Spring 4-24-2023

Superfly Amphibian

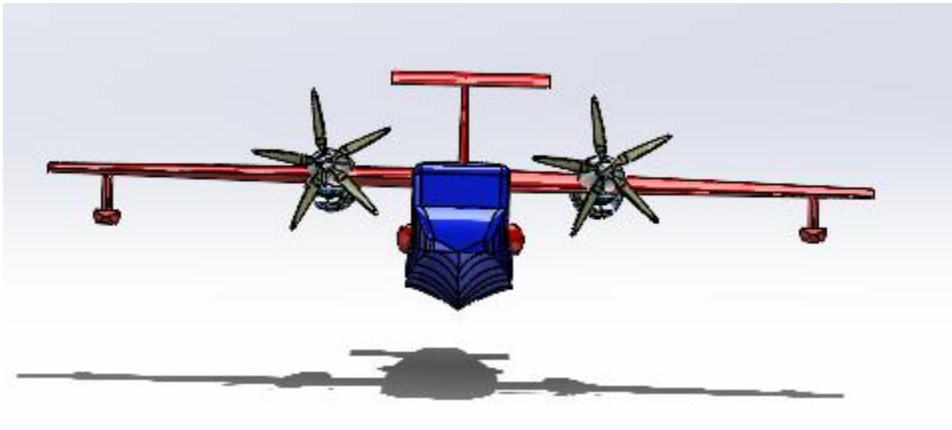
Devonte Andrews
Kennesaw State University

Ahmed Hamza
Kennesaw State University

Kwesi Onumah
kennesaw

Eva Sanchez
Kennesaw State University

Superfly Amphibian



Devonte Andrews: Project Manager

Kwesi Onumah: Propulsion Lead Engineer

Eva Sanchez: Mechanical Associate Engineer

Ahmed Hamza: Financial Resource Manager

Faculty Advisor: Dr. Adeel Khalid

Kennesaw State University

Abstract:

Following a Short Takeoff and Landing (STOL) mission profile, this seaplane is designed to carry 19 passengers and 1 flight crew with a range of 200 nautical miles. The seaplane is equipped with two turbo-prop engines and is economically comparable to current seaplanes in terms of servicing and operating expenses. The aircraft is capable of operating in remote locations with limited infrastructure due to its STOL abilities, allowing for increased access to difficult-to-reach areas. The seaplane's design incorporates modern materials and technologies to enhance efficiency, safety, and comfort for passengers and crew. The aircraft's versatility and cost-effectiveness make it an attractive option for regional air transportation, tourism, and other applications.

List of Tables:

Table of Contents

Chapter 1: Background and Overview

1.1 Introduction and Problem statement:

There is increasing demand for more purpose-built aircraft to be able to perform specific missions. We have aircraft currently manufactured that can be converted to do various missions. However, the aviation market is moving towards investing in aircraft that are designed to complete specific missions. Island nations and developing countries often have limited resources and land to create airports. Air passenger and cargo commerce can be useful in the economic development of outlying communities. The goal of this project is to design an amphibious aircraft capable of both passenger and cargo missions with the same airframe. The entry into service is slated for 2031 for the passenger model. Current aircraft designs can fill this purpose. However, as conversions of land planes, they are not optimized for amphibious operations. The current aircraft designs that serve these markets include the Twin Otter, Beaver, Otter and Cessna Caravan that can be put on amphibious floats. Purpose-built amphibians include the SeaStar, US-2, Be-200 and Bombardier 415.

1.2 Design Concepts and Justifications:

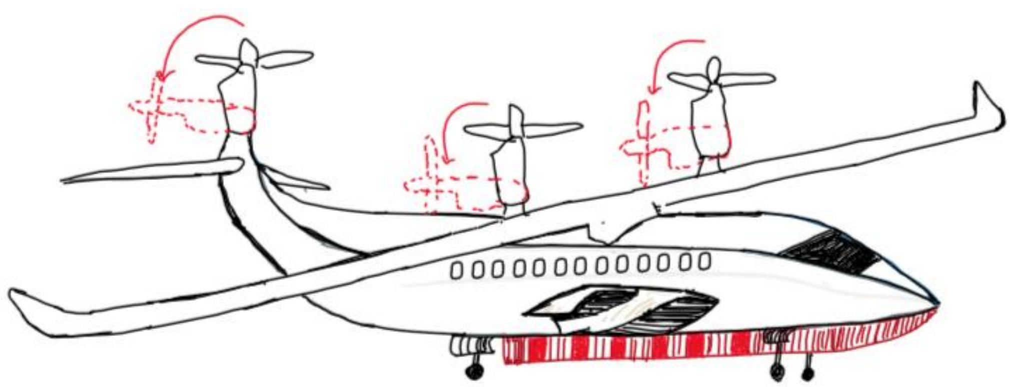


Figure 1 Design Concept 1

This design concept utilizes a tilt rotor mechanism to convert from VTOL mode to pusher mode. The wings have a very high aspect ratio to minimize the vertical thrust area impeded by the wings.The aircraft is designed to be amphibious and have the capacity to transport up to 20 passengers. Permanent buoyant attachments on either side of the aircraft allow smooth take off and landing on calm waters, and the aircraft also is equipped with retractable landing gear to land on the ground. Due to the aircraft's capability to hover and thus land softly, the landing gear of the aircraft is small, lightweight, and optimized for taxi.

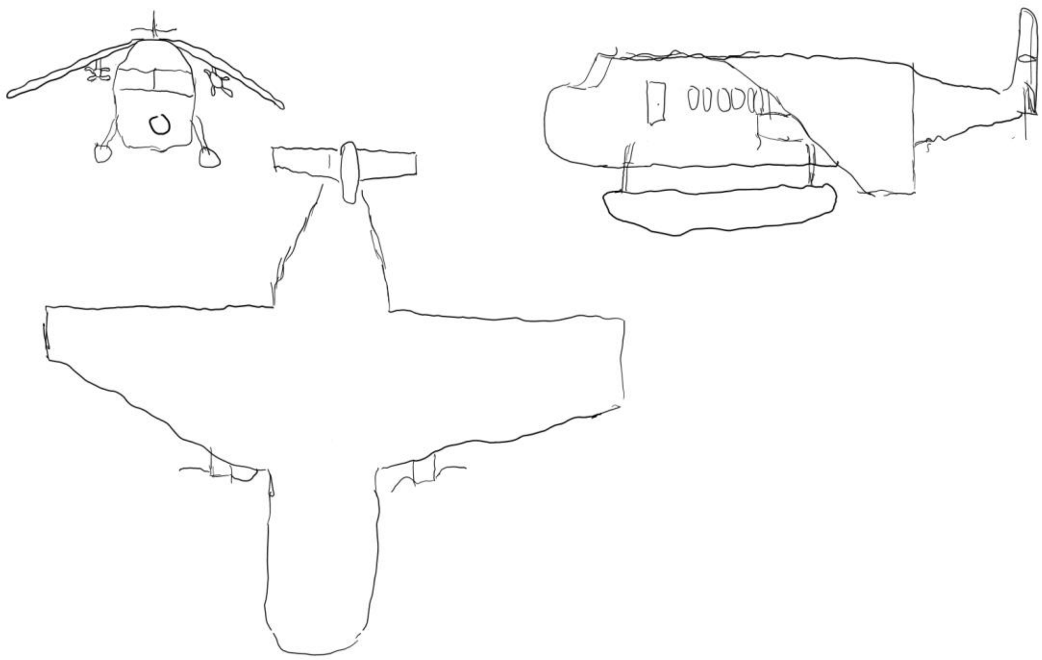


Figure 2 Design Concept 2

This aircraft concept features a thick airfoil design so that takeoff it can take off at slower speeds. Considering this aircraft will land in bodies of water, viscosity will increase significantly thus increasing drag. Also, note the high aspect ratio for the wings. This feature is intended to increase the lift and stabilize plane while in flight. The passenger comfort is paramount therefore, stability is a key parameter. The wings are also higher up and anhedral to have high ground clearance. This makes loading cargo a lot easier without the need for special equipment. The engines are close to the fuselage and higher up as well. This feature should permit designing lighter wings. Wings also have thicker airfoil to permit greater lift capability at lower speeds. Retractable hydrofoils are at the bottom of the aircraft. These retract into the same bay as the wheels.

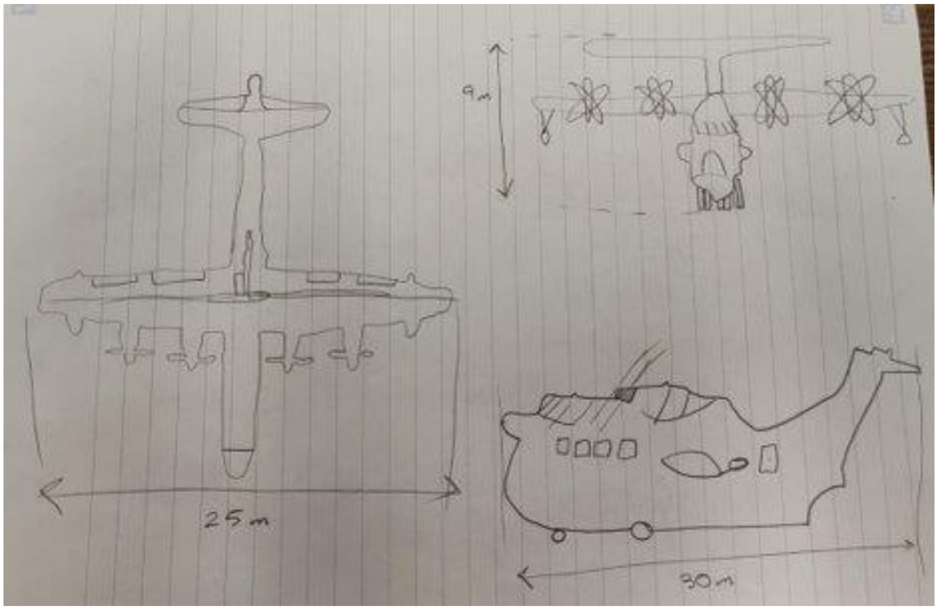


Figure 3 Design Concept 3

This aircraft can cruise at extremely low speeds (about 90km/h) and can take off and land on the water within a very short distance. This aircraft is equipped with a Spray suppressor to redirect water flow downward, as well as a spray strip to redirect water flow laterally. These aspects ensure that the airframe of the aircraft is not damaged when landing on water. This aids in the outstanding seaworthiness of the aircraft. The aircraft also features a slight dihedral in the wings to provide lateral stability during flight. Additionally, it has a vertical stabilizer that keeps the nose of the aircraft from producing adverse yaw and a horizontal stabilizer that helps reduce adverse pitch.

1.3 Interior Configuration

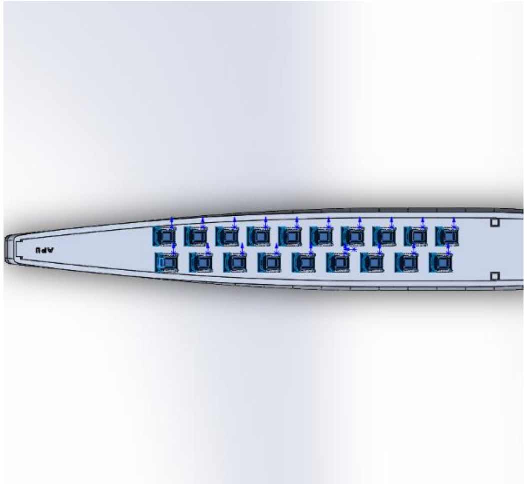


Figure 4 Passenger Compartment Top Down View

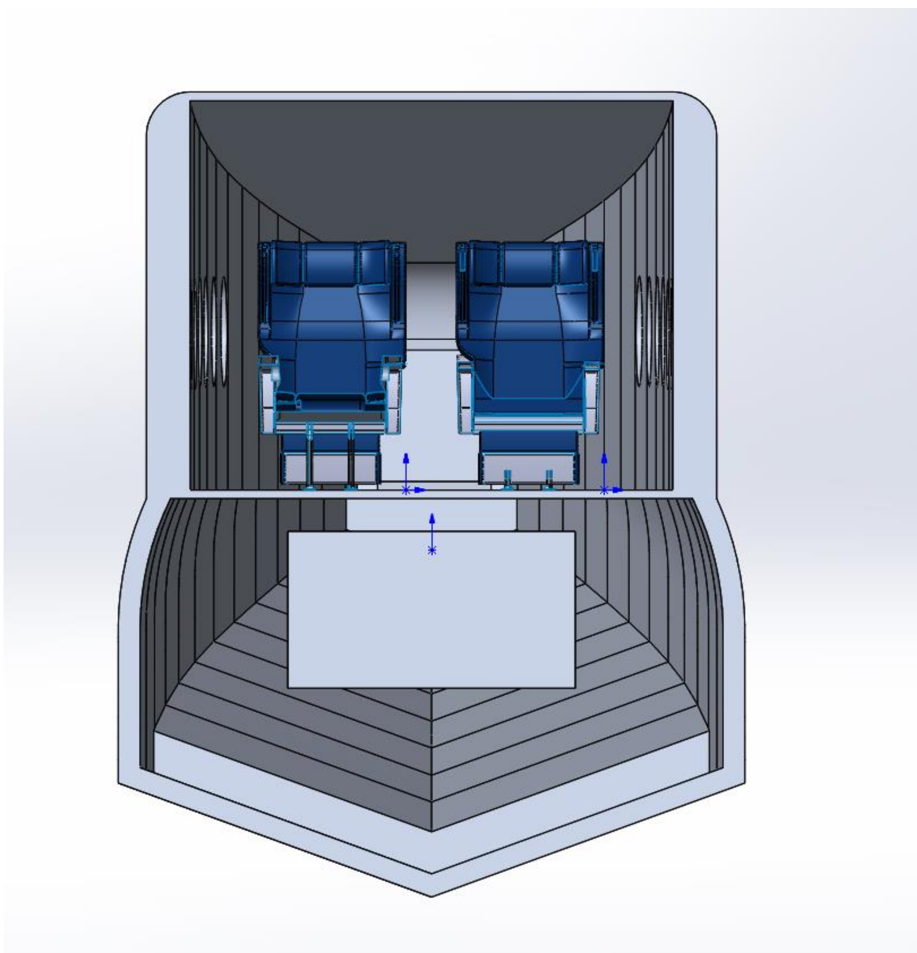


Figure 5 Passenger Compartment Front View

With the final design following the design requirements, the seating will be 10 passengers on one aisle and next to them will be 9 passengers on the other aisle. Each seat will be adjustable for leg room and all passengers will be in one cabin separated from the pilot and control room. The hull at the bottom will be for luggage and cargo. Towards the tail of the fuselage will house the APU of the plane. The aisle width is 1.7ft, seat width is 1.8ft with a 28" pitch across all the seats. The maximum height for passenger compartment is 6.5ft.

1.4 Trade Study Items

Trade studies were conducted to analyze various characteristics of the seaplane's geometry and their impacts on its performance, cost, and operability. The following six characteristics were examined: wing, tail, propulsion placement, propulsion sizing, and aircraft sizing.

Methodology

To identify key considerations for each design characteristic, the engineers of this project conducted a thorough review of relevant literature and industry standards. Various design alternatives and their pros and cons were evaluated using a multi-criteria decision analysis (MCDA) approach. The examination criteria used for the analysis primarily focused on performance, safety, cost, manufacturability, and maintainability.

Wing

Several design alternatives, such as high-wing, mid-wing, and low-wing configurations, are available. The mid-wing design offers better lift distribution and fuel efficiency, but it may be more complex and expensive to manufacture. The low-wing design provides better maneuverability and ground effect, but it is more prone to water spray and damage. Although an increase in drag is a tradeoff for the high-wing design, it provides better visibility, stability, water clearance, and is also easiest to manufacture. Based on the analysis, the high-wing design appears to be the most suitable for the seaplane.

Tail

The tail design of a seaplane affects its stability, control, and water handling. Several design alternatives are available, such as T-tail, V-tail, and conventional tail configurations. The V-tail design offers better pitch and yaw control and less drag, but it may also be more difficult to manufacture and maintain. The conventional tail design provides a simpler approach, but it is prone to water spray and damage. Based on the analysis, the T-tail design appears to be the most suitable for the seaplane.

Trade studies will be conducted to meet design criteria documentation at minimum and further trade studies will be conducted for analyzing different components of the design. Below is a list of trade studies that will be completed.

Geometry

- Wing and tail
- Fuselage
- Propulsion placement and sizing
- Initial sizing

1.5 Minimum Success Criteria

At minimum, the design goal is to present proof of concept. The aircraft must achieve the STOL criteria from land and sea. The aircraft must be able to cruise at 200 knots minimum. These parameters are essential for the aircraft's mission.

Chapter 2: Literature Review

Most successful seaplane designs have low takeoff speeds to reduce landing impact accelerations and high bollard pull thrust, to overcome hydrodynamic resistance. Bollard pulls thrust is like horsepower or thrust to overcome weight in aerospace language. The critical components of a seaplane's hydrodynamic hull are the forebody, afterbody, sternpost angle, deadrise angles, and the spray root line. These components play a significant role in stabilizing the aircraft in the water (buoyancy), controlling pitching moments in the water, and controlling the water spray so that the engines do not get damaged. Critical features of concerns for amphibian aircraft are [1]:

1. The hull meets static and damaged stability criteria.
2. The hull does not have dynamic instabilities such as skipping or proposing.
3. Spray does not damage wing structures or propellers or the bottom structure.
4. Airframes can withstand impact pressures and accelerations.
5. Engines must produce enough thrust to get past hump speed and takeoff [1]

Seaplanes have aerodynamic and hydrodynamic tradeoffs. Since seaplanes feature hulls, they are not aerodynamic efficient. reducing the rate of climb and cruise speed. The engines must work harder to get the same amount of power as a conventional aircraft. These types of aircraft operate at lower altitudes, giving rise to noise reduction considerations. Anti-corrosive materials and paint are of high importance due to the aircraft being in contact with water. The hull must be strong for landing impacts and debris impacts in the water making the aircraft heavier than conventional aircraft, so hydrofoils are used to increase aerodynamic efficiency. Chine and spray rails are components that could help keep water spray away from propulsive components [2].

The most used metals for aircraft are aluminum-based, magnesium-based, and titanium-based composites. The structure of commercial aircraft is composed of 50% composite material and about 45% pure metal material such as Titanium, steel, and aluminum. Aluminum matrix composites are suited for harsh environments where reliability and safety are required, as they possess superior fatigue strength as compared to steel. Titanium matrix composites have excellent corrosive resistance and high strength at elevated temperatures and are widely used in aerospace, marine, and automotive industry. Magnesium based matrix composites are widely known for being less dense than aluminum providing lightweight structures in aircraft [3].

Hydrofoils help reduce the viscous effects of the water. Initial sizing of a hydrofoil involves considering the area, sweep angle, taper, dihedral and aspect ratio. Hydrofoil produces a pitching moment, so it is recommended to place the hydrofoil ahead of the center of gravity. In this position the hydrofoil will provide a lift and oppose the pitching moment, minimizing the takeoff distance [5].

Disk loading is a parameter which defines a propeller or engine's thrust divided by the area over which that thrust is produced. Direct-Lift jet engines have an exceedingly high disk loading to achieve VTOL, whereas helicopters have a low disk loading. The disk loading of a thrust mechanism directly indicates the achievability to efficiently produce the required amount of hover thrust. [6]

For aircraft which use a hybrid of rotary blades and wings as methods of generating lift, a tiltwing design offers certain advantages relative to a tiltrotor design. One reason the tiltrotor mechanism is suboptimal is due to the large area of potential thrust being impeded by the wings. During the vertical take-off phase of flight, the aircraft must rely on the downward slipstream generated from the rotor blades to achieve lift; the slipstream is blocked by the wings when they are oriented horizontally. With a tiltwing mechanism, the slipstream of the rotor blades strikes the wing at a lesser area, allowing the engine power to be fully directed toward generating lift. Another reason tiltrotors are unfavorable is due to the difficulty in transition between VTOL and horizontal flight. Tiltrotors require the rotors-or entire aircraft- to pitch forward like a helicopter before the wings can generate enough lift to sustain flight. Contrarily, tilt-wing aircraft can transition from VTOL mode to aircraft mode at zero forward airspeed. [7]

The wings on a rotor-to-trailer tiltwing aircraft can be used as flaps which extend from leading edge to trailing edge due to their ability to rotate about the horizontal axis. The wings can be programmed to adjust the wing tilt angle in accordance with optimal angles of attack. Maintaining the full wing area in the enclosed space of the slipstream of the propellers in conjunction with variable attack angle will ensure that the wings never stall. [8]

Tiltrotor aircraft which go from rotor to pusher mode are optimal for hovering. Rotors in this configuration are oriented downward. Counter moments are generated by each opposing propeller to always maintain a steady state of hovering during helicopter mode. During the transition to pusher mode, the aft rotors tilt slightly upward to generate forward propulsion. Once the wings have generated sustainable lift, the aft rotors are rotated a full 90 degrees to pusher configuration. The tilt mechanism performance can be optimized by using a cascade control system with PID (proportional–integral–derivative) controllers, which sense the necessary adjustments needed during the 3 phases of hover, transition, and push thus relieving the pilot of manually set the pitch angles. [9]

With the ever-growing travel industry, there is demand for a VTOL passenger aircraft that can carry lots of passengers. Current airports are becoming overwhelmed with the number of landings of large aircraft that require large runways, and airports designed for small aircraft usually cannot handle landing commercial airliners due to local terrain conditions and short runways. One way to achieve VTOL is the blown wing mechanism. The blown wing design has a flap on the wing that deflects the slipstream of air a full 90 degrees toward the ground, thus permitting vertical lift. Once an aircraft with blown flaps reaches proper altitude, the flaps retract and revert the thrust along the horizontal axis. [10]

Electric motors in the propulsion system of VTOL aircraft perform better than fueled engines. Electric motors reduce needed runway space in comparison to fueled engines even when wing planform is not optimized. For electric motors, the power required for takeoff is significantly higher- up to 18 times higher- than the power required for cruising. This is good because takeoff only takes a couple seconds; the aircraft will be okay using high power briefly. The ESTOL will use less power during cruise. [11]

Selecting the most optimal locations for the VTOL hotspots will be essential to the success of the new transportation structure. Mathematical modeling can be performed to analyze how passenger drones can interact with existing infrastructure. Projected service area calculations can predict a yield clientele potential of 12.6 million for an area of 70,550 square kilometers. Ensuring ease of access between the VTOL hotspots is also important; an optimal service area is 70% of the population with a 30-minute rotation.

By incorporating the best properties of each material, the composites can acquire the best attributes that neither of the constituent materials could perform on their own. Mixed materials in aerospace applications due to their increased power to weight and stiffness to weight proportion, and high decay resistance. Like Aluminum alloys for framings and coats, also, composites for designs.

Amphibious aircraft get affected by aerodynamic parties, motor thrust, and hydrodynamic pressures during the water launch procedure. The motion parameters of aircraft, such as the slope angle, current, and flying speed, change rapidly with the period and the interpretation of these parameters.

Some amphibian airplanes use a pusher propeller interpretation, which generates exhaust to give through the propeller aircraft, which can increase racket. High branch and control effects caused by an inverted pusher propeller deliver enough longitudinal solidity for the strategy with a much lower horizontal tail volume ratio than the traditional design value.

The power of the wing increased mainly when the number of carbon fiber layers increased, and the cost of production also increased. The main spar with at least Twenty carbon coatings and ribs with six combination carbon fiber and glass fiber layers can sustain the maximum fixed load without any injury or enduring deformation.

The tail helps as a stabilizer like in a conventional airplane and shows good performance for stability, behaving like an airplane on a cruise; flight control could relate to the refined control strategy of the airplane meeting efficiency, productivity, and versatility needs and ensuring that life and safety come first. The tail provides stability in the longitudinal and directional axes during flight. Also, it assists in the aircraft's pitch and yaw control by conditioning power surfaces affixed to the stabilizing surfaces.

Chapter 3: Problem Definition

3.1 Problem Solving Approach:

Having an organized approach to this challenge is essential to analysis. Starting with the conceptual design phase, tasks will be divided, and a thorough literature review will be conducted to understand project parameters. Concept designs will be drawn and presented. Initial sizing will be completed. The preliminary design phase will begin by finalizing design concepts using decision matrix and detailed analysis will begin to select and justify different airplane configurations and characteristics.

3.2 Requirements:

General Requirements

This aircraft shall be capable of taking off and landing from runways (dirt, grass, metal mat, gravel, asphalt & concrete).

This aircraft shall be capable of taking off and landing from fresh and salt water.

This aircraft shall have a minimum cruise speed of 200 knots.

This aircraft shall be capable of VFR and IFR flight.

This aircraft shall be capable of flight in known icy conditions.

This aircraft shall meet applicable certification rules in FAA 14 CFR Part 23. All missions below assume reserves and equipment required to meet applicable FARs.

This aircraft shall have a mission energy cost per passenger at least 20% better than an existing aircraft on a similar mission length.

Design Passenger Missions

This aircraft shall have the capacity to carry 19 passengers and 1 flight crew (pilot, co-pilot, and flight attendant).

This aircraft shall have a 28” or greater seat pitch per passenger.

This aircraft shall be able to accommodate a body weight of 193.6 lb. (88 kg) per passenger, as well as a baggage weight of 37.4 lb. (17 kg) per passenger.

This aircraft shall be able to accommodate adequate luggage space at a volume of at least at least 4 cubic feet (0.113 m^3) per passenger.

STOL Mission

This aircraft shall be able to perform a 250 Nmi Short Takeoff and landing (STOL) runway mission with 19 passengers and 1 flight crew.

This aircraft shall be able to take off and land given a maximum runway length of 1500’ on dry pavement and clear a 50’ high obstacle (ISA + $18°\text{F}$ day).

This aircraft shall be able to show takeoff and landing performance at 5,000’ above mean sea level (ISA + $18°\text{F}$ day).

This aircraft shall be able to reliably perform takeoff and landing from dirt, grass, metal mat, gravel, asphalt & concrete fields at sea level (ISA + $18°\text{F}$ day).

This aircraft shall have the ability to take off and land in Sea State 3 conditions.

Design Cargo Mission

This aircraft shall be able to support a 5000 lb. (about 2267.96 kg). (2,268 kg) cargo payload.

This aircraft shall be able fly a range of 200 Nmi.

This aircraft shall be unloaded, refueled (or re-energized) and re-loaded with cargo in no more than 60 minutes.

Economic Mission

This aircraft shall support missions optimized for minimum energy cost. Minimum cruise speed of 200 knots.

Miscellaneous Design requirements

This aircraft shall be visually appealing to guarantee marketability.

3.3 Flow Charts:

Flow Chart Diagram

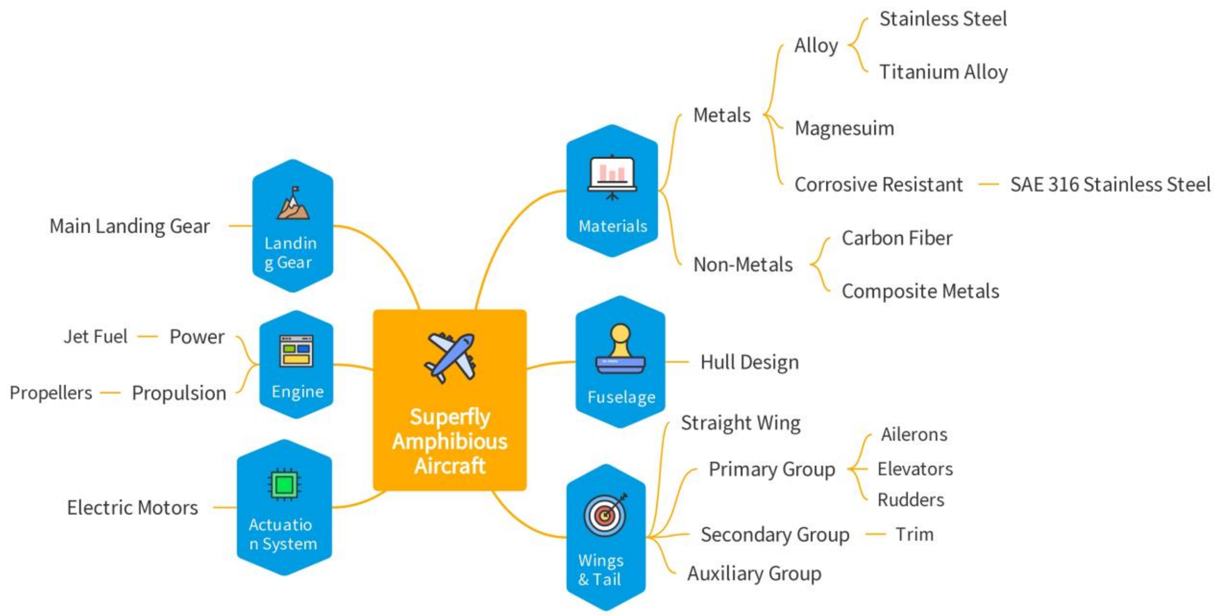


Figure 6 Flow Chart Diagram

The flow depicts the design considerations that would be implemented on the Superfly aircraft to meet mission requirements and safety standards. Although these are not all the required functions, the flow chart provides an overhead view of what should be implemented. These are not limiting factors.

3.5 Project Management and responsibilities:

The progress of each team member was tracked utilizing a gantt chart for over tasks. A more detailed task list was created and maintained to show the actual work completed by team members.

To maintain progress and meet required deadlines, tasks were delegated to define performance capabilities and operational limits of proposed aircraft design. The preliminary tasks included initial sizing calculations and pertinent analysis studies to support early design choices such as engine selection and primary body material. Economic analysis will also be performed to decide between optimal alternatives. The schedule was maintained utilizing the Gantt chart which implemented a tracking system of weekly progress and kept a record of the statuses of tasks.

3.6 Schedule:

The Gantt chart will be utilized so that the project manager can track overall progress. A more detailed schedule will be utilized by team members to track specific tasks contributing to the overall goal. A detailed schedule of specific tasks is kept in appendix E.

3.7 Budget:

This design will be built using software with a potential for a physical downscaled prototype. 3D printing materials from Kennesaw State University cost vary with material.

Table 1. Prototyping Materials Cost

Table 2 Prototyping Materials Cost

Materials	$ per Gram (g)
PLA	$.25
PETG	$.30
TPU	$.40
TPE	$.40
Nylon Carbon Fiber	$.50
Carbon Fiber PLA	$.40
Wax	$.70
HIPS	$.25
PVA	$.80

KSU offers 3D printing services for select materials. 3D printing will be used for display models of our amphibian. CAD models will be developed first to perfect dimensions and accuracy. The CAD model will be used to complete the 3D printed prototype.

Table 3. Average Wrap Rates

Average hourly rate	$/hour (2012)
Tooling	115
Engineering	118
Quality Control	108
Manufacturing	98

3.7 Development Cost:

Table 4. Average Wrap Rates

Average hourly rate	$/hour (2012)
Tooling	$115
Engineering	$118
Quality Control	$108

Manufacturing	$98

3.7.1 Development and Procurement Costs of Aircraft Variables

The values provided for each category in Table 2 ($115 for engineering, $118 for tooling, $108 for quality control, and $98 for manufacturing) represent the labor cost per hour for each category. The average wrap rate represents the total labor cost (including wages or salaries, benefits, taxes, and overhead expenses) per hour worked across all four categories. The specific average wrap rate would depend on the total cost of labor and the total number of hours worked for each category.

The quantity of the number of aircraft produced is 100—historical values to quantify the initial batch of aircraft production. The Canadair CL-215 was referenced for this value.

The Average wrap rates are used to help find the RDT&E + flyaway, but I first had to update them to 2023 because the inflation rate was for 2012.

The Rand Corporation publishes the DAPCA IV (Development and Procurement Costs of Aircraft) model. DAPCA estimates the various costs for all departments, including engineering, tooling, manufacturing, and quality control groups. Development support, flight test, and manufacturing material costs

The process involves using historical values for different amphibious aircraft like the Canadair CL-215 and Piaggio P.136 and choosing a production quantity of 100 aircraft to match the other aircraft. The cost of labor associated with various departments like engineering, tooling, manufacturing, and quality control is estimated using average wrap rates of $115 for engineering, $118 for tooling, $108 for quality control, and $98 for manufacturing. These rates are updated to 2023 to account for inflation.

Next, equations are used to estimate the engineering hours, tooling hours, manufacturing hours, and QC hours required to produce the aircraft. Additionally, costs for development support, flight testing, manufacturing materials, engine production, and avionics are estimated using equations specific to each cost category. Finally, the RDT&E + flyaway cost is calculated by multiplying the total hours and costs with their respective average wrap rates and adding them up. The total RDT&E + flyaway cost for 100 aircraft is estimated at $2.29876E+16 in 2023 dollars and $560619947.5 for one aircraft.

Unit (fps)

We= empty weight [(lb.) or {kg}] = 34387.50582 lb.

V = maximum velocity [(kt) or{km/h}] = 250 kt

Q = lesser of production quantity or number to be produced in five years = 100

FTA = number of flight-test aircraft = 4

Neng = total production quantity times number of engines per aircraft =200

Tmax = engine maximum thrust [(lb.) or {kN}] = 6609.38611 lb.

Mmax = engine maximum Mach number= 0.38820136

Tturbine inlet = turbine inlet temperature [(°R) or {K}] = 2075.67°R

C- avionics = avionics cost = 10,090,000$

R_e=115$

R_t=118$

R_m=98$

R_q=108$

Development and Procurement Costs of Aircraft Equations

Engineering hours = $H_e = 4.86 * (34387.50582^{0.777}) * (250^{0.894}) * (100^{0.163})$= 4799300.716

Tooling hours = H_t =$5.99 * (34387.50582^{0.777}) * (250^{0.696}) * (100^{0.263})$ =3141784.512

Mfg hours =H_m = $7.37 * (34387.50582^{0.82}) * (250^{0.484}) * (100^{0.641})$ = 10713194.93

QC hours = H_q= 0.133

Devel support cost =C_d = $91.3 * (34387.50582^{0.63}) * (250^{1.3})$ = 86243270.08$

Flt test cost = C_f = $2498 * (34387.50582^{0.325}) * (250^{0.822}) * (4^{1.21})$ = 37283951.18$

Mfg materials cost = C_m = $22.1 * (34387.50582^{0.921}) * (250^{0.621}) * (100^{0.799})$ = 406947179.2$

Engine production cost =C_{eng}= 3112*(0.043* 6609.38611 +243.25* 0.38820136 +0.969*5892.5 -2228) = 504012.7158$

RDT&E + flyaway (2012) = (H_e*R_e) +(H_t*R_t) +(H_m*R_m) +(H_q*R_q)+ C_d +C_f +C_m +(C_{eng}*N_{eng}) + $C_{avionics}$= 2613910214$

RDT&E + flyaway (2023) =3436379885.16 $

But for one out of the hundred the cost is 34 million$

<u>For one aircraft</u>

RDT&E + flyaway (2012) = (H_e*R_e) +(H_t*R_t) +(H_m*R_m) +(H_q*R_q)+ C_d +C_f +C_m +(C_{eng}*N_{eng}) + $C_{avionics}$= 570704055$

RDT&E + flyaway (2023) = 750276702.11 $

Three crew cost (2012) =608.138 cost per block hour

Three crew cost (2023) =799.49 cost per block hour

Similar aircrafts

The CL-415EAF and Bombardier 415 are both twin-engine amphibious planes designed for firefighting operations. The CL-415EAF is an upgraded variant of the Bombardier 415, with new avionics, engines, and other improvements that enhance its performance and efficiency. It has a range of 2,000 km and a top speed of 359 km/h, with a price of approximately $30 million. The Bombardier 415 is the original model, with a larger water capacity of up to 6,137 liters and a longer range of up to 2,460 km. It has a list price of around $37 million.

Direct operating cost per airplane flight hour include:

44% is the aircraft operating expense.

29% is the servicing expense.

14% is the reservations and sales expense.

13% is the overhead expense.

The total operating costs of a major airline in the US can be divided into four major expense categories: aircraft operating expenses, servicing expenses, reservations and sales expenses, and overhead costs. Understanding these expenses is essential for analyzing the financial health of the airline industry.

Aircraft operating expenses are the largest category, accounting for 44% of total operating costs. This includes expenses related to fuel, maintenance and repairs, aircraft leases, and insurance. These expenses are directly related to the airline's fleet and the number of flights it operates.

The second largest expense category is servicing expenses, which account for 29% of total operating costs. These expenses include salaries and benefits for ground crew, baggage handling, cleaning, and catering services. These expenses are related to the airline's ground operations and depend on the airline's number of passengers and flights.

Reservations and sales expenses make up 14% of total operating costs. These expenses include operating reservation systems, marketing and advertising, and commissions paid to travel agents. These expenses are primarily fixed prices and do not vary significantly with changes in the number of passengers or flights.

Table 5. Operating Cost in 2017

Aircraft Operating Costs	Per Block Hour	2550
Aircraft Servicing Costs	Per Aircraft Departure	800
Traffic Servicing Costs	Per Enplaned Passenger	15
Passenger Servicing Costs	Per RPM	0.015
Reservation and Sales Costs	% of Total Revenue	average 14%
Other Indirect and System Overhead Costs	% of Total Operating Expense	(Average 13%)

Table 6. Operating Cost in 2023 (accounted for inflation)

Aircraft Operating Costs	Per Block Hour	3712.14
Aircraft Servicing Costs	Per Aircraft Departure	1164.59
Traffic Servicing Costs	Per Enplaned Passenger	21.84
Passenger Servicing Costs	Per RPM	0.01
Reservation and Sales Costs	% of Total Revenue (average 14%)	747.5233
Other Indirect and System Overhead Costs	% of Total Operating Expense (average 13%)	636.8154

The cost for making only one aircraft is 737 million, but the cost for making one aircraft out of one hundred is 34 million. For the Bombardier 415 the list price today is 37 million so the price for the aircraft being built will be 36,900,000. The net profit margin is 7.86%. The net profit: $2,900,000.00. The profit percentage: 8.53%.

According to the Wall Street Journal, the average "profit per passenger" of the seven largest U.S. airlines was $17.75 — for just a one-way flight — and the average profit margin across those seven airlines was 9% in 2017.)

T = Aircraft Operating Costs + Aircraft Servicing Costs + Traffic Servicing Costs + Passenger Servicing Costs.

T = (3712.14+ 1164.59 + 21.84 + 0.01) = 4898.58

For the Reservation and Sales Costs = (T+(0.09*T)) *0.14= 747.5233

For the Other Indirect and System Overhead Costs = (T*0.13) = 636.8154

3.8 Avionics Selection:

Table 7. Avionics comparison primary flight display

Name	Cost
Honeywell Primus Epic	$2 million
Garmin G5000	$3 million
Universal Avionics Insight	$1 million
Meggitt Avionics MAGIC 1A	$600,000

The average is 1.4 million. The one we are using is The Garmin G5000, also a modern and advanced system that offers a high-resolution display with intuitive controls. It includes synthetic vision, 3D audio, and automatic flight control system integration. The Garmin brand is also well-known and respected in the aviation industry.

Table 8. Navigation System comparison

Name	Cost
Honeywell Primus Epic	$2 million
Garmin GTN 750	$70,000
Universal Avionics UNS-1Fw	$200,000
Meggitt Avionics Magic 2100	$100,000

The average is 592,500. The one we are using is the Honeywell Primus Epic navigation system may be a good option due to its highly advanced features, including synthetic vision, enhanced situational awareness, and 3D maps, as well as its advanced GPS and inertial navigation systems for accurate position tracking. These features can benefit amphibious aircraft that may operate in various environments and conditions.

Table 8. Communication systems comparison

Name	Cost
Honeywell HF-1050	$150,000
Garmin GSR 56	$200,000
Universal Avionics UniLink UL-800/801 Communications Management Unit	$300,000
Meggitt Avionics BlueCore	$20,000

The average is 167,500. The one we are using is the Universal Avionics UniLink UL-800/801 CMU would be the best option for communication. This system offers a comprehensive solution that includes dual-channel VHF communications, satellite communications, and datalink messaging, which would be necessary for communication during a flight over long distances and water. Additionally, the system is designed to be reliable and can be integrated with other Universal Avionics systems for seamless operation.

Table 9. Flight Systems Comparison

Name	Cost
The Honeywell Primus Epic flight control system	$3 million
Garmin GFC 700	$80,000
Universal Avionics UNS-1Fw	$100,000
Meggitt Avionics MAGIC 2100	$80,000

The average is 815,000. We are using the Honeywell Primus Epic flight control system; however, all the methods listed have advanced automation features that can improve flight safety and efficiency. The Honeywell Primus Epic and Garmin GFC 700 are known for their user-friendly interfaces, while the Universal Avionics UNS-1Fw and Meggitt Avionics MAGIC 2100 offer flexibility in terms of customization and integration with other avionics systems. The best flight control system for a specific aircraft will depend on the aircraft's capabilities, the operator's needs, and the budget.

Table 10 Weather Radar Systems comparison

Name	Cost
Honeywell IntuVue RDR-4000	$250,000
Garmin GWX 80	$150,000
Universal Avionics TAWS+R	$200,000
Meggitt Avionics Magic 2100	$150,000

The average is 187,500. The one we are using is the Honeywell IntuVue RDR-4000 would be the best choice for a 19-passenger amphibious aircraft as it is a high-performance weather radar system that provides pilots with real-time weather information, including precipitation intensity, storm location, and turbulence detection. The IntuVue RDR-4000 is designed to be reliable and easy to use, and it can be integrated with other avionics systems to provide a comprehensive weather monitoring solution. The system uses advanced technology to detect and display weather information, providing pilots with the knowledge to make informed decisions about their flight path. Additionally, Honeywell is a well-known and reputable brand in the aviation industry, which adds to the reliability and trustworthiness of the product.

Table 11. Instrument Landing Systems comparison

Name	Cost
Honeywell SmartPath	$300,000
Garmin GCA-2000	$250,000
Rockwell Collins ILS-4000	$300,000
Thales ILS 420	$500,000

The average is 337,500. We are using the Honeywell SmartPath; however, the Honeywell SmartPath ILS and the Thales ILS 420 offer more advanced features, such as Autoland capability and enhanced weather monitoring, which may be particularly useful for amphibious aircraft. Some operators may prefer these systems over the Garmin GCA-2000 and Rockwell Collins ILS-4000, which are reliable and efficient systems but need more advanced features.

Table 12. Engine and Fuel Monitoring Systems comparison

Name	Cost
Honeywell FMS	$500,000
Universal Avionics UniLink UL-801/ UL-802	$250,000
Meggitt Avionics SFAR-88	$150,000
Garmin G3000	$750,000

The average is 412,500. We are using the Garmin G3000, a widely used and well-regarded system that includes advanced features such as automated fuel balancing and maintenance alerts, making it a popular choice for many modern aircraft. Its user-friendly interface and customizable displays also make it easy for pilots to access and interpret the real-time data provided by the system.

Table 13. Collision Avoidance Systems comparison

Name	Cost
Honeywell TCAS	$100,000
Garmin GTS	$80,000
Rockwell Collins TCAS II	$200,000
L3Harris TCAS 3000SP	$200,000

The average is 145,000. We use Honeywell TCAS, the most widely used and well-known collision avoidance system in the aviation industry. It has a proven track record of helping pilots avoid collisions. It also has a long history of successful integration with other avionics systems. However, Garmin GTS and L3Harris TCAS 3000SP also have advanced features such as ADS-B In integration and predictive avoidance guidance, which may be helpful for some operators. Rockwell Collins TCAS II is also a reliable option with features such as resolution advisories to help pilots avoid collisions. Ultimately, it is up to the operator to determine which collision avoidance system is best suited for their specific needs and budget.

Table 14. Inertial Navigation Systems comparison

Name	Cost
Honeywell Laseref VI	$300,000
Northrop Grumman LN-251	$200,000
Collins Aerospace INS-4000	$300,000
Safran Electronics & Defense Sigma 95	$350,000

The average is 287,500. We are using the Safran Electronics & Defense Sigma 95; the systems mentioned are reputable and widely used in the aviation industry.

Table 9 Cockpit Voice and Data Recorders comparison

Name	Cost
L3Harris Technologies CVR/FDR	$40,000
Universal Avionics CVR-120	$25,000
Honeywell Aerospace CVR/FDR	$40,000
L-3 Aviation Products FA2100 CVR	$25,000

The average is 32,500. The one we are using is the L3Harris Technologies CVR/FDR. The L3Harris Technologies CVR/FDR, Honeywell Aerospace CVR/FDR, and Universal Avionics CVR-120 are all combined cockpit voice and flight data recorder systems, which some operators may prefer for their convenience and efficiency in terms of space and weight savings. On the other hand, the L-3 Aviation Products FA2100 CVR is a dedicated cockpit voice recorder, which may be preferred by some operators who prioritize the quality and reliability of audio recording. The total $10,090,000 for avionics

3.9 Material Required/Used & Resources Available:

There is a wide variety of resources available to Kennesaw State University students which will help establish a solid foundation for the project's final product. The resources that will be used will include but are not limited to professors at Kennesaw State University, research journals for academic sources, online libraries, fabricated aircraft available for gathering flight data, and simulated flight modules that give accurate flight performance and piloting experience.

AutoCAD software will be used for modeling and computer aided design tasks. Software and hardware are available to aid in the development of this project. CFD analysis was performed using software such as SOLIWORKS, XFLR5, Matlab, and others in order to optimize airfoil topology and reduce unfavorable aerodynamic obstructions.

Table 10 Properties and Applications of Metal Matrix Composites in Aircraft

Table 11 .Properties and Applications of Metal Matrix Composites in Aircraft

Matrix Material	**Reinforcement Material**	**Properties**	**Application**	**References**
Titanium	SiC	-High-impact energy -Weight reduction (32%)	Landing gear	[3]
Aluminum	Cu-Nb	-Improved high-temperature strength	Engines	[3]
AL Alloy (LM25)	SiC	-Light-weight -Optimum performance -Reduces fuel costs	Aircraft wing	[3]
AL Alloy	SiC	-Low density -High elastic modulus -High thermal conductivity -Preventability of resonance vibration	Fuel tank (door part) and fans (F-16	[3]

			fighter aircraft)	
AL Alloy (AA6061)	Activated Carbon	-Good thermal resistance	Engines	[3]
Cu	NB3SN	-Creep resistance -Stiffness	Engines	[3]
Composites	Reinforced plastic	Lightweight, strong	airframe	

The most used metals for aircraft are aluminum-based, magnesium-based, and titanium-based composites. The structure of commercial aircraft is composed of 50% composite material and about 45% pure metal material such as Titanium, steel, and aluminum. Aluminum matrix composites are suited for harsh environments where reliability and safety are required, as they possess superior fatigue strength as compared to steel. Titanium matrix composites have excellent corrosive resistance and high strength at elevated temperatures and are widely used in aerospace, marine, and automotive industry. Magnesium based matrix composites are widely known for being less dense than aluminum providing lightweight structures in aircraft (3)

Chapter 4: Engineering Analysis

4.1 Main Equations:

1. Maximum takeoff weight (MTOW): $w_0 = \frac{w_c+w_p}{1-\frac{w_f}{w_0}-\frac{w_e}{w_0}}$
2. Empirical formula for refined sizing method: $\frac{W_e}{W_0} = \left[a + bW_0^{c1}AW_0^{c2}\left(\frac{HP}{W_0}\right)^{c3}\left(\frac{W_0}{S}\right)^{c4}V_{max}^{c5}\right]K_{vs}$
3. Specific fuel consumption for propeller aircraft: $C = \frac{C_{BHP}*V}{550*\eta}$
4. Power-to-weight to thrust-to-weight conversion: $\frac{T}{W} = \frac{550\eta}{V\frac{ft}{s}} \times \frac{HP}{W}$
5. Wing loading: $\frac{W}{S}$
6. Engineering hours: H_e= $4.86 * (\mathrm{We}^{0.777}) * (\mathrm{V}^{0.894}) * (\mathrm{Q}^{0.163})$
7. Tooling hours = H_t = 5.99*$(\mathrm{We}^{0.777}) * (\mathrm{V}^{0.696}) * (\mathrm{Q}^{0.263})$
8. Mfg hours = H_m= 7.37*$(\mathrm{We}^{0.82}) * (\mathrm{V}^{0.484}) * (\mathrm{Q}^{0.641})$
9. QC hours = H_q= 0.133
10. Devel support cost = C_d = 91.3*$(\mathrm{We}^{0.63}) * (\mathrm{V}^{1.3})$
11. Flt test cost =C_f = 2498*$(\mathrm{We}^{0.325}) * (\mathrm{V}^{0.822}) * (\mathrm{FTA}^{1.21})$
12. Mfg materials cost = C_m = 22.1* $(\mathrm{We}^{0.921}) * (\mathrm{V}^{0.621}) * (\mathrm{Q}^{0.799})$
13. Engine production cost =C_{eng}= 3112*(0.043* T_{max} +243.25* M_{max} +0.969*$T_{turbine\ inlet}$ -2228)
14. RDT&E + flyaway (2012) = $(H_e$*$R_e)$ +$(H_t$*$R_t)$ +$(H_m$*$R_m)$ +$(H_q$*$R_q)$+ C_d +C_f +C_m +$(C_{eng}$*$N_{eng})$ + C_{avionics}
15. RDT&E + flyaway (2023) = (RDT&E + flyaway (2012)) *(1+i) ^n
16. Design lift coefficient $C_L = L = \frac{1}{q} * \frac{W_0}{S}$
17. Stall speed: $\frac{W_0}{S} = \frac{1}{2}\rho V_{stall}^2 C_{L_{max}}$
18. Landing distance: $S_{Landing} = 80\left(\frac{W}{S}\right)\left(\frac{1}{\sigma C_L}\right) + S_a$
19. Takeoff Parameter: $\frac{W}{S} = (TOP)\sigma C_{L_{TO}}\left(\frac{HP}{w}\right)$
20. Climb Gradient: $G = \frac{V(climb\ rate)}{V(forward\ velocity}$
21. Bouyancy force: $F_b = \rho V g$

22. Service Ceiling: $\frac{(HP_{const} \cdot velocity \cdot HP)}{MTOW}$
23. Maximum Ceiling: $\frac{(HP_{const} \cdot velocity \cdot HP)}{MTOW}$

4.2 Initial Weight analysis:

4.2.1 Initial Sizing Calculation:

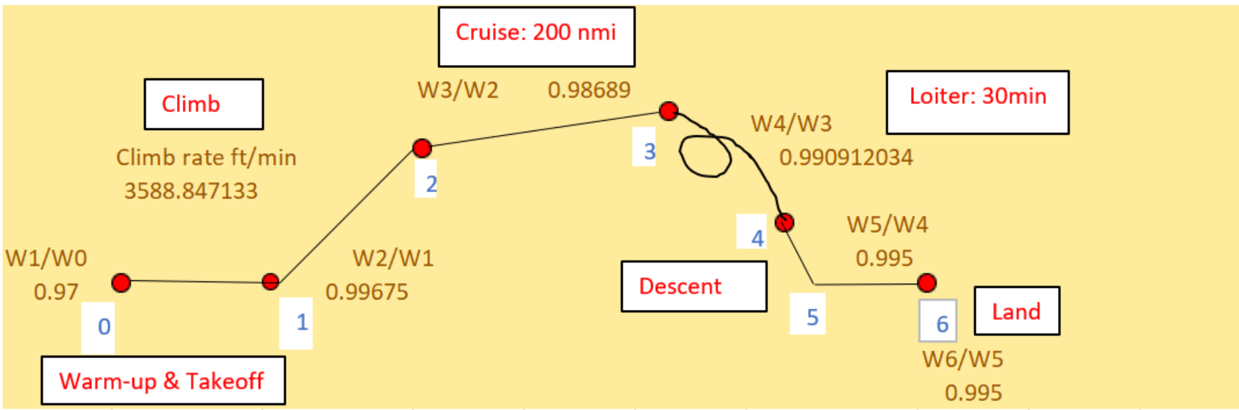


Figure 7 Mission Profile

The simple cruise mission profile will be used for typical missions for our aircraft. For safety, extra fuel would be carried to allow for 30 min of loiter time as the aircraft prepares to land. The FAA requires 30 min of extra fuel for daytime flights under VFR conditions and 45 min of additional fuel at night under IFR conditions.

Table 11 Historical mission segments weight fractions

Mission Segment		$\frac{W_i}{W_{i-1}}$	Reference
Warm-up and takeoff		.970	[5]
Climb	c	.985	[5]
Landing		.995	[5]

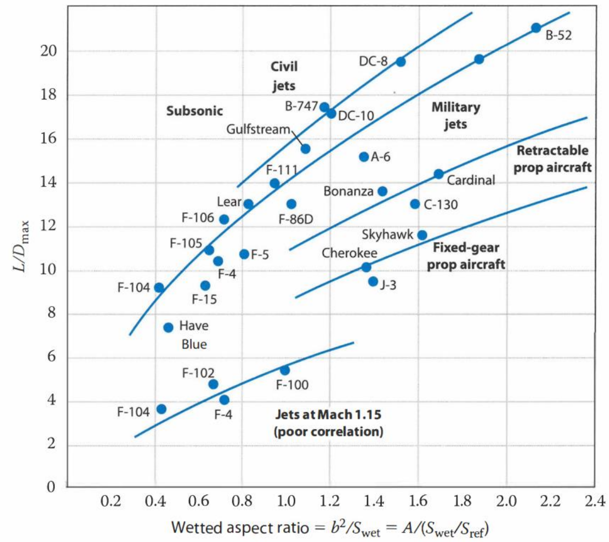


Table 12. Historical Maximum Lift-to-Drag Ratio Trends [5]

To determine the initial MTOW of the aircraft, it was necessary to estimate the $\frac{L}{D_{max}}$ to be used in the brequet equations. Therefore, the $\frac{L}{D_{max}}$ were selected from historical trends in figure 8 and used in the initial sizing calculation to determine the cruise and loiter weight fractions. The weight fractions for warm-up and takeoff, climb, and landing from table 16 were based off of historical data. Historical specific fuel consumption values for turboprop engines, and values from the mission requirements were used to calculate the initial sizing value.

- Commercial or Cargo plane
- Loiter = 30 min
- Range = 200 NM
- Cruise Speed = 200 knots
- Payload = 822.8 lbs. (baggage) + 5000 lb. (cargo)+ 4,259.2 lb. (• 22 people (2 pilots, 1 Flight attendant and 19 passengers) 193.6 lb./person)
- Cruise altitude: 30,000 ft

4.2.2 Mission Segment Weight Fractions Calculations:

1. Warmup & takeoff: $\frac{w_1}{w_0} = .970$
2. Climb: $\frac{w_2}{w_1} = .985$
3. Cruise: $\frac{w_3}{w_2} = e^{-\frac{RC}{V(\frac{L}{D})}} = .972$

$$V = 200\ knots = 337.6\frac{ft}{s}$$

$$\frac{L}{D_{max}} = 12$$

$$R = 200\ nm = 1{,}215{,}000\ ft$$

$$C = \frac{C_{BHP} * V}{550 * \eta} = \frac{.5 * 337.6}{550 * .8} = \frac{.38 \frac{lb}{hr}}{lb} = \frac{.00010656 \frac{lb}{s}}{lb}$$

4. Loiter: $\frac{w_4}{w_3} = e^{-\frac{EC}{\left(\frac{L}{D}\right)}} = .978$

$$E = 30\ min = 1800\ s$$

$$V = 337.6 \frac{ft}{s}$$

$$.866 * \frac{L}{D_{max}} = 10.392$$

$$C = \frac{C_{BHP} * V}{550 * \eta} = \frac{.6 * 337.6}{550 * .8} = \frac{.46 \frac{lb}{hr}}{lb} = \frac{.0001278 \frac{lb}{s}}{lb}$$

5. Landing: $\frac{w_5}{w_4} = .995$

- $\frac{w_1}{w_0} = .97$ $\frac{w_2}{w_1} = .985$ $\frac{w_3}{w_2} = e^{-\frac{RC}{V\left(\frac{L}{D}\right)}} = e^{-\frac{30381000 * .0001389}{596.9 * 16}} = .643$ $\frac{w_4}{w_3} = .9917$ $\frac{w_5}{w_4} = .995$
- $\frac{w_5}{w_0} = .97 * .985 * .972 * .978 * .995 = .9037$
- $\frac{w_f}{w_0} = 1.06\left(1 - \frac{w_5}{w_0}\right) = 1.06(1 - .9037) = .10205$
- $\frac{w_e}{w_0} = .642$
- $w_0 = \frac{10082}{1 - .10205 - .642} = 39{,}414\ lb$
- Initial Wing loading: $\frac{W}{S} = \frac{39414\ lb}{985\ ft^2} = 40 \frac{lb}{ft^2}$
- Initial power to weight value: .17 (based off the US-2 aircraft)

Table 12 Refined Sizing numerical results

Refined Sizing iterations													
W0(guess)	a	bW0^c1	A^c2	(HP/W0)^c3	(W0/S)^c4	Vmax^c5	Kvs	We/W0	We	Wcrew	Wpayload	Wf/W0	Wcalculated
20000	0	0.3804	1.231144	0.925497113	0.620993273	2.701651	1	0.727175	14543.5072	580.8	9501.2	0.067766	49166
30000	0	0.37886	1.231144	0.925497113	0.620993273	2.701651	1	0.724233	21726.98662	580.8	9501.2	0.067766	48470
40000	0	0.37777	1.231144	0.925497113	0.620993273	2.701651	1	0.722152	28886.09572	580.8	9501.2	0.067766	47990
41000	0	0.37768	1.231144	0.925497113	0.620993273	2.701651	1	0.721974	29600.93797	580.8	9501.2	0.067766	47950
42000	0	0.37759	1.231144	0.925497113	0.620993273	2.701651	1	0.7218	30315.60587	580.8	9501.2	0.067766	47910
43000	0	0.3775	1.231144	0.925497113	0.620993273	2.701651	1	0.72163	31030.10361	580.8	9501.2	0.067766	47871
47702	0	0.37711	1.231144	0.925497113	0.620993273	2.701651	1	0.720882	34387.50582	580.8	9501.2	0.067766	47702

Table 13. Refined Sizing numerical results

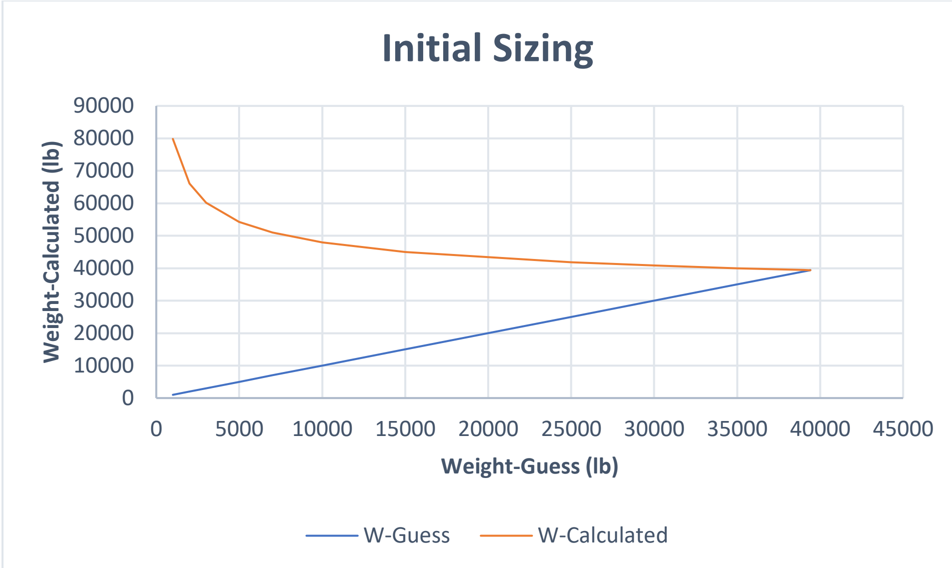


Table 14. Initial Sizing Iteration Graphical Results

The initial weight was calculated using the initial sizing method and corresponding brequet equations. Once the empty weight fraction was determined, the final MTOW was iterated until the guess weight and calculated weight converged. The calculated weight was determined using equation 1. Initially the MTOW size for this amphibian iterated to 39,414 lbs. Wing loading and power to weight ratio was initially selected using historical values for seaplanes and other aircraft that perform similar tasks. Subsequently, a refined sizing was completed to account for the actual wing planform, and power-to-weight ratio from the selected engines to narrow down on the actual takeoff weight value.

4.3 Refined Sizing:

At this stage, the engine has been selected, and the wing planform has been calculated. A low wing loading, and power-to-weight ratio contributes directly to the takeoff and landing performance which will be described in subsequent sections. The below power-to-weight values and wing loading were obtained by using the engine's power output and wing planform data. Using equation 2, the empty weight fraction was calculated and the new MTOW value was obtained after the guess weight and calculated weight were equal. The new power-to-weight and wing loading was then calculated. These new values were input back into equation 2 and the next aircraft sizing iteration process began. This iterative process was done until the input power-to-weight and wing loading matched the output power-to-weight and wing loading. Below are the final values for the aircraft's power-to-weight and wing loading.

Power to weight: $\frac{P\ (hp)}{W\ (lb)} = .21\,\frac{hp}{lb}$

Refined thrust-to-weight ratio: $\frac{T}{W} = \frac{550\eta}{V\,\frac{ft}{s}} \times \frac{HP}{W} = \frac{550(.75)}{421.9} \times .21\,\frac{hp}{lb} = .207$

Refined Wing loading: $\frac{W}{S} = \frac{47702\ lb}{882\ ft^2} = 54\,\frac{lb}{ft^2}$

New wing reference area: 882 ft^2

4.3.1 Refined Sizing Calculation:

1. Warmup & takeoff: $\frac{w_1}{w_0} = .970$
2. Climb and accelerate: $\frac{w_2}{w_1} = 1.0065 - 0.0325 * M^2 = .99675$
3. Cruise: $\frac{w_3}{w_2} = e^{-\frac{RC_{BHP}}{550\eta\left(\frac{L}{D}\right)}} = e^{-\frac{1215000*.000139}{550*.75*(20)}} = .98689$

   New L/D value obtained from drag polar: $\frac{L}{D_{max}} = 31$
4. Loiter: $\frac{w_4}{w_3} = e^{-\frac{RVC_{BHP}}{550\eta\left(\frac{L}{D}\right)}} = e^{-\frac{1800*337.6*.000167}{550*.75*(17.32)}} = .9909$

   $.866 * \frac{L}{D_{max}} = 17.32$
5. Decent for Landing: $\frac{w_5}{w_4} = .995$
6. Landing and Taxi Back: $\frac{w_6}{w_5} = .995$

$$\frac{w_6}{w_0} = .97 * .986 * .980 * .977 * .995 * .995 = .925$$

$$\frac{w_f}{w_0} = 1.06\left(1 - \frac{w_6}{w_0}\right) = 1.06(1 - .936) = .067$$

$$\frac{W_e}{W_0} = \left[a + bW_0^{c1}AW_0^{c2}\left(\frac{HP}{W_0}\right)^{c3}\left(\frac{W_0}{S}\right)^{c4}V_{max}^{c5}\right]K_{vs}$$

$$\frac{w_e}{w_0} = .721$$

Table 15. Refined Sizing Chart

To refine the initial sizing of the aircraft, the new max lift-to-drag ratio obtained from the drag polar of the aircraft wing was used in the brequet equations for cruise and loiter. A more refined method was used to calculate the specific fuel consumption during each flight mission segment. The wing loading and power to weight were used in the empirical formula in equation 2. for iterating the final MTOW value.

Refined MTOW: $w_{0_{refined}} = \frac{10082}{1-.067-.721} = \mathbf{47,702\ lb}$

4.4 Aerodynamic Analysis:

4.4.1 Airfoil Selection:

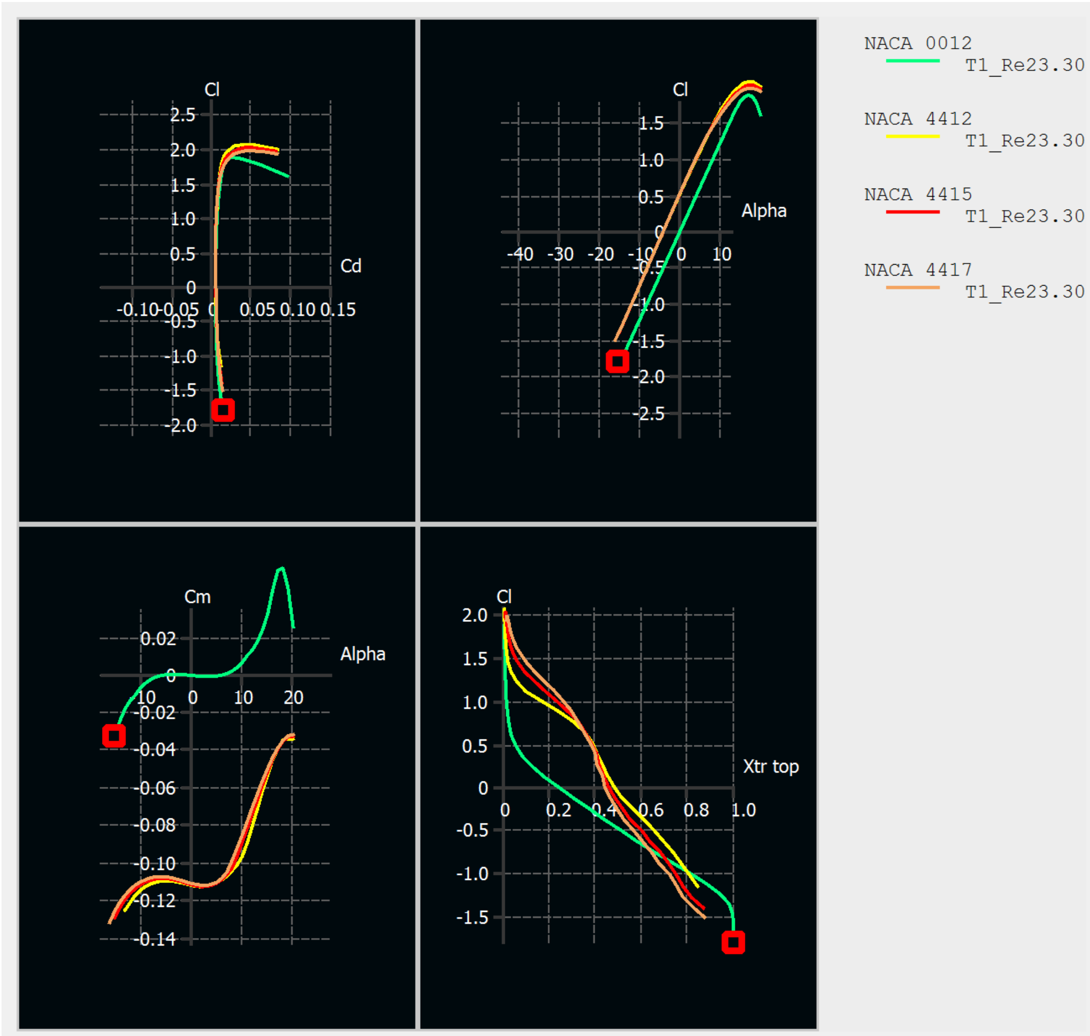


Figure 8 Airfoil comparison Data

NACA airfoils are amongst the common candidates for airfoil selections. According to historical trends, thicker cambered airfoils (12%-17% maximum thickness) benefit from a higher coefficient of lift (20). However, they do so at the cost of speed and a possible shorter stall angle. In figure 11, NACA airfoils were tested around the Reynolds number of the flight regime ($Re = 23.3 \times 10^7$). Otherwise, the airfoil data would be inaccurate and cannot be compared. The NACA 4417, 4415 and 4412 show similar characteristics for stall angle, lift coefficient and moment coefficient. The major difference is their maximum percentage chords. Thinner chords are better for faster speeds, and thicker chords are better for higher lift capability.

Although the thicker chord benefits lift, it trades off with speed. With this analysis considered the airfoils were selected. For the root airfoil, the NACA 4415 will be utilized. For the tip airfoil, the NACA 4412 will be utilized due to its reduction in percent chord which in theory should decrease the weight of the aircraft and allow it to fly a bit faster. The NACA 0012 airfoil is a symmetric airfoil and shows better stability due to its symmetry. Therefore, the 0012 airfoil will be used for the tail. The airfoil data for the selected airfoils can be found in the appendix D.

4.5 Wing and Tail Design:

Table 13 Wing & Tail Planform and Aerodynamic data

Wing Planform and geometry		
Wing Characteristics		reference
S (reference Area) ft^2	882	
B(wing Span) ft	84	20
A(Aspect ratio)	8.00	Table 4.1 (20)
CLmax	1.891242	
Clmin	-0.8566691	
Lift curve Slope	6.583228775	
t/c (airfoil thickness ratio)	15%	
Re(Reynolds number)	23338774.76	
lamda(Taper ratio)	0.5	fig 4.24 (20)
Dihedral	0	table 4.2(20)
Wing loading	53	table 5.5(20)
Wing Sweep	0	20
Wing tips	no winglet	20
Chord		
C_Root(root chord)	14	20
C_Tip(tip chord)	7	20
C_bar(mean aerodynamic chord)	10.88888889	20
Tail planform and geometry		
Incidence angle	3 degrees	20
Tail arrangement	T-tail	20
Horizontal tail placement	behind vertical tail	20
Horizontal tail aspect ratio	4	Table 4.3(20)
Horizontal tail sweep	5	20
Horizontal tail area (ft^2)	163.5685704	table 6.4(20)
Horizontal tail span (ft)	25	
horizontal tail taper ratio	1	Table 4.3(20)
Vertical tail aspect ratio	1.2	Table 4.3(20)
Vertical tail taper ratio	1	Table 4.3(20)
Vertical tail sweep	20 degrees	20
Vertical tail span (ft)	25	
Vertical tail area (ft^2)	234.612	table 6.4(20)

Table 16 gives calculated values for different characteristics of the wing and tail sizing. The maximum speed required is 250 knots (Mach .374) therefore wing and tail planform can be optimized for subsonic speeds. High aspect ratio is preferable for STOL applications. A high aspect ratio rectangular tapered wing was selected to achieve high lift and get lift distribution close to that of an elliptical wing. This is a more efficient wing design. This will optimize the best practical wing design for the given constraints with considerations to weight and performance. The wing area was driven by the aspect ratio and wing loading. In addition, a low wing Loading (large wing area) is desired for short takeoff applications.

This aircraft will have a high wing and T-tail configuration which benefits several things. Debris hitting the aircraft's wing or engine upon landing and takeoff can be prevented. Loading and unloading cargo and passengers is easier and expensive equipment is not required. Lastly, the propwash from the propellers does not interfere with the air flow over the tail. The aerodynamic analysis done on this configuration contributed to the refined sizing, performance calculations and load factors.

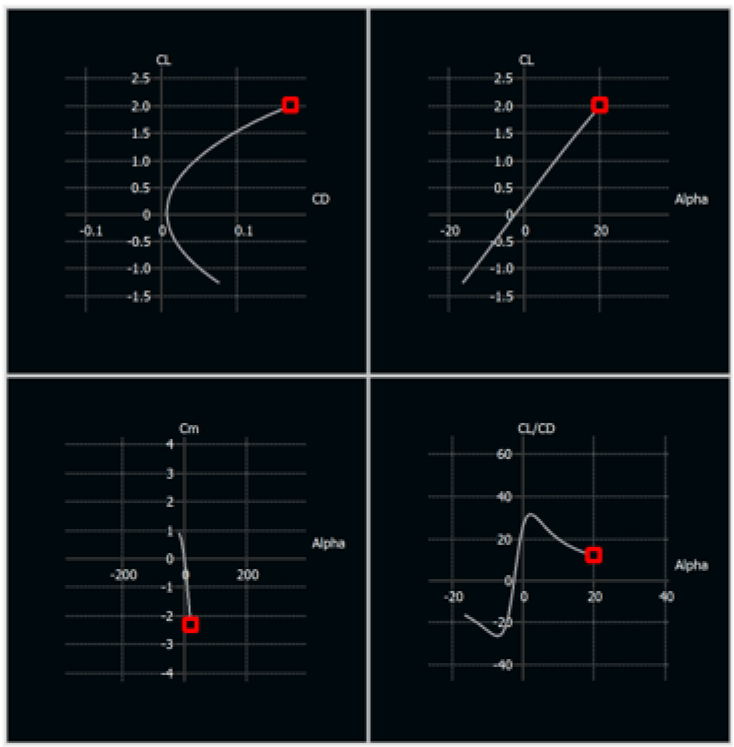


Figure 9 Wing and tail configuration analysis

Figure 12 shows an aerodynamic analysis of the wing and tail configuration, T-tail configuration. The planform details for this configuration can be seen in table 4. This configuration shows a high aspect ratio wing. The drag polar data suggests that this configuration has high lift capability which benefits the aircraft design. The high tail would give more ground clearance to make loading cargo and passengers much simpler. The new lift-to drag ratio was obtained from the drag polar and was used to refine the sizing of the aircraft. Aerodynamic characteristics and values can be found in table 16.

The design lift coefficient is determined by the equation below. It is recommended for the aircraft to be designed to fly at or around this lift coefficient to maximize efficiency. However, during cruise the aircraft's coefficient of lift will be .67. The drag at zero lift (C_{D_0}) was also obtained from aerodynamic data of the wing and was used in various stages of the design process such as performance and propulsion. This value was determined to be about .0073.

$$C_L = L = \frac{1}{q} * \frac{W_0}{S} = \frac{1}{.5 * 337.6^2 * .00089} * \frac{47{,}702}{882} = 1.06$$

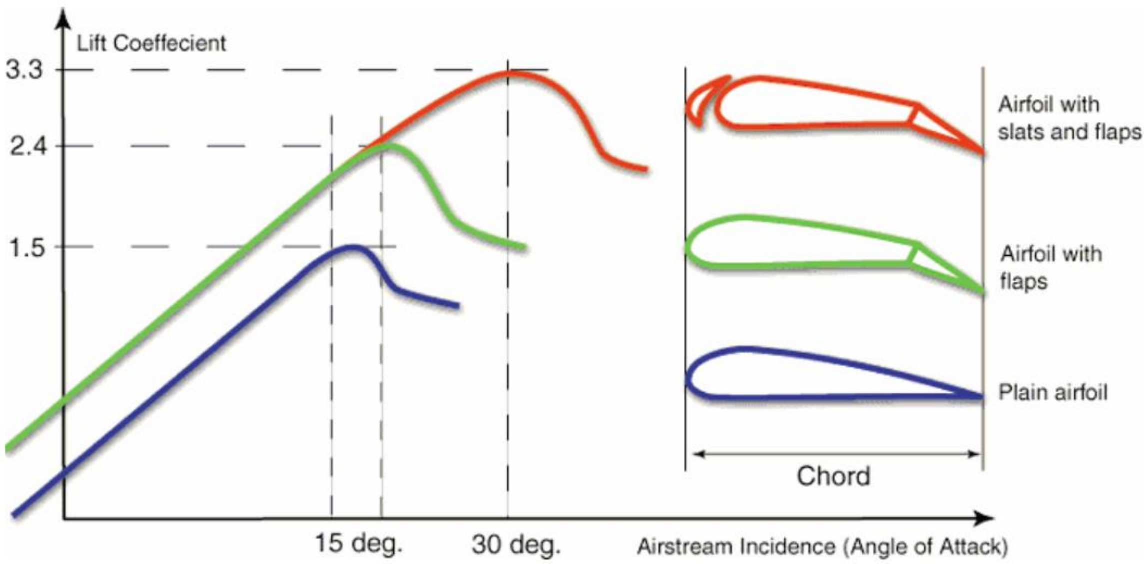


Figure 10 The effect of Slats and Flaps on the Lift Coefficient

Slats and flaps will be utilized to enhance lift performance of the wing. In figure, the diagram shows the difference in the effects between using slats and flaps versus only using the plain airfoil. The effectiveness of these devices clearly enhances the performance of the wing. This would benefit the STOL requirement could also serve as control surfaces for the aircraft. Control surfaces such as ailerons, horizontal & vertical stabilizers, inboard flap.

4.6 Buoyancy analysis:

4.6.1 Buoyancy Force Calculation

The buoyancy force acting on the hull of the aircraft is equal to the weight of the water displaced by the seaplane's hull. To calculate the buoyancy force on the hull, the volume of water displaced by the hull is multiplied by the density of the water. The buoyancy force acting on the seaplane must be equal to or greater than the weight of the aircraft- and passengers- for the seaplane to remain afloat. The main equation to be used for this calculation is $F_b = \rho V g$

4.6.2 Volume Displacement Calculation

Using CAD modeling software to perform a piecewise analysis of the submerged surface area, the total submerged area of the hull was determined to be 135.94 m^2. Multiplying this value by the expected height of the submerged area gives the volume of water displaced by the aircraft. The aircraft is expected to submerge up to a depth of 1 meter, making the total volume of water displaced 135.94 m^3.

4.7 Fight Envelope:

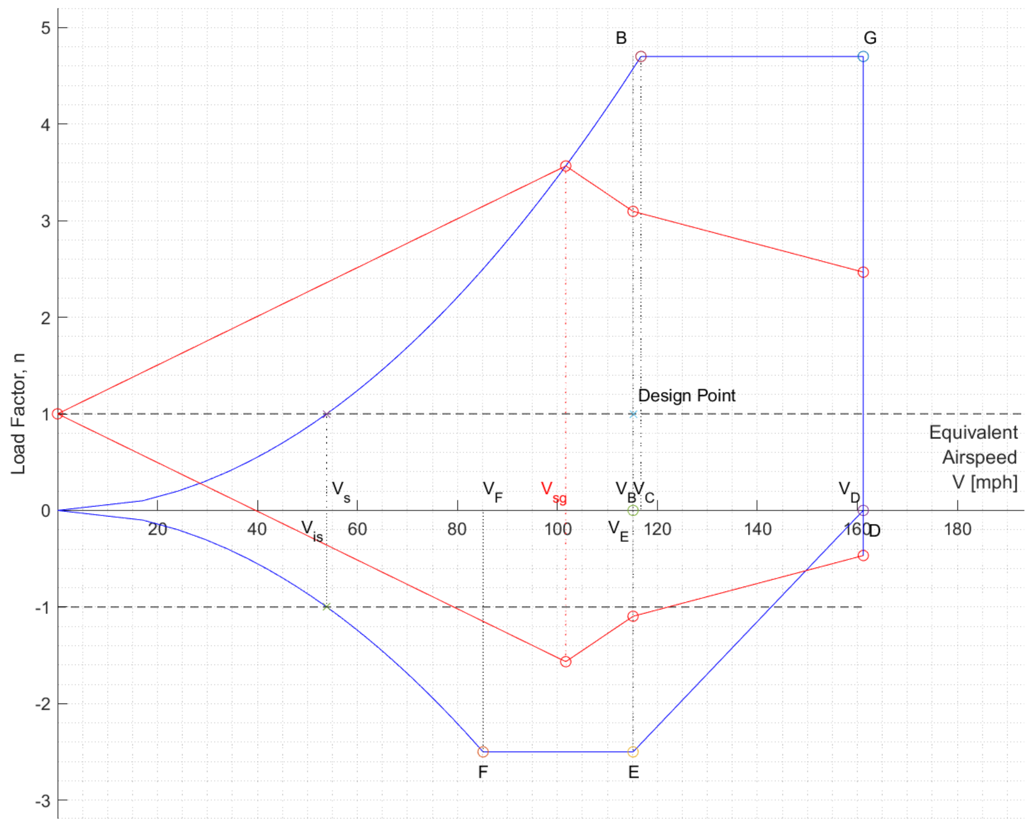


Figure 11 Design VN-Diagram

The figure above defines the flight maneuver limits the aircraft must fly within to maintain structural integrity and safe flight without stalling or inflicting structural damage on the aircraft. This diagram also takes into consideration the gusts loads which could impact flight mechanics suddenly. The maximum and minimum load factors were calculated using the aircraft's maximum and minimum lift coefficients specified in table 4. The stall and inverted stall speeds are specified in this diagram but also depended on the lift coefficients.

Chapter 5: Propulsion

5.1 Propulsion system description:

Preliminary Engine Selection

STOL aircraft perform better with turboprop engines at subsonic speeds. Most successful seaplane designs have low takeoff speeds to reduce landing impact accelerations and high bollard pull thrust, to overcome hydrodynamic resistance (1). Aircraft with similar mission capabilities such as the ShinMaywa US-2 aircraft, are used as a starting point to optimize the best power-to-weight ratio to satisfy performance requirements. The power-to-weight ratio based on the US-2 aircraft used for initial sizing is $.17\ \frac{Hp}{lb}$.

Table 14 Engine Selection Matrix

Engine Selections	Dry Weight	Max TakeOff Power(HP)	Max Cruise Pwer(HP)	Size (length / width / height)
Rolls Royce AE2100J (TP)	1670lb	4592	4592	9.84 ft / 2.72 ft / 4.4 ft
PW150A (TP)	1580lb	5070	5070	7.94ft / 2.59ft / 3.61 ft
PW127G (TP)	1050lb	2921	2921	6.99ft / 2.23ft
PW127D (TP)	1060lb	2750	2750	6.99ft / 2.23ft
TPE331-14GR (TP)	620lb	1649	1649	52.5in / 21n

Final Engine Selection

The PW150A aircraft engine is a turboprop engine developed by Pratt & Whitney Canada. It is known for its high reliability and efficiency, making it an optimal selection for seaplanes. Some of the key performance aspects of the PW150A engine include a power output of up to 5,000 shaft horsepower, high fuel efficiency (which reduces operating costs and environmental impact), a long life cycle permitting 10,000 hours between replacements, modular design that greatly reduces maintenance time, and strict noise and emissions standards which make it environmentally friendly. Overall, the PW150A engine is a high-performance, reliable, and efficient turboprop engine that is well-suited for amphibious aircraft.

Turboprop blade design considerations:

The optimal shape for the propellers of the turboprop is thin and hollow. Thin blades are ideal for low-speed travel and hollow blades will save on weight and improve efficiency of the engine. Thin material must also be strong enough to withstand torsional stress. A material which satisfies these requirements is titanium. The engine will need a power-to-weight ratio of about 5-7 due to the aircraft's mid-sized weight. Turboprops calculate their power to weight ratio using SHP.

Material:

Engine material is historically made of metal. Strong metals such as stainless steel and titanium are preferred due to its anticorrosive properties. Titanium is also a preferred metal to utilize in aircraft components due to its high strength at higher temperatures. Engines require a metal that also has high heat resistance and high cycle fatigue (HCF) strength so it will not deform under routine use. Weight conservation is also an integral factor in engine selection. Modern technologies have begun to incorporate composite materials into engine designs to save weight on small internal components that do not need to be made of metal. New manufacturing techniques allow for plastics to be reinforced to withstand higher tension loading and heat capacity. Aircraft such as the Bell v280 Valor utilize engines.

5.3 Engine Performance:

The selection of the engine was chosen with many aspects of the performance of the plane in mind. The selected engine is a Pratt & Whitney Canada PW150A. This choice was based on its power to weight to ratio, dimensions, and length. It has a prop RPM of 1020 and horsepower of 5070 for takeoff performance and cruise also. It has a weight of 1580 which is suitable for airplane in terms of wanting to keep our weight down and performance high.

Figure 12 PW150A Engine

5.4 Engine Sizing and Integration:

The dimensions of the Pratt & Whitney Canada PW150A are as follows; it has a length of 7.94ft, width of 2.59ft and height of 3.61ft. It has 4 compressor stages, 1 gas generator stage and 2 power turbine stages. For our integration of the engine to our aircraft, we chose a fixed engine as to rubber engines because the use of these engines has dominated the aircraft of the amphibious designs. Its performance and design give room for many applications and far exceeds our power requirements for the required missions of our plane. With such power, we only had to use two engines as compared to 4 engines that are used by an aircraft of similar fashion of economic requirement of 20 passengers i.e., US-2. With this engine chosen our configurations come to be as follows

- Thrust ((Max HP * 550) / Vmax) = $\frac{(10140 \cdot 550)}{421.9} = 13218.77222$lb
- Inlet Temperature of 2075 Rankine
- Uninstalled thrust (HP per engine / Propeller Eff * V_{tip}) = $\frac{5070}{0.79876748 \cdot 675.9927575} = 9.389566474 lbf$

- With typical losses of 10% from engine data, the installed thrust =

  $$9.389566474lbf * (1 - 0.1) = 8.4506098266lbf$$

From the engine data and the definitive propulsion data from “Aircraft Design, A Conceptual Approach” by Dan Raymer, the propeller details are as follows

$$D = K_p \sqrt[4]{\text{Power}}$$

	British Units	Metric Units
No. Blades	K_p	K_p
2	1.7	0.56
3	1.6	0.52
4+	1.5	0.49
Power units	hp	kW
Diameter units	ft	m

Figure 13 Historical Values for sizing (20)

Propeller Diameter = $1.5\ (5070)^{\frac{1}{4}} = 12.65736339$

According to research the larger the diameter, the more efficient it is. Therefore, we chose the larger diameter plus it meets the reduced noise at takeoff requirement of Vtip being under 700 fps

Propeller Airfoil: The selected airfoil HQ-2 airfoil has a thickness-to-chord ratio of 12.5% and a chamber of 2.7%. Its lift coefficient at maximum lift-to-drag ratio is around 1.5. This was selected based on the performance of our plane and its mission.

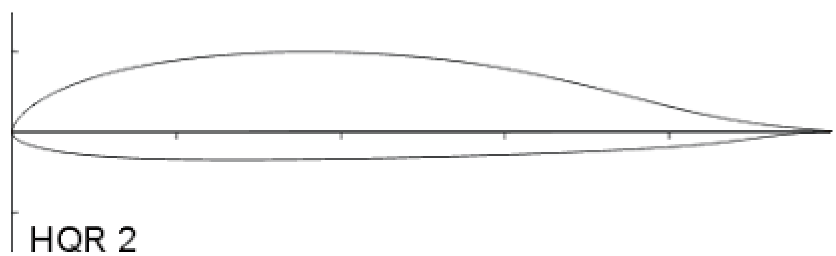


Figure 14 HQR 2 Airfoil illustration

Vtip(Static): Tip Speed of propeller as it moves through the air.

$$(V_{\text{tip}})_{\text{static}} = \pi n D \qquad \pi \cdot D \cdot n = 675.9927575 \frac{ft}{s}$$

N is rotational rate from the engine data. 1020 / 60 = 17

Vtip(Helical): Tip Speed for forward flight speed.

$$(V_{\text{tip}})_{\text{helical}} = \sqrt{V_{\text{tip}}^2 + V^2} \qquad \sqrt{675.9927575^2 + 337^2} = 755.3378106 \frac{ft}{s}$$

V^2 is the cruise velocity which is given in the requirement.

The number of blades chosen with configuration is a 5 bladed propeller.

The type of propeller to be used in this aircraft will be a constant speed propeller. Since the aircraft will have to adapt to different sea states and different weather conditions, a propeller that can be adjusted for changing conditions is better suited.

5.5 Fuel System:

The PW100/PW150 engine family is the benchmark for low fuel consumption on routes of 350 miles or less. That means they consume 25% to 40% less fuel and avoid an equal measure of CO_2 emissions than similar-sized regional jets.

BSFC from engine data = 0.433 lb./(hp·hr)

Based on the engine specifications and aircraft requirements, the power curve associated with the engine performance is as follows:

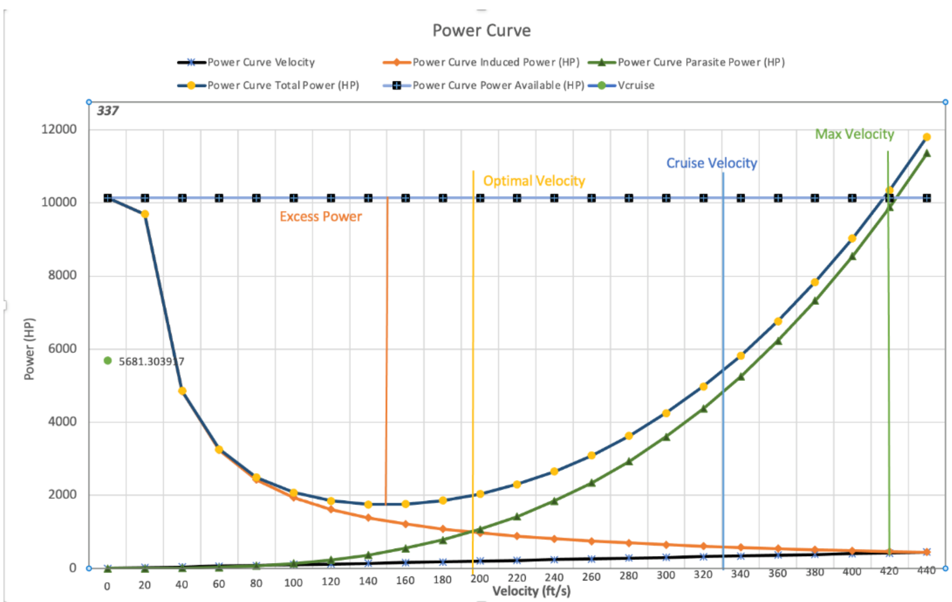


Figure 15 Graphical Power Curve results

Table 15 Power Curve numerical results

Power Curve				
Velocity	Induced Power (HP)	Parasite Power (HP)	Total Power (HP)	Power Available (HP)
0	10140	0	10140	10140
20	9691.490954	1.067316218	9692.55827	10140
40	4845.745477	8.538529745	4854.284007	10140

60	3230.496985	28.81753789	3259.314522	10140
80	2422.872738	68.30823796	2491.180976	10140
100	1938.298191	133.4145273	2071.712718	10140
120	1615.248492	230.5403031	1845.788795	10140
140	1384.498708	366.0894628	1750.588171	10140
160	1211.436369	546.4659037	1757.902273	10140
180	1076.832328	778.0735231	1854.905851	10140
200	969.1490954	1067.316218	2036.465314	10140
220	881.0446322	1420.597886	2301.642519	10140
240	807.6242461	1844.322425	2651.946671	10140
260	745.4993041	2344.893731	3090.393035	10140
280	692.2493538	2928.715703	3620.965057	10140
300	646.0993969	3602.192236	4248.291633	10140
320	605.7181846	4371.72723	4977.445414	10140
340	570.0877032	5243.72458	5813.812283	10140
360	538.4161641	6224.588184	6763.004349	10140
380	510.0784713	7320.721941	7830.800412	10140
400	484.5745477	8538.529745	9023.104293	10140
420	461.4995692	9884.415497	10345.91507	10140
440	440.5223161	11364.78309	11805.30541	10140

Table 18. Power Curve numerical results

The power curve above is result of the velocity versus power curve. This is by calculating the induced power required for the aircraft to maintain lift, and the parasite power, the power required to overcome body drag. With the summation of these two, the total power can be attained with an increasing velocity until the curve surpasses the power available line. By this curve, performance of the aircraft due to engine can be analyzed.

The excess power at cruise speed is power available – total power at the cruise speed of 337 ft/s

Which is $P_{available}$– P_{req} = $10140 - 5681.303917 = 4458.696083$

From the engine data the fuel type is PW150: Kerosene Jet A, A-1/JP8; Wide Cut Jet B/JP4; High Flash JP5/JP1.

Chapter 6: Layout

6.1 Fuselage Sizing:

The optimum fineness ratio should be 3 for minimum drag in theory however, it can be 6 to 8 for subsonic aircraft (20). An equivalent diameter is calculated based off the cross-section since the fuselage will not be a regular circular geometry due to the need for ahull installation for amphibious missions. Using an empirical formula based off historical data, the fuselage cross section's max diameter is 13 ft.

$$Length = aW_0^c = 1.05 * 47702^{.4} = 78.1\ ft$$

$$\frac{L}{D} = \frac{78.1\ ft}{13\ ft} = 6$$

6.2 Hull Design:

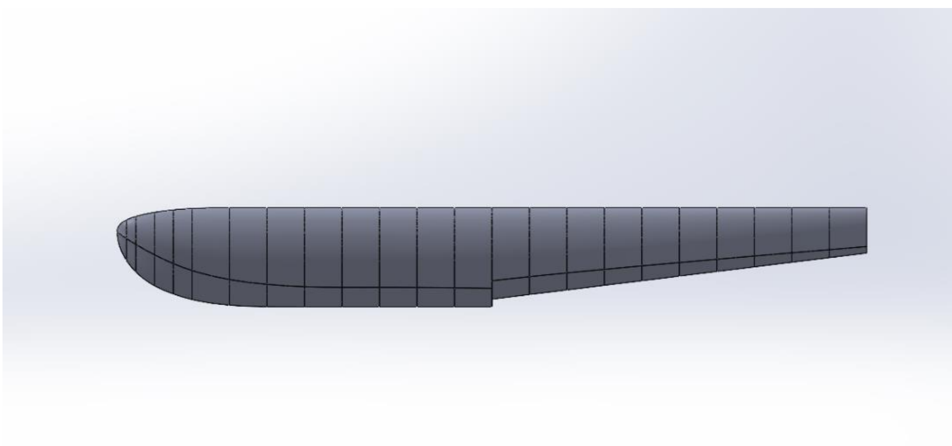


Figure 16 NACA 57-A Hull

The seaplane's hull design is critical in its performance and safety during amphibious operations. The hull is the part of the seaplane that contacts the water during takeoff and landing and is designed to provide stability, buoyancy, and hydrodynamic efficiency. To easily break the surface tension on the bottom of the seaplane upon liftoff, a substantial portion of the hull is shaved behind the bow. This ensures that the water will not maintain a strong grip on the plane as it attempts to takeoff, which would prevent the aircraft from detaching from the water. The seaplane's hull design also includes a wide base, which helps to stabilize the aircraft during water operations and reduce the risk of capsizing. Additionally, the hull includes landing gear which provides support during takeoff and landing on land and can be retracted when operating on water.

6.3 Superfly Model:

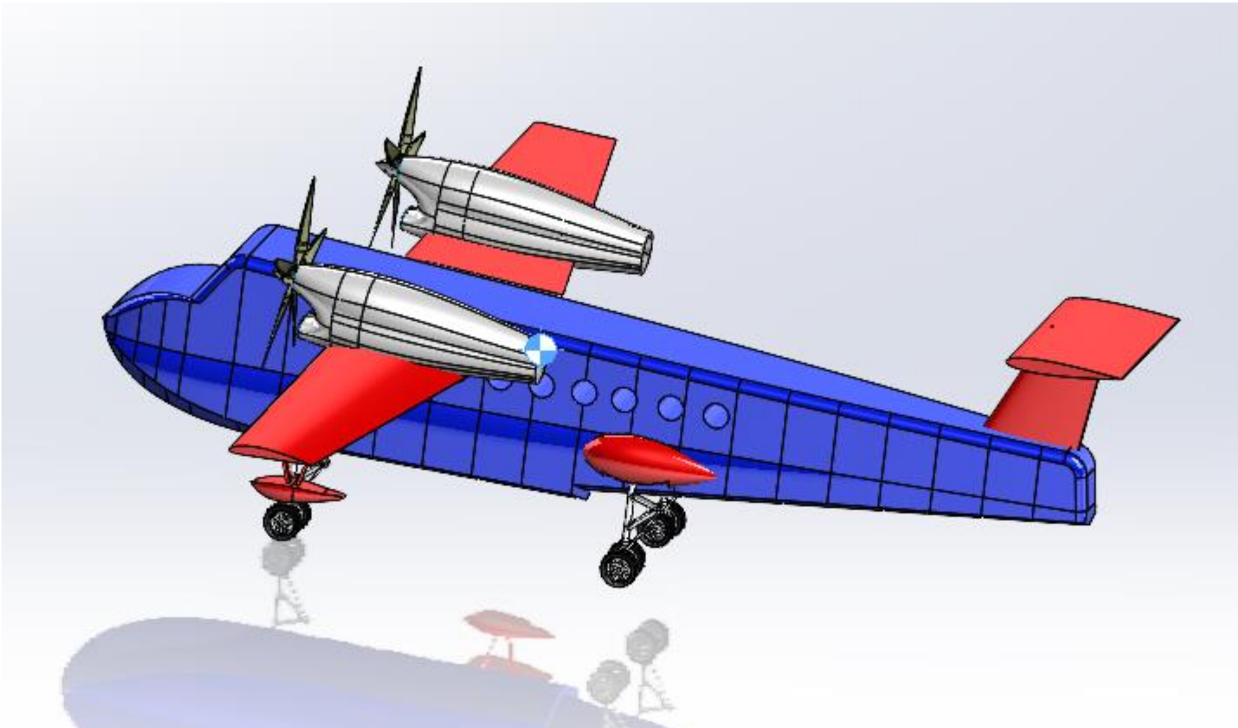


Figure 17 Isometric view of Superfly

The airframe of the Superfly aircraft is made of composite matrix material to be lightweight. Since it will operate in an amphibious environment, more attention was put into anti-corrosive material. A good paint finish is the most effective barrier between metal surfaces and corrosion prone medium. Two-part epoxy paint will be implemented. The landing gear and engine material is titanium for high impact energy and high strength at elevated temperatures.

6.4 Landing Gear:

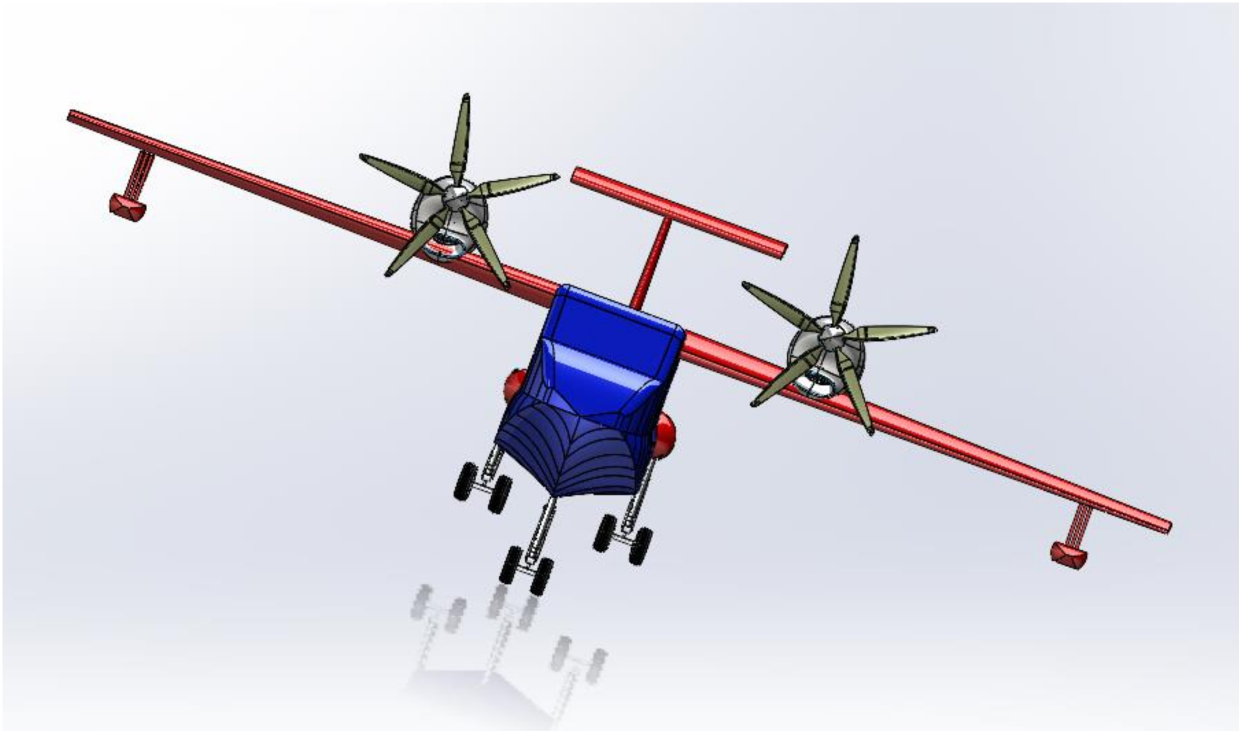


Figure 18 Front view of Superfly

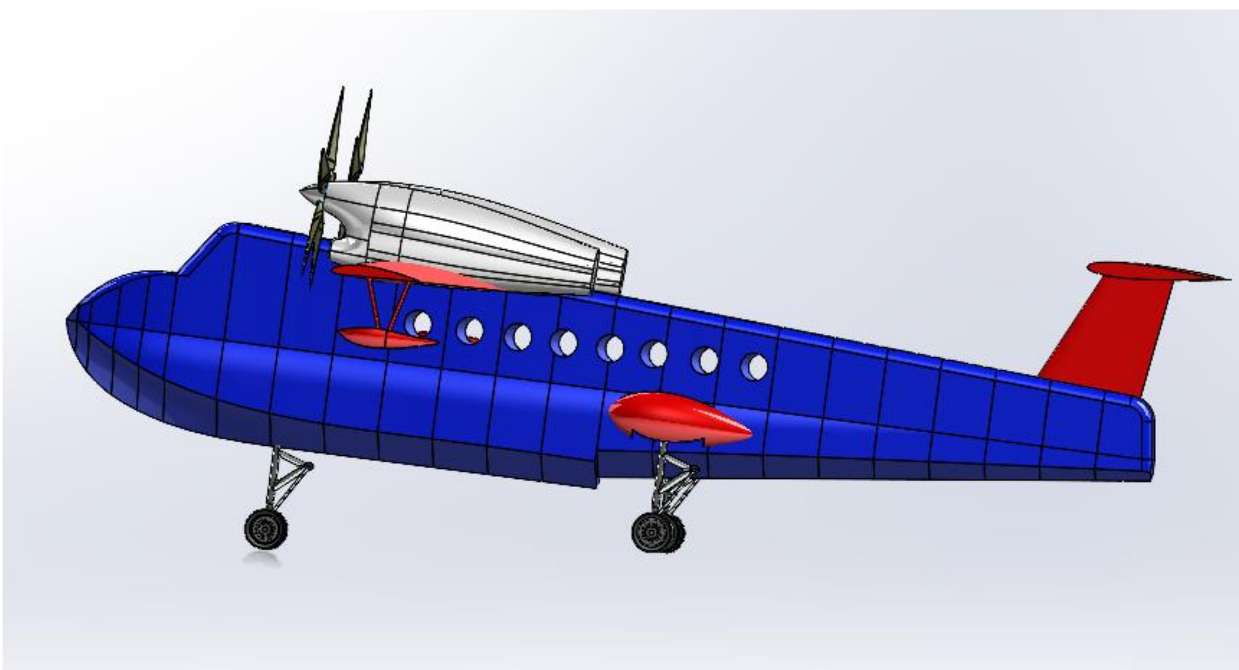


Figure 19 Sideview of Superfly

The above figures depict the landing gear a tricycle retractable configuration chosen for the amphibious aircraft. Tricycle retractable landing gear provides several benefits to the overall performance and safety of the plane, including hydraulic shock absorbers and brakes, tricycle configuration, and retractability. These factors contribute to improved stability and structural integrity.

Chapter 7: Performance

7.1 Aircraft performance:

The plane's wing loading, power to weight ratios, and lift coefficient were critical factors in determining performance parameters such as the stall speed, takeoff & landing distance, climb rate, service ceiling and maximum ceiling of the aircraft. The performance values of the aircraft were calculated using parameters from the sizing, aerodynamic, and propulsion quantities previously calculated.

Although the aircraft has its own mission requirements, the FAA also has requirements the aircraft must adhere to primarily. According to FAR 23, the approach(dive) speed sets the approach speed at 1.4 times the stall speed for commercial applications. Takeoff & landing distance was an important part of the design criteria. To have STOL capability an aircraft must be able to takeoff or land within 1500 ft over a 50 ft obstacle. The static margin is 5-10%, typical for transport aircraft (5).

Stall speed: $\frac{W_0}{S} = \frac{1}{2}\rho V_{stall}^2 C_{L_{max}} = 154\frac{ft}{s} = 91.2\ knots$

$$V_d = 1.4V_s$$

$$1.4 * \ 91.1\ knots = 127.54\ knots$$

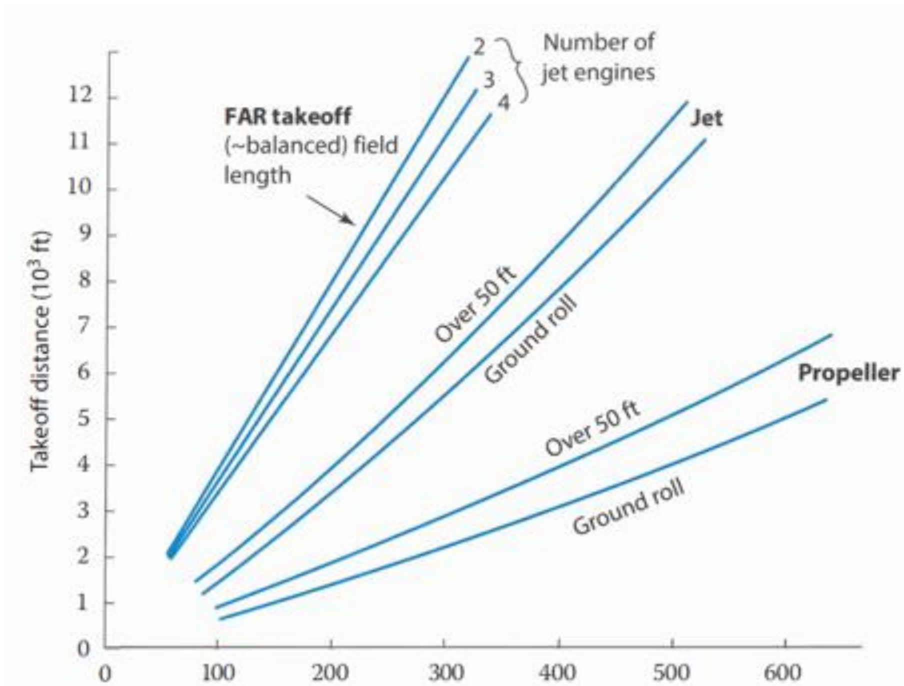


Figure 20 Historical Takeoff Distance chart

Solving for the take-off parameter in figure 19 using the wing loading and power to weight values from the refined sizing calculations would give the aircraft a takeoff distance of approximately 1300 ft. This meets the short take off requirement, however it does not meet the landing distance requirement. Lower wing loading could result in the aircraft meeting 1500 ft takeoff and landing distance, which will then increase in weight, and this could alter the aircraft's performance. The aircraft still must meet performance and mission requirements.

At takeoff conditions: $C_{L_{TO}} = C_{L_{max}}$

$$TOP = \frac{\left(\frac{W}{S}\right)}{\sigma C_{LTO}\left(\frac{HP}{w}\right)} = \frac{(54)}{1*1.89(.21)} = 134$$

At takeoff conditions: $C_{L_{TO}} = C_{L_{max}}$

$$S_{Landing} = 80\left(\frac{W}{S}\right)\left(\frac{1}{\sigma C_L}\right) + S_a = 80\left(54.4\frac{lb}{ft^2}\right)\left(\frac{1}{1*1.89}\right) + 450\,ft = 2734\,ft$$

Required landing distance: $1500\,ft = 80\left(\frac{W}{S}\frac{lb}{ft^2}\right)\left(\frac{1}{1*1.6}\right) + 450\,ft$

Required wing loading at for landing 1500 ft: $\frac{W}{S} = 21\frac{lb}{ft^2}$

The service ceiling, maximum climb rate, and maximum ceiling were determined using the propulsion data. The climb rate could be determined using the climb gradient and forward speed of the aircraft. It should be equal to the rate of climb calculated from the propulsion analysis.

Maximum rate of climb: $G = \frac{V(climb\ rate)}{V(forward\ velocity)} = .17 = \frac{V(climb\ rate)}{337\frac{ft}{s}}$ $\quad V_{climb} = 57.29\frac{ft}{s} = 3588\frac{f}{m}$

Service Ceiling: $\frac{(HP_{const} \cdot velocity \cdot HP)}{MTOW} = \frac{(550 \cdot 220 \cdot 10140)}{47702} = 25720ft$

Maximum Ceiling: $\frac{(HP_{const} \cdot velocity \cdot HP)}{MTOW} = \frac{(550 \cdot 421.9 \cdot 8538)}{47702} = 41532ft$

7.2 Stability and Control Characteristics:

Typical transport aircraft have a static margin of 5-10% (5).

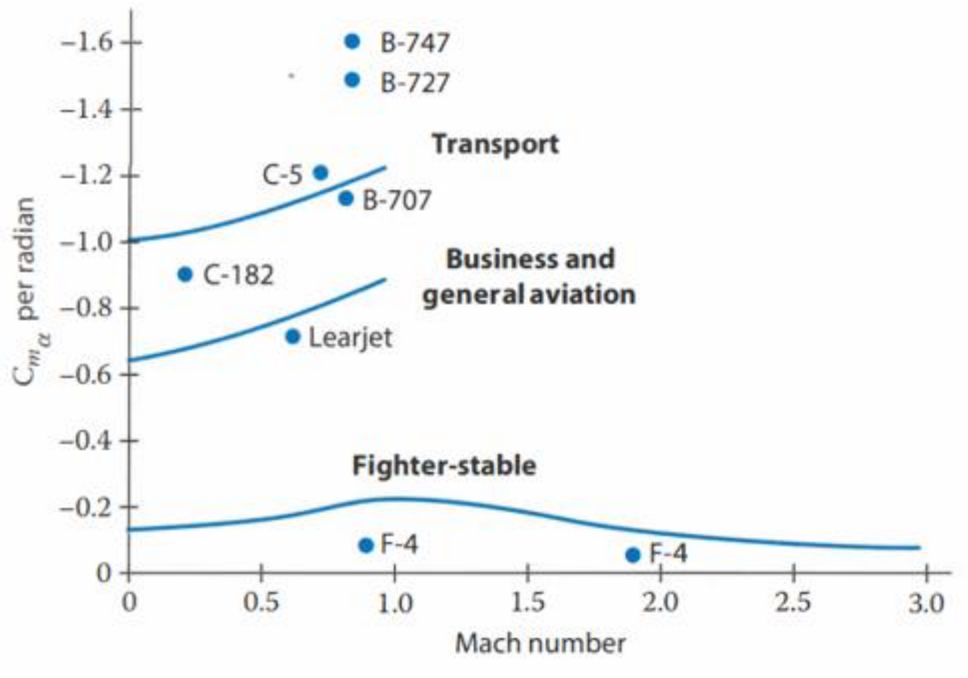


Figure 21 Typical Pitching-moment Derivatives Values

Chapter 8: Lifecycle emissions analysis

8.1 Environmental Impact by the Manufacturer:

Aircraft and aircraft engines must meet minimum international standards to be allowed to fly. These standards are developed by the International Civil Aviation Organization (ICAO) and cover safety and the environment. In environmental terms, the key standards are around aircraft noise and engine emissions. It is in the commercial interests of aircraft manufacturers to ensure their aircraft meet these standards. To help improve environmental performance further, ICAO has also set longer term targets and announced a future, more stringent standard for CO2 emissions. Each generation of new aircraft is likely to be quieter and cleaner than the aircraft that they replace. However, aircraft typically have a long service life, and the design and manufacturing process takes a long time to complete. This in turn means it can be some years before the performance benefits of newer aircraft make a substantial difference to overall emissions and noise levels.

8.2 Emission produced by aircraft production industries:

Left unchecked international flights will generate an evaluated 43 metric gigatons of carbon dioxide emissions by 2050, constituting almost 5% of the emissions permitted to keep international warming below 1.5 degrees Celsius. The engine has high efficiency and durability, low emissions, and low noise. The PW150 engine family is the benchmark for low fuel consumption on 350 miles or fewer routes. That means they consume 25% to 40% less fuel and avoid an equal measure of CO2 emissions than similar-sized regional jets. According to Pratt & Whitney Canada, the PW150A engine produces approximately 200 grams of CO2 per kilometer flow.

Chapter 9: Climax

9.1 Results and Discussion:

Estimating the RDT&E + flyaway cost for a new amphibious aircraft, the production quantity of 100 aircraft was chosen based on similar aircraft and their historical price points for distinct aspects of the research and development process, and the average wrap rates for various departments were updated to 2023 to account for inflation. Empirical equations based off historical data were then used to estimate the engineering, tooling, manufacturing, and QC hours needed to produce the aircraft. In addition, costs for development support, flight testing, manufacturing materials, engine production, and avionics were estimated using equations specific to each cost category. Finally, the RDT&E + flyaway cost was calculated by multiplying the total hours and costs with their respective average wrap rates. The total RDT&E + flyaway cost for 100 aircraft is estimated at $3,436,379,885. To procure one aircraft the cost would be $36,000,000 for one of the 100 aircraft.

The sales cost of one aircraft is comparable to similar amphibious aircraft, however, offers a better capability for its design mission. The cost of producing an aircraft may seem high, but the benefits of using advanced avionics are significant. The Bombardier 415 aircraft is an excellent example, with its high-quality avionics and advanced automation features. While the production costs may be high, the resulting net profit margin and profit percentage are impressive, making it a worthwhile investment.

The final MTOW of the aircraft was determined to be 47,702 lb. The aircraft's sizing was the most important calculation. It directly affected every discipline of aircraft design to include aerodynamics, propulsion, weights, and performance calculations. The thrust to weight ratio and wing loading was used in the refined sizing process and constantly iterated until it did not change as the weight changed. The final thrust-to-weight and wing loading values were .21 lb./lb. and 53 lb./ft^2.

Airfoil data were tested at the Reynolds number regime of 23338774.76. The airfoils used were NACA 4415,4412,0012 for the wing and tail airfoils. However, there was uncertainty when it came to analyzing the wing's aerodynamic data. The drag polar graph was clear however, more efforts could be put into analyzing and interpreting the moment coefficient. The graph showed the moment coefficient decreasing linearly with angle of attack. This could be because of the tail sizing. For future endeavors,

Aircraft performance was affected by the weight of the aircraft, wing & tail aerodynamics, as well as the power-to-weight values. Mathematically, aircraft can achieve the 1300 ft takeoff distance which meets the short takeoff requirement. However, due to its size it is not able to achieve the short landing distance (2734 ft). This may be a moot point if the aircraft has access to land on a local body of water. The climb rate was estimated based on the power to weight, wing loading and climb gradient. The rate of climb for this aircraft is 3,588 fpm. This rate of climb is between the typical ranges for commercial aircraft. The CAD model was designed using solidworks with information gathered from the analysis.

Critical values which affect the buoyancy force calculation are gravitational acceleration and fluid density. A value of 9.81 m/s^2 is used for the gravitational constant of planet Earth. The density of water is affected by several factors, including temperature, salinity, and pressure. The density of pure water is 1000 kg/m3, however ocean water is denser because of its high salt content. The density of ocean water at the sea surface is about 1027 kg/m3.

The final buoyancy force is calculated as 1,369,578 N, or 307,893 lbf. This is more than sufficient to keep the aircraft afloat with cargo and passengers at maximum capacity.

Engine and propellers parameters come because of the performance output on the aircraft based off design requirements and choices of design concepts. Going with a fixed engine had its merits of less iterations when it came to engine performance and weight, but it did increase the number of blades for the propellers. Though it is suggested that more is better, it is not sufficient in the noisy environment. Overall, distance to fuselage and ground are more important than the blade number so with the safety factor of those in mind, this concept is the most efficient for the mission.

9.2 Recommendations:

When analyzing this aircraft's economic factors, using the wrong inflation factor seriously affected financial calculations and decision-making processes. Inflation is the speed at which the general level of prices for goods and services rises, and it is a critical factor in determining the purchasing power of money over time. When calculating future values of investments or making projections, it is essential to use an accurate inflation factor to account for the effects of inflation on the importance of money over time. If the wrong inflation factor is used, the resulting calculations can be accurate and potentially lead to better financial decisions.

Another essential factor to consider when conducting scientific research is consistent units. Using inconsistent units can lead to errors and confusion in data analysis, making comparing results and drawing accurate conclusions difficult. For example, mixing units of measurement such as feet and meters or pounds and kilograms can lead to incorrect calculations and inaccurate data.

It was important to link all calculations to the MTOW value in a computer program like MATLAB or excel to streamline the iterative process when values change. For future endeavors, a more refined sizing process would be completed to get as accurate sizing as possible to help the other disciplines. More effort could be put into determining an accurate tail size that would give better stability results. While determining the coefficient of lift at cruise, the reference area for the top of the fuselage was used to because a moment is produced on the fuselage as the aircraft pitches up and down. The cruise coefficient is .67. This led to a reasonable lift coefficient, however, it differentiated from the design lift coefficient which is 1.06. This was due to the use of two different reference areas. The goal is to obtain the most efficient coefficient of lift for the aircraft to fly at. There are some discrepancies in these findings that could be studied further for clarity.

The CAD design could be more refined to give a better fuselage profile to offer more efficiency and less profile drag. CFD analysis could also be implemented to compare the calculated performance requirements with the actual performance values of the physical model. The CAD package used in the modeling process did not offer all the desired materials required for the aircraft, which affected the mass properties of the model.

When starting the first iterative design of an aircraft, the engine should be in mind whether rubber or fixed, that should be one of the first check boxes. Choosing an engine in the middle of an iterative process can be a setback in the completion of a well thought out design.

9.3 Trade Study: Range vs. Initial Weight:

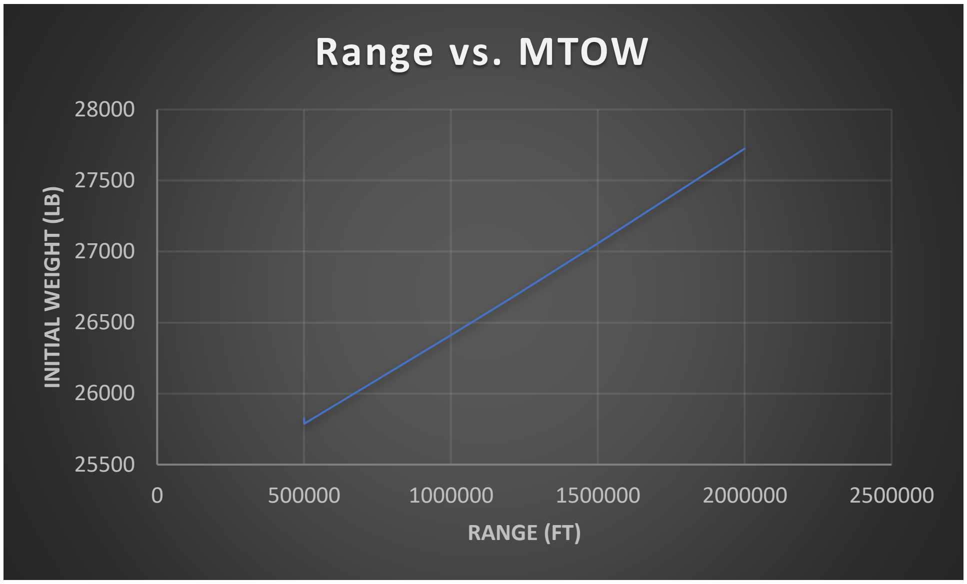


Figure 22 Trade study: Range vs. Maximum Takeoff Weight

This trade study shows that an increase in range will increase the aircraft's initial weight. Fuel required is important to consider. Aircraft that fly further will require more fuel, hence increasing initial weight.

9.3: Trade Study: Payload vs. Initial Weight:

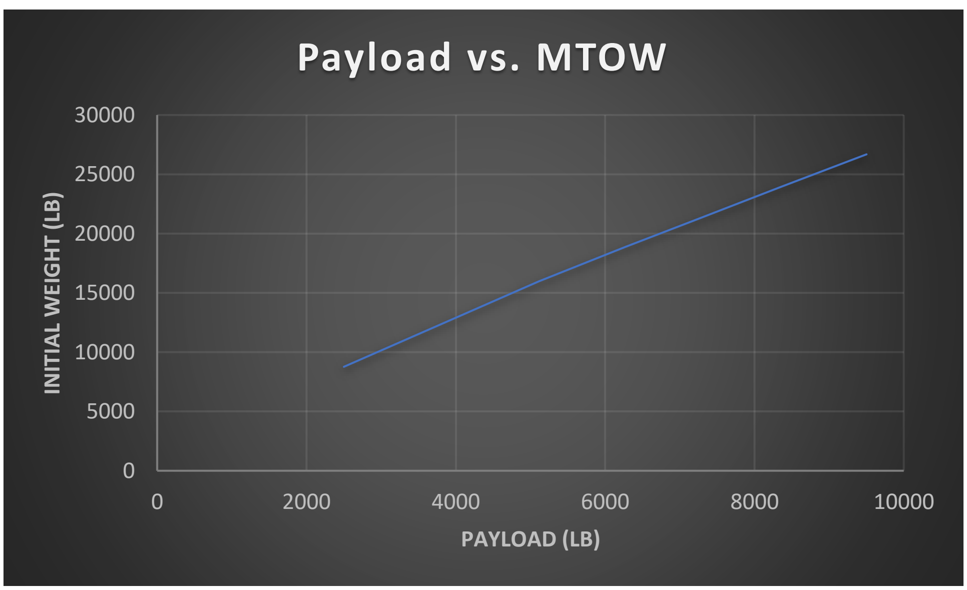


Figure 23 Trade study: Payload vs. Maximum Takeoff Weight

This trade study demonstrates that an increase in payload will increase overall initial takeoff weight of the aircraft. The payload directly affects the MTOW of the aircraft and fuel consumption

Chapter 10: Conclusion:

An amphibious aircraft's development and procurement costs were estimated using various equations and historical data. The average wrap rates for engineering, tooling, quality control, and manufacturing were updated to 2023 using the inflation rate from 2012. The total RDT&E + flyaway cost for 100 aircraft was estimated to be $2.29876E+16 in 2023 dollars, while the cost for one aircraft out of the quantity to be produced would cost an $36,000,000.

In addition to the cost considerations, it is essential to note that aircraft emissions significantly impact the environment. The aviation industry is responsible for significant global greenhouse gas emissions. Efforts are being made to reduce emissions using more fuel-efficient engines, sustainable aviation fuels, and other technologies. As such, it is essential to consider the environmental impact of any aircraft development and procurement project.

Overall, while the estimated costs for developing and procuring an amphibious aircraft are high, it is essential to consider the potential benefits of such a project and its environmental impact. By carefully considering both the costs and benefits, it is possible to make informed decisions that will lead to more sustainable and efficient aircraft development and procurement in the future.

The materials selected for this aircraft were narrowed down by utilizing material currently available and practical for aviation. Materials were an important consideration because all analysis depended on the weight of the aircraft. The engine analysis is a challenge and there are more iterations to add to find the service ceiling and the maximum ceiling. The aircraft’s operating altitude is 30,000 feet. However, a low thrust-to-weight and wing loading was achieved. Subsequently, this aircraft was able to meet the STOL requirement. Further CFD analysis can be tested to obtain more accurate results.

The results of this design come out satisfactory to meet its requirements, as they were the most important aspects of the project. It comes as a challenge to make an iterative process in a short manner of time but with great resources at hand and a good team to work with, it becomes a smooth process.

References:

[1] M. G. Morabito, “A Review of Hydrodynamic Design Methods for Seaplanes,” *Journal of Ship Production and Design*, pp. 1–22, Feb. 2021, doi: https://doi.org/10.5957/jspd.11180039.

[2] R.-6. P. Liem, “Review of Design Aspects and Challenges of Efficient and Quiet Amphibious Aircraft,” *Journal of Physics: Conference Series*, vol. 1005, no. 1742–6588, p. 012027, Apr. 2018, doi: https://doi.org/10.1088/1742-6596/1005/1/012027.

[3] B. Parveez, M. I. Kittur, I. A. Badruddin, S. Kamangar, M. Hussien, and M. A. Umarfarooq, “Scientific Advancements in Composite Materials for Aircraft Applications: A Review,” *Polymers*, vol. 14, no. 22, p. 5007, Nov. 2022, doi: https://doi.org/10.3390/polym14225007.

[4] R Kyle Schmidt, *The design of aircraft landing gear*. Warrendale, Pennsylvania, Usa: Sae International, 2020.

[5] A. Seth and R. P. Liem, “Amphibious Aircraft Developments: Computational Studies of Hydrofoil Design for Improvements in Water-Takeoffs,” *Aerospace*, vol. 8, no. 1, p. 10, Dec. 2020, doi: https://doi.org/10.3390/aerospace8010010.

[6] M. D. Maisel, D. J. Giulianetti, and D. C. Dugan, “The XV-15 Tilt Rotor Research Aircraft From Concept to Flight,” 2000. Available: https://history.nasa.gov/monograph17.pdf

[7]H. Zheng, “Canadair CL-84 | Encyclopedia MDPI,” encyclopedia.pub, Jan. 04, 2014. https://encyclopedia.pub/entry/history/show/74895 (accessed Feb. 18, 2023).

[8]M. D. Maisel, D. J. Giulianetti, and D. C. Dugan, “The XV-15 Tilt Rotor Research Aircraft From Concept to Flight,” 2000. Available: https://history.nasa.gov/monograph17.pdf

[9]H. Zheng, “Bombardier Dash 8,” encyclopedia.pub, Jan. 04, 2014. https://encyclopedia.pub/entry/30612 (accessed Feb. 18, 2023).

[10]R. Czyba and G. Kronhof, “Motion Equations and Longitudinal Control of a Convertible VTOL Aircraft,” IEEE Xplore, Jun. 01, 2020. https://ieeexplore.ieee.org/document/9263980 (accessed Feb. 18, 2023).

[11]R. Liu, J. Bai, Y. Qiu, and G. Guozhu, “Effects of Geometrical Parameters of Internal Blown Flap and Its Optimal Design,” Feb. 2020. https://www.researchgate.net/publication/341316190_Effects_of_Geometrical_Parameters_of_Internal_Blown_Flap_and_Its_Optimal_Design (accessed Feb. 18, 2023).

[12]P. Mahvelatishamsabadi and A. Emadi, “Electric Propulsion System for Exceptionally Short Takeoff and Landing Electric Air Vehicles,” IEEE Transactions on Transportation Electrification, vol. 6, no. 4, pp. 1–1, 2020, doi: https://doi.org/10.1109/tte.2020.2993609.

[13]C. Maget, S. Gutmann, and K. Bogenberger, “Model-based Evaluations Combining Autonomous Cars and a Large-scale Passenger Drone Service: The Bavarian Case Study,” IEEE Xplore, Sep. 01, 2020. https://ieeexplore.ieee.org/document/9294183 (accessed Feb. 18, 2023).

[14] F. Barra, P. Capone, and G. Guglieri, “A Methodology for Preliminary Performance Estimation of a Hybrid-Electric Tilt-Wing Aircraft for Emergency Medical Services,” IEEE Xplore, Sep. 01, 2020. https://ieeexplore.ieee.org/document/9214025 (accessed Feb. 18, 2023).

[15] M. Thianwiboon, “Optimization of a hybrid carbon/glass composites afterbody of the amphibious plane with Finite Element Analysis,” *Engineering Journal*. [Online]. Available: https://engj.org/index.php/ej/article/view/3446. [Accessed: 10-Feb-2023].

[16] Author links open overlay panel Lixin WANG a, a, b, and Abstract Owing to the strong coupling among the hydrodynamic forces, “Water takeoff performance calculation method for amphibious aircraft based on Digital Virtual Flight,” *Chinese Journal of Aeronautics*, 17-Jun-2020. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1000936120301953. [Accessed: 11-Feb-2023].

[17] Author links open overlay panel Wu Dawei a, a, b, and Abstract Ultra-light and very light amphibious aircraft are the special kinds of low-speed general aircrafts. They are low weighted and small sized but can take off and land either on land or water without changing the structure of any parts. These charact, “Safety and airworthiness design of ultra-light and very light amphibious aircrafts,” *Procedia Engineering*, 30-Nov-2011. [Online]. Available: https://reader.elsevier.com/reader/sd/pii/S1877705811027020?token=38FB6E3E1B25D49078316926957077670B72EE8C2BFA8FFBFEF8F9B10F0AB9033BA42C80E5813CDCCDEEF6DD381A2410&originRegion=us-east-1&originCreation=20230211181758. [Accessed: 11-Feb-2023].

[18] Author links open overlay panel Sinchai Chinvorarat and Abstract A lightweight amphibious aircraft hybrid composite wing was designed and optimized in this study. The Ansys Composite Prep Post and Ansys Mechanical Module use finite element modeling to simulate and assess the static structural test. It is possible, “Composite wing structure of light amphibious airplane design, optimization, and experimental testing,” *Heliyon*, 22-Nov-2021. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S2405844021025135. [Accessed: 11-Feb-2023].

[19] “(PDF) conceptual design of an amphibious vehicle: Vector - ResearchGate.” [Online]. Available: https://www.researchgate.net/publication/267406476_Conceptual_design_of_an_amphibious_vehicle_Vector. [Accessed: 11-Feb-2023].

[20] D. P. Raymer, *Aircraft design: A conceptual approach*. Reston: American Institute of Aeronautics and Astronautics, 2021.

[20] X. Vouvakos, Y. Kallinderis, and P. Menounou, “Preliminary design correlations for twin civil turboprops and comparison with jet aircraft,” *Aircraft Engineering and Aerospace Technology*, vol. 82, no. 2, pp. 126–133, Mar. 2010, doi: https://doi.org/10.1108/00022661011053427.

Www.aircraftspruce.com, “Garmin G5 primary electronic attitude display - stc'd for certified aircraft with LPM,” *Aircraft Spruc*e. [Online]. Available: https://www.aircraftspruce.com/catalog/avpages/garmin-g5-cert.php. [Accessed: 19-Mar-2023].

“Pratt,” *Wikipedia*, 18-Mar-2023. [Online]. Available: https://en.wikipedia.org/wiki/Pratt_&_Whitney. [Accessed: 19-Mar-2023].

“Amphibious aircraft,” *Wikipedia*, 12-Jan-2023. [Online]. Available: https://en.wikipedia.org/wiki/Amphibious_aircraft. [Accessed: 19-Mar-2023].

"Inflation calculator: Find US Dollar's value from 1913-2023," *US Inflation Calculator | Easily calculate how the buying power of the U.S. dollar has changed from 1913 to 2023. Get inflation rates and U.S. inflation news.*, 14-Mar-2023. [Online]. Available: https://www.usinflationcalculator.com/. [Accessed: 19-Mar-2023].

H. E. Boren, "DAPCA: A computer program for Determining Aircraft Development and production costs," *RAND Corporation*, 01-Jan-1967. [Online]. Available: https://www.rand.org/pubs/research_memoranda/RM5221.html. [Accessed: 19-Mar-2023].

"Grumman HU-16 Albatross - price, Specs, photo gallery, history," *Aero Corner*. [Online]. Available: https://aerocorner.com/aircraft/grumman-hu-16-albatross/. [Accessed: 16-Apr-2023].

"Amphibious," *Aero Corner*. [Online]. Available: https://aerocorner.com/aircraft-categories/amphibious/. [Accessed: 16-Apr-2023].

C. Dyer, "How the $30 million 'Super scooper' cl-415eaf plane was built to fight wildfires," *Business Insider*. [Online]. Available: https://www.businessinsider.com/cl-415eaf-super-scooper-plane-aerial-firefighter-technology-2021-3. [Accessed: 16-Apr-2023].

"Bombardier 415 - price, Specs, photo gallery, history," *Aero Corner*. [Online]. Available: https://aerocorner.com/aircraft/bombardier-415/#:~:text=Bombardier%20415%20Current%20Price,%24%2037%20million%20U.S. [Accessed: 16-Apr-2023].

"ShinMaywa US-2," *Wikipedia*, 18-Mar-2023. [Online]. Available: https://en.wikipedia.org/wiki/ShinMaywa_US-2. [Accessed: 16-Apr-2023].

"Beriev Be-200," *Wikipedia*, 09-Apr-2023. [Online]. Available: https://en.wikipedia.org/wiki/Beriev_Be-200. [Accessed: 16-Apr-2023].

"Here's how much airlines are profiting off your plane ride," *Money*. [Online]. Available: https://money.com/airline-profit-per-passenger/#:~:text=According%20to%20the%20Wall%20Street%20Journal%2C%20the%20average,across%20those%20seven%20airlines%20was%209%25%20in%202017. [Accessed: 16-Apr-2023].

"Honeywell MD-80 PFD 4056510-903 primary flight display MD-81,82,83,87,88," *eBay*. [Online]. Available: https://www.ebay.com/itm/124129510852?campid=5338967980&mkevt=1&mkcid=1&toolid=10050&customid=9fd431d8184f170711fc55ef00688221&mkrid=710-53481-19255-0. [Accessed: 16-Apr-2023].

Www.aircraftspruce.com, "UAVIONIX AV-30-C primary flight display - certified," *Aircraft Spruce*. [Online]. Available: https://www.aircraftspruce.com/catalog/inpages/uavionix_11-17556.php?clickkey=60913. [Accessed: 16-Apr-2023].

"Meggitt Avionics Primary Flight Display unit - part number:84-133-1," *eBay*. [Online]. Available: https://www.ebay.com/itm/285158234713?epid=12021720143&hash=item4264c15a59%3Ag%3A1kQAAOSwGoNj9-Zg. [Accessed: 16-Apr-2023].

s.r.o. AIR TEAM, "Garmin GDU 1240A G1000 display - part number: 011-01440-00, unit condition: Serviceable," *www.airteam.shop*. [Online]. Available: https://www.airteam.shop/p/gdu-1240a-3#. [Accessed: 16-Apr-2023].

"Home," *Civil Aviation Authority*. [Online]. Available: https://www.caa.co.uk/Consumers/Environment/Environmental-stakeholders/Manufacturers/#:~:text=The%20way%20that%20aircraft%20are%20designed%20can%20help,sustainable%20aviation%20through%20its%20Greener%20By%20Design%20programme. [Accessed: 16-Apr-2023].

Airplane Emissions. [Online]. Available: https://www.biologicaldiversity.org/programs/climate_law_institute/transportation_and_global_warming/airplane_emissions/#:~:text=Left%20unchecked%20global%20aviation%20will%20generate%20an%20estimated,to%20keep%20global%20warming%20below%201.5%20degrees%20Celsius. [Accessed: 16-Apr-2023].

"PW100/150 engines | pratt & whitney." [Online]. Available: https://www.prattwhitney.com/en/products/regional-aviation-engines/pw100-150. [Accessed: 17-Apr-2023].

"Grumman HU-16 Albatross - price, Specs, photo gallery, history," *Aero Corner*. [Online]. Available: https://aerocorner.com/aircraft/grumman-hu-16-albatross/. [Accessed: 16-Apr-2023].

"Airline operating costs and productivity - ICAO." [Online]. Available: https://www.icao.int/mid/documents/2017/aviation%20data%20and%20analysis%20seminar/ppt3%20-%20airlines%20operating%20costs%20and%20productivity.pdf. [Accessed: 17-Apr-2023].

"Pratt & Whitney Canada PW100," *Wikipedia*, 12-Dec-2022. [Online]. Available: https://en.wikipedia.org/wiki/Pratt_%26_Whitney_Canada_PW100. [Accessed: 16-Apr-2023].

"Primus epic integrated flight deck," *Integrated Flight Deck*. [Online]. Available: https://aerospace.honeywell.com/us/en/products-and-services/product/hardware-and-systems/cockpit-systems-and-displays/primus-epic. [Accessed: 19-Apr-2023].

Garmin and G. L. or its subsidiaries, "Garmin G5000®: Integrated flight deck," *Garmin*. [Online]. Available: https://www.garmin.com/en-US/p/90821. [Accessed: 19-Apr-2023].

"Insight display system," *Default*. [Online]. Available: https://www.universalavionics.com/home/products/flight-displays/insight-flight-display-system. [Accessed: 19-Apr-2023].

Meggitt.com. [Online]. Available: https://www.meggitt.com/products-services/flight-displays/. [Accessed: 19-Apr-2023].

"Primus epic Flight Management Systems," *Home*. [Online]. Available: https://aerospace.honeywell.com/us/en/products-and-services/product/hardware-and-systems/cockpit-systems-and-displays/primus-epic-flight-management-systems. [Accessed: 19-Apr-2023].

Garmin and G. L. or its subsidiaries, "GTN™ 750: Ads-B," *Garmin*. [Online]. Available: https://www.garmin.com/en-US/p/67886#overview. [Accessed: 19-Apr-2023].

"UNS-1Fw - aircraft FMS by Universal Avionics Systems Corp.: AeroExpo," *The B2B marketplace for aeronautical equipment*. [Online]. Available: https://www.aeroexpo.online/prod/universal-avionics-systems-corp/product-173348-3186.html. [Accessed: 19-Apr-2023].

S. Pope, "Meggitt magic autopilot keeps turboprops flying," *Aviation International News*, 19-May-2008. [Online]. Available: https://www.ainonline.com/aviation-news/aviation-international-news/2008-05-19/meggitt-magic-autopilot-keeps-turboprops-flying. [Accessed: 19-Apr-2023].

"Primus HF-1050," *Home*. [Online]. Available: https://aerospace.honeywell.com/us/en/products-and-services/product/hardware-and-systems/navigation-and-radios/primus-hf-1050. [Accessed: 19-Apr-2023].

S. A. Inc, "Garmin GSR-56," *SEA*. [Online]. Available: https://www.seaerospace.com/sales/product/Garmin/GSR-56. [Accessed: 19-Apr-2023].

"Unilink CMU," *Default*. [Online]. Available: https://www.universalavionics.com/home/products/communications/unilink-cmu. [Accessed: 19-Apr-2023].

Meggitt.com. [Online]. Available: https://www.meggitt.com/. [Accessed: 19-Apr-2023].

"The Federal Register," *Federal Register :: Request Access*. [Online]. Available: https://www.federalregister.gov/documents/2003/06/09/03-14426/guidance-for-the-certification-of-honeywell-primus-epic. [Accessed: 19-Apr-2023].

"GFC™ 700 Digital Autopilot," *Skye Avionics*, 05-Jun-2021. [Online]. Available: https://skyeavionics.com/product/gfc-700-digital-autopilot/. [Accessed: 22-Apr-2023].

"UNS-1Fw," *Default*. [Online]. Available: https://www.universalavionics.com/home/products/flight-management/uns-1fw. [Accessed: 19-Apr-2023].

"Meggitt Avionics/S-TEC launches New magic 2100 digital flight control system," *Aviation Week Network*, 29-Apr-2002. [Online]. Available: https://aviationweek.com/meggitt-avionicss-tec-launches-new-magic-2100-digital-flight-control-system-0. [Accessed: 19-Apr-2023].

"IntuVue RDR-4000 3D weather radar system," *Home*. [Online]. Available: https://aerospace.honeywell.com/us/en/products-and-services/product/hardware-and-systems/weather-radar/intuvue. [Accessed: 19-Apr-2023].

"GWX 80," *Sarasota Avionics*. [Online]. Available: https://sarasotaavionics.com/avionics/gwx80. [Accessed: 19-Apr-2023].

"Taws - AEA." [Online]. Available: https://aea.net/PilotsGuide/pdf/04_Archive/PG04TAWS.pdf. [Accessed: 19-Apr-2023].

"Fact Sheet Meggitt at a glance." [Online]. Available: https://www.meggitt.com/wp-content/uploads/2020/03/Fact-sheet-1.pdf.[Accessed: 19-Apr-2023].

"SmartPath ground-based augmentation system," *Home*. [Online]. Available: https://aerospace.honeywell.com/us/en/products-and-services/product/hardware-and-systems/sensors/smartpath-ground-based-augmentation-system. [Accessed: 19-Apr-2023].

Garmin and G. L. or its subsidiaries, "Garmin G2000®: Integrated Flight Deck," *Garmin*. [Online]. Available: https://www.garmin.com/en-US/p/97668. [Accessed: 19-Apr-2023].

"Nav-4000/4500/vir-4000/ADF-4000 navigation receivers," *CA*. [Online]. Available: https://www.collinsaerospace.com/what-we-do/industries/business-aviation/flight-deck/additional-flight-deck/datalink-communications-and-navigation/navigation/nav40004500vir4000adf4000navigationreceivers. [Accessed: 19-Apr-2023].

"ILS 420," *Thales Group*. [Online]. Available: https://www.thalesgroup.com/en/worldwide/aerospace/ils-420. [Accessed: 19-Apr-2023].

"FMZ-2000 Flight Management System (FMS)," *Home*. [Online]. Available: https://aerospace.honeywell.com/us/en/products-and-services/product/hardware-and-systems/cockpit-systems-and-displays/fmz-2000. [Accessed: 19-Apr-2023].

M. Thianwiboon, "Optimization of a hybrid carbon/glass composites afterbody of the amphibious plane with Finite Element Analysis," *Engineering Journal*. [Online]. Available: https://engj.org/index.php/ej/article/view/3446. [Accessed: 19-Apr-2023].

"Sfar 88 & Related Regulatory Sections - faa.gov." [Online]. Available: https://www.faa.gov/sites/faa.gov/files/2022-11/SFAR88Summary.pdf. [Accessed: 19-Apr-2023].

Garmin and G. L. or its subsidiaries, "Garmin G3000®: Integrated Flight Deck," *Garmin*. [Online]. Available: https://www.garmin.com/en-GB/p/66916. [Accessed: 19-Apr-2023].

"Traffic collision avoidance system (TCAS) change 7.1," *Home*. [Online]. Available: https://aerospace.honeywell.com/us/en/pages/tcas-change-7-1. [Accessed: 19-Apr-2023].

"Aircraft Traffic Surveillance Systems," *Garmin*. [Online]. Available: https://www.garmin.com/en-US/c/aviation/general/active-traffic-tcas/. [Accessed: 19-Apr-2023].

"TTR 4100 TCAS II," *CA*. [Online]. Available: https://www.collinsaerospace.com/what-we-do/industries/business-aviation/flight-deck/additional-flight-deck/traffic-awareness/ttr-4100-tcas-ii. [Accessed: 19-Apr-2023].

"TCAS 3000SP™ Traffic Collision Avoidance System," *L3Harris® Fast. Forward.* [Online]. Available: https://www.l3harris.com/all-capabilities/tcas-3000sp-traffic-collision-avoidance-system. [Accessed: 19-Apr-2023].

"LASEREF VI Micro Inertial Reference Systems," *Home*. [Online]. Available: https://aerospace.honeywell.com/us/en/products-and-services/product/hardware-and-systems/sensors/laseref-vi-micro-inertial-reference-systems. [Accessed: 19-Apr-2023].

"LN-251 advanced airborne INS/GPS (EGI)," *Northrop Grumman*, 01-Mar-2023. [Online]. Available: https://www.northropgrumman.com/what-we-do/air/ln-251-advanced-airborne-ins-gps-egi/. [Accessed: 19-Apr-2023].

"CMU 4000 Communications Management Unit," *CA*. [Online]. Available: https://www.collinsaerospace.com/what-we-do/industries/business-aviation/flight-deck/additional-flight-deck/datalink-communications-and-navigation/datalink-and-communications/cmu-4000-communications-management-unit. [Accessed: 19-Apr-2023].

“Sigma 95 - inertial & hybridized navigation systems for combat aircraft,” *Safran*. [Online]. Available: https://www.safran-group.com/products-services/sigma-95. [Accessed: 19-Apr-2023].

“SRVIVR25™ series cockpit voice and flight data recorders,” *L3Harris® Fast. Forward.* [Online]. Available: https://www.l3harris.com/all-capabilities/srvivr25-series-cockpit-voice-and-flight-data-recorders. [Accessed: 19-Apr-2023].

“Kapture CVR/FDR: Universal Avionics,” *Default*. [Online]. Available: https://www.universalavionics.com/home/products/flight-recorders/kapture-recorders. [Accessed: 19-Apr-2023].

“EASA certifies Honeywell, Curtiss-Wright 25-hour flight data recorder for the Air Transport Market,” *Home*. [Online]. Available: https://aerospace.honeywell.com/us/en/about-us/press-release/2021/05/easa-certifies-honeywell-curtiss-wright-25-hour-flight-data-recorder. [Accessed: 19-Apr-2023].

“FA2100 series cockpit voice and Flight Data Recorders,” *L3Harris® Fast. Forward.* [Online]. Available: https://www.l3harris.com/all-capabilities/fa2100-series-cockpit-voice-and-flight-data-recorders. [Accessed: 19-Apr-2023].

J. BROUTIER, “Pratt & Whitney Canada PW150A,” Aircraft database. [Online]. Available: https://aircraft-database.com/database/engine-models/pw150a. [Accessed: 23-Apr-2023].

Avatar, “Aircraft Propeller Basics,” Southern Wings, 26-Sep-2020. [Online]. Available: https://www.southernwings.co.nz/aircraft-propeller-basics/#:~:text=There%20are%20three%20basic%20types,or%20the%20ground%20adjustable%20propeller. [Accessed: 24-Apr-2023].

Appendix A: Acknowledgement

Dr. Khalid provided valuable feedback that helped connect different principles between the different aerospace disciplines. His insight contributed to the successful completion of the project. The contact information for this faculty adviser can be found in Appendix B.

Appendix B: Contact Information

Team members:

Devonte Andrews	KSU email: dandre47@students.kennesaw.edu	Personal email:devonte.andrews@yahoo.com
Eva Sanchez	KSU email: esanch43@students.kennesaw.edu	Personal email: sanchezevacatherine@gmail.com
Kwesi Onumah	KSU email: konumah@students.kennesaw.edu	Personal email:kwesionumah@hotmail.com
Ahmed Hamza	KSU email: ahamza1@students.kennesaw.edu	Personal email: ahmedhamza877@gmail.com

Faculty Advisor(s):

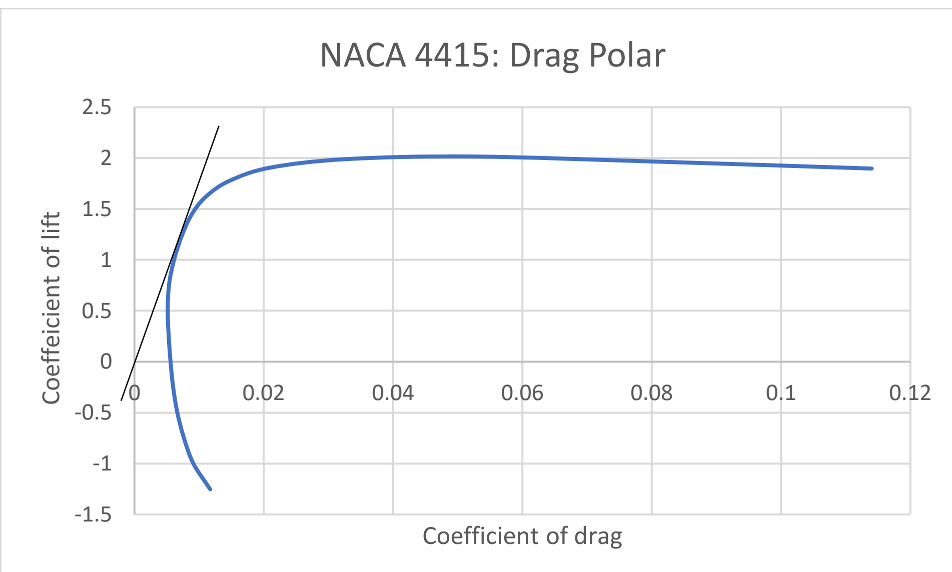
Dr. Adeel Khalid : akhalid2@kennesaw.edu

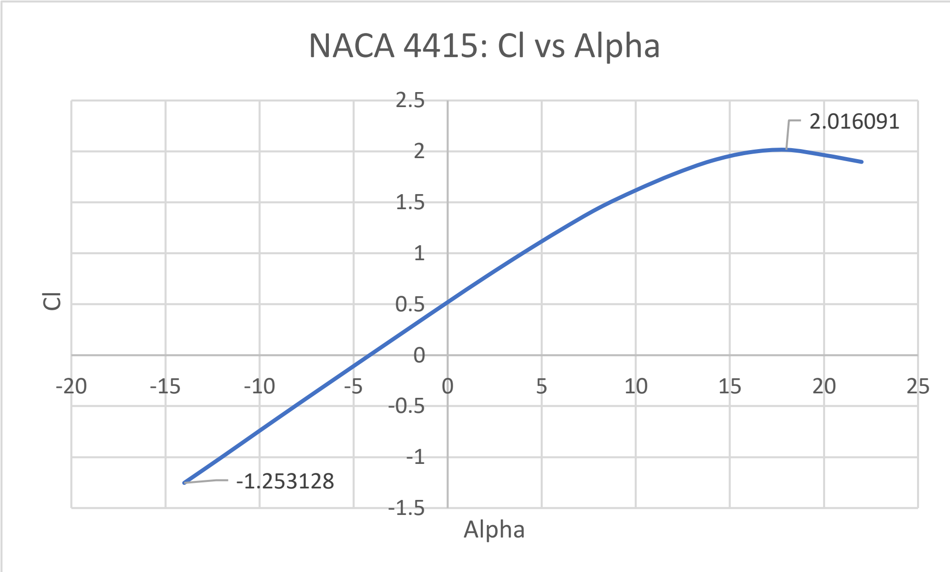
Appendix C: Reflections

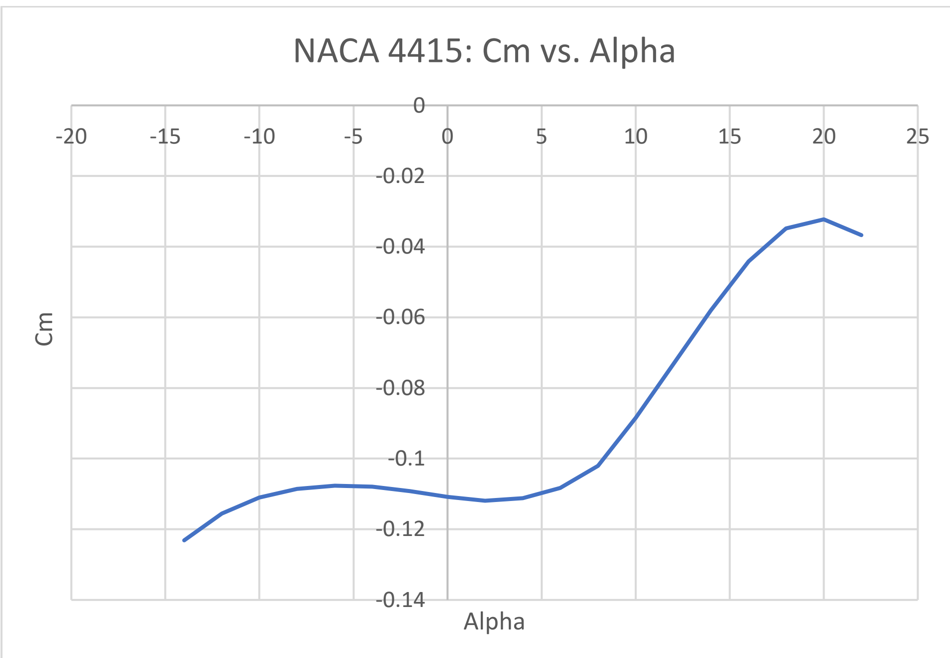
There were a lot of unforeseen challenges while completing this project. The amount of analysis required was very extensive for such a small team in a small-time frame. Hand calculating things made iterating our design a lot harder than it needed to be. Throughout the process, it was discovered that using excel and other powerful software made the calculation process a lot smoother. Using graphs and tables made the data presentation more professional and clearer for the reader. There was a huge learning curve when completing the aerodynamic and propulsion analysis. Learning how to calculate quantities such as the skin friction drag for different surfaces such as the wing, tail, fuselage, and knowing which skin friction drag to use with which calculation was difficult. This design process required extensive research and learning to understand how to apply engineering knowledge to solve problems. Working between the different disciplines highlighted the interconnectivity of each analysis between the different disciplines. With such high learning curve, it takes dedication and professionalism to get acute results not just in the completion of an assignment but the growth of taking new challenges and frontiers.

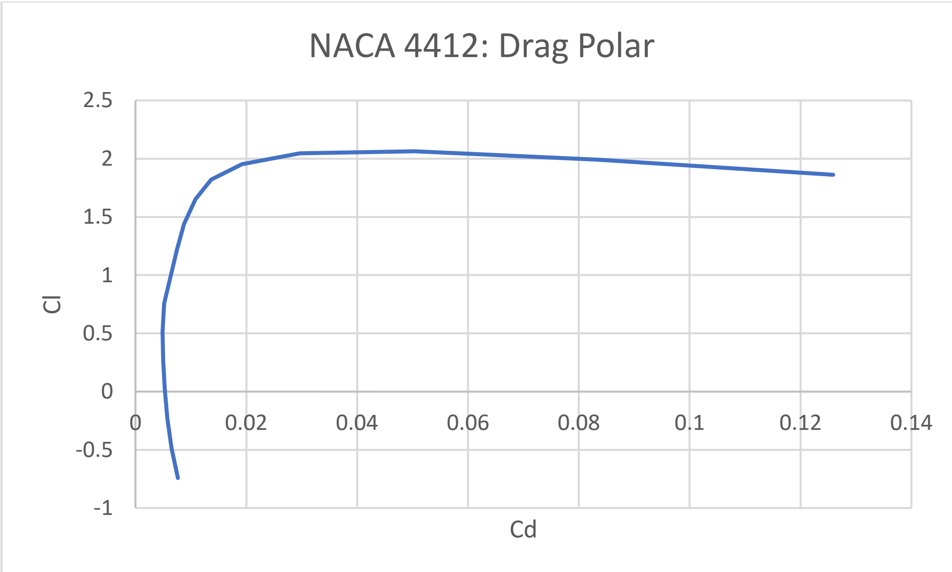
Appendix D: Airfoil Data

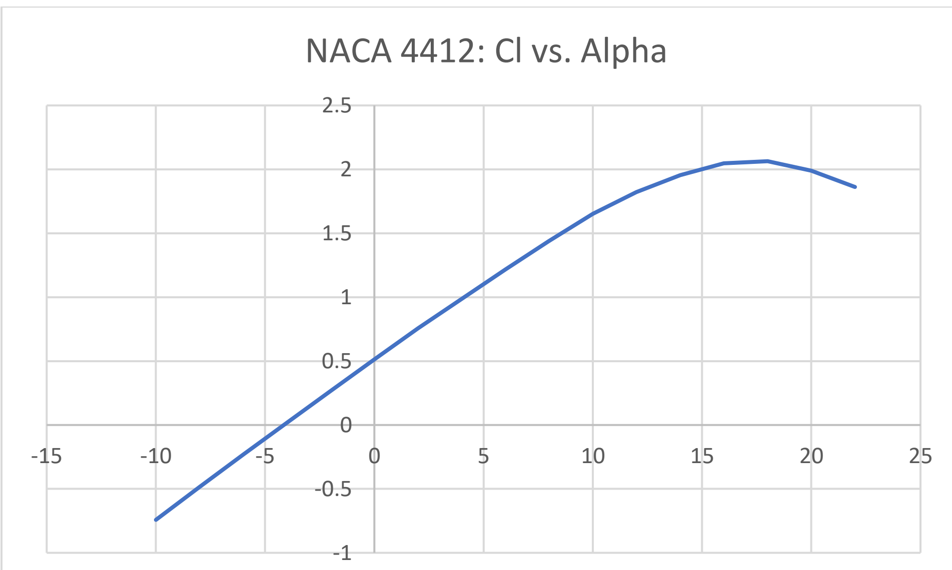
Below is the airfoil data for each individual airfoil used on this aircraft.

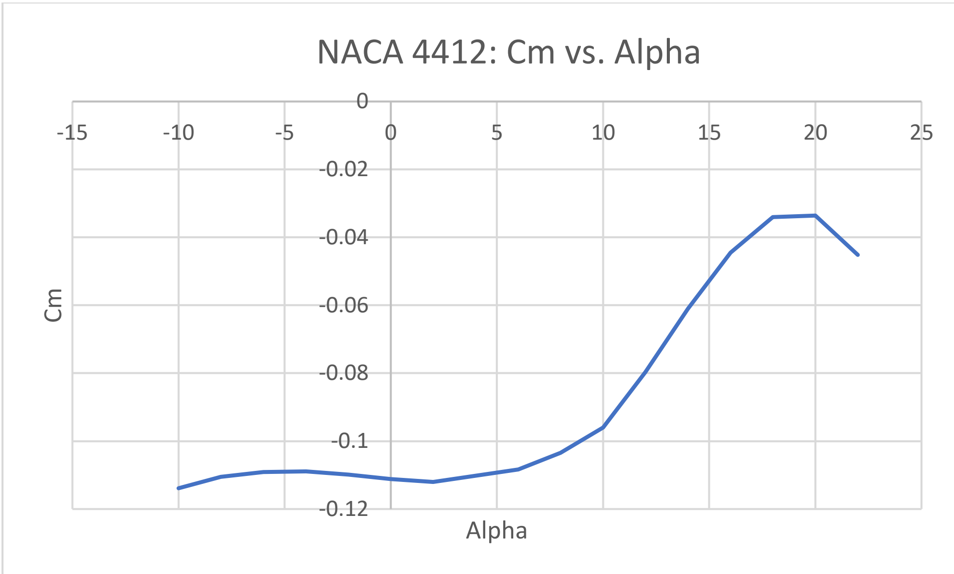


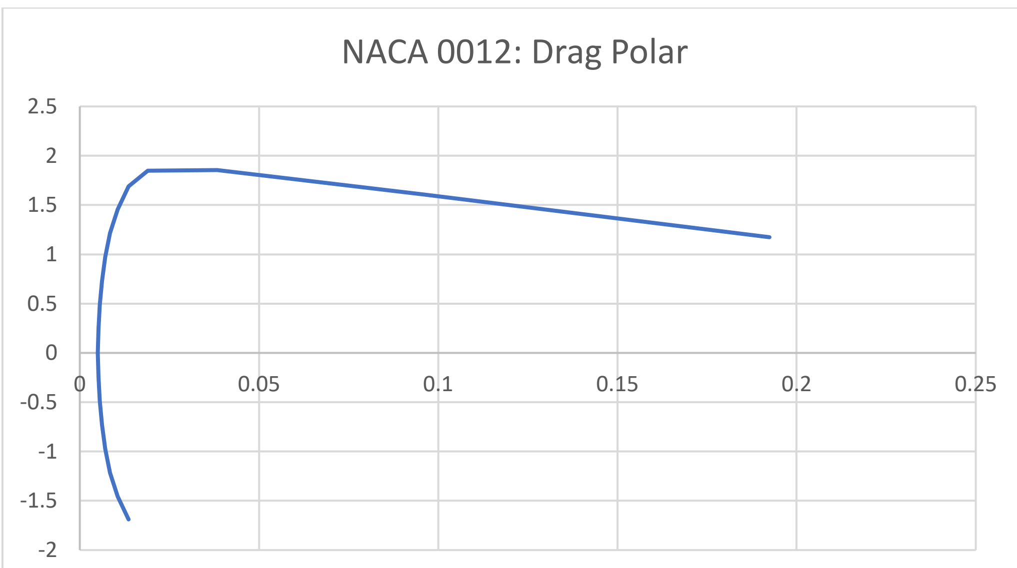

NACA 4415: Cl vs Alpha
2.016091
-1.253128
Cl
Alpha
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-20
-15
-10
-5
0
5
10
15
20
25

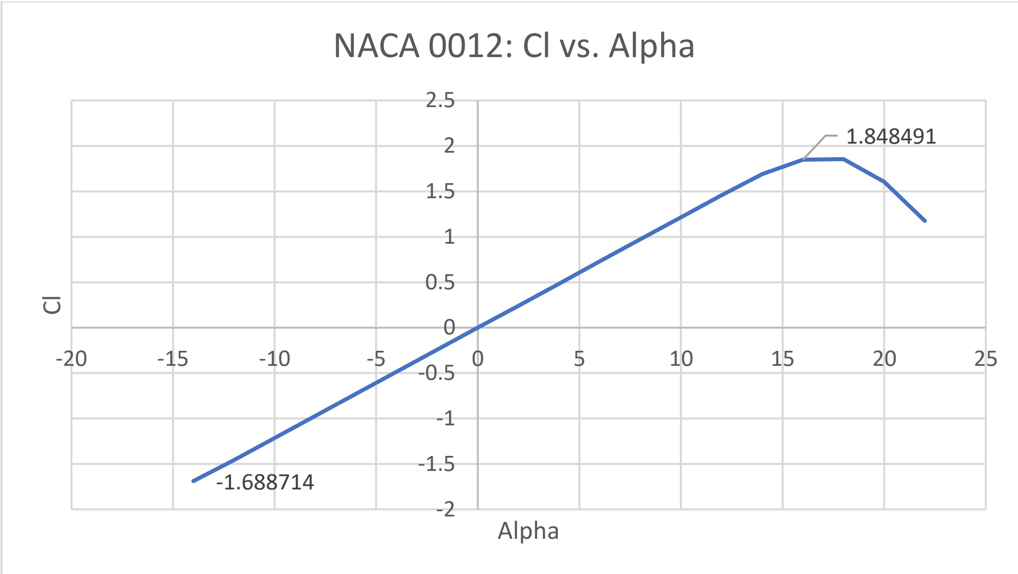

NACA 4415: Cm vs. Alpha
Cm
Alpha
0
-0.02
-0.04
-0.06
-0.08
-0.1
-0.12
-0.14
-20
-15
-10
-5
0
5
10
15
20
25

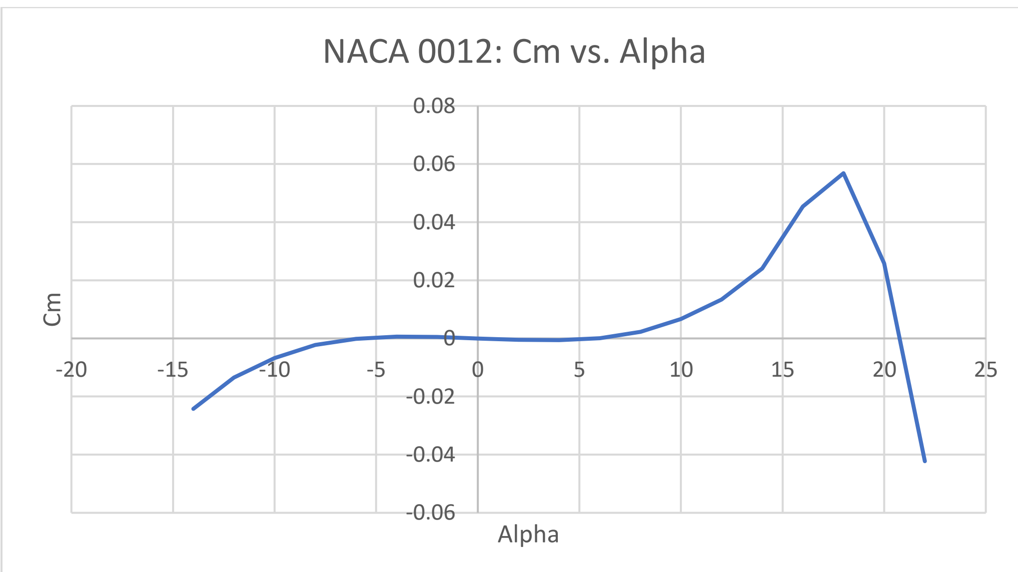

NACA 4412: Drag Polar
Cl
Cd
2.5
2
1.5
1
0.5
0
-0.5
-1
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14


NACA 4412: Cl vs. Alpha
2.5
2
1.5
1
0.5
0
-0.5
-1
-15
-10
-5
0
5
10
15
20
25


NACA 4412: Cm vs. Alpha
Cm
Alpha
0
-0.02
-0.04
-0.06
-0.08
-0.1
-0.12
-15
-10
-5
0
5
10
15
20
25


NACA 0012: Drag Polar
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0
0.05
0.1
0.15
0.2
0.25





Appendix E: Assigned Tasks

Detailed Project Task:

Assigned Tasks: Ahmed Hamza
Lifecycle emissions analysis, which includes: a. Emissions associated with aircraft production b. In-service emissions i. Analysis should include key greenhouse gases such as Carbon Dioxide and Nitrous Oxide
Summary of cost estimate and a business case analysis. This assessment should identify the cost groups and drivers, assumptions, and design choices aimed at the minimization of production costs. a. Estimate the non-recurring development costs of the airplane including engineering, FAA/EASA

Assigned Tasks: Devonte Andrews
Airfoil & wing design and analysis
certification, production tooling, facilities, and labor b. Estimate the fly away cost of each member of the family c. Estimate of direct operating cost per airplane flight hour d. Avionics package cost analysis & Diagram showing where avionics are located.
Complete geometric description, including dimensioned drawings, control surfaces sizes and hinge locations, and internal arrangement of the aircraft illustrating sufficient volume for all necessary components and systems. a. Scaled three-views (dimensioned) and 3-D model imagery of appropriate quality are expected. The three-view must include at least: i. Fully dimensioned front, left, and top views ii. Location of aircraft aerodynamic center (from nose) iii. Location of average CG location (relative to nose) iv. Tail moment arms
A description of the design missions defined for the proposed concepts for use in calculations of mission performance as per design objectives. This includes the selection of cruise altitude(s) and cruise speeds supported by pertinent trade analyses and discussion. Aircraft performance summaries shall be documented and the aircraft flight envelope shall be shown graphically. Payload range chart(s). Complete Aircraft sizing. A V-n diagram for the aircraft with identification of necessary aircraft velocities and design load factors. a. Required gust loads are specified in Federal Aviation Regulations (FAR) Part 25.
Materials selection for main structural groups and general structural design, including layout of primary airframe structure as well as the strength capability of the structure and how that compares to what is required at the ultimate load limits of the aircraft. The maximum dive speed of the aircraft shall be specified. Calculate takeoff and landing distance. Hull/float design and analysis Landing Gear Design and analysis i: CAD Design landing gear ii: Design CAD model of aircraft. iii: Design and analysis of the seaplane's structures, including the fuselage, wings, tail, and landing gear.

Assigned Tasks: Kwesi Onumah
b. Diagrams and/or estimates showing that internal volume requirements are met, including as a minimum the internal arrangements of the passenger, cargo and maritime surveillance variants. i. Cross-section showing passenger and cargo configuration ii. Layout Of Passenger Accommodations (LOPA) for 28” pitch single class iii. Layout of cargo and size and location of any unique cargo doors iv. Fuselage centerline diagram c. Diagrams showing the location and functions for all aircraft systems. d. Figure showing the waterline and center of buoyancy at maximum taxi weight for both forward and aft CG conditions. e. crew stations
Aircraft weight statement, aircraft center-of-gravity envelope reflecting payloads and energy weight allocation. Establish a forward and aft center of gravity (CG) limits for safe flight in the normal categories. a. Weight assessment summary shall be shown at least at the following level of detail: i: Propulsion, ii: Airframe Structure -1. Wing 2. Empennage 3. Landing Gear 4. Fuselage, iii: Control systems, iv: Payloads, v: Systems- 1. Instruments and Avionics 2. Fuel/oil (battery if electric) 3. Hydraulic/pneumatic/electrical systems (if chosen).
Hull/float design and analysis CAD Design landing gear and Hull+wing floats Perform stress & strain analysis (solidworks simulation) to ensure structures and materials can support aircraft.
Propulsion system description and characterization including performance, dimensions, and weights. The selection of the propulsion system(s), sizing, and airframe integration must be supported by analysis, trade studies, and discussion. fuel system, fuel tank type and location (2D diagram) Perform thermal analysis to ensure materials can withstand thermal output of engine Calculate rate of climb, maximum ceiling, service ceiling

Assigned Tasks: Eva Sanchez
Summary of basic stability and control characteristics This should include, but is not limited to i: static margin. ii: Compliance with applicable regulations, including FAA regulations for aircraft design, certification, and testing.
Perform thermal analysis i: ensure materials can withstand thermal output of engine ii: Selection of materials, including metals, composites, and other advanced materials, based on strength, weight, corrosion resistance, and other factors. Perform stress & strain analysis (solidworks simulation) to ensure structures and materials can support aircraft