Final Report

Course #: MAAE 3002

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Compliance Checklist

Description	Requirements	Compliance
Crew and Passenger Capacity	1 Pilot + 1 Passenger	1 Pilot + 1 Passenger
Maximum Takeoff Weight	1653.5 lb	1416.46 lb
Maximum Takeoff Distance	1500 ft and clears a 50 ft obstacle	1000 ft and clears a 50 ft obstacle
Maximum Landing Distance	1500 ft	1200 ft
Minimum Endurance	3 hours	4 hours
Minimum Ferry Range	400 n mi	400 n mi
Minimum Service Ceiling	10,000 ft	12,000 ft
Maximum Stall Speed	40 KTAS	40 KTAS
Maximum Operating Airspeed	120 KCAS	110 KTAS (for cruise)
Minimum X-Wind Tolerance	12 KTAS	12 KTAS
Engine is Widely Available by 2025	Must be widely available by 2025	Engine is currently widely available

Executive Summary

The team of Skunkworks 2 would like to present the UCA which will be one of the leading aircraft to be released on the market. This proposal will be submitted to Professor Edward Cyr on the 14th of April for evaluation. The UCA is to be considered a light motorsport aircraft (LMA) that will follow and comply with all regulations set by CARs. The plane will be attached with one turboprop engine situated at the front of the plane to pull the aircraft into the skies. The main design application put into place when fabricating the UCA is that it will be used as a trainer aircraft for incoming and new pilots. The plane's overall length is roughly 23ft, a maximum weight of 5.75 ft, and a total wingspan of 27.5 ft. There are also 3.5 hours of fuel inside the wings, with another 45 minutes of fuel for reserve also situated inside the wings. The UCA will use an H1-tail with a mid-wing NACA 4412-style airfoil to ensure the flight will be as simple as possible.

The UCA is powered by a single Continental O-200 engine which provides 100 BHP and is mounted at the front of the plane. The UCA is a two-person plane (1 pilot + 1 passenger) with a maximum takeoff weight of 1416.46 lb. It has been designed to cruise at an altitude of 10,000 ft at an airspeed of 110 KTAS and climb at an 800 ft/min rate. The aircraft meets the required takeoff and landing distance of 1500 ft and endurance of 4 hours. The aircraft costs $165,580.07 per unit and has a minimum selling price of $190,417.08.

1. Introduction

1.1 Goal

Our mission for this aircraft is to provide an easy-to-use platform for beginners to learn to fly. The proposed design has been catered to be a safe option for teaching flying with the addition of various features. For example, our design features a reinforced landing gear system. Throughout our research, it was determined that landing was a common point of difficulty for incoming pilots, and this will mitigate any serious damage to the plane during rough landings. The primary mission requirements will be two crew members (trainer and trainee) and 3.5 hours of flight time with a

1/2-hour reserve tank. Our team will also implement a takeoff distance of 1000 ft and a landing distance of 1200 ft. These distances are hoped to be met since most runways for the plane being designed are grassy fields surrounded by tall trees that need to be cleared quickly.

1.2 Requirements and Constraints

Table 1.1 Requirements and Constraints

Requirements	
Capacity = 2 people (1 pilot + 1 passenger)	Max operating airspeed = 120 KCAS
MTOW = 1653.5 lbf	Max takeoff and landing length = 1200 ft
Capable of both VFR and IFR flight	Capable of flight in icing conditions (optional)
Endurance > 4 hours	Ferry range > 400 n miy7
Stall speed < 40 KTAS	Service ceiling > 12000 ft ASL
X-wind tolerance < 12 KTAS	Capable of semi-autonomous flight with an autopilot (optional)
Meets applicable certification rules in CARS (AWM) 523	Capable of level constant velocity turn radius of 200m (optional)

1.3 Mission Design

The main design for the aircraft presented in this report will be used for a trainer craft that is optimized to be durable. The main characteristics used to accomplish this goal are reinforcing landing gears and a landing gear configuration that makes it easier for fresh incoming pilots to learn how to fly. The aircraft's mission consists of 8 segments, represented by the figure below.

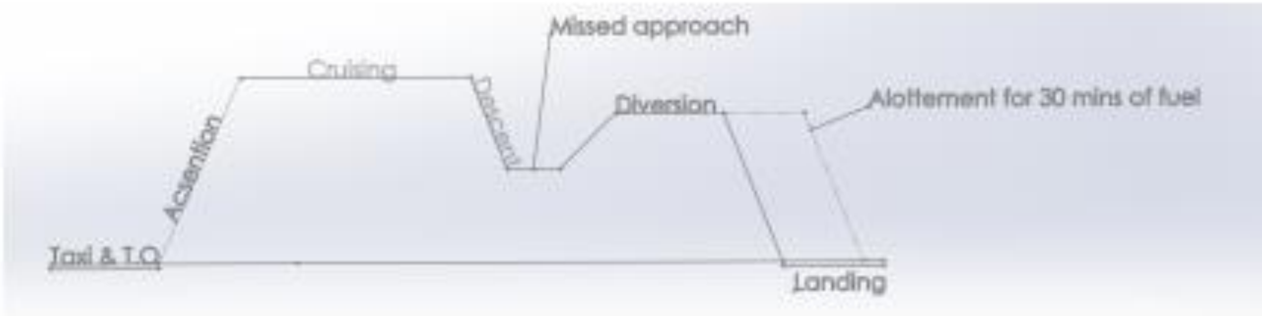


Figure 1.1: Mission profile diagram

We expect the designed aircraft to taxi, take off, ascend to a maximum height of 12000 ft, and stay at a cruising speed of 110 knots. The next step will consist of descending and a potential diversion in case of problems on the plane or the designated runway for landing. There will be an allotted 30 minutes of cruise time to reach the next available airport and another 10 mins of fuel for the plane to be able to land. A detailed outline of the circuit that will be run is shown in Figure 1.2.

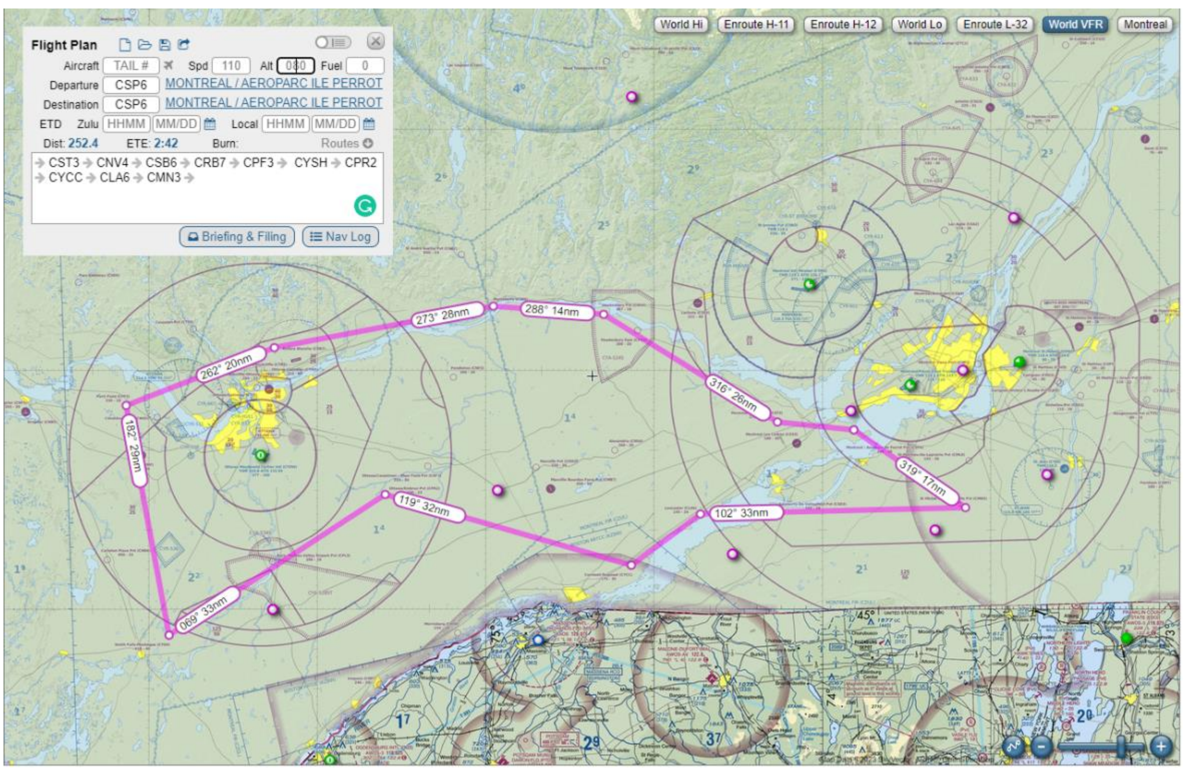


Figure 1.2: outlined circuit of plane trajectory

This is one of the plane trajectories that can be performed by the designed aircraft outlined in this report. The flight plane can be altered to take off from most field airports in the southern regions of Ontario and Quebec, and we suggest that the plane is only flown in ideal conditions, such as clear skies and mild gusts.

2. Sizing Analysis

2.1 Constraint Analysis

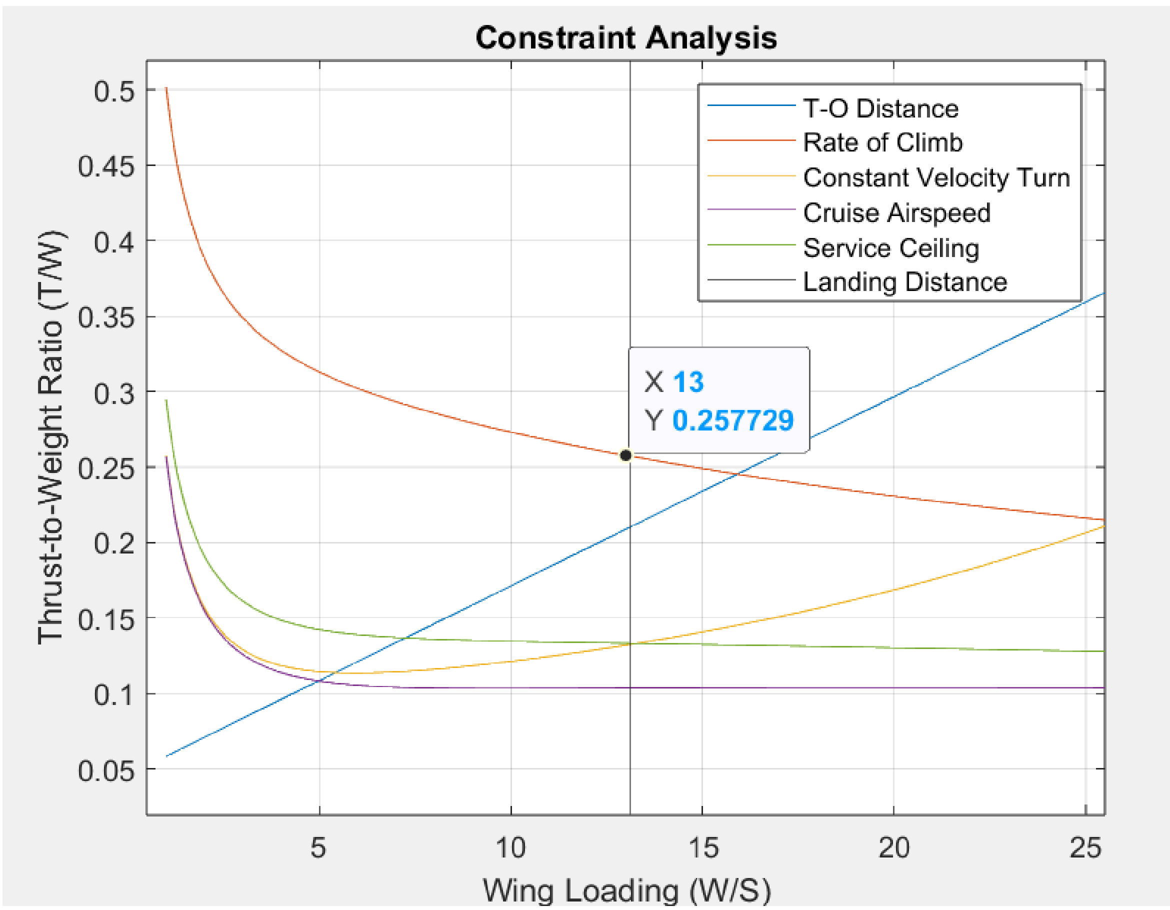


Figure 2.1 Constraint Diagram with target design point

Table 1.2 Variables for Constraint Diagram

g	32.2 ft/s	**Height of obstacle**	50 ft
CL max	1.26	$\rho\, at\, 10000\, ft$	0.0018 slugs/ft^3
SG	1000 ft	V_{stall}	40 KTAS
CD_TO	0.045	$V_{airspeed}$	110 Knots
CL_TO	0.72	**CVT radius**	200 m
Rate of Climb	800 ft/min	μ_{to}	0.037
k	0.04	$\theta_{descent}$	**30** ^{o}
τ	3	**Ground Roll Distance**	113.4 ft
CD min	0.033	$\rho_{sea\ level}$	0.002378 slugs/ft^3
τ	3	**CD_ldg**	0.4
CL_ldg	1.6	**Cruise Altitude**	12000 ft

The constraint diagram was drawn by defining the constraints vital to the mission. Takeoff and landing, velocity turns and level flight in cruise, and ascent are among the constraints. Equations from the textbook [1, pp. 59–61] were used to calculate all constraints. The constraint diagram aims to maximize wing loading (W/S) and minimize the thrust-to-weight ratio (T/W) to achieve a small wing and engine. The chosen design point was taken with W/S and T/W to be 13 and 0.2577, respectively. It was assumed that aircraft take off and land at sea level with turn, altitude change at 1000 ft with the rate of climb at 800 ft/min, and take off the run at 1000 ft. The descent angle was 30 degrees with a total ground land run of 1200 ft.

The max lift coefficient (CL max) was taken as 1.26. To accommodate for landing and effects of flaps, it was assumed 90% of CL max. CD_{min}, C_{DTO} and C_{LTO} were taken from Table 3-2 from the textbook [1, pp. 62]. According to RFP requirements, variables such as ROC, stall and cruise speed were chosen. Dynamic pressure was calculated by taking different altitudes such as descent, cruise, and ascend taking into account. The design points from the constraint diagram fall in the range for LSA aircraft. The constraint diagram was sensitive to the CL max value. Changing it would result in the whole analysis. W/S and T/W values were crucial for weight analysis for determining the MTOW of the aircraft

2.2 Weight Analysis

The six planes that were compared for the concept design were the 22 LS, 7ACA, Cessna 140, Velis Club Aircoup-Alon, and finally Ercoup. These 6 planes also were used to determine the MTOW and EWF for the aircraft designed in this report which can be viewed below in Figure 2.2.

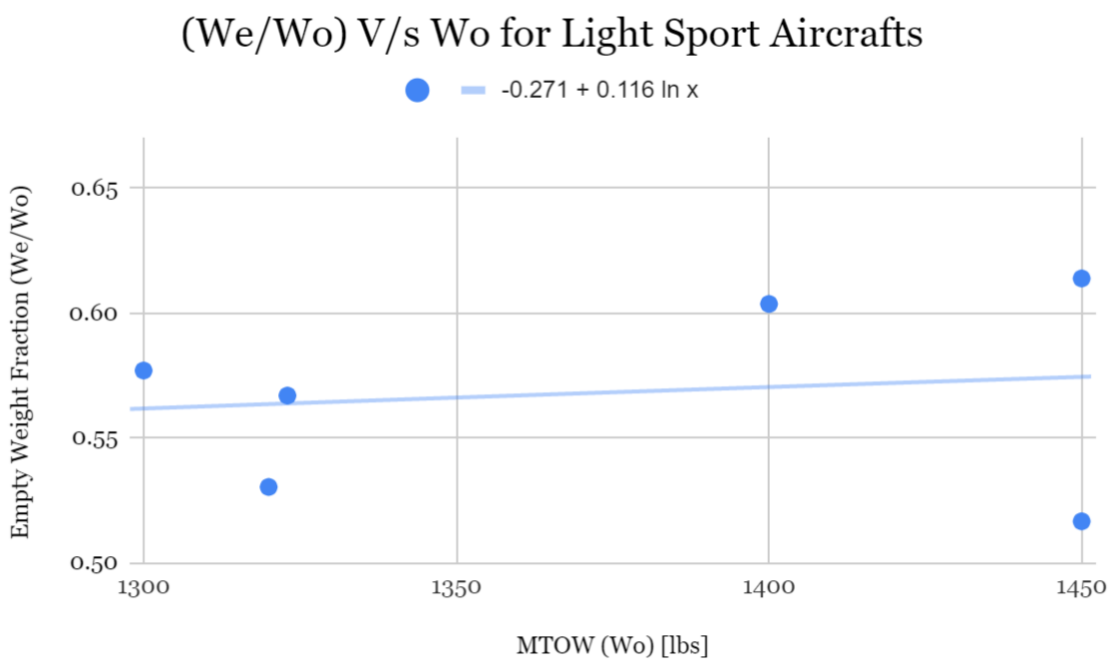


Figure 2.2: (We/Wo) V/s Wo for Light Sport Aircraft from historical data

Used Weight segments:

Table 1.3: Weight Ratios for each mission segment

Weight Ratios (Propellers)	
Taxi- Take Off	0.9975157568
Climb to altitude	0.9896489868
Cruise (Endurance)	0.9340038372
Descent	0.9917191895
Reserve Cruise	0.9902938782

We allotted 50 lbs for payload as well as the weight of two full adult males making a final cabin weight being 500lbs for crew and payload. So once all the above was determined and using an iterative process, the aircraft's total weight was 1416.46 lbs.

2.3 Comparison to Competitive Aircraft

Selling the aircraft designed on the open market means there will be competition with other aircraft designed to achieve the same or similar mission profile that our team has set out to succeed.

Some advantages of the plane design are the reinforced landing gears as well as a slight 90-degree angle that will reduce the rigidity that some more common planes have that make one of the most dangerous parts of a flight more reassuring to the pilot, flight instructor and insurance companies that will be ensuring the planes. Our mid-wing configuration allows us to take the best parts of the high and low-wing airplanes and creates a good balance between the stability control of the high-wing and the low-wing designs. Low-wing aircraft are mostly used for acrobatic-style planes that create an unstable scenario for new and upcoming pilots. The high wing design makes the plane too stable with an H-1 tail design, and it would feel like you are fighting the plane when turning into a corner. These stability controls were the main reasons our team believes that the mid design is superior to other planes on the market that use either a high or low-wing design.

With the wing determined, we also ensured that the tail of the UCA would yield better utility than other modern configurations that use a common design of the T-tail. The H-tail provides a lower weight for the vertical and the horizontal stabilizer, which means that the tail can be smaller to ensure that most of the volume and weight can be used for cabin space and engine compartments. Another major component of the H1-tail is that the spin characteristics have a greater recovery speed than most other tails. Since there are two vertical stabilizers, two fins will aid the recovery instead of just a single one that could have been damaged [4]. There is one drawback of the H1-tail: more moving components could come faulty.

The third and final characteristic is the landing gear that is reinforced and has a configuration in tandem with outriggers. This eliminates the visibility and landing issues that normal tail dragger landing gear allows. Below in Figure 2.3, you can see that the cockpit is pointed upwards, making it harder for newer pilots who view the runway ahead when taking off and landing.

Figure 2.3: Side View of taildragger and tricycle configuration[5].

So with the drawback of the tail dragger outlined, the better choice for our designed aircraft is a tricycle-style landing gear. Yet with inexperienced pilots, there is a larger possibility of tail strikes when taking off. To put all of the odds in favour of the pilot, a fourth outrigger wheel provides extra stability to the plane and makes it harder for tail strikes to happen upon take-off. The three characteristics listed above allow for better performance and stability than some leading training aircraft, such as the Cessna 172, which has a high wing and tricycle landing gear configuration.

3. Performance Analysis

3.1 Cruise Conditions, Max Speed, Stall

The UCA can fly with the cruising velocity of 122 KTAS at an altitude of 10,000 ft with the lift-to-drag ratio of 16.5, using the performance equation from the textbook. The actual cruising velocity of UCA is slightly higher than it was designed for at the desired cruising altitude of 10,000 ft. In addition, the maximum speed of aircraft is limited to 139 KTAS at an altitude of 10,000 ft due to the regulations specified in CARS (AWM) 523 for general aviation aircraft. Furthermore, the UCA meets the required stall speed of 40 KTAS as required by the RFP. The calculated cruising velocity of UCA is comparable to the cruising velocity of Ercoupe, which is 115 KTAS.

The table below shows the optimum speed at different parameters and max speed at sea- level, 5000 ft and cruise altitude.

Table 3.1 Max Speed at sea- level, 5000 ft and cruise altitude

V_{MAX} (KTAS)		
Sea Level	**5000 ft**	**Cruise Altitude (10000 ft)**
119	113.1	108.2

Table 3.2 Optimum Speed at sea- level, 5000 ft and cruise altitude

V_{opt} for different conditions (KTAS)			
	Sea Level	**5000 ft**	**Cruise Altitude (10000 ft)**
Best L/D	105	113	122
Best AOD (V_{BA})	35	38	41
Best AOD (V_{BG})	41	44	48
Best ROC (V_Y)	66	64	61
Best AOC (V_X)	35	38	41

Best Endurance (V_E)	73	75	79
Best Range (V_R)	107	112	116

3.2 Drag

The total drag can be split up into different components and analyzed separately. Some of the major contributors to drag are pressure drag (C_{Do}), skin friction drag (C_{Df}), lift-induced drag (C_{Di}), wave drag (C_{Dw}), and miscellaneous drag (C_{Dmisc}). Using the drag analysis method presented in Guddmunsonn's textbook [1], it was determined that the pressure drag is 0.012019, the skin friction drag is 0.009585, the lift-induced drag is 0.0860256, the wave drag is 0.002, and the miscellaneous drag is 0.122137.

The miscellaneous drag was determined by summing the drag from various external parts of the aircraft. This includes drag from the landing gear, fuselage, and wings. The values are calculated using tabulated constants for drag [1] and multiplying them by their respective surface area. The wing's area S is about 108 ft^2. The landing gear and wing flaps also use the wing's area. For the horizontal and vertical tails, the surface area of the horizontal tail is used (S_{HT} = 24.2445 ft^2). The rest all use the cross-sectional area of the fuselage A_C = 13.1737 ft^2. These calculations are tabulated below.

Table 3.3: Calculations for miscellaneous drag

Components	Drag Coefficients	Area	Product
Wing	0.007	108.50022	0.7595
Horizontal and Vertical Tail	0.007	24.2445	0.1697
Wing Flaps	0.025	108.50022	2.7125
Fuselage	0.11	13.1737	1.4491
Landing Gear	0.014	108.50022	1.5190
Wing Fuel Tank	0.2	13.1737	2.6347

Taking all the products from the table above and summing them results in a total of 9.251. Dividing this number by the wing's surface area (108.50022 ft^2) results in the final delta miscellaneous drag of 0.085203.

Finally, after correcting using the crud factor, the miscellaneous drag is 0.122137 and by summing all of the individual drag components, the total drag coefficient C_D= 0.231764
Max Lift to drag was calculated at 8.69 from the simplified drag model and CD_{min} as 0.122.

3.3 Take-off & Landing

The requirements for take-off and landing are taken from the RFP, which are the total take-off and landing distance of 1000 ft, including the 50 ft height obstacle on a grass runway. The UCA meets the total take-off and landing distance requirements and is capable of taking off from a 750 ft long runway and landing on a 600 ft long runway at an altitude at sea level as calculated using the performance equations given in the textbook [1]. The best rate of descent (ROD) was found to be 312 fpm at 36 KTAS and the best angle of descent was found to be 3° at 41 KTAS calculated by the performance equation. For a safe landing, the rate of descent (ROD) would be 412 fpm at 50 KTAS and a safer angle of descent would be 5° at 50 KTAS.

3.4 Climb

The UCA is designed to maintain a ROC of 584 fpm at the optimum ROC airspeed of 58 KTAS up to the cruising altitude of 10,000 ft. The best ROC for UCA is 1063 fpm at the optimum ROC airspeed of 66 KTAS during its initial climb from sea level, which was calculated using the performance equation [1]. The figure below shows the rate of climb versus airspeed for UCA.

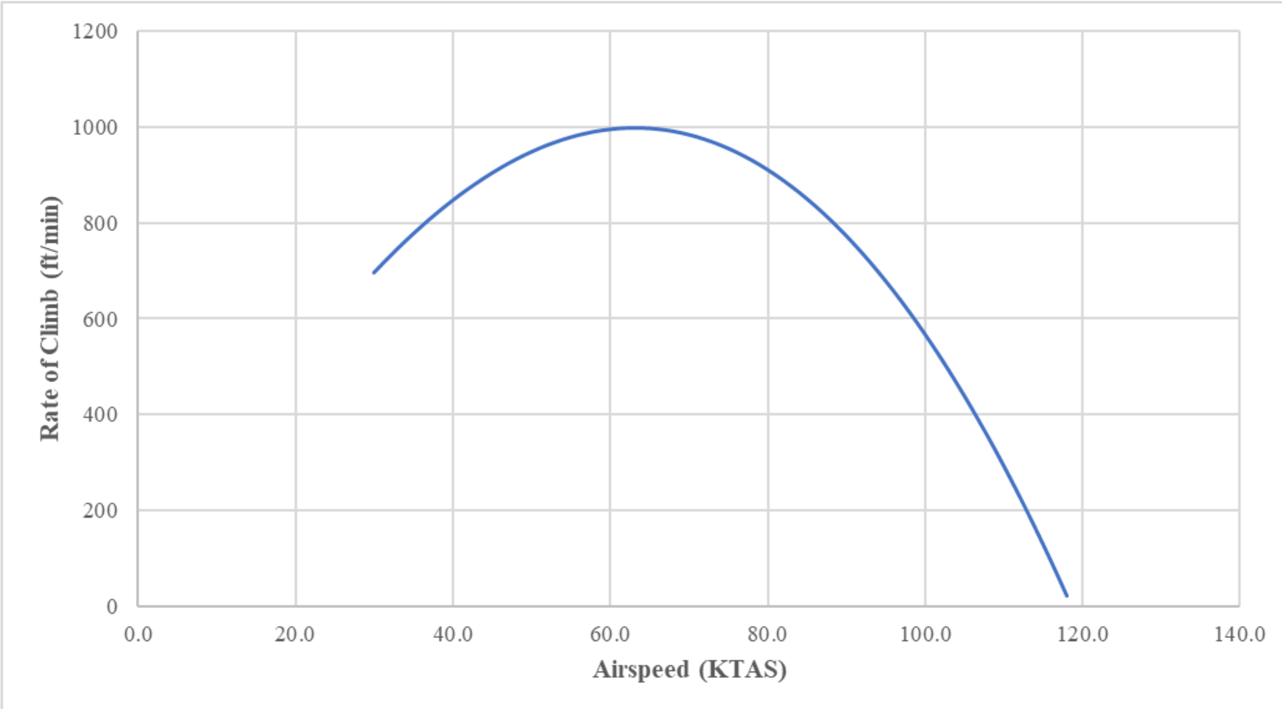


Figure 3.1 Rate of Climb versus Airspeed

3.5 Fuel Estimation

In order to calculate the fuel consumption for the outlined mission, it was split into separate mission segments, where the fuel weight ratios were calculated. Using these ratios, the total weight of fuel used for each mission segment was determined and tabulated below.

Table 3.4: Fuel weight estimations

Mission Segment	Fuel Weight Ratios (%)	Fuel Weight (lb)
Taxi- Take Off	0.002484243159	3.51883
Climb to altitude	0.01035101316	14.6617
Cruise (Endurance)	0.0659961628	93.4809
Descent	0.008280810529	11.72943
Reserve Cruise	0.009706121765	13.74833
Total	0.09681835141	134.106 lbs

3.6 Loiter & Range Performance

For range and loiter analysis, power (ft lb/s), L/D and available power was plotted against calibrated airspeed. The significant feature of aircraft is the ability for long-range travel at high airspeed. Average power becomes constant as airspeed increases. Required power shows exponential increase as airspeed is increased while L/D decreases over airspeed.

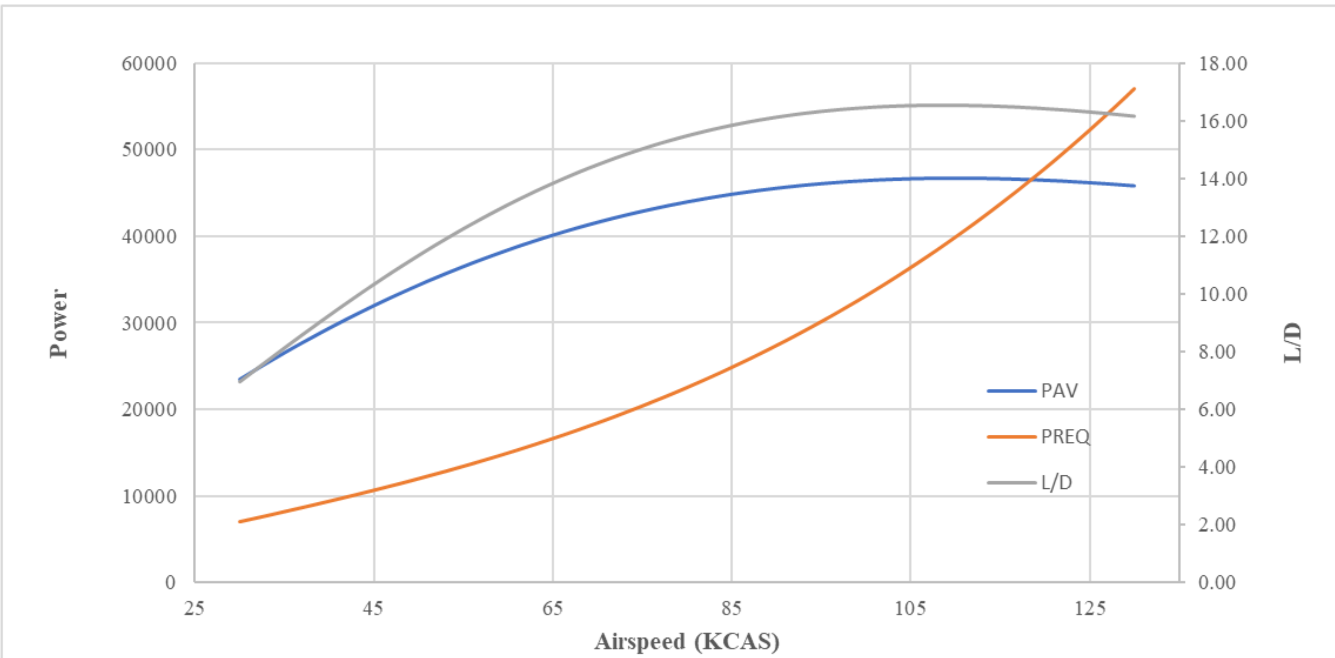


Figure 3.2 Graph for Power, Lift to Drag and Required Power versus Airspeed (KCAS)

3.7 Emergency Divert

The RFP requirement for endurance is at least 4 hours plus the reserve. However, the UCA is capable of having an endurance of 7.6 hours at the cruise speed of 79 KTAS at an altitude of 10,000 ft, which was calculated using the performance equation [1]. This suggests that we have 3.6 hours extra as endurance for the aircraft. Furthermore, we are taking fuel for an extra 30 mins with the diversion.

In the event UCA would not be able to land safely at an airport due to unsafe weather conditions, blocked runway or any other reason. The aircraft's mission profile accounts for an aborted landing or a go-around, and the performance analysis for UCA's range and endurance indicates that it meets the requirements for an emergency diversion.

3.8 Trade Studies

Sensitivity analysis was done for the trade study to compare various parameters such as SFC, L/D, Endurance and Change in EWF. The sensitivity graph gives more in-depth predictions that may be far more reliable. To satisfy aircraft in the light sport category, we can change parameter values to get an empty weight fraction in the range of 0.54-0.58. Empty weight fraction and L/D were susceptible, as seen in Fig 3.3. Drastic change was observed when the SFC value changed based on the empty weight ratio to 0.59. It is critical to evaluate if a tradeoff can be made to reduce the weight of UCA while keeping its mission intact. This would directly result in decrease in its manufacturing cost which would result in a decrease in its selling price and thus an increase in its sales would be inevitable.\

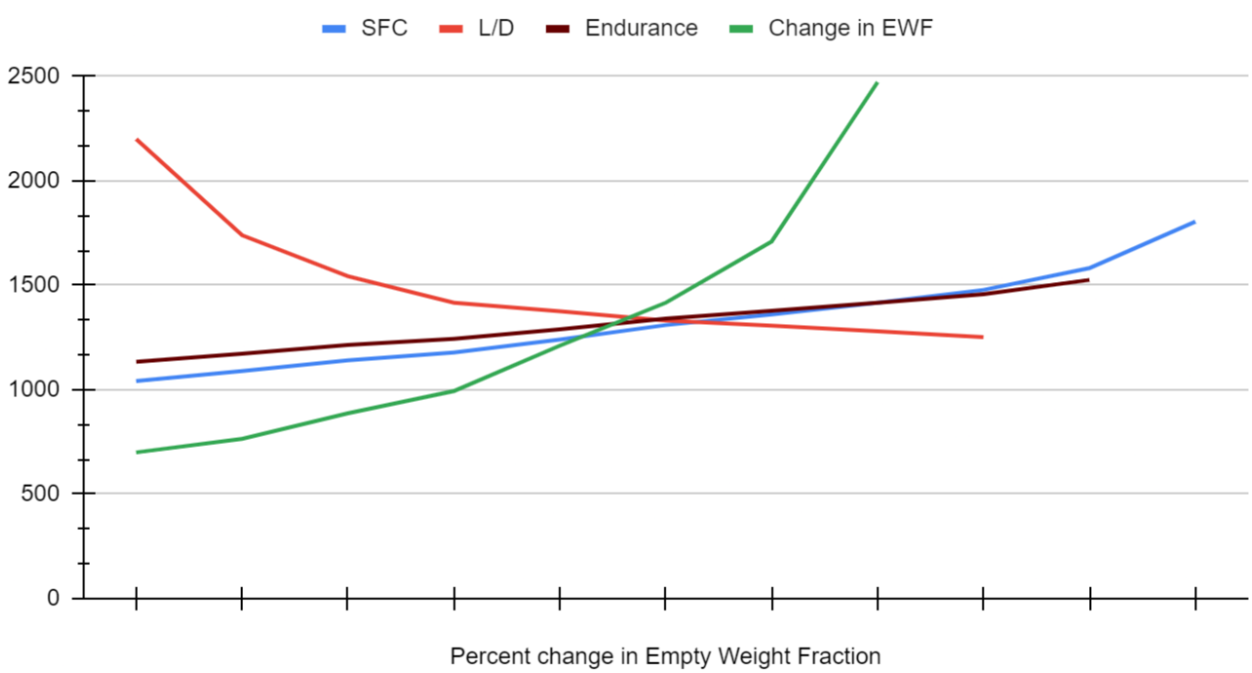


Figure 3.3 Sensitivity Analysis

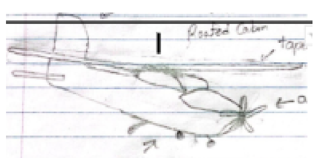
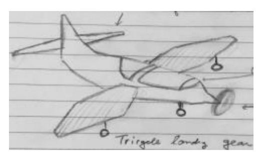
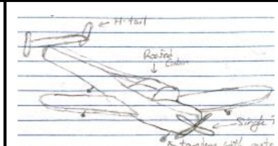
4. Configuration

The overall configuration of the aircraft was made by using a comparison method of three other aircraft and analyzing the pros and cons of each aircraft. After this evaluation and chose the design that would best be suitable for the mission design stated earlier.

4.1 Design Morphology

Below is a table of the decision that was made and used in order to determine the best configuration.

Table 4.1: Decision Matrix for plane configuration

Score: 1-Good 2- Better 3- Best		**Configuration 1- High Wing, Conventional Tail, Roofed Cabin, Tricycle landing gear**	**Configuration 2- Shoulder Wing, Cruciform Tail, Canopy Cabin, Tricycle landing gear**	**Configuration 3- Mid Wing, H-l Tail, Roofed Cabin, Tandem with outrigger landing gear**
Feature	**Weight**			
Drag (less is good)	**2**	**2**	**2**	**3**
Aesthetics	**1.5**	**2**	**1**	**3**
Cost	**1.75**	**3**	**2**	**2**
Operation - cabin entry	**1**	**2**	**2**	**3**
Fuel system - is a simple fuel system possible?	**1.25**	**2**	**2**	**3**
Stability - wing Configuration	**3**	**2**	**3**	**3**
Stability- landing gear	**2.5**	**2**	**2**	**3**
Take-off distance (shorter the better)	**1.5**	**2**	**2**	**3**
Ease of use	**1**	**2**	**2**	**3**

Sum of Weight x Score	**-**	**32**	**32.5**	**44.75**

The configuration that was chosen was a mid-wing, H-1 tail with the tandem outrigger landing gear. The landing gear will be fixed, increasing the drag on the aircraft but reducing weight on the overall design since there will be no need for a hydraulic lifting mechanism. Fixed landing gear will also reduce the overall sizing of the aircraft since there will be no need for compartments inside the aircraft for the landing gear.

4.2 External Layout

4.2.1 General sizing

The UCA is designed to transport the pilot and one passenger in a tandem style with a small compartment area behind the passenger seat for a small duffle bag. The plane's overall length is roughly 23ft, a maximum weight of 5.75 ft, and a total wingspan of 27.5ft. The tail is the recommended length of 60% of the total fuselage and follows the recommended aspect ratio of around 7.

4.2.2 Engine

The UCA features a single engine mounted in the nose of the aircraft. The propulsion system selected is the Continental O-200, a 4-cylinder horizontally opposed gas engine that outputs 100 BHP at maximum power. This engine weighs 196.8 lb and has a height of 23.18 in, a width of 31.4 in, and a length of 26.22 in, which gives it a total displacement of 201 in^3.

4.2.3 Wing configuration

The wing is placed at the center of gravity of the fuselage so that the plane is completely balanced and there is a draw to either the front or rear end of the aircraft. We believe that the wings placed directly at the center of gravity will create easier flying conditions for the pilot, who won’t need to be constantly battling the plane for control. A mid-wing also takes the best parts of each a high-wing design that is typically much more stable and requires a lot more force when turning around a radius. Our team did not want to go as low as a low-wing design since this is typically reserved for acrobatic-style aircraft. For learning, there is no need for high maneuverability which is typically seen in aerobatic airplanes.

4.2.4 Tail configuration

The tail that is chosen for the UCA is an H-tail which consists of two vertical stabilizers and one horizontal stabilizer in between the two verticals. This allows the plane to have a lower maximum and creates better spin recovery characteristics since there are two vertical stabilizers to control the flow of air instead of only a large one. These two vertical stabilizers also provide an extra form of redundancy in the design in the case of a strike mid-air on one of the verticals that comes either unavailable or damaged mid-flight; there is another vertical that can be used for an emergency landing. With spin recovery and the vertical redundancy in the H-tail design, it was a clear choice that this would be the best tail design to ensure that the mission profile was achieved.

4.2.5 Fuelselage shape

The fuselage shape was made by hand sketching a generally ovoid shape onto a piece of and then transferred into CAD software where import dimensions such as engine bay and cockpit that do have minimal sizing parameters. Such as, the plane needs to fit two grown males as well as a 90 hp engine whose size has been determined. Once input into CAD, it was trial and error until there was a style that seemed aerodynamic and would meet all of the parameters that had been already predetermined by the team. Based on the sketches of the side and top view there, a skeleton of multiple ovoids was constructed, and then a sheet of aluminum was placed on designated areas so that there would be a full shell and giving form to a full-fledged fuselage. An ovoid shape was used so that the internal pressure used the same techniques as a soda can, where the internal hoop pushes outwards, and so the frame is very strong even if there is only a thin layer of aluminum. This shape also eliminates any sharp angles that would cause high-stress areas.

4.2.6 Engine location

At the beginning of the design process, it was chosen that the UCA would be developed as a tractor-style engine location and not a pusher location. This was chosen so that the H1-tail can still be used in the plane. Also, the puller-style engine placement also allows the plane to be smoother with less turbulence and noise created by the powerplant. This decision was also made to teach pilots how to fly planes, with most common engine placements being in the puller configuration means that training on a puller-style aircraft will also create a precedent for pilots for when they move onto a larger aircraft.

4.2.7 3 View drawing

Below there is a 3 view drawing of UCA with all critical dimensions displayed as well as the location of the door for entry, fuel storage location, and finally, storage location and dimension.

4.3 Internal Layout

4.3.1 Fuel Tanks

The fuel tanks are situated in the wings to better diversify the loads that are acting on the plane. With the main lift points during the flight, Skunkworks 2 felt as though this was the best way to maximize the sizing of the interior cabin as well as make use of otherwise dead space between the spares of the wings.

4.3.2 Avionics

The avionics are described in further detail in Section 8. A brief overview of what will be implemented for the UCA will be a simple design with the bare minimum that is required for the pilot to operate the plane, which includes Navigation, a flight deck display, weather and air traffic system. Skunkworks 2 believes that the new pilots should not be overwhelmed with too much instrumentation as it would not be productive for them to be overwhelmed and then not focus on the actual learning of flying a plane. A main pilot's view can be seen below in Figure 4.2.

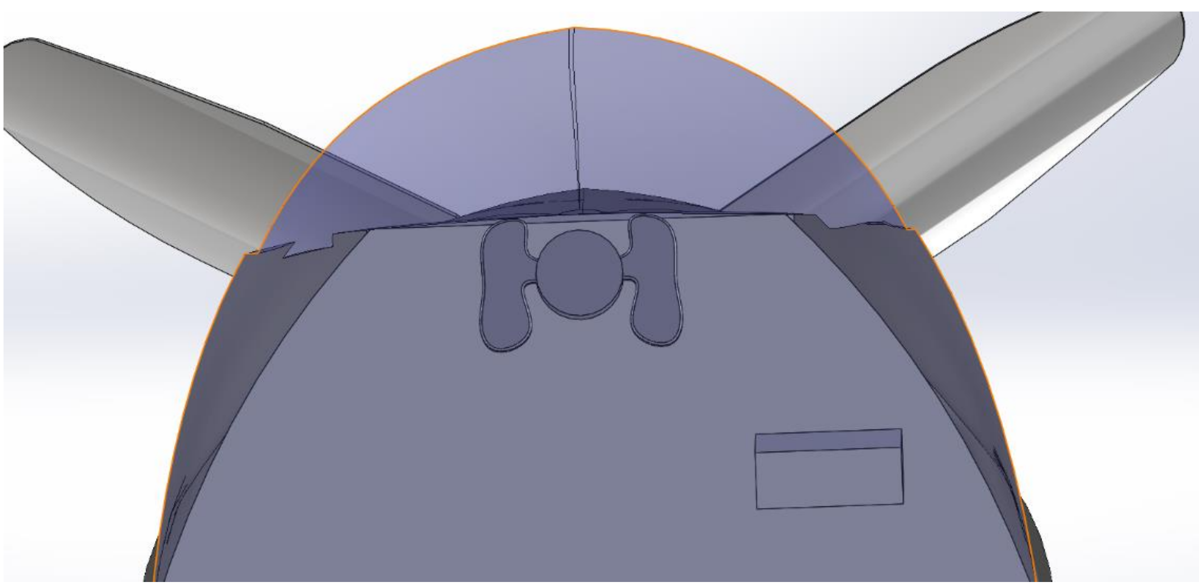


Figure 4.2: Pilots view of UCA

4.3.3 Seats

There are two seats situated in the cockpit of the plane which can fit two adult males. These seats can be adjusted with a rail system along the floor and a pivot mechanism to adjust the pitch of the seat which is situated at the connection point between the vertical and horizontal segments. To assure that the seats don't adjust mid-flight there is a spring-actuated deadbolt system to assure that the seats do not move along the flight. This is necessary since there is only one door situated on the right side of the plane if you are at the front of the plane looking back at the aircraft. Since there is only one door the pilot's seat must be fully pushed to the front of the plane with the pitch positioner completely rested to the front. With the pilot's seat correctly positioned the passenger can then move into their seat. The same procedure for the pilot's seat can be done with the passenger seat to access the storage compartment.

4.3.4 Storage

There is a small compartment situated behind the passenger seat that can store a small duffle bag. The choice was made to make the storage space smaller so that there was more room in the cockpit for both the passenger and the pilot. Since the plane is designed for training incoming pilots there is no need for major storage compartments for transporting personal items or trade goods. Keeping a smaller storage compartment also allows for less weight on the plane which will make the fuel efficiency much greater than having a large storage compartment that would allow the back of the plane to accrue a large amount of weight

5. Aerodynamics

5.1 Airfoil Selection

The process of selecting the airfoil had some of the criteria that needed to be satisfied, the airfoil should have a high CL to increase the lift without increasing the area too much. Next, the airfoil should have a high CLmax in order to reduce the takeoff distance. The airfoil should also have a high stall angle of attack, to reduce the risk of stalling during the climb. Lastly, for manufacturing purposes, the lower surface of the wing should be as flat as possible to make attaching the wing simpler. The list of NACA airfoils that were used for comparison is NACA 2412, NACA 2415, NACA 2421 and NACA 4412. Fig. 5.1 shows the thickness of NACA airfoils used for comparison. The experimental data for lift coefficient v/s angle of attack, drag coefficient v/s angle of attack, pitching moment coefficient v/s angle of attack and drag polar for each airfoil were accumulated from Airfoil tools [] for different Reynold numbers. This was compared with analysis in XFLR5 for Reynolds number of 750000 and subsonic Mach of 0.3. The comparisons are shown in Fig. 5.2 and Fig. 5.3. The airfoil was analyzed for an angle of attack of 0^o to 20^o based on stall, lift, moment and drag characteristics in the flight regime.

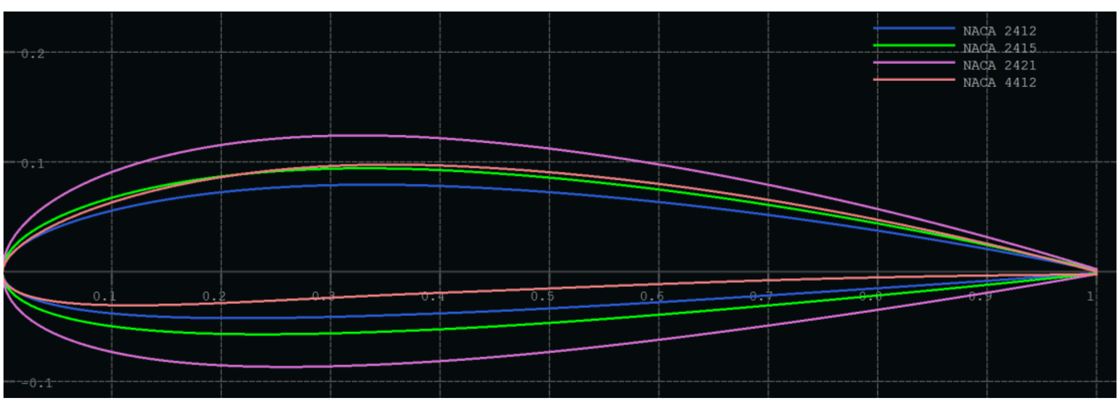


Figure 5.1 NACA Airfoils used for comparison

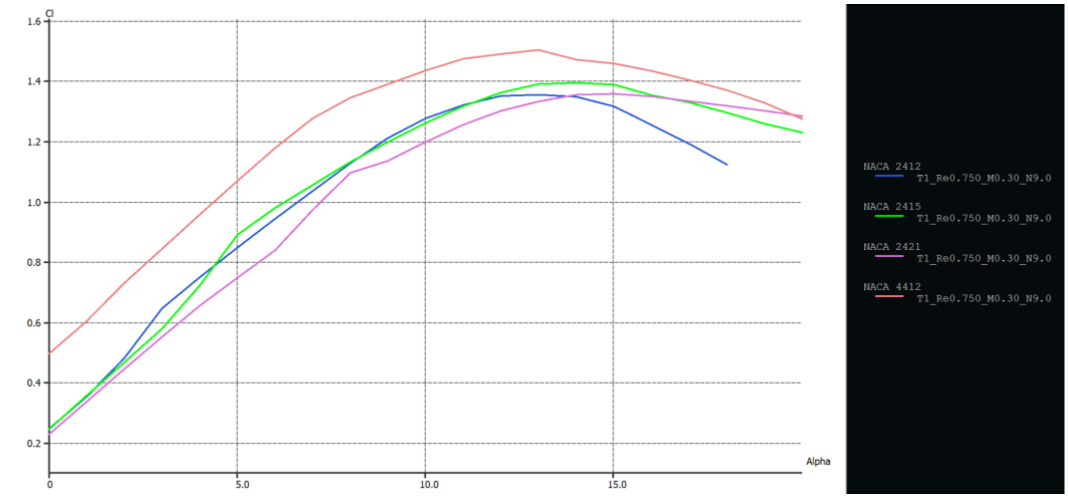


Figure 5.2 Lift coefficient v/s angle of attack for different NACA Airfoils

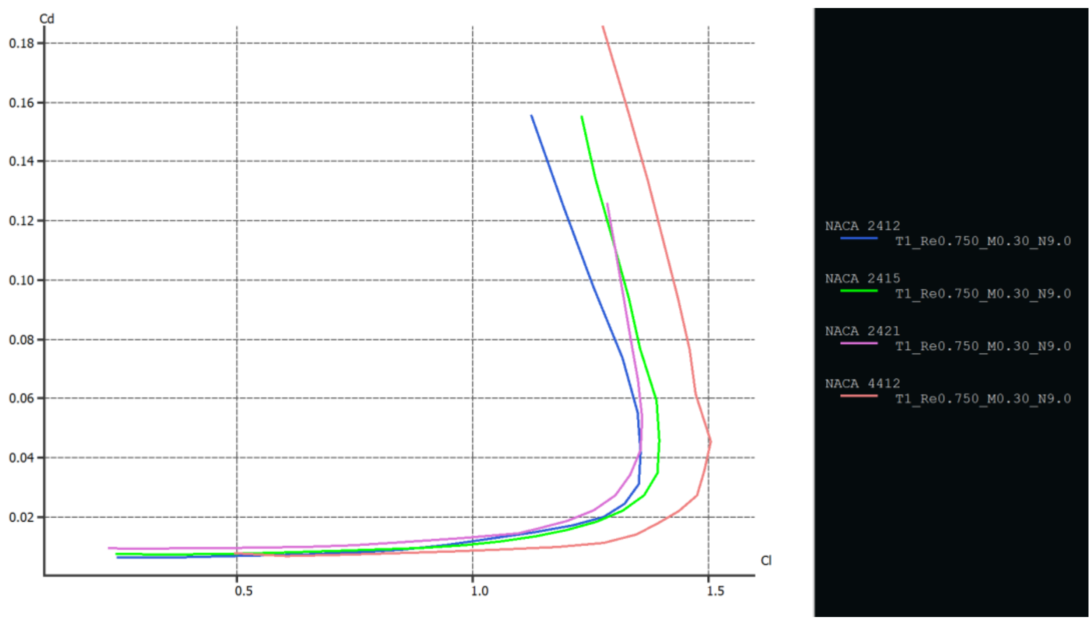


Figure 5.3 Drag Polars for different NACA Airfoils

From the comparison, a symmetrical airfoil such as NACA 4412 has significantly lower max CL and lower stall angle.
Further investigation into cambered airfoils yields the above selections of 4412 and NACA 2412, as well as the NACA 2415 revealing that only the NACA 2415 and NACA4 4412 have high enough max CL for the proposed design. NACA 4412 was chosen as the airfoil for wing design. In addition, the NACA 4412 has a significantly higher 'lower surface flatness', making manufacturing easier.

5.2 Wing Geometry

With the above discussion on the features of the wing, a finalized wing design is generated. Shown below is a drawing of the proposed wing. Taking the performance trends of each parameter into account, the wing geometry was determined to best accommodate the requirements set for each aircraft, including cruise velocity, takeoff performance, and desired efficiency. All of the geometric parameters of the wing are given in Table 5.

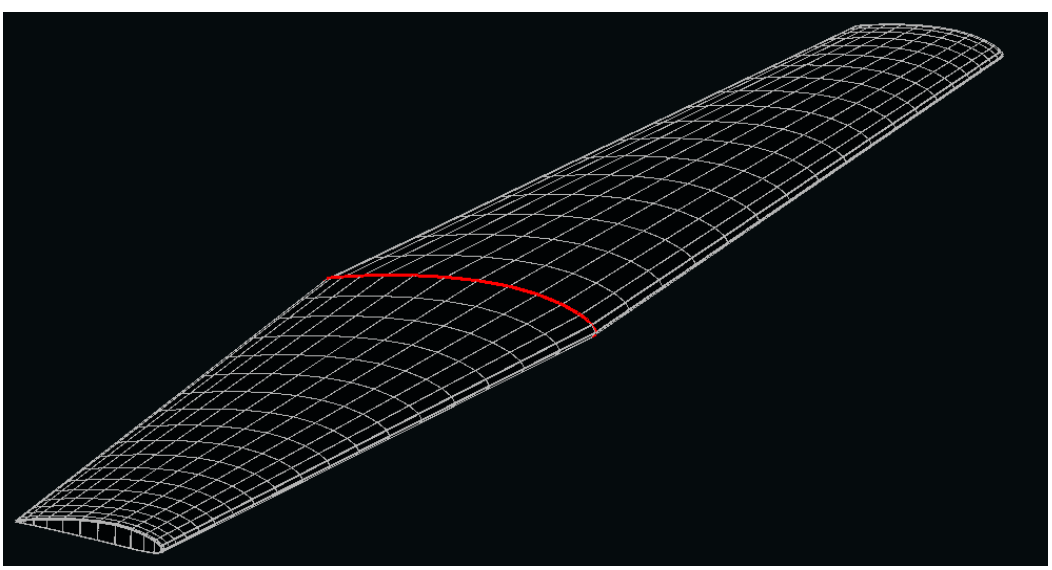


Figure 5.4 Designed Wing in XFLR5

Table 5.1 Wing Geometric Parameters

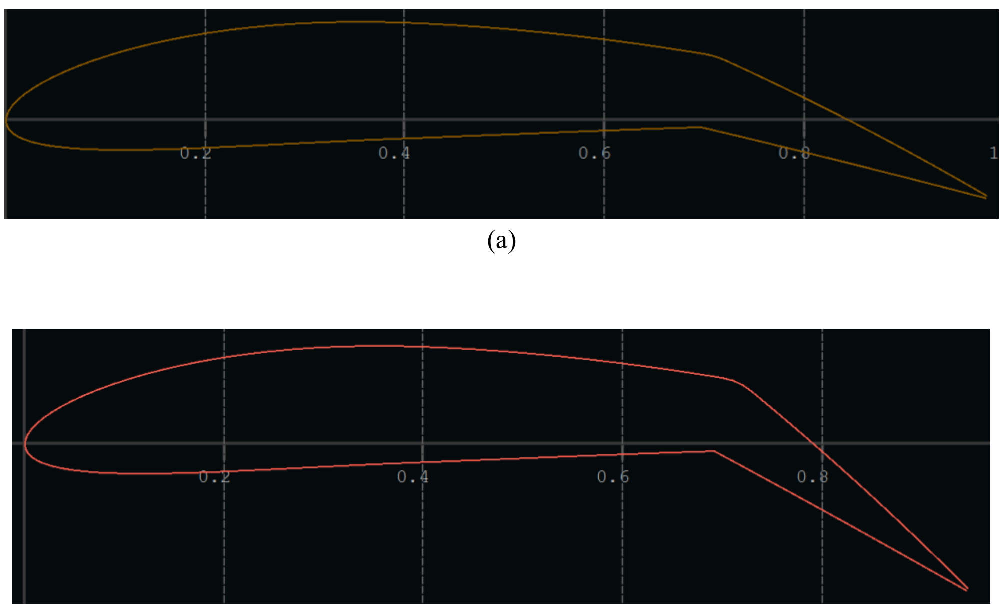
Parameter	Symbol	Value
Planform Area	S	108.5 ft^2
Leading Edge Sweep	λ	-1.43°
Span	b	27.56 ft
Dihedral Angle	φ	2°
Aspect Ratio	AR	7
Root Chord	c_r	5.08 ft
Tip Chord	c_t	2.78 ft
Taper Ratio	λ_{taper}	0.55
Wing Loading	W/S	13.05 lb/ft
Mean Geometric Chord	C_{MGC}	3.94 ft
Mean Aerodynamic Chord	C_{MAC}	4.03 ft
Twist Angle	ϵ_t	0°

5.3 High Lift Devices

For high lift devices, the flaps were down at an angle of 15° and 30° for take-off and landing respectively. The hinge position of X and Y for the airfoil was taken at 70% of the chord and 50% of the thickness. The figure shows NACA 4412 with flaps at an angle of 15° and 30°.

Table 5.2 Flap dimensions and parameters

Flap deflection during takeoff	*15°*
Flap deflection during landing	30°
Max Flap deflection	40°
Hinge X Position	70% of chord
Hinge Y Position	50% of thickness



(a)

(b)

Figure 5.5 Flaps at take-off (a) and landing deflections (b)

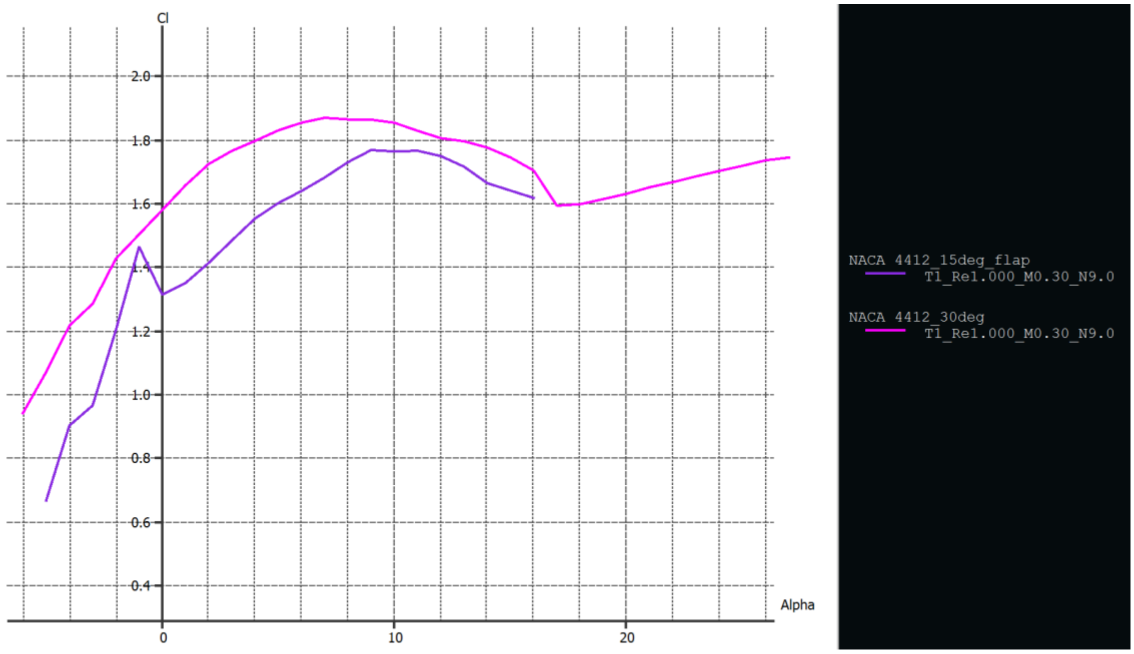


Figure 5.6 Lift coefficient v/s angle of attack for NACA 4412 for take-off and landing configuration

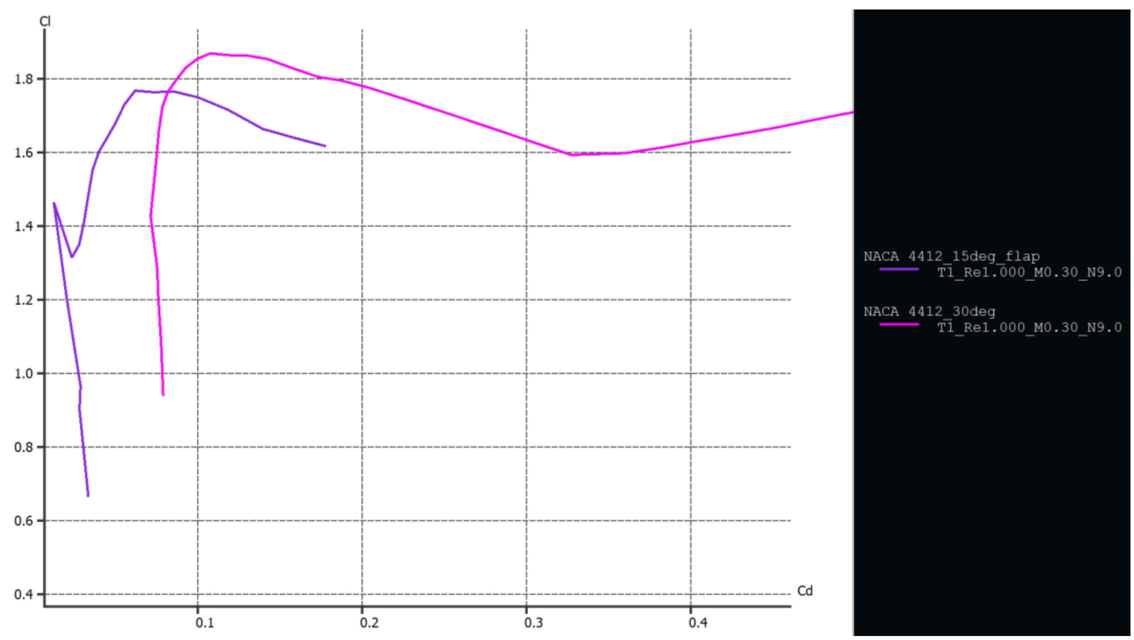


Figure 5.7 Drag Polar for NACA 4412 for take-off and landing configuration

5.4 Lift & Drag Estimation

5.4.1 2D Drag Polar and Lift coefficient versus angle of attack

The analysis for wing aerodynamics was done in XFLR5 at 40 m/s, cruise speed (56.6 m/s) and 70 m/s. Drag polar and lift coefficient v/s angle of attack. The CL_{max} obtained for the wing was in the range between 1.69 - 1.76, and CD_{min} was obtained as 0.0067. Figure 5.8 and 5.9 shows simulation results from XFLR5.

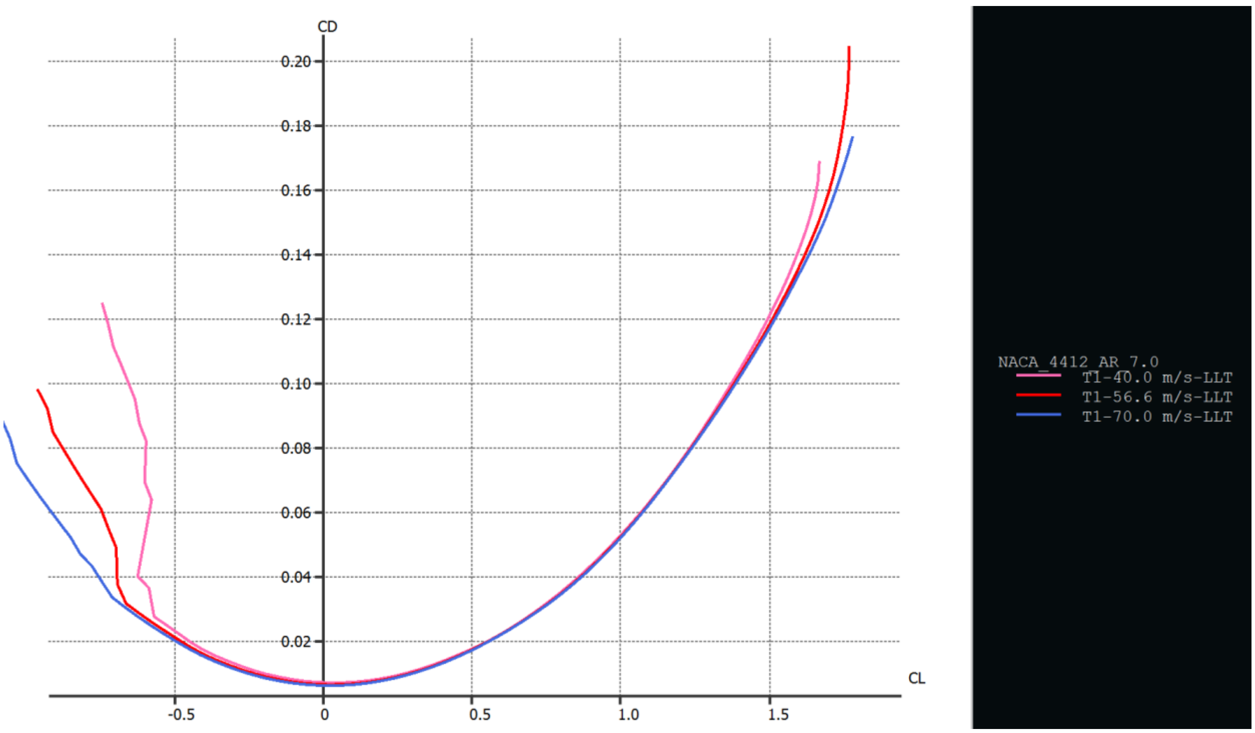


Figure 5.8 Drag Polar for Wing at different cruising speed

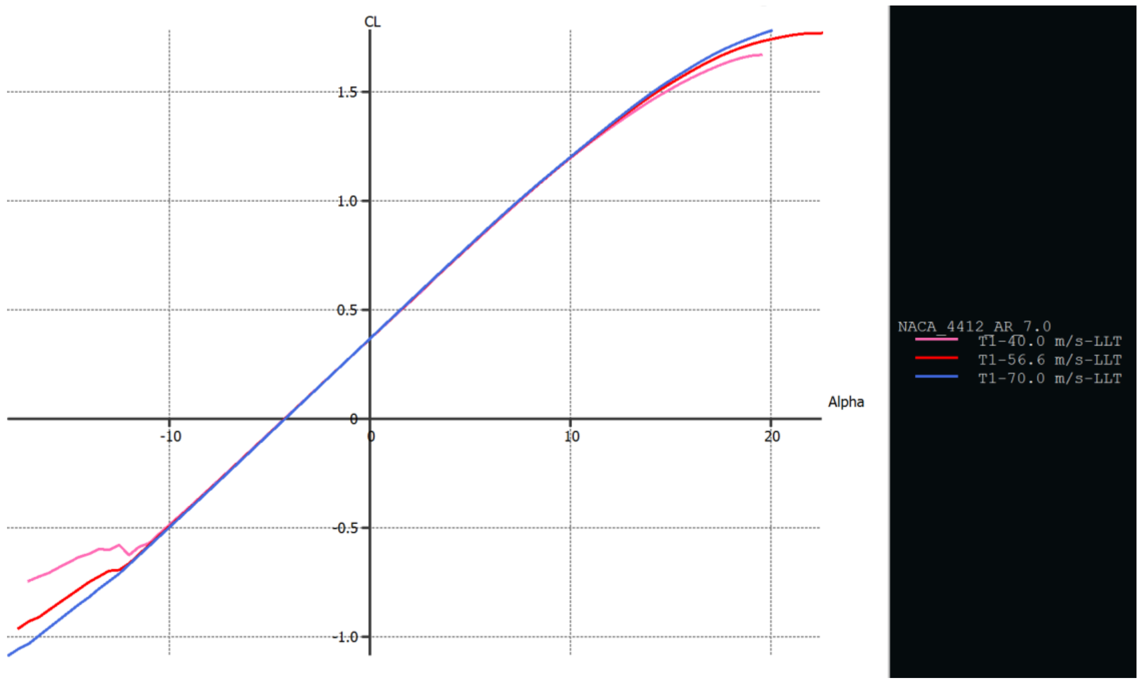


Figure 5.9 Lift coefficient v/s angle of attack for Wing at different cruising speed

5.4.2 XFLR5 vs Analytical Determination

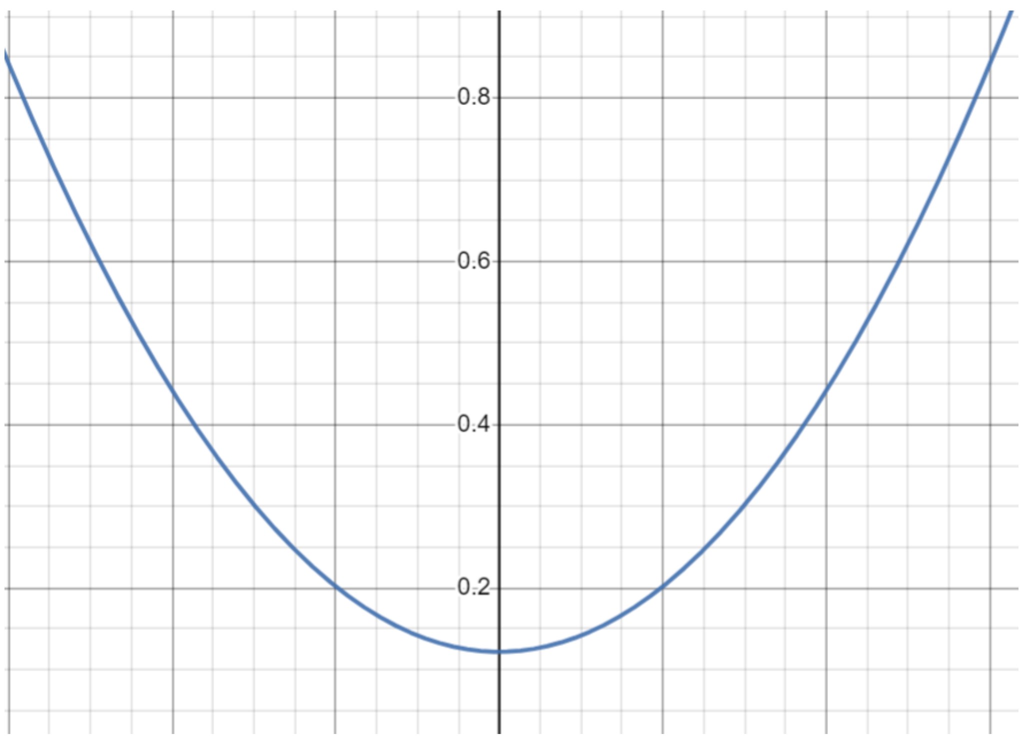


Figure 5.10 Calculated Drag Polar

For comparison for XFLR5, simplified drag model equation was used with calculated CD_{min}. This was plotted in Desmos as shown above in Figure 5.10. The CD was on the x-axis and CL was on the y-axis. The drag polar can be seen quite similarly to wing analysis with XFLR5. The equation used for comparison was $\boldsymbol{C_D = C_{D_{min}} + k\,{C^2}_L}$

5.4.3 Pressure/ Lift Distribution

Pressure and Lift distribution of NACA 4412 airfoil and wing are simulated in XFLR and can be seen in Fig. Lift distribution shown below is at cruise speed and angle of 3°.

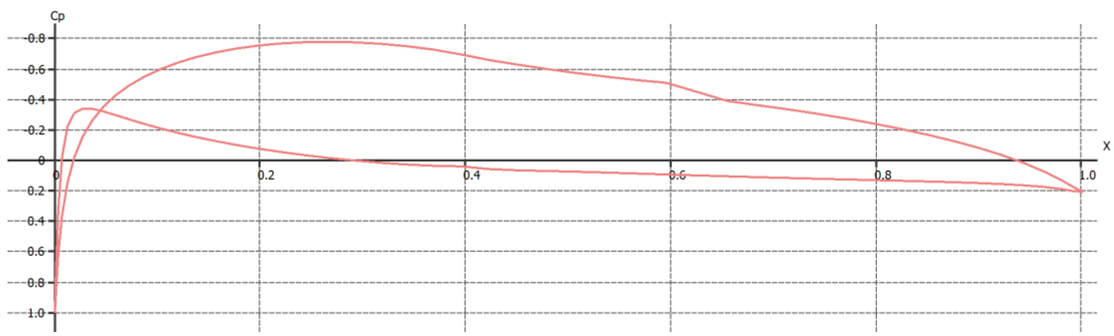


Figure 5.11 Chordwise Pressure distribution of NACA 4412 at Reynolds number of 1,000,000

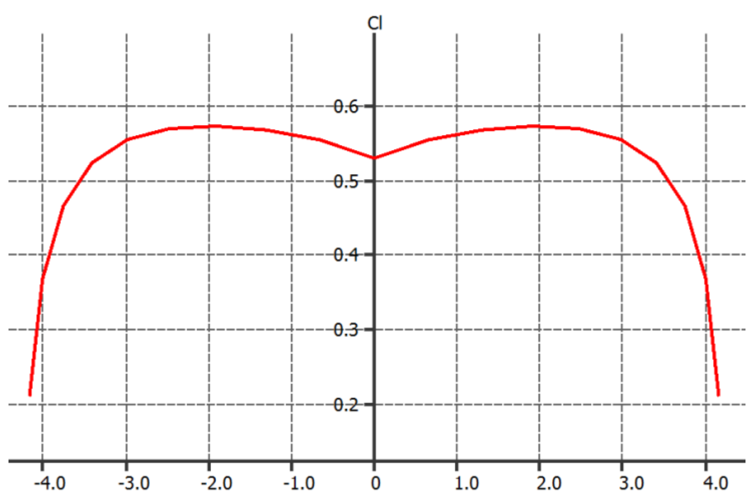


Figure 5.12 Spanwise lift distribution for Wing at Cruise Speed and angle of 3°

6. Propulsion

6.1 Engine Requirements

The main factors affecting the selection of the propulsion system is meeting the performance requirements and minimizing weight. The performance requirements that needed to be met by the propulsion system include takeoff within 1000 ft, a climb rate of 800 ft/min, and a cruise speed of 110 KTAS at an altitude of 10,000 ft.

While researching, it was discovered that the selected aircraft design is closely related to ERCO Ercoupe, which utilizes the Continental O-75 as its powerplant. Using this information, it was deduced that the powerplant selected should have similar/better capabilities compared to the O-75.

6.2 Engine Selection

Using the Ercoupe for inspiration, the selected propulsion system for the UCA is the Continental O-200. This engine is similar to the O-75 used in the Ercoupe but offers an extra 25 BHP to help achieve the aircraft's mission requirements. The O-200 is a naturally aspirated, horizontally opposed, 4-cylinder gasoline engine. The engine will be paired with a fixed, 3-bladed propeller.

6.3 Engine Performance

Tabulated below are the specifications of the selected engine for the UCA, the Continental O-200.

Table 6.1: Continental O-200 Engine Performance and Specifications

Continental O-200 Engine Performance	
Engine Parameter	**Values**
Dry Weight	196.8 lb
Displacement	201 in^3
Maximum Rated RPM	2750
Cruise RPM	2500
Maximum Engine Power	100 BHP
Cruise Power	75 BHP
SFC	0.3939 lbf/(hr*BHP)

The table below summarizes the sizing calculations for the propeller. It was determined that the diameter required for the aircraft is 5.06 ft which results in a propeller area of 20.11 ft^2. Using this data along with other parameters such as geometric pitch and efficiency, the tip velocity and thrust produced were calculated.

Table 6.2: Propeller calculations

Fixed 3-Blade Propeller	
Propeller Parameters	**Values at Cruise Conditions**
Propeller Diameter	5.06 ft
Propeller Area	20.11 ft^2
Spinner Area	0.80436 ft^2
Geometric Pitch	55.044
Propeller Efficiency	0.79

Expected L/D	7.9754
Tip Velocity (at max power)	751.335 ft/s (< 0.8 Mach)
Maximum Static Thrust (Diehl's Method)	434.959 lbf
Maximum Static Thrust (Momentum Theory)	365.08 lbf

6.3.1 Thrust Modelling

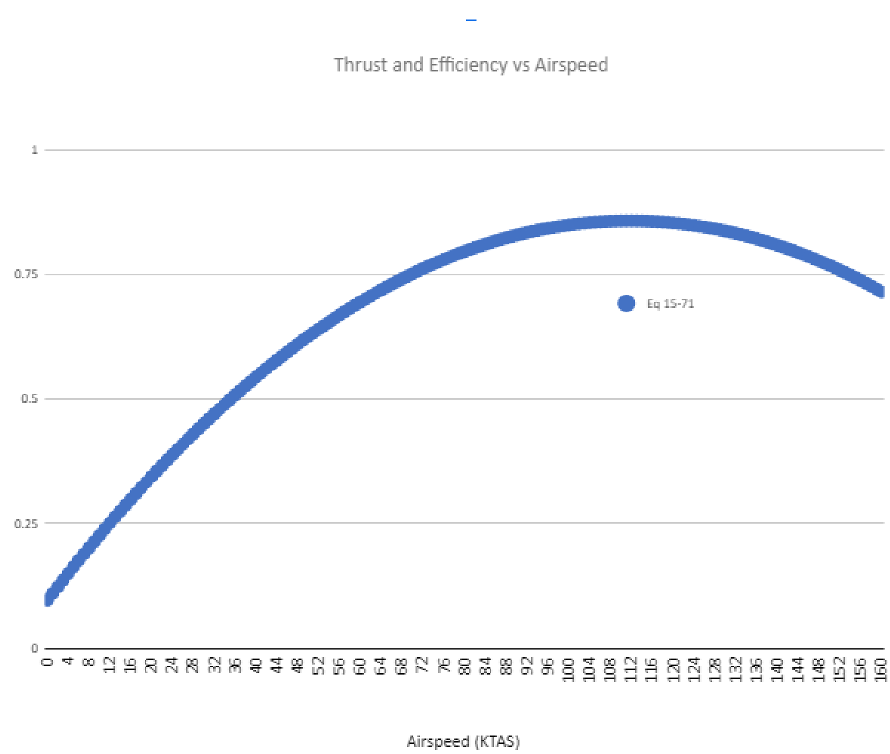


Figure 6.1 Thrust and Efficiency vs Airspeed

6.4 Electrification Architecture Study

The following two graphs demonstrate how an electric engine would affect the aircraft. Looking at the second graph it's clear that changing the UCA design to be electric significantly lowers the cruise range for the aircraft. The goal for the mission is to get about 400 nautical miles and in order to achieve similar results with an electric model a battery much larger would be required. Due to LSA regulations, the aircraft has a maximum takeoff weight of 1653.5 lb and increasing the battery size would likely prove difficult because of this weight limit.

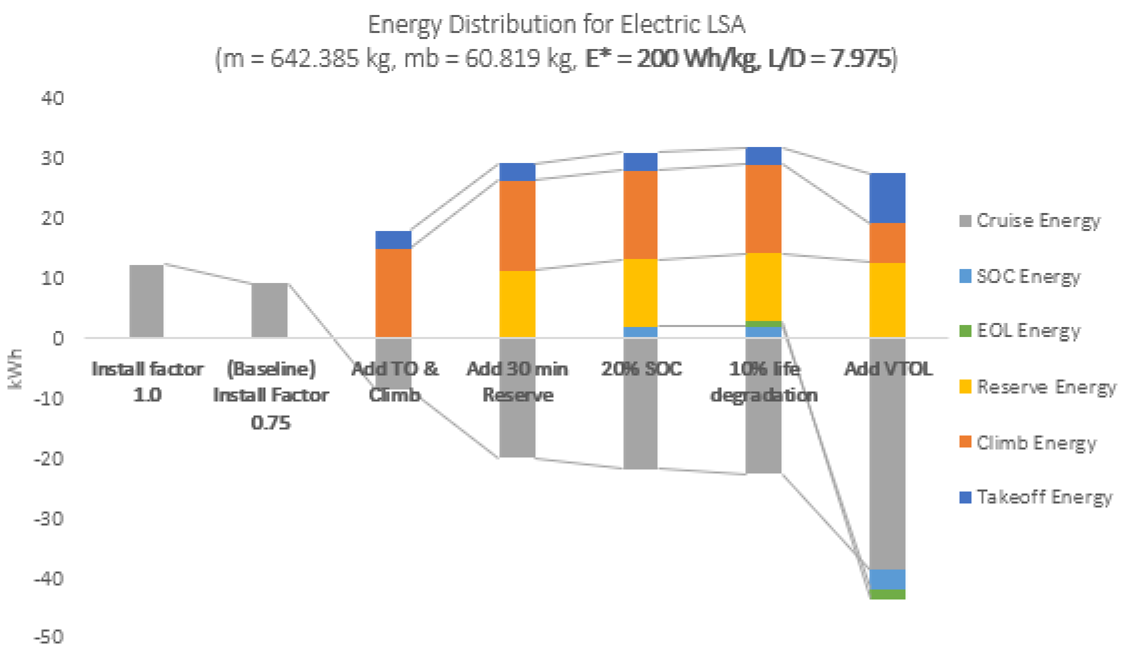


Figure 6.2 Energy distribution for electric LSA

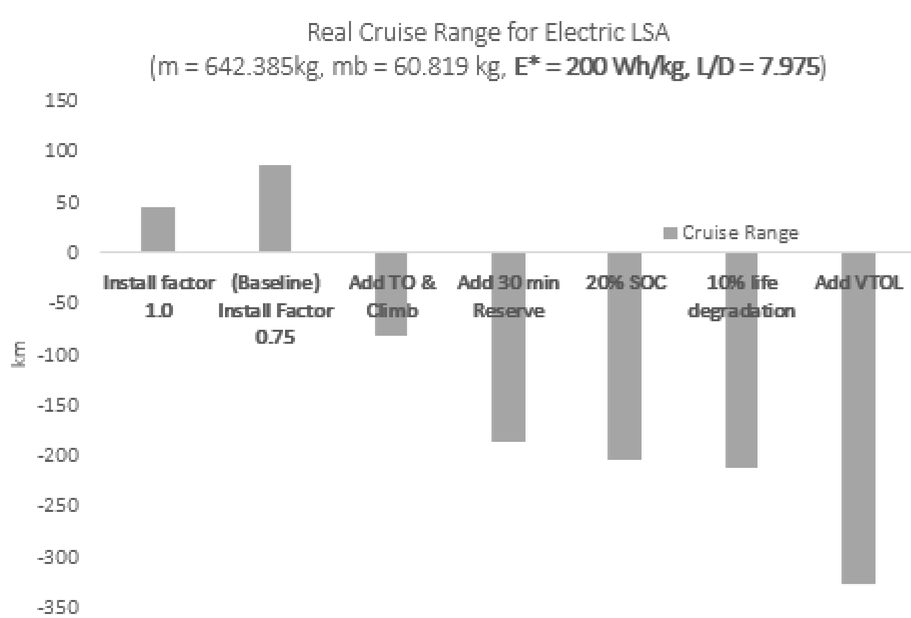


Figure 6.3 Cruise range for electric LSA

7. Structures & Loads

7.1 Aircraft Flight Maneuver Loads

The wings take most of the loads during flight being the main point that provides a lift for the plane. With this in mind, the UCA is outfitted with 6 ribs that are equally spaced throughout the wing. Connecting all 6 ribs there are two horizontal support beams that are used to connect the beams. These horizontal beams then tie into the main structure of the ribs making up the main part of the fuselage. The ribs themselves are completely solid except for tube holes to connect the fuel system together. The decision behind this is that if the ribs are solid they will be easier to maintain as well fix. This provides owners that find a plane with either potentially optimized or worse rib design the possibility of interchanging the newly found ribs with the already found wings. The goal of this aircraft is also to be a trainer plane so this solid rib design allows incoming pilots the room to make some larger mistakes and not be overly punished for learning.

7.2 V-n Diagram

One of the main building steps in designing an aircraft is the V-n diagram which uses stall speed, gust lines and maximum dive speed to determine how the plane will react in different scenarios. The V-n diagram is shown in the graph below in Figure 7.1.

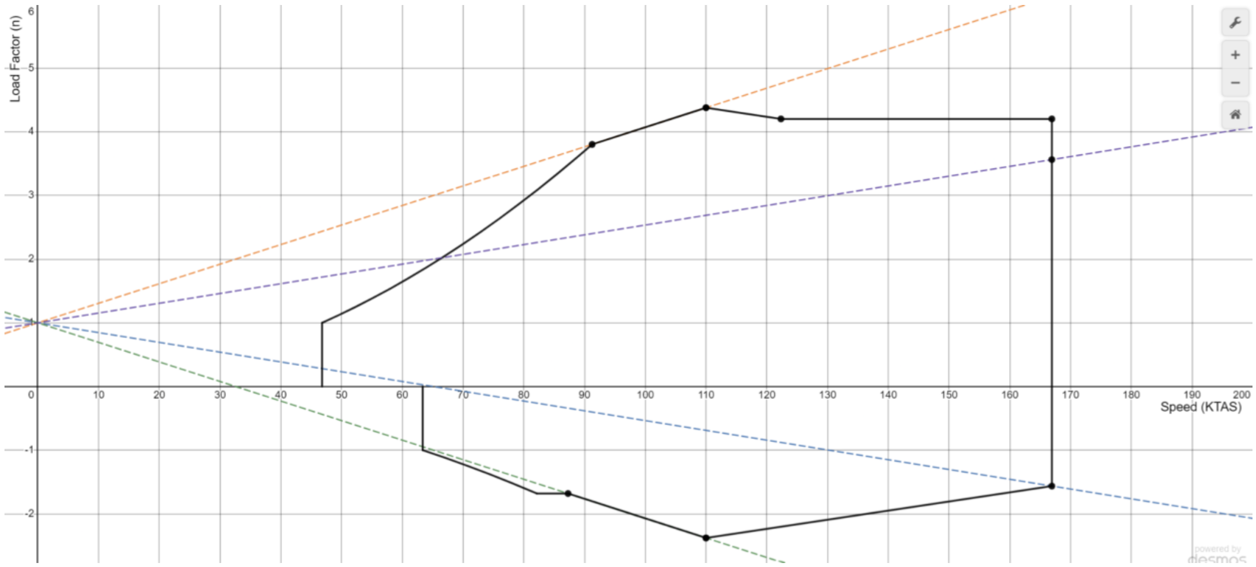


Figure 7.1 V-n Diagram of UCA aircraft

Some of the characteristics that are shown in the V-n diagram is the cruising speed which is set to 110 KTAS and the maximum dive speed of the plane 166.93 KTAS. The stall speed is approximately 49 KTAS and the main maneuvering speeds are 91 KTAS using the positive stall line and 87 KTAS using the negative stall line. The V-n diagram was confirmed to be accurate based on the V-n diagrams that were provided for utility-style planes. These graphs were provided by Professor Ed Cyr during the AERO 3002 class.

8. Auxiliary Systems

8.1 Avionics Overview/ Selection

The avionic components for the UCA are as follows:

Table 8.1: Avionics Overview

Component	**Model**
Navigation	GNC 355
Flight Deck Display	G500 TX
Weather	GDL 39
Air Traffic System	GTS 800

The avionics systems listed in Table 8.1 were chosen specifically to meet the requirements stated in the CFR Part 23. Given these requirements, the goal of UCA is to choose systems that not only meet these conditions but also minimize the cost of the project. To do this, the plane will only have navigation, a flight deck display, and weather and air traffic systems. This will help not overcomplicate the cockpit for beginner pilots.

9. Cost Analysis

9.1/9.2 Initial Cost Estimate & Breakdown/Operations & Maintenance Cost

Table 9.1 Cost breakdown

Development Costs	Total	Units	Vendor Supplied Components	Total	Units
Engineering Working Hours (H_ENGR)	21,566.1963	Hr	Fixed Landing Gear (C_VCS1)	-17,500	USD
Tooling Workhours (H TOOL)	34,430.7849	Hr	Avionics (C VSC2)	7,007.88	USD
Manufacturing Labour Hours (H_MFG)	220,352.7912	Hr	Cost of Engines (C_VSC3)	63,762.66	USD
Total Cost of Engineering (C ENGR)	1,984,090.06	USD	Cost of Propellers (C VSC4)	2,737.77	USD
Total Cost of Development Support (C DEV)	203,334.67	USD	Quantity Discount Factor (QDF)	0.67565	N/A
Total Cost of Flight Test Operations (C_FT)	1,228,385.49	USD	**Operating Costs**		
Total Cost of Tooling (C_TOOL)	2,730,361.24	USD	Maintenance Costs	6,600	USD
Total Cost of Manufacturing (C_MFG)	1,5182,307.3	USD	Storage Costs	3,300	USD
Total Cost of Quality Control (C_QC)	986,849.97	USD	Annual Fuel Cost	16,620	USD
Total Cost of Materials (C_MAT)	3,232,283.31	USD	Annual Insurance Cost	3,356.26	USD
Fixed Cost (C_FIX)	6,146,171.49	USD	Annual Inspection Cost	500	USD
Variable Cost (C_VAR)	134,849.21	USD	Engine Overhaul Cost	2,500	USD
Cost per Unit	165,580.07	USD	Annual Loan Payment	28,945.44	USD
Manufacturer's Liability Insurance per Unit	24,837.01	USD	Total Yearly Costs	61,821.70	USD
Minimum Selling Price	190,417.08	USD	Cost per Flight Hour	123.64	USD/Hr

The cost analysis is based on the production of 200 aircraft over a 5 year period. The aircraft has an estimated airframe weight of 800 lb and is entirely made out of aluminum. This plane will be certified as LSA and have tapered wings, a pressurized cabin, and a simple flap system. The plane incorporates a fixed landing gear and a 3 blade propeller. Using these parameters, the minimum selling price was determined to be $190,417.08. The annual operating cost of this aircraft, with 500 flight hours per year, is $61,821.70.

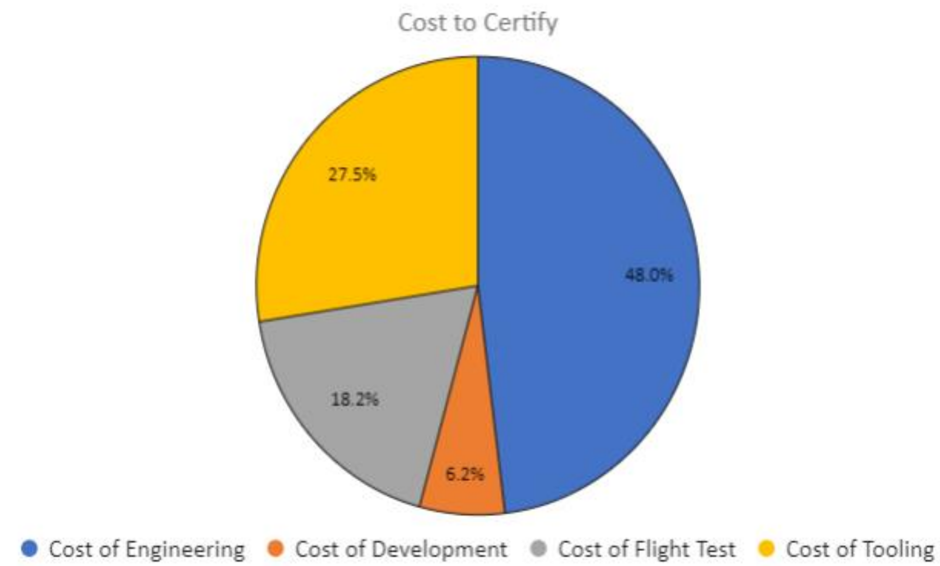


Figure 9.1 Breakdown of the total cost to certify

10. Conclusion

In conclusion, the team known as Skunkworks 2 has created a new groundbreaking light sport aircraft known as the UCA. This light sport aircraft is designed to be a two-seater trainer for incoming pilots to learn how to fly. To achieve the mission profile, the UCA is fitted to be a mid-wing configuration with an H-tail and tandem landing gears with a single outrigger. On top of all of that, our team designed the landing gear to be reinforced with a bend. With these criteria, we compared the UCA to 6 other planes similar in geometry or trying to achieve the same goal. It was found that in most criteria, the UCA outshined all other competitors. Some of the main components of the plane are the use of a NACA 4412-style wing and an H-style tail.

The dimensions of the plane are as follows, 330.71-inch wing span, max height of 68.68in and max length of 274.04 in. It is provided that there is a ground clearance of 15.12 in and a max takeoff angle of 6.79 degrees. The minimum selling price for the UCA will be 190,417.08$ USD with an annual operating cost under the assumption that there are 500 hours of flight per year being 61,821.70$ USD. These will be fair prices for most incoming pilots in today's economy, and there will be a demand for roughly 200 aircraft over a 5-year operation period. Some of the internal operating components included in the UCA will be the GNC 355 for navigation, the G500 TX for the flight deck display, GDL 39 for weather and GTS 800 for the air traffic system. Only the key components are installed into the UCA to ensure that the pilot can concentrate on flying and not be distracted by unnecessary instrumentation.

References

[1] Gudmundsson, Snorri. General Aviation Aircraft Design : Applied Methods and Procedures. Second edition. Kidlington, Oxford ;: Butterworth-Heinemann, 2022. Print.

[2]Durden, R. (2013) Erco Ercoupe, AOPA. Available at: https://www.aopa.org/go-fly/aircraft-and-ownership/aircraft-fact-sheets/erco-ercoupe (Accessed: February 19, 2023).

[3] Consumer, A. (2013) Aircraft history, Cessna 120-140 Association. Available at: https://cessna120140.com/history/ (Accessed: February 19, 2023).

[4] B. Wainfan, "H-tails and triple tails," *KITPLANES*, 07-Nov-2022. [Online]. Available: https://www.kitplanes.com/h-tails-and-triple-tails/. [Accessed: 13-Apr-2023].

[5] Prateek, "Nose/Tip Over Take off and landing problem on Tail-Draggers," *Nose/tip over take-off and landing problem on tail-draggers - India's Open Forum for RC Flying, Aeromodelling, cars and Hobby Stores*. [Online]. Available:http://www.rcindia.org/rc-maneuvers-and-skills/nose-over-take-off-and-landing-on-tail-draggers/. [Accessed: 13-Apr-2023].

Appendix

MATLAB Code for Constraint Diagram

```
WS = (1:0.1:40)';
%% T/W for desired T-O Distance
g = 32.2;    % ft/s^2
CL_max = 1.26;    % for T-O
Sg = 1000;    % ft
CD_TO = 0.045;    % Table 3-2
CL_TO = 0.72;    % Table 3-2
u_TO = 0.037;    % Table 23-3
dens_SL = 2.378 * 10^-3;    % slugs/ft^3
H_TO = 0;  % ft, Zero means S-L
dens_H_TO = dens_SL * (1-6.8756*10^-6*H_TO)^4.2561;
TW_TO = (1.21/(g*dens_H_TO*CL_max*Sg))*WS + (0.605/CL_max)*(CD_TO -
u_TO*CL_TO) + u_TO;
TW_TO_SL = TW_TO/(1.132*(dens_H_TO/dens_SL)-0.132);    % Gagg-Ferrar Model
for SL
plot(WS, TW_TO_SL);
hold on; box on; grid on;
%% T/W for desired Rate-of-Climb
V_v = 800/60;    %  ft/s at S-L, Table 19-3
V_y = (43.591+2.2452.*WS)*1.6878;    % ft/s, Table 3-1
CD_min = 0.033 ;    % Table 16-22, Cessna Skycatcher 162
k = 0.040;    % Lift Induced Drag Constant, k = 1/(pi*AR*e)
H_ROC = 10000;  % ft, Zero means S-L
dens_H_ROC = dens_SL * (1-6.8756*10^-6*H_ROC)^4.2561;
q_ROC = 0.5*dens_H_ROC*(V_y.^2);
TW_ROC = (V_v./V_y) + (q_ROC.*CD_min)./(WS) + (k./q_ROC).*(WS);
TW_ROC_SL = TW_ROC/(1.132*(dens_H_ROC/dens_SL)-0.132);    % Gagg-Ferrar Model
for SL
plot(WS, TW_ROC_SL);
%% T/W for Level Constant Velocity Turn (CVT)
R_turn = 656.168;     % ft [200 m]
H_CVT = 10000;  % ft, Zero means S-L
dens_H_CVT = dens_SL * (1-6.8756*10^-6*H_CVT)^4.2561;
q_CVT = 0.5*dens_H_CVT*(V_y.^2);
n = sqrt(((V_y.^4)./(R_turn^2*g^2)) + 1); % Load Factor
TW_CVT = q_CVT.*((CD_min./WS) + k*(((n./q_CVT).^2).*WS));
TW_CVT_SL = TW_CVT/(1.132*(dens_H_CVT/dens_SL)-0.132);    % Gagg-Ferrar Model
for SL
plot(WS, TW_CVT_SL);
%% T/W for desired Cruise Airspeed
H_CRZ = 10000;  % ft, Zero means S-L
dens_H_CRZ = dens_SL * (1-6.8756*10^-6*H_CRZ)^4.2561;
```

```
q_CRZ = 0.5*dens_H_CRZ*(V_y.^2);
TW_V_CRZ = q_CRZ.*CD_min.*(1./WS) + k.*(1./q_CRZ).*WS;
TW_V_CRZ_SL = TW_V_CRZ/(1.132*(dens_H_CRZ/dens_SL)-0.132);    % Gagg-Ferrar
Model for SL
plot(WS, TW_V_CRZ_SL);
%% T/W for desired Service Ceiling
H_SC = 12000;  % ft, Zero means S-L
dens_H_SC = dens_SL * (1-6.8756*10^-6*H_SC)^4.2561;
q_SC = 0.5*dens_H_SC*(V_y.^2);
TW_SC = (1.667./V_y) + (q_SC./WS).*CD_min + (k./q_SC).*WS;
TW_SC_SL = TW_SC/(1.132*(dens_H_SC/dens_SL)-0.132);    % Gagg-Ferrar Model
for SL
plot(WS, TW_SC_SL);
%% W/S for a Desired Stalling Speed
V_stall = 40*1.6878;    % ft/s
CL_max_stall = 2.5;   % with flaps
H_Alt = 8000;  % ft, Zero means S-L
dens_H_Alt = dens_SL * (1-6.8756*10^-6*H_Alt)^4.2561;
q_stall = 0.5*dens_H_Alt*(V_stall^2);
WS_stall = CL_max_stall * q_stall;  % lbf/ft^2

roh_ldg = 23.78 *(10^(-4));
C_Lmax0 = 0.9*CL_max;
A = roh_ldg*C_Lmax0 ;
C_DLDG = 0.4;
C_LLDG = 1.6;
tau = 3;
mu_f = 0.3;
syms w
a = 0.01583;
b = ((1.556*tau)*sqrt(A/w));
c=  32.2*( (0.605/(C_Lmax0))* (C_DLDG - (mu_f*C_LLDG)) +mu_f ) ;
c_n = 32.2*((0.605/(C_Lmax0))*(C_DLDG - (mu_f*C_LLDG)) +mu_f );
d = (w/A) ;
eqn = (a + b + 1.21/c)*d == 1113.4;
Land_Dist = vpasolve(eqn);
display(Land_Dist)
xline(13.12)
%%
title('Constraint Analysis');
xlim([0, 25])
ylim([0,0.5])
xlabel('Wing Loading (W/S)'); ylabel('Thrust-to-Weight Ratio (T/W)');
legend('T-O Distance', 'Rate of Climb', 'Constant Velocity Turn', ...
   'Cruise Airspeed', 'Service Ceiling', 'Landing Distance');
hold off;
```

Weight Analysis Sheet

Aircraft	Empty Weight (lbs)	MTOW (lbs)	Emplty Weight Ratio
Aircoup -Alon	749	1450	0.5165517241
22LS	700	1320	0.5303030303
7ACA	750	1300	0.5769230769
Cessna 140	890	1450	0.6137931034
Ercoupe	845	1400	0.6035714286
VELIS CLUB	750	1323	0.566893424

A	B
-0.271	0.116

Ercoupe	
SFC	
0.393	lbf/hr - BHP

Parameters can be Changed

Constants				
t (taxi) Hrs	0.3333333333		ROC [ft/min]	800
t (max) Hrs	0.01666666667		Delta_H (altitude) [ft]	10000
Delta_H_2 (altitude) [ft]	-5000		p_climb	0.1264245882
			eta_p [prop effifciency]	0.68
SFC	0.3939		L/D	10
p_idle	0.01264245882			
p_max	0.1264245882		Endurance (hr)	3.5
p_descent	0.1264245882		ROD [ft/min]	-500
V (KTAS)	110		Endurance_2	0.5

	110 Knots	
True Airspeed	183.48	ft/s
T/W	0.2577	
W/S	13	

Weight Ratios (Propellers)	
Taxi- Take Off	0.9975157568
Climb to altitude	0.9896489868
Cruise (Endurance)	0.9340038372
Descent	0.9917191895
Reserve Cruise	0.9902938782

Mission Weight Ratio=	
W_N/W_0	0.9055291192

		lbs	
Payload Weight		50	
Crew weight		424	<--

W_f/W_0	0.09447088077

w_o_guess	1416.46			
(w_e/w_o)_iterate	0.571	0.571	0.571	0.571
w_o_iterate	1415.589	1415.288	1415.184	1415.147

Weight variables	Weights in lbs
W_f	133.81
W_e	808.22
W_o	1416.46

Final Empty Weight	808.3543701
Final Fuel Weight	134.1059528

Desmos File for Vn Diagram- https://www.desmos.com/calculator/rmwbo9edak

CDmin Calculations

	S	108.50022	ft^2		

S_VT	9.6979
S_HT	24.2445
Ac	13.1737

Additional Drag Values

	CD_pi	**Area based on**		Sum
Wing	0.007	108.50022		0.75950154
HT and VT	0.007	24.2445		0.1697115
Wing Flaps	0.025	108.50022		2.7125055
Fuselage	0.11	13.1737		1.449107
Landing Gear(close)	0.014	108.50022		1.51900308
				0
	0	0		0
Wing Tank	0.2	13.1737		2.63474
			Delta CD_min	0.08520322466

Original CD_min	
from XFLR5 (Clean configuration)	