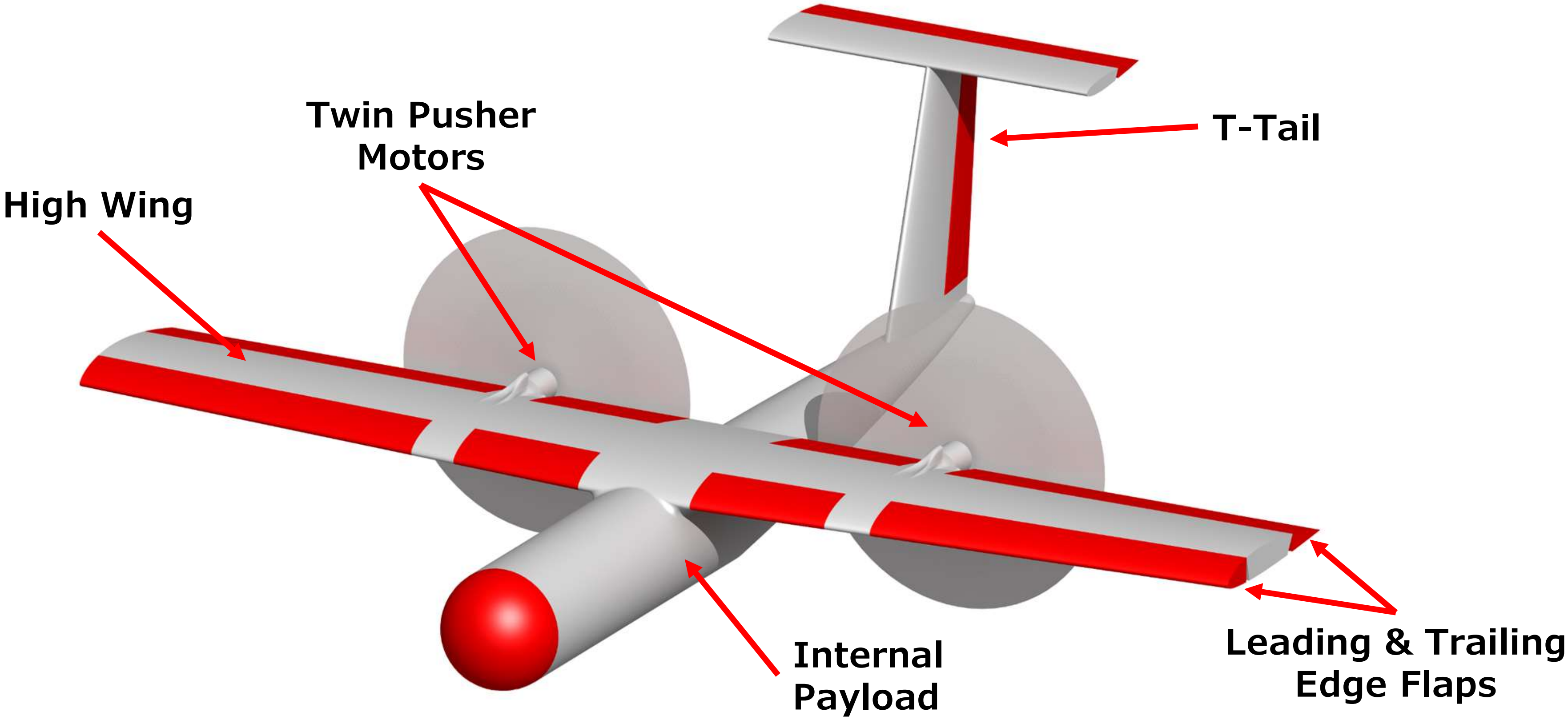
Project Calypso:
Maritime Search & Rescue

Preliminary Design Review

Design Overview



Team Introduction

Joshua Carver
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Avionics Engineer

Khaled Alhammadi
Propulsion Engineer

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Structures Engineer

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Aerodynamics Engineer

Presentation Objectives

- Introduce mission and **design-driver requirements**
- Present **twin motor conventional aircraft** design
- Demonstrate current design choices and aircraft sizing
- Show aero model fabrication and flight test results
- Provide risk-assessment and risk mitigation analysis

Naval Experience Defines Calypso's Operational Environment

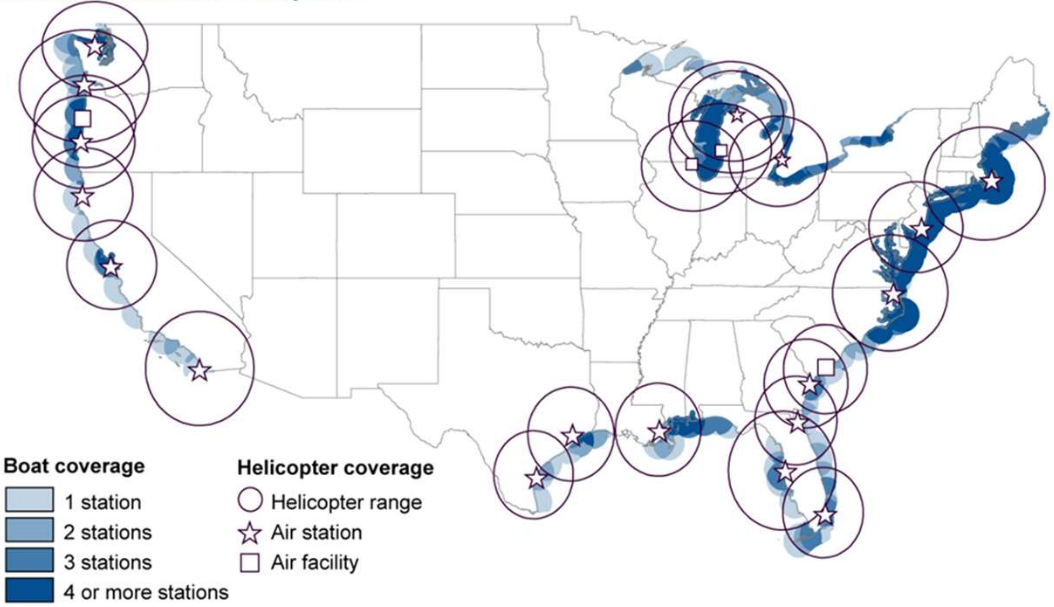
William Woodman (O-6), USN, Ret. defined following criteria:

- Small operational footprint
- Land-launch & ship-launch capable
- Supplement existing Navy & Coast Guard assets
- Organic search & rescue capability for large civilian vessels

Problems With Current Search & Rescue (SAR) Infrastructure

- Current SAR missions standardized around **two-hour** response time
- Majority of lives lost during **search stage** of SAR mission
- Slow response driven by lack of rescue aircraft and poor readiness

Overlap of Coast Guard Search and Rescue Coverage Provided by Boat Stations, Air Stations, and Air Facilities as of May 2017



Source: GAO analysis of U.S. Coast Guard information; MapInfo (maps). | GAO-18-9

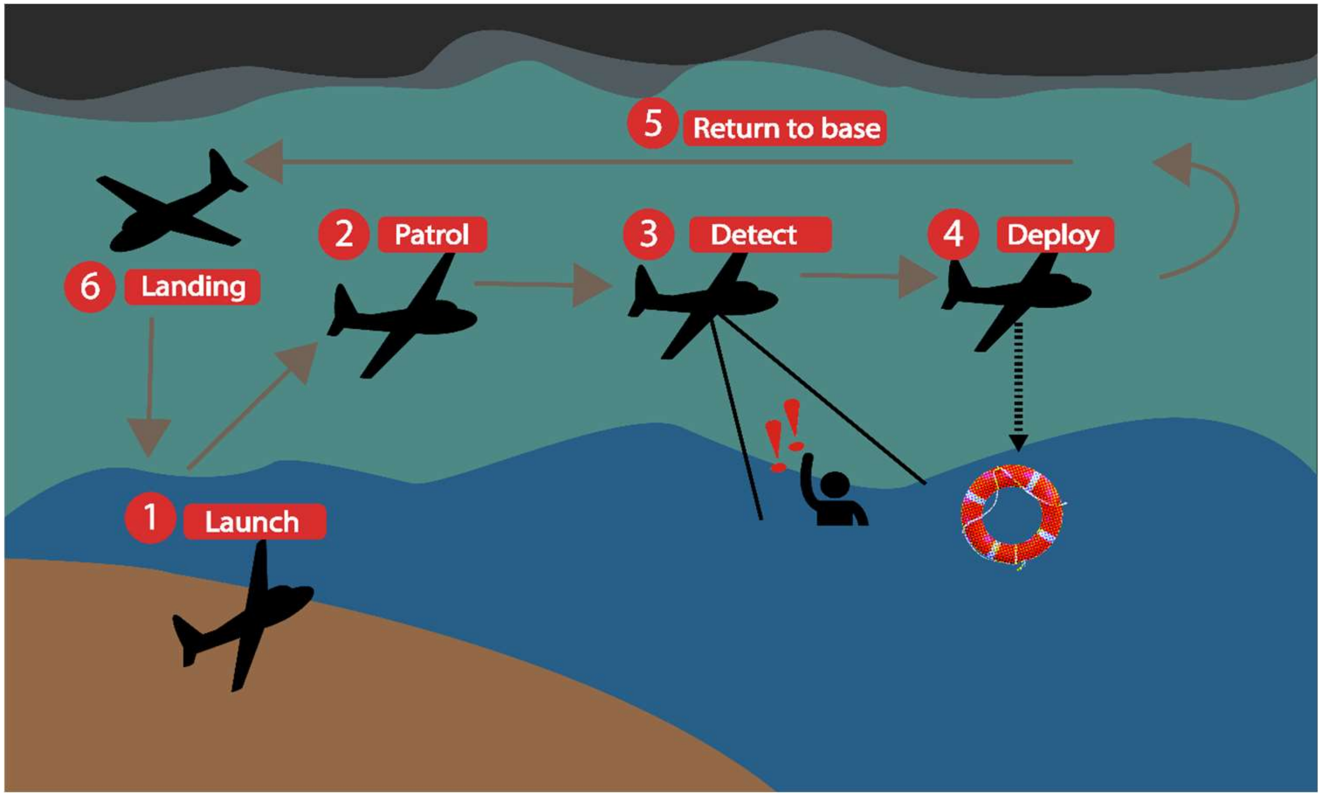
Manned Platforms Not Suitable for Rapid-Response Search Missions

- United States Coast Guard response time **limited** by dwindling aircraft fleet
- Risk to USCG personnel is substantial in adverse weather conditions

Calypso Aircraft Offers Organic SAR Capability Both on Land and Sea

- Aircraft is **launched** and **recovered** with **standalone** infrastructure
- **Autonomous** launch, search, and recovery of aircraft
- **Low cost** compared to manned aircraft allows for widespread deployment
- Reduce rescue personnel risk in poor weather conditions

Concept of Operations



Requirements

Requirements from Statement of Work

Item	Requirement
Operating Altitude	Sea level to 400 ft MSL
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
Payload	**4-lb self-powered sensor** **Deployable life raft**
Maximum Takeoff Weight	**35-lb**
Stand-by	3 months
Launch System Size	**Mountable on 4 ft x 4 ft elevated platform**

Derived Requirements

Item	Requirement
Weather Conditions	Up to Beaufort Force 7 (32-38 mph winds, 13-19 ft waves)
Derived Minimum Cruise Speed Requirement	**115-mph**
Derived Endurance	**90 minutes (15-minute dash, 30-minute patrol, 45-minute return to base)**
Maximum Raft Weight	5-lb
Minimum Raft Buoyancy	Fully support two adults (360-lb)
Raft Stability	Withstand 19-ft waves
Raft Deployment	Automatic upon release from aircraft

Aircraft Sizing

Aircraft Weight Driven by Performance Requirements

	Payload	Propulsion	Structural	MTOW
Weight Fraction	30%	38%	22%	100%
Weight, lb	10	**11.5**	8.5	30

Selected Design Point Minimizes Wing Loading and Provides Excess Power

Wing Loading

- 4.66-lb/ft^2
- 37 ft/s takeoff speed to allow for catapult launch

Power

- 175-W/lb
- 90% excess power to meet climb rate requirement

Life Raft and Payload Deployment

Life Raft Must Meet Size, Weight, and Deployment Requirements

Item	Requirement
Maximum Weight	**5-lb**
Size	Internal to Aircraft
Deployment	Automatic Inflation
Stability	Withstand 19-ft waves (Beaufort Force 7)
Minimum Buoyancy	**360-lb (2 adults)**

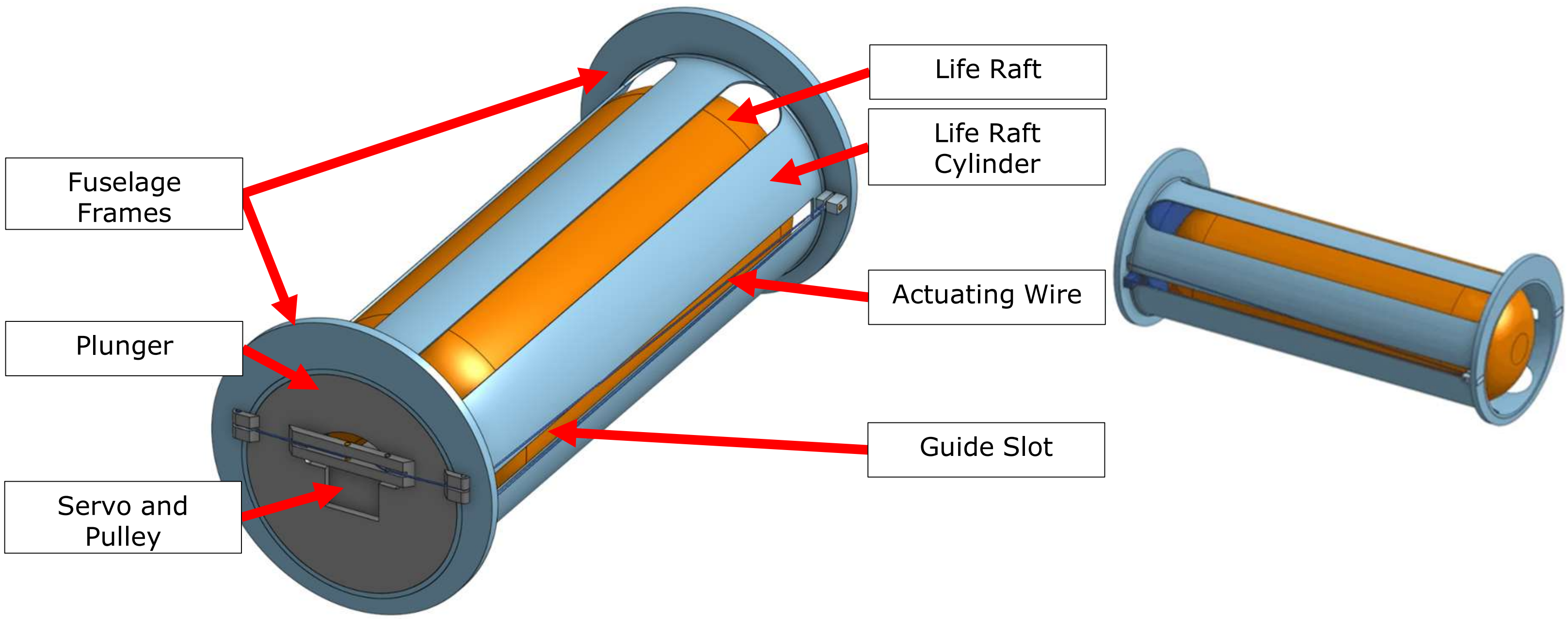
Modified Version of Raft Meets Requirements

- Added ballast bags and CO_2 inflator
- 15-in long by 5.25-in diameter packed dimensions
- 4.91-lb weight
- 400-lb rated buoyancy

Life Raft Deployment System Must Meet Following Requirements

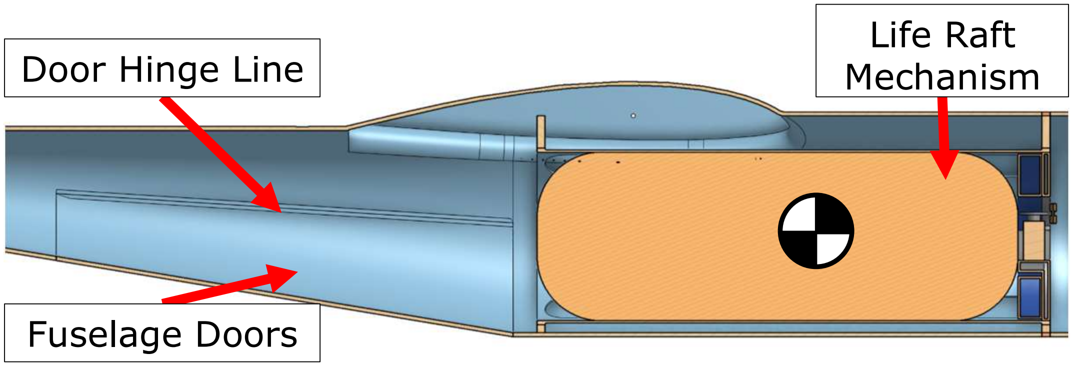
Item	**Requirement**
Maximum Weight	**1-lb**
Size	No more than 7-in diameter
Transmitter Channels	One
Deployment	**No affect on center of gravity**

Life Raft Deployment is Simple and Lightweight



Raft Deployment System Fits Within Fuselage with Minimal Modifications

- Sprung fuselage doors open passively when payload is deployed
- Maintains 25% static margin before and after payload deployment



Life Raft Deployment System Meets Requirements

Item	**Specification**
Maximum Weight	0.756-lb
Size	16″ x 5.5″Ø
Transmitter Channels	One
CG	Placed at CG

Flight Controller and Communications

Mission Requirements for Avionics

Flight Controller

- Fully autonomous takeoff, cruise, and landing
- Operator can command waypoints and loiter pattern

Communication

- Minimum range of 20 miles
- Maintain communication during all phases of flight
- Transmit telemetry and video to operator

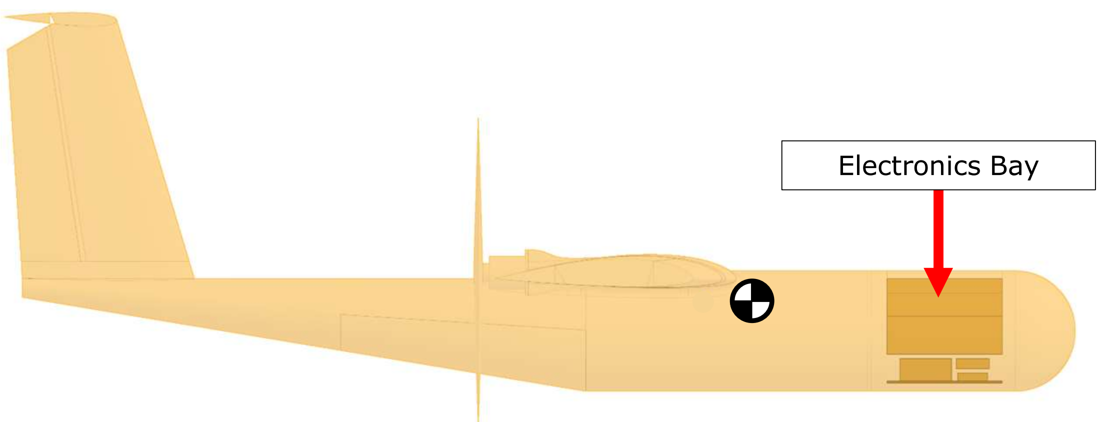
Pixhawk 4 Flight Controller Exceeds Derived Requirements

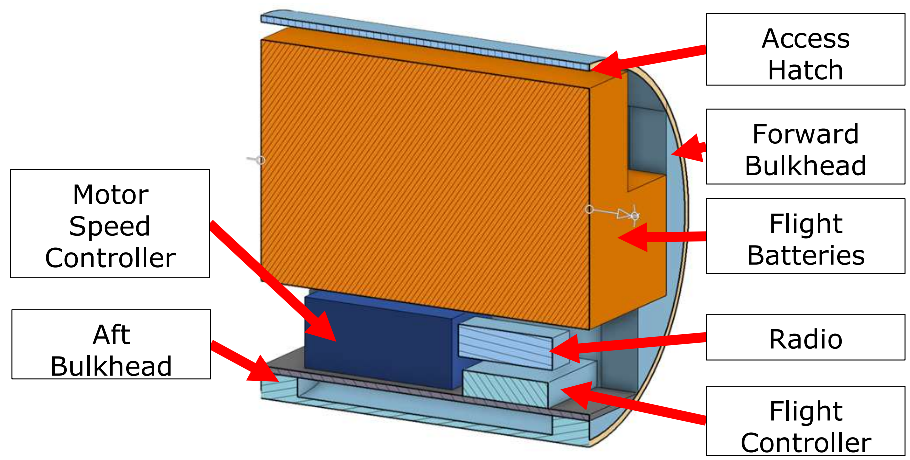
Item	Requirement	Specification
I/O ports	≥ 8	16
Cost	≤ \$250.00	\$190.00
Implementation	Easy to implement	Good availability, good documentation

Commtact MDLS Meets All Communication Requirements

Item	Requirement	Specification
Weight	≤0.5-lb	0.22-lb
Range	≥20-mi	25-mi
Bandwidth	Support any video transmission	Supports HD video

Electronics Bay Maintains Access to Components and Positive Margin





Launch and Recovery

Design Requirements Drive Launch & Recovery System Selection

	Design Requirement	Specification
SOW Reqs.	Load Factor	3.5 g
	Aircraft Weight	**30-lb**
	Launch Platform Size	**4 ft x 4 ft platform**
	User Input	**Autonomous**
Derived Reqs.	Launch Energy	**665 ft-lbs**
	Catapult Length	6.5 ft
	Aircraft Takeoff Speed	37 ft/s

Elastic System Best Fits Project Needs

Elastic Launch System

- Elastic cables and rail
- Similar to ElevonX Scorpion

Specification	Requirement	ElevonX Scorpion
Energy	≥ 665 ft-lb	737 ft-lb
Size	4 ft x 4 ft platform ≥ 6 ft length	12 ft length
User Input	Autonomous	Trigger

Cable System Best Fits Project Needs

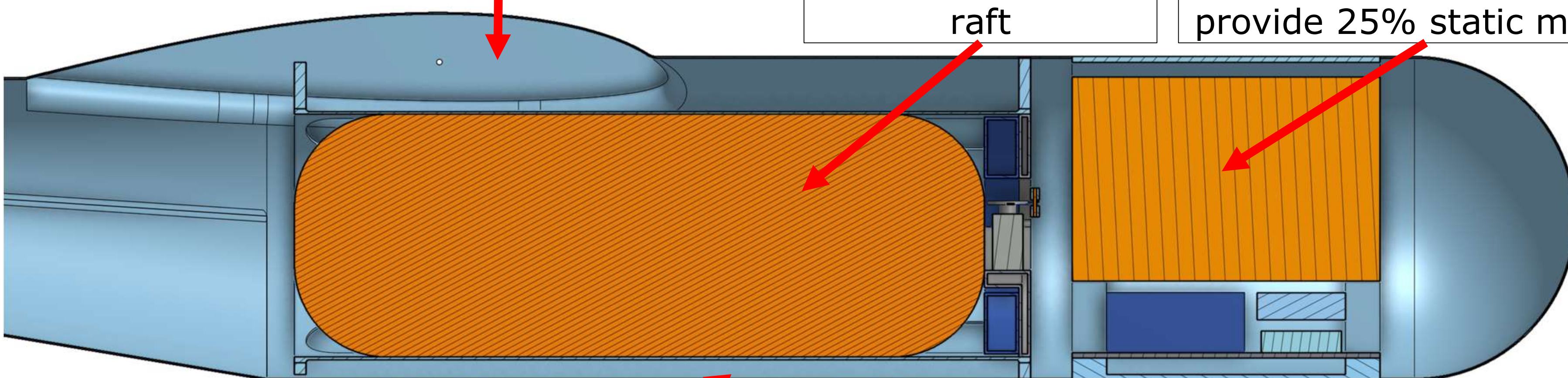
Cable Recovery System

- Cables hook into LE of wing
- Similar to Boeing Skyhook System

Specification	Requirement	Boeing Skyhook
Energy	≥ 665 ft-lb	1625 ft-lb
Size	4 ft x 4 ft platform	8 ft x 12ft mount
User Input	Autonomous	Passive

Structural Design

Fuselage Designed for Life Raft Selection

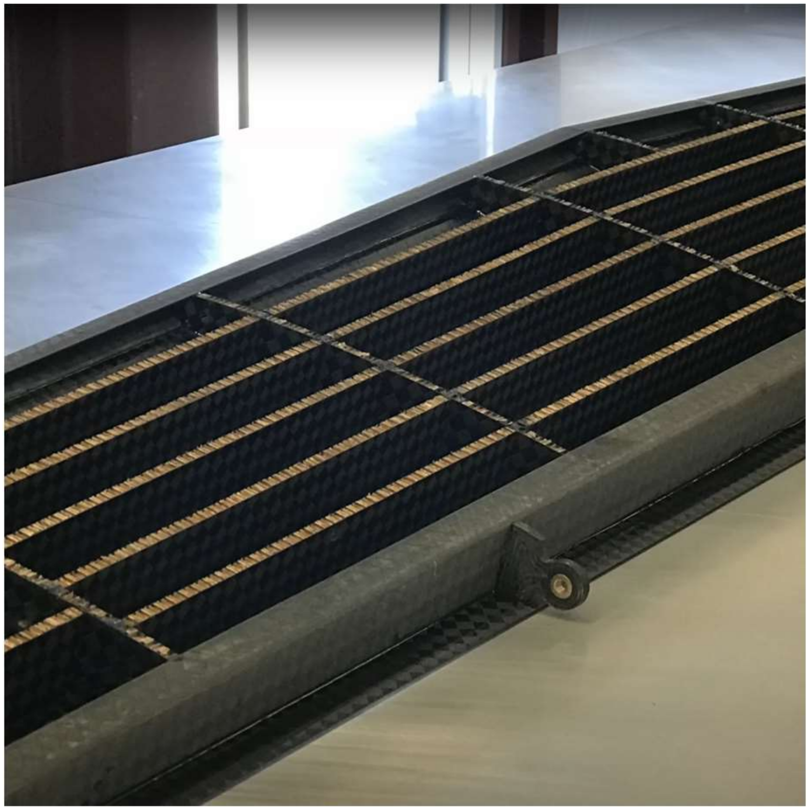


Aircraft Structure Will Use Composites to Meet Weight and Loading Requirements

Aerodynamic Surfaces
- Skin-stringer construction
- Composite honeycomb ribs and stringers
- Composite molded skin

Fuselage
- Composite honeycomb fuselage frames
- Composite molded skin

Benefits of Composite Structure
- Lightweight and flexible implementation
- Allows up to 3.5 g loading

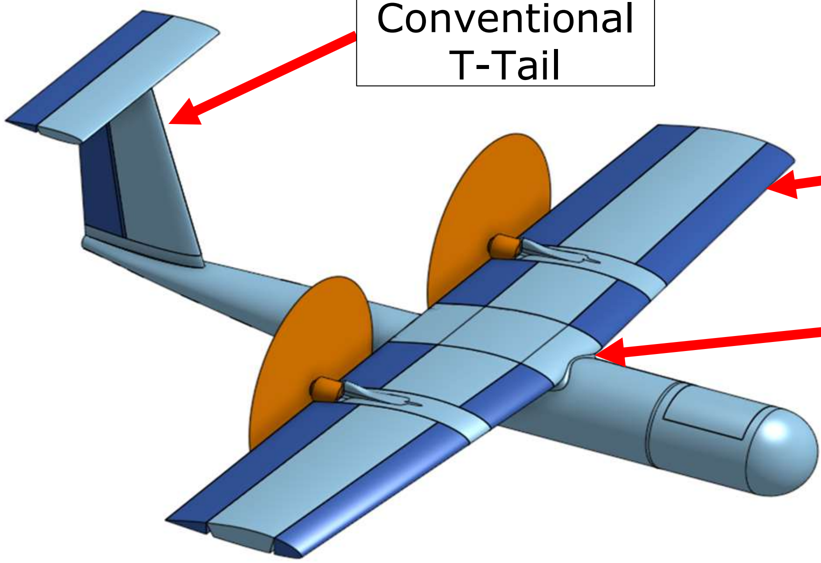


Aerodynamics Design

Aerodynamic Configuration Driving Requirements

Item	Requirement
Operating Altitude	Sea level to 400-ft MSL
Environmental Conditions	Beaufort Force 7 (32-38 mph winds)
Minimum Dash Speed	115-mph

Configuration Determined from Aerodynamic Trade Studies

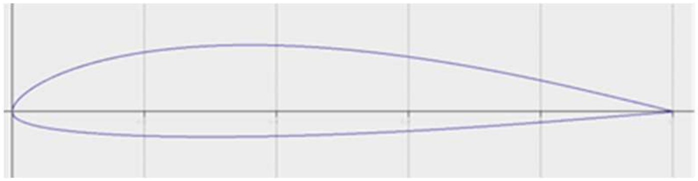


- Overall Length : 61.2-in
- Wingspan : 72-in

Aerodynamics of Wing Airfoil

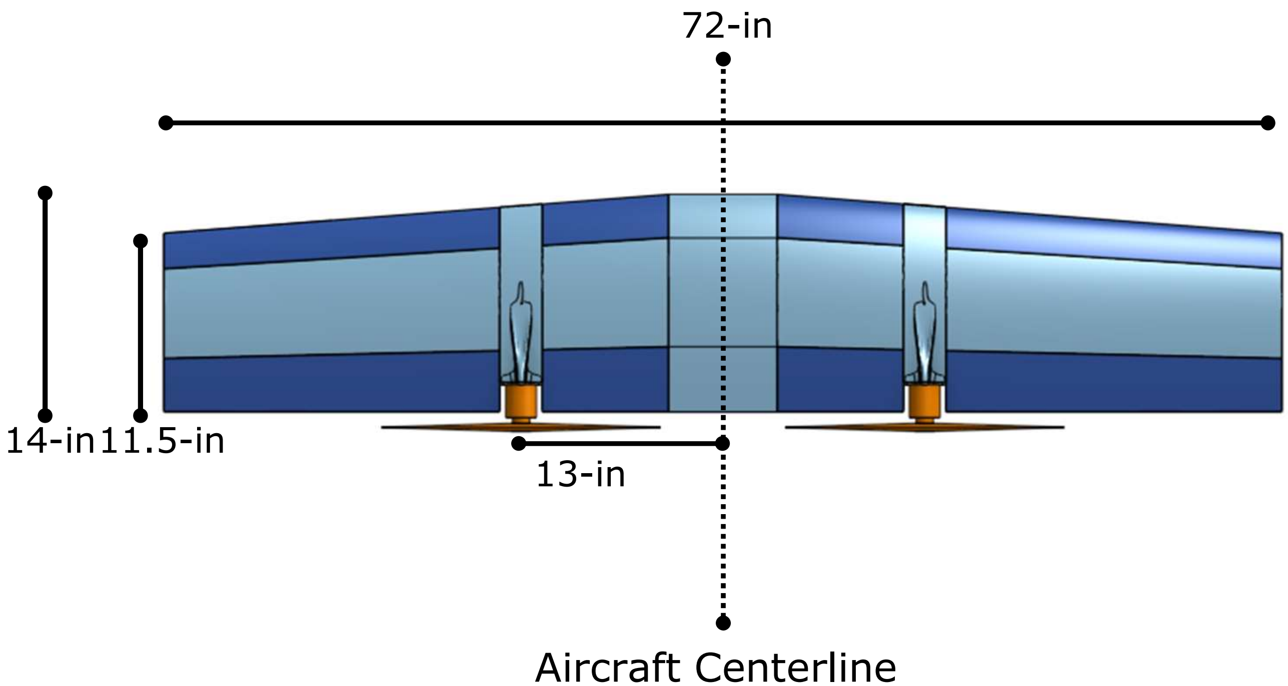
Drela MRC-16

- Post-stall characteristics
- Low drag
- Easy fabrication
- Control surface mounting



Variable Simulated	Value
C_L Max	**1.5 at 16 AoA**
C_L/C_D Max	130 at 6 AoA
C_{L0}	0.35
C_M vs Alpha	Negative Gradient

Wing Dimensions and Performance



Item	Value
Wing Area (in^2)	918
Airfoil	MRC-16
Stall speed (ft/s)	**37**
Wing loading (psf)	**4.706**
C_L Max	1.4, 14° AoA
C_L/C_D Max	**30, 4° AoA**
Wing C_{D0}	0.010
Whole Aircraft Cruise C_D	**0.015**

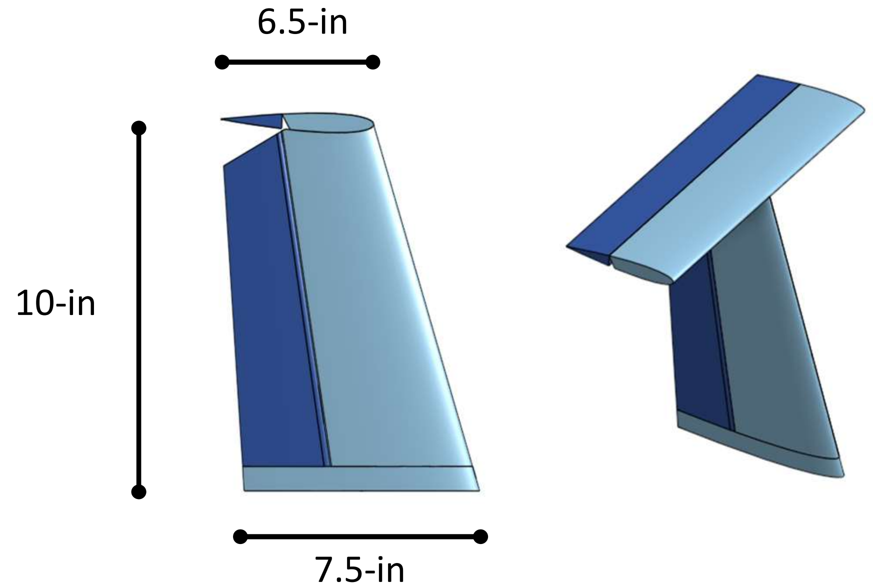
Empennage Airfoil and Configuration

NACA 0012

- Symmetrical airfoil
- Vertical Tail Coef. = 0.067
- Horizontal Tail Coef.= 0.35

T-Tail

- Less prop interference
- Ease of future modification
- Control surface mounting

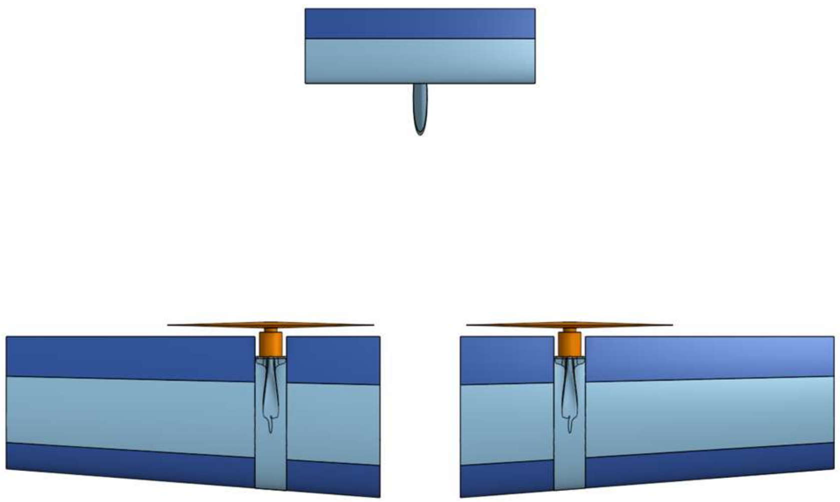


Simulations Prove Aircraft Configuration is Stable

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

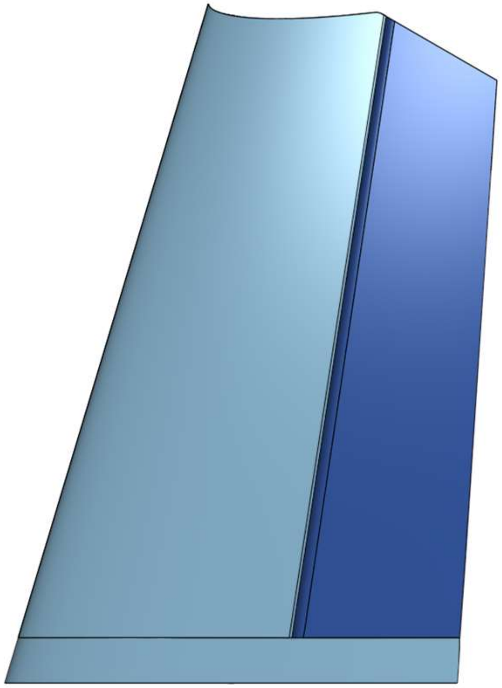
Control Surface: Ailerons & Elevator

Control Surface	Length	Width	Effectiveness (τ)
Ailerons	55% to 100% of wing	30% of chord	0.52
Elevator	Full Span	40% of chord	0.60



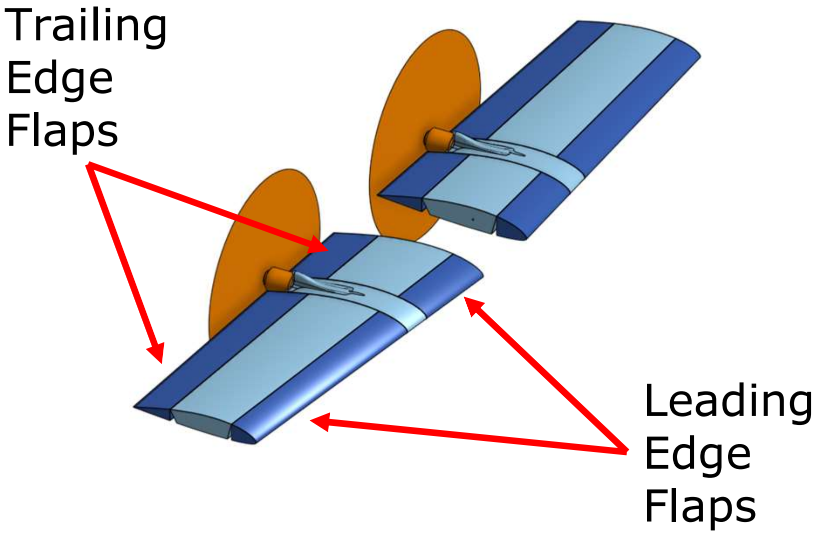
Control Surface: Rudder

Control Surface	Length	Width	Effectiveness (T)
Rudder	90% Span	40% of chord	0.55



Leading and Trailing Edge Flaps Selected

High Lift Device	Width	Length	Deflection (degrees)
TE Flap	30% chord	90%	30
LE Flap	30% chord	90%	10



- Ailerons act as flaperons
- Provides C_L Max = 2.1

Propulsion

Requirements Which Drive Propulsion Configuration

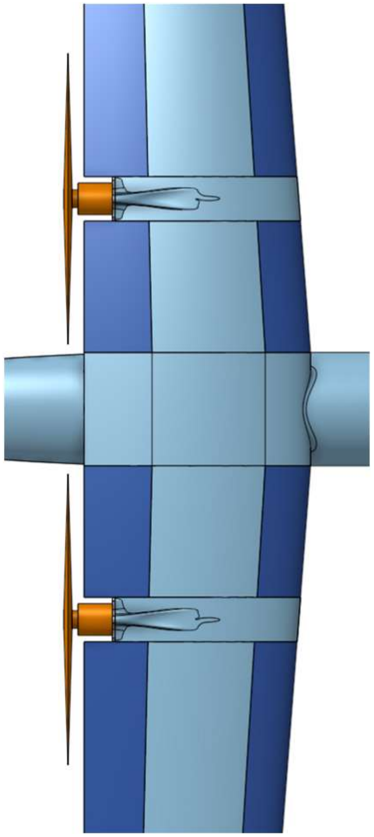
Specification	Requirement
Minimum endurance	90-min
Minimum power	175-W/lb, or 5,500-W
Minimum speed	**115-mph**
Standby time	3 months
Reduction of Recovery Risk	Avoid damage from net or wire recovery
Whole Aircraft Drag	C_{D0} = 0.012 Cruise C_D = 0.0131

Twin Pusher Configuration Meets Recovery and Packaging Requirements

- Pusher propellers allow for use of leading edge as wire contact surface

- Single pusher motor would place thrust axis too high

- Twin motors reduce thrust moment and simplify packaging



Selected Propellers Allow for Flight at 115-mph

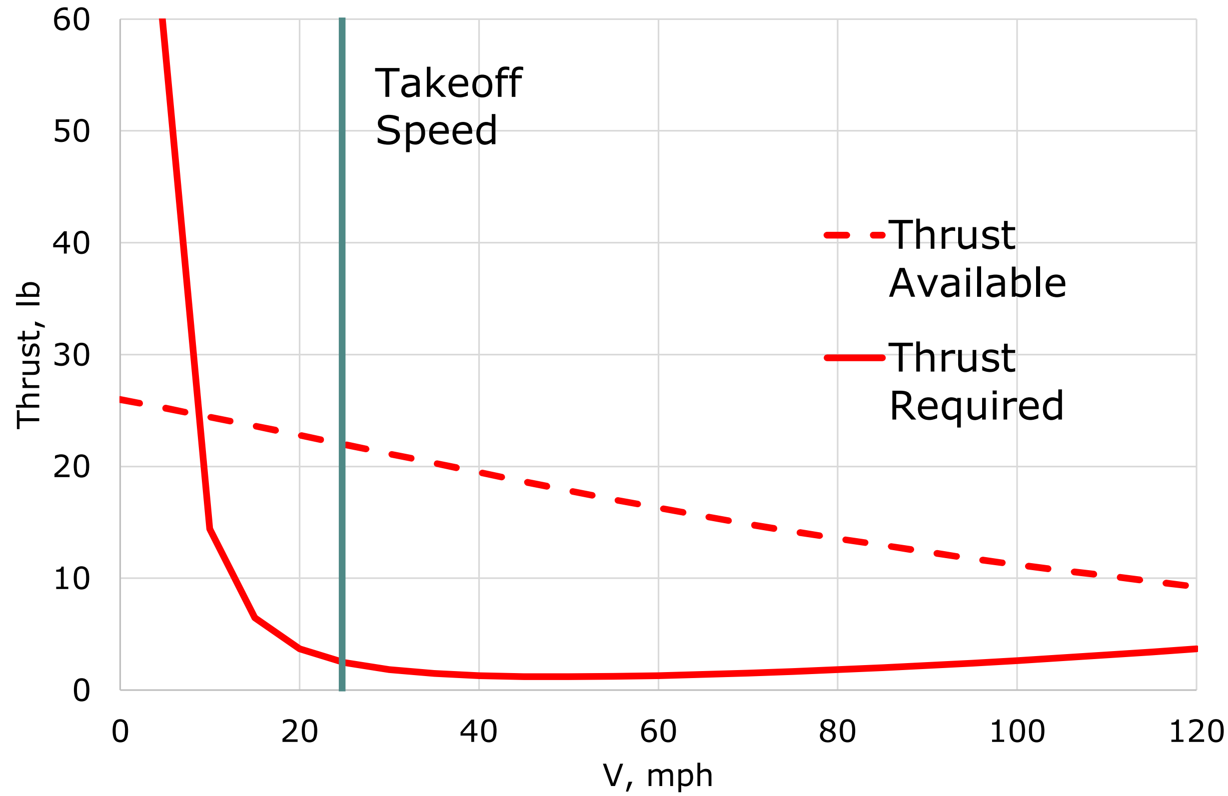
- 18-in diameter propellers with 12-in pitch are sufficient to meet requirement
- At 10,000-RPM at 115-mph, generate 9.74-lb of thrust, greater than the 3.7-lb of drag generated

Motors are Sufficient to Drive Propellers

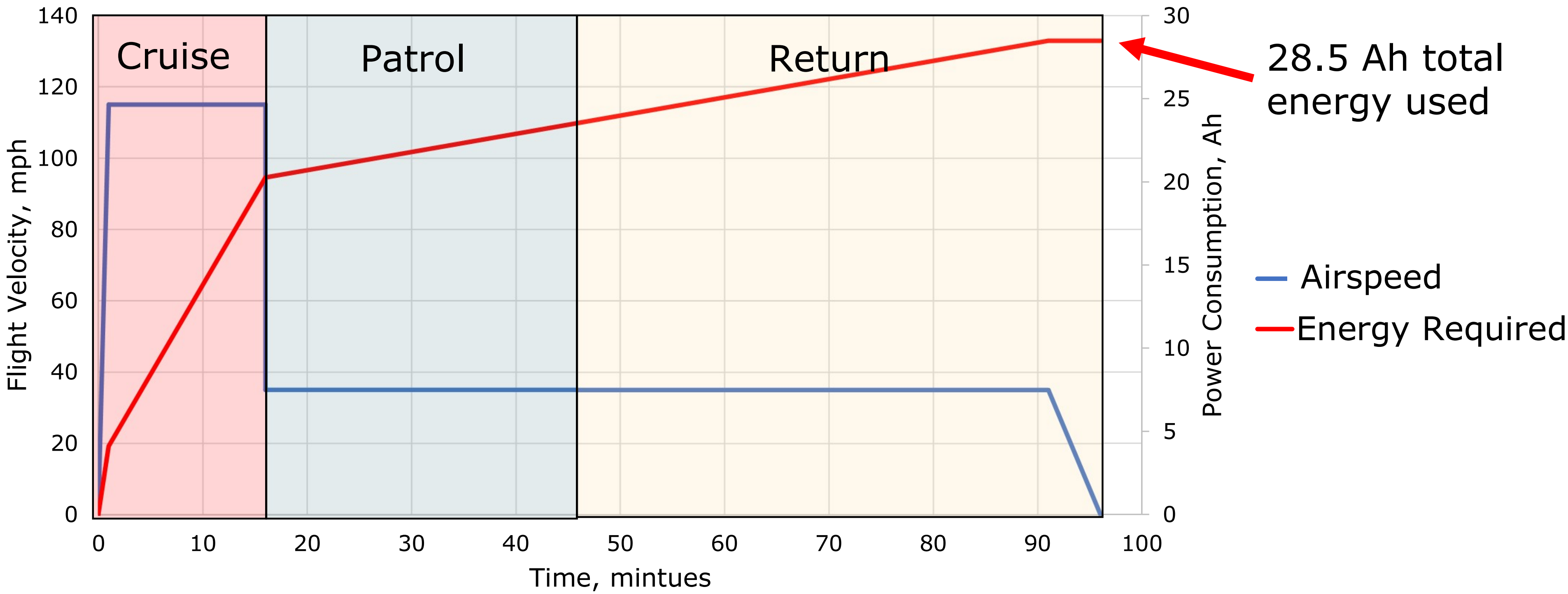
Specification	Requirement
Type of Motor	Sunnysky X4125 V3 480-kV
Number of Motors	2
RPM	Maximum 10,500-RPM
Required Power	5,500 W total
Mounting Location	Fitted on the trailing edge of the wings
Standby Time	Unlimited with battery trickle charging

Propulsion Configuration Produces Excess Thrust at All Flight Speeds

- Net thrust generated from 10-120 mph
- Takeoff speed limited by aerodynamics, not propulsion



Energy Required Primarily Driven by Cruise Phase Speed



Selected Battery Configuration Provides Sufficient Energy

Item	Specification
Energy Required	28.5 Ah
Per Battery Energy	10 Ah
Total Energy	30 Ah
Energy Margin	5.34%

Propulsion Configuration Meets Performance Requirements

Item	Requirement	Design
Maximum speed	115 mph	>115 mph
Minimum Endurance	90 minutes	5.3% margin for 90-minute mission
Weight	11.5-lb	3x batteries: 8.73 lb 2x motors: 1.56 lb 2x propellers: 0.33 lb 2x ESCs: ~0.55 lb Total: 11.17 lb

Aerodynamic Model Fabrication & Testing

Aerodynamic Model Was Constructed to Validate Design

- Aircraft was constructed at full scale with comparable components
- Catch major design flaws before detail semester build
- Allowed for build experience and developing a fabrication and testing process

Fabrication of Aerodynamic Model Was Not Identical to Design

Propulsion

- Lower kV motors
- Lower pitch propellers
- Comparable static thrust but much lower maximum speed

Structures

- Box fuselage used for simplicity
- Additional drag due to landing gear

Aerodynamic Model Uses Expedient Fabrication Materials

Construction Material

- 3/16-in foam board
- Rigid foam insulation
- Fiberglass
- 3D printed parts

Landing Gear

- Carbon fiber rear gear
- Aluminum steerable front gear
- Plastic and rubber wheels

Flight Testing Validated Propulsion System and Longitudinal Stability

- Climb rate in excess of 1,000 ft/min at much higher altitude than designed for
- Aircraft had excellent elevator authority
- Stability in longitudinal axis was sufficient to maintain pitch control without augmented stability

Further Flight Testing is Needed to Completely Validate Performance

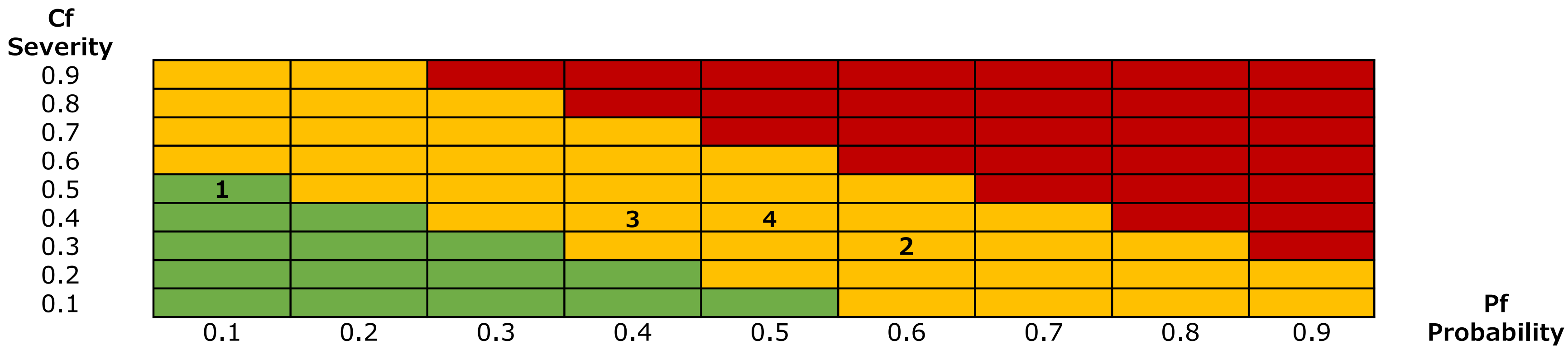
Further testing is needed to validate the following:

- Lateral/Directional stability and control
- Landing performance
- High speed controllability

Aerodynamic model will be repaired and testing will continue during the summer

Risk Assessment

Risk Assessment



1. Business closure for avionics providers
2. Catapult unavailable for testing, conventional take-off necessary
3. Exceeding design weight from necessary design changes
4. Piloting inexperience results in airframe loss in high wind conditions

Risk Mitigation

Risk 1: Business Closure

- Additional avionics specified to fulfill role if Pixhawk cannot be procured
- Selected avionics common enough that second-hand components remains viable alternative

Risk 2: Conventional Take-Off

- Recommended design incorporates excess power, allowing for alternative take-off methods
- Flight Test Article verifies conventional take-off is possible

Risk Mitigation Continued

Risk 3: Exceeding Weight Budget

- Composite manufacturing to reduce structural weight
- Aligning payload with center of gravity so counteracting ballast is unnecessary

Risk 4: Test Flight Wind Conditions

- Adjusting control surface sizing to improve low-speed handling
- Using wind forecasts to determine days for acceptable testing conditions

Conclusion

Design Studies & Testing Indicate All Requirements Met

Item	Requirement	Recommended Design
Altitude	400-ft ASL	>5,000-ft ASL
Speed	80-mph	115-mph
Operating Radius	20 miles	>20 miles
Loiter Time	30 minutes	>30 minutes
Climb Rate	1000 ft/min	>1,500 ft/min
Sensor Payload	4-lb self-powered sensor	4-lb self-powered sensor
Life Raft Payload	Deployable life raft	5-lb self-inflating life raft, carried internally
Maximum Takeoff Weight	35-lb	30-lb

Calypso Team Recommends to Move to Detail Fabrication Phase

Preliminary design satisfies critical design requirements

Aerodynamic model has verified aircraft viability

- Recommended to repair flight model and resume flight testing

Create wind tunnel testing plan

- Validation of aerodynamic surfaces and propulsion systems

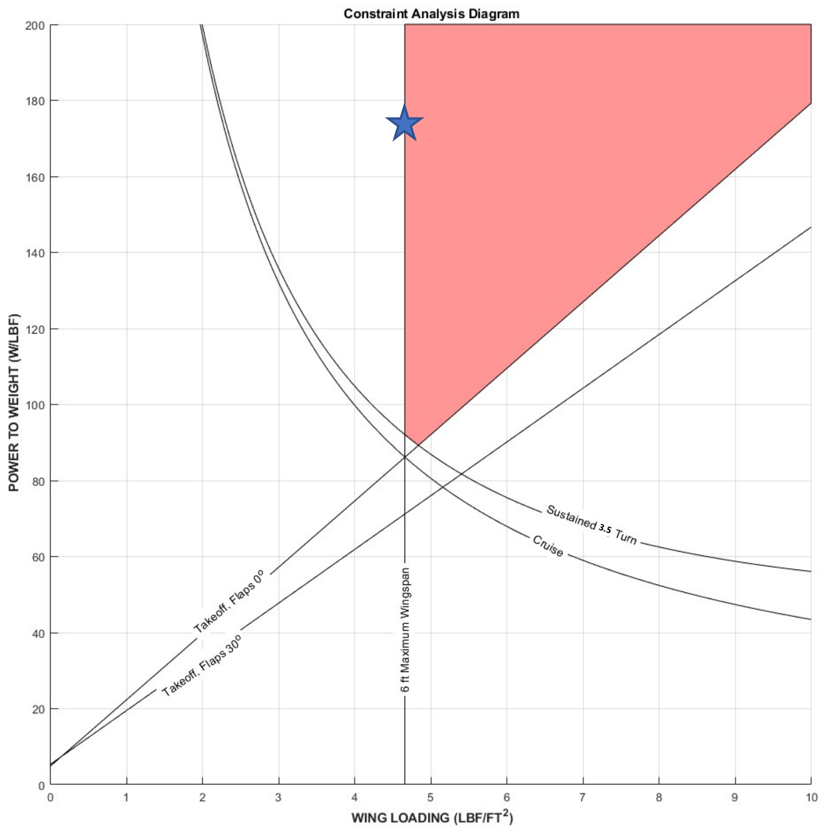
Questions?

Appendix

Statement of Work 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-min
Operating Radius	20-miles
Minimum Loiter Time	30-min
Load Factor	3.5-g
Climb Rate	1000-ft/min
Weather Conditions	Up to Level 7 Beaufort scale (32-38-mph winds, 13-19-ft waves)
Sensor Payload	4-lb self-powered payload.
Maximum Takeoff Weight	25-lb.
Stand-by	3 months
Maximum Reset Time	1-hr.
Minimum Service Life	250-hrs.
Launch System Size	Mountable on 4 ft x 4 ft elevated platform

Constraint Analysis Diagram



Red area is design space

Blue star is design point

Launch System Comparison

Design Consideration	Elastic Launch	Pneumatic Launch	Rocket Propelled
Takeoff Speed	1	2	3
G-Loading	3	2	1
Size	2	1	3
User Input	3	1	2
Cost	3	2	1
Total	**12**	**8**	**10**

Recovery System Comparison

Design Consideration	Net Recovery	Cable Recovery	Parachute Recovery
Accuracy	3	2	1
Airframe Impact	2	3	1
G-Loading	2	1	3
User Input	2	3	1
Cost	2	3	1
Total	**11**	**12**	**7**

Aircraft Configuration Trade Study Table

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	

Wing Configuration Trade Study Tables

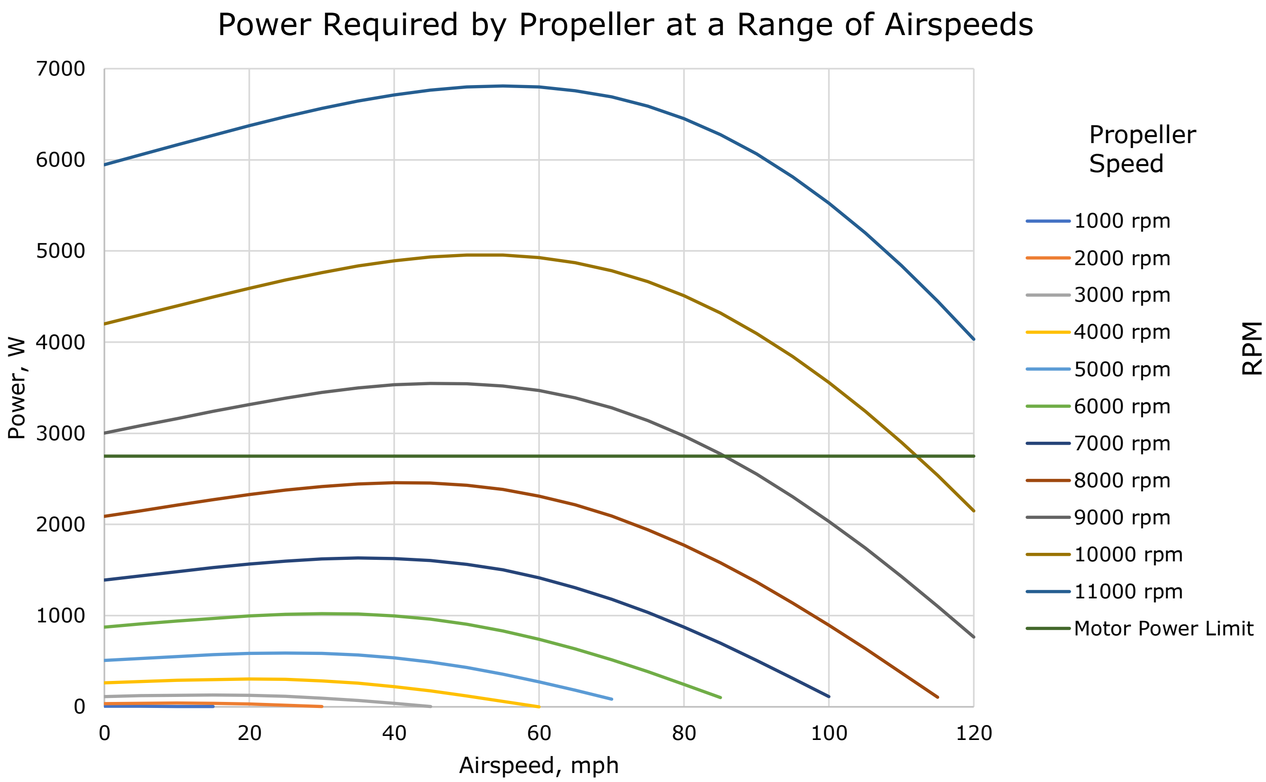
Wing Configuration						
	Regtangular	Tapered Straight	Sweptwing (low speed)	Elliptical	Rear Wing Canards	Score Factor
Stablity	5	3	3	4	2	4
Lift	4	4	4	3	4	4
Drag	1	4	3	4	3	3
Manueverability	3	3	2	3	3	3
Fabrication	4	4	2	1	3	2
Structural Weight	2	3	3	3	3	2
Totals:	60	63	53	57	54	

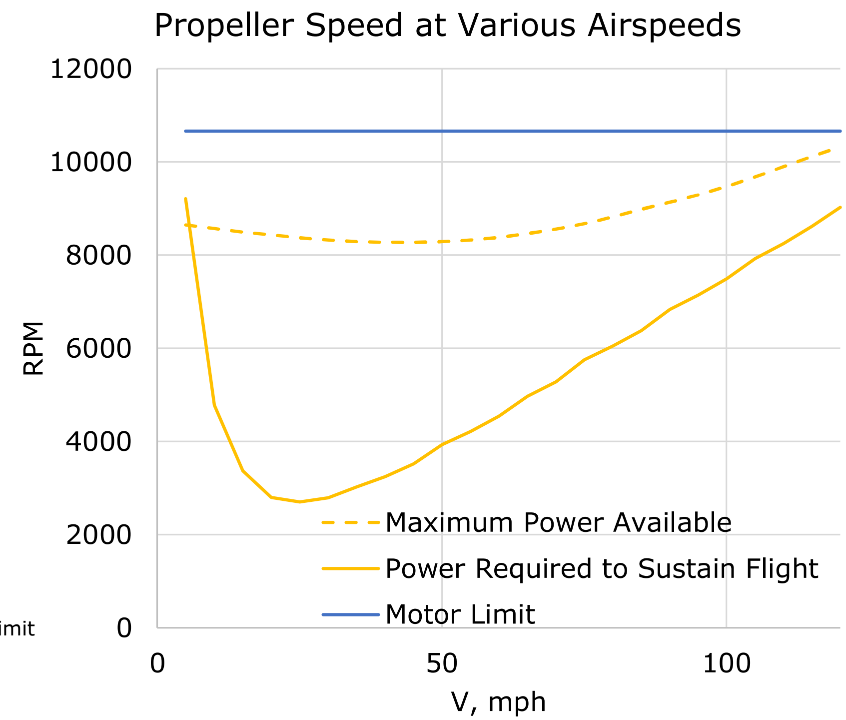
Wing Location				
	High	Mid	Low	Score Factor
Roll and Stablity	4	4	3	4
Tail Interference	3	3	4	2
Manueverability	3	4	4	2
Cruise	3	2	3	2
Payload	4	2	4	3
Stall Characteristics	4	5	3	4
Totals:	62	60	58	

Tail Configuration Trade Study Table

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	

Motor and Propeller Performance





References

Slide #	Item
6	United States Coast Guard, *Search and Rescue Summary Statistics*, 2017.
6	Schuldt, D. and Kurucar, J., *Maritime Search and Rescue via Multiple Coordinated UAS*, MIT Lincoln Laboratory, 2017.
6	Remmers, T., “U.S. Coast Guard Unmanned Systems,” *U.S. Coast Guard Assistant Commandant for Capability*, 2022.
18	Uncharted Supply Co., “Rapid Raft,” *https://unchartedsupplyco.com/products/rapid-raft*, 2023.
25	PX4 Dev Team, “Pixhawk 4,” *PX4 Autopilot User Guide,* 2020.
26	Commtact Systems,“Mini Micro Data Link System (MDLS)”, *https://commtact-systems.com/products/micro-data-link-system/,* 2023.

References

Slide #	Item
41-43	Aileron design Chapter 12 design of Control Surfaces" Available: http://aero.us.es/adesign/Slides/Extra/Stability/Design_Control_Surface Chapter%20 12.%20Desig%20of%20Control%20Surfaces%20(Aileron).pdf
41-43	"Design and fabrication of a fixed-wing unmanned aerial vehicle (UAV)," Ain Shams Engineering Journal Available: https://www.sciencedirect.com/science/article/pii/S2090447922004051
41-43	"Rudder design Chapter 12 design of Control Surfaces" Available: http://aero.us.es/adesign/Slides/Extra/Stability/Design_Control_Surface/Chapter%20 12.%20Desig%20of%20Control%20Surfaces%20(Rudder).pdf
41-43	Charles River Radio Controllers - conventional vs. V-tails Available: http://www.charlesriverrc.org/articles/design/donstackhouse_conventionalvsvtail.htm.
41-43	"Comparative analysis of aerodynamic characteristics of rectangular and ..." Available: https://www.researchgate.net/publication/344160569_Comparative_Analysis_of_Aero dynamic_Characteristics_of_Rectangular_and_Curved_Leading_Edge_Wing_Planforms

Figure References

Slide #	Item	Source
6	Render Background	Link
7	USCG Coverage Map	Link
8	MH-65 Dolphin Helicopter	Link
19	Uncharted Supply Co. Rapid Raft Outdoors	Link
25	Pixhawk 4 Flight Controller	Link
26	Commtact MDLS Radio Communications	Link
30	ElevonX Scorpion Elastic Catapult	Link
31	Wire Recovery of Boeing ScanEagle	Link
34	DarkAero 1 Wing Design	Link

Figure References

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48	APC 18x12e Propeller	Link
52	Turnigy 20 Ah LiPo Battery	Link