal Airport in order to save costs on sales tax compared to California. California is our target market based on our service ceiling and large number of airports that cater to general aircrafts. Arizona is in close proximity to California, where aircraft can be traveled between locations, allowing it to serve as the best option when it comes to cost of manufacturing and location.

A facility near Chandler Municipal Airport was selected due to its close proximity to the Lycoming engine supplier (Aero Performance), a general aircraft market parts provider (Aero-Zone), a certified avionics installation facility and an authorized Garmin provider (Chandler Avionics). All of the aforementioned providers are located inside the airport, which can reduce time and shipping costs. Although there is a maintenance facility at Chandler Aviation, all airports generally have maintenance facilities on site, allowing the buyer or Director of Maintenance to decide which maintenance facility best fits their needs. Unfortunately, no parachute suppliers operate nearby. However, reducing logistics to only requiring parachute shipments is reasonable. The manufacturing process is shown in Figure 69 and will be performed as an assembly line type process.

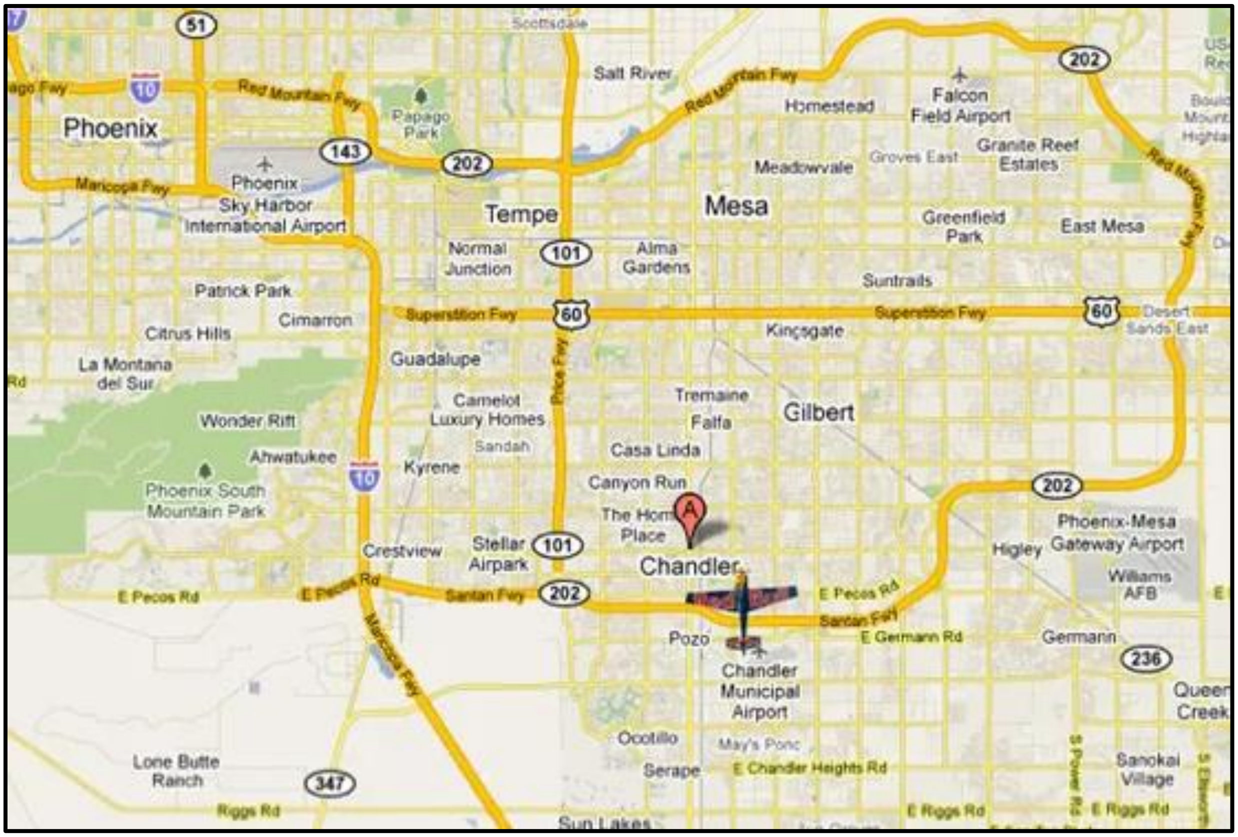


Figure 68: Chandler, Arizona – Manufacturing Location

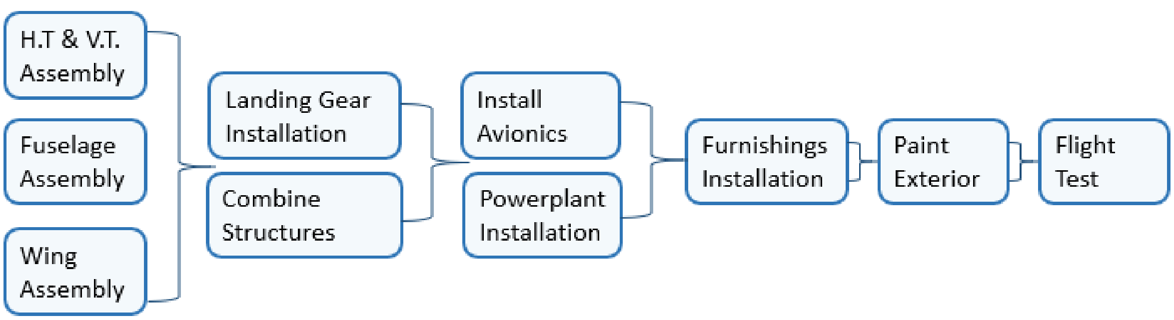


Figure 69: Manufacturing Process for EFA-1

26 ETHICAL AND ENVIRONMENTAL CONCERNS

Ethical and environmental concerns were implemented throughout the design process for the EFA-1 by addressing the RFP regulations while simultaneously designing an economically feasible aircraft. The EFA-1 cruise altitude of 6,000 feet with a cruise velocity of 210 kt was determined as the cruise point to avoid the cabin pressurization requirement necessary at 12,500 feet. This cruise point was determined to be the most optimal, based on the horsepower necessary during the 45-minute timeframe requirement.

The EFA-1 aircraft is designed with one reciprocating powered engine to minimize the cost of two engines and reduce total emissions set into the environment. The EFA-1 has a full body parachute shown in Section 10 based on the RFP requirement provided by the customer. Environmental noise limits were also taken into consideration, especially because operations take place in smaller communities. Therefore, considering EFA-1's MGTOW of 2,940 lb, the noise level must not exceed 85 dB(A). Analysis of the EFA-1 shows a noise level of 76 dB(A), which is below the maximum noise level requirement using Nicolai and Carichner [3].

27 Compliance Matrix

Table 19: Compliance Matrix

Req.	Requirement Description	Met (Y,N)	Comment
1	Single engine aircraft with full-aircraft parachute or multi engine	Y	Addressed in Fuselage layout
2	Single-engine noise limits per Part 36 Sec.G36.301(c)	Y	Addressed in Ethical and Environmental Concerns
3	Payload: Four passengers (800 lbs.)	Y	Addressed in Fuselage layout
5	Single pilot (180 lbs.)	Y	Addressed
6	Takeoff distance over 50' obstacle in ≤ 2500 ft	Y	Addressed in Takeoff and Landing Analysis
7	Landing distance over 50' obstacle in ≤ 2500 ft	Y	Addressed in Takeoff and Landing Analysis
8	Rate of Climb FAR 23.65 Climb: All Operating Engines	Y	Addressed in EFA-1 Reference Mission
9	Stall speed FAR 23.49 Stalling Speed	Y	Addressed in Baseline Design
10	Loiter at best endurance speed for 45 mins	Y	Addressed in EFA-1 Reference Mission
11	Average ground speed for reference mission (≥ 180 ktas)	Y	Addressed in EFA-1 Reference Mission
12	Total range of reference mission flight (≥ 135 nmi)	Y	Addressed in EFA-1 Reference Mission
13	Total range of sizing mission flight (≥ 250 nmi)	Y	Addressed in EFA-1 Sizing Mission
14	Max Operating Ceiling FAR 91.211 (12,500 ft)	Y	Addressed in Operating Envelope

28 CONCLUSION

Using direct operating cost as the driving factor in the design process, the EFA-1 was selected. The baseline design was used to optimize the design by lowering weight and direct operating cost of the EFA-1. The resulting flyaway cost and yearly direct operating cost of the EFA-1 is $234,300 and $412,500, respectively. Comparing these values to a similar aircraft, such as the Cirrus SR22, it was found that the EFA-1 had a 4.5% lower flyaway cost and a 2.1% lower direct operating cost. Considering the higher cruise speed of the EFA-1 and its ability to service small airports with frequent and regular schedule, it is a competitive alternative with its lower flyaway and direct operating costs. Therefore, the EFA-1 is a viable candidate for future configurations with these same requirements.

29 REFERENCES

[1] Abbott, Ira Herbert., and A. E. Von. Doenhoff. *Theory of Wing Sections*. Dover Pubns.

[2] *AEIO-580-B1A Operations and Installation Manual*, Lycoming, June 2007.

[3] Bruhn, E. F. Analysis and Design of Flight Vehicle Structures. Tri-State Offset, 1973.

[4] Carichner, Grant E., and Leland M. Nicolai. *Fundamentals of Aircraft and Airship Design*. American Institute of Aeronautics and Astronautics, 2013.

[5] Cirrus Aircraft. "CAPS Training." *Cirrus Aircraft*, cirrusaircraft.com/flight-training/caps-training/.

[6] "Code of Federal Regulations Part 23." *ECFR*, www.ecfr.gov/cgi-bin/text-idx?SID=ef1a9cb4ac051a045772746522a1e081&mc=true&tpl=/ecfrbrowse/Title14/14cfr23_main_02.tpl.

[7] "Code of Federal Regulations Part 91." *ECFR*, www.ecfr.gov/cgi-bin/text-idx?SID=1983e72d2d95ea48e16bbf3d66787df8&mc=true&tpl=/ecfrbrowse/Title14/14cfr91_main_02.tpl.

[8] Raymer, Daniel P. *Aircraft Design: a Conceptual Approach*. American Institute of Aeronautics and Astronautics, 2019.

[9] Roskam, Jan. *Airplane Design*. DARcorporation, 1985.

[10] "SolidWorks 2007 Education Edition."