PRELIMINARY DESIGN REVIEW

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Calypso

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 the Calypso 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. The Calypso aircraft meets current operational needs as described in the request-for-proposal, consequently the Project Calypso team is moving forward with the fabrication of the aircraft design.

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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
RC	=	Remote Control
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 increasing 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. Even in regions with one or more overlapping stations, as shown in *Figure 1.1*, the on-site response time is two hours in ideal conditions. Resulting from elongated search-response times, 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.

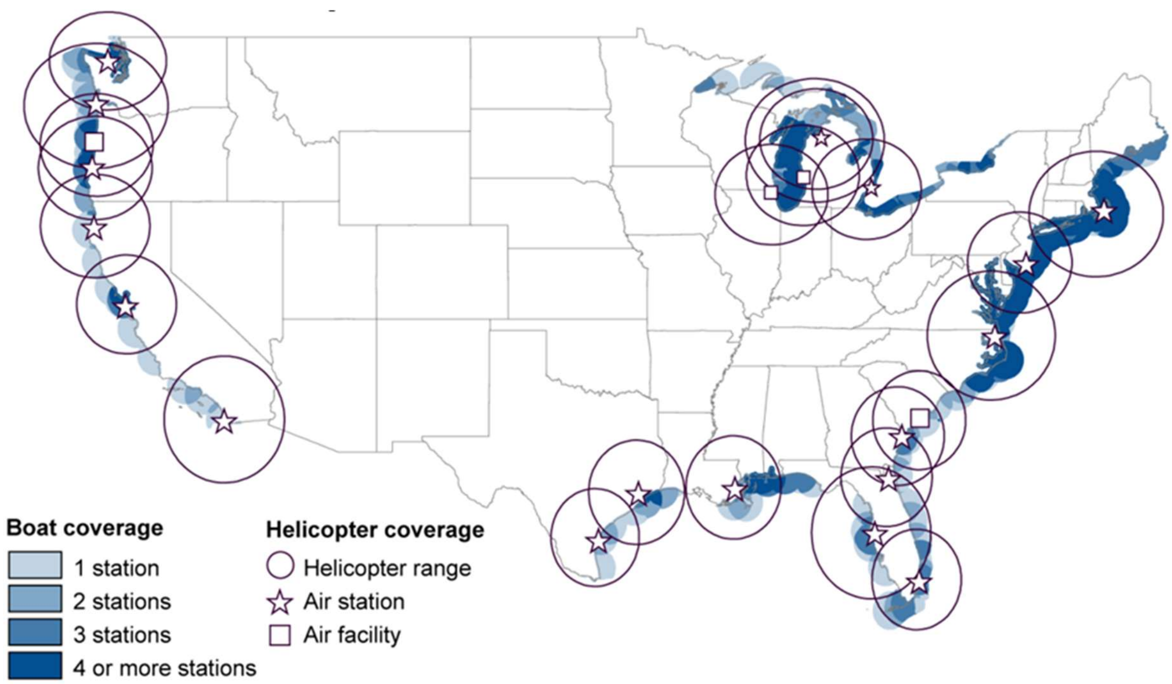

Figure 1.1: Overlap of Coast Guard Search and Rescue Coverage Provided by Surface Vessels and Aircraft as of May 2017 [1]

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. From domestic search and rescue attempts, 3,991 lives have been lost from 2000-2015, with the majority being considered survivable if the USCG's response could have initiated in a quicker timeframe. 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 use of MH-65s allow a manned response out to a 400-mile one-way range [2]. However, manned aircraft necessitate a timely response to receive a mission, crew the aircraft, and take-off in transit to the search area—requiring precious time where no search is being performed, and which cannot reasonably be decreased beyond the limits of human factors. Consequently, manned helicopters are 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 US 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 [3]. 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 that 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 [4]. However, multirotor VTOL 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.

Figure 1.2: Project Calypso Aircraft Rendering in Transit

2.0 CONCEPT OF OPERATIONS

To accomplish a search and rescue mission, the Calypso aircraft will follow a mission plan with seven 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*.

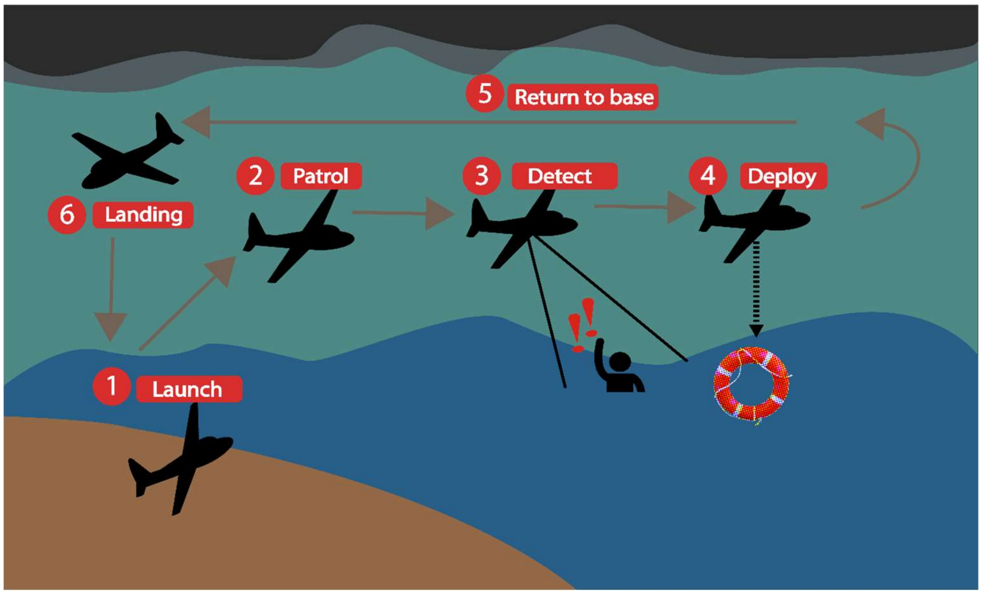

Figure 2.1: Typical Mission Profile for the Calypso UAV

2.1 Launch and Transit

The launch phase begins when a signal is transmitted to the Calypso aircraft and base station from the nearest United States Coast Guard 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 or organic search and rescue capability when deployed on surface vessels.

2.2 Patrol

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 search pattern is a proven search technique used by the USCG [5] 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.

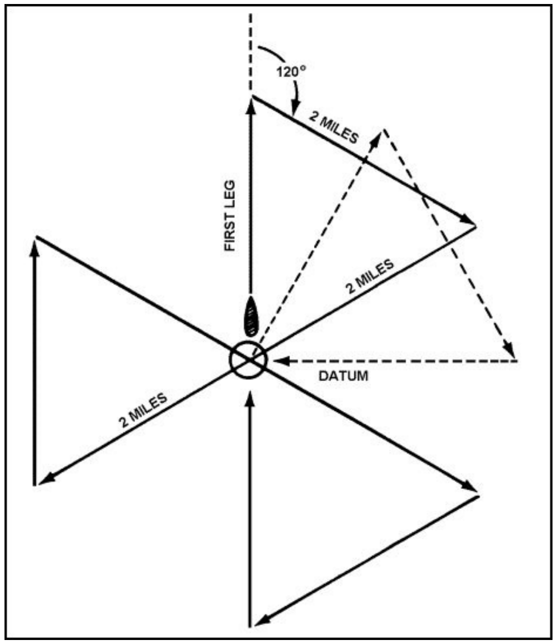

Figure 2.2: Victor-Sierra Single Unit Search Pattern [6]

2.3 Victim Detection and Payload Deployment

Once a victim is detected, the Calypso aircraft will switch to manual control using long-range radio communication to provide flight commands and a video feed. The operator can then decide to deploy the life raft based on the situation encountered. The life raft is designed to fit within the aircraft, deploy while the aircraft is at speed, and provide enough buoyancy to keep at least two 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. The duration depends on the remaining battery power, as the aircraft must return to base at 15% remaining power.

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 within an hour to minimize the logistics of operating a larger fleet of aircraft. A resupply mission for the aircraft will require at most two people to remove the aircraft from the recovery apparatus, and any replacement parts are small enough to be carried in a backpack by a single person.

3.0 MISSION REQUIREMENTS

3.1 Statement of Work Requirements

The given requirements are explicitly stated in the SOW 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 shown 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 no more than 15 minutes
Operating Radius	20 miles
Minimum Loiter Time	30 minutes
Load Factor	3.5 g
Climb Rate	1000 ft/min
Weather Conditions	Up to Force 7 Beaufort scale (32-38 mph winds, 13-19 ft waves)
Sensor Payload	4-lb self-powered payload.
Maximum Takeoff Weight	35-lb.
Stand-by	3 months
Maximum Reset Time	1 hr.
Minimum Service Life	250 hours
Launch System Size	Mountable on 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. The aircraft must be able to cover a 20-mile distance in less than 15 minutes, which equates to an average speed of no less than 80 miles per hour. Factoring in an average head wind component from the Force 7 Beaufort winds, the derived cruise speed should be no less than 115 mph (100 kts).

Table 3.2: Derived Cruise Speed Requirement

Item	Requirement
Speed Requirement	Cover 20 miles in no more than 15 minutes
Weather Conditions	Up to Force 7 Beaufort scale (32-38 mph winds, 13-19 ft waves)
Derived Minimum Cruise Speed Requirement	115 mph

Because the aircraft must be launched and retrieved from a 4 ft x 4 ft platform, the aircraft must either take off and land vertically (VTOL) or be launched and recovered by an external system. If an external system is used, the propellers must be protected from collisions into nets or wires. Thus, a derived requirement is that the motors should be arranged in a pusher configuration.

As the primary operating environment for the aircraft is the ocean, additional environmental requirements were derived. First, 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 standby period. Second, the aircraft must also be buoyant in water. In the event of a power or structural failure during a mission, the aircraft should be recoverable if it lands in the ocean. A buoyant airframe also prevents hazardous materials like fuel or batteries from being lost. Third, the power source for the aircraft must be able to sustain a 3-month standby period without becoming ineffective.

The aircraft must be able to deploy a life raft to fulfill its mission. Since the specifications of the life raft were not given in the SOW, the following requirements were derived from the operation conditions and capabilities of an aircraft of this size:

Table 3.3: Derived Life Raft Requirements

Item	Requirement
Maximum Weight	5-lb
Minimum Buoyancy	Fully support two adults (360-lb)
Stability	Withstand 19-ft waves
Deployment	Automatic upon release from aircraft

3.3 Design-Driver Requirements

Of the explicitly stated SOW requirements and implicitly stated derived requirements, four were chosen as design-driver requirements which influenced the aircraft's design the most. These requirements are listed in *Table 3.4*.

Table 3.4: Selected Design-Driver Requirements

Item	Requirement
Takeoff/Landing	Take off and land from a 4 ft x 4 ft elevated platform
Payload Capacity	4-lb sensor gimbal and deployable life raft
Minimum Cruise Speed	115 mph
Minimum Endurance	90 minutes, 20% at high cruise speed

The most important design driving requirement is the ability to take off and land on a 4-ft x 4-ft platform. This requirement drives the aircraft to either use a VTOL design or utilize a catapult. A VTOL aircraft requires a thrust-to-weight ratio of greater than one and a powerful propulsion system. A catapult requires structural reinforcements to the airframe to carry the shock of launch in addition to low speed aerodynamics to minimize the size of the catapult. This requirement greatly influences the configuration of the aircraft and its propulsion system.

The aircraft must carry both a 4-lb sensor package and a life raft which can be deployed in flight. This requirement drives the placement of these large payload masses, as an electro-optical sensor should be placed in the nose of the aircraft to maximize its field of view and the life raft should be placed at the center of gravity to maintain the static margin after deployment.

The third design driving requirement is the minimum cruise speed of 115 mph. This cruise speed directly drives the size and weight of the aircraft's propulsion system, as well as requiring the aircraft to be designed to reduce drag wherever possible to reduce the power required at cruise.

Finally, the aircraft is required to fly at 115 mph for 15 minutes, followed by at least 30 minutes of loiter time, then return to base. The estimated minimum mission time is 90 minutes, which drives the amount of fuel or battery power, and thus propulsion system weight.

4.0 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 requirements. 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 using estimated aerodynamic performance figures was used to determine the required propulsion system power and wing loading to meet takeoff, cruise, and maneuvering requirements.

4.1 Weight Fractions

The maximum takeoff weight (MTOW) of the Calypso aircraft is defined as 35-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 30%. A 30% payload fraction allows for an additional 6-lb of payload to carry the life raft. Guidelines for propeller sizing recommend at least 16-inch diameter propellers to reach the required cruise speed of 115 mph [7]. An estimation of the motors required to effectively power these propellers and the energy needed determined the weight fraction for the propulsion system. From these estimations, a weight fraction of 38% was defined for motors, batteries/fuel tanks, and avionics. The remaining 22% of the takeoff weight was assigned to the airframe structure. *Table 4.1*, below, summarizes the weight distribution for the vehicle.

Table 4.1: Summary of Calypso Weight Fractions

	Payload	Propulsion	Structural	MTOW
Weight Fraction	30%	35%	22%	100%
Weight, lb	10	11.5	8.5	30

4.2 Constraint Analysis

With the weight fractions defined, a constraint analysis to determine the required wing and power loading was conducted. The constraint analysis uses takeoff distance equation and specific excess power equation to determine these values. The 6-ft maximum wingspan, 30-lb MTOW, weight fractions calculated in Section 4.1, and maximum maneuvering load of 3.5 g as inputs to these equations. The maximum lift coefficient for the aircraft was assumed to be 1.4 without flaps and 2.0 with flaps and a simple drag analysis based on the calculated wing area and fuselage size completed the aerodynamic information required.

The resulting minimum power loading was 90 W/lbf with a minimum wing loading of 4.66 lb/ft^2. The design point was defined as 175 W/lbf of power loading and 4.66 lb/ft^2 of wing loading. The selected power loading provides a 90% excess of power to ensure the aircraft can successfully take off from a catapult and rapidly gain airspeed. By using the minimum wing loading, and thus the maximum wing area, take off velocity is reduced to improve catapult launch performance. The constraint analysis diagram is shown in *Figure 4.1* and a larger version is shown in Appendix.

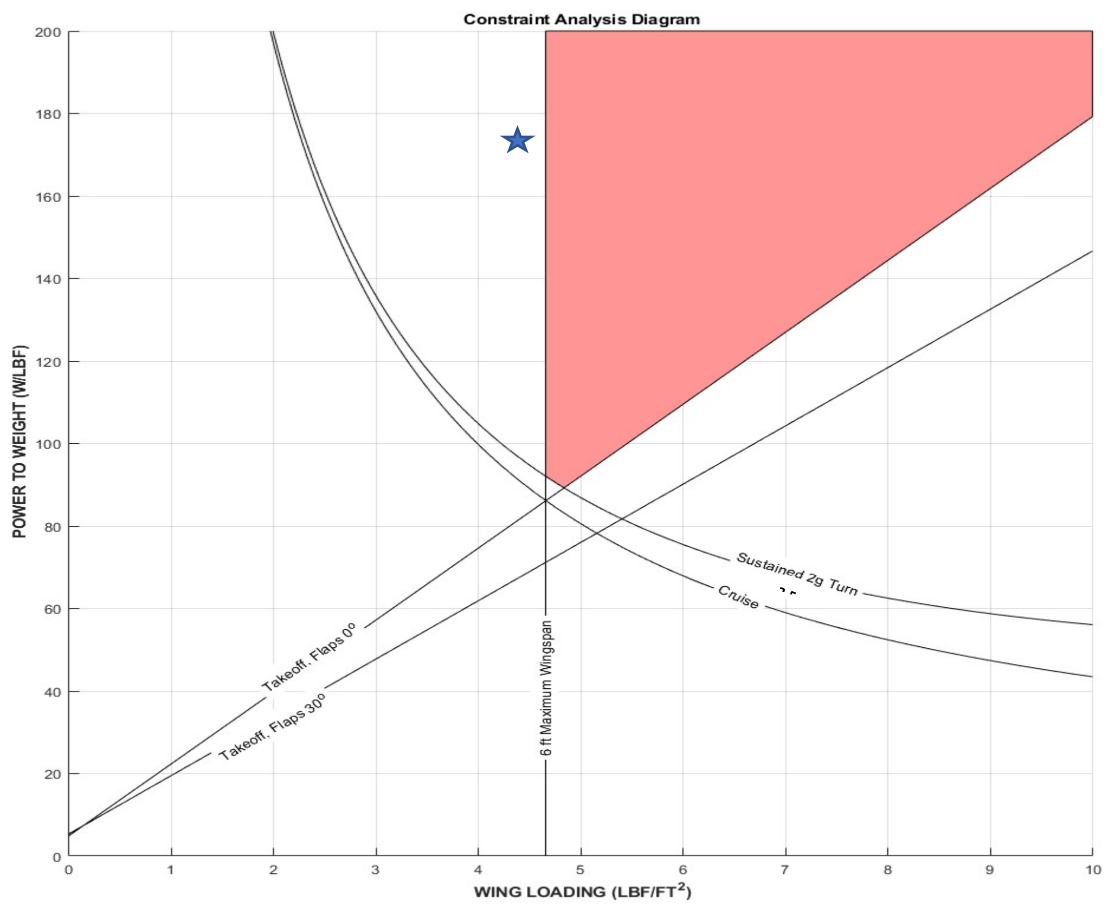

Figure 4.1: Constraint Analysis for Calypso Aircraft. Red Shaded Area is Solution Space, Blue Star is Design Point

5.0 PAYLOAD

To fulfill the requirements set for the Calypso aircraft, subsystems to deploy the life raft and perform the autonomous segments of the mission plan were designed. A 5-lb life raft that provides enough buoyancy for at least two adults was chosen. The deployment mechanisms for this raft have been designed with considerations for fuselage diameter and weight. Life Raft and Deployment Mechanism

As a search and rescue platform, the life raft to be deployed by the Calypso aircraft is required to improve the odds of survival for victims at sea until the Coast Guard can arrive for recovery. To meet this requirement, the life raft must fulfil the following:

- Remain stable in up to 19-ft waves (from Beaufort Force 7 conditions)
- Provide sufficient buoyancy for multiple victims to remain afloat
- Self-inflate upon impacting the water
- Weigh no more than 5-lb to fit within planned weight fractions
- Fit entirely within the fuselage of the aircraft

Additionally, the mechanism to deploy this life raft must fulfil the following:

- Weigh no more than 1-lb to fit within planned weight fraction
- Fit within a 7-in diameter tube
- Use a single transmitter channel to reduce complexity

5.1.1 Life Raft

A variety of existing off-the-shelf (OTS) products exist which meet at least one of the requirements for Calypso's life raft. These products include Type IV personal flotation devices (PFDs), aviation-rated life rafts, and inflatable rafts for outdoor use by hunters or backpackers. However, none of these meet every requirement, 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 will be used to satisfy requirements.

The modified life raft is based on the Uncharted Supply Co. Rapid Raft [8], an inflatable raft designed for transiting small lakes or rivers. This raft is rated for 400-lb of buoyancy, enough to support two adults fully. It weighs 3.8-lb and is packed into a cylinder with dimensions 15-in long by 5-in in diameter in unmodified form.

Two modifications are necessary to meet the life raft requirements:

- Addition of a CO_2 inflator to automatically inflate the raft on contact with water
- Addition of ballast bags to stabilize the raft in rough seas

These modifications increase the weight of the raft to 5-lb and the packed size to 15-in long with a 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 5.1* and a product image of the raft is shown in *Figure 5.1*.

Table 5.1: Modified Uncharted Supply Co. Rapid Raft Specifications

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

Figure 5.1: Inflated Rapid Raft

Since this raft requires modification from the OTS specification, an agreement with the manufacturer to procure the modified raft would need to be made. Additionally, these rafts would have increased prices due to lower economies of scale and more complex manufacturing. Further, certification and testing of the raft would need to be done before deployment at scale. Despite all these limitations, using a modified version of an OTS raft is currently the only way to meet the requirements specified, and as such is recommended for Project Calypso.

5.1.2 Life Raft Deployment System

The life raft mechanism utilizes a cylinder fixed in the fuselage which contains the life raft. Since the diameter of the life raft is 5.25 inches while the fuselage is 7 inches, fuselage frames with a vertically offset bore are used to locate the cylinder within the fuselage. To move the life raft out of the aircraft, a plunger in the foreward frame is pulled aft by thin actuating wires. These wires are fastened to two tabs at 90° and 270° from the top, which follow guide slots in the life raft cylinder. These wires are wound in by a servo mounted to the rear of the cylinder. *Figure 5.2* shows the full assembly from the front. This mechanism weighs 0.95-lb and is 7 inches in diameter, meeting the weight and size requirements. It only requires a single continuous rotation servo, and thus a single transmitter channel, fulfilling the transmitter requirement. Furthermore, this mechanism only uses three moving parts, including the wires, minimizing the possibility of failure to deploy.

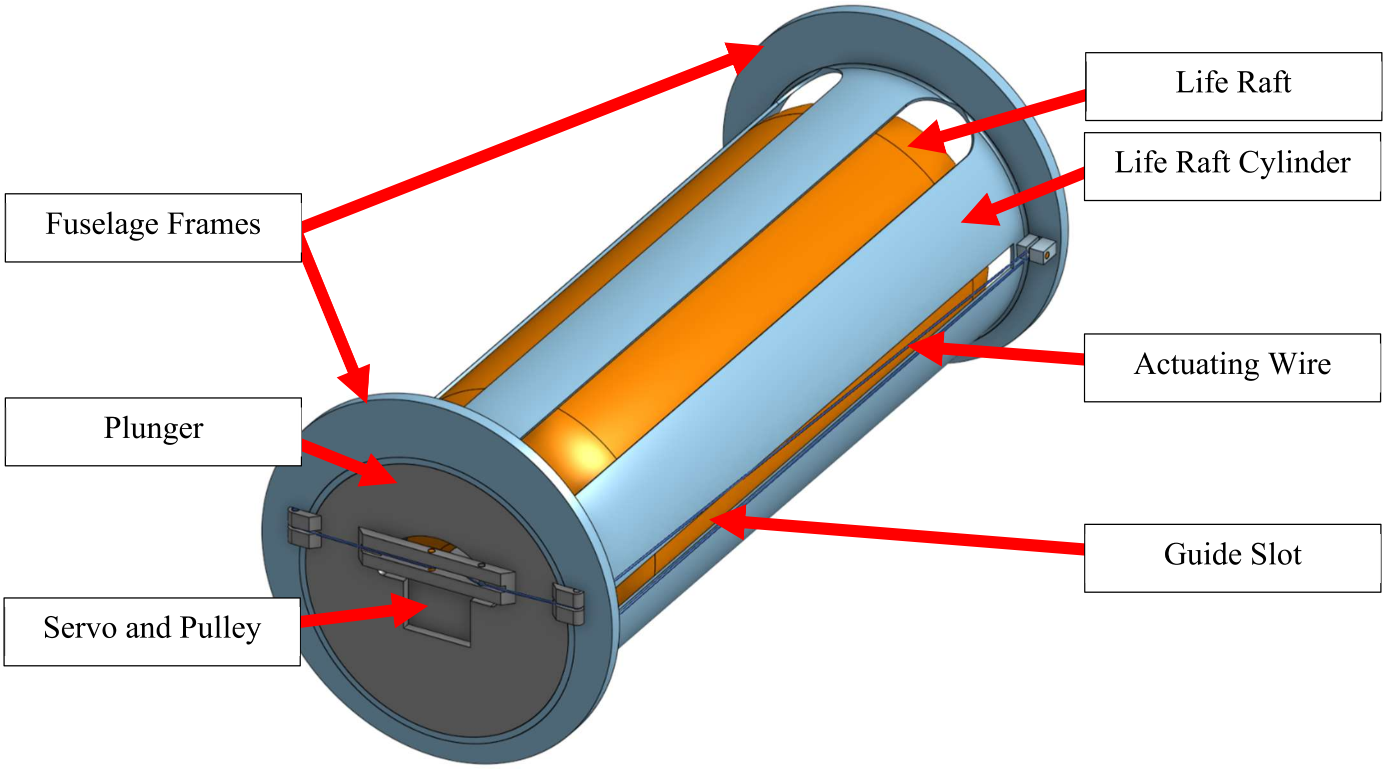

Figure 5.2: Isometric View of CAD Model of the Ejector Type Mechanism

The assembly is installed in the aircraft at the center of gravity to eliminate changes in stability after payload deployment. To facilitate the ejection of the payload, two payload doors are installed in the aft fusealge. These doors have a hinge line at the point of maximum fuselage width to allow for the greatest possible open area. These doors are held shut in flight by torsional springs mounted on the hinge line. When the life raft is deployed, the weight of the raft opens the doors, allowing it to fall out. Since the springs only need to be stiff enough to hold the doors closed under gravity, friction between the raft and doors should be minimal, ensuring that the mechanism will not jam during deployment. *Figure 5.3* shows the position of the life raft mechanism within the fuselage and the location of the fuselage doors.

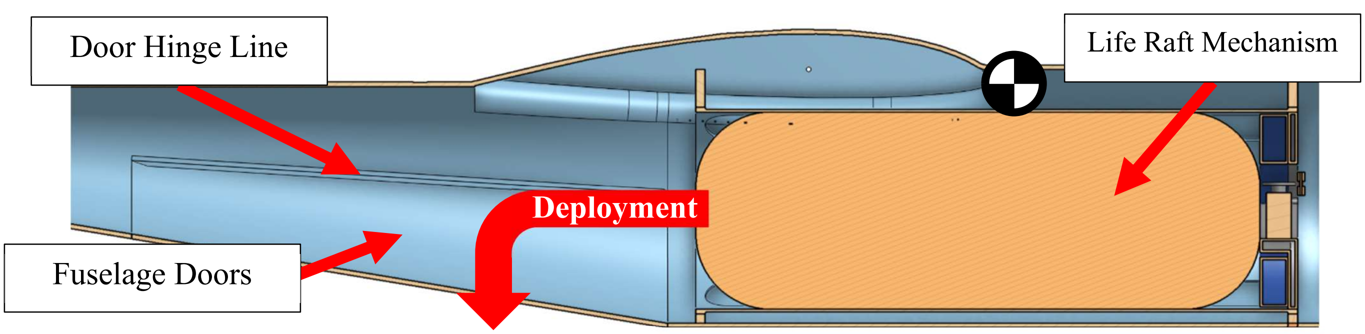

Figure 5.3: Side View of the Life Raft Mechanism Installed in Aircraft

6.0 ELECTRONICS

A flight controller must be capable of autonomous navigation and communications hardware to maintain a link between the base station and aircraft were specified using off-the-shelf components.

6.1 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 necessary, due to the large latency in communication between the ground station and aircraft.

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 surfaces to motors and payload release mechanisms. The number of I/O ports available on the Pixhawk 4 exceeds the number of I/O ports we need for our aircraft. The Pixhawk 4 is also reasonably priced at 190 USD allowing for the viability of the aircraft to be mass produced without heavily imposing on the total cost.

6.2 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. This radio 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 and telemetry.

The communication system was picked on the premise of having adequate range, being light weight, and having good bandwidth. The Commtact radio has a weight of 0.22-lb which is far lower than the competitors 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 35-lb. The radio has a range of 25 miles, which meets the range requirement of 20 miles. In addition to the long range and weight, the Commtact radio possesses good bandwidth allowing for HD video transmission. The ability to send to HD video will allow operators to access the situation and 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.

6.3 Electronics Bay and Integration

To facilitate a positive static margin, all electronics are placed in the nose of the plane. For easy access, the batteries are placed at the top of the electronics bay, with the motor speed controllers, radio, and flight controller placed below. For modularity, these components are supported by bulkheads which separate electronics bay from the rest of the fuselage. A hatch placed at the top of the fuselage allows for quick access to these components. *Figure 6.4* shows the position of the electronics bay in the nose of the aircraft and *Figure 6.5* shows the layout of the components.

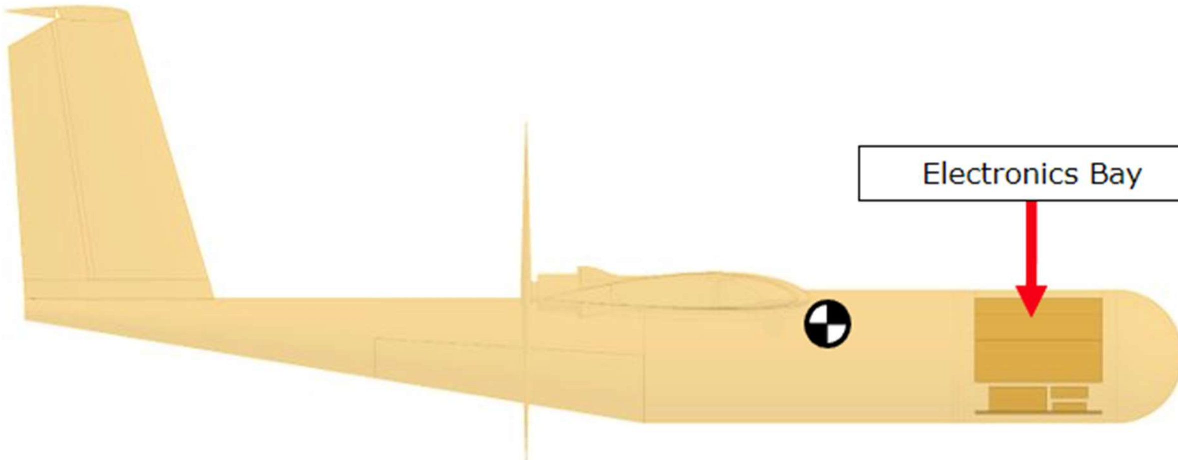

Figure 6.1: Location of Electronics Bay

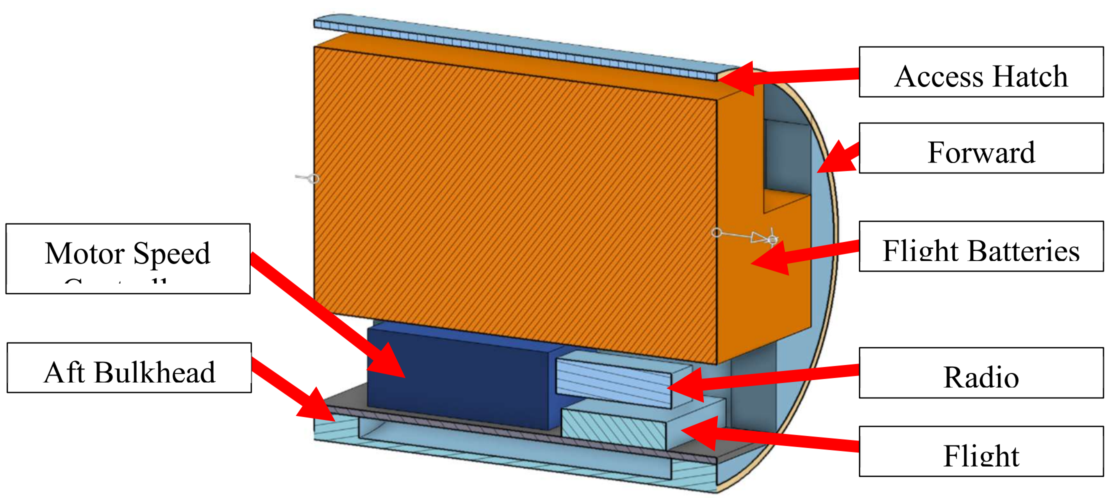

Figure 6.2: Section View of Electronics Bay (Symmetric About Section Plane)

7.0 LAUNCH AND RECOVERY

7.1 Launch

Calypso's aircraft is designed with the intention of having no landing gear. The aircraft will be launched from an elastic catapult mechanism comparable to the ElevonX Scorpion as seen in *Figure 7.1*. The current design weight of 30-lb and takeoff speed of 37 ft/s equate to a required launch energy of 665 ft-lbs. The ElevonX Scorpion is capable of 737 ft-lbs, indicating that an elastic system is most appropriate for this design project. Because the project requires a 37 ft/s launch speed, 3.5 g-loading maximum, and autonomous input conditions not available in off-the-shelf systems, Project Calypso has decided to 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.

Figure 7.1: ElevonX Scorpion Elastic Launch Catapult System

7.2 Recovery

Project Calypso will model a cable recovery system comparable to the Boeing Skyhook pictured in *Figure 7.2*, to return the aircraft to the ground.

Figure 7.2: Wire Recovery System in Use

The Skyhook System is capable of passively dispersing 1625 ft-lb of energy, well in excess of this project's requirements. The designed recovery system will retrieve the 30-lb airframe at 37 ft/s on a double cable gantry mounted on the same 4-ft x 4-ft platform as the launch system, collecting and dispersing the same 665 ft-lb of energy. The airframe will fly into the cable, intending to hook both wings with a latch integrated into the leading edge of each wing, similar to the method used by the Skyhook System depicted in *Figure 7.3*.

Figure 7.3: Boeing ScanEagle Skyhook Recovery Latch

8.0 STRUCTURES

The structures of Calypso's aircraft need to be strong enough to withstand loading. The aircraft will be launched from an elastic cable and rail catapult and recovered by a cable hook that will wrap around the leading edge of the wing.

8.1 Fuselage Sizing

The decision made for the structure of the aero model is solely based on the desired life raft as seen in *fig. 8.1*. The lift raft payload is 5.25-in in diameter and 16-in long. There the determined size of the fuselage is seven inches in diameter and 61.2 inches long. The main wing is a high wing configuration that is integrated into the fuselage to reduce drag. The horizontal tail is 10 inches, and the vertical tail is six inches. The main wing and the electronic bay are in a fixed location due to the 25% static margin that is gained. This percentage of static margin allows the aircraft to have a CG ahead of the main wing and guarantee increased stability.

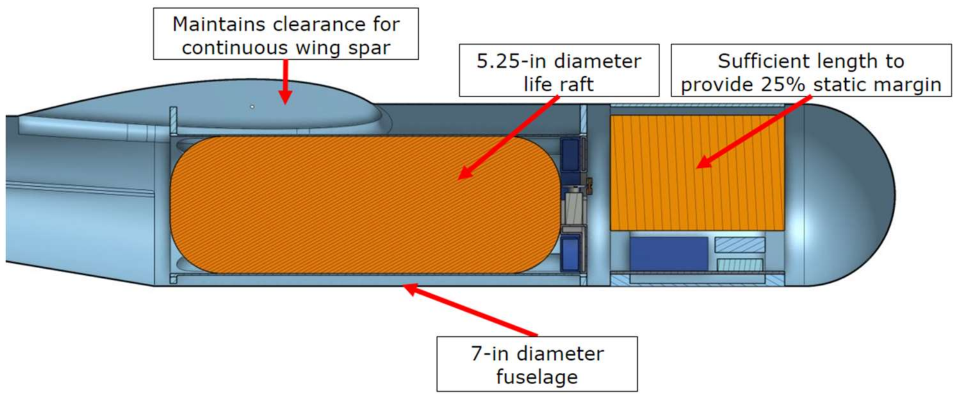

Figure 8.1: Fuselage layout

8.2 Fuselage Materials and configurations

Calypso's current PDR design is primarily built from composites. The fuselage will consist of composite honeycomb fuselage frames. The main wing will have a hollow carbon fiber spar that is the span for the wing. The carbon fiber spars also pass through fuselage above life raft. This allows the spar to transfer load from the wing to the fuselage. Ideal for a significant amount of strength to prevent the main wing from overachieving its maximum wing loading and ultimately snapping. The external skin of the main wing will have a fiberglass shell. The main wing, horizontal tail, and vertical tail will have skin stringers and honeycomb composites that ensures wing strength and provides wing loading of 4.66 lb/ft^2. Overall, the aircraft is designed to withstand a 3.5 g loading factor.

9.0 AERODYNAMICS

9.1 Configuration

The final concept design shown in *Figure 9.1* was decided using trade studies and weighted design tables. Current drones, RC model aircraft, and experimental aircraft were researched and compared to assign values to a table, shown in the appendix. Trade studies, as referenced in the appendix, conducted on similar configurations were also examined to give additional performance information, improve the down-selection process used to determine the best configuration.

The final design aircraft configuration has remained unchanged since the design concept review. The aircraft is set up in a twin pusher propeller, tapered high wing, t-tail configuration. The high wing placements allows maximum space for the fuselage to store the payload, batteries, electrical controls, and wiring. The high elevator placement mitigates interference from the prop wash generated by the wing and propellers. Lastly, the propellers are mounted in a pusher configuration to prevent damage during landing, as the final design will be using a catch recovery method.

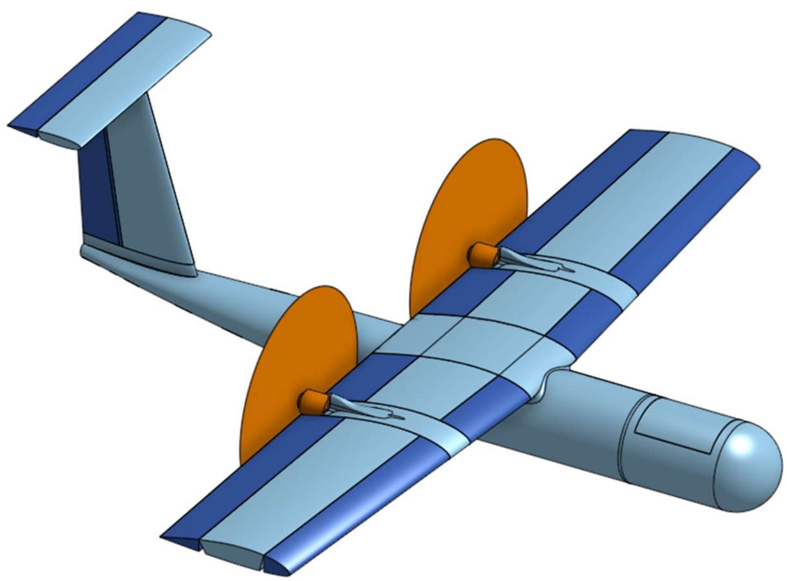

Figure 99.1: Conceptual Aircraft Configuration

9.2 Wing Airfoil and Geometry

The priorities of the chosen airfoil and the main wing are the production of high lift, and a low drag profile. These aerodynamic characteristics allow for the aircraft to loiter at the required speeds and have the necessary control to handle specified weather conditions. The airfoil used for the main wing is a Drela MRC-16, shown in *Figure 9.2*. This airfoil was chosen as it outperformed other airfoils in performance, specifically post stall characteristics, drag, ease of fabrication and control surface mounting options. These advantages of the chosen airfoil allow for the cruise speed and climb rate requirements to be met. Graphs displaying the MRC-16s performance are shown in *Figure 9.3*. The data from the simulations was conducted at a Re of 1,150,000—the Reynold's number which the aircraft will be cruising in at 115-mph. Using this Re gives an accurate performance of the airfoil during the operational stages of flight.

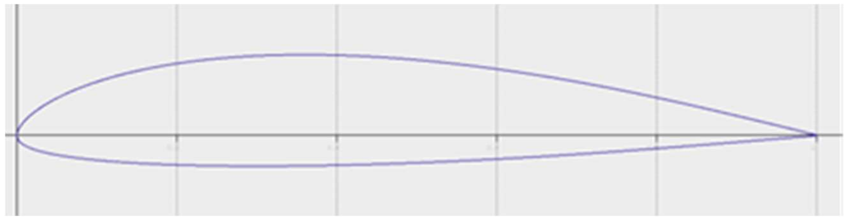

Figure 99.2: Drela MRC-16 2D Cross Section

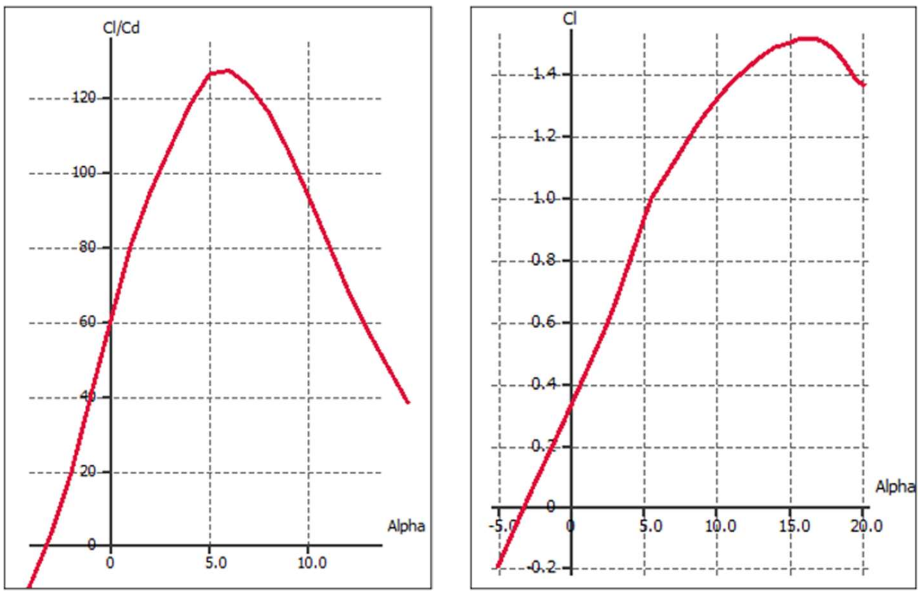

Figure 99.3: MRC-16 Aerodynamic Performance,
Re = 1,150,000

Performance for the selected airfoil was simulated on XFLR5 in both direct airfoil analysis and plane design. *Table 9.1* displays values given at the calculated expected Re: 1,150,000. This value was calculated at conditions during the cruise and loiter phase of flight. The representation of airfoil performance at this Re was used as a reference when designing the wing and empennage sections.

Table 99.1: 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	0.35
C_m vs Alpha	Negative Gradient

Airfoil analysis results vary from the 3D wing design, due to the physical profile of the wing, compared to a 2D airfoil. However, the designed wing was simulated with estimated loads during cruise condition, in order to verify results, meet load factor, max payload, and cruise time requirements. Figure 9.4 shows the improved wing design utilizing an increased surface area to reduce wing loading and allow for a shorter take off distance.

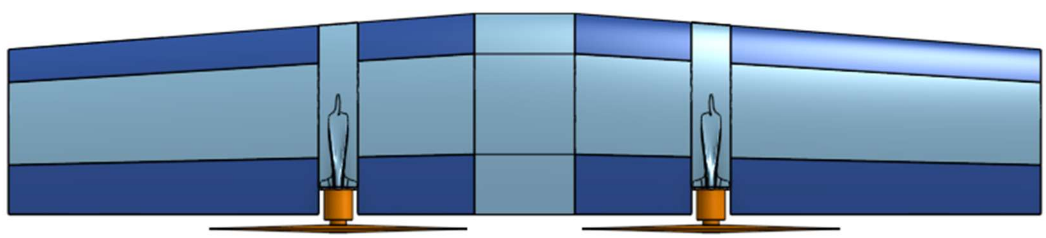

Figure 9.4: Wing with Motor Mounts, Motors, and Propellers

The leading edge of the wing is tapered to reduce drag but maintain the required lift performance. One of the main changes to the wing design was to increase the surface area of the wing, to reduce wing loading during takeoff. The simulation results yielded from the improved wing geometry is shown in *Table 9.2.*

Table 9.2: 3D Wing Aerodynamic Performance

Variable	Value
Wing Area (in^2)	918
Root Chord (in)	14
Stall speed (ft/s)	37
Wing Loading (psf)	4.706
C_D	0.010
Cruise C_D	0.015

The aerodynamic surface of the wing was followed when creating the engine mounts as seen in Figure 9.4. This keeps continuity with the wing surface to minimize drag and reflect the simulated performance as close as possible. *Figure 9.5* shows the drag results when operating at its cruising speed of 115 mph.

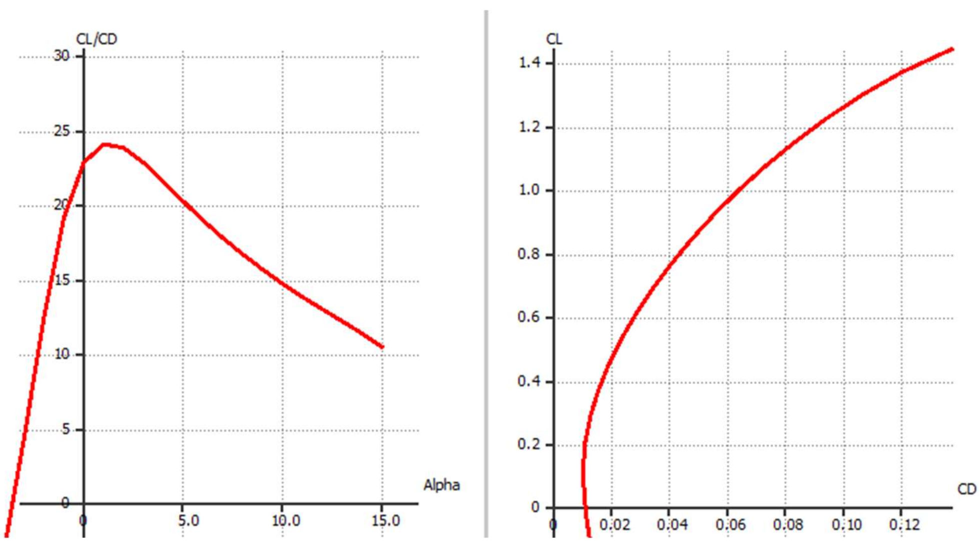

Figure 9.5: Aircraft Drag Simulation Results

9.3 Empennage Design and Sizing

The airfoil used for the tail was a NACA 0012. This airfoil was chosen because it allows for simple manufacturing as well as predictable results when adjusting for optimal control and stability. The 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. These two variables were essential as they would dictate meeting stability criteria, allowing the aircraft to be flyable in Beaufort force 7 conditions and sustain a load factor of 3.5Gs. A negative tilt of 2° was added to the elevators, as well as a vertical taper of 0.8 to the tail fin. The vertical taper was added to decrease drag and improve the airflow around the structure. Distances from the empennage and main wing were also focused around keeping a negative C_M as alpha increases. This process was to ensure that the aircraft would be longitudinally stable and can be seen in *Figure 9.6.*

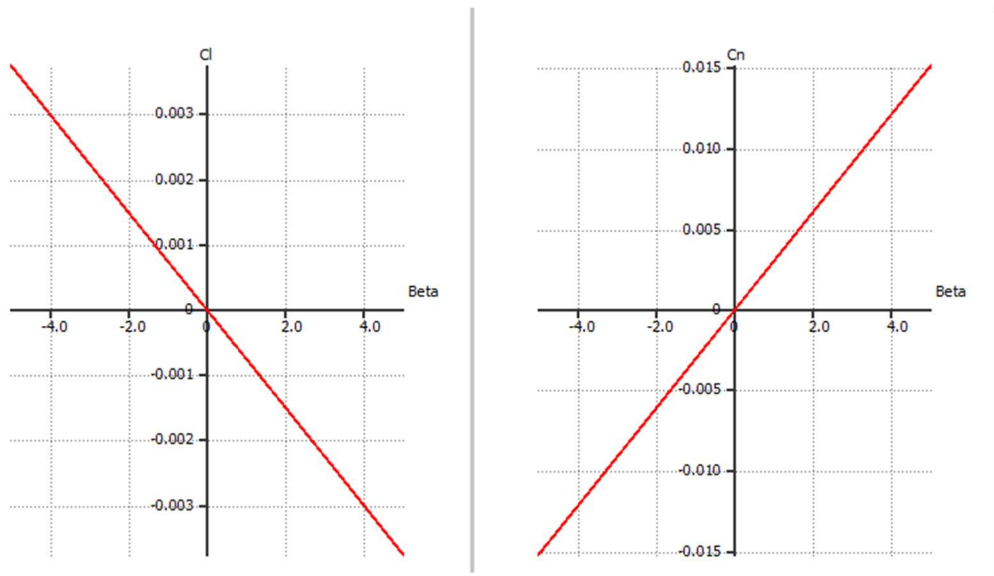

Figure 9.6: Aircraft Stability Simulation Results

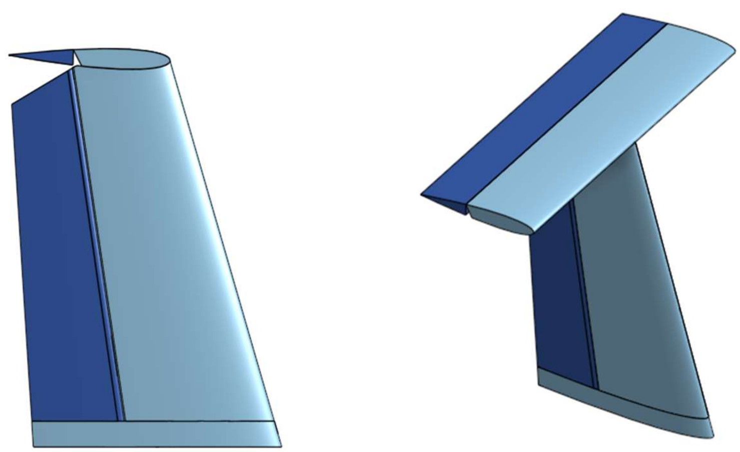

Figure 9.7: Empennage Section with Control Surfaces

Table 9.3: Empennage Volume Coefficients

Variable	Value
Vertical Tail Coef.	0.067
Horizontal Tail Coef.	0.35

The vertical tail coefficient in *Table 9.3* is large to provide the aircraft with the necessary yaw control. Both tail sizing coefficients demonstrated that the aircraft is stable in *Section 9.4*.

9.4 Performance and Stability

Results from the stability simulations were expected to be mirrored by our full-scale prototype. XFLR simulations were conducted with added weights, estimated to be reflected on the working prototype. Added weight was to give a more accurate simulation of the aircraft performance in the cruise phase of flight to meet derived requirements such as speed and handling listed in requirements *Table 3.1*

Table 9.4: Simulation Results Showing Aircraft is Stable

Test Type	Stability	Damping Ratio
SPPO	Stable	0.283
Phugoid	Stable	0.056
Roll Mode	Stable	~
Dutch Roll	Stable	0.060
Spiral Mode	Unstable	~

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.

9.5 Control Surface Design

A rough estimate of control surface area and position was derived from control surface design guidelines from the aircraft design textbook [9]. The areas for the control surfaces were then compared against aircraft with similar flight regimes. Factors such as ease of manufacturing also contributed to the design of control surfaces.

9.5.1 Ailerons

The ailerons start at 55% of the wingspan and extend out to the edge of the wing shown in *Figure 9.8*. The width of the ailerons is a constant 30% of the chord length. Due to the aircraft being catapult launched, the control surfaces must be effective at our take off speed of 37-fps. To achieve aileron effectiveness at these low speeds, the ratio of the area between the control surface and the wing must be high. To make the manufacturability of the ailerons easier, the ailerons extend to the edge of the wing, and have a width of 30% of the chord. The length of the aileron was determined using the textbook guideline [9], based on the width. The aileron deflection was determined from guidelines based on the surface area of the aileron.

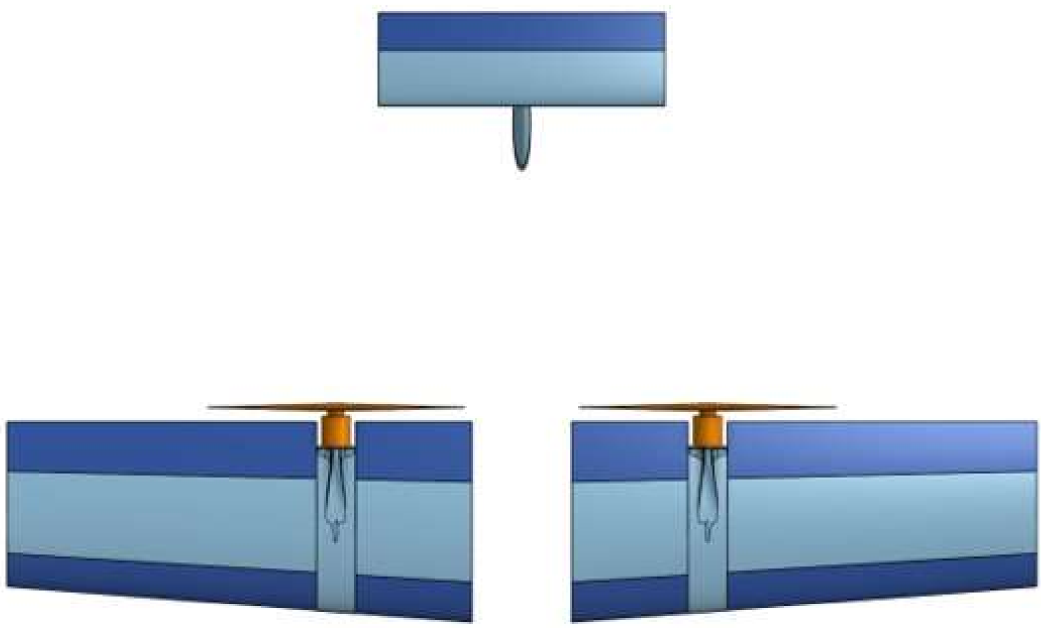

Figure 9.8 Ailerons and Elevator

9.5.2 Rudder

The rudder has a width of 40% of the chord and spans the full length of the vertical tail shown in *Figure 9.9*. Due to the slow take off speed from the catapult launch system and strong winds, an effective rudder is required. Since rudders typically span the whole length of the vertical stabilizer, to ease manufacturing, to change the effectiveness of the rudder, the rudder width is adjusted.

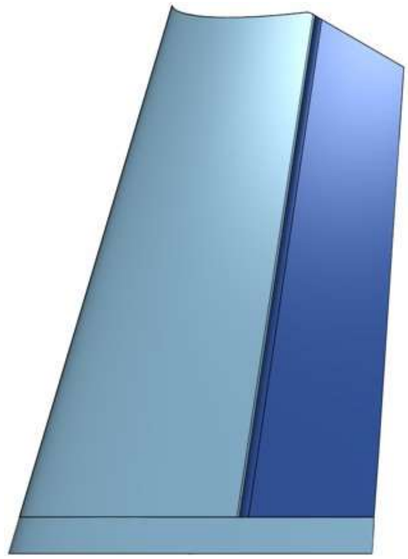

Figure 9.9 Rudder

9.5.3 Elevator

The elevator spans the full length of the horizontal stabilizer, with a width of 40% of the stabilizer chord shown in *Figure 9.8*. Allowing for the length of the rudder to fully span the horizontal stabilizer makes manufacturing easier, as only one cut can be made on the stabilizer. Having the elevator run the full width of horizontal stabilizer allows for greater pitch control.

9.6 High Lift Devices

Due to the aircraft necessitating a catapult launch, high lift devices are required to achieve the desired takeoff performance. We have selected both leading and trailing edge flaps as our high lift devices. The flaps have a width of 30% of the chord and span the full length of the wing. With a 30-degree deflection of the trailing edge flap and a 10-degree deflection of the leading-edge flap, we are able to achieve a Cl of 2.051 at our takeoff speed. This C_l is sufficient for the aircraft to become airborne. *Figure 9.10* shows the main wing airfoil with the flaps at full deflection.

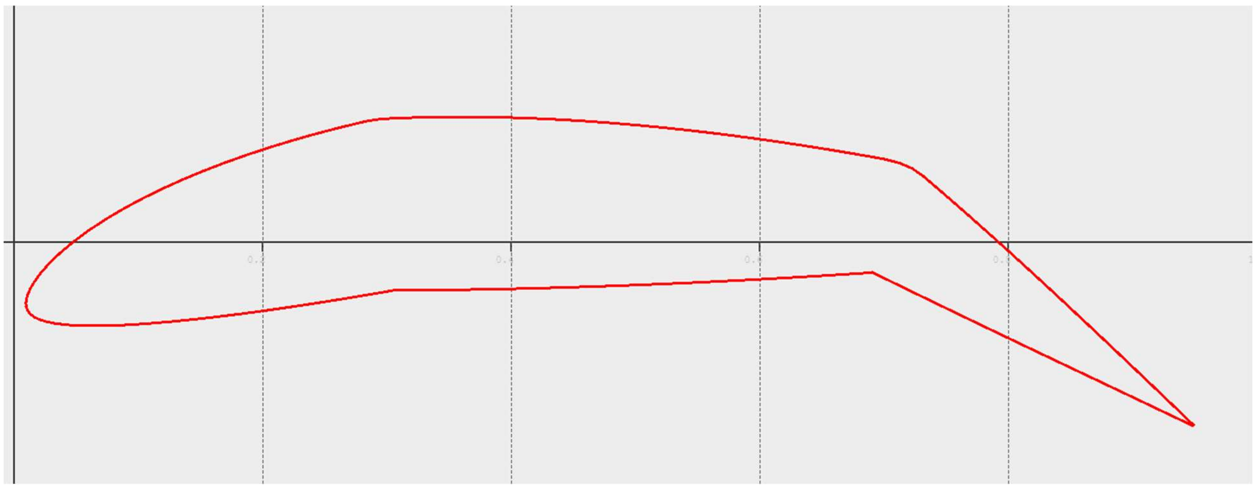

Figure 99.10: Airfoil with Leading and Trailing Edge Flaps Deployed

10.0 PROPULSION

The Calypso aircraft's propulsion system must meet the following requirements derived from the SOW and constraint analysis detailed in Section 4.2:

- Provide at least 175 W/lb of propulsive power
- Sustain flight at 115 mph for 15 minutes
- Provide at least 90 minutes of endurance
- Remain operable after three months of standby
- Avoid damage from net or wire recovery

An electric power system meets the requirements for the aircraft's power system as it does not degrade from contact with humid air. Nitro fuel and gasoline were considered for their higher energy density, but they absorb moisture from the air resulting in degradation of motor performance.

To provide sufficient thrust to meet the cruise speed requirement, a twin-motor, pusher-prop configuration will be used. This configuration provides 5,500 W of power and enough thrust at 115 mph to overcome aerodynamic drag, meeting the requirements.

10.1 Propulsion Configuration

To avoid damage from net or wire recovery, a pusher propeller arrangement must be used. Since the payload must be ejected from the rear of the aircraft, a single centered propeller is infeasible. A twin motor pusher arrangement with the motors mounted to the wings provides clearance for the payload to be deployed and allows for recovery without propeller damage, meeting the requirements for the propulsion system. From the aerodynamic information in Section 9.4, the drag generated at 115 mph by the aircraft is 3.42-lb. To overcome this drag, two 18-in diameter propellers with 12 inch pitch can be used. This propeller is shown in *Figure 1010.1*. When turned at 10,000 rpm at 115 mph, these propellers generate 9.74-lb of thrust [7], exceeding the thrust required and meeting the minimum cruise speed requirement.

Figure 1010.1: 18x12e (Electric Profile) Propeller [10]

To turn the selected propellers at the required speed, the Sunnysky X4125 V3 480 kV motors will be used. A product image of this motor is shown in *Figure 1010.2*. A 480 kV motor connected to a standard 22.2 V six cell battery will spin at 10,500 rpm, enough to meet the thrust requirement. Each of the specified motors provide 2,750 W of continuous power which exceeds the 4,375 W total power requirement by 25.7%.

Figure 1010.2: SunnySky X4125 V3 Brushless Motor [11]

To ensure that this motor is sufficient to drive the selected propellers at all airspeeds, an analysis of the power required to drive the propeller was conducted. This data is shown in *Figure 1010.3*, where the motor has sufficient power to drive the propeller at all airspeeds greater than 5 mph without exceeding the motor rpm limit.

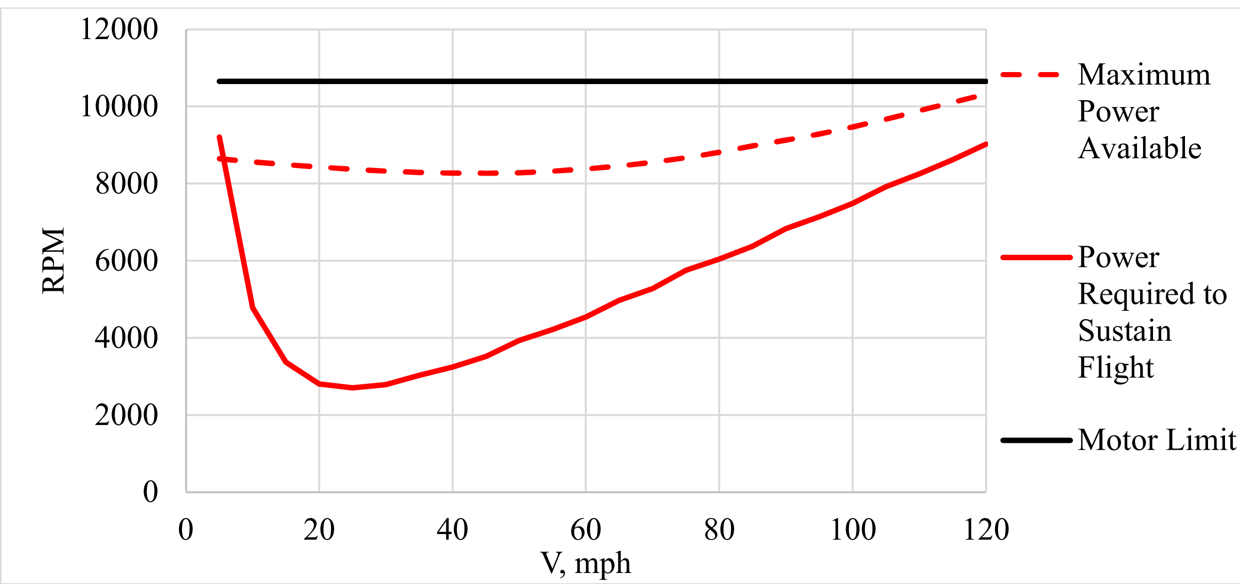

Figure 1010.3: Propeller Power Required, X4125 Motor and 18x12e Propeller

10.2 Propulsion Power Analysis

From the specified motors and propellers, the energy requirements of the aircrafts propulsion system can be found. In absence of wind tunnel thrust testing, data from the propeller manufacturer is used to determine the amount of thrust the propeller makes and amount of power required at any given airspeed and motor speed. From this data and drag calculations based on the aerodynamic design of the aircraft the required and available power and thrust can be compared. This data is shown in *Figure 1010.4,* where it is seen that thrust available exceeds thrust required at 10 mph, or about 15 ft/s. Since this value is lower than the stall speed calculated in Section 9.20, the aircraft's takeoff performance is limited by aerodynamics, not power. The aircraft can also generate net thrust at the 115-mph cruise velocity, fulfilling the cruise speed requirement.

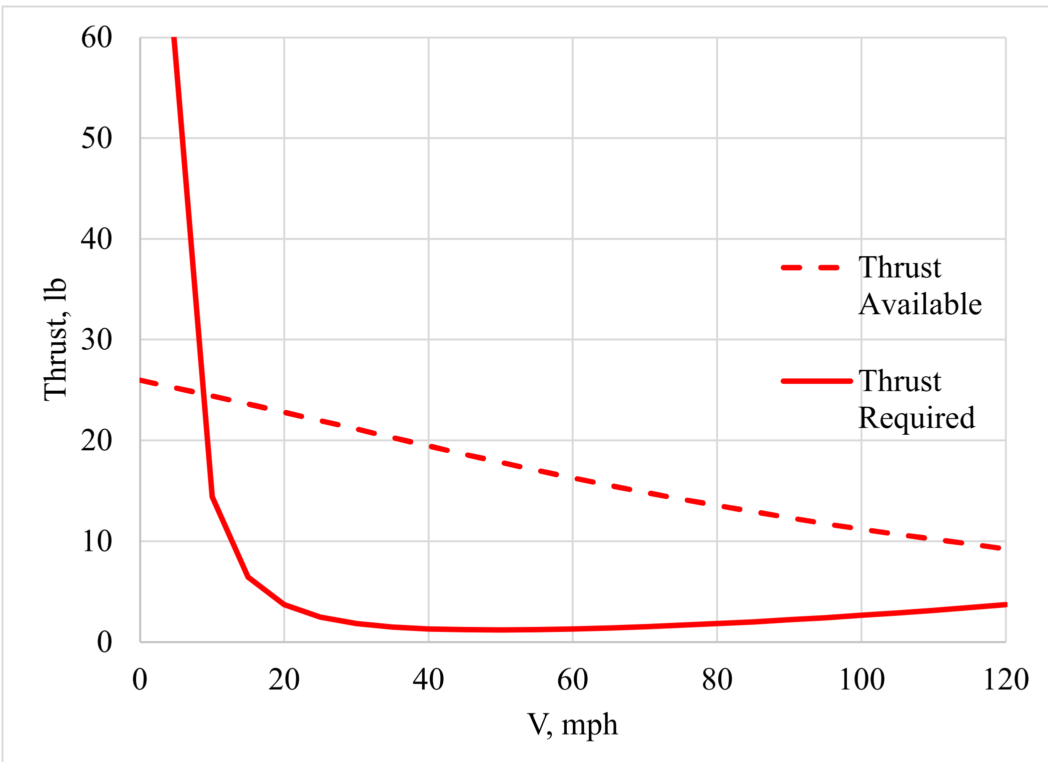

Figure 1010.4: Thrust Available vs. Required, X4125 Motor and 18x12e Propeller

The overall energy required during a typical mission can be calculated using the propeller power curves developed previously and the average airspeed during each mission phase. The cruise phase speed is required to be 115-mph, while the loiter and return phases are set at 35-mph, which is the aircraft's speed for minimum drag. The aircraft will use six cell lithium-polymer batteries, which are common and less expensive than higher voltage systems. These batteries have a typical output voltage of 22.2 V, which can be used to calculate the energy required as 28.5 Ah. The typical mission profile is shown in *Figure 1010.5* and *Table 10.1.* By using three six cell 10 Ah batteries connected in parallel, the typical mission for the aircraft can be completed with a 5.34% energy reserve. This amount of energy reserve allows the aircraft to meet the endurance requirement. These batteries weigh a total of 8.73-lb [12], bringing the total estimated aircraft weight to 30-lb. At this weight the power loading remains above 175 W/lb, meeting the power loading requirement.

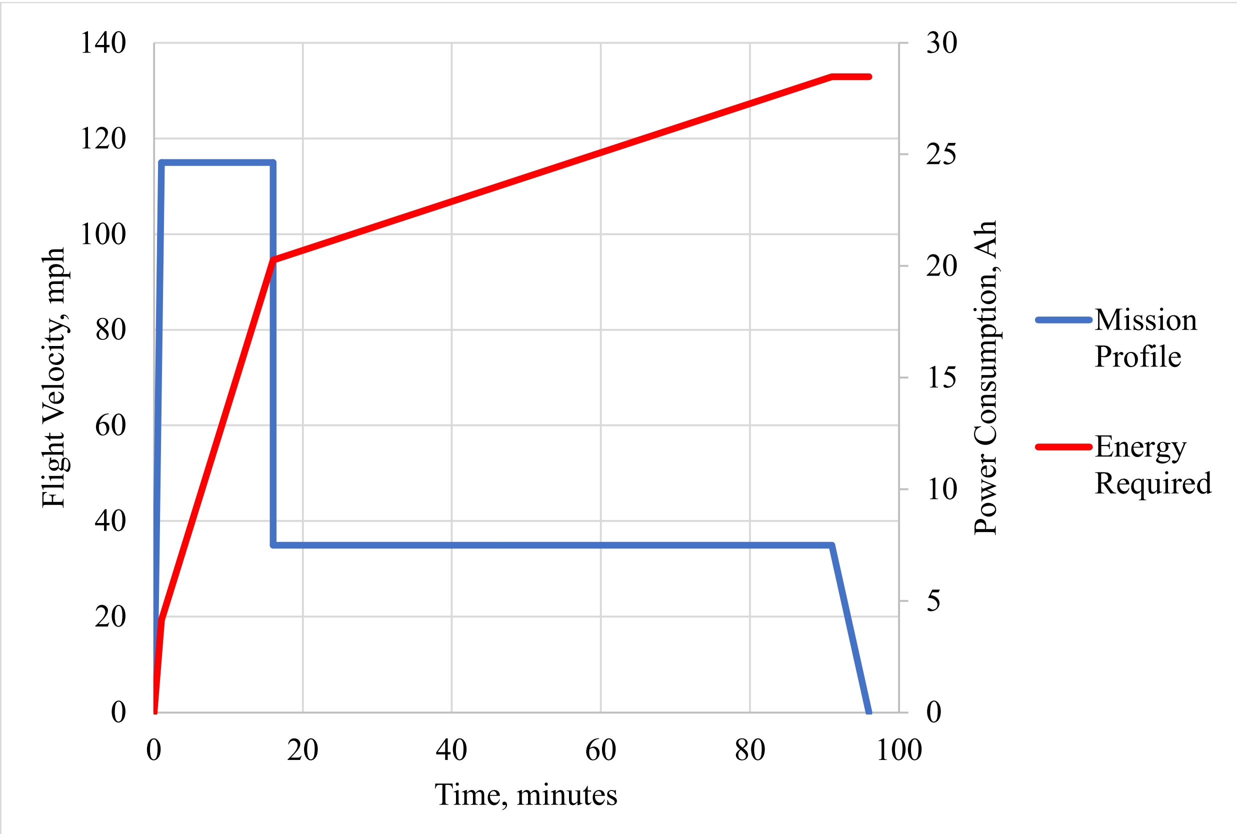

Figure 1010.5: Mission Profile, Velocities and Energy Required

Table 10.1: Typical Mission Profile, Mission Phases and Flight Speeds

Mission Phase	Elapsed Time, minutes	Flight Speed, mph
Takeoff	1	Increasing to 115
Cruise to Target	16	115
Loiter	46	35
Return to Base	91	35
Landing	96	Decreasing to 0

11.0 FLIGHT TEST ARTICLE

The purpose of this flight test article is to test and validate the design model. A full scale, simplified version of the design, shown in *Figure 11.1*, was constructed to reveal any major design errors before moving on to a detailed aircraft model.

Figure 11.1 Flight Test Article

11.1 Fabrication

All lifting surfaces were constructed out of wire cut rigid insulation foam skinned in fiberglass. Strips of Kevlar were imbedded into the fiberglass skin to later act as hinges for control surfaces. The fuselage consists of 3D printed parts and foam board reinforced with fiberglass around the edges. The nose of the aircraft was 3D printed and steel ballast was added to correctly position the center of gravity.

The electronics used on the flight test article are similar to what the final design will be equipped with. The propulsion system consisted of two E-flight Power 60 brushless motors each controlled by a Phoenix Edge 160-amp ESC powered by a 6 cell 7000 mAh LiPo battery. The main wing control surfaces used Spectrum A6380 servos while the tail section control surfaces used Hitec HS-225MG servos.

11.2 Flight Testing

Flight testing of the aircraft validated the following design parameters:

- Climb performance
- Longitudinal stability
- Aileron and elevator sizing

The estimated climb rate of the aircraft based on the height of surrounding objects exceeded 1,000 ft/min, indicating that the aircraft will still meet the climb rate requirement at maximum takeoff performance. No changes need to be made to the propulsion system to meet this requirement.

During the takeoff roll, the pilot commanded maximum up elevator, resulting in a rapid but controllable rotation and transition to level flight. The aircraft exhibited the tendency to return to level flight without control inputs and was stable in this attitude. No changes need to be made to the longitudinal stability of the aircraft.

In flight the aircraft's response to roll and pitch inputs was sufficient to maintain control of the aircraft in banks and climbs. This responsiveness shows that the size of these control surfaces is appropriate for this aircraft configuration.

The test flight ended after the aircraft entered an unrecoverable dive after a deep bank, resulting in a crash and the loss of the airframe. The aftermath of the crash can be seen in *Figure 10.1*. The crash was attributed to an insufficiently sized vertical stabilizer to counteract the adverse yaw from the large ailerons and wing. Adverse yaw led to the aircraft yawing nose up while in a deep left wing down roll, stalling, and crashing. Enlarging the vertical stabilizer and rudder is recommended to counteract adverse yaw and improve directional stability. Additionally, the thin control rods used to link the servos to control surfaces may have bent, reducing control surface effectiveness at high speeds. This lack of control effectiveness may have also contributed to the crash, therefore increasing the rigidity of the control rods is recommended for future aircraft.

Figure 11.2: Aftermath of Flight Test Article Crash

12.0 RISK ASSESSMENT

12.1 Risk Analysis

Risk analysis of the Calypso Project is intended to identify and prepare for 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 12.1* 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 is unavailable for sale or closes.
2. Inability to source catapult launching system necessitates conventional take-off of the Calypso aircraft.
3. Weight requirements in SOW cannot be met within, structural endurance, and propulsion requirements.
4. Pilot inexperience results in airframe loss from sudden wind gusts or other unexpected aerial phenomena.

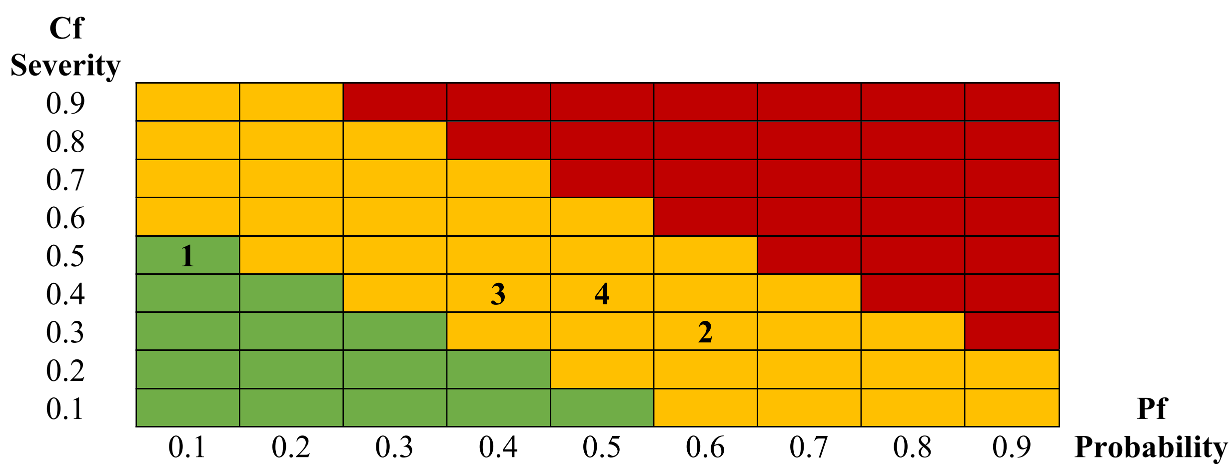

Figure 12.1: Risk Analysis Matrix

In *Figure 12.1* the risk analysis matrix has four 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 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.

12.2 Risk Mitigation

12.2.1 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 systems available that the same parts selected for the Project Calypso aircraft could be sourced through second-hand marketplaces. However, to minimize the risk inherent in a reliance on these avionics, secondary line-of-sight systems have been specified for the Project Calypso aircraft, so that they provide a usable secondary in the event of supply shortages.

12.2.2 Conventional Take-Off

Since the design of the launch and recovery systems are outside the scope of the Calypso Project, it is considered likely that a conventional take-off and landing will be required for the aircraft. This likelihood is increased as due to size and speed requirements of the aircraft, a very large or otherwise highly expensive catapult launch system would be required which is infeasible within the scale of funding for the Calypso Project. This is remedied at the core level of the design process, with the Calypso aircraft being designed with substantial excess power and elevator authority sufficient that a conventional take-off with fixed landing gear is possible. The aerodynamic flight tests have verified the pitch and take-off viability of the Calypso aircraft, even with the use of weaker and suboptimal airframe design. Since the detail aircraft design is intended to use composite manufacturing which will drive down weight, stronger motors to increase performance, and revised aerodynamic surface sizing for better control authority—the risk of inadequate performance for a conventional take-off is substantially reduced.

12.2.3 Exceeding Weight Requirements Due to Structural Reinforcement

Under the current performance requirements in the SOW, the Calypso aircraft meets all provided performance criteria. With testing of the aerodynamic flight test article, the structure of the aircraft was substantially heavier than the design weight due to use of heavier but production-expedient materials in the fabrication material. Even considering the heavier weight of the airframe, the aircraft overall was under the weight budget requirements as expressed in the SOW. Use of composite manufacturing and a more refined fuselage design will further reduce weight of the aircraft, while allowing for structural reinforcement to key areas. Consequently, the risk of exceeding the weight budget as provided is deemed small with the current risk mitigation strategies.

12.2.4 Loss of Airframe Control Due to Pilot Inexperience in Wind Conditions

The current design iteration of the Project Calypso aircraft is designed for flying in headwinds up to Force 7 Beaufort wind conditions, though while the aircraft is predicted to handle these conditions well, a sudden gust condition across the lateral axis may prove uncontrollable to inexperienced pilots. Inexperience with the Calypso aircraft is a direct result of low flight-time with the experimental designs, and as a result is only rectified by increasing the pilot flight-time with the flight test article. To accommodate this risk, the aerodynamic flight test article is to be repaired and returned to flight-ready status, such that additional flight-time and experience can be obtained prior to the flight of the detail aircraft. Additionally, the creation of an aerodynamic simulation will be completed to provide take-off and landing experience in a controlled and low-risk environment.

13.0 CONCLUSIONS AND RECOMMENDATIONS

The Project Calypso team recommends further simulation and testing of different tail and empennage arrangements to best determine an ideal compromise between structural rigidity and control response for flight test designs. Project Calypso has additionally down-selected to a conventional high-wing and t-tail arrangement as these provide the best compromise between takeoff and cruise performance. The current Calypso aircraft arrangement minimizes aircraft shore-to-search times and increases 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 six 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 that repairs be made to the aerodynamic model so flight testing can resume, and airframe improvements can be validated, while incorporating industry feedback into the design and operation of the finalized aircraft.

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15.0 ATTRIBUTIONS

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16.0 APPENDIX A

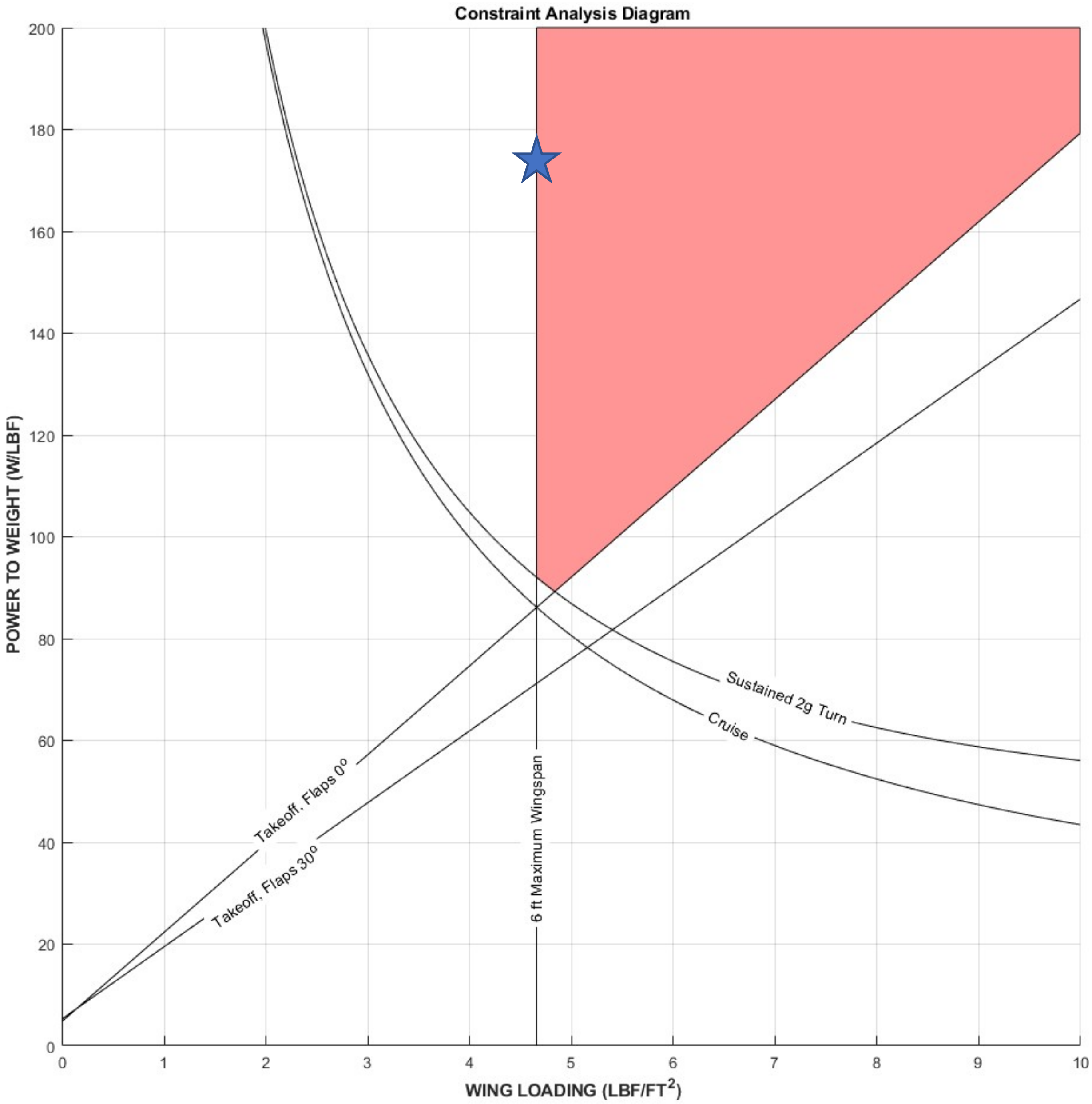

Figure 16.1: Constraint Analysis for Calypso Aircraft. Red Shaded Area is Solution Space, Blue Star is Design Point

Table 16.1: Constraint Analysis Key Parameters

Parameter	Value
Wing Profile	MRC-16
Empennage Profile	NACA 0012
Aspect Ratio	5.59
Taper Ratio	0.82
V_{dash}, ft/s	170
$V_{stall,\ flaps}$, ft/s	37
C_{D0}	0.156
Weight Fractions	See Section 4.1

Table 16.2: 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

Table 16.3: 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 16.4: Comparison of Commercially Available Life Rafts for Aviation Use

	ThrowRaft Survivor [13]	Uncharted Supply Rapid Raft [8]	Winslow RescueRaft [14]
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

Table 16.5: Risk Impact & Associated Totals

Risk Type	P_f	C_f	*Total*	Risk Impact
1. Business Closure	0.1	0.5	0.05	Minor
2. Conventional take-off	0.6	0.3	0.18	Moderate
3. Exceeds weight budget	0.4	0.4	0.16	Moderate
4. Loss of control due to wind	0.5	0.4	0.20	Moderate

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 16.2: 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 16.3: 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 16.4: 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 16.5: Aircraft Configuration Trade Study