CONCEPTUAL DESIGN REVIEW

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ABSTRACT

The Project Calypso team presents an unmanned aerial vehicle designed to perform quick-response shore-to-search operations in aid of United States Coast Guard craft performing search and rescue operations. The down-selected concept is a catapult-launched but arrested recovery aircraft which contains an off-the-shelf sensor payload in an internal housing with additional accommodations for a lightweight life raft which can be deployed to persons in distress. The aircraft's mission requires an operational endurance of at least one hour, providing real-time video feed to Coast Guard personnel during the loiter phase of flight. The aerodynamic design of this aircraft features a conventional high-wing and t-tail arrangement for maximum takeoff and cruise performance while also reducing prop interference over the aircraft's control surfaces. Preliminary sizing and analysis of the Project Calypso aircraft was completed to simulate and predict the behavior and response of the aircraft to various impulses. This includes the preliminary weight and structural sizing, simulated aerodynamic data, fuselage sizing and design, propulsion, and power selection, as well as control response analysis for the down-selected aircraft type. A preliminary risk analysis and risk mitigation plan is also outlined for various deficiencies or anticipated issues with producing a functional flight test article.

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LIST OF VARIABLES

ζ	=	Damping Ratio
Ø	=	Diameter
AR	=	Aspect Ratio
C_D	=	Drag Coefficient
ΔC_D	=	Change in CD
C_L	=	Lift Coefficient
C_M	=	Moment Coefficient
CG	=	Center of Gravity
$F1$	=	Damped Natural Frequency
ft	=	Foot
kts	=	Knots
lb	=	Pound (force)
Re	=	Reynold's Number
V_{dash}	=	Dash Velocity
W	=	Watts

LIST OF ACRONYMS

AoA	=	Angle of Attack
AR	=	Aspect Ratio
ASL	=	Above Sea Level
CAD	=	Computer Aided Design
CATOBAR	=	Catapult Assisted Takeoff but Arrested Recovery
HD	=	High Definition
I/O	=	Input/Output
MSL	=	Mean Sea Level
MTOW	=	Maximum Takeoff Weight
PFD	=	Personal Flotation Device
OTS	=	Off-the-Shelf
SAR	=	Search and Rescue
SOW	=	Statement of Work
UAS	=	Unmanned Aerial System
UAV	=	Unmanned Aerial Vehicle
USCG	=	United States Coast Guard

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1.0 INTRODUCTION

1.1 Need / Business Case

As the proliferation of Unmanned Aerial Systems (UAS) has grown, there is demand to use such craft to decrease the time required in locating and providing aid to persons lost at sea—a process known as Search and Rescue (SAR). The United States Coast Guard (USCG) maintains a long history of search and rescue operations across the United States, though the efficacy and response times of these rescue attempts is limited by proximity to manned stations. A series of small, unmanned ground stations to launch and recover a shore-based Unmanned Aerial Vehicle (UAV) would dramatically decrease SAR response times and increase the likelihood of a safe recovery of persons lost at sea.

When the precise location of a person in distress is not known, the process of searching and locating the individual is the most time-intensive phase of the SAR process [1]. Even in regions with one or more overlapping stations, as shown in *Figure 1.1*, the on-site response time is set to two hours [2]. As a result, the USCG has failed to meet its maritime response goals for the last five fiscal years, with 2,582 deaths occurring over the same period due to a failure to meet search and rescue needs [3].

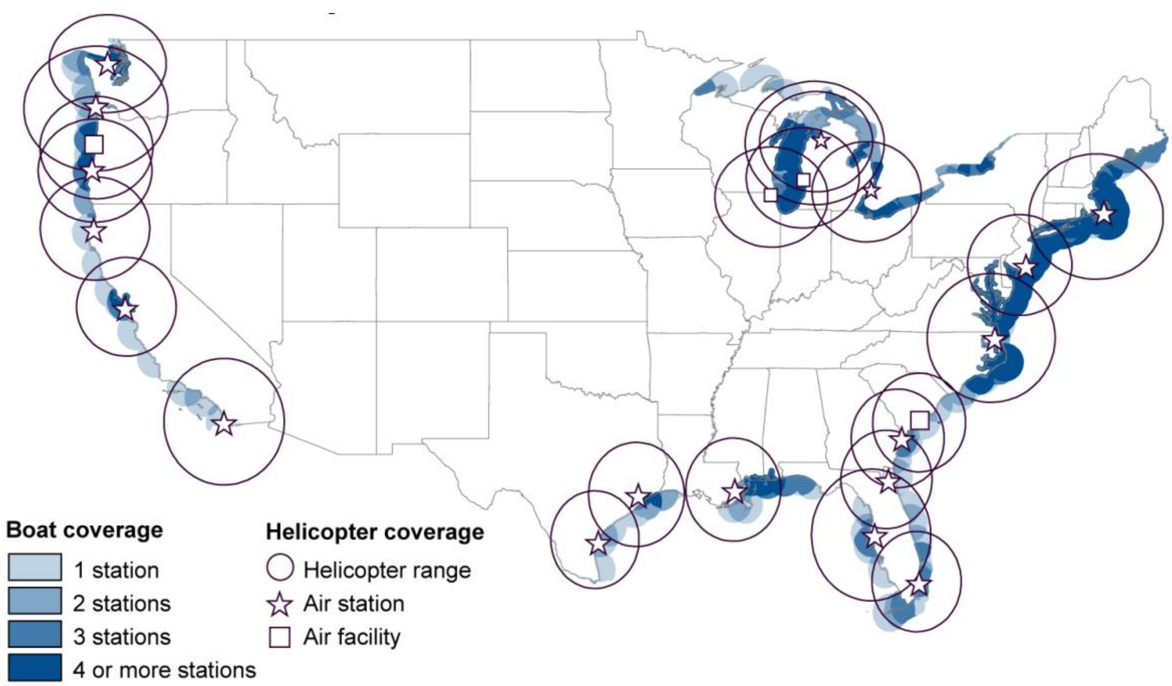


Figure 1.1: Overlap of Coast Guard Search and Rescue coverage provided by, air stations, and air facilities as of May 2017 [4]

Most lives lost in search and rescue attempts occurred before the USCG has received notification of a person in distress. From the years of 2000-2015, approximately 66% of lives lost occurred before a Coast Guard mission was sent. Since this notification period cannot reasonably be improved without major infrastructure improvement, Project Calypso will instead focus on reducing shore-to-search response periods for a SAR mission. In this regime, 3,991 lives have been lost from 2000-2015, with the majority being considered survivable if the USCG's rescue attempt could've been managed in a quicker timeframe [4]. Consequently, an unmanned search and rescue craft needs to prioritize a low search-acquisition time and ideally would provide the victim with a flotation device to extend their survival time in the water as long as possible.

1.2 Existing Platforms

The USCG currently operates the Eurocopter MH-65 as its primary aerial search and rescue platform. With 102 aircraft distributed around the continental United States coastline, the MH-65s 400-mile range allows it to cover nearly the entire country [5]. However, this manned helicopter is not well suited to the mission of rapid-response search and rescue. The need to scramble crews, conduct routine maintenance, and operate from established air stations make the MH-65 too costly to operate in this role.

Another platform operated by the USCG in a limited capacity is the Boeing/Insitu ScanEagle. This is a medium-scale UAS used for reconnaissance by several branches of the U.S. military and well as coastal search by the USCG. The ScanEagle can cruise at 80 kts for up to 18 hours, making it an exceptional long-endurance platform [6]. For the purposes of a search and rescue platform, the ScanEagle is not suitable due to its lack of an internal payload bay for a life raft.

The UAVision Spyro is a heavy-lift octocopter platform which has been trialed for use as a short-range SAR platform. The aircraft can lift 15 lb which is sufficient for life raft deployment and can loiter for up to an hour [7]. However, multirotor platforms suffer in high crosswinds and the short range of only 15 miles makes the Spyro a poor choice for rapid-response search and rescue, despite its low cost.

2.0 CONCEPT OF OPERATIONS

To accomplish a search and rescue mission, the Calypso aircraft will follow a mission plan with four phases. The aircraft will autonomously launch from a ground station, climbing to 400 feet, then will cruise to the location of the distress signal within a 15 minute period at a maximum operational range as defined in the operational requirements, at which point it will begin to search for victims using its sensor package. Once a victim has been identified, the aircraft will deploy a life raft to the persons in distress. At this point, the aircraft can either continue to loiter or return to base. A visual depiction of the search mission is shown in *Figure 2.1*.

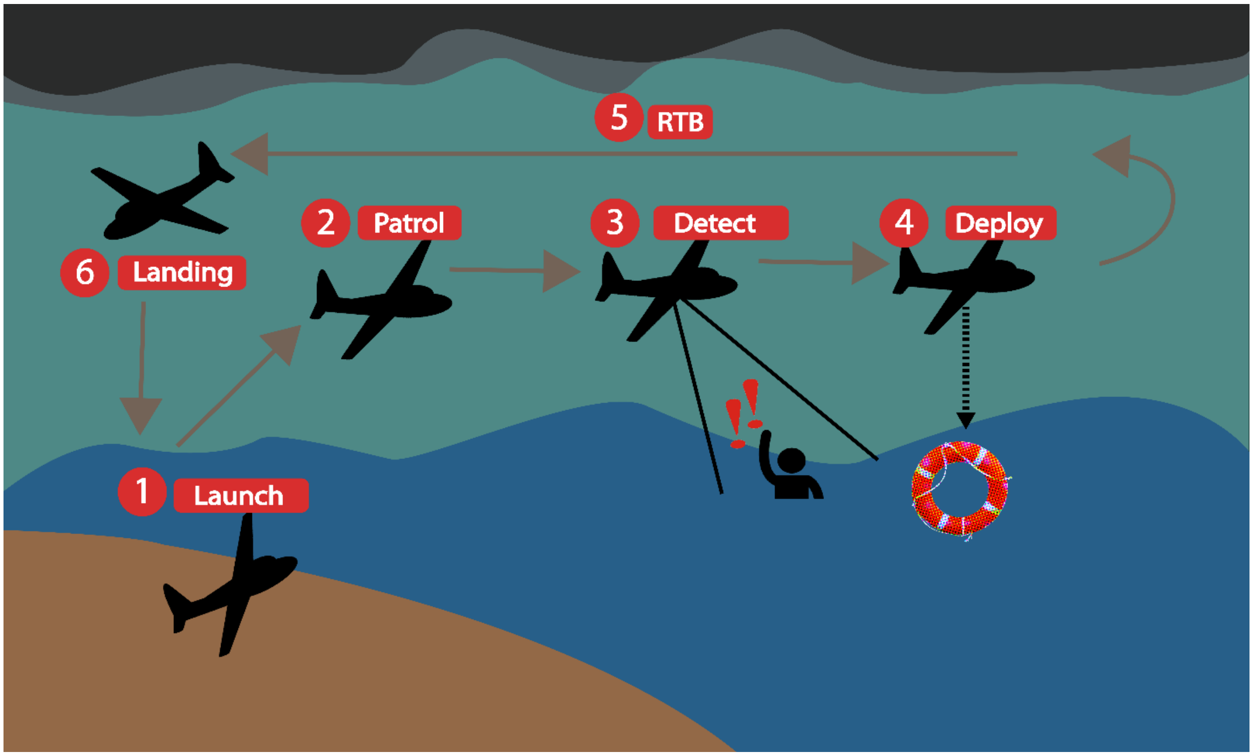


Figure 2.1: Typical Mission Profile for the Calypso UAV

2.1 Launch and Transit

The launch phase begins when a signal is transmitted to the Calypso aircraft and base station from the nearest USCG base. This signal contains information from a distress signal sent to the Coast Guard, including last known location. The Calypso aircraft will then autonomously launch from the base station and climb to 400 feet ASL. Once at its operational altitude, the aircraft will autonomously fly up to 20 miles offshore to the last known location within 15 minutes. This allows for extensive shore-to-search coverage of a coastline with a Calypso aircraft deployed every 30 miles.

2.2 Search

Once the aircraft arrives at the last known location of the victim it will begin to search for the target using the Victor-Sierra search pattern. This is a proven search technique used by the USCG [2] when only a single search unit is available. The datum is located at the last known location of the victim and a rotating sector search based on this datum accounts for wind and wave drift. *Figure 2.2* displays this search pattern. The aircraft will search for at least 30 minutes, which allows for one complete rotation of the sector search. During this time, the aircraft will use its sensor package to scan for persons in distress. If one is detected, the mission proceeds to the deployment phase.

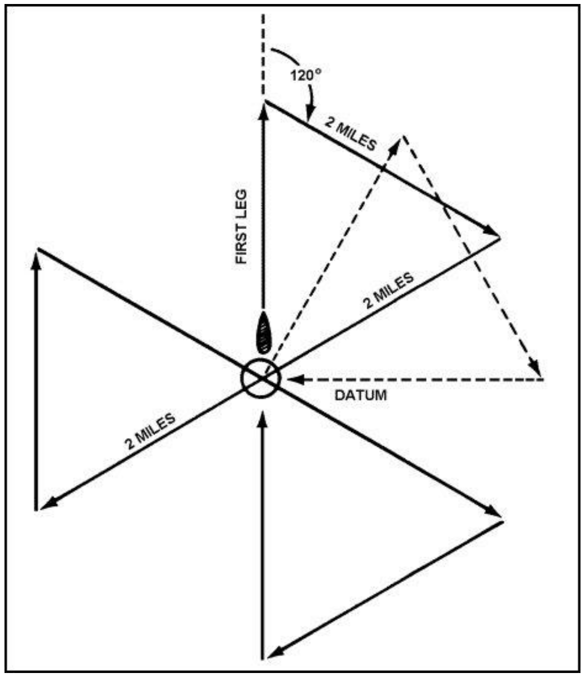


Figure 2.2: Victor-Sierra Single Unit Search Pattern [8]

2.3 Payload Deployment

Once a victim is detected the Calypso aircraft will deploy a life raft. The life raft is designed to fit within the aircraft, deploy while the aircraft is at speed, and provide enough buoyancy to keep multiple victims safe until the USCG arrives with surface vessels or rescue helicopters. In order to deploy the raft, the aircraft will fly upwind toward the victim, reduce altitude to improve accuracy, and release the life raft so that it impacts near the victim. Once this has been completed, the aircraft can either loiter near the victim to provide real-time video and location information or return to base.

2.4 Return and Landing

After the aircraft is commanded to return to base it will switch to autonomous operation. It will then fly to the base station at 400 feet ASL for recovery. Calypso will then land autonomously at the base station for reloading and recovery. Since base stations will likely be in remote areas, the aircraft will be able to be returned to launch status again with a new life raft and fresh batteries or fuel within an hour to minimize the logistics of operating a larger fleet of aircraft.

3.0 MISSION REQUIREMENTS

The following includes requirements listed in the statement of work (SOW) as well as derived requirements. The derived requirements were created to combine certain given requirements or to provide requirements necessary to accomplish a mission. In addition, the derived requirements also contributed to the refinement of the design by providing a clear understanding of the needs that are expected of the Calypso aircraft.

3.1 Statement of Work Requirements

The given requirements are explicitly stated in the statement of work laying out the design process for the aircraft. The primary objective of the aircraft is to provide a method for the Coast Guard to search for victims in a reliable but more time-responsive manner. In addition to relaying video feed, the aircraft must also be able to deploy a 4-pound life raft and be capable of autonomous flight. The complete list of given requirements is listed in *Table 3.1*.

Table 3.1: RFP Design Requirements

Item	Requirement
Operating Altitude	Sea level to 400 ft MSL
Operating Temperature	-20° to 40° C
Speed Requirement	Cover 20 miles in less than 15 minutes.
Operating Range	20 mile minimum
Loiter Time	30 minute minimum
Load Factor	3.5 g
Climb Rate	1000 ft/min
Weather Limit	Level 7 Beaufort scale
Sensor Payload	4-lb self-powered payload.
Takeoff Weight	25 lb.
Stand-by	3 months
Reset time	< 1hr.
Service Life	< 250 hours
Launch System Size	4 ft x 4 ft elevated platform

3.2 Derived Requirements

Based on the given requirements, subsequent derived requirements have been formed. The most important derived requirement formed is the cruise speed of the aircraft. In the statement of work, the aircraft must be able to cover a 20-mile area in less than 15 minutes. This equates to an average speed of no less than 80 miles per hour. Factoring in a maximum head wind component from the level 7 (38mph) Beaufort winds, we derived that our cruise speed should be no less than 103 knots (118mph). This requirement was deemed to be the main driving requirement due to it posing the biggest challenge to achieve.

Since the aircraft must be launched and retrieved from a 4 ft x 4 ft platform, we derived that a cable recovery system is to be used. Since a cable recovery system works by catching the leading edge of the wing, we derived that the engines must be placed in a pusher configuration to avoid damage to the propeller.

Since the primary objective involves coastal search and rescue, additional environmental requirements were derived. The main derived environmental requirement is for the aircraft to be resistive to corrosion. Since the aircraft will primarily be operating around saltwater coastlines and remain on stand-by for extended periods of time, resistance to saltwater corrosion is a necessity to achieve a 3-month stand-by period. In addition to corrosion resistance, we derived that the aircraft must also be buoyant in water. This is to ensure that the aircraft can be recovered in the event of a water landing.

One of the main needs requested from the aircraft is the ability to deploy a life raft. Since the size and weight of the life raft have not been defined, we derived that payload should weigh no more than 5 lb and be large enough to support 2 people. In addition to the size and weight requirements, the life raft must also be self-inflating.

3.3 Design-Driver Requirements

The largest requirement driving the overall design of the aircraft is the high cruise speed. This characteristic of the aircraft is highly crucial in the design, as an increase in speed drastically reduces the response time. This parameter also offers an edge over the competition as currently search and rescue operations are conducted with full size manned aircraft with a response time on the order of hours. With a rapid launch system and fast cruise speed, Calypso is able to reach a victim within 15 minutes. In addition to the fast response time, the Calypso aircraft is also capable of delivering a life raft. This provides an advantage over similar platforms such as the Boeing ScanEagle which is not capable of payload deployment. With the Beaufort level 7 wind and weather requirement, the stability of the aircraft plays an important role in design considerations. This has pushed design methodology to adopt a more conventional design with large control surfaces in order to maintain aerodynamic stability. Another factor contributing to aerodynamic stability is the rapid deployment of the payload. Since the payload contributes to a significant portion of the total aircraft weight, the choice of airframe types has been reduced

4.0 LAUNCH AND RECOVERY

The launch and recovery systems for Project Calypso will need to meet the scope and scale of the intended mission set for the airframe. Most off-the-shelf solutions for launch and recovery do not fit the mission set for Project Calypso. For example, the Robonic Ltd KONTIO MC2555LLR, capable of launching a 220 lbs airframe up to 230 ft/s and pictured below in *Figure 4.1*, would provide a solution far beyond the scale of the project.

Figure 4.1: Robonic Ltd KONTIO MC2555LLR [9]

From this absence of suitable launch and recovery systems in an off-the-shelf capacity, Project Calypso has decided to design custom launch and recovery systems. Project Calypso will collaborate with other current design teams to build a launch system for the testing and execution of this and future capstone projects at Embry-Riddle Aeronautical University, Prescott. Additionally, a recovery system will be specified, and a mock-up created for evaluation.

4.1 Launch

Project Calypso will use an elastic launch system, comparable to the Elevon X Scorpion pictured in *Figure 4.2*, to achieve takeoff.

Figure 4.2: Elevon X Scorpion [10]

The designed launch system will launch the 25 lb airframe at 50 ft/s off a rail mounted within the required 4 ft x 4 ft design requirement. This requires a total of 1316 J or 971 ft-lb of energy stored in the launcher and transmitted to the airframe.

Elastic launch systems comprise one of three primary launch system designs. The others include pneumatic and ballistic launch systems, depicted below in *Figure 4.3* and *Figure 4.4*.

Figure 4.3: Pneumatic Launch System [9]

Figure 4.4: Ballistic Launch System [11]

Where elastic systems utilize stored energy in elastic cables, pneumatic and ballistic systems use compressed air or rockets, respectively. Both pneumatic and ballistic systems are well suited for intensive commercial or military use, where heavy airframes and very high takeoff velocities are required. For the purposes of Project Calypso, both alternative systems are too expensive or large and fail to meet cost and footprint requirements. The pneumatic system pictured in *Figure 4.3*, the Robonic Ltd KONTIO MC2555LLR, measures 6.5 ft by 52.5 ft. The ballistic system pictured in *Figure 4.4*, the Kratos Launch System, costs approximately $330,000 per unit. Therefore, an elastic launch system best fits the project requirements, being both small and inexpensive while still providing enough energy to effectively launch the airframe.

4.2 Recovery

Project Calypso will model a cable recovery system like the Boeing Skyhook pictured in *Figure 4.5*, to return the aircraft to the ground. An actual recreation of the recovery system falls outside the scope of the project.

Figure 4.5: Boeing Skyhook [12]

The designed recovery system will retrieve the 25 lb airframe at 50 ft/s on either a single or double cable gantry mounted on the same 4 ft x 4 ft platform as the launch system, collecting and dispersing the same 971 ft-lb of energy. The airframe will fly into the cable, intending to hook one or both wings with a latch integrated into the leading edge of each wing.

Cable recovery systems comprise one of three primary recovery system designs. The others include net and parachute recovery systems, depicted below in *Figure 4.6* and *Figure 4.7*.

Figure 4.6: Parachute Recovery System [13]

Figure 4.7: Net Recovery System [14]

Comparable to the cable recovery system, the net recovery system utilizes a fixed gantry to catch and recover the airframe. In the parachute recovery system, the airframe undergoes a stall maneuver over the intended recovery location, and then a parachute is deployed to complete a safe recovery. Both systems are preferred in use cases where high margins of error are a driving expectation. For the purposes of Project Calypso, both systems restrict the design and structure of the airframe in a manner that is unfavorable for the project's mission set. A typical parachute system, shown in *Figure 4.6*, consumes valuable fuselage space and impacts airframe weight fractions and center of gravity positioning. Net systems, like the one shown in *Figure 4.7*, require all moving parts, including propellers and gimbals, to be placed behind the leading edge of the airframe's wing. The design restrictions imposed by these systems make the cable recovery system as the best fit for Project Calypso.

5.0 PRELIMINARY SIZING

Before beginning with the aerodynamic and structural design of the aircraft, the weight of the aircraft systems was defined along with performance parameters that would allow the Calypso aircraft to achieve speed and range targets. From the provided sensor gimbal weight and maximum takeoff weight, weight fractions were calculated for the payload, airframe structure, and avionics and propulsion. A constraint analysis provided optimal wing loading and power loading values, and a sensitivity analysis determined which performance parameters to prioritize to remain within weight targets.

5.1 Weight Fractions

The maximum takeoff weight of the Calypso aircraft is defined as 25 lb from the SOW requirements and a 4 lb sensor gimbal is required to be carried. Based on other heavy-lift UAS with 6 ft wingspans, the weight fraction for payload was defined as 40%. This allows for an additional 6 lb of payload to carry the life raft. Considering the high-speed requirement, powerful motors and large amounts of energy storage are required, so a weight fraction of 30% was defined for motors, batteries/fuel tanks, and avionics. The remaining 30% of the takeoff weight was assigned to the airframe structure. *Table 5.1*, below, summarizes the weight distribution for the vehicle.

Table 5.1: Summary of Calypso Weight Fractions

	Payload	Structural	Propulsion	MTOW
Weight Fraction	40%	30%	30%	100%
Weight, lbf	10	7.5	7.5	25

5.2 Constraint Analysis

With the weight fractions defined, a constraint analysis to determine the required wing- and power-loading was conducted. Using the 6 ft maximum wingspan, 25 lb MTOW, 10 lb payload capacity, and maximum maneuvering load of 2.5 g, the minimum power loading was 120 W/lbf with a maximum wing loading of 6.06 lb/ft^2. The design point was defined as 175 W/lbf of power loading and 6.06 lb/ft^2 of wing loading. This provides a 45% excess of power to ensure the aircraft can successfully takeoff from a catapult and minimizes cruise drag by reducing the total wing area. More details on the constraint analysis process can be found in Appendix A.

5.3 Sensitivity Analysis

A sensitivity analysis based on the takeoff weight equation determined the three design driving parameters to be endurance, range, and payload weight. In order to double the planned endurance of one hour, the takeoff weight would increase by 4.16 lb, while doubling the planned range of 60 miles increases takeoff weight 2.49 lb, and each additional pound of payload weight increases the takeoff weight by 2.48 lb. From the figures, the most effective way to ensure the aircraft hits the range and speed targets is to keep the payload weight as small as possible. More detailed sensitivity information can be found in Appendix A.

6.0 AERODYNAMICS

The current aircraft utilizes a leading edge tapered wing, located above the fuselage, paired with a T-tail. Two pusher propellers are mounted on the wings. Aerodynamic surfaces including the wings, elevator, and tail were selected to best meet performance requirements, manufacturing capabilities, and resource efficiency. To achieve this, multiple configurations were researched for the wing shape, airfoils, wing location, and tail design. Eventually, trade study tables and simulations narrowed down the options to a single design which best meets the criteria as listed previously.

6.1 Configuration

Final concepts seen in *Figure 6.1* were decided using trade studies and weighted tables. Current drones, RC model aircraft, and experimental aircraft were researched and compared in order to assign values to a table. Trade studies, referenced in the appendix conducted on similar configurations were also looked at to give additional performance information, improving the down-selection process used to determine the best configuration.

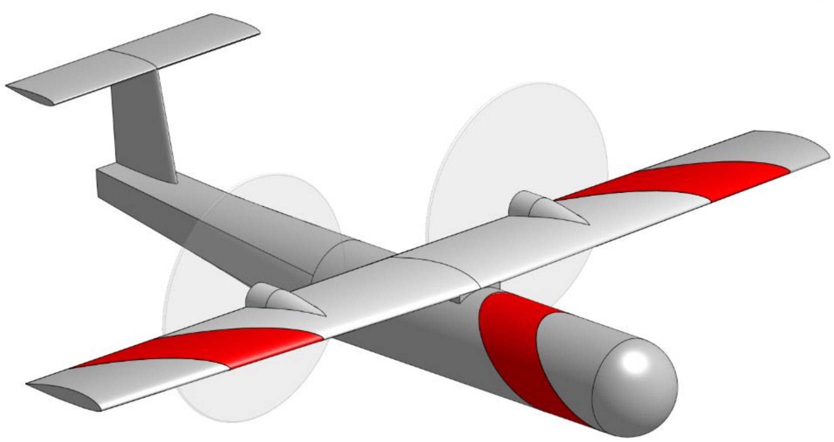


Figure 6.1: Aircraft Configuration Render

The current aircraft configuration will have key benefits during the simulation and testing phases of design. These benefits include having a smaller drag profile in the tail section, a higher cruising speed, larger payload capacity due to the high wings, and simplified controls and stability due to the T-tail and wing shape.

Additional choices for wing shape and tail configuration were both researched as a secondary option. However, simulation was limited to the current configuration and future modifications will be performed on this setup.

6.2 Wing Airfoil and Geometry

The airfoil used in simulation of the current aircraft design is a Drela MRC-16. Four other airfoils were researched and simulated for performance at a range of Reynold's numbers. High lift, low drag, and stall characteristics were initial factors when determining the best suitable airfoil. However, physical manufacturing and control mounting on the airfoil became the deciding factors, as other airfoils shown below have a thin profile. This limited the size and mounting of control surfaces as well as creating possible issues with wing fabrication in the future.

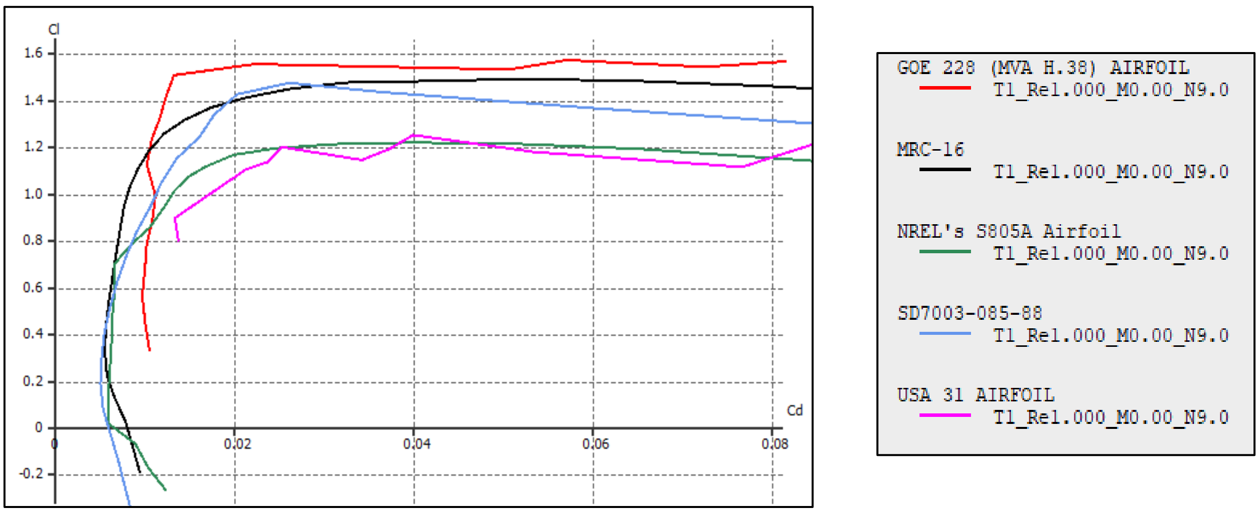


Figure 6.2: Airfoil Comparison, Selected Airfoil in Black

According to *Figure 6.2*, our selected airfoil is slightly outperformed by the GOE 228. However, due to the 2-D profiles, manufacturing concerns, and control surface mounting area, it was decided that the MRC-16 would be the best airfoil overall, given a small amount of performance was traded for testability. *Figure 6.3* and *Figure 6.4,* shown below, compare the cross sections of the selected MRC-16 vs GOE228 airfoil.

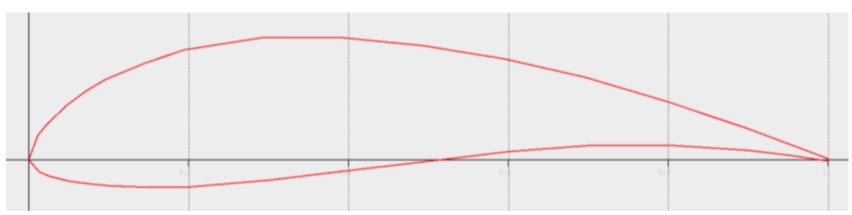


Figure 6.3: GOE 228 Airfoil Profile

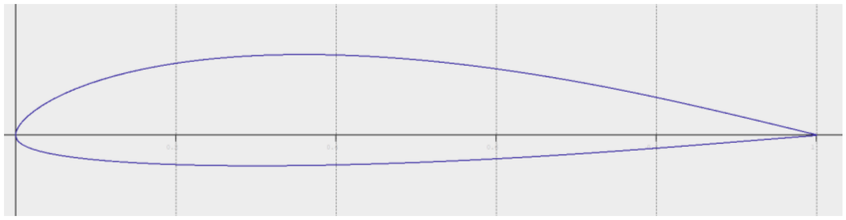


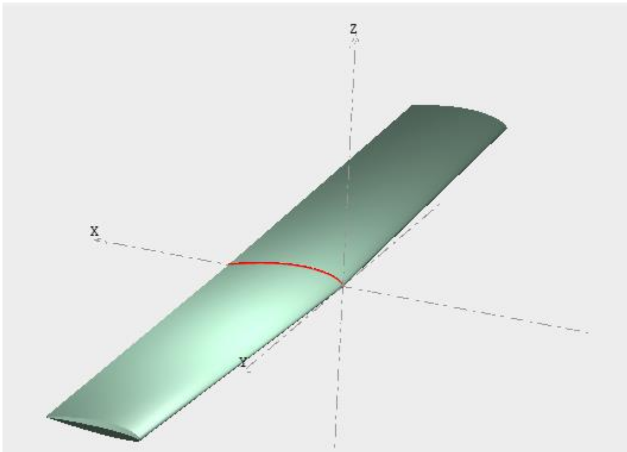
Figure 6.4: Drela MRC-16 2-D Cross section

Performance for the selected airfoil was simulated on XFLR5 in both a direct foil analysis and plane design. *Table 6.1* displays values given at a certain Reynold's number: 1,150,000. This value is the calculated estimate Re during the high cruise phase. The representation of airfoil performance at this value was used to as a reference when designing the wing and empennage sections.

Table 6.1: Airfoil Characteristics, Re = 1,150,000

Variable Simulated	Value
C_L Max	~1.5 at 16° AoA
C_L/C_D Max	130 at 6° AoA
C_L at 0° AoA	.35
C_M vs Alpha	Negative gradient

When designing the wing, a maximum wingspan of 6 ft, and aspect ratio greater than 8 was used for preliminary simulations. One variable was changed at a time between every iteration. Taper ratio was set to half the value of the difference between root and tip chord lengths. This way, the wing had a straight trailing edge, but tapered leading edge. This allowed for easier mounting and connection of control surfaces, with a minor increase in induced drag. It was decided that the benefits of fabrication outweighed the increase of drag, as $\Delta C_D < .01$.



Wing Span	72.00 in
Area	594.00 in²
Projected Span	72.00 in
Projected Area	594.00 in²
Mean Geom. Chord	8.25 in
Mean Aero Chord	8.27 in
Aspect ratio	8.73
Taper Ratio	0.83
Root to Tip Sweep	1.79 °

Figure 6.5: Final Wing Design and Dimensions

6.3 Empennage Design and Sizing

The airfoil used for the tail was a NACA 0012. This is a symmetric airfoil which allows for simple manufacturing as well as predictable results when adjusting. Design of the tail used a similar process to that of the wing. However, C_M and C_D were the main points of focus when adjusting dimensions. Negative C_M meant that the aircraft was longitudinally stable, and a low C_D meant that no unnecessary drag was added in order to increase overall aircraft stability. A negative tilt of 2° was added to the elevators, as well as a vertical taper of .8 to the tail fin. Distances from the empennage and main wing were also focused around keeping a negative C_M as alpha increases.

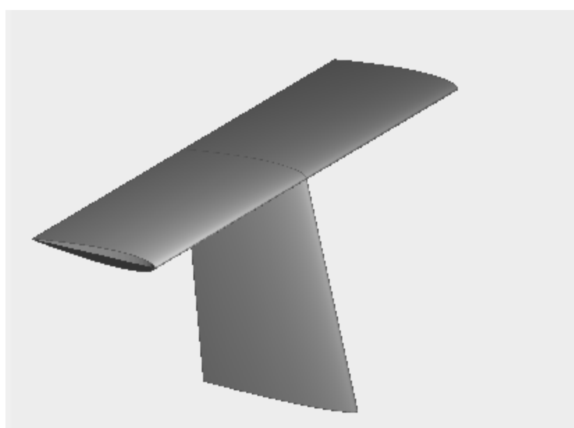


Figure 6.6: Final Tail Design

6.4 Performance and Stability

Stability testing was performed to ensure that the aircraft would return to a stable state if affected by external forces such as turbulence, gusts, and wind shear. Performance and stability simulations were conducted with a max takeoff weight of 25 lb, and an estimated inertia location for all components. This gives more accurate simulations of the aircraft performance in the cruise phase of flight. Lateral and longitudinal stability were conducted at a 0° AOA and 0° sideslip angle. All modes were simulated and are shown below.

Table 6.2: Aircraft Stability Results

Test Type	Stability	Damping Ratio
SPPO	Stable	.283
Phugoid	Stable	.056
Roll Mode	Stable	~
Dutch Roll	Stable	.060
Spiral Mode	Unstable	~

Results from *Table 6.2* were conducted on XFLR using stability analysis simulations. Both modes of longitudinal stability resulted in the aircraft returning to its original state, as the damping ratio is a positive value less than one. Two of the three modes in lateral stability returned to the original state except for spiral mode. While spiral mode is unstable, in practicality, it can be corrected with aileron input. The dynamic stability demonstrates that the current aircraft configuration, combined with current estimated load locations is stable. This is crucial as further design and modifications will be used to help maintain stability.

7.0 PROPULSION

Learning from the records of previous capstone design programs, propulsion has shown to be a key design element in determining the success or failure of each project. Project Calypso aims to achieve an overabundance in propulsion capability to ensure the best odds for success. Careful consideration will have to be taken balancing the benefits of additional thrust and the incursion of additional weight on the airframe. From the constraint analysis detailed in Section 5.2, an aircraft power requirement of 175 W/lb is required. This corresponds to a total sustained power of 4.375 kW, which will provide sufficient power for both the high-speed cruise phase and the maximum power takeoff phase.

7.1 Selected Propulsion Configuration

To achieve a dash speed of 100 kts with the MTOW of 25 lb. the amount of power needed is great enough for weight considerations and the limited placement options of a single engine to cause substantial concern. A twin-engine configuration was chosen for engine placement versatility and to minimize the propeller diameter.

Engine placement has a considerable effect on center of gravity location both with and without the payload. Engine placement on the main wing of the aircraft allows for little center of gravity movement between loaded and unloaded payload configurations. The placement of the engines behind the trailing edge of the main wing tends to be more stabilizing in both static longitudinal and static directional stability when compared to a pusher style configuration. Due to these factors, the selected engine placement is mounting the engines on the trailing edge of the main wing.

7.2 Selected Propulsion System

The main fuel types used in these engines are combustion engines and electric engines. Combustions engines are fueled with gasoline or nitro fuel but due to these fuels being susceptible to water contaminants over time, they are unstable when present in humid environments for extended periods. An electric engine running off commercially available 6 cell lithium polymer batteries allow the aircraft to achieve the stand-by time of 3 months with a trickle charger present at the base station.

The specific motors to be used will be SunnySky X5320 370 Kv brushless motors which weigh 1.09 lb each and provide 2.19 kW of continuous power [15]. With two of these motors, the power loading of the aircraft is 175.44 W/lb, meeting the power loading requirement set by the constraint analysis. The propellers selected are 18” diameter by 10” pitch, two of which can achieve 4.94 lb of thrust at 103.7 kts forward velocity, which will bring the aircraft to the required cruise speed of 100 kts. See Appendix A for thrust required versus thrust available data.

8.0 AIRCRAFT SUBSYSTEMS

To accomplish the objectives set for the Calypso aircraft, subsystems to deploy the life raft and perform the autonomous portions of the mission plan were designed. A 5 lb life raft with enough capacity for at least 2 adults was chosen and deployment mechanisms for this raft have been designed with considerations for fuselage diameter and weight. Additionally, a flight controller capable of autonomous navigation and communications hardware to maintain a link between the base station and aircraft were specified using off-the-shelf components.

8.1 Life Raft and Deployment Mechanisms

As a search and rescue platform, the life raft to be deployed by the Calypso aircraft must be able to improve the odds of survival for victims at sea and keep them safe until the Coast Guard can arrive for recovery. To achieve this goal, the life raft must fulfill the following requirements:

- Remain stable in up to 19 ft waves
- Provide sufficient buoyancy for multiple victims to remain afloat
- Self-inflate upon impacting the water
- Weigh less than 5 lb to fit within planned weight fractions
- Fit entirely within the fuselage of the aircraft

The selection of a life raft that meets the requirements is detailed in the following sections as well as the mechanisms that facilitate the storage and deployment of this life raft from the aircraft.

8.1.1 Life Raft Selection

A variety of existing off-the-shelf (OTS) products exist which meet a least one of the requirements for Calypso's life raft. These products include throwable Type IV personal flotation devices (PFDs), aviation-rated life rafts, and inflatable rafts for outdoors use. However, none of these meet every requirement set, with Type IV PFDs being too small to carry multiple people or withstand rough seas, aviation-rated life rafts typically weighing more than the aircrafts MTOW, and inflatable rafts not including ballast or self-inflating mechanisms. To remedy this issue, a modification of an OTS product to meet requirements will be used.

The modified life raft is based on the Uncharted Supply Co. Rapid Raft [16], an inflatable raft designed for transiting small lakes or rivers. This raft supplies 400 lb of buoyancy, enough to support two adults fully. It weighs 3.8 lb and packs into a cylinder with dimensions 15" long by 5" in diameter in unmodified form. Two modifications are necessary to meet all requirements: first, a CO_2 inflator which activates upon immersion in water, and second, ballast bags which fill with seawater and stabilize the raft by increasing its mass and lowering its center of gravity. These modifications increase the weight of the raft to 5 lb and the packed size to 15" long by 5.25" in diameter. With these modifications the Rapid Raft meets all requirements for use by Project Calypso. A summary of the specifications of the Rapid Raft is presented in *Table 8.1* and a product image of the raft is shown in *Figure 8.1* with a person for scale.

Table 8.1: Modified Rapid Raft Specifications

Buoyancy, lb	400
Weight, lb	5
Packed Dimensions, in	15 x 5.25Ø
Deployed Dimensions, in	72 x 33 x 12

Figure 8.1: Inflated Rapid Raft

8.1.2 Life Raft Deployment Mechanism

With the dimensions of the fuselage and life raft determined, mechanisms to deploy the life raft in flight can be designed. These mechanisms need to be optimized for weight, power consumption, and number of receiver channels required. Two different concepts were designed, one which vertically drops the life raft out of the aircraft, named the Bomb Bay Type, and one which ejects the life raft behind the aircraft, named the Ejector Type. A preferred concept has not yet been selected, as physical prototyping is required to validate the performance of these mechanisms. The following sections describe the mechanical principle of each type and compare their respective strengths and weaknesses.

8.1.3 Bomb Bay Type

The Bomb Bay Type, pictured in *Figure 8.2*, utilizes a bracket which mounts to the life raft with elastic bands. This eliminates the need to modify the raft to add a rigid, integral bracket. The fuselage frames in the payload bay are modified to leave the belly of the aircraft open allowing for the life raft to drop vertically out. To hold the raft to the fuselage, latches interlock with loops on the bracket. By connecting these latches with an over-centered linkage, the weight of the life raft closes the latches more securely. When the payload is released, the camshaft that the latches are mounted to rotates, unlocking the over-centered linkage and allowing the weight of the life raft to spread the latches apart and drop the raft. This design requires a single servo to turn the camshaft and weighs 0.25 lb, including 3 fuselage frames. The entire assembly fits within a 7” diameter tube and is 15” long, making it very compact. However, this design is complex, using 18 different parts, of which 11 rotate. This increases the likelihood of failure when trying to deploy the life raft.

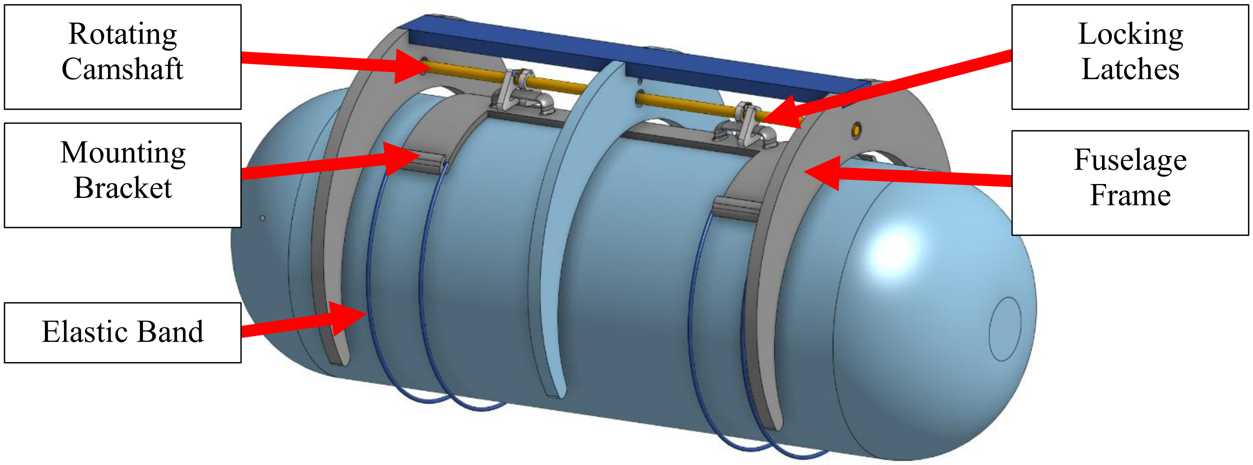


Figure 8.2: CAD Model of the Bomb Bay Type

8.1.4 Ejector Type

The Ejector Type, pictured in *Figure 8.3*, was designed to be simpler and more reliable than the Bomb Bay Type. In order to meet this goal, it uses a different deployment strategy. Instead of vertically dropping the life raft, a tube containing the life raft pivots out of the fuselage and a spring ejects the life raft from the aircraft. This design only uses 6 parts which are larger and stronger than the small linkages used in the Bomb Bay Type. It is also driven by a single servo. However, this mechanism it weighs 1.60 lb, nearly 6.5 times more than the Bomb Bay Type. It is also physically larger with a diameter of 7” and a length of 17.7”. Whether this weight and size increase is worth the added reliability is undetermined and requires further testing.

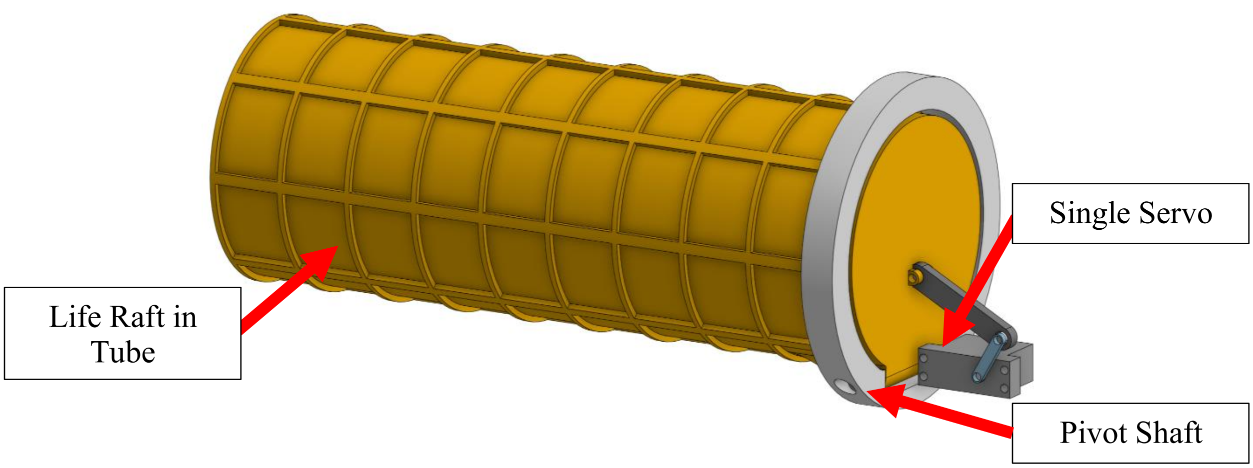


Figure 8.3: CAD Model of the Ejector Type

8.2 Flight Control and Communications

Due to the long range of operation, a flight controller and long-range communication is selected. The flight controller can be remotely programmed with the mission through the use of the long-range communication. This allows for the aircraft to automatically perform a search pattern allowing for the operator to focus on detecting the victim. The victim detection is accomplished with the radio communication sending video feed back to the operator.

8.2.1 Flight Controller

The Pixhawk 4 flight controller is selected to perform the autonomous commands of the flight. This task is necessitated from the given and derived requirements listed in the statement of work. The flight controller is used to program missions needed for autonomous flight as well as pre-programed flight patterns such as the Victor Sierra pattern. The flight controller is also capable of operating the aircraft in an aerodynamically unstable configuration as a failsafe.

The flight controller was picked on the premise of being inexpensive, having an adequate number of I/O ports and good accessibility. The Pixhawk 4 has a total of 16 I/O ports which can control anything from control surface to motors and payload release mechanisms. This far supersedes the amount of we need for our aircraft. The Pixhawk 4 also has good documentations which allows the integration and development process to be easier. The Pixhawk 4 is also reasonable priced at 190 USD allowing for the viability of the aircraft to be mass produced without heavily imposing on the total cost.

8.2.2 Radio Communications

The Commtact MDLS is selected as the primary radio communication system. Since our aircraft is to operate at a maximum range of 20 miles, a long-range communication system is necessary. This requirement is met with the Commtact MDLS radio. The Commtact MDLS is used to communicate to the aircraft in order to provide the aircraft with new mission profiles, and for the aircraft to send back a video feed.

The communication system was picked on the premise of having adequate range, being light weight, and having a good bandwidth. The Commtact MDLS has a weight of 0.22 lb which is far lower than the competitor which weigh in excess of 2.2 lb. Having a lightweight system is crucial since one of the given requirements necessitates that the aircraft weigh less than 25 lb. The Commtact MDLS has a range of 25 miles, which meets range requirements of 20 miles. In addition to the long range and weight, the Commtact MDLS possesses good bandwidth allowing for HD video transmission. This will provide the operators with live video feedback on the condition of the victim. The operators will also be capable of assessing the situation of the victim in order to develop an appropriate rescue procedure.

9.0 STRUCTURES

9.1 Fuselage Design

The fuselage was designed around the lift raft that was chosen with more space. Therefore, the diameter of the fuselage is 7” to 8”. The length of the fuselage is 42” to 46”. When the length of the fuselage is divided by the diameter of the fuselage a fineness ratio is derived. A higher fineness ratio gives less drag which results in higher speeds. When dividing the stated values above a fineness ratio close to 6 is calculated. A fineness ratio of 6 is ideal in subsonic flows for Calypso air raft, which meets mission parameters.

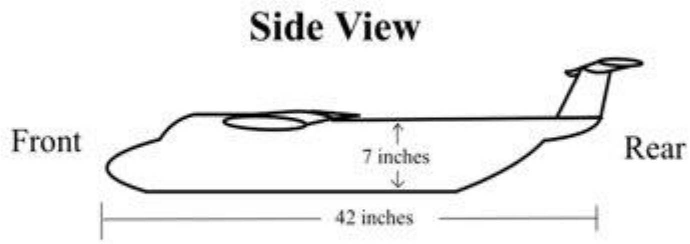


Figure 9.1: Type A Fuselage

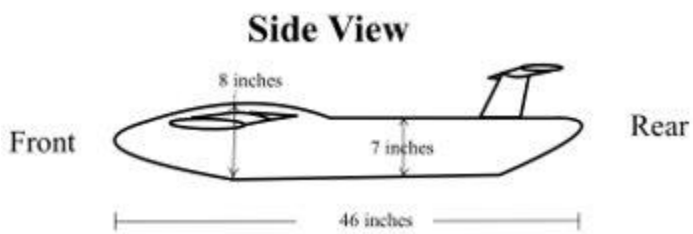


Figure 9.2: Type B Fuselage

Type A and Type B fuselage is derived from a visual aspect of cargo planes. Additionally, the two fuselage designs are meant to be interchangeable. Meaning the fuselages can be paired with either a bomb bay payload method or the ejector payload method. The Type A fuselage is best paired with the bomb bay payload method due to the positioning of the wing, vertical tail, and smaller fuselage length. The Type B fuselage works better with the greater length requirements of the ejector payload method and its requirement for a sturdy pivot mounting point.

9.2 Manufacturing Considerations

When manufacturing either fuselage, clearance integrity is the main concern. This concern is properly addressed by considering the dimensions of the payload delivery method and rescaling the fuselage to scale. The fuselage’s center of gravity is design-critical due to the aircraft’s requirement of deploying a mission payload.

10.0 RISK ASSESSMENT

10.1 Risk Analysis

Risk analysis of the Calypso Project is intended to identify and prepare for probable or impactful circumstances which may cause a mission failure during the prototyping, production, manufacture and testing of the aircraft. The probability of occurrence ranges from 0.1-0.9 with the highest possible probability of 0.9 indicating an event which is almost certain to occur, whereas a probability of 0.1 indicates an event which is very unlikely to occur. Severity is determined from the same range, with 0.9 indicating catastrophic mission impact and 0.1 indicating a negligible impact from the event. The following risks in *Figure 10.1* are design-drivers in influencing how Project Calypso will approach its design and fabrication process:

1. Manufacturer of Pixhawk flight controllers and associated avionics sub-systems goes out of business. Inability to use designed mission deployment and flight control schemes.
2. Hard landing of aircraft with potential damage to airframe and components due to inability to arrest via recovery mechanism.
3. Requirements in SOW cannot be met within weight, endurance, and propulsion requirements. Design parameters of aircraft change to meet overall mission profile.
4. Strong wind conditions as specified occur laterally and instantaneously upon aircraft, resulting in a large rolling / yawing moment which causes momentary loss of control for aircraft.
5. Catapult launch system is unable to meet specification or is unable to be built in-time for launch testing. Conventional takeoff necessary.

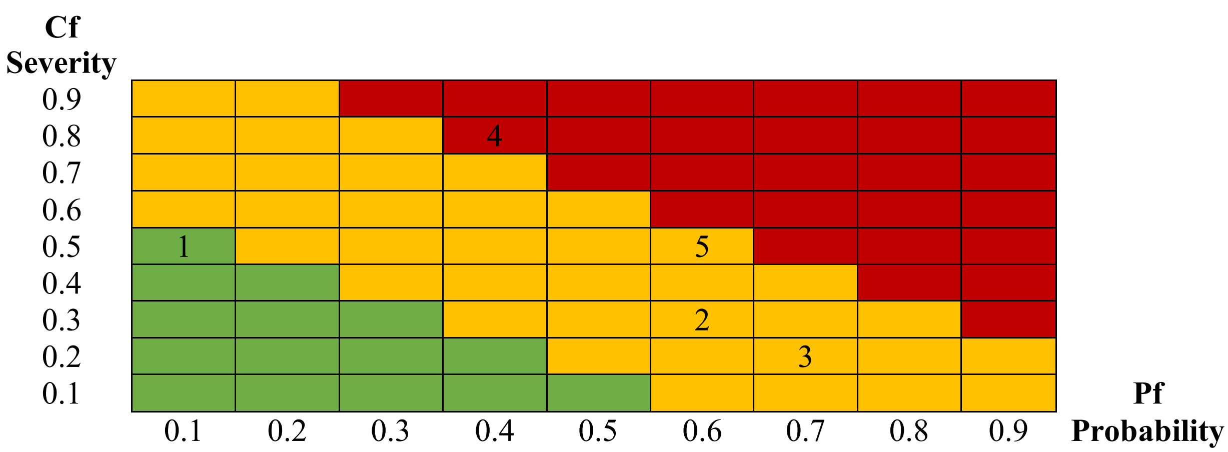


Figure 10.1: Risk Analysis Matrix

In *Figure 10.1* the risk analysis matrix has three degrees of risk impact, which is a product of the risk probability and the risk severity. The green region indicates a minor overall impact on the project, which generally have a low probability of occurrence and/or have minimal impact on the project if they were to occur. The second region is colored yellow which indicates a moderate impact on the project, constituting of somewhat likely and reasonably impactful risks associated with the project which may require additional resources or investment to overcome and rectify. The final region is colored red and indicates a major risk impact to the project, which requires either substantial risk mitigation or else poses mission-critical significance to the success of the project.

Table 10.1: Risk Impact & Associated Totals

Risk Type	P_f	C_f	$Total$	Risk Impact
1. Business Closure	0.1	0.5	0.05	Minor
2. Hard Landing	0.6	0.3	0.18	Moderate
3. Inability to meet all requirements	0.7	0.2	0.14	Moderate
4. Loss of control due to wind	0.4	0.8	0.32	Major
5. Catapult launch failure	0.6	0.5	0.30	Moderate

10.2 Risk Mitigation

10.2.1 Business Closure of Avionics Retailer

The likelihood of this event is extremely small, with Pixhawk being a ubiquitous producer and retailer of unmanned avionics sub-systems. In the event Pixhawk were to go out of business, there is enough volume of components still available that the same parts selected for the Project Calypso aircraft could be sourced through second-hand marketplaces or via dedicated retailers. However, to minimize the risk inherent in a reliance on these avionics, secondary line-of-sight and non-line-of-sight datalinks have been specified for viability in the Project Calypso aircraft, so that they provide a usable secondary option if the prior two options are unsuccessful.

10.2.2 Mandatory Hard Landing

Since the recovery system of the Project Calypso aircraft is outside the scope of this design, the likelihood that a hard landing will be required is increased. Decisions on a safer methodology of recovery are ongoing, but in the interim to safeguard against the potential of a hard landing the fuselage and wing sections of the aircraft will have to be strengthened to endure non-ideal landing conditions. Since the design of the Project Calypso aircraft already requires mandatory strengthening to be catapult-launched, the issue of structural weakness is partially alleviated. Further focus will be placed at the front and central portions of the fuselage to avoid material buckling or shearing should the nose be the first point-of-contact in a hard landing.

10.2.3 Failure to Meet Speed, Endurance, and Payload Requirements with Weight Budget

Failure to meet initial requirements is an inherent component of the design process, with certain restrictions or design intentions set forth being unattainable in the manner requested. Especially with the current weight fractions with the aircraft payload necessitating such a large proportion of the aircraft weight, it is likely that the weight budget will have to fluctuate in order to meet speed and endurance goals.

Presently, the major design limiting factor is the endurance of the aircraft, with expected climb and speed performance being achievable for only limited periods of time before the power consumption becomes extraneous and the aircraft must revert to a far smaller cruising speed. To accommodate for this, trade studies are being done to verify the most mass-efficient propulsion and power arrangement at the current weight budget. Additionally, initial design simulation is being conducted at higher weight thresholds to determine where the most performance benefit can be obtained relative to the accommodating mass increase and cruise performance decrease.

10.2.4 Loss of Airframe Control due to Lateral Winds or Gusts

The current design iteration of the Project Calypso aircraft is optimized for flying in headwinds up to Level 7 Beaufort wind conditions, though while the aircraft is predicted to handle these conditions well, a sudden gust condition across the lateral axis may result in undesirable oscillations of the aircraft. At lower altitudes during the launch and recovery phase, such gusts are particularly impactful as there is insufficient altitude or speed to allow for aircraft recovery. To accommodate for this risk, the launch system must be adaptable such that the aircraft can takeoff into the wind without undue lateral instability. Further simulations in XFLR5 will refine our wing and tail design to reduce the effect of lateral gusts and to maximize control authority in this regime of flight.

10.2.5 Inability to Use Catapult or Failure of Catapult to Meet Acceptable Performance

To optimize cruise, payload, and endurance, the Project Calypso aircraft utilizes a conventional design, using a catapult to achieve the short takeoff objectives of the overall design. Coordination between three Capstone teams has been initiated to compile all catapult designs and configurations to allow cooperation on design and sharing of the physical launch devices. The intention of this approach is to reduce the risk of lacking a suitable catapult for launch, as previous teams have had issues with. However, communication between the different Capstone teams will be improved by introducing monthly status updates on catapult designs and/or specifications. Further specification and information sharing between teams will reduce the likelihood of a catastrophic launch failure, minimizing risk to the aircraft on launch.

11.0 CONCLUSIONS AND RECOMMENDATIONS

The Project Calypso team recommends further simulation and testing of different fuselage arrangements to best determine an ideal compromise between structural rigidity and payload capacity. It has additionally down-selected to a conventional high-wing and t-tail arrangement as these provide the best compromise between takeoff and cruise performance. This arrangement is optimal for minimizing aircraft shore-to-search times and increasing payload allowance, while still allowing for acceptable takeoff and recovery performance. A catapult-assisted launch system is also recommended to minimize the takeoff profile of the aircraft as well as increasing maximum gross takeoff weight. A wingspan of 6 feet is selected with an MRC-16 airfoil to provide the largest lift and payload capacity to the aircraft within the given design constraints. Due to design potential and market demand in the use of small-scale search partition aircraft to aid in search and rescue operations, the Project Calypso team recommends further refinement of the aircraft design and concept, and that

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15.0 APPENDIX A

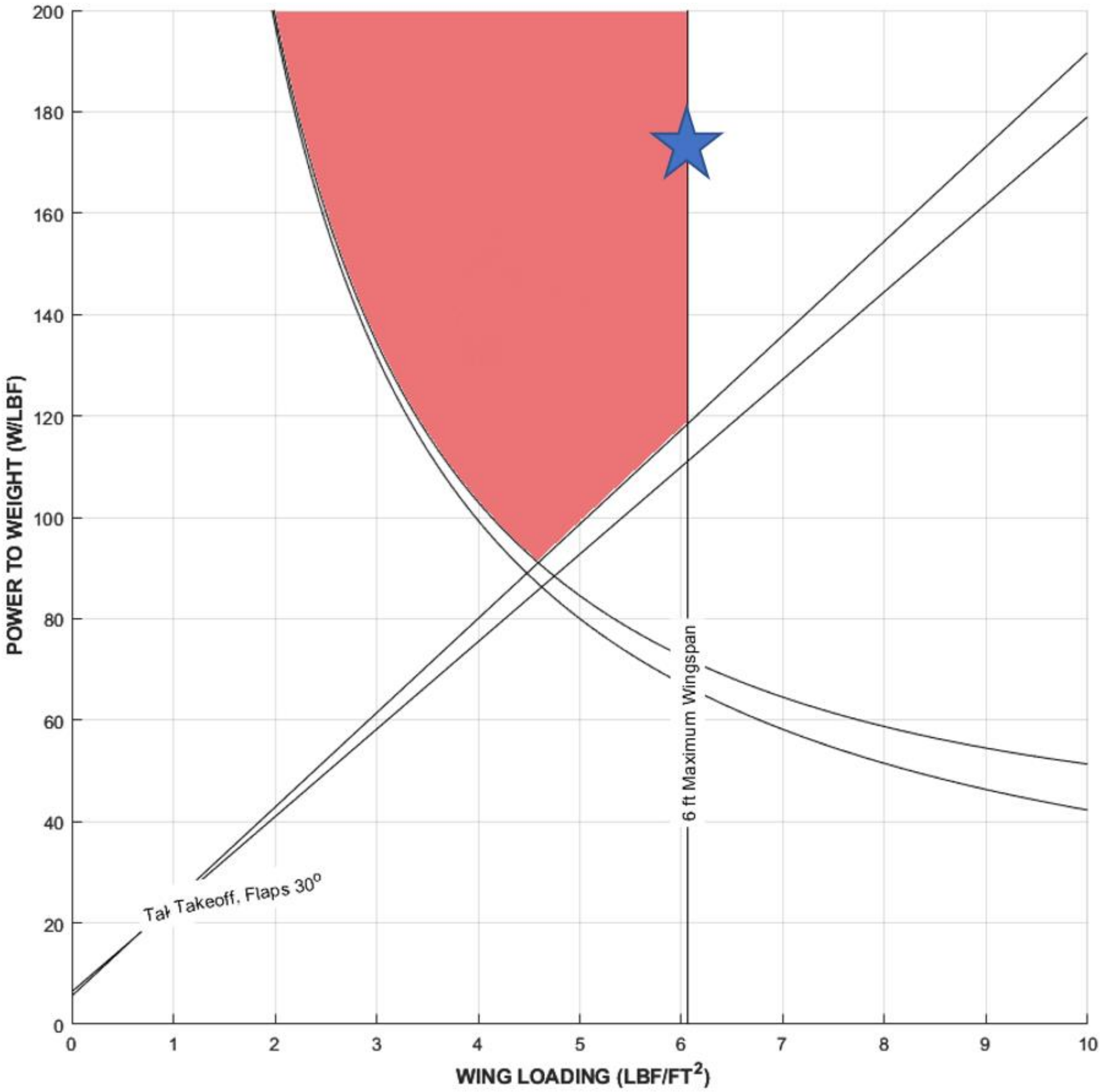

Figure 15.1: Constraint Analysis for Calypso Aircraft. Red Shaded Area is Solution Space, Blue Star is Design Point

Table 15.1: Constraint Analysis Key Parameters

Parameter	Value
Wing Profile	MRC-16
Empennage Profile	NACA 0012
Aspect Ratio	8.75
Taper Ratio	1
V_{dash}, ft/s	170
$V_{stall, flaps}$, ft/s	50
C_{D0}	0.156
Weight Fractions	See Section 5.1

Table 15.2: Preliminary Sensitivity Calculations

Parameter to Be Changed	Change in Takeoff Weight, lbf
Payload Weight, per 1 lbf	2.479
Empty Weight, per 1lbf	1.900
Range, per 60 mi	0.04158
Specific Fuel Consumption, per 1 lb/hp/hr	0.3717
L/D, per 1	-0.1247
Propeller Efficiency, per 0.1	-0.3119
Endurance, per 1 hr	4.158

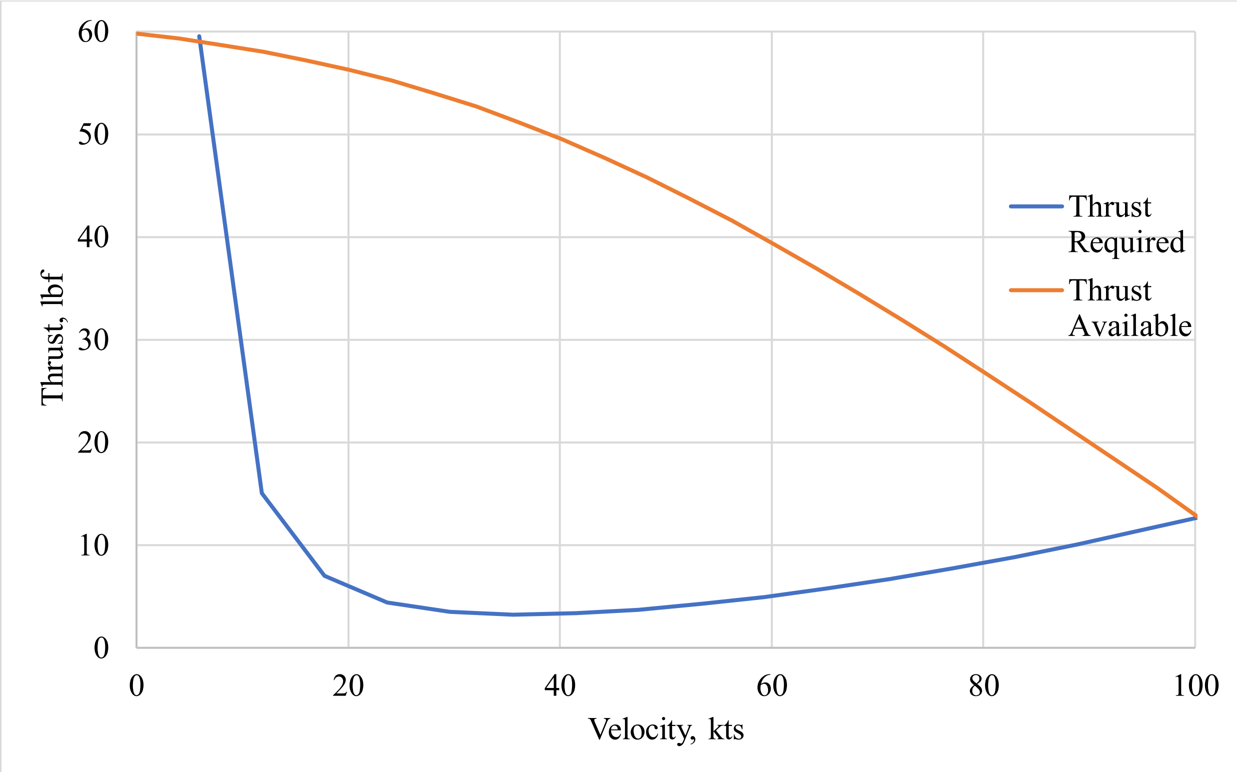

Figure 15.2: Thrust Required vs Thrust Available, 18x10 Propeller, 8000 rpm

Table 15.3: Sensitivity Analysis Key Parameters

Parameter	Value
Payload Weight, lbf	10
MTOW, lbf	25
Range, mi	60
Endurance, hr	1
Dash Speed, kts	100
L/D	20
etaP	0.8
Cp, lb/hp/hr	6.71

Table 15.4: Comparison of Commercially Available Life Rafts for Aviation Use

	ThrowRaft Survivor [17]	Uncharted Supply Rapid Raft [16]	Winslow RescueRaft [18]
Buoyancy, lb	100	400	800
Weight, lb	2.8	3.8	16
Packed Dimensions, in	12x2.5x9	15x5Ø	8x14x16
Deployed Dimensions, in	48x42x4	72x33x12	72x72x18

Wing Configuration						
	Regtangular	Tapered Straight	Sweptwing (low speed)	Elliptical	Rear Wing Canards	Score Factor
Stablity	5	3	3	4	2	4
Lift	4	4	4	3	4	4
Drag	1	4	3	4	3	3
Manueverability	3	3	2	3	3	3
Fabrication	4	4	2	1	3	2
Structural Weight	2	3	3	3	3	2
Totals:	60	63	53	57	54	

Figure 15.3: Wing Configuration Trade Study

Wing Location				
	High	Mid	Low	Score Factor
Roll and Stablity	4	4	3	4
Tail Interference	3	3	4	2
Manueverability	3	4	4	2
Cruise	3	2	3	2
Payload	4	2	4	3
Stall Characteristics	4	5	3	4
Totals:	62	60	58	

Figure 15.4: Wing Location Trade Study

Tail Configuration					
	Conventional	T- Tail	V Tail	Inverted V tail (twin boom)	Score Factor
Stablity	4	4	2	3	4
Control	3	4	4	3	5
Drag	3	4	3	2	2
Structural Weight	3	2	4	2	2
Totals:	43	48	42	35	

Figure 15.5: Tail Configuration Trade Study

Aircraft Configuration				
Category	4+1	Tailsitter VTOL	Catapult Conventional	Score Factor
TO/Landing	9	9	1	5
System Weight	1	3	9	3
Speed	3	3	9	5
Stability	3	9	9	2
Controllability	3	9	9	3
Power requirements	3	3	9	1
Complexity	9	3	9	4
Total:	117	129	167	

Figure 15.6: Aircraft Configuration Trade Study