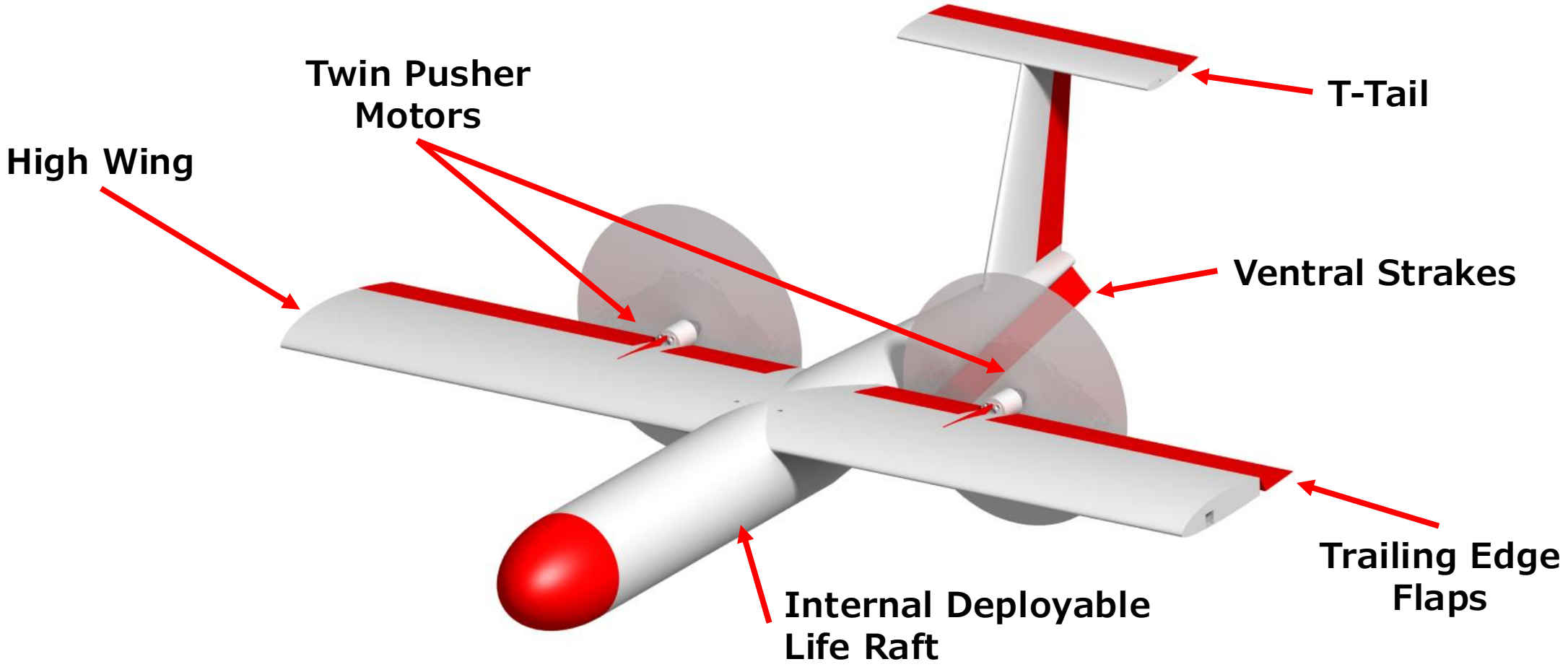
Project Calypso:
Maritime Search & Rescue

Final Design Review

Maritime SAR Aircraft Design Overview



Team Introduction

Jacob McMillin
Program Manager

Ryan Lundell
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Systems Engineer

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Propulsion Engineer

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Structures Engineer

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Aerodynamics Engineer

Presentation Objectives

- Introduce mission and **design-driver requirements**
- Present **final aircraft design**
- Justify design choices
- Validate design with wind tunnel testing
- Show performance of flight test article

Naval Experience Defines Calypso's Operational Environment

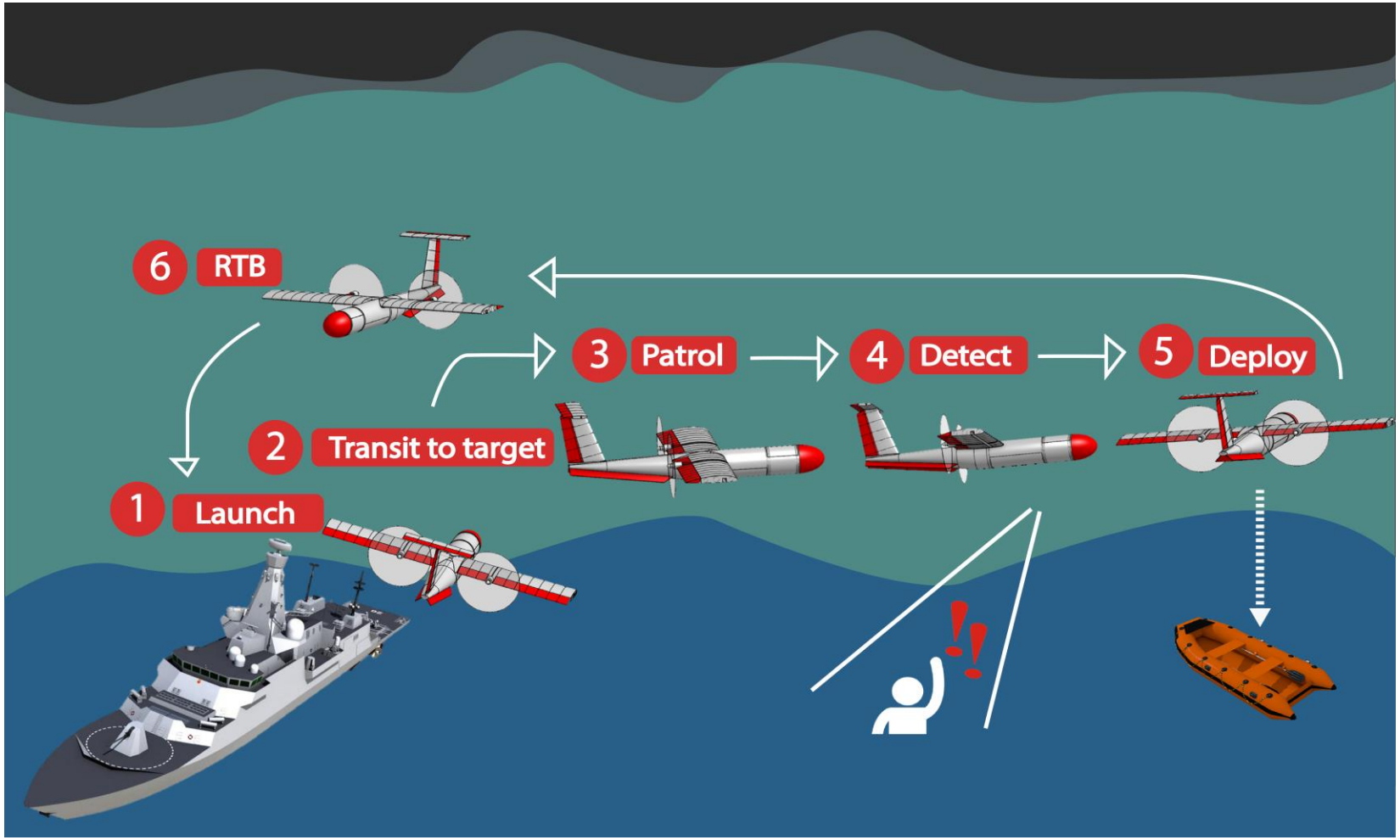
Key Operation Parameters

- Small operational footprint
- Land- & ship-launch capable
- Supplement existing assets
- Integration with civilian systems

Calypso Aircraft Offers 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 during search phase

Concept of Operations



Requirements

Requirements from Statement of Work

Parameter	Requirement
Operating Altitude	Sea level to 400 ft ASL
Speed Requirement	Cover 17.5 nm in no more than 15 minutes
Operating Radius	17.5 nautical miles
Minimum Search Time	30 minutes
Load Factor	3.5 g
Climb Rate	1000 ft/min
Payload	**4 lbs. self-powered sensor** **Deployable life raft**
Maximum Takeoff Weight	**35 lbs.**
Minimum Service Interval	3 months
Launch System Size	**Mountable on 4 ft x 4 ft elevated platform**

Derived Requirements

Parameter	Requirement
Weather Conditions	Up to Beaufort Force 7 (28-33 kts winds, 13-19 ft waves)
Derived Minimum Cruise Speed Requirement	**100 kts**
Derived Endurance	**90 minutes (15-minute dash, 30-minute search, 45-minute return to base)**
Maximum Raft Weight	5 lbs.
Minimum Raft Buoyancy	Fully support two adults (360-lb)
Raft Stability	Withstand 19-ft waves
Raft Deployment	Automatic upon release from aircraft

Life Raft and Payload Deployment

Life Raft Must Meet Size, Weight, and Deployment Requirements

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

Modified Version of Off-the-Shelf Raft Meets Requirements

Added ballast bags and CO_2 inflator

15 in long by 5.25 in diameter packed dimensions

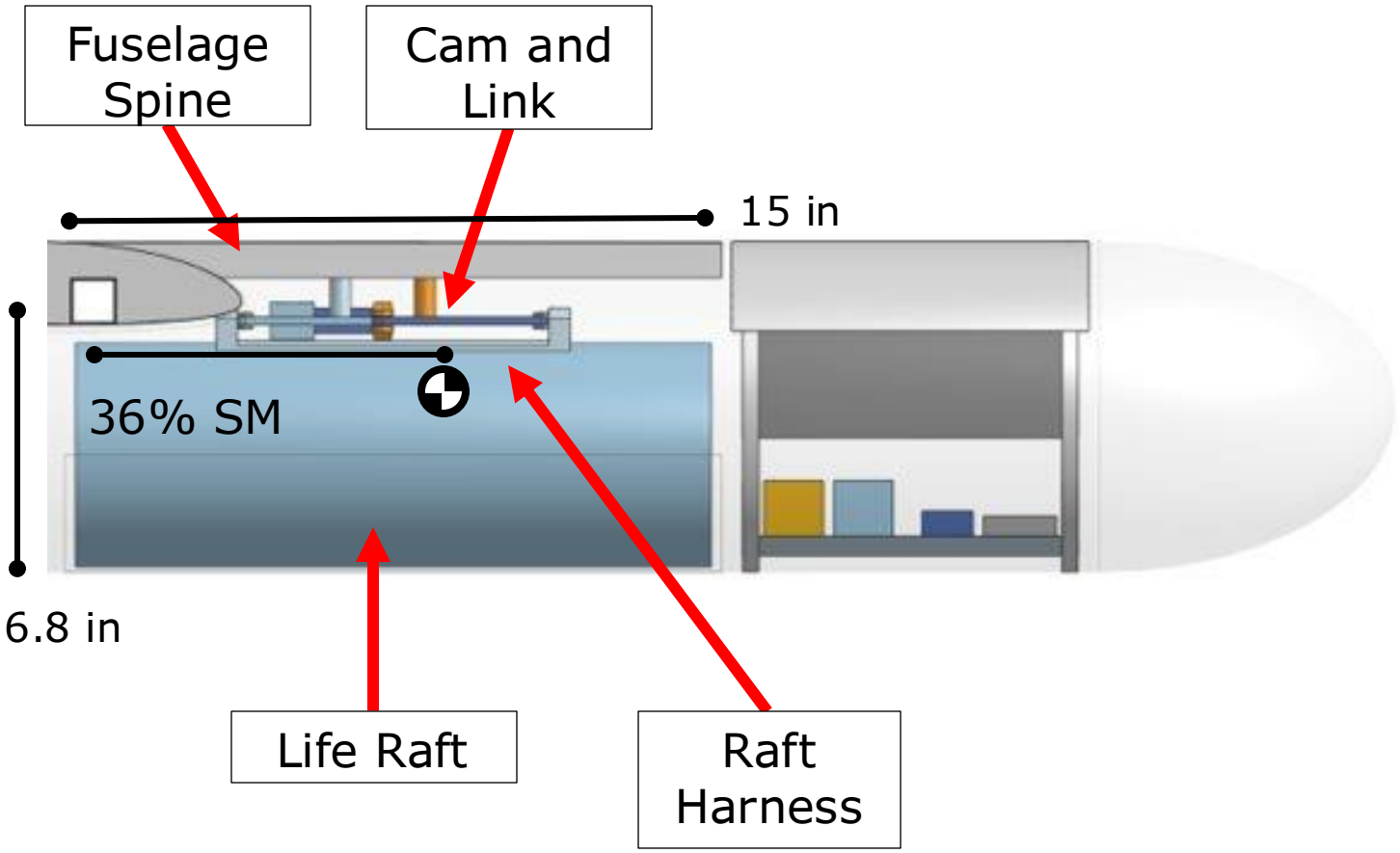
5 lbs. weight

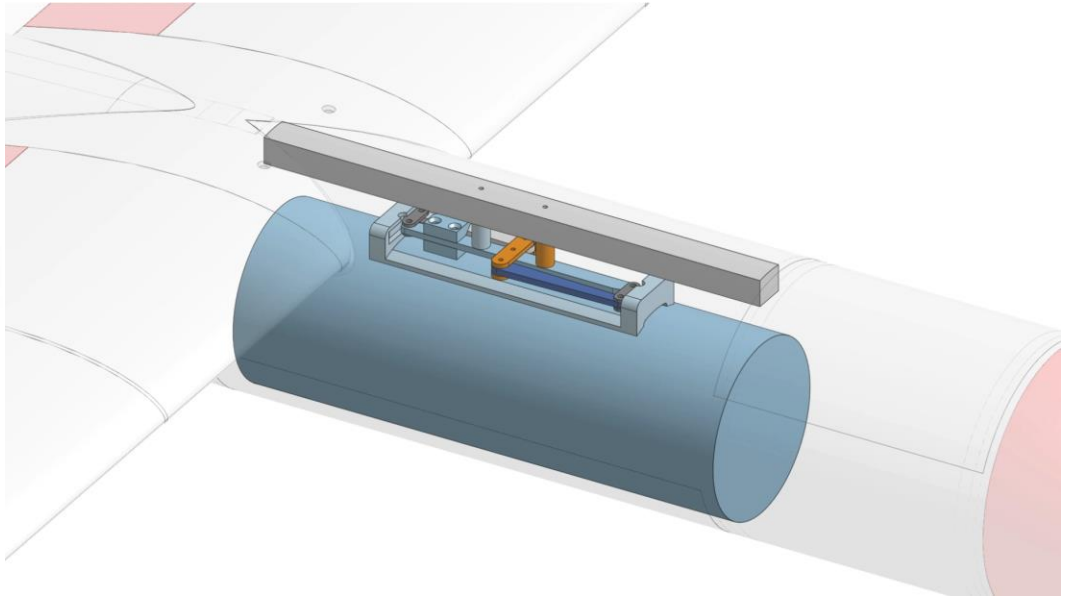
400 lbs. rated buoyancy

Life Raft Deployment System Must Meet Following Requirements

Item	Requirement
Maximum Weight	**1 lbs.**
Size	No more than 7-in diameter
Transmitter Channels	One
Deployment	**Does not decrease static margin**

Life Raft Mechanism Integrates with Fuselage to Maintain Stability





Life Raft Deployment System Meets Requirements

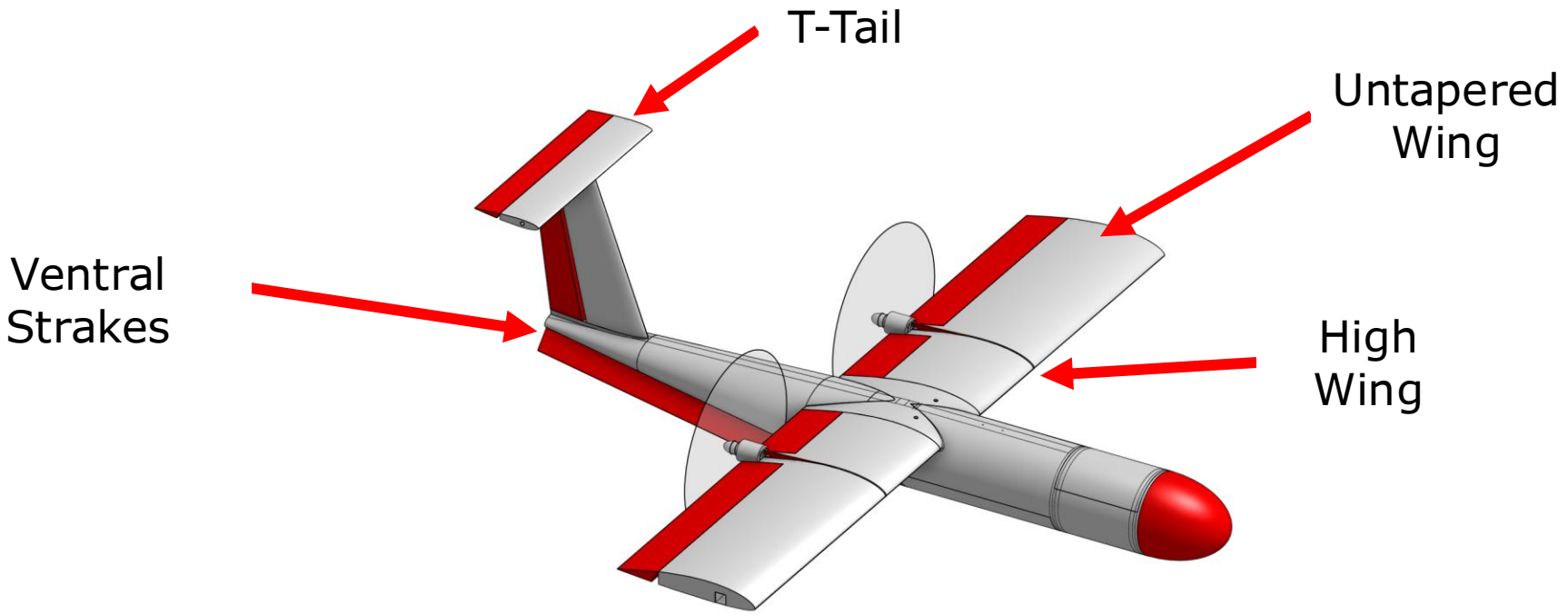
Parameter	Requirement	Design
System Weight	< 6 lb total	5.32 lbs.
System Size	< 7-inch diameter	6.8-inch diameter
Life Raft Buoyancy	> 360 lbs.	400 lbs.
Self-Inflate on Deployment	Yes	Yes
Raft Stability	Capable of handling 19 ft waves	Capable of handling 19 ft waves

Aerodynamic Design

Aerodynamic Configuration Driving Requirements

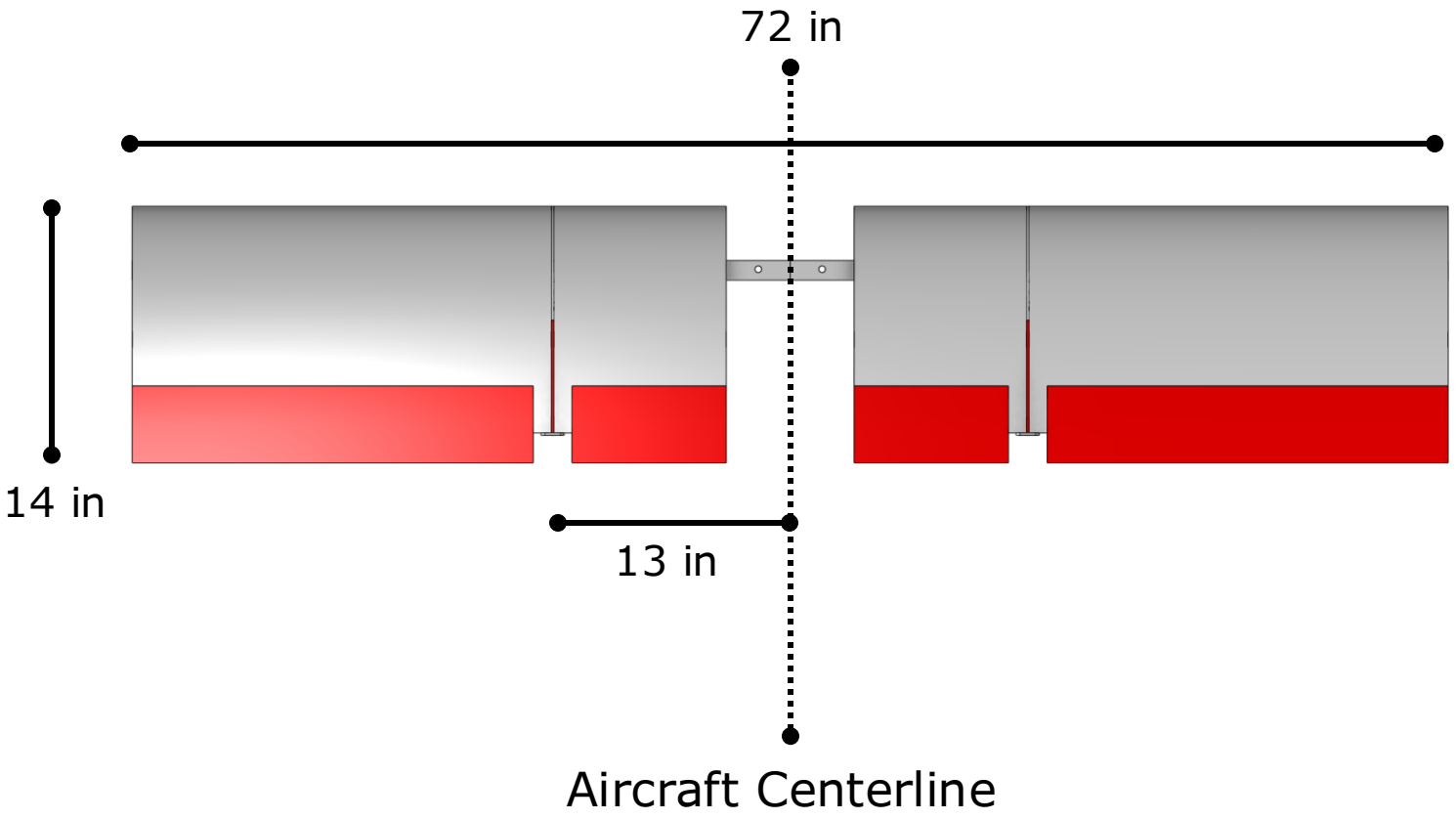
Parameter	Requirement
Operating Altitude	Sea level to 400 ft ASL
Environmental Conditions	Beaufort Force 7 (28-33 kts winds)
Minimum Dash Speed	100 kts
Maximum Stall Speed	33 kts

Configuration Determined from Wind Tunnel & Trade Studies



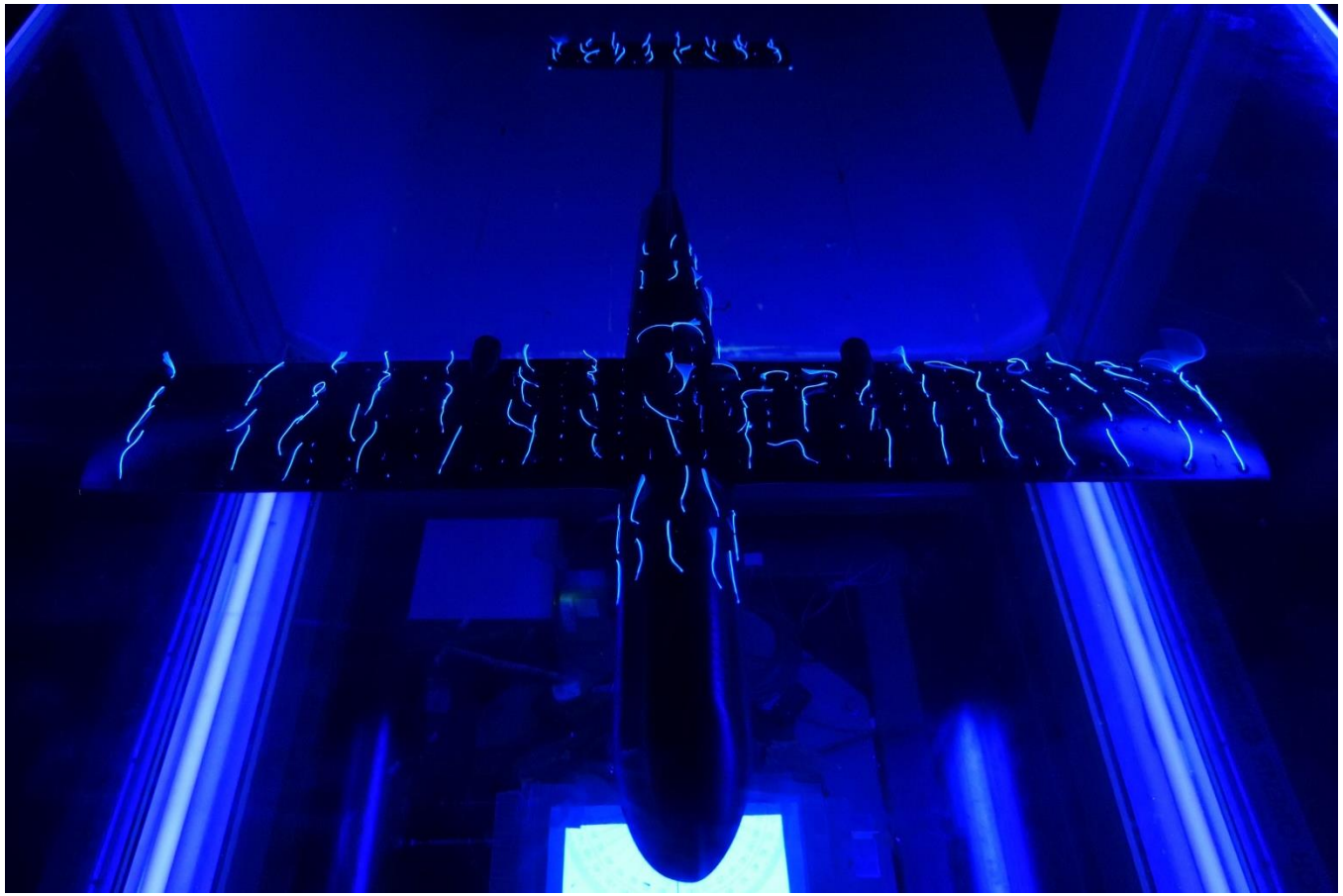
- Overall Length: 68.75 in
- Wingspan: 72 in

Aerodynamics of Wing



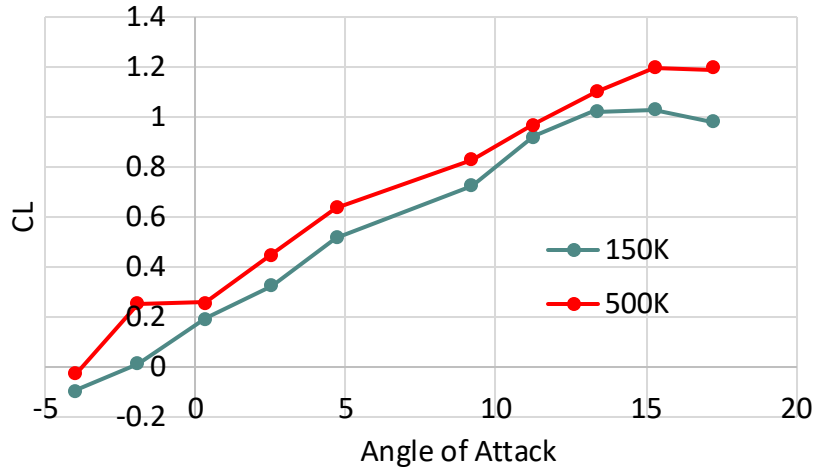
Parameter	Value
Airfoil	MRC-16
C_L Max	**0.94 at 12° AoA**
C_L/C_D Max	9.06 at 7° AoA
C_{L0}	0.10
C_{D0}	0.021

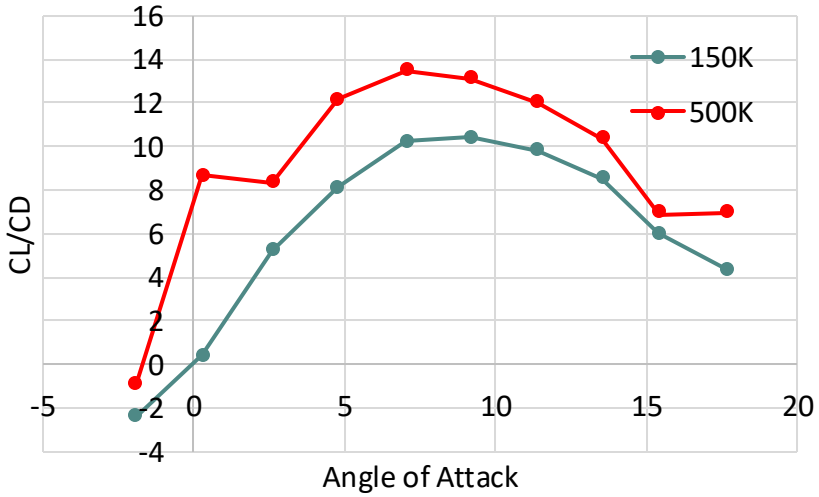
Aircraft Aerodynamic Performance Meets Mission Criteria



Parameter	Value
Wing Area (in^2)	1008
Stall speed (kts)	**26.7**
Wing loading (psf)	**4.464**
C_L/C_D Max	**13.49, 7° AoA**
Aircraft C_L Max	1.20, 16° AoA
Aircraft C_{D0}	0.029
Aircraft Cruise C_D	**0.047**

Aircraft Demonstrates Recoverable Stall Characteristics

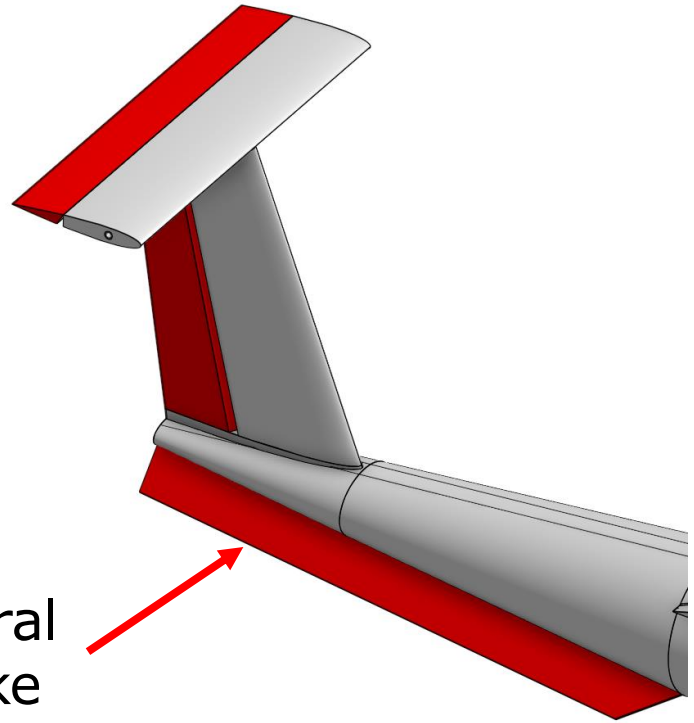




- Aircraft stalls gradually, onset at approximately 13-15° Alpha
- Strakes improve stall recovery, acting as node of attachment
- Stall occurs around fuselage first, maintaining aileron, elevator and rudder authority

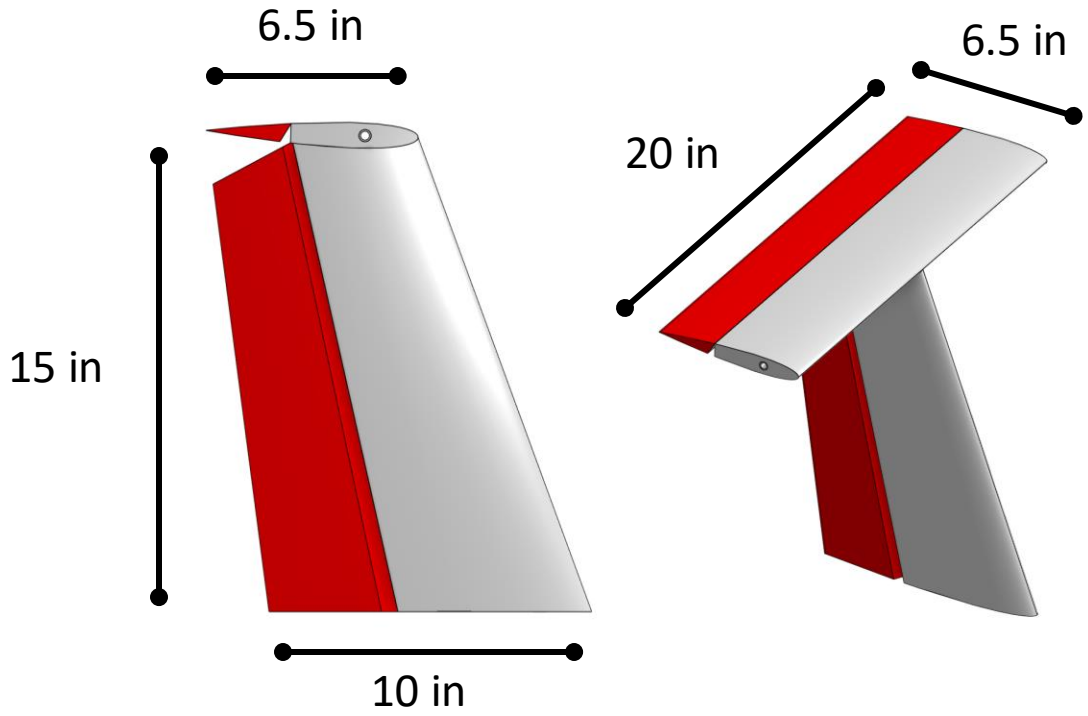
Strakes Improve Aerodynamic Stability in Sideslip Conditions

Parameter	Unmodified	Modified With Strakes
Vertical Surface Area (in^2)	123.75	206.33
C_L/C_{Dmax}	12.40	13.49
C_Y ($\beta=10°$, $\alpha=10°$)	0.00197	0.00340



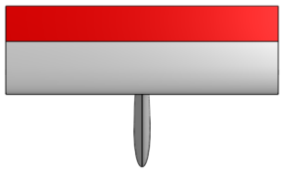
Empennage Configuration

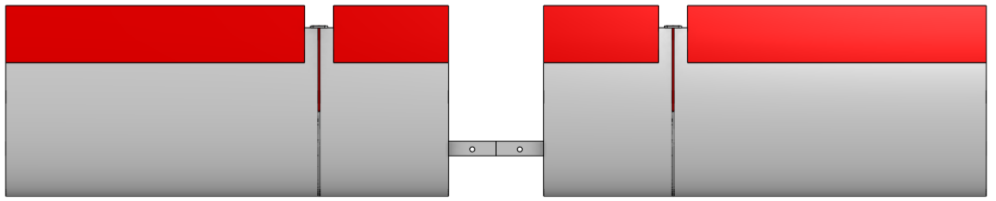
Parameter	Value
Vertical Tail Airfoil	NACA 0012
Vertical Tail Coefficient	**0.072**
Horizontal Tail Airfoil	**NACA 0012**
Horizontal Tail Coefficient	**0.0387**



Control Surface: Ailerons & Elevator

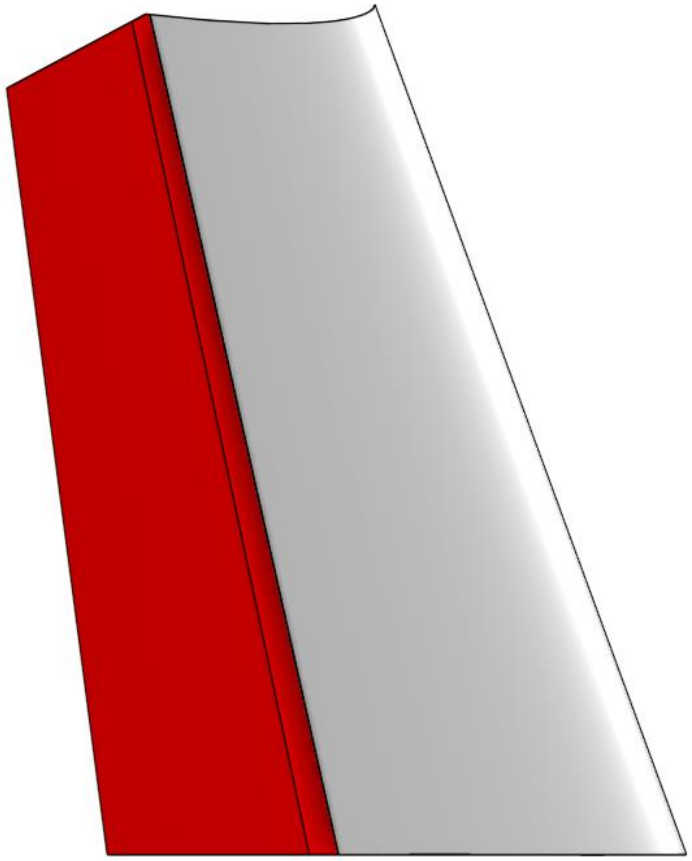
Control Surface	Length	Width	Effectiveness (τ)
Ailerons	55% to 100% of wing	30% of chord	0.54
Elevator	Full Span	40% of chord	0.60



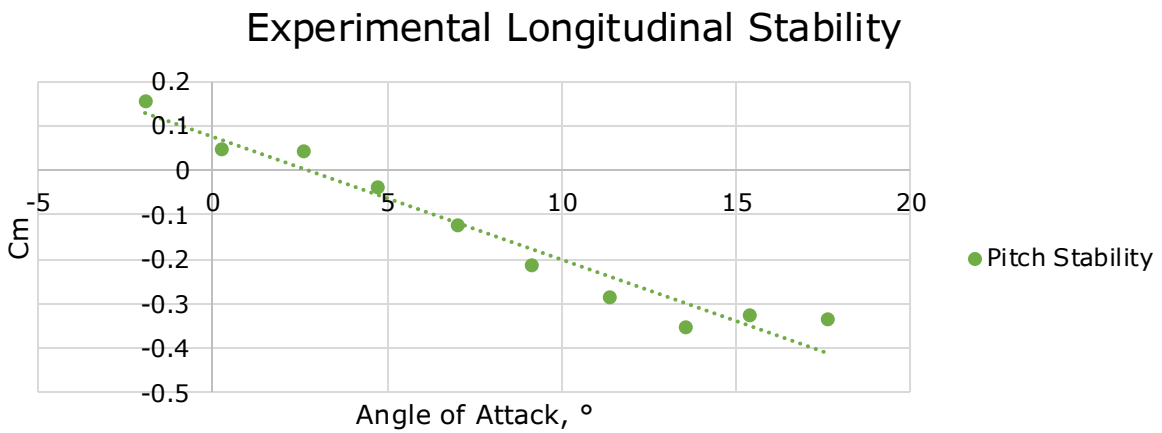


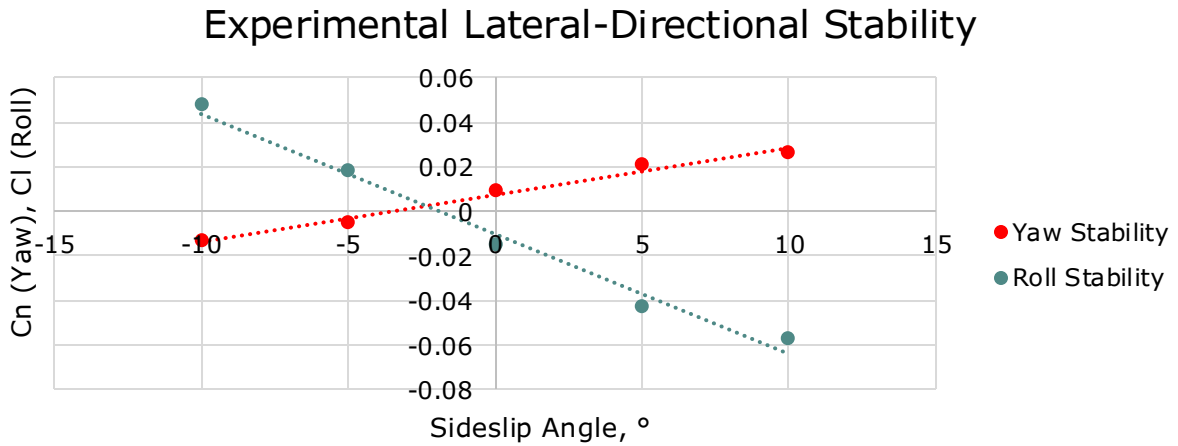
Control Surface: Rudder

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



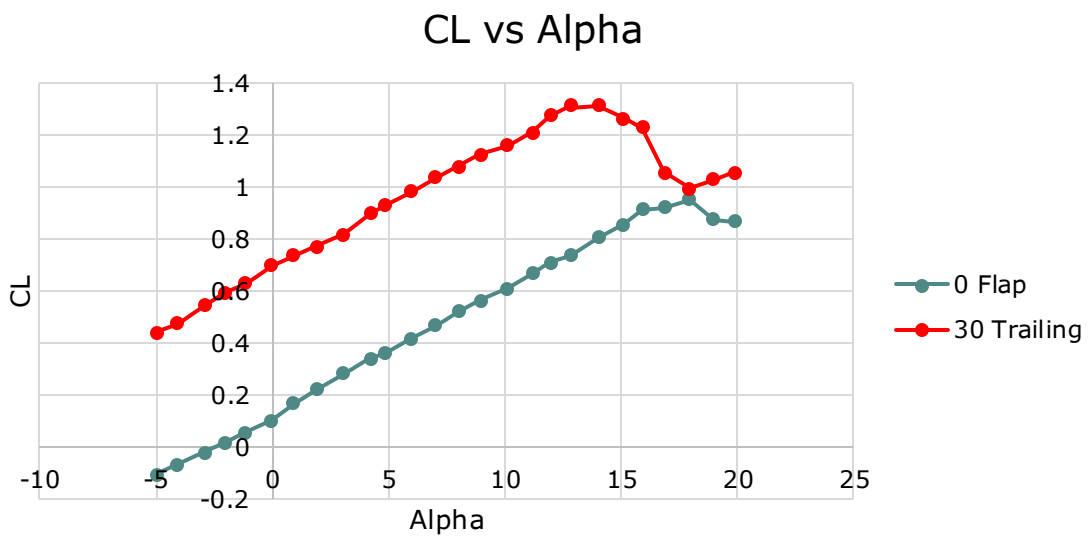
Simulations and Testing Agree that Aircraft is Stable

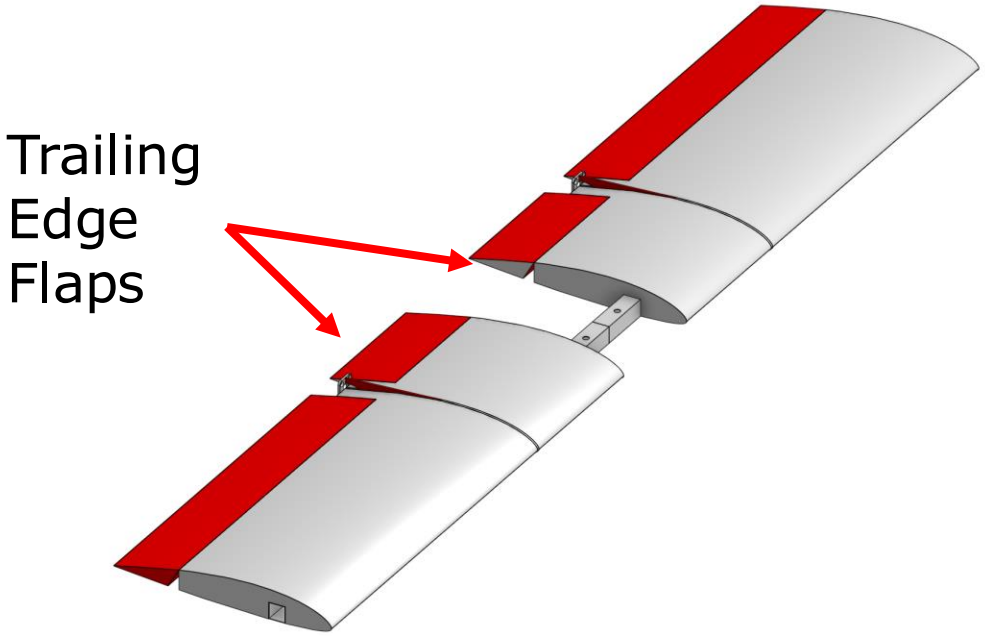




Simulation Type	Stability	Damping Ratio
SPPO	Stable	0.283
Phugoid	Stable	0.056
Roll Mode	Stable	~
Dutch Roll	Stable	0.060
Spiral Mode	Unstable	~

Trailing Edge Flaps Selected





- Ailerons act as flaperons
- Provides C_L Max = 1.31

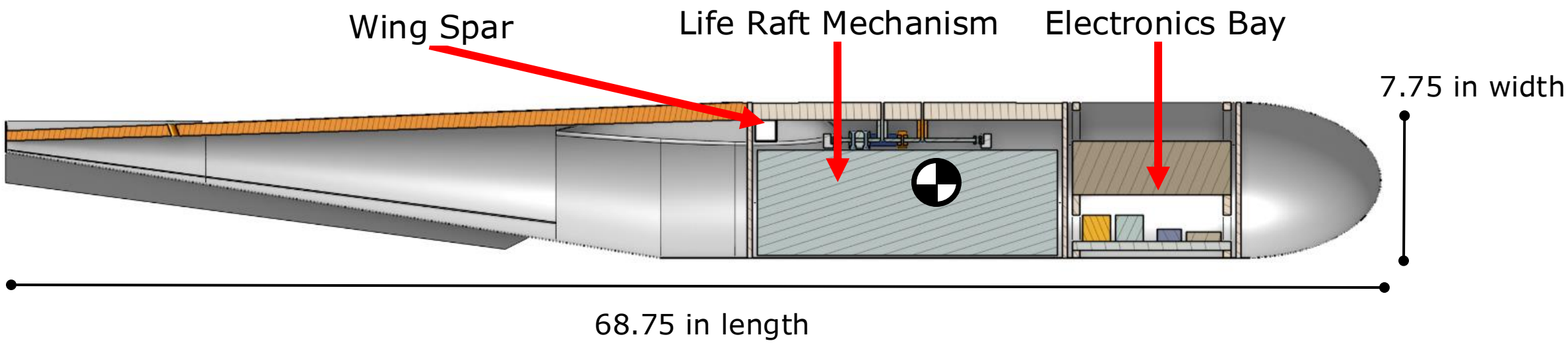
Width	Length	Deflection (degrees)
30% chord	90% span	30

Structural Design

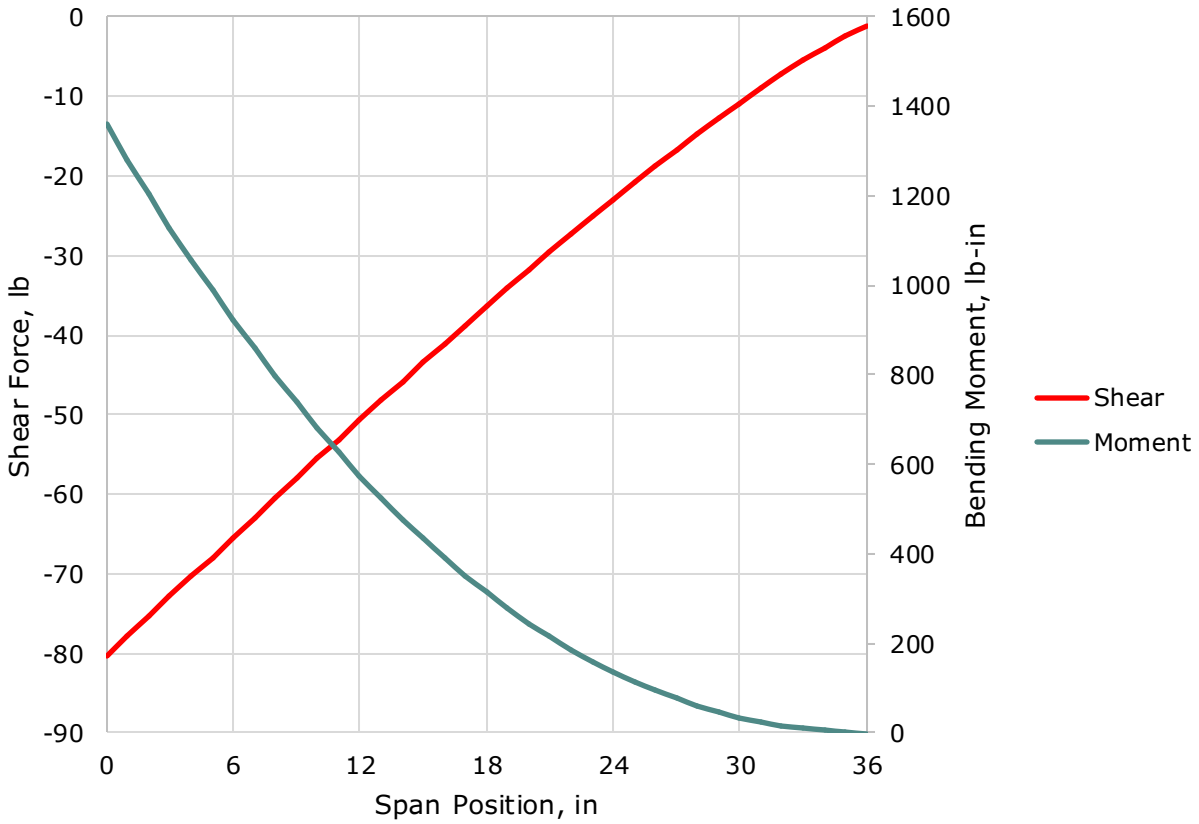
Requirements

Parameter	Requirement
Maximum g Loading	3.5 g
Life Raft Mechanism Support	Aerodynamically enclosed
Static Margin	Positive before and after raft deployment
Aircraft Total Weight	≤35 lbs.

Fuselage Sized to Fit Life Raft Mechanism



Structural Loading



Maximum Stress at Wing Root

Maximum Shear Force = 80 lb

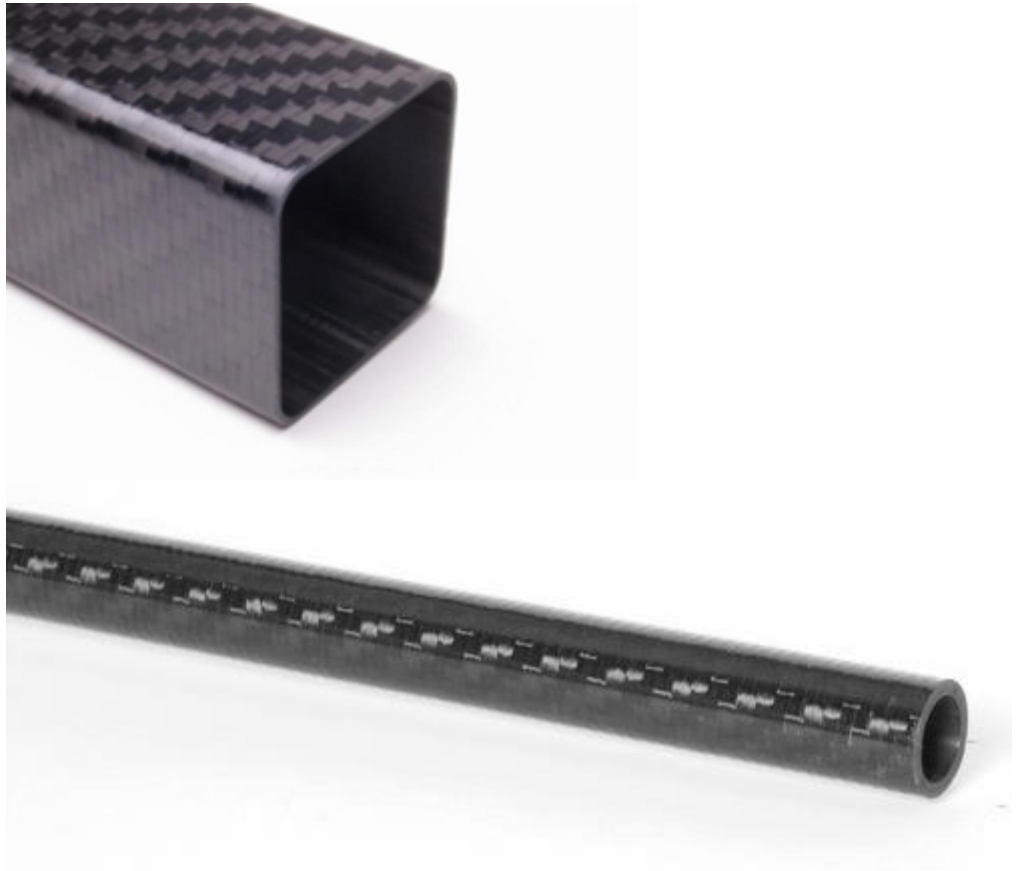
Maximum Moment = 133 lb-ft

Using Tsai-Hill Method:

Maximum Stress = 29.616 ksi

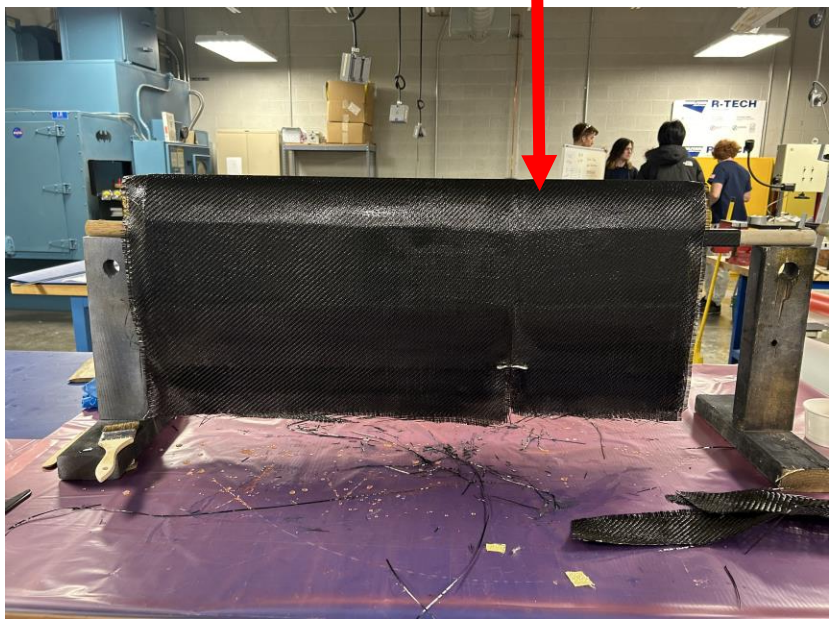
Spars Sized to Provide High Margin of Safety

Parameter	Wing Spar	Tail Spars
Shape	Square	Round
Outside Dimension	1.07 in.	0.375 in.
Wall Thickness	0.035 in.	0.07 in.
Margin of Safety	1.2	2.4

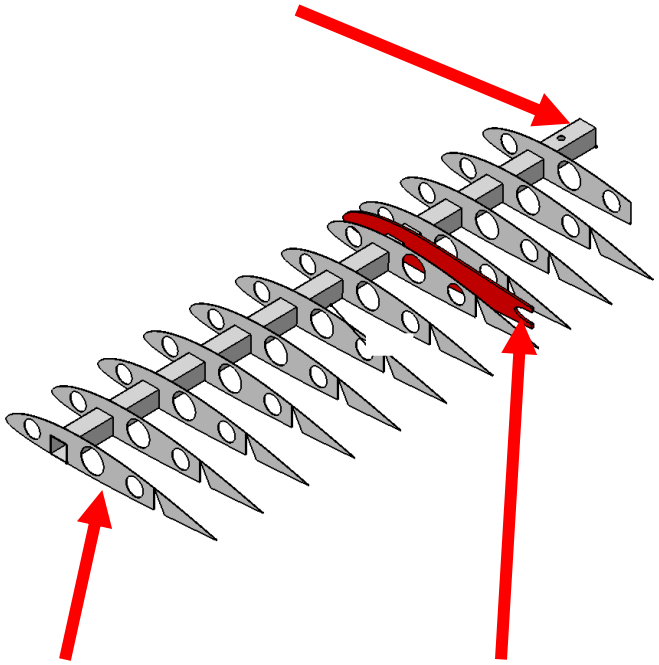


Aerodynamic Surfaces Use Composite Spar-Rib Construction

Carbon Fiber wing layup



1 in square carbon spar



Carbon Fiber ribs

Aluminum motor mount

Parameter	Design
Rib Thickness	0.04 in
Rib Spacing	Wing: 3 in V Tail: 3 in H Tail: 3.5 in

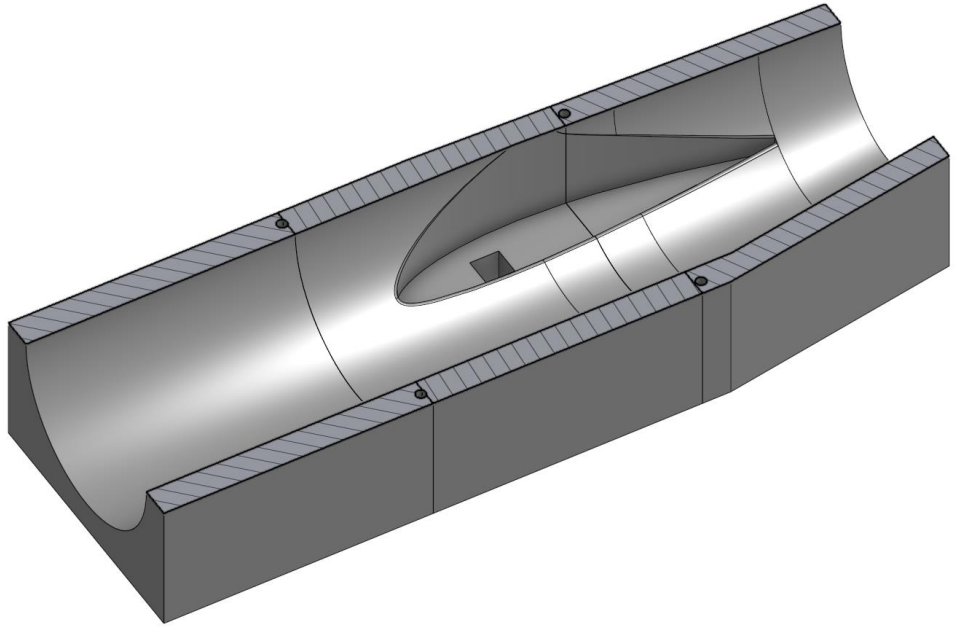
Fuselage Uses Molded Composite Skin and Bulkheads

Negative molds of fuselage sections

- 3 layers of carbon fiber fabric

Composite bulkheads

- 0.25 in. Nomex honeycomb core, 1 layer of carbon fiber fabric



Aircraft Weight Meets Requirements

Component	Weight, lbs.
Structures	11.37
Life Raft	5.00
Raft Mechanism	0.32
Avionics	4.12 (including sensor)
Propulsion	4.74
Battery	5.64
Aircraft Total Weight	**31.25**

Structural Design Provides Sufficient Strength to Meet Requirements

Parameter	Requirement	Design
Maximum g Loading	3.5 g	7.8 g
Life Raft Mechanism Support	Aerodynamically Enclosed	Fully enclosed
Static Margin	Positive before and after raft deployment	36% before, 39% after
Aircraft Total Weight	35 lbs.	31.25 lbs. (estimated)

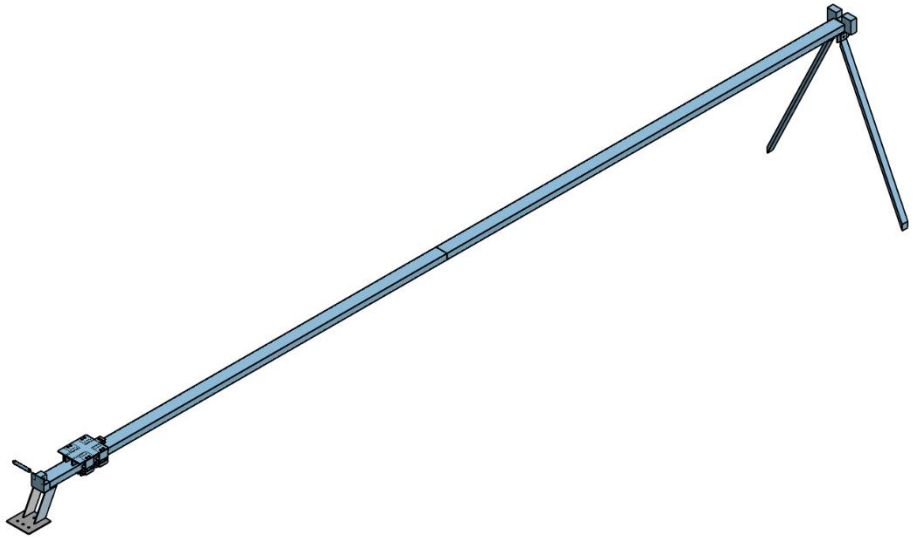
Launch and Recovery

Design Requirements Drive Launch & Recovery System Selection

Parameter	Requirement
Maximum Load Factor	3.5 g
Aircraft Weight	**31.25 lbs.**
Launch Platform Size	**4 ft x 4 ft platform**
User Input	**Autonomous**
Launch Energy	**>975 ft-lbs**
Aircraft Takeoff Speed	33 kts

Elastic Launch System Best Fits Project Needs

Parameter	Requirement	Calypso Catapult
Energy	≥ 945 ft-lb	975 ft-lb
Size	4 ft x 4 ft platform	10 ft length with bipod mount
User Input	Autonomous	Trigger



Cable Recovery System Best Fits Project Needs

Parameter	Requirement	Calypso CRS
Energy	≥ 945 ft-lb	1475 ft-lb
Size	4 ft x 4 ft platform	8 ft x 12 ft mount
User Input	Autonomous	Passive

Flight Controller and Communications

Mission Requirements for Avionics

Parameter	Requirement
Flight controller capabilities	Fully autonomous takeoff, cruise, missions, and landing
Flight controller operation	Allow for operator takeover
Flight controller integration	Good sensor redundancy
Communication bandwidth	Transmit telemetry and HD video to operator
Communication range	**≥ 17.5 NM**
Total avionics weight	**≤ 1 lbs.**

Pixhawk 4 Flight Controller Exceeds Derived Requirements

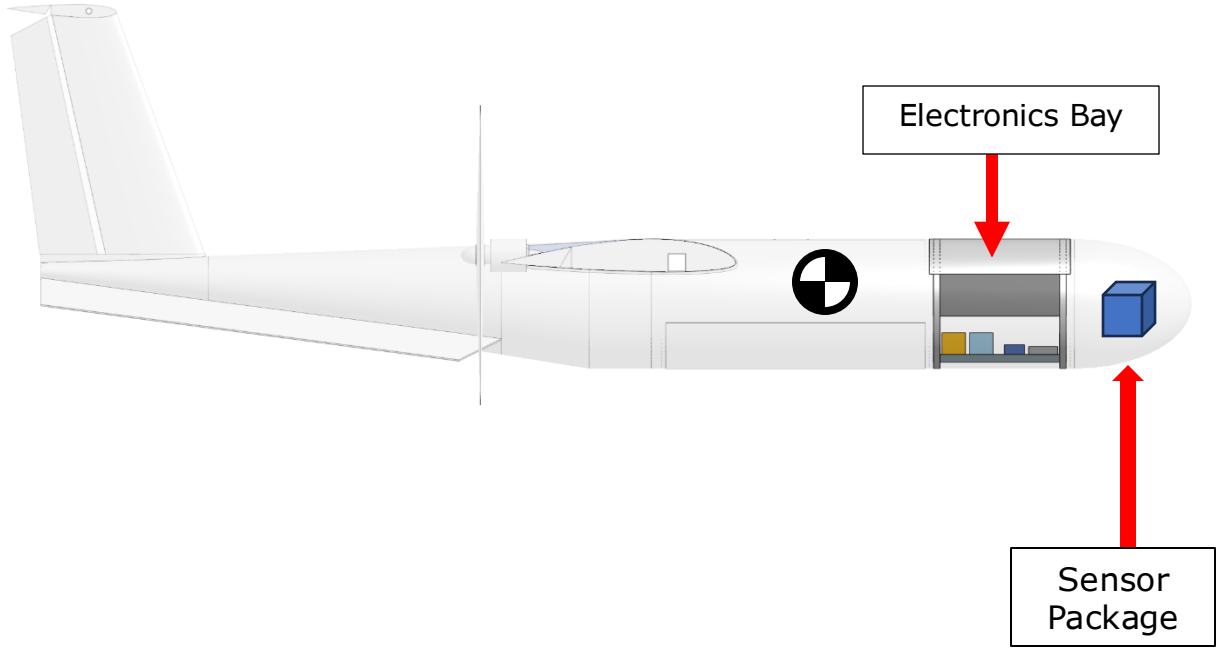
Parameter	Requirement	Specification
I/O ports	≥ 8	16
Implementation	Easy to implement	Good availability, good documentation
Weight	≤ 0.5 lbs.	0.03 lbs.

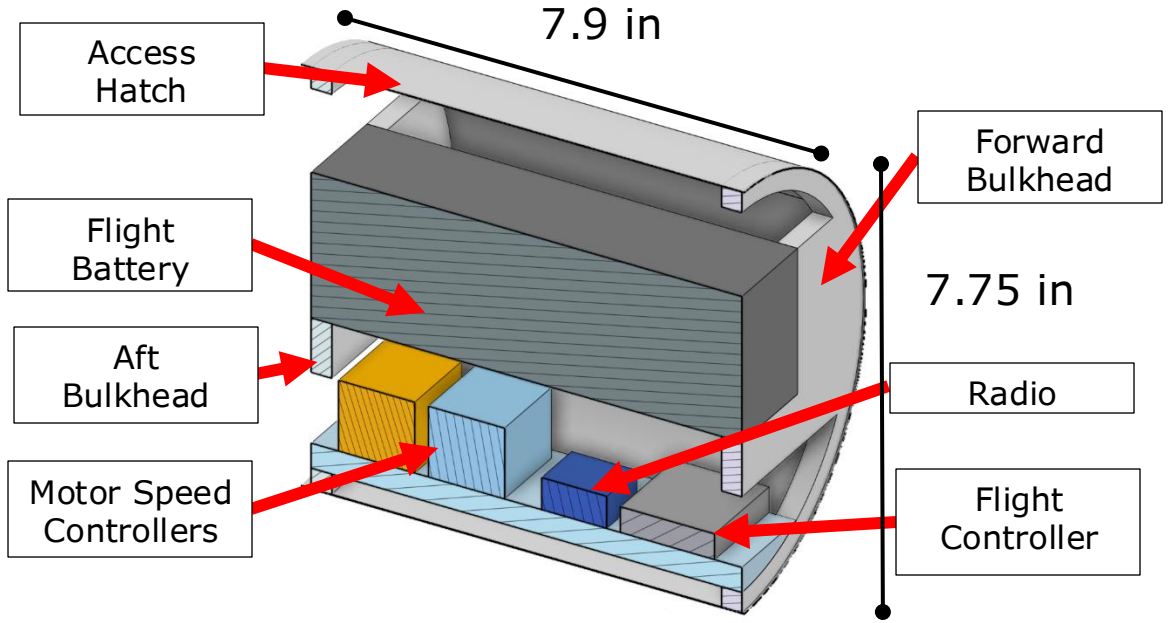
Commtact MDLS Radio Meets All Communication Requirements

Parameter	Requirement	Specification
Weight	≤0.5 lbs.	0.22 lbs.
Range	≥17.5 NM	**21.75 NM**
Bandwidth	Support any video transmission	Supports HD video

Electronics Bay Maintains Access to Components and Positive Margin

36% static margin before raft deployment, 39% after deployment





Propulsion

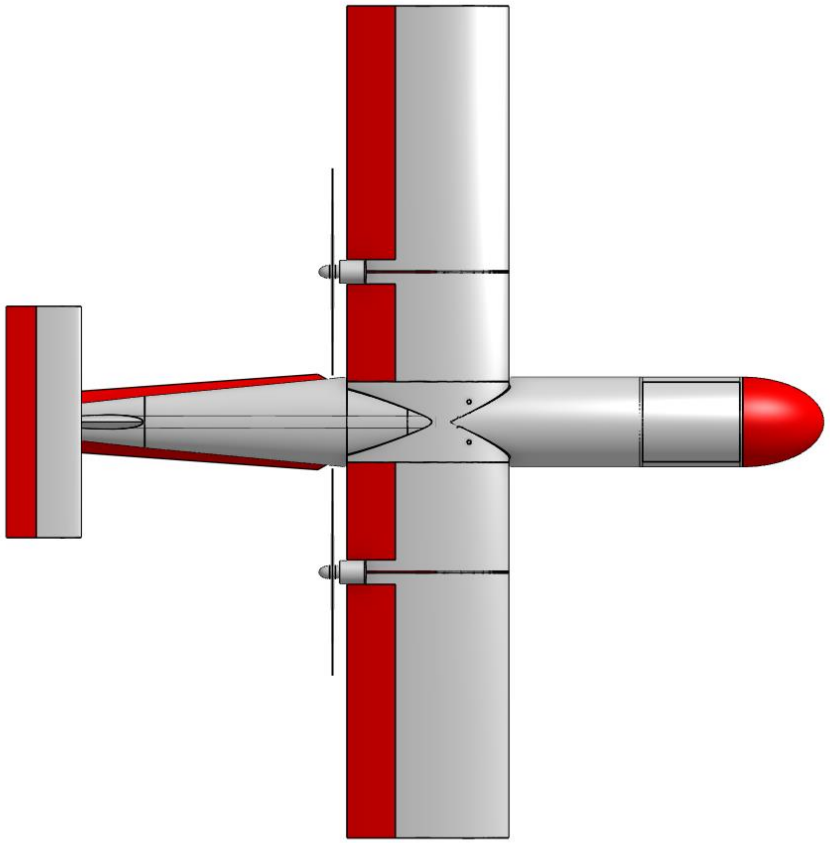
Requirements That Drive Propulsion Configuration

Parameter	Requirement
Minimum endurance	**90 min**
Minimum power	5,500 W
Minimum cruise speed	**100 kts**
Minimum Service Interval	3 months
Reduction of Recovery Risk	Avoid damage from net or wire recovery
Whole Aircraft Drag	**Cruise C_D = 0.047** **Cruise Drag = 7.72 lbf**

Twin Pusher Configuration Meets Recovery Requirement

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

Twin motors reduce thrust moment and simplify integration



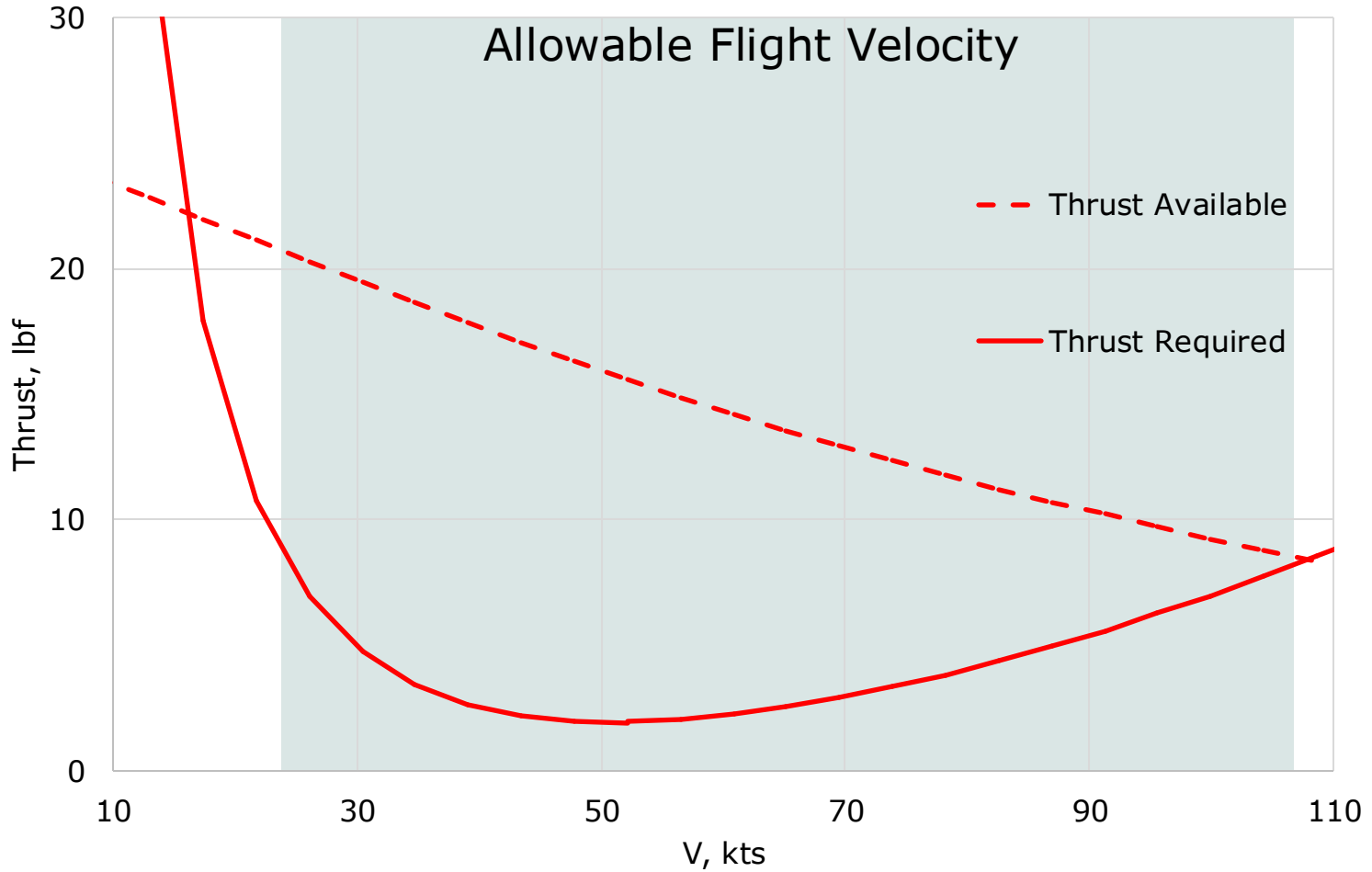
Selected Propellers Allow for Flight at 100 kts

18 in Diameter, 12 in Pitch Propellers

- 7.72 lbf thrust @ 100 kts and 10,000 rpm
- Counter-rotating propellers reduce thrust moment

Propulsion Configuration Produces Excess Thrust at All Flight Speeds

- Net thrust generated from 17-100 kts
- Takeoff speed limited by aerodynamics, not propulsion



Motors Provide Sufficient Power for Flight at 100 kts

Parameter	Requirement	Design
Propulsive Power	≥5,500 W Total	2,750 W per motor
Motor Max RPM	10,000 RPM	10,500 RPM

Sunnysky X4123 V3 480kV Motors

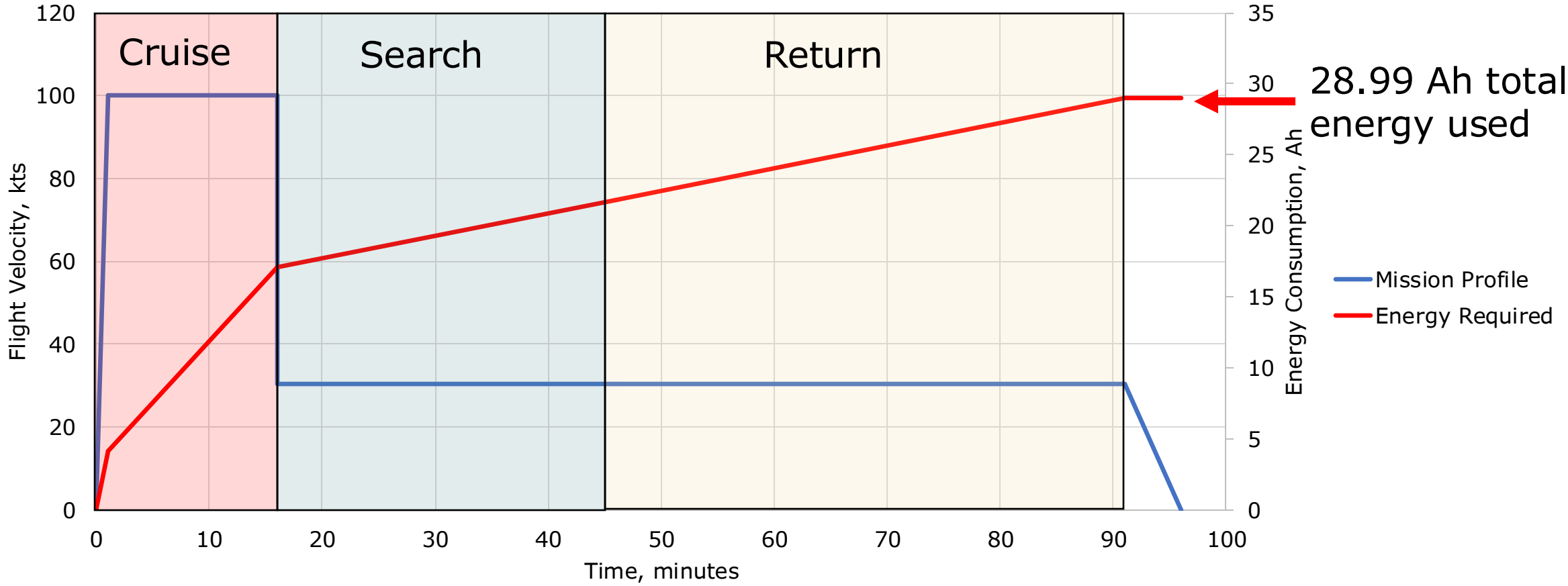
Propulsion Configuration Meets Performance Requirements

Parameter	Requirement	Design
Propulsive Power	≥5,500 W	5,500 W
Maximum cruise speed	100 kts	108 kts
Minimum Service Interval	>3 months	Unlimited with battery trickle charging
Propeller Protection	Avoid damage from wire or net recovery	Propellers behind wing
Minimum Thrust	7.72 lbf @ 100 kts	9.74 lbf @ 100 kts

Selected Battery Configuration Provides Sufficient Energy

Parameter	Specification
Energy Required	28.99 Ah
Total Energy	30 Ah
Energy Margin	3.5%

Energy Required Primarily Driven by Cruise Phase Speed



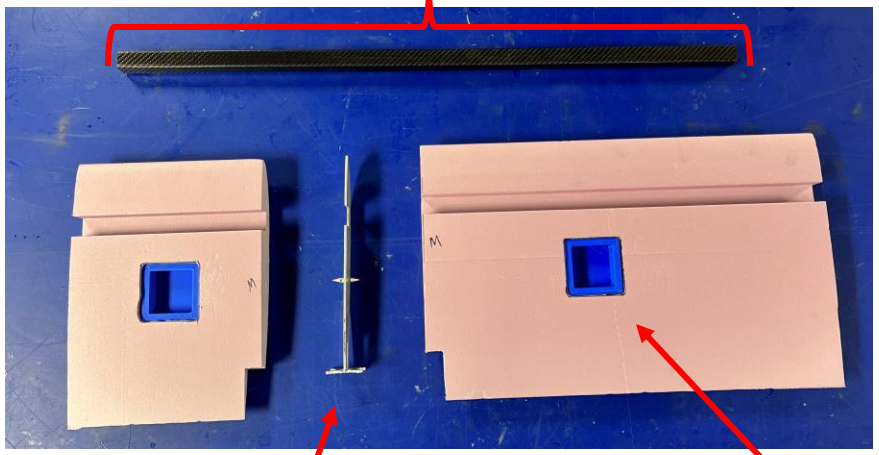
Battery Configuration Meets Performance Requirements

Parameter	Requirement	Design
Minimum Endurance	90 minutes	3.5% margin for 90-minute mission
Maximum Propulsion System Weight	13.3 lb	1x battery: 5.63 lb 2x motors: 1.56 lb 2x propellers: 0.33 lb 2x ESCs: ~0.55 lb Total: 8.07 lb

Flight Test Article

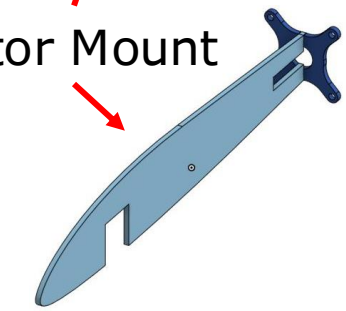
Main Wing Construction

Carbon Fiber Spar

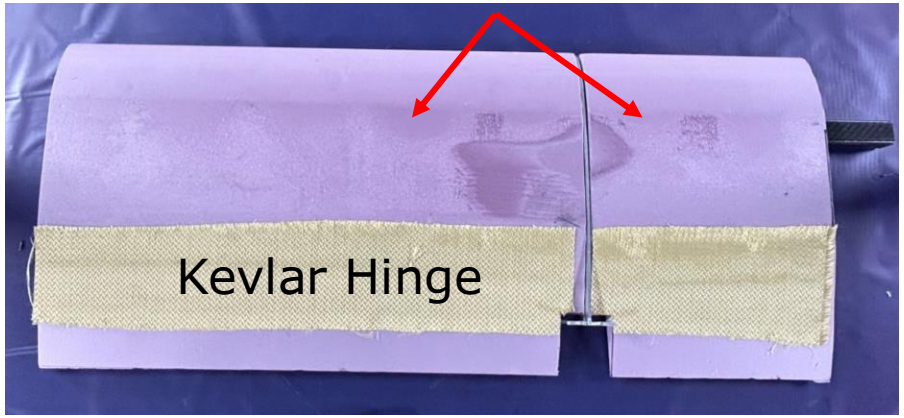


Servo Cups

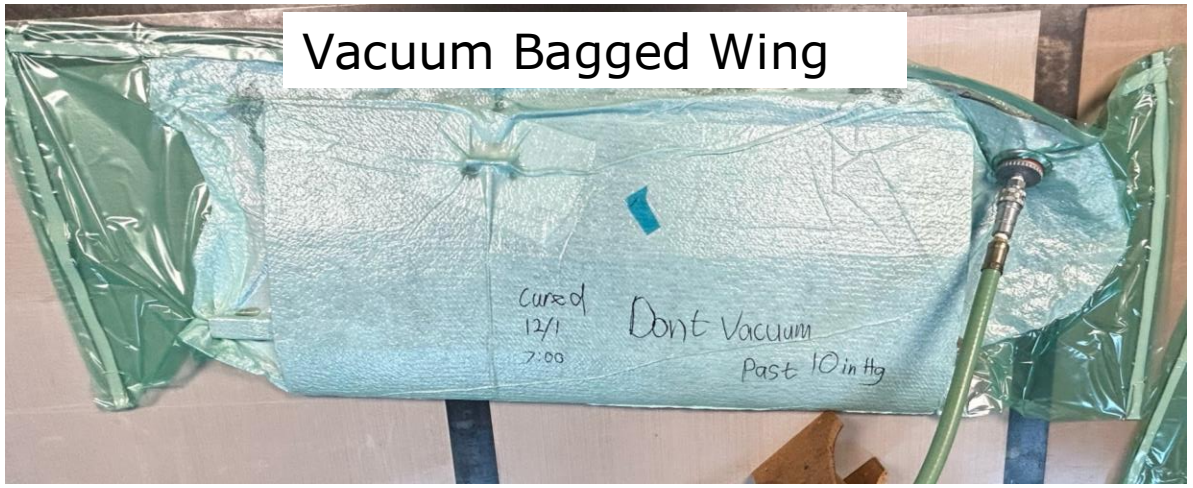
Motor Mount

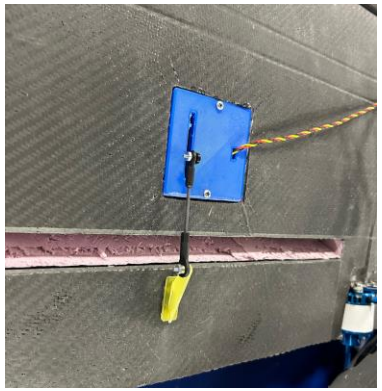


Rigid Foam Core



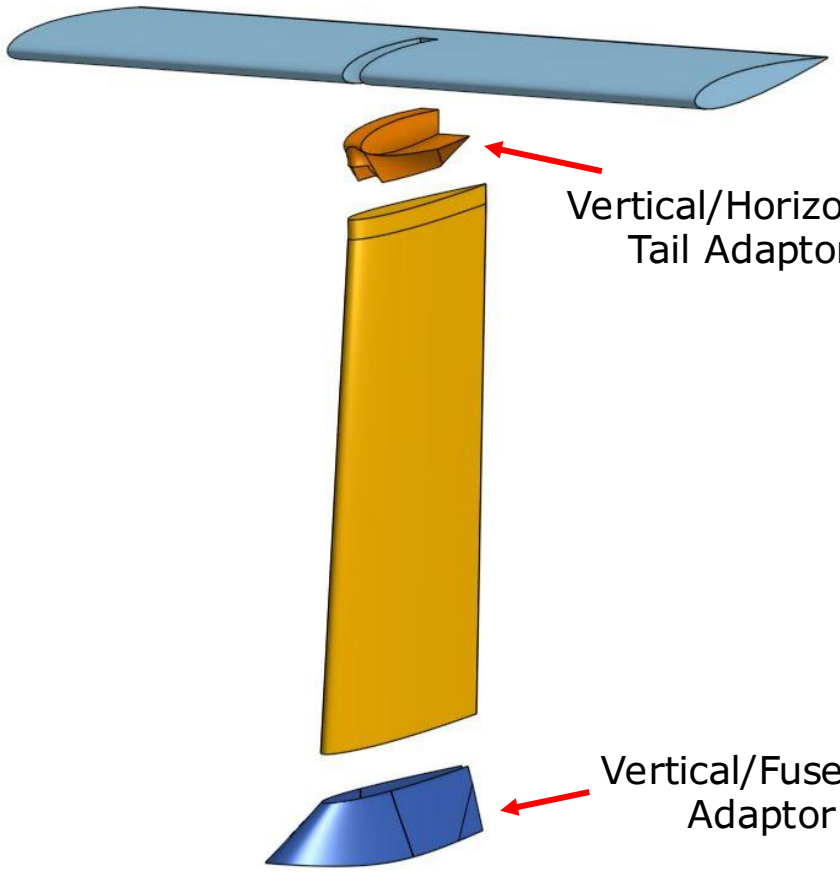
Main Wing Construction





Integrated Servo Cup

Tail Wing Construction



Fuselage Construction – Nose Section

Kevlar Reinforcement

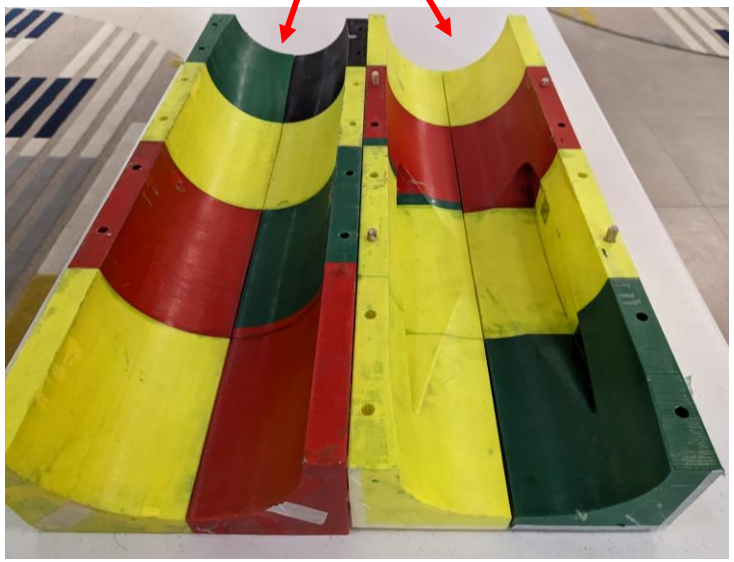
Positive Mold

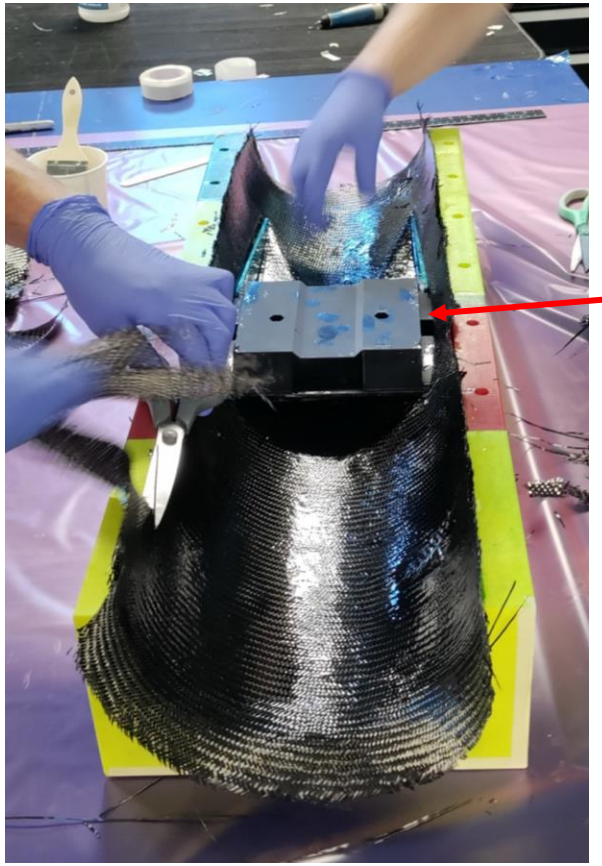
Carbon Fiber Sleeves

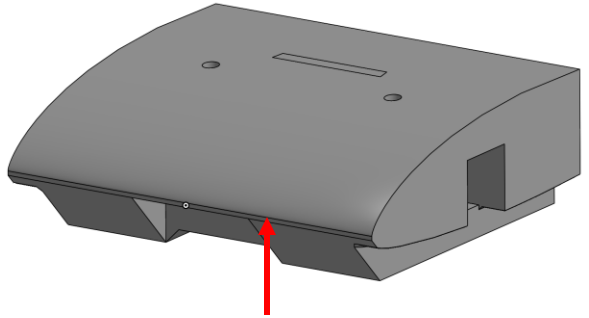
Finished Product

Fuselage Construction – Mid-Section

Top and Bottom
Negative Molds

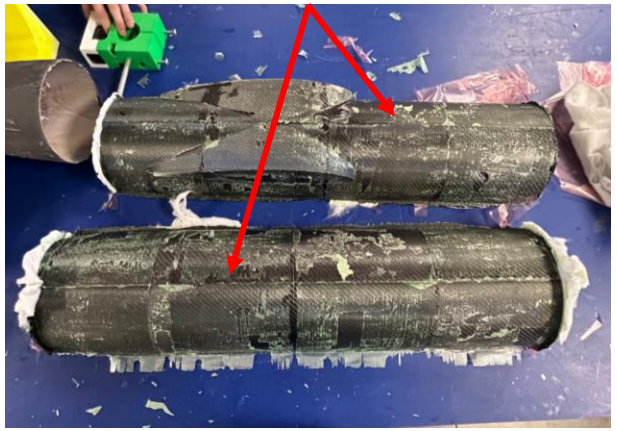




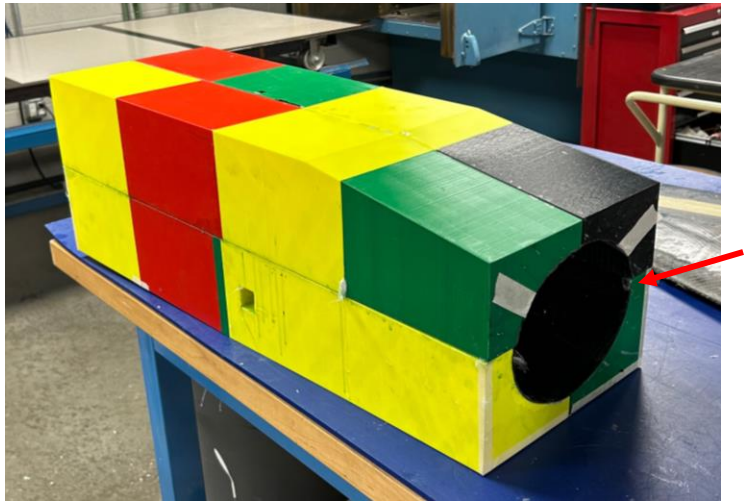


Wing Box

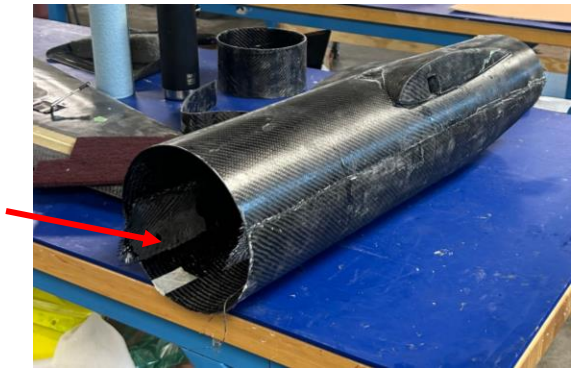
Pre-Processed
Fuselage Halves

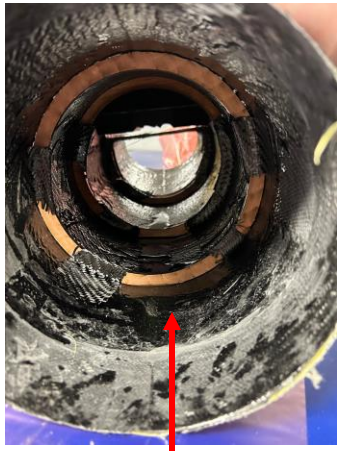


Fuselage Construction – Mid-Section



Carbon Fiber Strips Joining Halves





Plywood Reinforcements

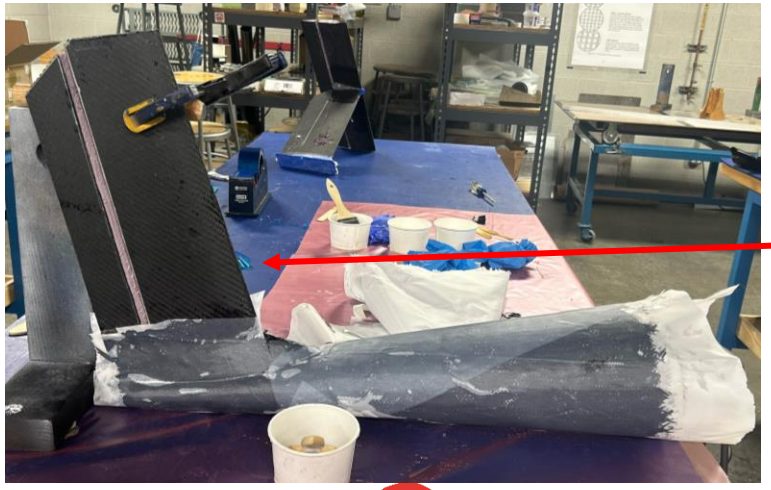
Carbon Fiber/Kevlar Reinforcement on Mating Ends

Fuselage Construction – Tail Section

Positive Mold

Carbon Fiber Sleeves

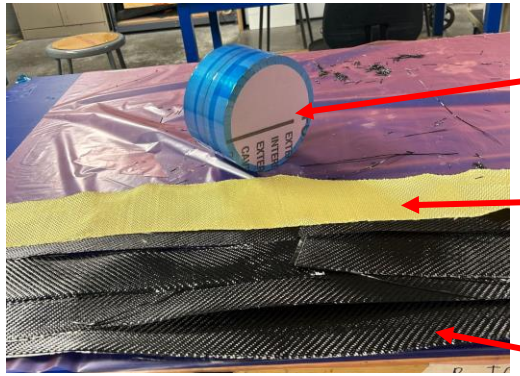
Kevlar Reinforcement



Integrated Vertical Tail

Finished Product

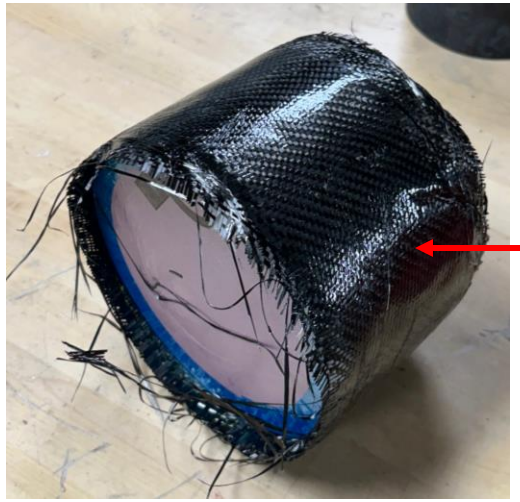
Nose/Mid-Section Adapter



Positive Mold

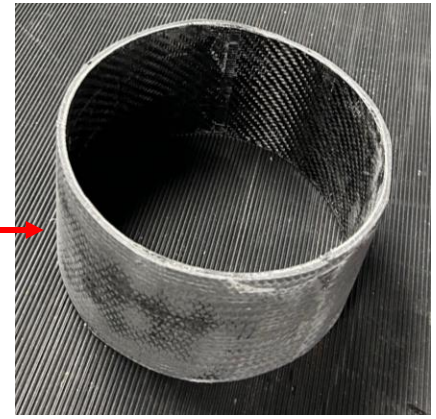
Kevlar Reinforcement

Carbon Fiber Strips

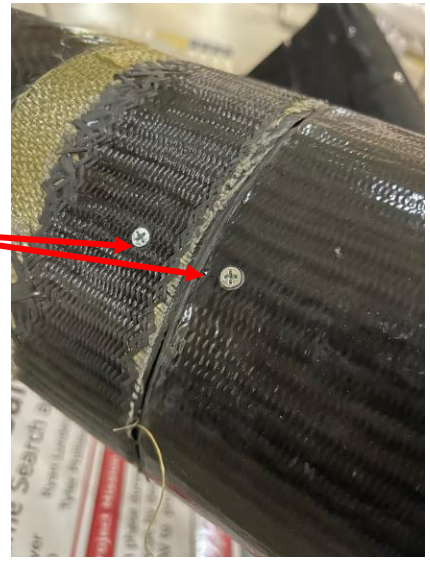


Pre-Processed Part

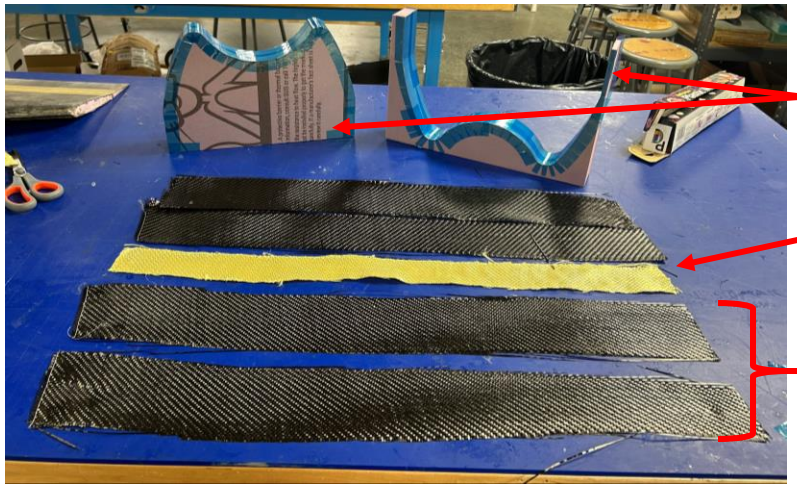
Post Processed Part



Machine Screws



Landing Gear



Negative Molds

Kevlar Reinforcement

Carbon Fiber Strips

Shape Matches Fuselage Curvature

Reinforced with Threaded Rod

Fabrication of Flight Test Article is Not Identical to Design

Structures

- Extensive use of foam cores in layups to simplify fabrication
- Increased structural weight

Propulsion

- Lower capacity battery(10 Ah vs. 30 Ah)
- Lower pitch propellers(18x10e vs. 18x12e)

Landing Gear Included

Prototype used for Flight Test Differs From Final FTA

- Fiberglass skin on wing with 2 smaller spars
- Foam board/plywood reinforced square fuselage
- Taller landing gear

Flight Test Results

Right propeller ejected after take off

Aircraft is stable with one engine

Operator error resulted in loss of control

Flight Test Data

Parameter	Value
Time of Flight (s)	13.5
Take Off Distance (feet)	220
Take Off Speed (kts)	30.2
Max Speed (kts)	47.0
Max Climb Rate (ft/min)	1100
Longitudinal Stability?	Yes
Lateral Stability?	Yes

Conclusion

Design Studies & Testing Indicate All Requirements Met

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.

Calypso Team Recommends Additional Testing

Wind tunnel testing has verified design features

Flight test article has given **limited validation** of aircraft performance

Additional flight testing is required to confirm that the aircraft meets all requirements

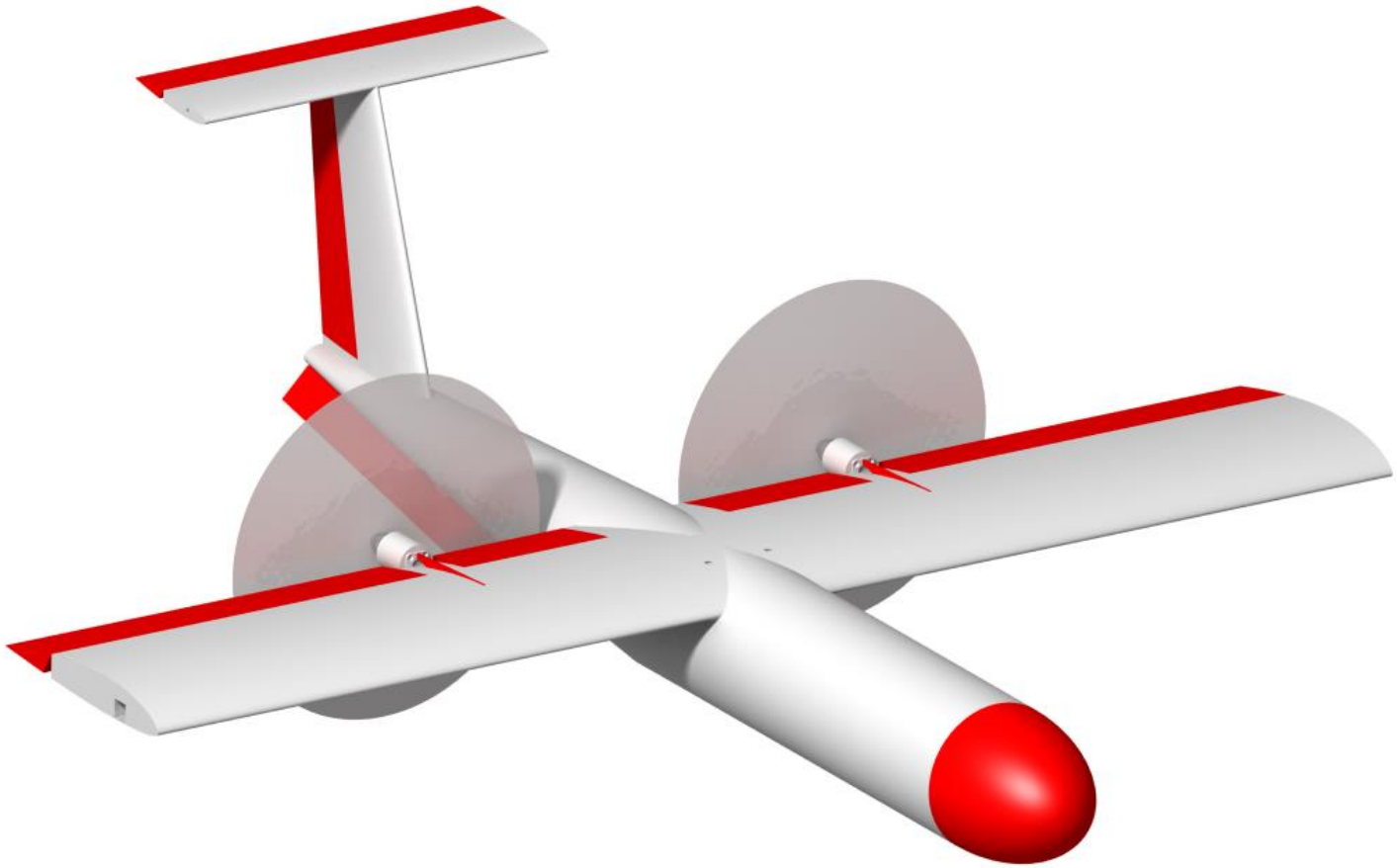
Recommendations for Future Work

Ensure that FTA is designed according to manufacturing capabilities

Plan to include landing gear on FTA from beginning of design process

Follow wing loading and power loading guidelines for RC aircraft

Questions?

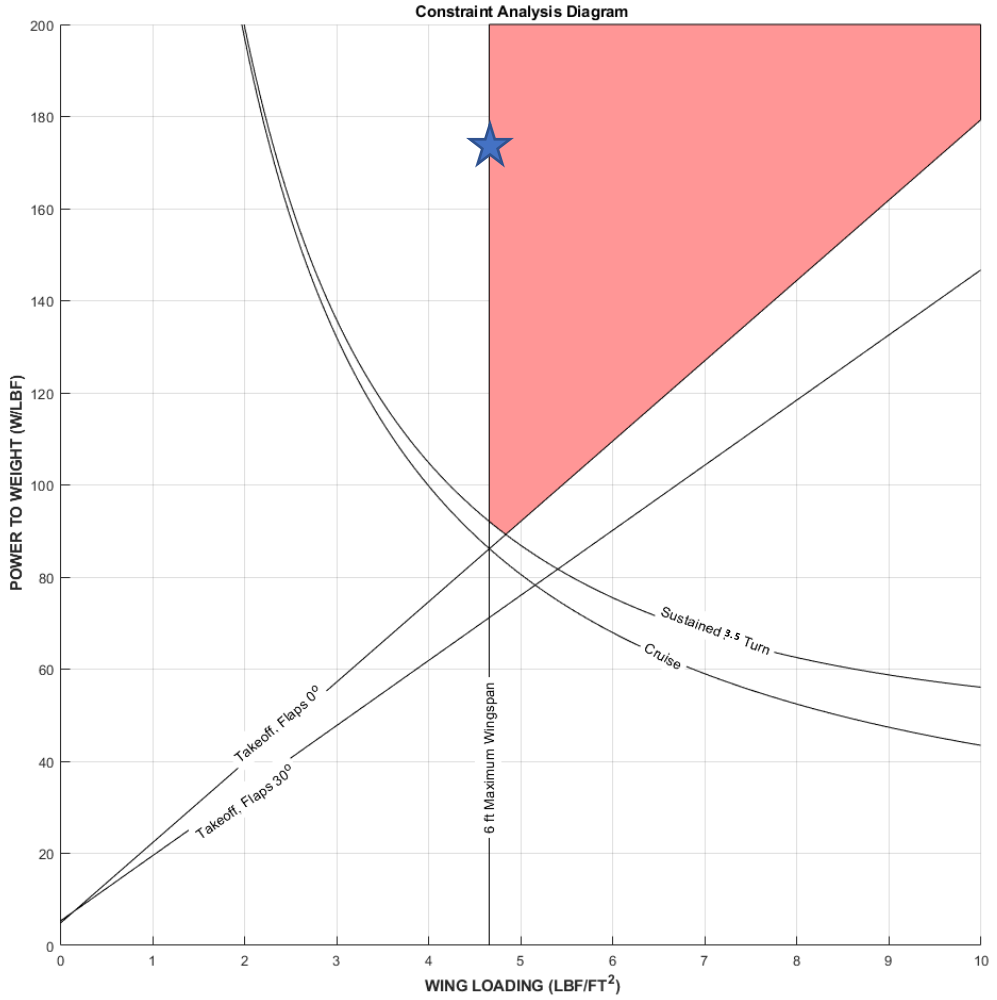


Appendix

Statement of Work Requirements

Parameter	Requirement
Operating Altitude	Sea level to 400-ft ASL
Operating Temperature	-20° to 40°-C
Speed Requirement	Cover 20-miles in no more than 15-min
Operating Radius	17.5 NM
Minimum Loiter Time	30-min
Load Factor	3.5-g
Climb Rate	1000-ft/min
Weather Conditions	Up to Level 7 Beaufort scale (28-33 kts winds, 13-19 ft waves)
Sensor Payload	4-lb self-powered payload.
Maximum Takeoff Weight	35-lb.
Minimum Service Int.	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

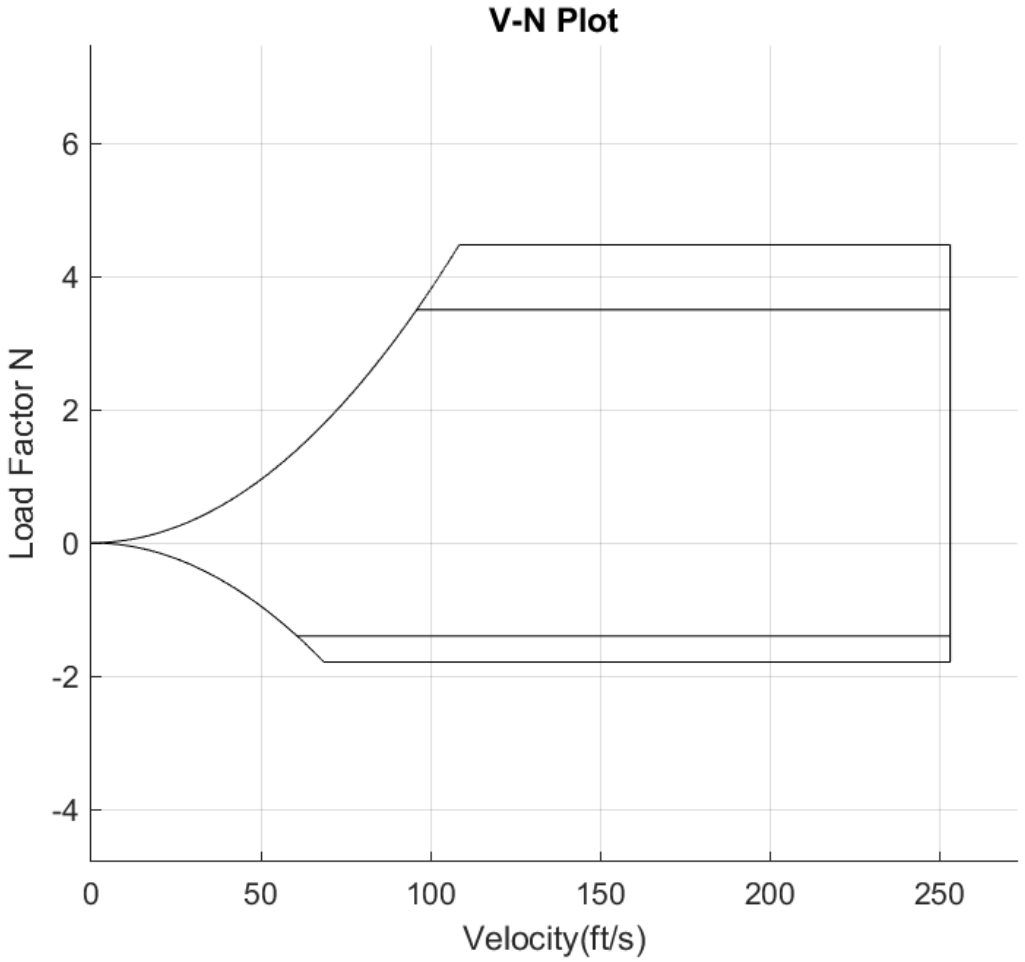
Wing Configuration						
	Regtangular	Tapered Straight	Sweptwing (low speed)	Elliptical	Rear Wing Canards	Score Factor
Stablity	5	3	3	4	2	4
Lift	4	4	4	3	4	4
Drag	1	4	3	4	3	3
Manueverability	3	3	2	3	3	3
Fabrication	4	4	2	1	3	2
Structural Weight	2	3	3	3	3	2
Totals:	60	63	53	57	54	

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	

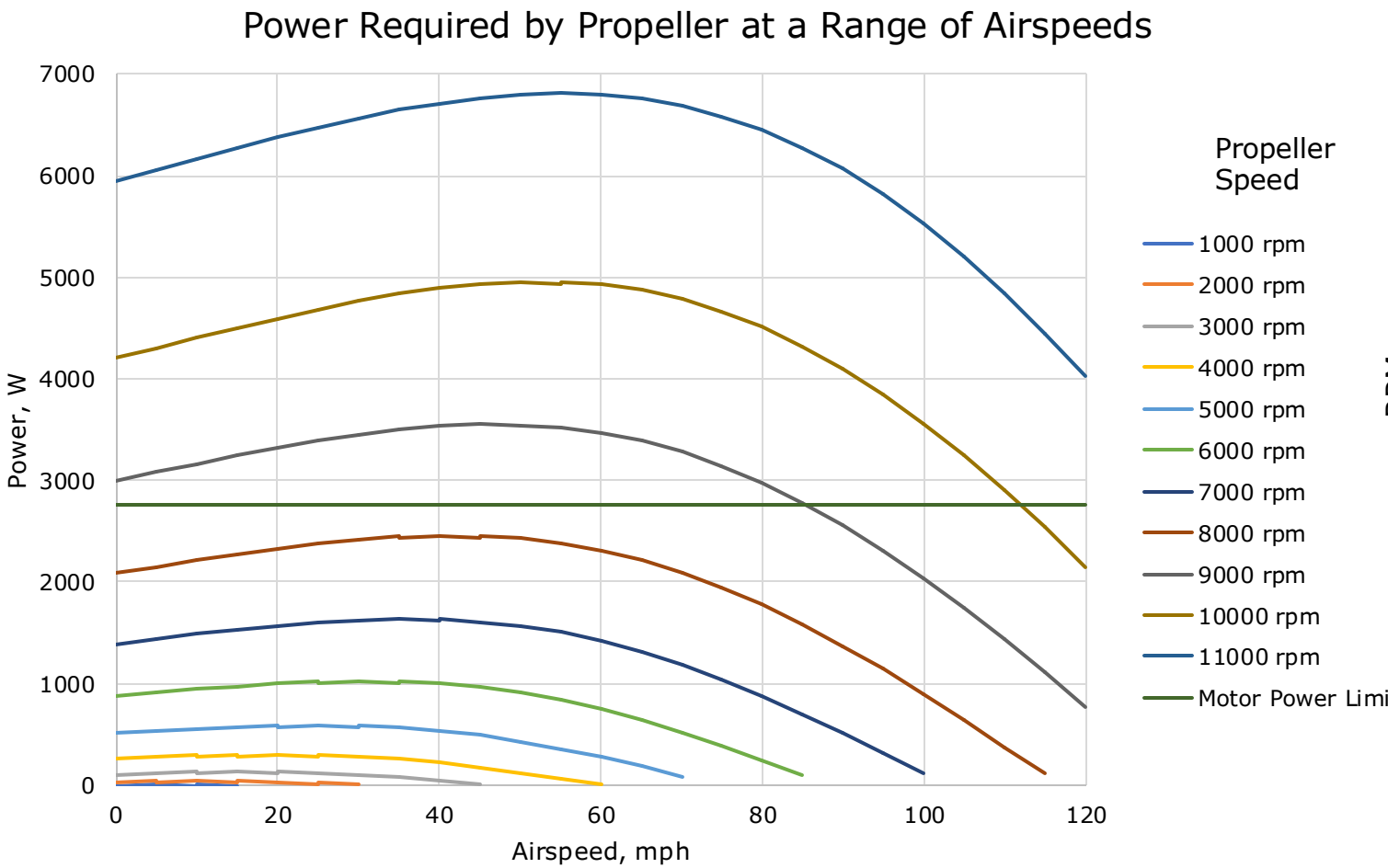
Aircraft Performance Flight Envelope

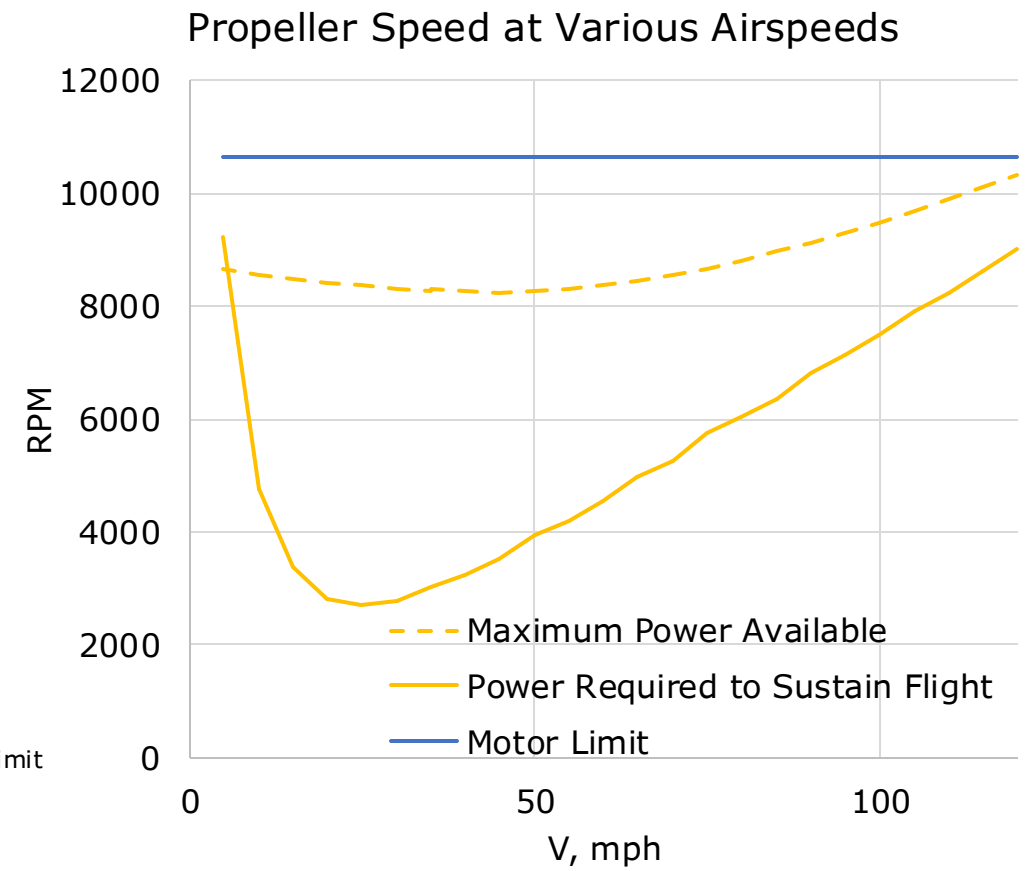


Velocity	V_d	V_c	V_{cmin}	V_a	V_s
(kts)	120	100	80	75	30
Maneuver Loads	+	-	**Ref: Sec. 23.337 Amd 23-7**		
(n)	4.492	-1.79665	MTOW		
(n)	4.494	-1.798	MINTOW		

At MTOW	
Ug_3D	26.796217
Kg_3D	0.7346869
n_3D (+)	**7.170473**
n_3D (-)	**-5.170473**
At MINTOW	
Ug_3D	19.140155
Kg_3D	0.6891665
n_3D (+)	**9.10342**
n_3D (-)	**-7.10342**

Motor and Propeller Performance





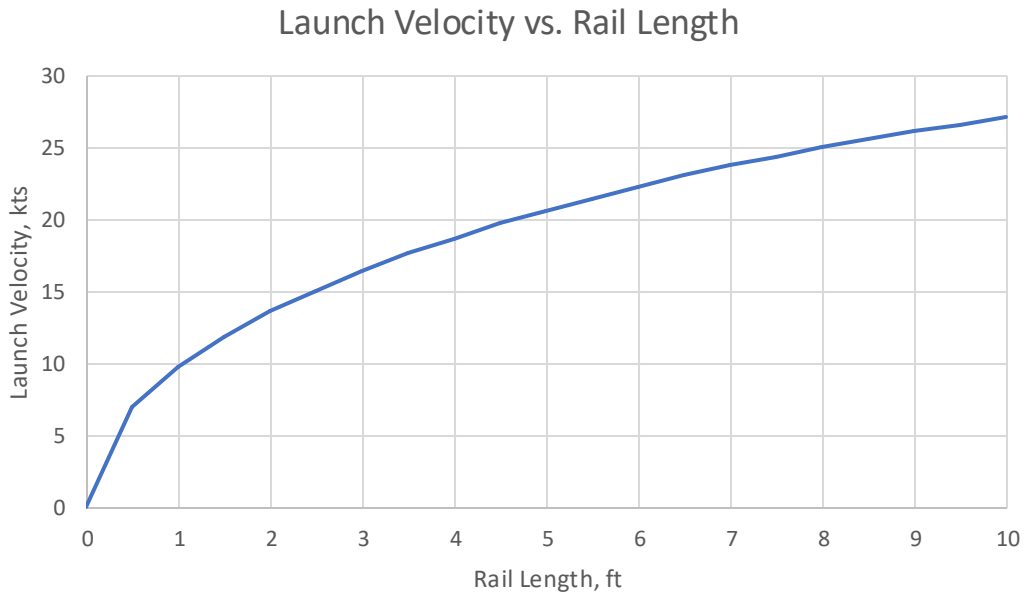
Catapult Performance

4 bands, 0.375-in ID, 0.125 wall silicone tubing

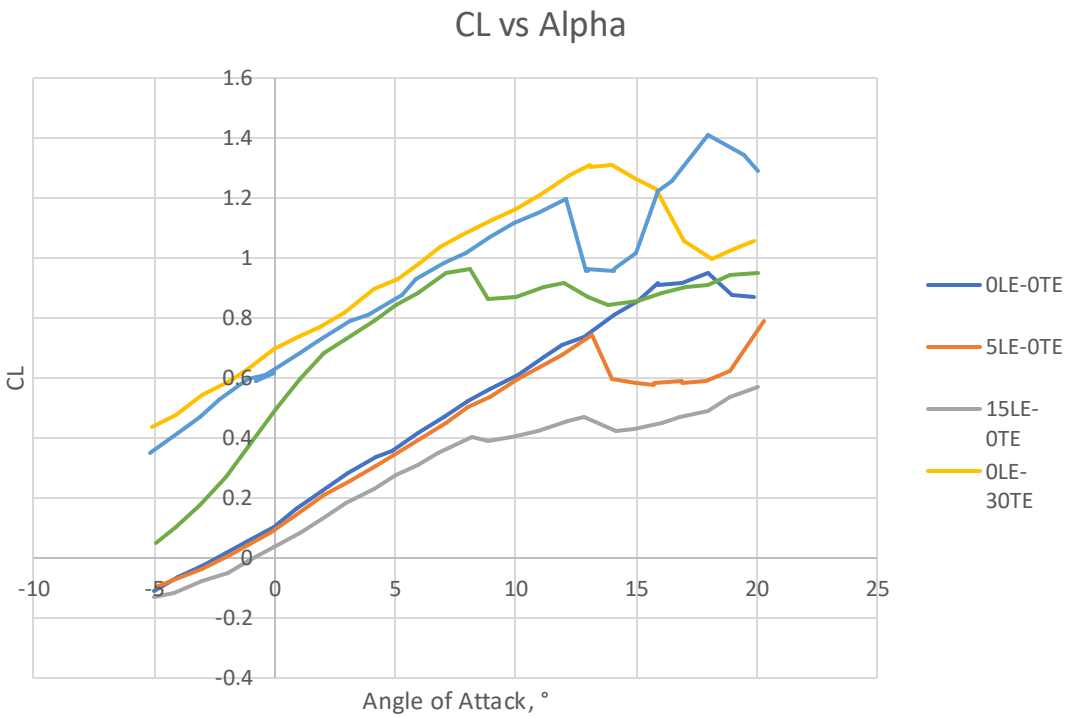
Launch Velocity: 27.1 kts

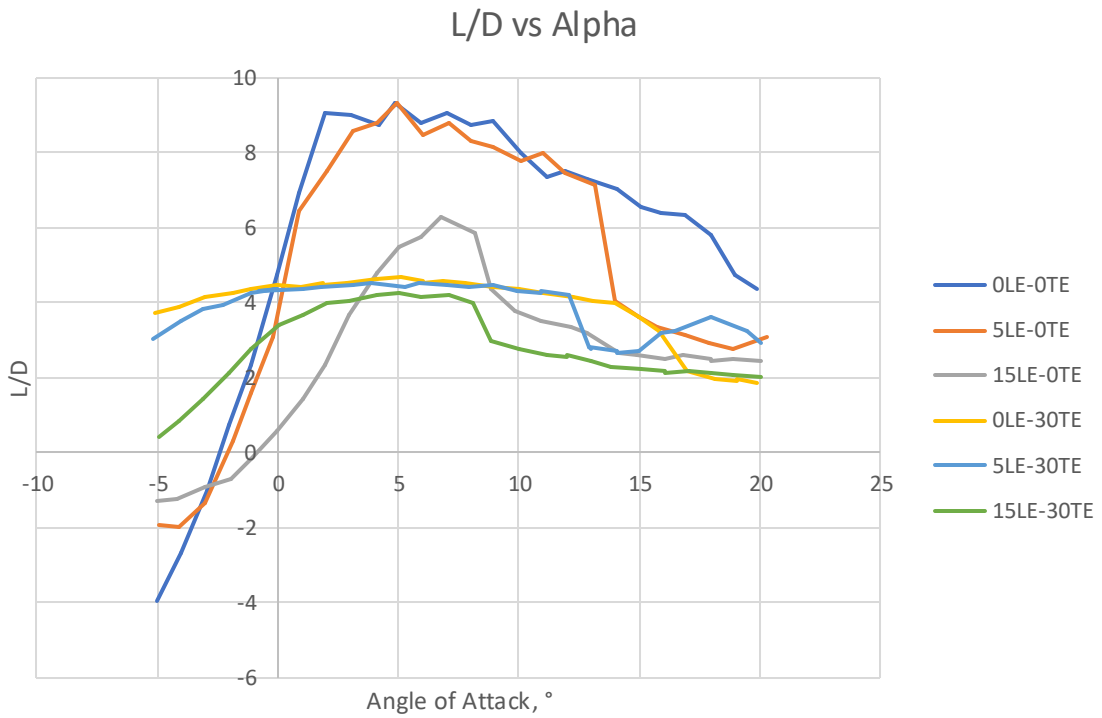
Avg g-load: 3.3

Maximum Energy: 975 lbf-ft



Wind Tunnel Test Data – Mechanized Wing





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Slide #	Item
5	United States Coast Guard, *Search and Rescue Summary Statistics*, 2017.
5	Schuldt, D. and Kurucar, J., *Maritime Search and Rescue via Multiple Coordinated UAS*, MIT Lincoln Laboratory, 2017.
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13	Uncharted Supply Co., "Rapid Raft," *https://unchartedsupplyco.com/products/rapid-raft*, 2023.
19	PX4 Dev Team, "Pixhawk 4," *PX4 Autopilot User Guide,* 2020.
20	Commtact Systems,"Mini Micro Data Link System (MDLS)", *https://commtact-systems.com/products/micro-data-link-system/,* 2023.

References

Slide #	Item
41-42	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
41-42	"Design and fabrication of a fixed-wing unmanned aerial vehicle (UAV)," Ain Shams Engineering Journal Available: https://www.sciencedirect.com/science/article/pii/S2090447922004051
41-42	"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
41-42	Charles River Radio Controllers - conventional vs. V-tails Available: http://www.charlesriverrc.org/articles/design/donstackhouse_conventionalvsvtail.htm.
41-42	"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
5	Render Background	Link
13	Uncharted Supply Co. Rapid Raft Outdoors	Link
19	Pixhawk 4 Flight Controller	Link
20	Commtact MDLS Radio Communications	Link
32	Wire Recovery of Boeing ScanEagle	Link
48	APC 18x12e Propeller	Link
50	Sunnysky X4125 V3 Motor	Link
52	Liperiair 30,000 mAh Battery	Link