FINAL 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 the United States Coast Guard. The aircraft is catapult-launched and contains an off-the-shelf sensor payload with accommodations for a lightweight life raft that can be deployed to persons in distress. The aircraft can cruise at over 100 KTAS with an operational range of 17.5 nautical miles and can patrol an area for up to 36 minutes. A self-inflating life raft capable of carrying two adults is held internally and can be released in flight. Wind tunnel testing and flight tests of a dimensionally identical flight test article (FTA) have validated the design's aerodynamic performance. The FTA was constructed using simplified internal structures to reduce construction time without compromising the structure of the aircraft or its accuracy to the design. The propulsion system and avionics of the FTA are comparable to the design, which allows for performance comparisons between the two. Flight testing has been conducted using integrated landing gear to demonstrate takeoff and landing performance. This flight testing was intended to show that the design meets all stated project requirements.

REVISION BLOCK

Revision No.	Date Revised	Revised By	Changes Made
1	11/17/2023	JM	• Removed risk analysis section to reflect current project state
2	11/30/2023	JC, MM	• Refined plots in aerodynamics section • Added requirement summary to aerodynamics section
3	12/3/2023	JM, TP	• Included additional detail on competing platforms in introduction • Included more structural analysis detail
4	12/8/2023	RL	• Expanded FTA and testing section to explain fabrication process
5	12/11/2023	JM, JC	• Revised grammar and wording throughout • Added recommendations for additional testing due to limited results of completed tests

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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
CFR	=	Code of Federal Regulations
F1	=	Damped Natural Frequency
FAA	=	Federal Aviation Administration
ft	=	Foot
kts	=	Knots
lbs	=	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
S.M.	=	Static Margin
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. Producing a small Unmanned Aerial Vehicle (UAV) that can be launched and recovered from civilian and military vessels 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.

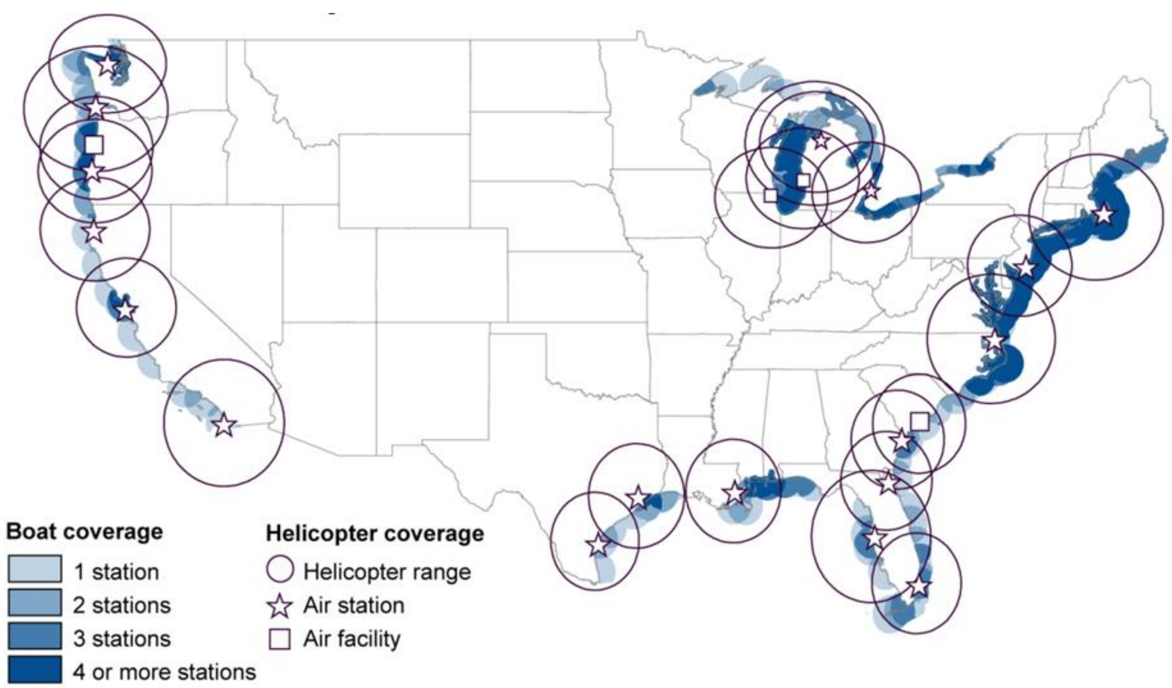


Figure 1.1: Overlap of Coast Guard Search and Rescue Coverage Provided by Surface Vessels and Aircraft as of May 2017 [1]

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 notification-to-search response periods for a SAR mission. Consequently, an unmanned search and rescue craft needs to prioritize a fast 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]. 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 exceptionally 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. Furthermore, using manned platforms for the search process places human lives into danger by requiring extended flights in poor conditions.

Another platform operated by the USCG in a limited capacity is the Boeing/Insitu ScanEagle, shown in *Figure 1.2*. 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 limited in its capabilities due to its lack of an internal payload bay for a life raft.

Figure 1.2: Boeing/Insitu ScanEagle in a Maritime Environment [4]

Another aircraft is the UAVision Spyro is a heavy-lift octocopter platform that has been trialed for use as a short-range SAR platform. An image of this aircraft is shown in *Figure 1.3*. The aircraft can lift 15 lbs., which is sufficient for life raft deployment and can loiter for up to an hour [5]. 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 1.3: UAVision Spyro Operating from Ship Deck [6]

1.3 Design Solution

To fill this gap in SAR platform capabilities, the Calypso aircraft provides autonomous and unmanned deployment of life-preserving devices. The aircraft cruises at a high speed and can be launched and recovered from standalone hardware, allowing integration with both military and civilian platforms. Further, the simplicity of the airframe allows for mass-deployment to improve the capabilities of search and rescue operations at any scale.

Figure 1.4: Rendering of Calypso Aircraft After Launch

2.0 CONCEPT OF OPERATIONS

To accomplish a search and rescue mission, the Calypso aircraft will follow a mission plan with six phases. The aircraft will autonomously launch from either a ground station or a maritime vessel and climb to 400 feet. It will then cruise to the location of a distress signal up to 17.5 NM away within a 15-minute period, 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 a typical mission is shown in Figure 2.1.

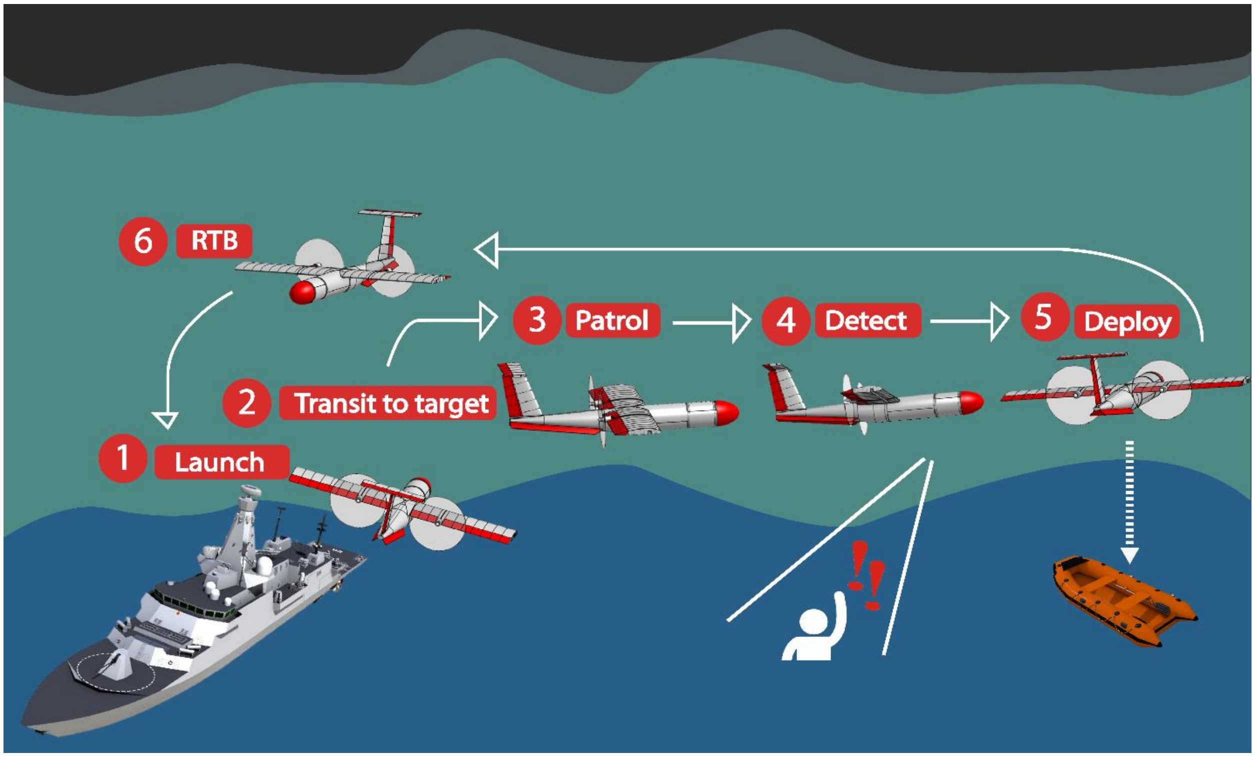


Figure 2.1: Typical Mission Profile for the Calypso UAV

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 the last known location of the victim. The Calypso aircraft will then launch from the base station using a remotely triggered catapult and climb to 400 feet ASL. Once at its operational altitude, the aircraft will autonomously fly up to 17.5 NM from the station to the last known location. This range allows for extensive shore-to-search coverage of a coastline with a Calypso aircraft deployed every 27.5 NM or self-contained 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 [7] 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.

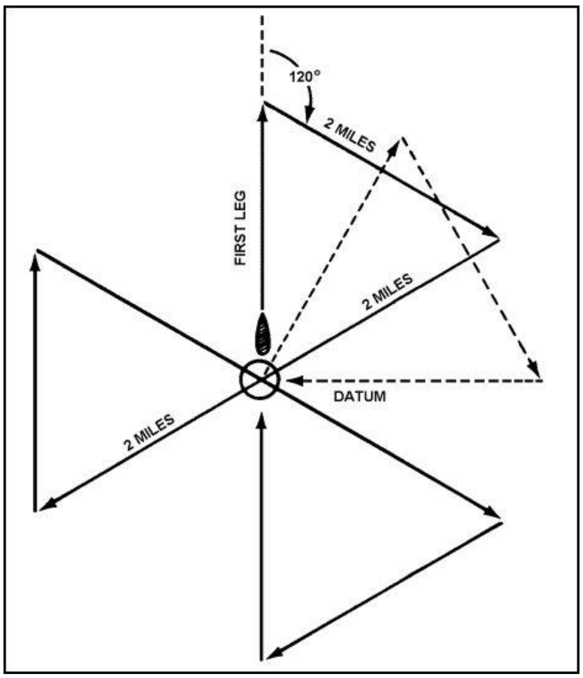


Figure 2.2: Victor-Sierra Single Unit Search Pattern [8]

2.3 Victim Detection and Payload Deployment

Once a victim is detected, the Calypso aircraft can be switched 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. 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. The impact location can be accurately calculated using the GPS and airspeed sensors onboard the aircraft. 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 return to the base station at 400 feet ASL for recovery. The Calypso aircraft will then be captured by a dedicated recovery station. The aircraft will be designed to need a minimal amount of time to return to flight-ready condition. This will be accomplished by placing the battery and life raft in easy to access locations. This process should take less than an hour.

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 5-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

Parameter	Requirement
Operating Altitude	Sea level to 400 ft ASL
Operating Temperature	-20° to 40° C
Speed Requirement	Cover 17.5 NM in no more than 15 minutes
Operating Radius	17.5 NM
Minimum Loiter Time	30 minutes
Load Factor	3.5 g
Climb Rate	1000 ft/min
Weather Conditions	Up to Force 7 Beaufort scale (28-33 kts winds, 13-19 ft waves)
Sensor Payload	4 lbs., self-powered payload.
Maximum Takeoff Weight	35 lbs.
Minimum Maintenance Interval	3 months
Maximum Turnaround 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 17.5 nautical mile distance in less than 15 minutes, which equates to an average speed of no less than 70 knots. Considering a headwind in Force 7 Beaufort winds, the derived cruise speed should be no less than 100 kts. These requirements are summarized in *Table 3.2*.

Table 3.2: Derived Cruise Speed Requirement

Parameter	Requirement
Speed Requirement	Cover 17.5 NM in no more than 15 minutes
External Conditions	Up to 33 kts headwind
Derived Minimum Cruise Speed Requirement	100 kts

Because the aircraft must be launched and retrieved from a 4 ft x 4 ft platform, the aircraft must 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, two additional environmental requirements were derived. First, the aircraft must 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 minimum service interval. Having an extended service interval will lower the cost of operating this system. 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.

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 requirements given in *Table 3.3* were derived from the operation conditions and capabilities of an aircraft of this size:

Table 3.3: Derived Life Raft Requirements

Parameter	Requirement
Maximum Weight	5
Minimum Buoyancy	Fully support two adults (360 lbs.)
Stability	Withstand Force 7 Beaufort scale (13-19 ft waves)
Deployment	Automatic upon release from aircraft

From the constraint analysis and weight fractions determined during the preliminary phase, the weight, wing loading, and power loading requirements shown in *Table 3.4* were derived. These requirements drive the weight of aircraft systems, the aerodynamic design, and the propulsion system.

Table 3.4: Derived Requirements from Constraint Analysis

Parameter	Requirement
Maximum Payload System Weight	10.5 lbs.
Maximum Propulsion System Weight	13.3 lbs.
Maximum Structural Weight	11.2 lbs.
Minimum Wing Loading	4.66 lb/ft^2
Minimum Power Loading	175 W/lb

3.3 Design-Driver Requirements

Of the explicitly stated SOW requirements and derived requirements, four were chosen as design-driver requirements that influenced the aircraft's design the most. These requirements are listed in *Table 3.5*.

Table 3.5: Selected Design-Driver Requirements

Parameter	Requirement
Takeoff/Landing	Take off and land from a 4 ft x 4 ft elevated platform
Payload Capacity	4 lbs. sensor gimbal and deployable life raft
Minimum Cruise Speed	100 kts
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 utilize a catapult. A catapult requires structural reinforcements to the airframe to carry the shock of launch in addition to low speed designed 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 lbs. sensor package and a 5 lbs. life raft that can be deployed in flight. These requirements drive the placement of these 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 100 kts. 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 100 kts 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 battery power and thus propulsion system weight.

4.0 PAYLOAD SYSTEM

4.1 Requirements

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. This raft and deployment mechanism must meet the following requirements:

- Raft will remain stable in up to 19-ft waves (from Beaufort Force 7 conditions)
- Raft will provide sufficient buoyancy for multiple victims to remain afloat
- Raft will self-inflate upon impacting the water
- Raft and mechanism will weigh no more than 6 lbs. to meet planned weight fractions
- Raft and mechanism will fit entirely within the fuselage of the aircraft
- Mechanism will use a single transmitter channel to reduce complexity

4.2 Life Raft and Deployment Mechanism

To fulfill the requirements set for the Calypso aircraft, a life raft was selected and a mechanism to deploy this life raft was designed. A 5 lbs. life raft that provides enough buoyancy for at least two adults was chosen. The deployment mechanism for this raft has been designed with considerations for fuselage diameter and weight.

4.2.1 Life Raft

No existing off-the-shelf products exist which fulfill all requirements. To meet these requirements, a modified version of an existing product will be used. The modified life raft is based on the Uncharted Supply Co. Rapid Raft [9], an inflatable raft designed for transiting small lakes or rivers. This raft is rated for 400 lbs. of buoyancy, enough to support two adults fully. It weighs 3.8 lbs. and is packed into a cylinder with dimensions 15” long by 5” 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 lbs. and the packed size to 15” long by 5.25” in diameter. These values were determined based on the weight and diameter of a typical CO_2 cannister used in life rafts. 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 4.1* and a product image of the raft is shown in *Figure 4.1*.

Table 4.1: Modified Uncharted Supply Co. Rapid Raft Specifications

Specification	Value
Buoyancy, (lbs.)	400
Weight, (lbs.)	5
Packed Dimensions, (in)	15 x 5.25Ø
Deployed Dimensions, (in)	72 x 33 x 12

Figure 4.1: 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.

4.2.2 Life Raft Deployment System

The life raft deployment mechanism utilizes a downward-opening bay ahead of the wing spar. This bay allows for a vertical drop from the aircraft, minimizing the risk of the raft impacting the fuselage or propellers when deployed. The raft is suspended from a spine running the length of the fuselage, which provides structural support to the wing and tail spar. The mechanism and its parts are shown in *Figure 4.2*.

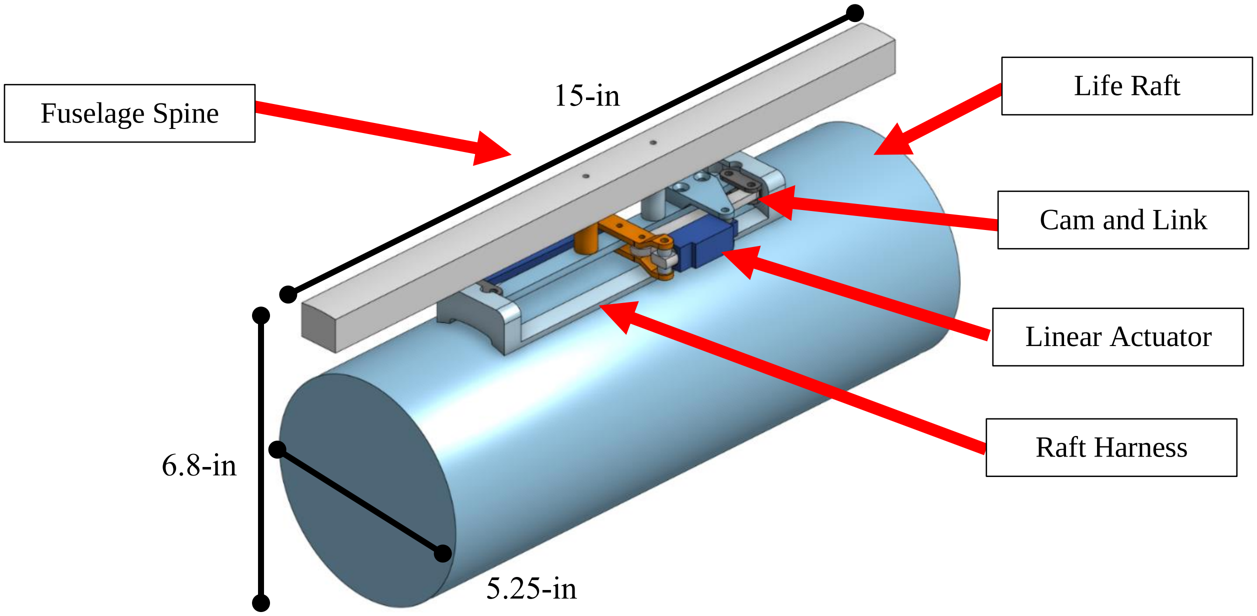


Figure 4.2: Isometric View of the Life Raft Deployment Mechanism

A parallel 4-bar mechanism is used to secure the raft with rotating cams, which do not allow movement of the raft in flight. The links of the mechanism are made of aluminum, with the cams made of Delrin, a tough, low friction plastic. These materials allow the mechanism to function while loaded. The mechanism is powered by a linear actuator with a stroke of 1.2 inches. Overall, this mechanism weighs 0.32 lbs., fits within a 6.8-inch cylinder, and uses a single transmitter channel, meeting the requirements set out for it.

The assembly is installed in the aircraft near the center of gravity to eliminate changes in stability after payload deployment. *Figure 4.3* shows the position of the life raft mechanism within the fuselage and the CG location.

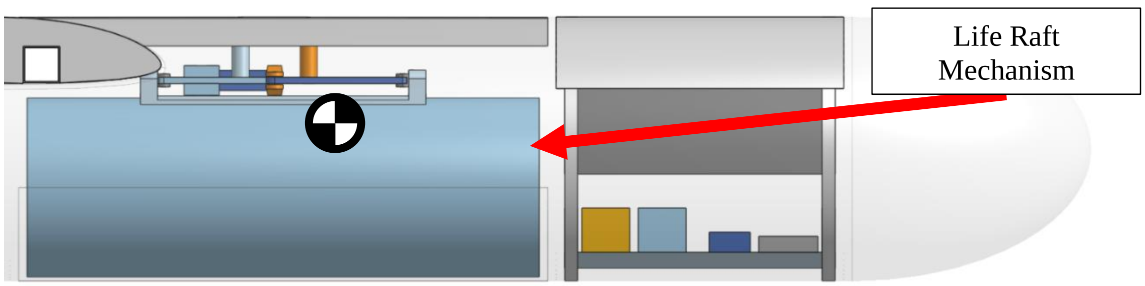


Figure 4.3: Side View of the Life Raft Mechanism Installed in Aircraft

To facilitate the deployment of the payload, two payload doors are installed in the life raft compartment. 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. *Figure 4.4* shows the location of fuselage doors and their position during deployment.

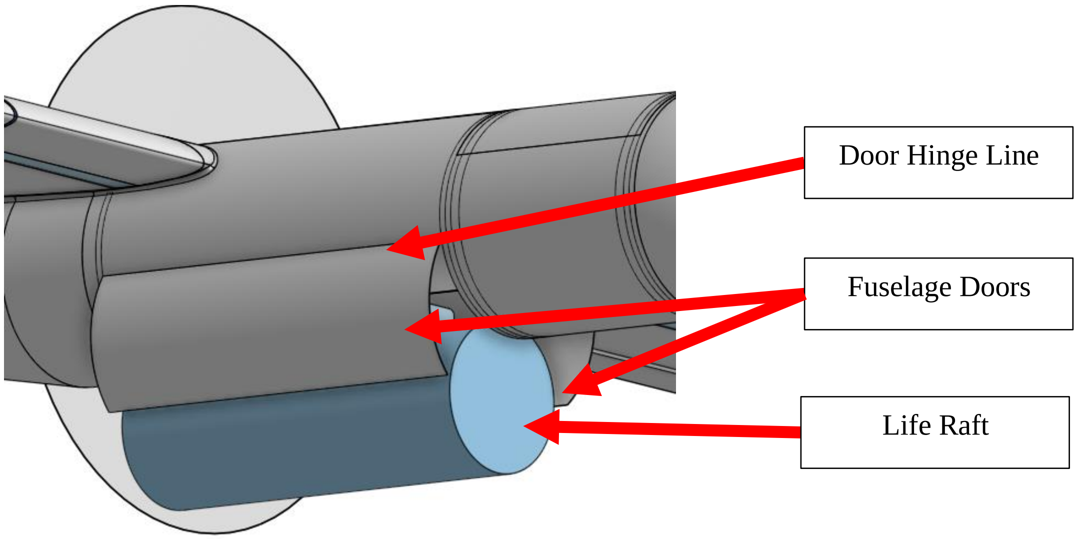


Figure 4.4: Deployment of Raft Showing Opening Doors

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.

4.3 Requirements Summary

Both the life raft and its deployment mechanism exceed the requirements defined in the RFP and the corresponding derived requirements. *Table 4.2* shows a summary of these requirements and the relevant design parameters.

Table 4.2: Summary of Payload System Requirement Compliance

Parameter	Requirement	Design
Raft Stability	Capable of handling 19-ft waves	Capable of handling 19-ft waves
Life Raft Buoyancy	> 360 lbs.	400 lbs.
Self-Inflate on Deployment	Yes	Yes
System Containment	Fits entirely within fuselage	Fits entirely within fuselage
Total System Weight	< 6 lbs. total	5.32 lbs.
Total System Size	< 7-inch diameter	6.8-inch diameter
Transmitter Bandwidth	1 channel	1 channel

5.0 ELECTRONICS

5.1 Requirements

To accomplish the mission of autonomous search and rescue, the aircraft is equipped with a flight controller to follow waypoints, a long-range radio system to maintain communications with the base station, and several additional components to allow these two to function properly. These components must meet the following requirements:

- Maintain communication with the aircraft at a range of at least 17.5 NM
- Transmit aircraft telemetry and HD video
- Allow for autonomous flight and waypoint missions
- Control at least 8 radio channels
- Fit entirely within the fuselage
- Maintain positive static margin with electronics bay placement

5.2 Flight Controller

The Pixhawk 4, shown in *Figure 5.1*, 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 base station and the aircraft. The large latency makes control of the aircraft difficult as there will be a lag between control inputs and the aircraft response.

Figure 5.1: Pixhawk 4 Flight Controller

The flight controller was picked on the premise of being inexpensive, having an adequate number of I/O ports, and extensive documentation. 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 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.

For the flight controller to perform autonomous missions, additional peripherals are needed. One of these peripherals is a GPS module. The module that is selected is the Beitian BN-880 GPS shown in *Figure 5.2*. This GPS allows the aircraft to know its position and fly towards preset GPS waypoints. An airspeed indicator sensor is also needed. The airspeed indicator probe that is selected is the Hobbypower Digital Airspeed Sensor shown in *Figure 5.3*. This sensor allows that aircraft to have an accurate indication of its airspeed allowing for autonomous takeoff and landing. The airspeed sensor is mounted on the nose to attain an accurate reading. The GPS module could be mounted anywhere in the aircraft away from electronics due to the small size having a negligible impact on the CG of the aircraft.

Figure 5.2: BN-880 GPS Module

Figure 5.3: Digital Airspeed Sensor

5.3 Communications

The Commtact MDLS is selected as the primary radio communication system. Since our aircraft is to operate at a maximum range of 17.5 NM, a long-range communication system is necessary. This radio is used to provide the aircraft with new mission profiles and for the aircraft to send back video feed and telemetry. The range requirement is met with the Commtact MDLS radio, which has a range of 21.75 NM while maintaining line of sight. Operations of the aircraft beyond the horizon will be done autonomously and without the need for radio communication. The radio has a weight of 0.22 lbs., which is far lower than alternative solutions like satellite communication systems which can weigh more than 10 times as much. In addition to the long range and weight, the radio is capable of transmitting HD video which will allow operators to assess the situation and condition of the victim.

5.4 Electronics Speed Controller

To drive the electric motors for propulsion, an electronic speed controller (ESC) is needed. For this task Spektrum Avian 130Amp ESCs have been selected, which are shown in *Figure 5.4*. This ESC has a 3S-6S (11.1V-22.2V) rated voltage which works with the batteries and motors detailed in Section 9.0. The current rating of 130 amps is also sufficient for the motors under full load. These ESCs will be mounted underneath the battery in the electronics bay.

Figure 5.4: Spektrum Avian 130A Brushless Smart ESC

5.5 Electronics Bay and Integration

To facilitate a positive static margin, all electronics are placed in the nose of the plane. For easy access, a hatch is placed at the top of the fuselage. *Figure 5.5* shows the position of the electronics bay in the nose of the aircraft and the location of the aircraft's center of gravity. Note that the electro-optical sensor specified in the RFP is placed ahead of the electronics bay, depicted as a blue cube in the figure.

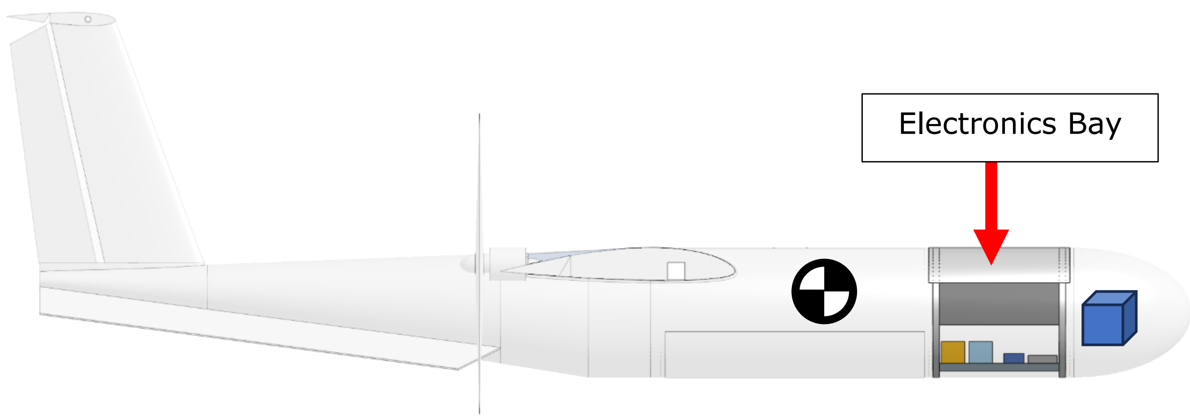


Figure 5.5: Electronics Bay and CG Location

The design of the electronics bay allows for modularity of components which need to be exchanged. The battery is supported on both ends by bulkheads with the remaining electronics attached to a tray on the bottom of the compartment. This design allows for room for wiring and reduces the time involved in battery swaps. *Figure 5.6* shows a section view of the electronics bay and the components inside.

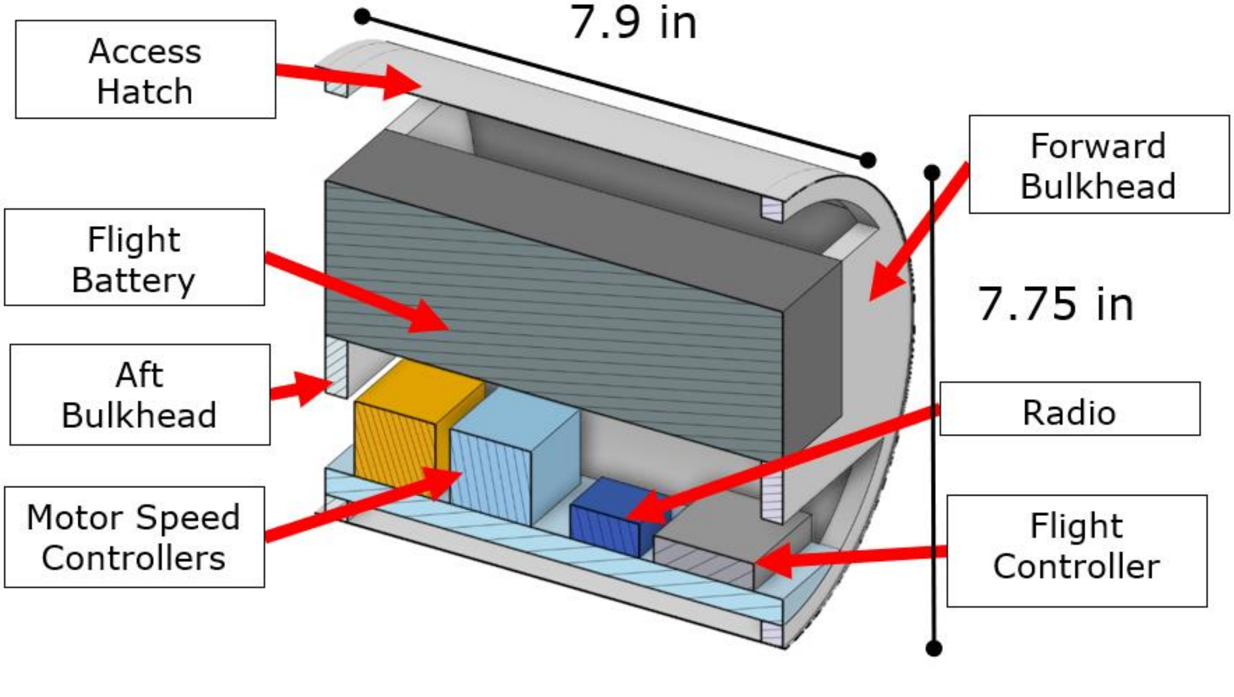


Figure 5.6: Electronics Bay and Components

5.6 Requirement Summary

The electronics selected for the Calypso aircraft meet or exceed all requirements. These components will allow the aircraft to successfully complete its mission in all environments. A summary of the requirements for the electronics system is shown in *Table 5.1*.

Table 5.1: Summary of Electronics Requirement Compliance

Parameter	Requirement	Design
Communication Range	≥ 17.5 NM	21.75 NM
Communication Bandwidth	Video and Telemetry	HD Video and Telemetry
Mission Planning and Execution	Autonomous flight and waypoint navigation	Autonomous flight, waypoint navigation, survey patterns
Radio Channels	≥ 8	16
System Containment	Fits entirely within fuselage	Fits entirely within fuselage
Static Margin	Positive	+ 36%

6.0 LAUNCH AND RECOVERY

6.1 Requirements

The statement of work for this project identified that the Calypso team select appropriate systems for the launch and recovery of the rescue aircraft. Although a full design process and specification of these systems is not required, a catapult has been designed to allow for the flight test article to exclude landing gear. The launch and recovery systems must abide by the following requirements:

- Accelerate the aircraft at no more than 3.5 g
- Mount to a 4-ft by 4-ft elevated platform
- Triggerable remotely to function with the autonomous aircraft
- Accelerate the aircraft to at least 27 kts
- Launch an aircraft weighing up to 35 lbs.
- Produce at least 945 ft lbs. of launch and recovery energy

6.2 Launch

To best meet the objectives and design requirements stated in the project RFP, the Calypso aircraft is designed with the intention of having no landing gear. The aircraft will instead be launched from an elastic catapult mechanism. Trade studies considering size, launch energies, cost, and required user input, indicated that an elastic system would best fit the needs of the project.

The design, fabrication, and utilization of a customer ready launch system is beyond the scope of this design project. But, to successfully complete testing and evaluation of the test article aircraft, and accounting for the challenges presented by a 27 knot, 3.5 g-loading maximum, and absence of landing gear, Project Calypso has designed the preliminary elastic launch system displayed in *Figure 6.1*.

Figure 6.1: Project Calypso Elastic Launch System

This catapult utilizes a 10-ft long launch rail and a sliding carriage that the aircraft attaches to with a hook on the underside of the fuselage. Four strands of 0.375" OD 0.125" wall thickness silicone rubber tubing produce the force required to launch the aircraft. This catapult produces a total launch energy of 975 ft lbs., which is sufficient to launch a 35 lbs. aircraft at 27 kts. The maximum g-loading experienced during launch is 3.41 g.

6.3 Recovery

Project Calypso has selected a cable recovery system comparable to the Boeing Skyhook pictured in *Figure 6.2* to return the aircraft to the ground.

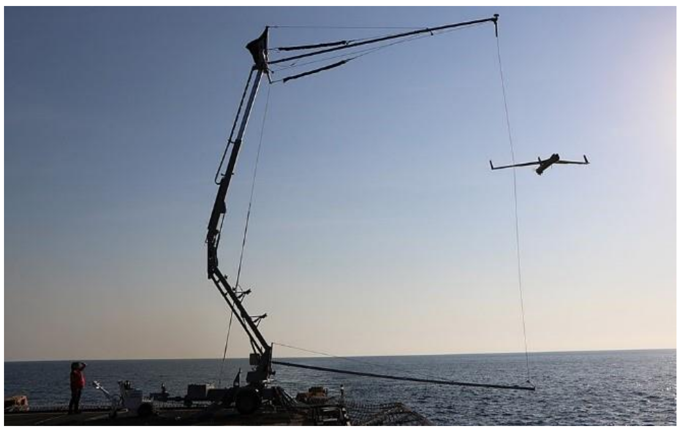


Figure 6.2: Wire Recovery System in Use

This system is extremely simple and capable of absorbing extremely large amounts of energy. A version of this system scaled down to the weights and speeds which the Calypso aircraft is capable of is specified to have the following properties. This scaled-down system can absorb 1475 ft lbs. of energy, which is sufficient to bring a 35 lbs. aircraft travelling at up to 34 kts to a complete halt. This allows for the recovery of the aircraft in case of a flap malfunction. The recovery system will utilize a double cable gantry mounted on the same 4-ft x 4-ft platform as the launch system. The airframe will fly into the cables, intending to hook one or both wings with a latch integrated into the leading edge of each wing. This mechanism is shown in *Figure 6.3*.

Figure 6.3: Boeing ScanEagle Skyhook Latch

6.4 Requirement Summary

The launch and recovery system selected for the Calypso aircraft meets most of the requirements. The notable exceptions are the size of the catapult and recovery system and triggering method of the catapult. The catapult design uses a bipod mount, but this can be changed to a pintle mount which will fit on a 4-ft by 4-ft platform. The catapult design uses a pin which is manually removed to trigger the launch, but this can be replaced with an electronically actuated latch, making this system fully autonomous. A summary of the requirements for the electronics system is shown in Table 6.1.

Table 6.1: Summary of Launch and Recovery Requirement Compliance

Parameter	Requirement	Design
Maximum Aircraft Load Factor	3.5 g	3.41 g
Launch and Recovery System Size	Mountable on 4-ft by 4-ft elevated platform	10-ft long catapult 8-ft by 12-ft recovery system
User Input	Autonomous	Manually triggered launch, passive recovery
Take Off Velocity	27 kts	27 kts
Maximum Take-off Weight	35 lbs.	35 ft lbs.
Minimum Launch Energy	945 ft lbs.	975 ft lbs.
Minimum Recovery Energy	945 ft lbs.	1475 ft lbs.

7.0 STRUCTURES

7.1 Requirements

The Calypso aircraft uses a composite structure comprised of carbon fiber and fiberglass fabrics. A continuous 1-inch square wing spar supports the main wing, and 0.375-inch round spars are used in the horizontal and vertical tails. A spar-rib construction technique is used in the aerodynamic surface to transfer load from the skin to the spar. The fuselage is 7.75-inches in diameter with an overall length of 68.75 inches. The sizing and material selection of the fuselage and aerodynamic surfaces was driven primarily by the following requirements:

- Maximum loading of 3.5 g
- Structural weight less than 11.2 lbs.
- Enclose a 7-inch diameter life raft mechanism
- Maintain a positive static margin after life raft deployment

7.2 Fuselage Sizing

The fuselage was sized based on the location of the wing spar and the life raft mechanism. Since the ideal location for the life raft is at the center of gravity, it overlaps longitudinally with the location of the spar. A 7.75-inch diameter fuselage gives sufficient clearance for the wing spar to pass above the life raft. As the longitudinal distance between the wing and tail is fixed by the aerodynamic design, the fuselage forward of the wing is used to move the CG forward. An overall length of 68.75 inches provides for sufficient room for the electronics bay and sensor package in the nose. *Figure 7.1* shows the location of these components withing the fuselage as well as the location of the center of gravity.

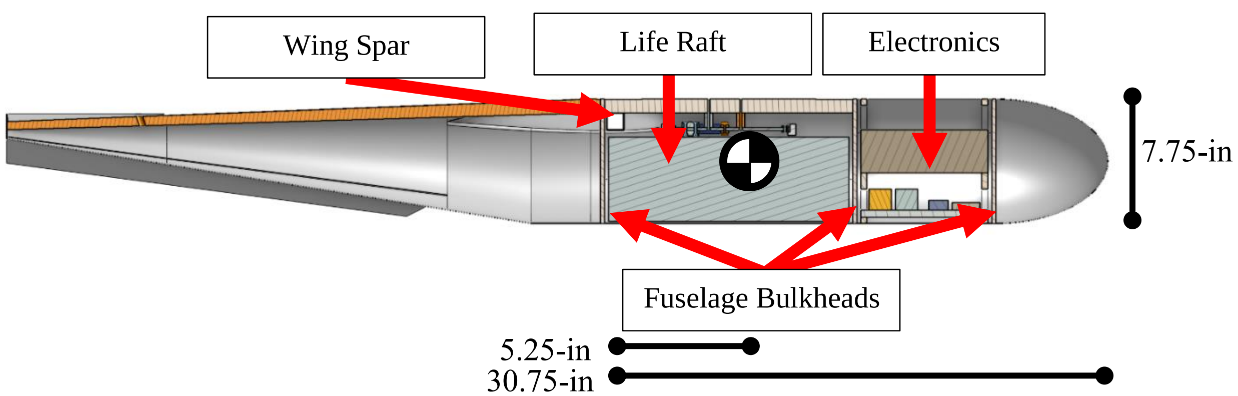


Figure 7.1: Fuselage Layout and Key Components

7.3 Structural Loading and Spar Sizing

The structural loads on the aircraft were determined using the maximum required loading of 3.5 g and a 0.5 margin of safety with Schrenk's Approximation for lift distribution. The lift distribution across the full wingspan is shown in *Figure 7.2*.

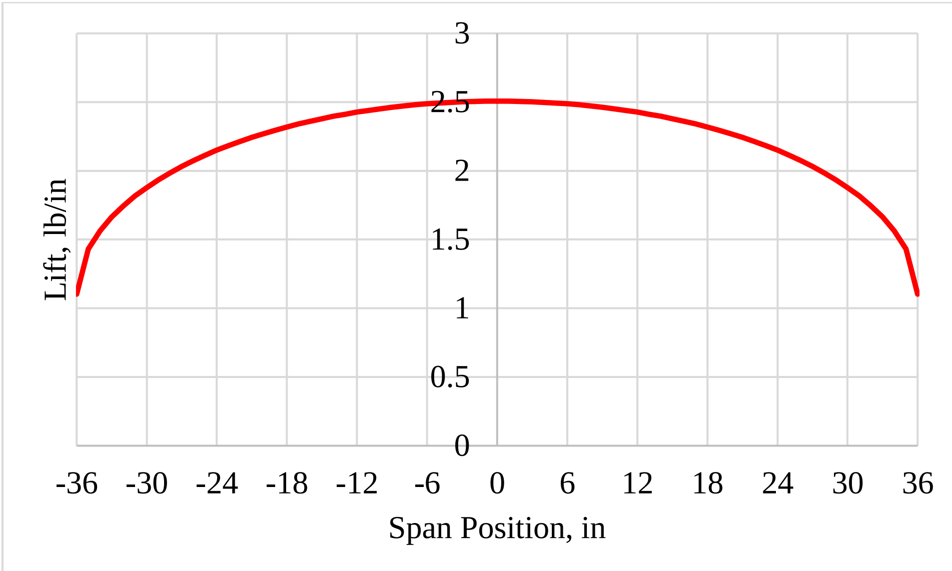
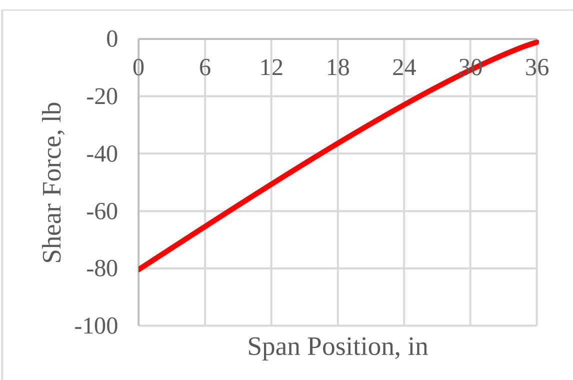


Figure 7.2: Lift Distribution on Wing Using Schrenk's Approximation

The lift distribution across the wing was then used to determine the shear and bending force on the wing at every point. The distribution of shear and moment on the wing is shown in *Figure 7.3*.



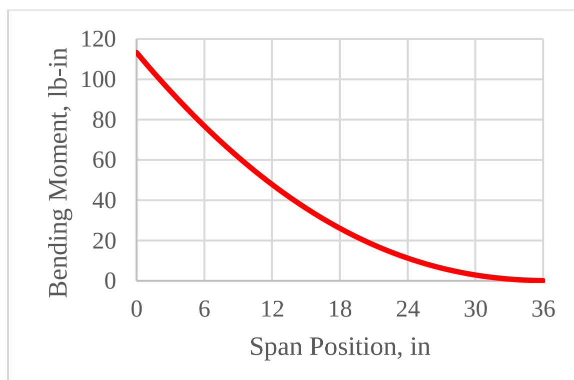


Figure 7.3: Shear Force (left) and Bending Moment (right)

From these shear force and bending moment distributions, the maximum stress in the wing spar could be found to be 29.62 ksi. The bending and shear stress were combined using the Tsai-Hill failure criterion for composite structures. A 1.07-in square tube carbon fiber spar with 0.035-in wall thickness was selected using this process. This spar has a margin of safety of 1.2, yielding a maximum loading of 7.8 g. The reason for this high of a safety factor is that no smaller commonly available size of square spar was able to withstand the required loading. The same process was used to size the tail spars, which were selected to be 0.375-in diameter round tube carbon fiber spars with 0.07-in wall thickness. The lift distribution for these spars used the typical tail downforce at cruise with the 3.5 g of loading applied, yielding a margin of safety of 2.4. Ultimate load limits of the aircraft under maneuver conditions are found within the V-n load diagram in *Figure 15.6*, with the maximum maneuver limit rated for 4.49 g, exceeding the 3.5 g requirement.

7.4 Material Selection and Construction

The fuselage is constructed using negative molds to form the skin, with bulkheads and a spine bonded to the shell to provide strength and provide a load path between the wing spar and tail spar. The skin aft of the nose cone is a single lamina of 2x2 twill carbon fiber vacuum molded to the correct shape. The nose cone is a single lamina of fiberglass to allow radio frequency transparency for communications. The bulkheads are laid up with two laminae of 2x2 twill carbon fiber on each side of a 0.25-in thick Nomex honeycomb, while the spine has four laminae of 2x2 twill carbon fiber on each vertical face of a 0.875-in thick Nomex honeycomb. These components are shown in *Figure 7.4*.

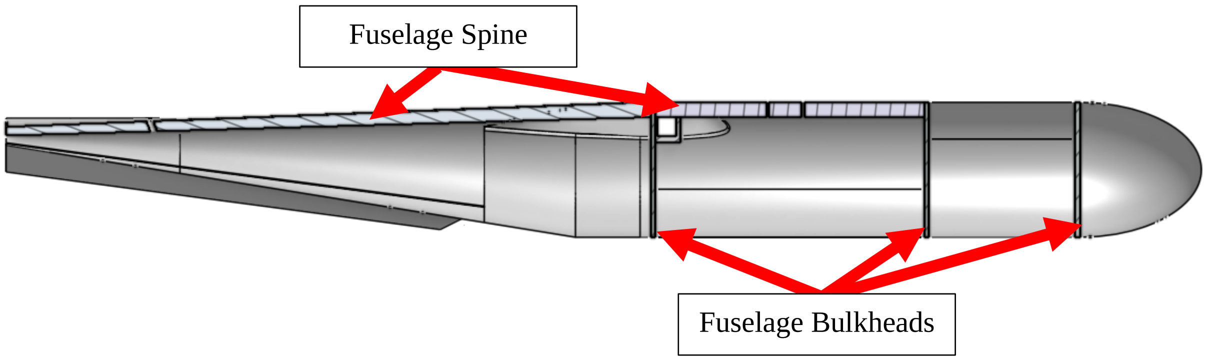


Figure 7.4: Fuselage Structural Members

The aerodynamic components use carbon fiber skin constructed using negative molds. Carbon fiber ribs transfer load from the skin to the spar. The ribs are spaced based on the expected pressure on the skin during flight to prevent buckling of the skin. The wing ribs are spaced 2.75-in on center inboard of the motor mount and 3.125-in on center outboard of the motor mount. The vertical tail ribs are spaced 3-in on center and the horizontal tail ribs are spaced 4-in on center. *Figure 7.5* shows the spacing of the ribs on the wing and tail.

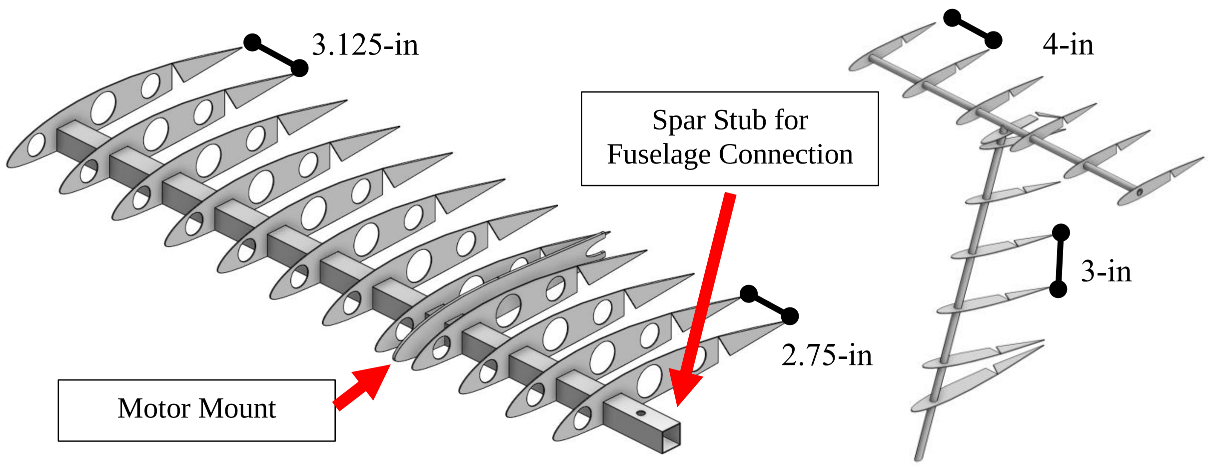


Figure 7.5: Spar-Rib Construction of Wing (left) and Tail (right)

All the ribs are constructed of four laminae of 2x2 twill carbon fiber fabric and cut to shape. Once the skin has been molded, the ribs can be bonded onto the skin. Kevlar hinges are used for the control surfaces to eliminate the structural complexity of control surface pivots.

7.5 Requirement Summary

The selected materials and construction methods allow the structure of the aircraft to exceed the requirements defined in the RFP and the relevant derived requirements. *Table 7.1* outlines the relevant requirements for this section.

Table 7.1: Summary of Structural Requirement Compliance

Parameter	Requirement	Design
Maximum Loading	3.5 g	7.8 g
Maximum Structural Weight	11.3 lbs.	11.27 lbs.
Life Raft Mechanism Support	Aerodynamically enclosed	Fully enclosed
Static Margin	Positive before and after raft deployment	36% before, 39% after

8.0 AERODYNAMICS

8.1 Requirements

The Calypso aircraft is designed to complete maritime search and rescue missions from either ocean-going vessels or remote areas of shoreline. A typical mission profile involves autonomous launch from a catapult and climbing to 400 ft above sea level. The following requirements have driven the aerodynamic configuration of the aircraft.

- Cruise at 70 kts
- Range of 17.5 NM
- Loiter duration of 30 minutes
- Capable of operations in Beaufort Force 7 conditions (28-33 knots)
- Maximum dash speed of 100 knots

8.2 Configuration

The Calypso aircraft is a twin pusher-propeller, non-tapered wing, t-tail configuration equipped with ventral strakes. 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. The propellers are mounted in a pusher configuration to prevent damage during landing, as the final design will be using a catch recovery method. Finally, ventral strakes are included to improve lateral-directional stability by adding additional vertical surface area to the aircraft. This configuration is shown in *Figure 8.1*.

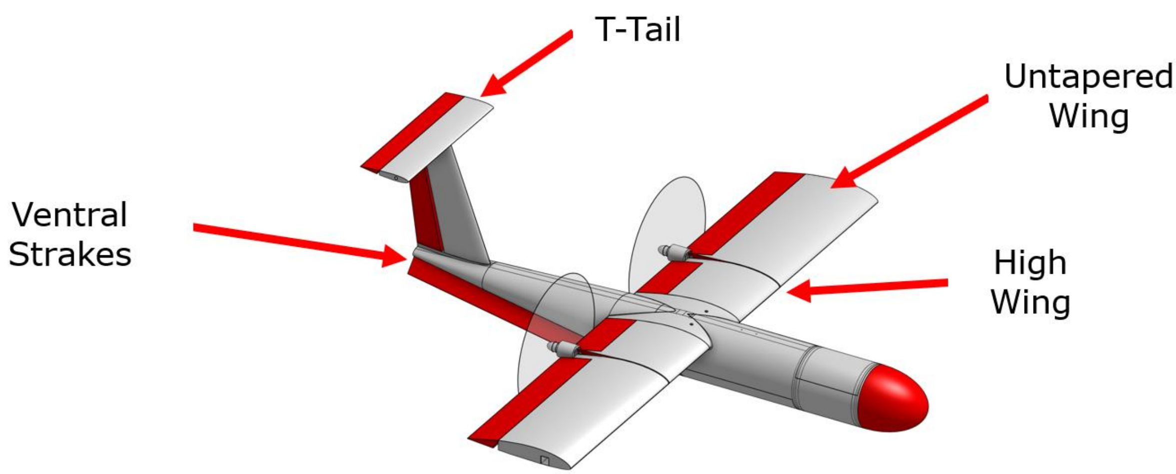


Figure 8.1: Calypso Aircraft Configuration

8.3 Wind Tunnel (Performance & Stability)

Two primary tests were conducted: a one-third scale wing with leading and trailing edge adjustable flaps, and a half scale aircraft model. The mechanized wing was tested in a 12-in by 12-in wing tunnel, with leading/trailing edge flap inclinations being adjusted at intervals of 15 degrees. The half scale aircraft was tested in a 48-in by 36-in wind tunnel at cruise and takeoff conditions. Strakes were then added to the half scale model and retested to compare data with and without strakes. Aerodynamic data shown in this section compares the use of 30 degrees of trailing edge flaps for the mechanized wing and the inclusion of strakes on the final aircraft model. These configurations allow the best improvement in aerodynamic performance.

8.3.1 Adjustable Flap Wing Section Testing

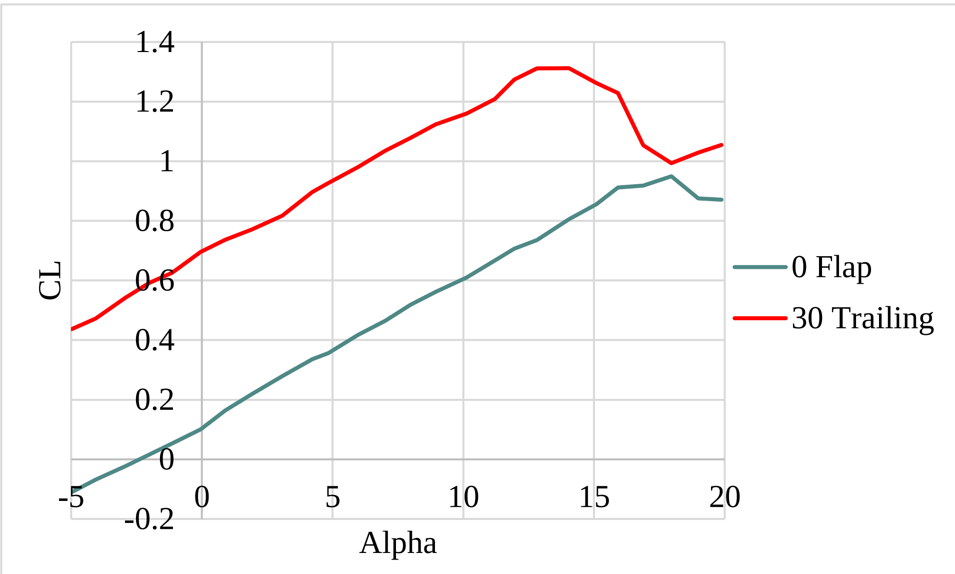


Figure 8.2: Mechanized Wing C_L vs Alpha Flap Comparison

The effect of added flaps was most increased with 30 degrees of trailing flap deflection shown in *Figure 8.2*. With an increase in CL, throughout all angles of attack, it was decided that the extra lift produced is necessary to achieve the catapult takeoff performance, even with the extra CD while flaps are in use. The decrease in critical angle of attack is due to an increase of drag with the flaps, decreasing the stall speed. This decrease in critical angle is not important for operations, as whole-aircraft testing showed that the tail loses effectiveness at low speeds at about 14°AoA, which limits the possibility of the aircraft stalling at low speeds.

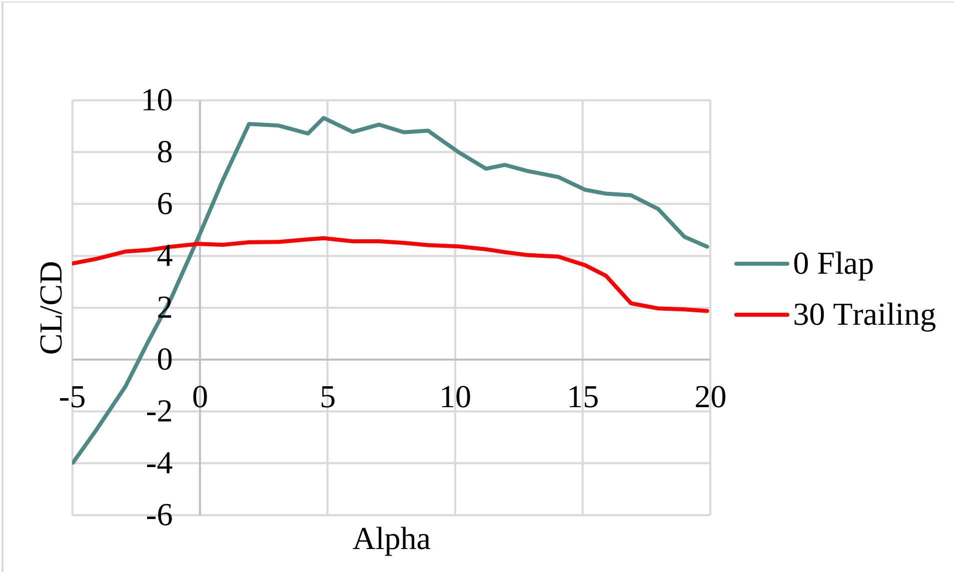


Figure 8.3: Mechanized Wing C_L/C_D vs Alpha Flap Comparison

As expected, there was a decrease in the lift to drag ratio when including flaps at the highest amount of deflection. *Figure 8.3* shows this decreased efficiency. However, since flaps will only be used at low air speeds, this increase in drag is allowable.

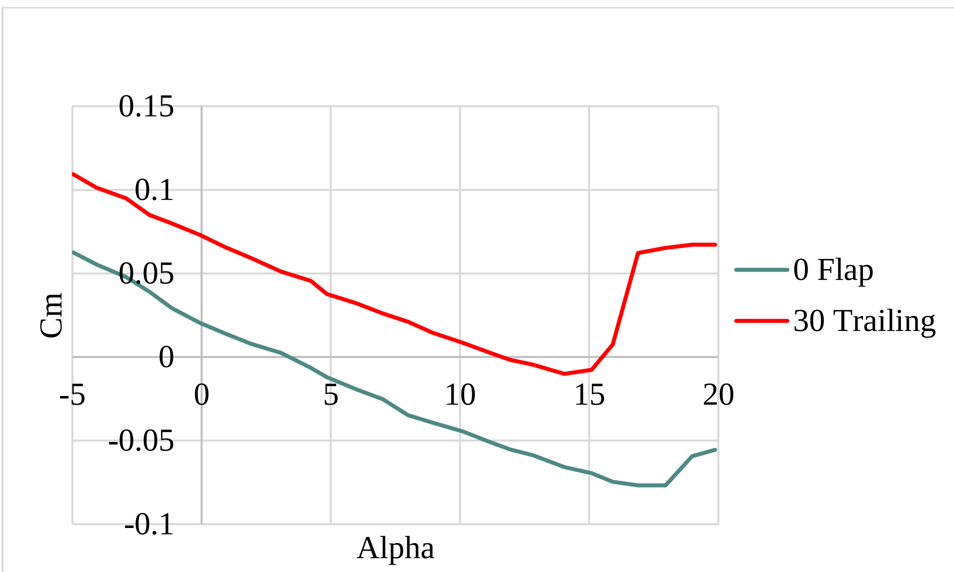


Figure 8.4: Mechanized Wing C_m vs Alpha Flap Comparison

In *Figure 8.4*, the moment coefficient was confirmed to still be negative even with the addition of trailing edge flaps. However, as the moment curve is shifted upward, the longitudinal stability of the aircraft will decrease when flaps are deployed. Since the aircraft has a very large static margin of 36%, stability should be maintained although the aircraft will need to be trimmed differently during takeoff.

8.3.2 Half Scale Aircraft Testing

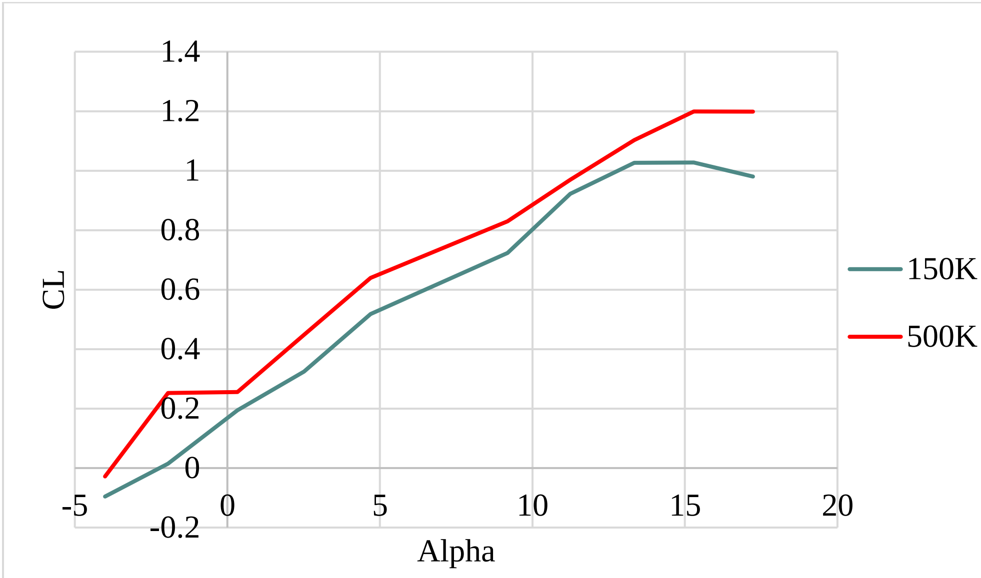
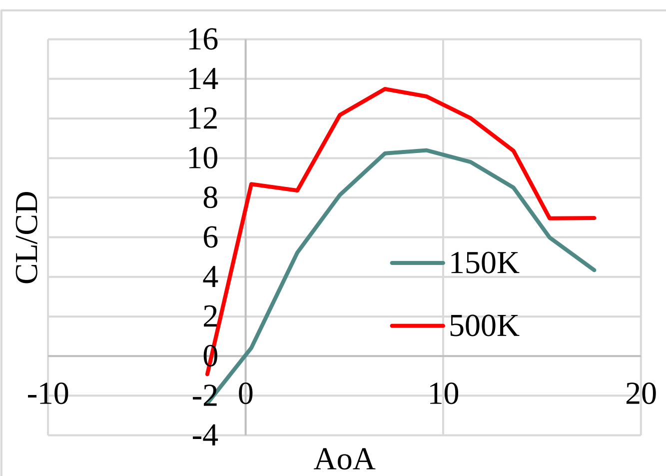


Figure 8.5: Comparison of Cl v Alpha with Strakes at Cruise and Takeoff Conditions

Half scale testing confirmed that the aircraft lift coefficient is behaving as expected and concurs with simulated data. *Figure 8.5* shows the lift curve for both takeoff and landing with the addition of strakes. Having a maximum lift coefficient of ~1.2 before stall validates aircraft design and aerodynamics, without any negative impact from the strakes.



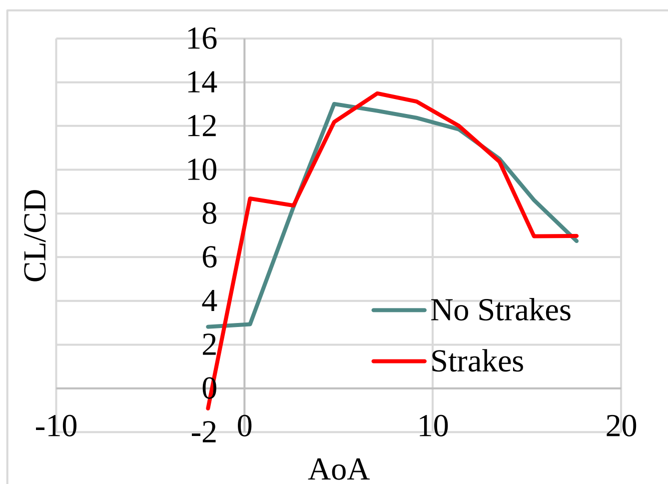


Figure 8.6: C_L/C_D vs Alpha at Cruise and Takeoff with and without Strakes

The addition of strakes increases the aircraft's lift to drag ratio as seen in *Figure 8.6*. The maximum CL/CD increased by 8.8% from 12.4 without strakes, to 13.5 with strakes. The alpha at which this occurred was slightly earlier, going from 9.23° AoA to 7.10° AoA. It was expected that the strakes would decrease drag forces due to minimizing vortices around the fuselage and empennage area. Having positive effects on lift while negligibly increasing drag at cruise is the main reason for implementing strakes. Sideslip was tested from -10° to 10° at 5° increments and verified controllable and acceptable stability responses in all regimes (shown below in *Figure 8.7)*. Notably, the addition of strakes improved roll response by mitigating the t-tail rolling moment, though this was at the cost of an increase to drag coefficient to create the restoring force.

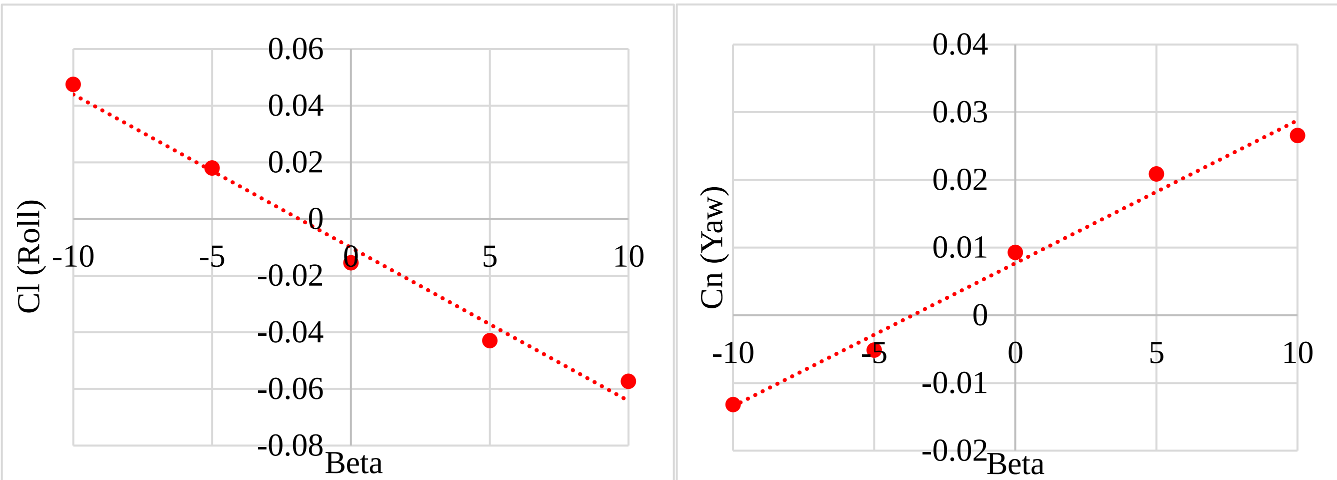


Figure 8.7: C_l vs Beta and C_n vs Beta with Strakes

Experimental testing revealed that the aircraft is longitudinally stable at higher Reynolds number but becomes unstable at takeoff Reynolds Numbers. This behavior is shown in *Figure 8.8*. However, the C_m curve still trends negative at these lower airspeeds and can be brought to stability by increasing the static margin. This data was collected with a static margin of 25% which has since been increased to 36%. Increasing the static margin will make the aircraft longitudinally stable.

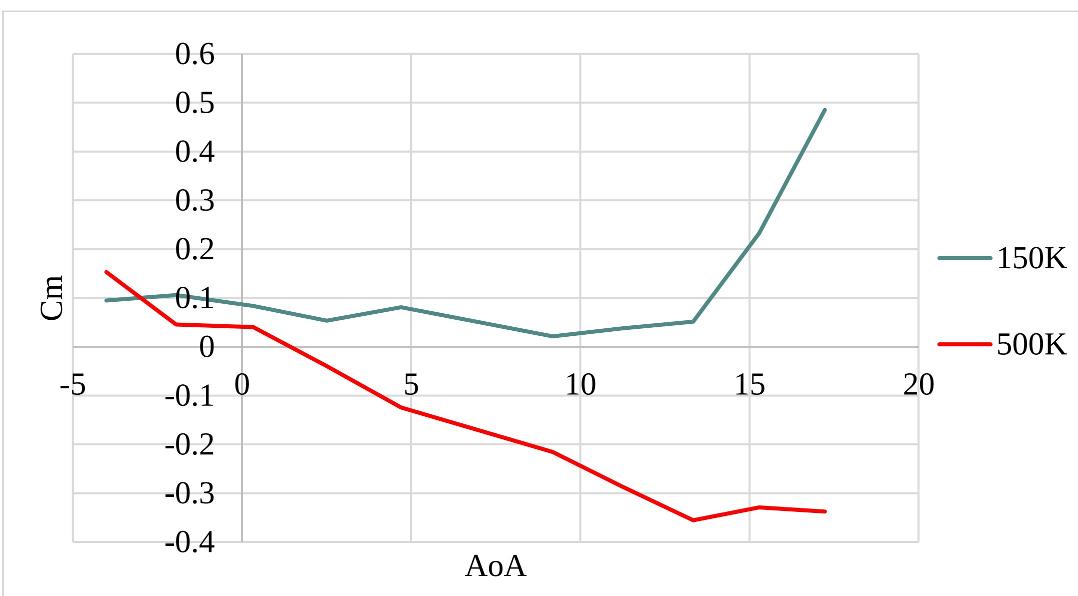


Figure 8.8: C_m vs Alpha at Takeoff and Cruise with Strakes

In addition to the experimental static stability data, XFLR5 was used to run dynamic stability simulations. The results of these simulations are shown in *Table 8.1*. It should be noted that XFLR5 makes several assumptions that reduce its accuracy when compared to real-world testing. Since the simulations agree with experimental data that the aircraft is stable in all axes, this XFLR5 information can be used for estimating the dynamic performance of the aircraft.

Table 8.1: Simulated Aircraft Stability Data at Cruise (Re = 1,150,000)

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. Both the simulated and testing data concluded that the aircraft is laterally and longitudinally stable.

8.4 Control Surfaces

Control surface area and position are intended to provide sufficient control authority as well as stability in all regimes of flight. The sizing and position were derived from control surface design guidelines from Aircraft Design a Conceptual Approach 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.

8.4.1 Ailerons

The ailerons start at 55% of the wingspan and extend out to the tip of the wing as shown in *Figure 8.9*. The width of the ailerons is constant at 30% of the chord length. Due to the aircraft being catapult launched, the control surfaces must be effective at the take-off speed of 37 ft/s. 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.

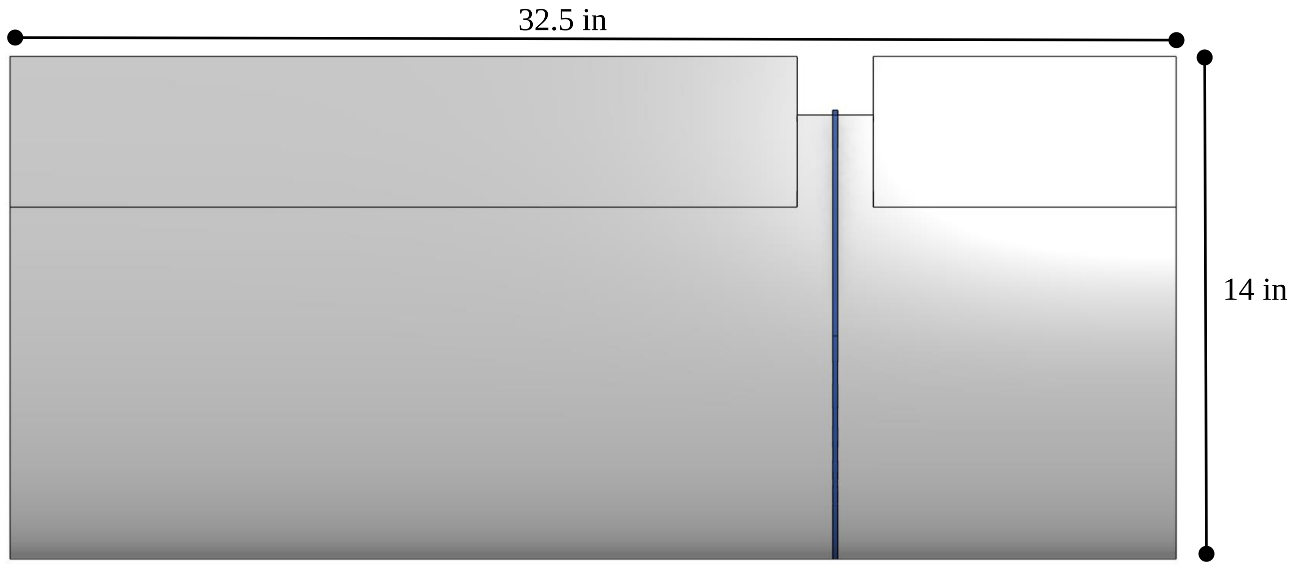


Figure 8.9: Aileron Sizing

8.4.2 Rudder

The rudder has a width of 40% of the chord and spans the full length of the vertical tail as shown in *Figure 8.10*. The current dimensions of the rudder provide adequate yaw authority during take-off and strong winds.

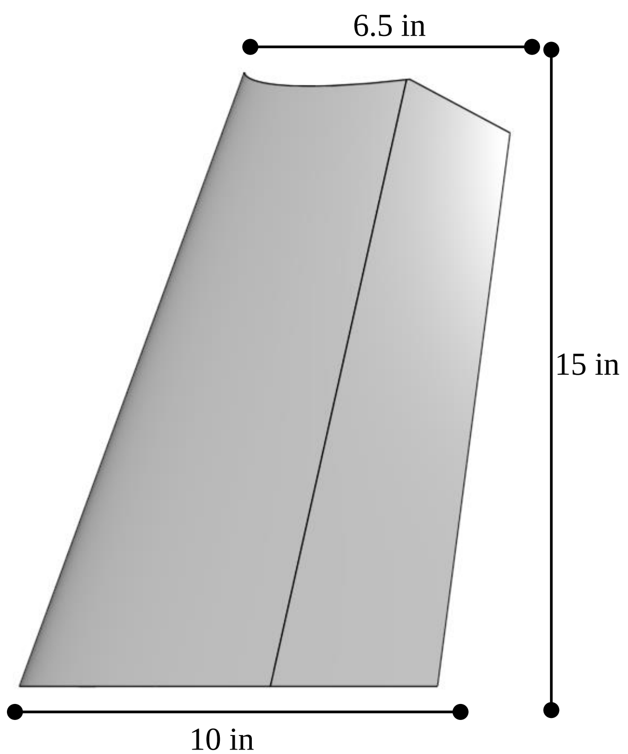


Figure 8.10: Rudder Sizing

8.4.3 Elevator

The elevator spans the full length of the horizontal stabilizer, with the width of 40% of the horizontal stabilizer as shown in *Figure 8.11*. The elevator configuration provides sufficient pitch authority during all phases of flight.

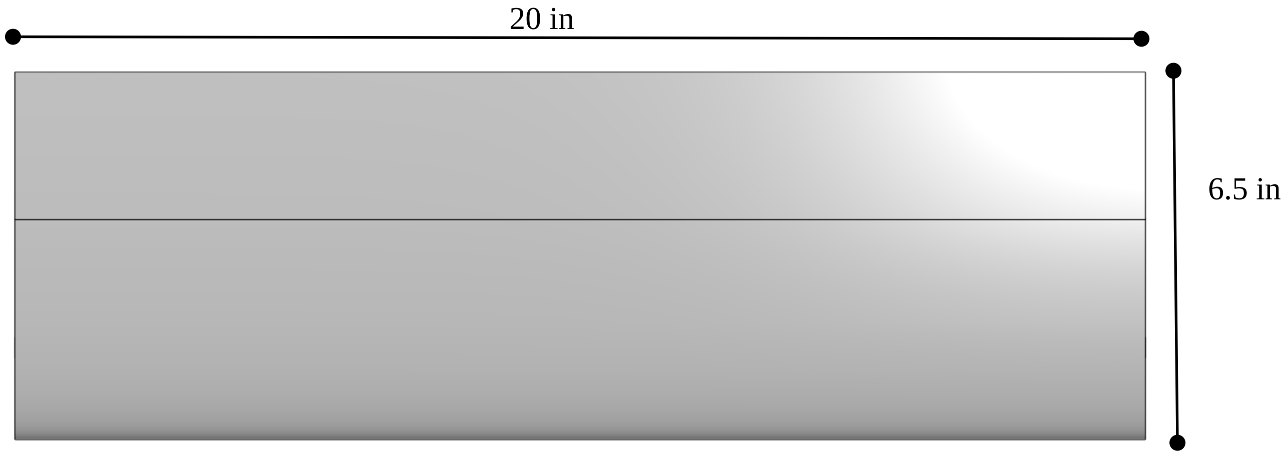


Figure 8.11: Elevator Sizing

8.5 High Lift Devices & Strakes

8.5.1 Trailing-Edge Flaps

Due to the aircraft necessitating a catapult launch, high lift devices are required to achieve the desired takeoff performance. We have selected trailing edge flaps as our high lift devices to increase our CL coefficient at takeoff. The flaps have a width of 30% of the chord and use the full length of the wing, as the ailerons act as flaperons during takeoff. With a 30-degree deflection of the trailing edge flap, we achieved a CL_{max} of 1.312 in wind tunnel testing at our takeoff speed. This CL is sufficient for the aircraft to become airborne. *Figure 8.12* shows the wing test section with the flaps at full deflection.

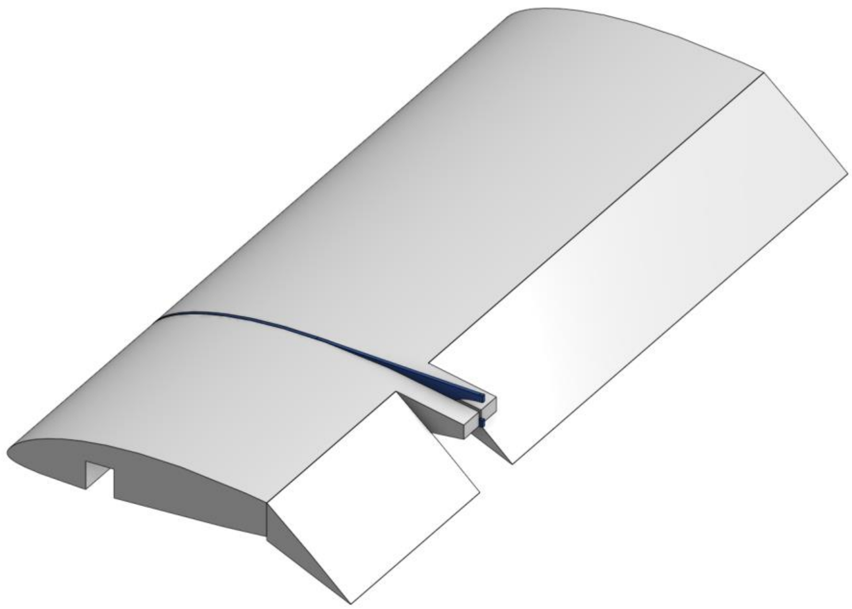


Figure 8.12: Full Flap Deflection

8.5.2 Aft-Body Strakes

To minimize drag at cruise and to maximize crosswind stability, two aft-body strakes are installed on the Calypso aircraft. These strakes have a vertical area of 82.85 in^2 which serves to improve lateral-directional stability. The strakes are oriented 45° off the central fuselage plane where they begin just aft of the fuselage taper and terminate at the end of the fuselage. Wind tunnel testing of the strake installation verified performance predictions by demonstrating improved aerodynamic characteristics—improved CL and decreased CD—as well as a pronounced counter-moment in the roll-axis opposite of the t-tail, which increases overall crosswind stability. *Figure 8.13* shows the location and relative sizing of these strakes.

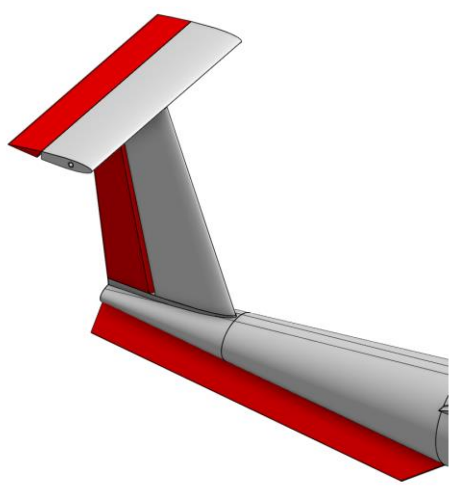


Figure 8.13: Aft-Body Strakes Along Underside of Fuselage

8.6 Requirements Summary

Wind tunnel testing of a scale aircraft and wing, in addition to XFLR5 simulations, has proven that the aerodynamic design meets or exceeds all requirements set out for it. *Table 8.2* shows a summary of the most relevant parameters for the aerodynamic design.

Table 8.2: Summary of Aerodynamic Requirement Compliance

Parameter	Requirement	Design
Maximum Stall Speed	33 kts	26.7 kts
L/D Max	Sufficient for cruise efficiency	13.49
Cruise Drag	Sufficient for cruise efficiency	C_D = 0.047 7.72 lb at 100 kts
Static Stability	Stable in all conditions	Stable in all conditions, longitudinal stability increased with S.M.
Dynamic Stability	Stable in all conditions	Stable in all conditions, spiral mode correctable by flight controller

9.0 PROPULSION

9.1 Requirements

The Calypso aircraft's propulsion system must meet the following requirements derived from the SOW.

- Provide at least 175 W/lb of propulsive power.
- Sustain flight at 100 kts for 15 minutes.
- Provide at least 90 minutes of endurance.
- Remain operable after three months of standby without maintenance.
- Reduce the likelihood of damage to the propeller during recovery.

An electric power system meets the requirements for the aircraft's power system as it does not degrade from contact with humid air.

To provide sufficient thrust to meet the cruise speed requirement, a twin-motor, pusher-prop configuration will be used. This configuration provides 175 W/lb of power shown and 9.74 lbs. of thrust at 100 kts, meeting the requirements.

9.2 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 safety requirements for the propulsion system. From the aerodynamic information in Section 8.0, the drag generated by the aircraft is 7.72 lbs. at 100 kts. To overcome this drag, two 18-inch diameter propellers with 12-inch pitch can be used. This propeller is shown in *Figure 9.1*. When turned at 10,000 rpm at 100 kts, these propellers generate 9.74 lbs. of thrust [10], exceeding the thrust required shown at Figure 9.4 and meeting the minimum cruise speed requirement.

Figure 9.1: 18x12e (Electric Profile) Propeller [11]

To turn these 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 9.2*. 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 of 9.74 lbs. Both motors combined provide 175 W/lb of continuous power, which meets the 175 W/lb total power requirement.

Figure 9.2: SunnySky X4125 V3 Brushless Motor [12]

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 9.3*, where the motor has sufficient power to drive the propeller at all without exceeding the motor rpm limit. It is capable of driving the propeller at over 10,000 rpm at 100 kts.

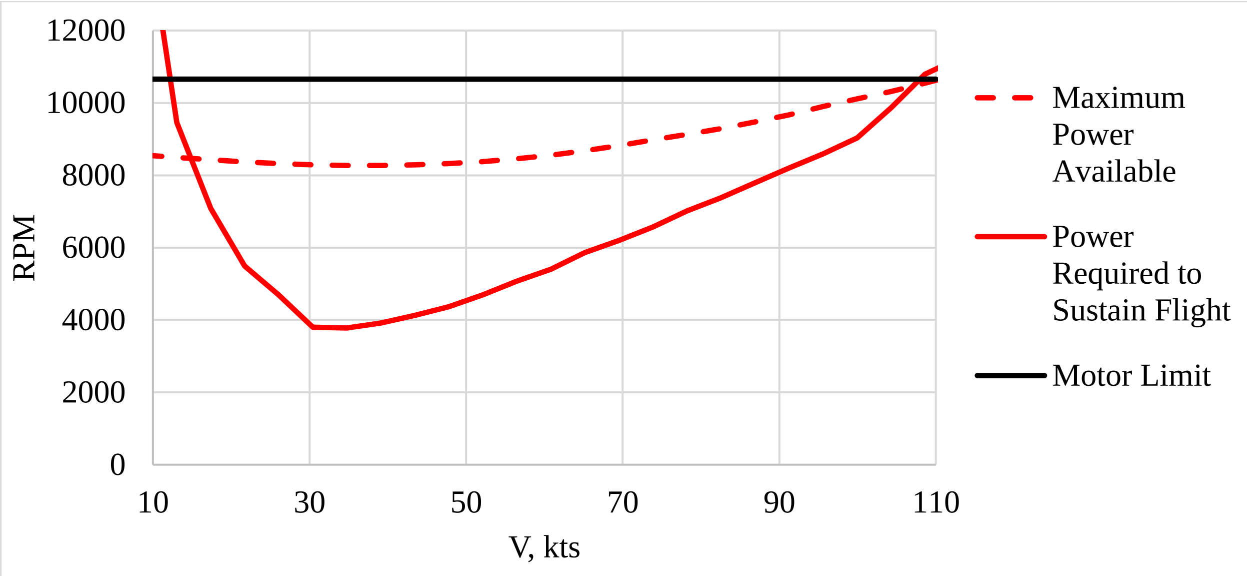


Figure 9.3: Propeller Power Required, X4125 Motor and 18x12e Propeller

9.3 Propulsion Power Analysis

From the specified motors and propellers, the energy required to sustain 100 kts for 15 minutes 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 9.4.* It is shown that thrust available exceeds thrust required at 17 kts. Since this value is lower than the stall speed of 27 kts calculated in Section 8.0, the aircraft's takeoff performance is limited by aerodynamics, not power. The aircraft can also generate net thrust at 100 kts cruise velocity and reach a maximum velocity of 108 kts.

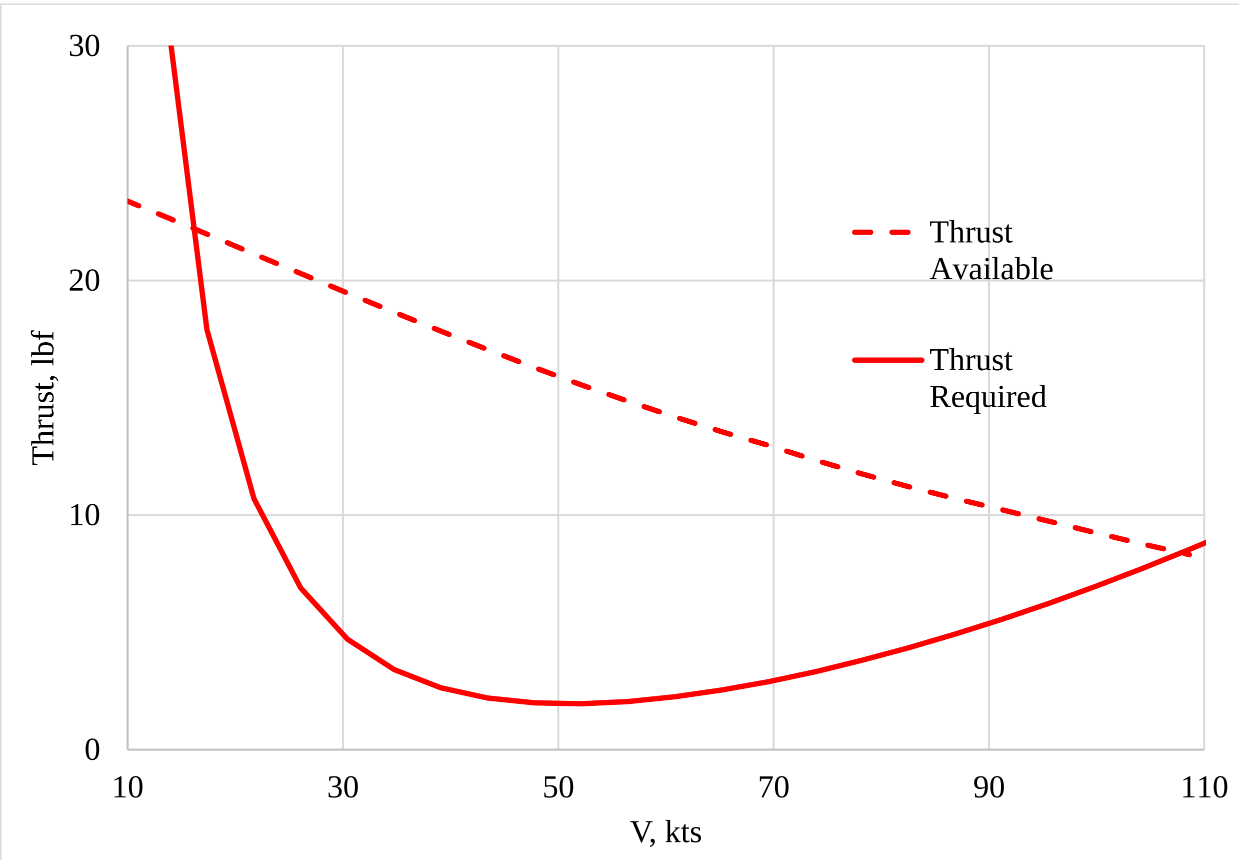


Figure 9.4: Thrust Available vs. Required, X4125 Motor and 18x12e Propeller

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 100 kts, while the loiter and return phases are set at 30 kts, 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 28.99 Ah. The typical mission profile is shown in Table 9.1 and Figure 9.5. A single 30 Ah battery provided sufficient energy to complete a typical mission with a 3.5% energy reserve. This amount of energy reserve allows the aircraft to meet the endurance requirement of 90 min. This battery weighs 5.65 lbs. [13], bringing the total aircraft weight to 31.25 lbs. estimated. At the operational weight the power loading remains above 175 W/lb, meeting the power loading requirement.

Table 9.1: Typical Mission Profile, Mission Phases and Flight Speeds

Mission Phase	Elapsed Time, minutes	Flight Speed, kts
Takeoff	1	Increasing to 100
Cruise to Target	16	100
Loiter	46	30
Return to Base	91	30
Landing	96	Decreasing to 0

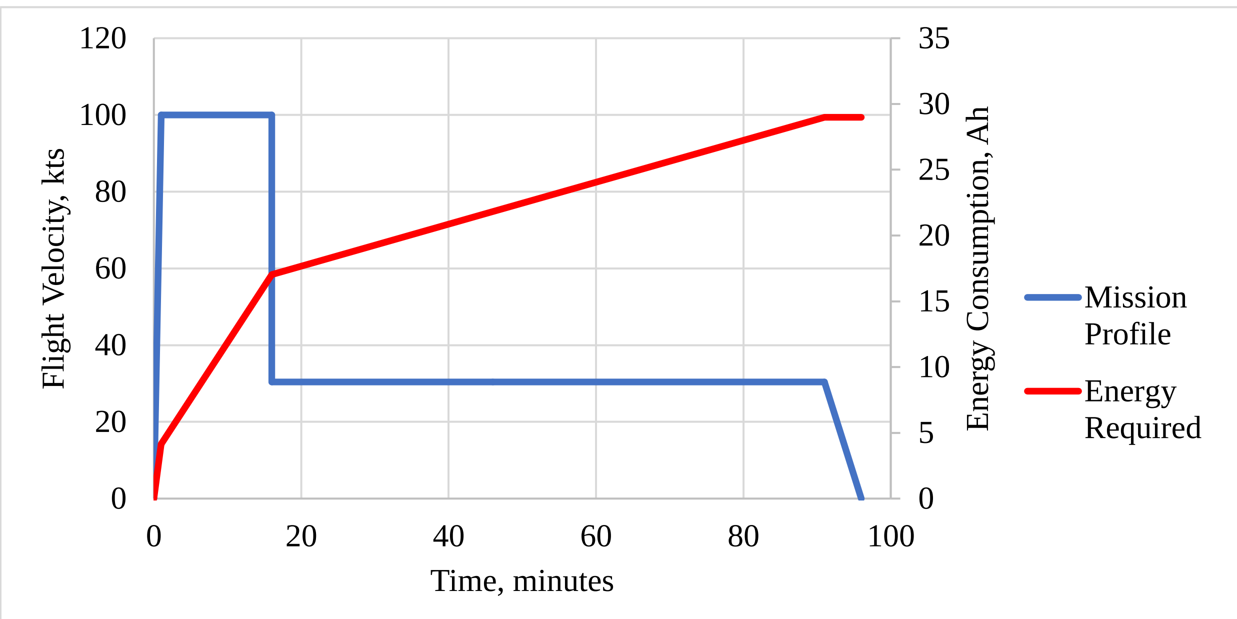


Figure 9.5: Mission Profile, Velocities and Energy Required

9.4 Requirement Summary

The selected propulsion system for the Calypso aircraft exceeds all requirements set out for it. A summary of these requirements is shown in *Table 9.2*.

Table 9.2: Summary of Propulsion Requirement Compliance

Parameter	Requirement	Design
Power Loading	$\geq$ 175 W/lb	175 W/lb
Cruise Speed	$\geq$ 100 kts	108 kts
Endurance	$\geq$ 90 minutes	Up to 96.5 minutes
Maintenance Interval	$\geq$ 3 months	Indefinite with trickle charging
Propeller Protection	Avoid damage during recovery	Pusher configuration avoids damage

10.0 FLIGHT TEST ARTICLE

The purpose of this flight test article is to test and validate the design model. A dimensionally accurate full-scale version of the design will be constructed using simplified fabrication methods.

10.1 Fabrication

The main building material selected for the conceptual design will be a 2x2 twill weave carbon fiber pre-impregnated cloth. This coupled with negative molds for the fuselage, tail, and main wing will provide a quick and repeatable manufacturing process. Carbon fiber coupled with the negative molds will reduce the number of internal structures needed including ribs and spars in the main wing, reducing the weight of the aircraft structure.

The final flight test article is constructed dimensionally identical to the conceptual design. All carbon fiber used is dry matte that is then wetted with laminating resin. The main difference being the use of positive molds for the nose and tail section of the fuselage made out of rigid foam wrapped carbon fiber. Two layers of carbon fiber sleeving were wrapped around the positive molds of both the nose and tail sections. Once cured, the foam molds are removed. The fuselage mid-section uses a 3d printed negative mold. The upper and lower molds are laid up separately using a 0/45 carbon fiber configuration. A 3d printed wing box that captures the spars of the main wing is in cased in the carbon fiber layers of the top mold. Both mold sections are then vacuum bagged during the curing process. Once cured, the top and bottom molds are joined, and 2 layers of carbon fiber strips are used to join the two sections. Strips of Kevlar and carbon fiber are then added to the ends of the fuselage mid-section and plywood rids are added to the interior of the mid-section. Carbon fiber rings are then constructed to adapt the the nose, mid-section, and tail of the fuselage together.

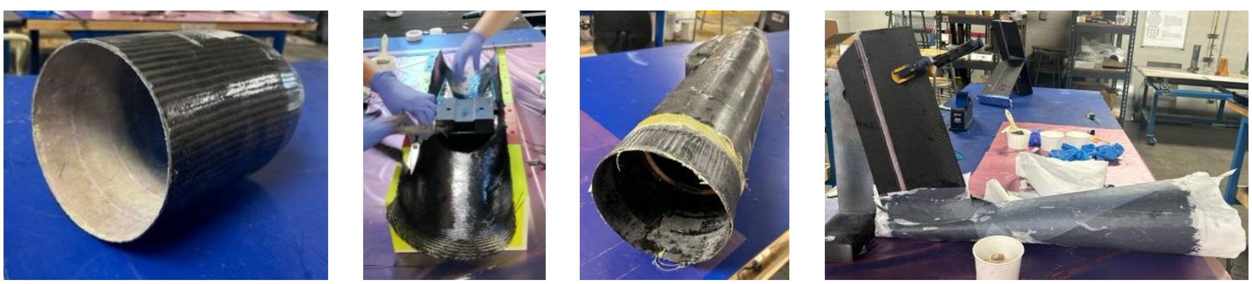


Figure 10.1: Fuselage Manufacturing Process (From Left: Nose Cone, Fuselage Half in Mold, Fuselage Halves Combined, Tail Attached)

All lifting surfaces are made from rigid foam cores wrapped in carbon fiber. A vacuum bag method is also used to ensure a quality surface finish. While the main wings do include the 1-inch by 1-inch square spar, the spars in the tail section are omitted to simplify the manufacturing process. Strips of Kevlar are imbedded into the carbon fiber skin to later act as hinges for control surfaces. The electronics used will be the same specified in the electronics and propulsion sections.

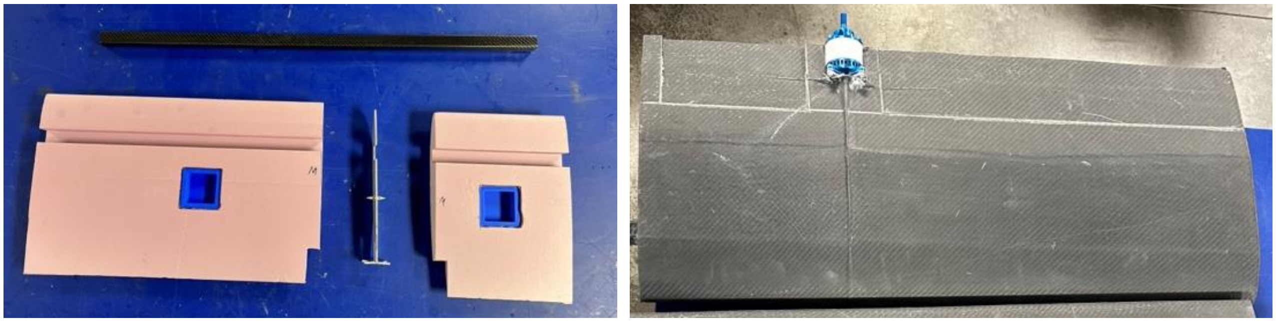


Figure 10.2: Wing Manufacturing Process (From Left: Foam Cores, Spar, and Motor Mount before Layup, Completed Wing)

10.2 Flight Test Procedure

The flight test was comprised of two separate phases: Taxi followed by high speed roll, and the flight portion. Prior to the taxi test, the aircraft was first assembled. Limited space for transportation requires that the aircraft tail section and nose are detached from the main fuselage/wings. During this time, the elevator, rudder, nose gear, and FPV camera controls are connected. When the aircraft and controller are powered on, a controls check is completed. This is to ensure that all input is matched with the correct control surface response, as well as a quick engine runup.

The taxi and roll test are conducted to ensure control authority on the ground, which is essential for takeoff. A half throttle pass was then executed to ensure that the power is even on both propellers, and that the surface is smooth enough for the chosen nose gear.

Once the taxi test has been completed, the aircraft is ready for flight testing. The aircraft will be lined up and applied full throttle for takeoff. Slight back pressure was applied during the ground roll, as exact takeoff speed was not able to be measured from the outside. When the aircraft reaches rotation speed, the pilot will conduct tests as they deem necessary. These tests are conducted through turning maneuvers, changing in pitching, and straight and level flight.

10.3 Flight Test Results

The flight test article successfully verified stability and basic performance behavior of the aircraft, as compared to simulated data. However, the flight test ended before cruise performance could be evaluated due to a mechanical failure. A propeller was lost due to insufficient retention methods, resulting in the loss of the airframe. A data recording phone was inserted into the fuselage to gather real time data during the flight test. Results are shown below in *Table 10.1*.

Table 10.1: Flight Test Results

Variable	Value
Time of Flight (seconds)	~13.5
Take off distance (ft)	220
Take off speed (knots)	30.2
Max speed (knots)	47.04
Max Rate of Climb (ft/min)	1100
Longitudinal Stability?	YES
Lateral Stability?	YES

Values in *Table 10.1* are taken strictly from the flight and may not indicate maximum values achievable by the aircraft. However, there are some values which are validated and meet the design requirements. The maximum rate of climb during the flight can be extrapolated to 1180 ft/min, which exceeds the 1000 ft/min climb rate required. Second, aircraft is shown to be in straight and level slight (referenced in flight test video) with both engines, and with only one operating engine. Takeoff distance and speed is higher than what was expected. This is mostly attributed to the aircraft being slightly heavier than planned, and the take-off surface not being a perfectly smooth surface. The maximum speed for the flight did not reach the maximum speed required. From the flight data gathered, there is little evidence to both prove or disprove if the aircraft could eventually reach the required speed of 100 knots during straight and level flight. During the flight, one of the propellers detached due to the counter rotating direction (6.5 seconds into flight). Even with the loss of thrust, the aircraft continued to fly, maneuver, and return to straight and level flight before stalling due to loss of thrust.

11.0 CONCLUSIONS AND RECOMMENDATIONS

The Project Calypso team concludes that the aircraft design meets or exceeds all requirements, which are summarized in *Table 11.1*. However, due to the limited amount of flight testing that was conducted, we conclude that further flight testing is needed before the aircraft can be approved for production and deployment. In the time after this report is submitted, the final flight test article will be completed and flown to obtain cruise performance data.

Table 11.1: Summary of Requirement Compliance

Parameter	Requirement	Recommended Design
Minimum Service Ceiling	400 ft ASL	>5,000 ft ASL
Minimum Cruise Speed	100 kts	108 kts
Operating Radius	17.5 NM	19 NM
Minimum Loiter Time	30 minutes	36.5 minutes
Climb Rate	1000 ft/min	2,525 ft/min
Sensor Payload	4 lbs. self-powered sensor	4 lbs. self-powered sensor
Life Raft Payload	Deployable life raft	5 lbs. self-inflating life raft, carried internally
Maximum Takeoff Weight	35 lbs.	31.25 lbs.

14.0 ACKNOWLEDGEMENTS

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15.0 APPENDIX A

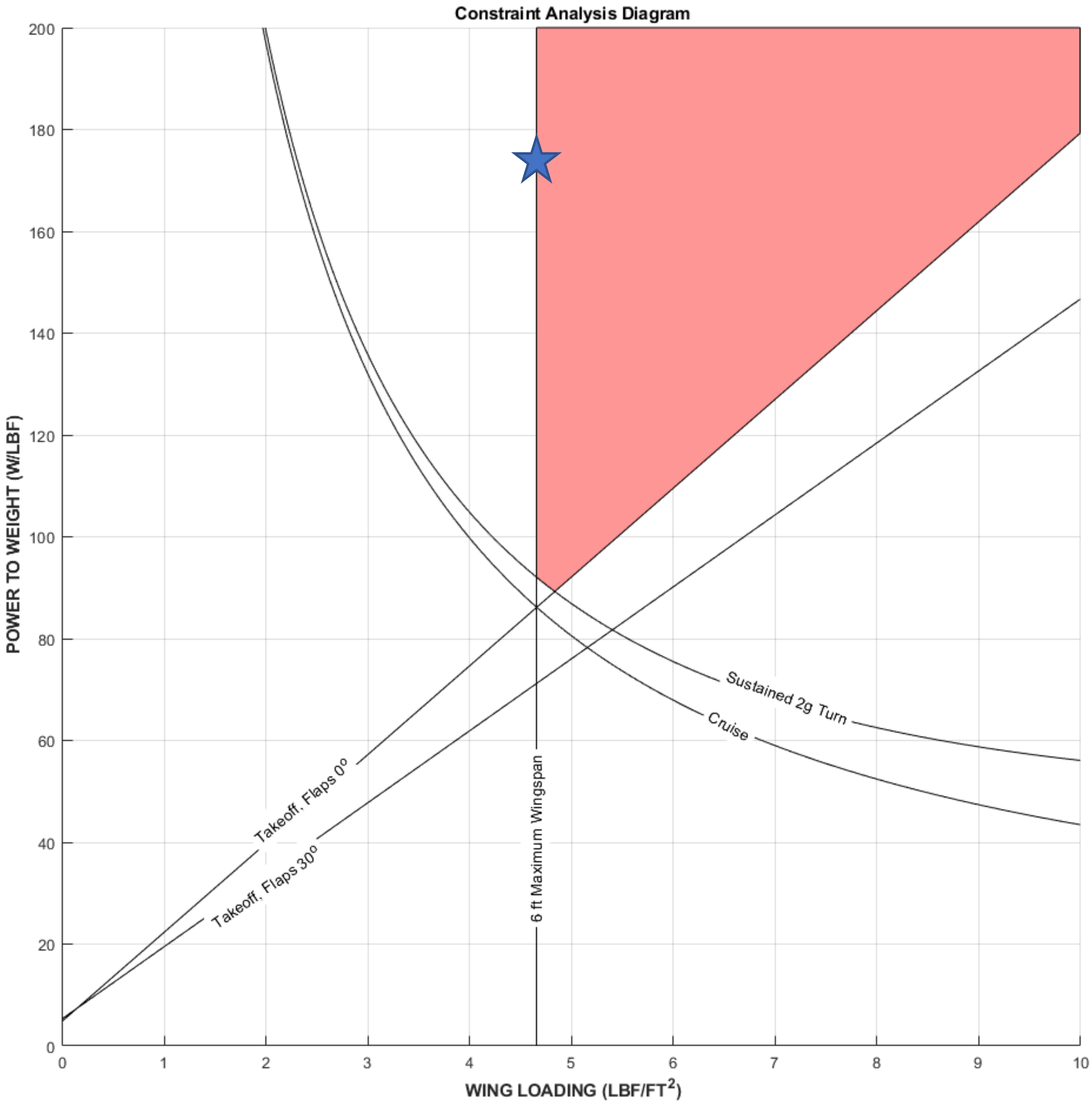

Figure 15.1: Constraint Analysis for Calypso Aircraft. Red Shaded Area is Solution Space, Blue Star is Design Point

Table 15.1: Constraint Analysis Key Parameters

Parameter	Value
Wing Profile	MRC-16
Empennage Profile	NACA 0012
Aspect Ratio	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 **Error! Reference source not found.**

Table 15.2: Sensitivity Calculations

Parameter to Be Changed	Change in Takeoff Weight, lbs.
Payload Weight, per 1 lbs.	2.479
Empty Weight, per 1 lbs.	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 15.3: Sensitivity Analysis Key Parameters

Parameter	Value
Payload Weight, lbs.	10
MTOW, lbs.	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 [14]	**Uncharted Supply Rapid Raft** [9]	**Winslow RescueRaft** [15]
Buoyancy, lbs.	100	400	800
Weight, lbs.	2.8	3.8	16
Packed Dimensions, in	12x2.5x9	15x5Ø	8x14x16
Deployed Dimensions, in	48x42x4	72x33x12	72x72x18

Table 15.5: 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 15.2: 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 15.3: 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 15.4: 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 15.5: Aircraft Configuration Trade Study

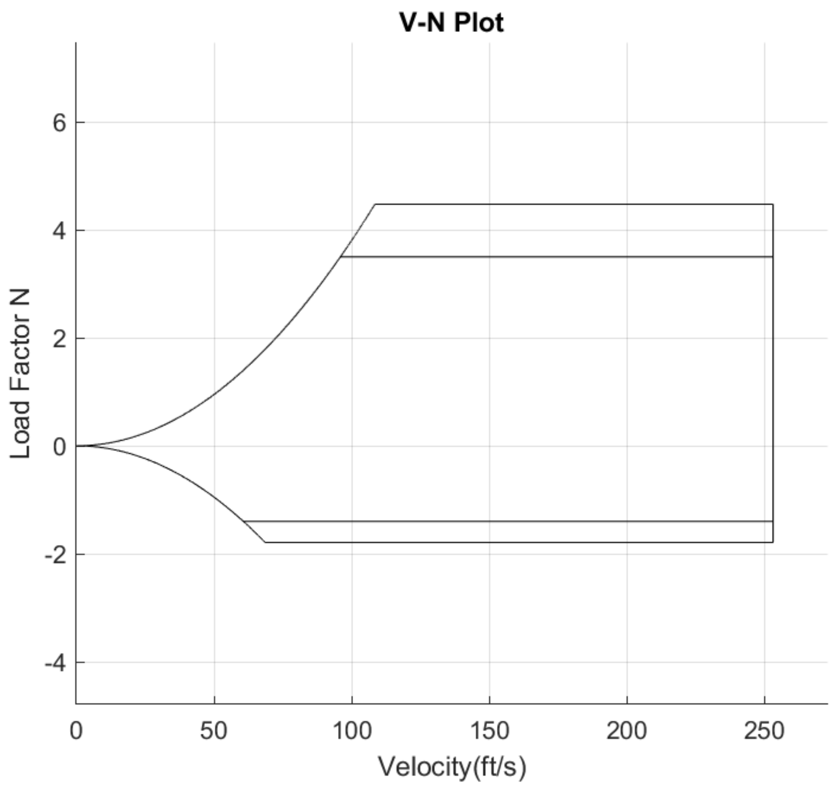

Figure 15.6: Aircraft Maneuver Limit V-n Diagram