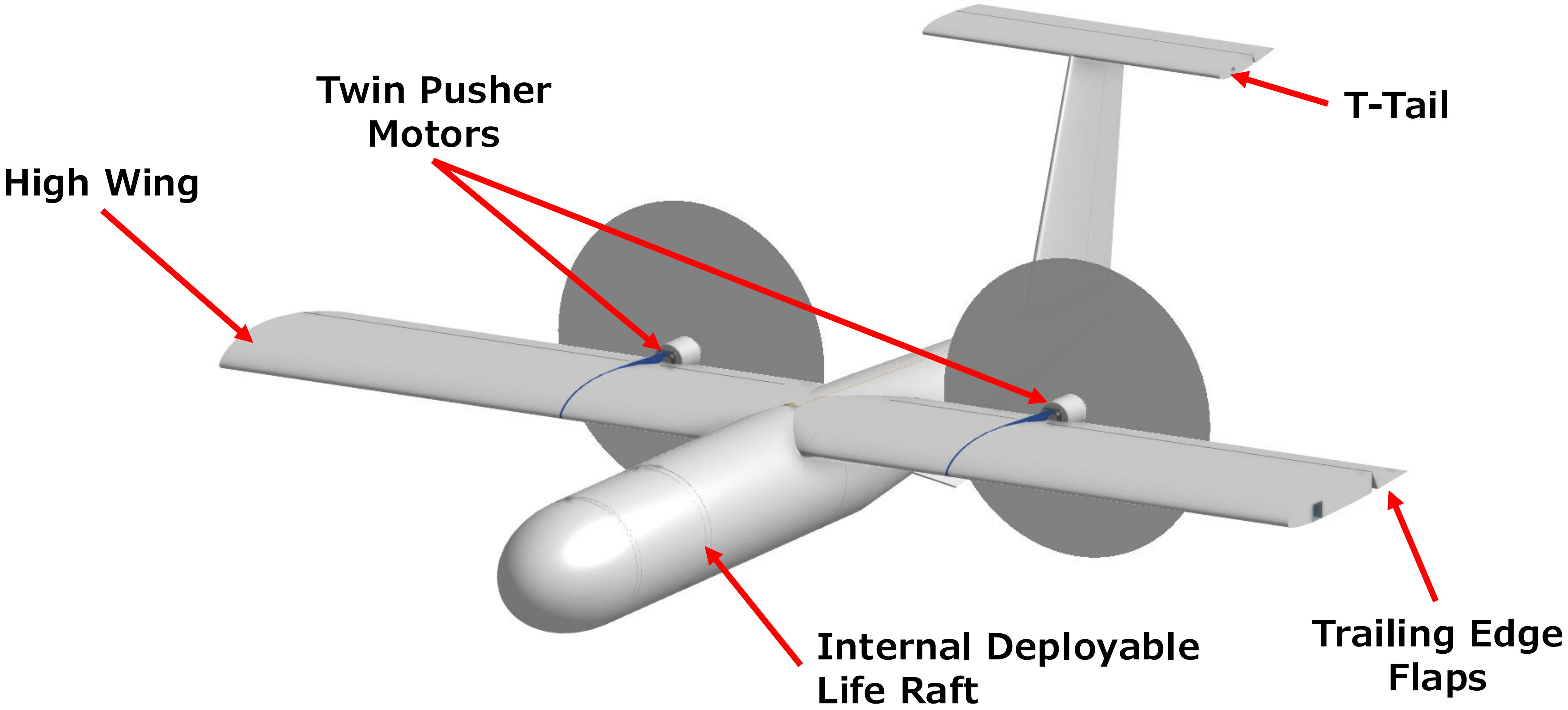
Project Calypso:
Maritime Search & Rescue

Critical Design Review

Design Overview



Team Introduction

Jacob McMillin
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Avionics 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 and aircraft sizing
- Validate design with wind tunnel testing
- 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- & 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
- Slow response driven by lack of rescue aircraft and poor readiness
- All phases of SAR require a significant manned presence

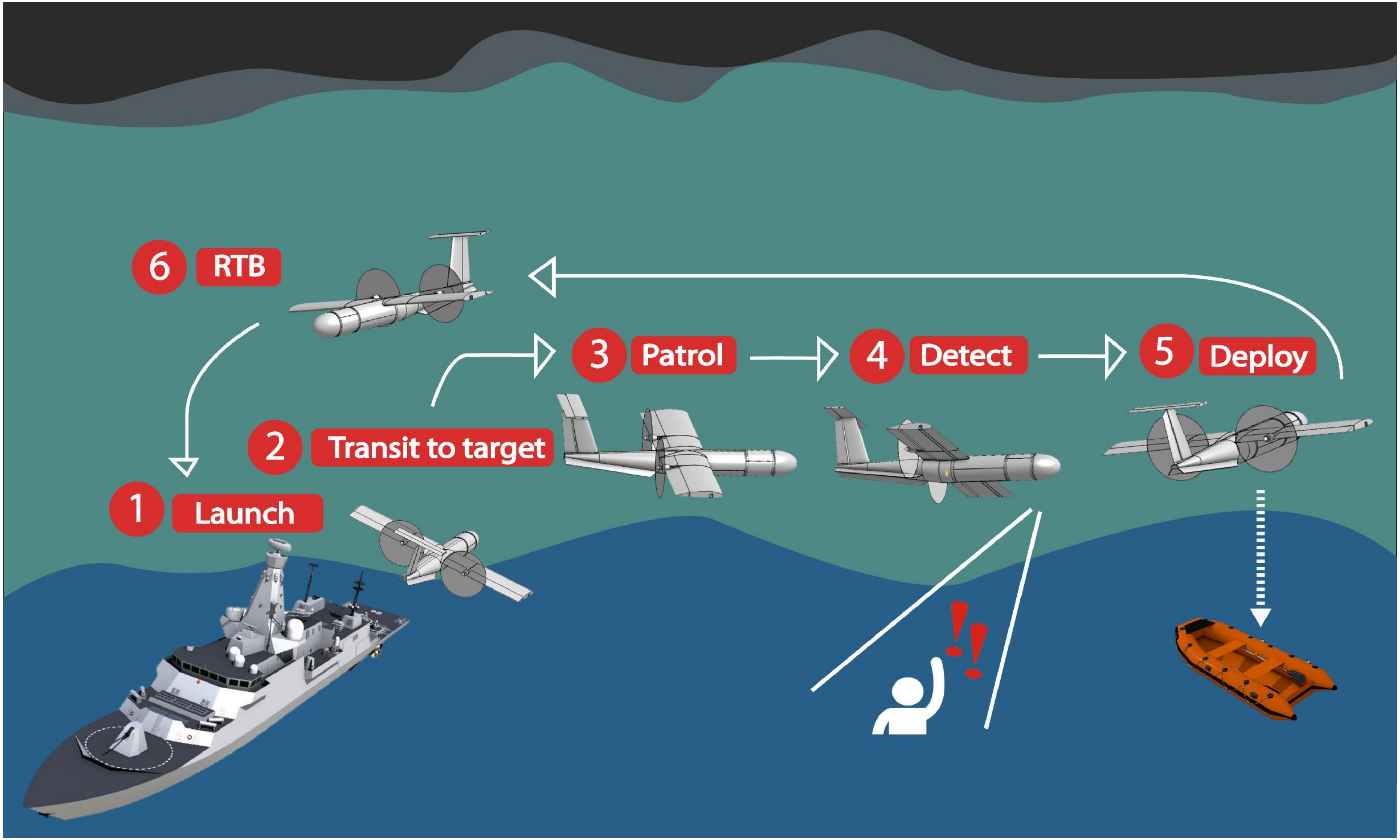
Manned Platforms are Limited in Rapid Response Search Missions

- 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 during search phase


6 RTB
3 Patrol
4 Detect
5 Deploy
2 Transit to target
1 Launch

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 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**
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 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 Fractions Driven by Performance Requirements

	Payload	Propulsion	Structural	MTOW
Weight Fraction	30%	38%	32%	100%
Weight, lb	10.5	**13.3**	11.2	35

Selected Design Point Minimizes Wing Loading and Provides Excess Power

Wing Loading

- 4.66-lb/ft^2
- 27 kts 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)**

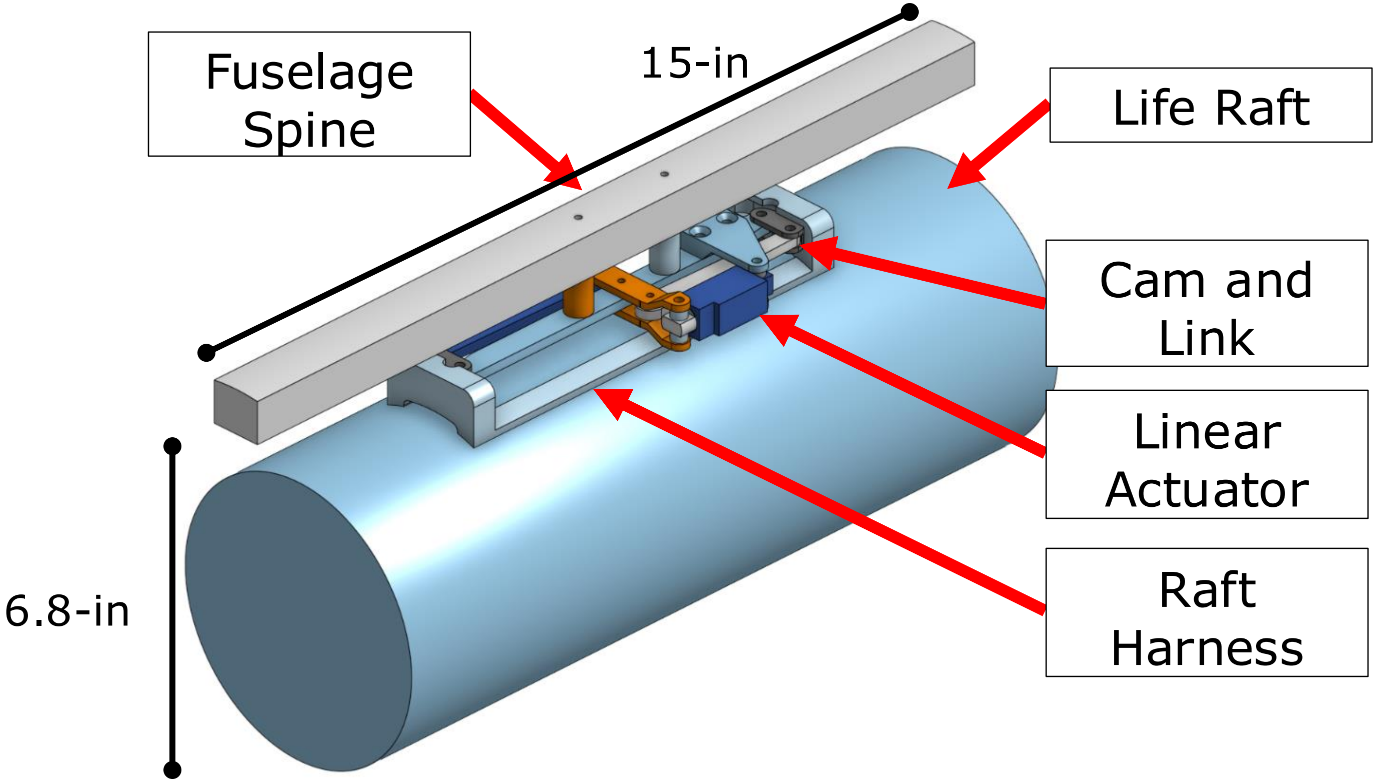
Modified Version of Off-the-Shelf Raft Meets Requirements

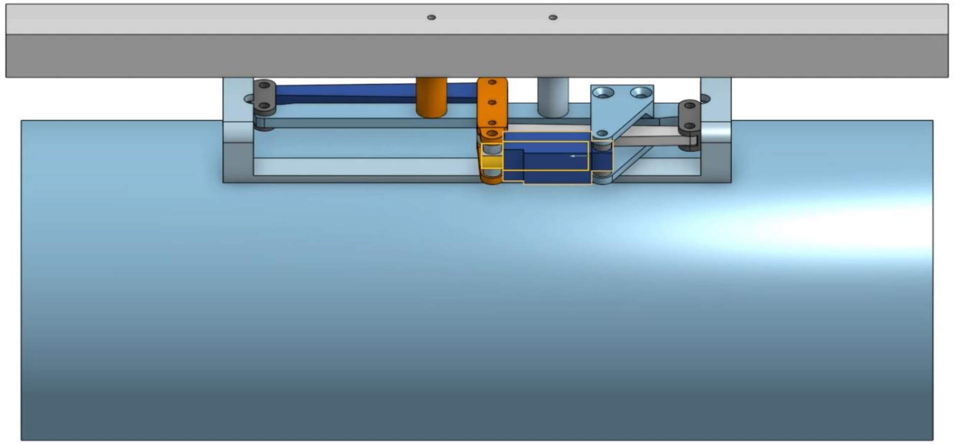
- Added ballast bags and CO_2 inflator
- 15-in long by 5.25-in diameter packed dimensions
- 5-lb weight
- 400-lb rated buoyancy

Life Raft Deployment System Must Meet Following Requirements

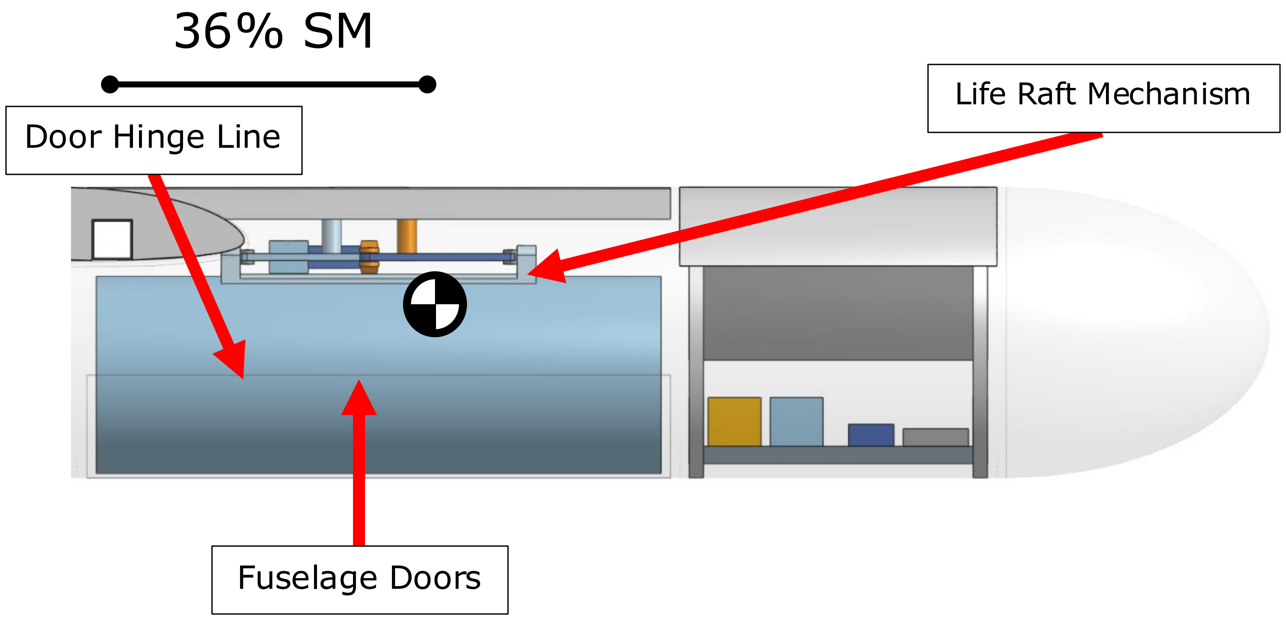
Item	Requirement
Maximum Weight	**1-lb**
Size	No more than 7-in diameter
Transmitter Channels	One
Deployment	**No effect on center of gravity**

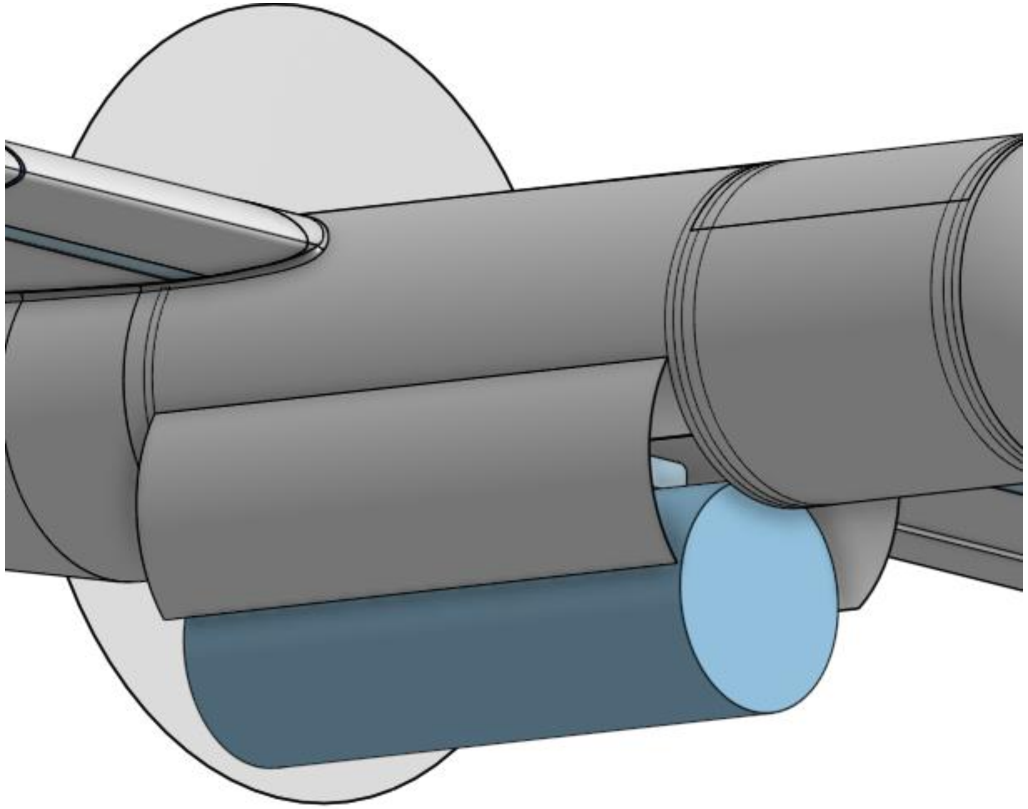
Life Raft Deployment is Simple and Lightweight





Raft Deployment System Fits Within Fuselage with Minimal Modifications





Spring-loaded doors open under the weight of the raft

Life Raft Deployment System Meets Requirements

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

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 17.5 NM
- Maintain communication during all phases of flight
- Transmit telemetry and video to operator

Pixhawk 4 Flight Controller Exceeds Derived Requirements

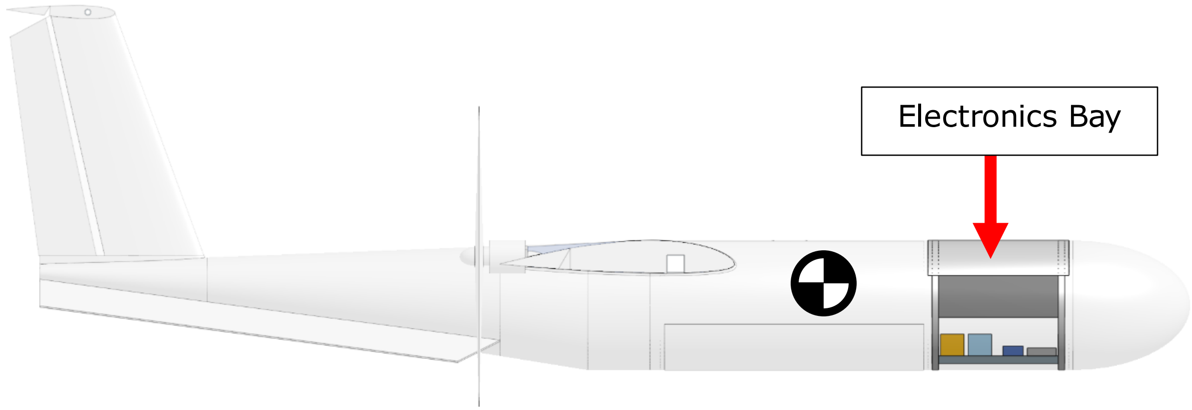
Parameter	Requirement	Specification
I/O ports	≥ 8	16
Cost	≤ $250.00	$190.00
Implementation	Easy to implement	Good availability, good documentation

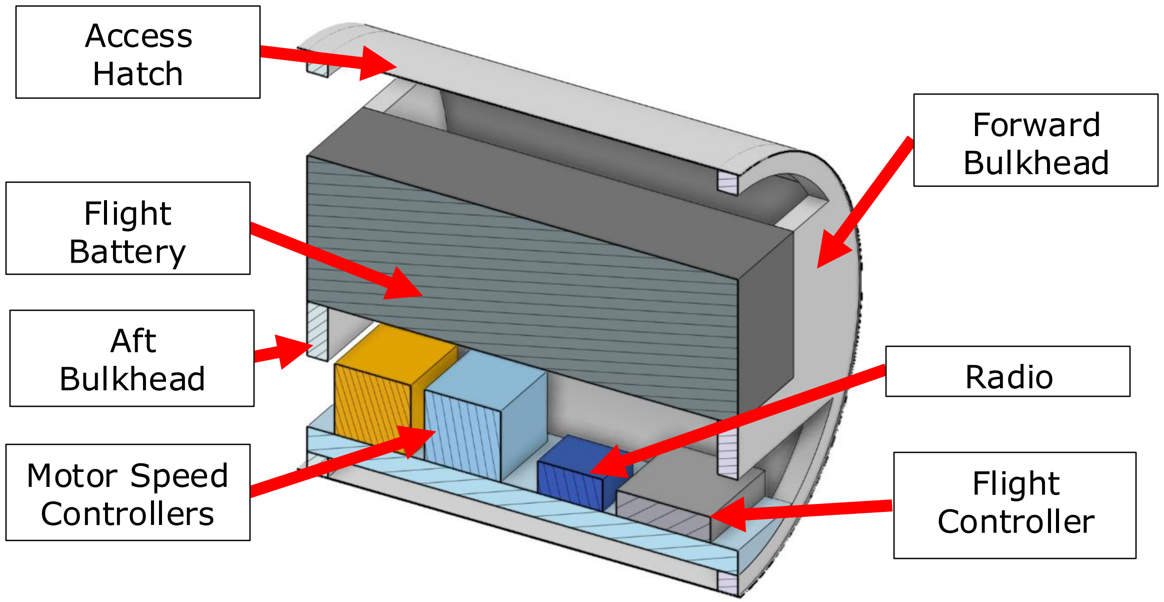
Commtact MDLS Meets All Communication Requirements

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

Electronics Bay Maintains Access to Components and Positive Margin

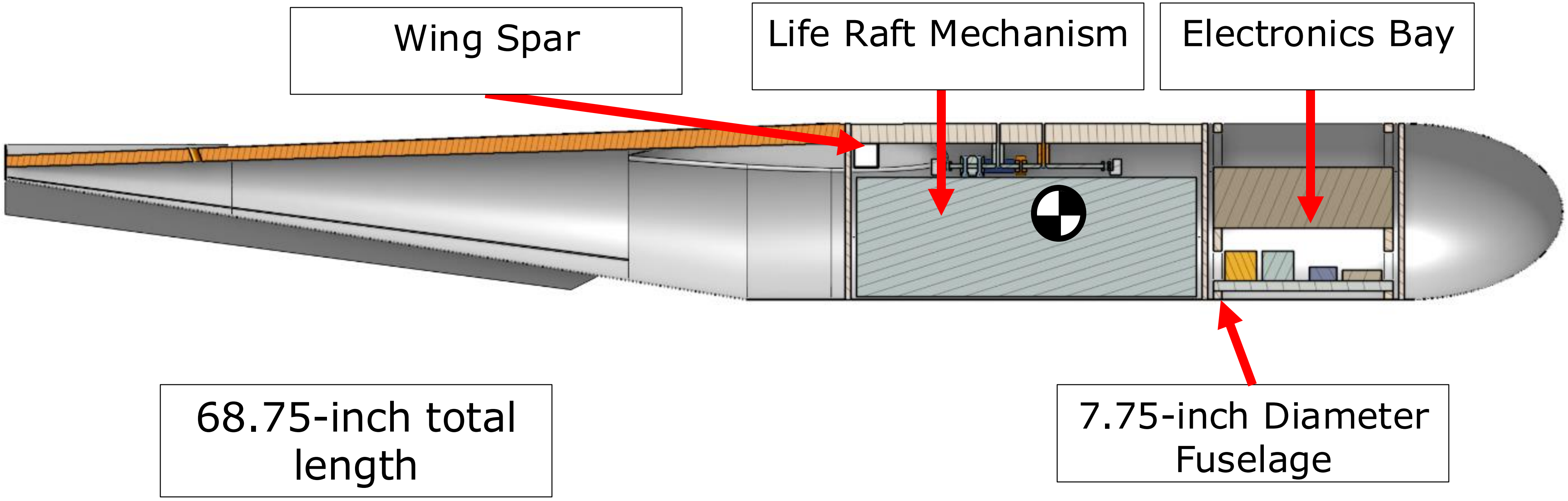
36% static margin before raft deployment, 39% after deployment





Structural Design

Fuselage Sized to Fit Life Raft Mechanism



Structural Loading and Spar Sizing

- Flight envelope and loading corresponds with CFR
- Maximum loads of 133 ft-lbs bending and 80 lbf shear at wing root
- 1-in square carbon spar with 0.035-in wall thickness selected using Tsai-Hill failure criteria
- 2.2 safety factor – 7.8 g max loading

Aircraft Structure Will Use Composites to Meet Weight and Loading Requirements

Aerodynamic Surfaces

- Spar-rib construction
- Carbon fiber molded skin
- Carbon fiber ribs

Fuselage

- Carbon fiber honeycomb fuselage spine and bulkheads
- Carbon fiber molded skin, nose is fiberglass for RF transparency

Structural Design Provides Sufficient Strength to Meet Requirements

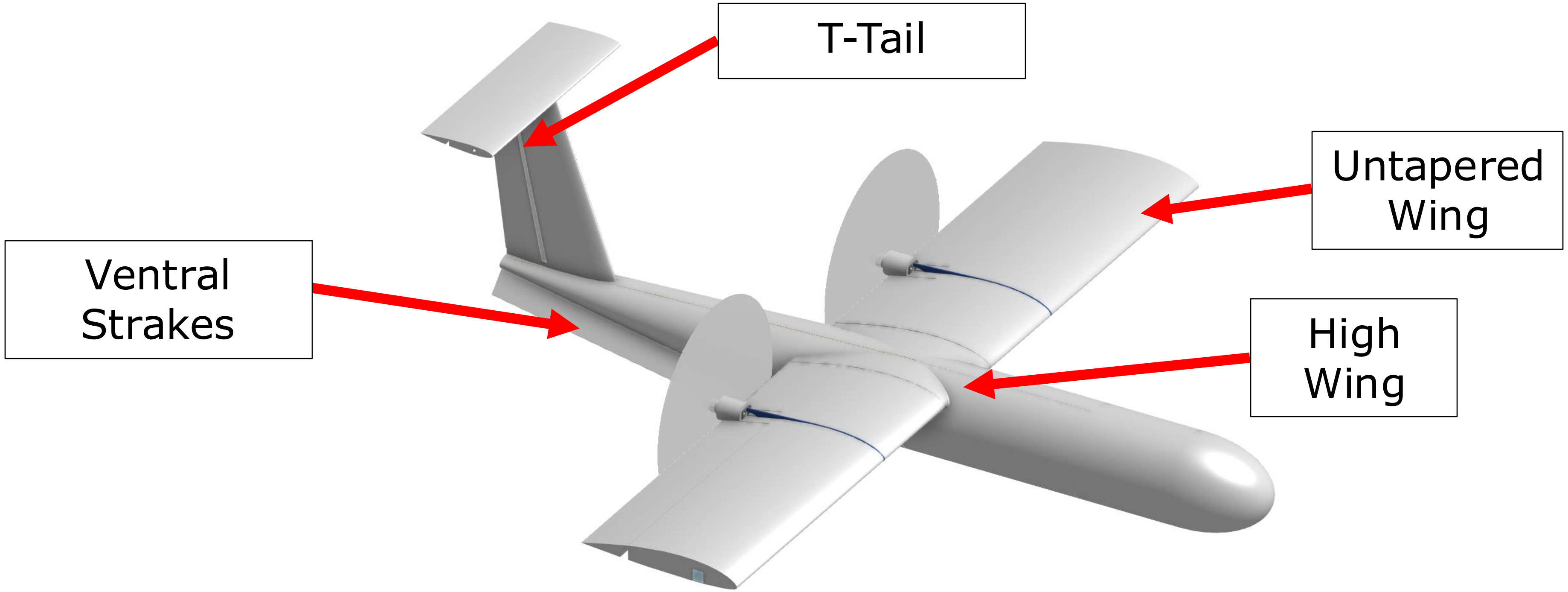
Parameter	Requirement	Design
Maximum g Loading	3.5 g	7.8 g
Life Raft Mechanism Support	Fully Enclosed	Fully enclosed
Static Margin	Positive before and after raft deployment	36% before, 39% after

Aerodynamic Design

Aerodynamic Configuration Driving Requirements

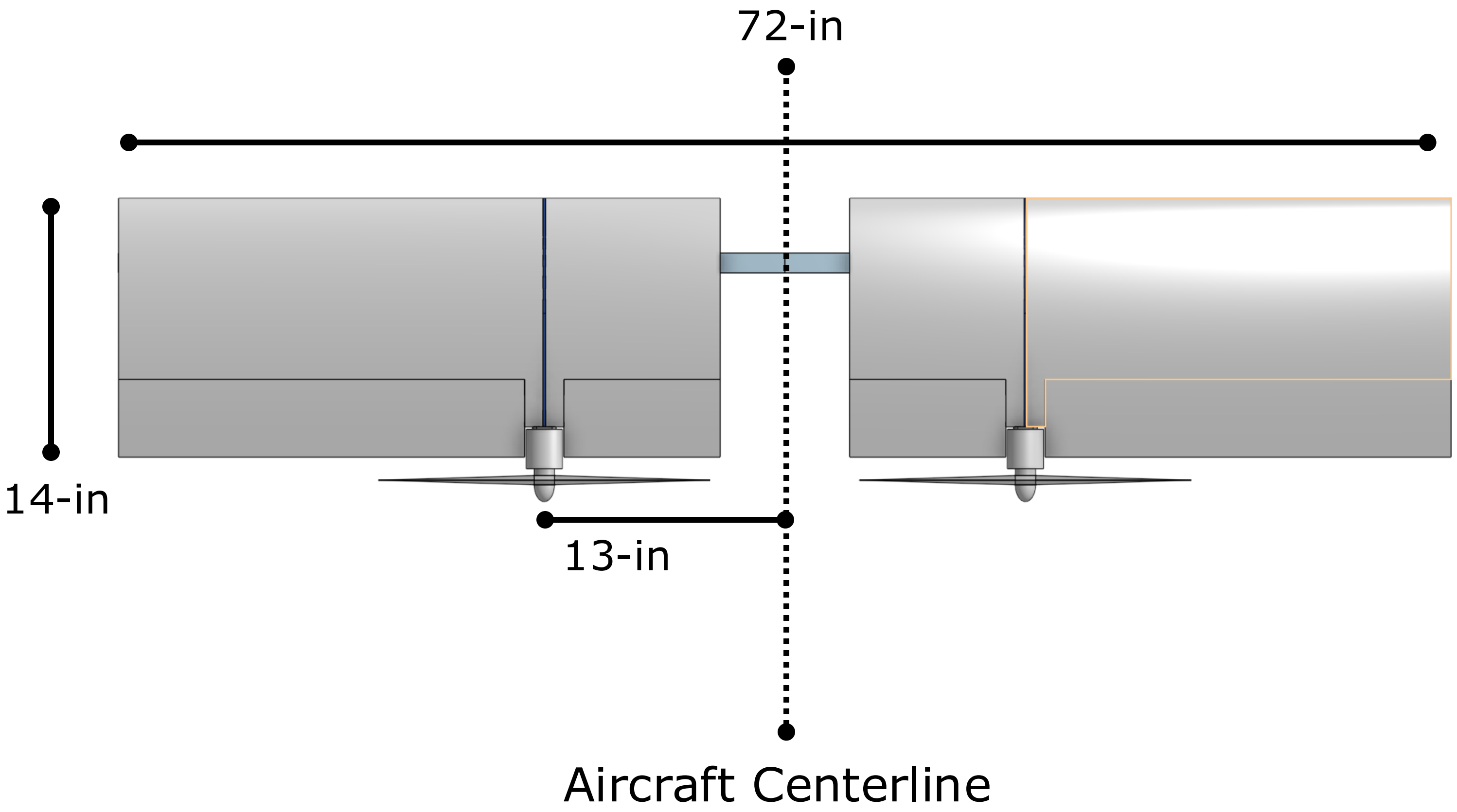
Parameter	Requirement
Operating Altitude	Sea level to 400-ft ASL
Environmental Conditions	Beaufort Force 7 (28-33 kts winds)
Minimum Dash Speed	100 kts

Configuration Determined from Wind Tunnel & Trade Studies



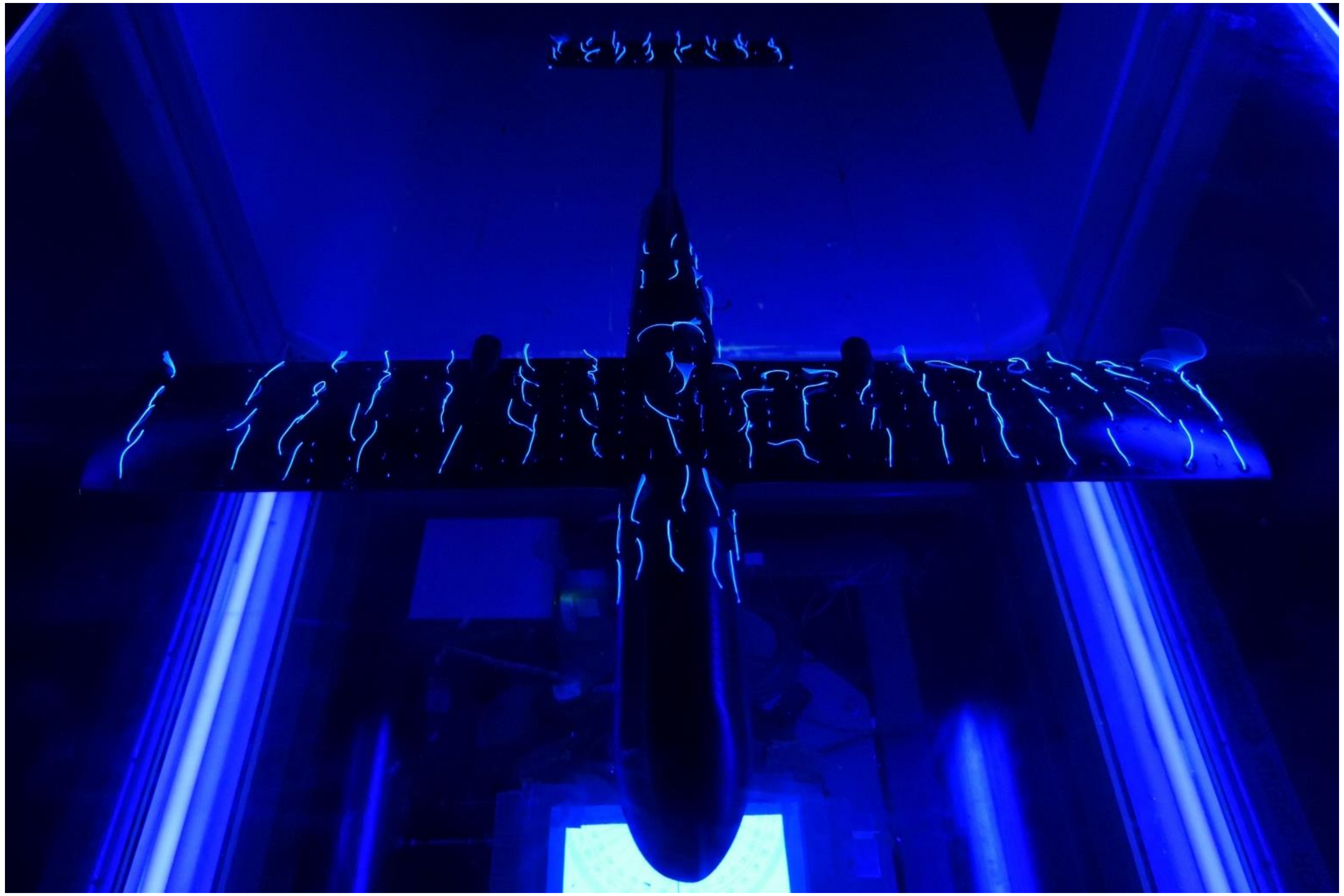
- Overall Length : 68.75-in
- Wingspan : 72-in

Aerodynamics of Wing



Parameter	Value
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

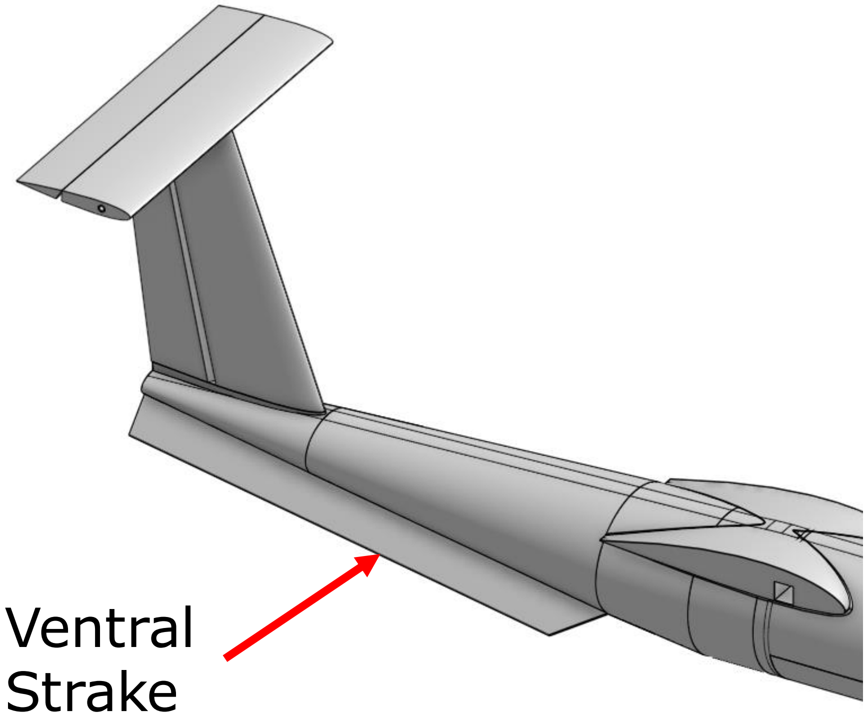
Aircraft Aerodynamic Performance Meets Mission Criteria



Parameter	Value
Wing Area (in^2)	1008
Airfoil	MRC-16
Stall speed (ft/s)	**45**
Wing loading (psf)	**4.464**
C_L Max	1.20, 16° AoA
C_L/C_D Max	**13.49, 7° AoA**
Whole Aircraft C_{D0}	0.029
Whole Aircraft Cruise C_D	**0.047**

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_D ($\beta=10°$, $\alpha=10°$)	0.0847	0.0916



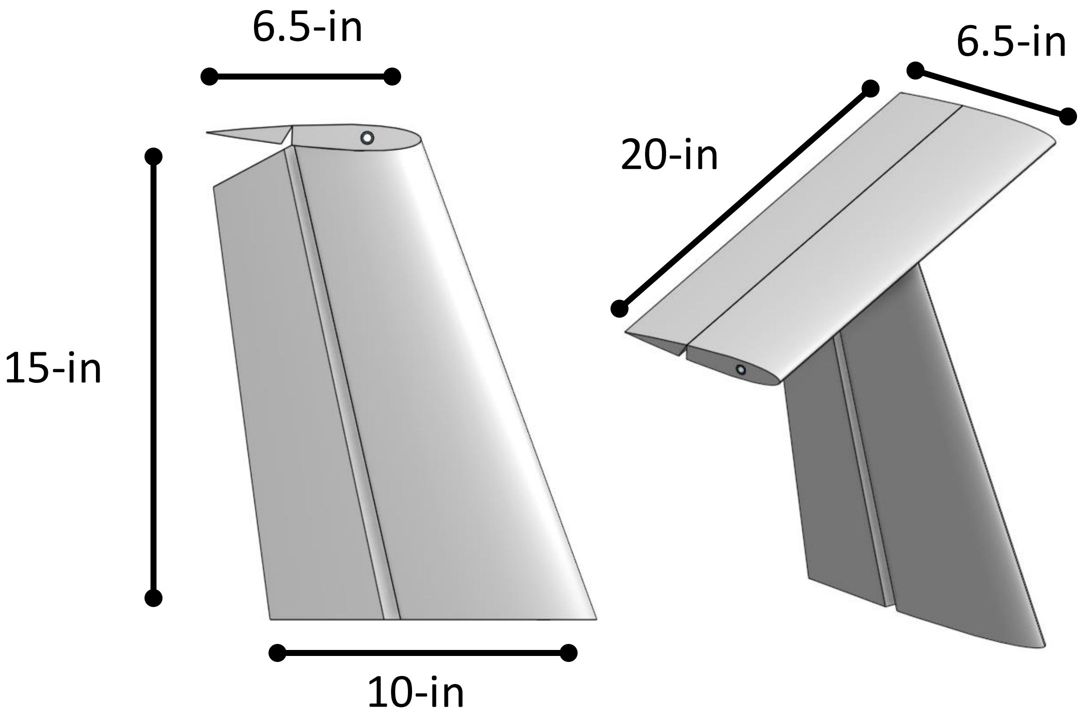
Empennage Airfoil and Configuration

NACA 0012

- Symmetrical airfoil
- Vertical Tail Coef. = 0.072
- Horizontal Tail Coef.= 0.387

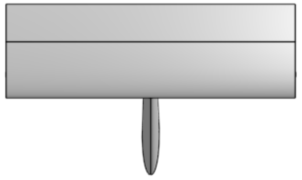
T-Tail

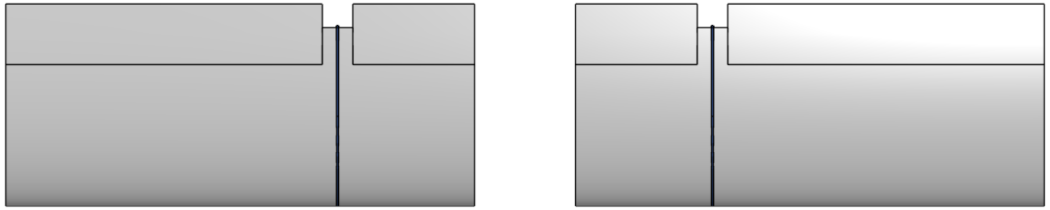
- Less prop interference
- Ease of future modification
- Control surface mounting



Control Surface: Ailerons & Elevator

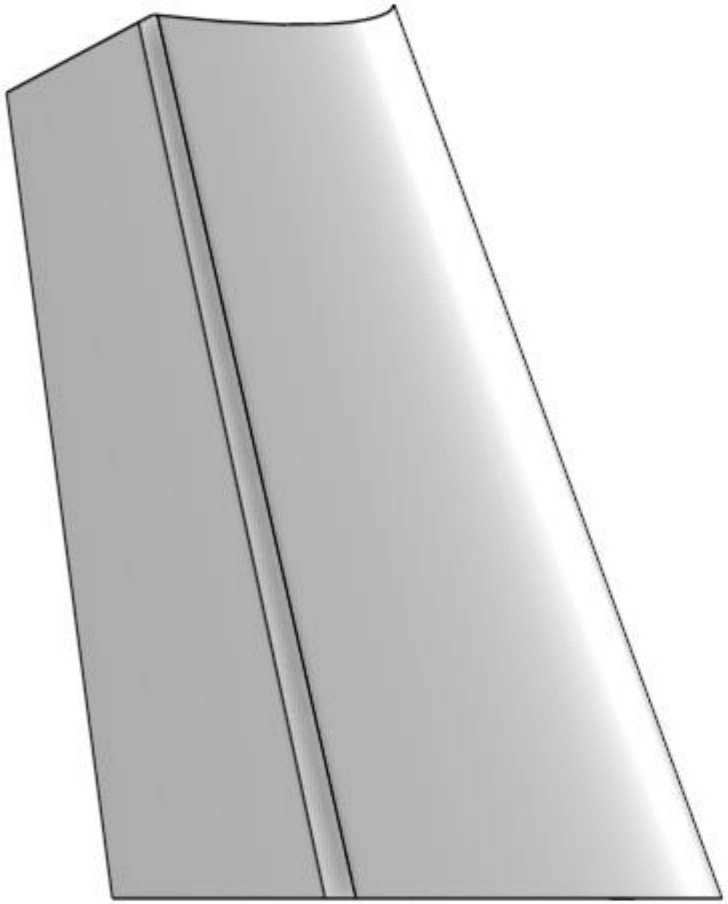
Control Surface	Length	Width	Effectiveness (τ)
Ailerons	55% to 100% of wing	30% of chord	0.54
Elevator	Full Span	40% of chord	0.60





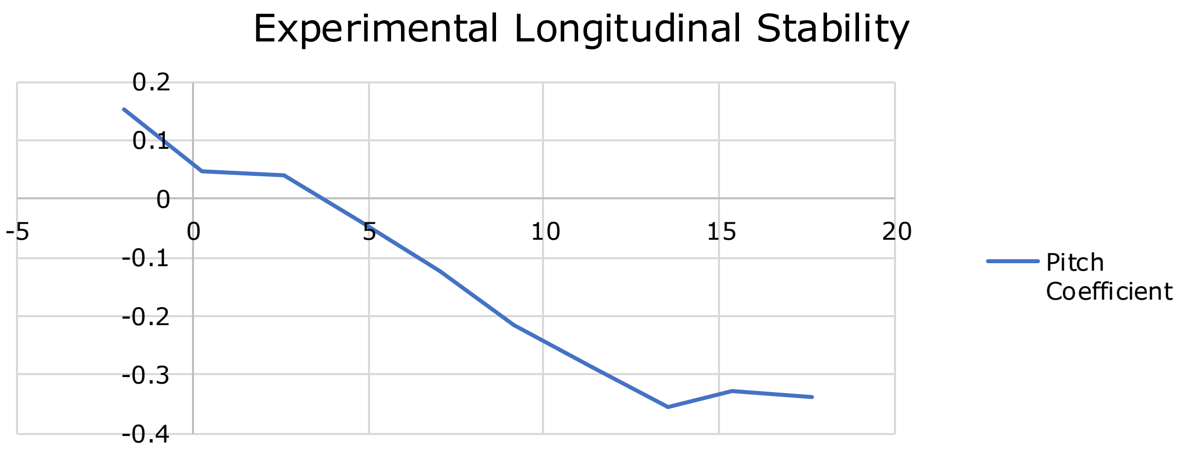
Control Surface: Rudder

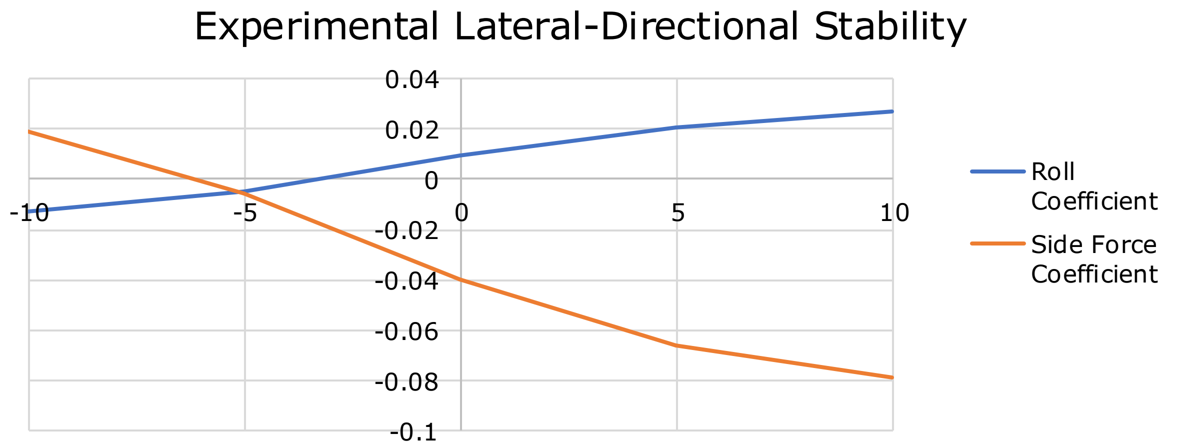
Control Surface	Length	Width	Effectiveness (T)
Rudder	90% Span	40% of chord	0.55



Simulations and Testing Agree that Aircraft is Stable

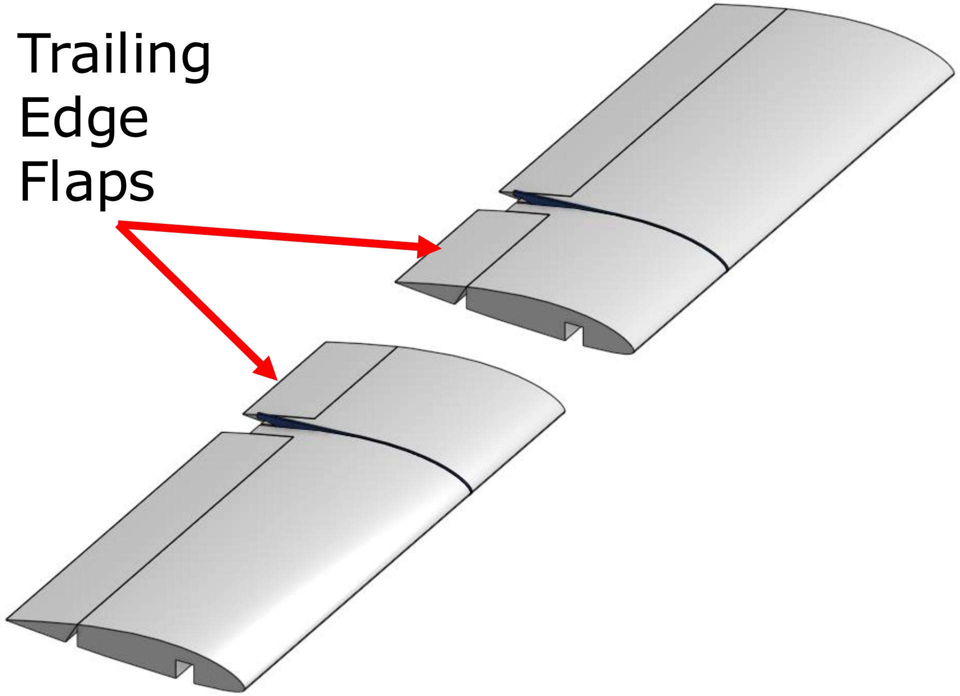
Simulation Type	Stability	Damping Ratio
SPPO	Stable	0.283
Phugoid	Stable	0.056
Roll Mode	Stable	~
Dutch Roll	Stable	0.060
Spiral Mode	Unstable	~





Trailing Edge Flaps Selected

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



- Ailerons act as flaperons
- Provides C_L Max = 1.42

Propulsion

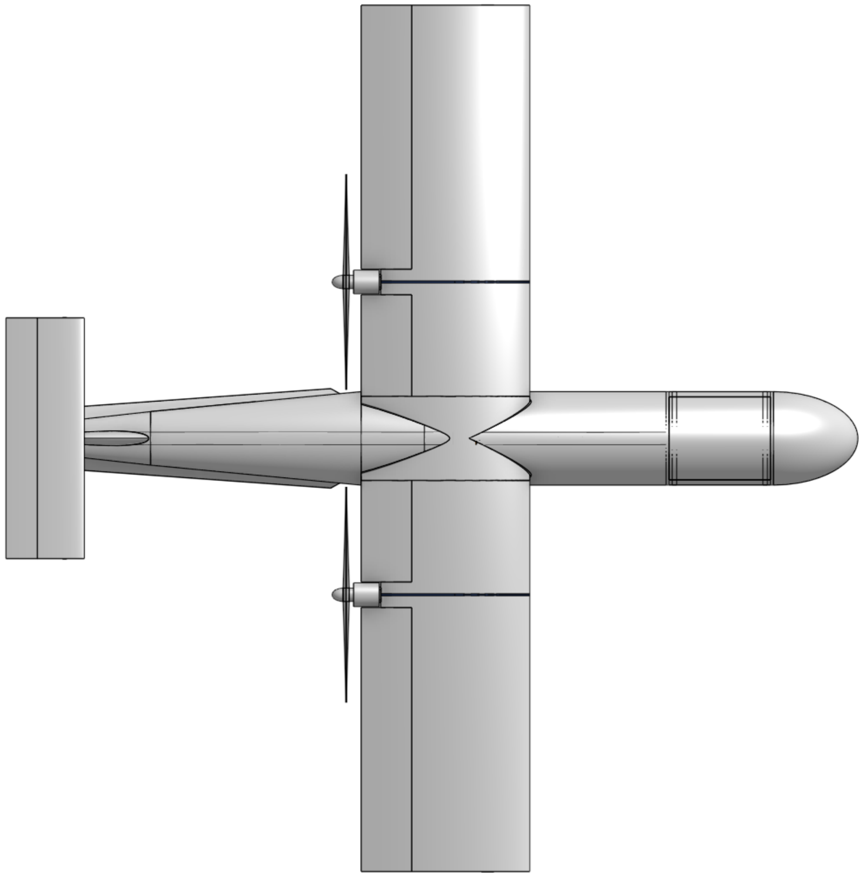
Requirements Which Drive Propulsion Configuration

Parameter	Requirement
Minimum endurance	**90-min**
Minimum power	175-W/lb, or 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 and Packaging Requirements

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

- Twin motors reduce thrust moment and simplify packaging

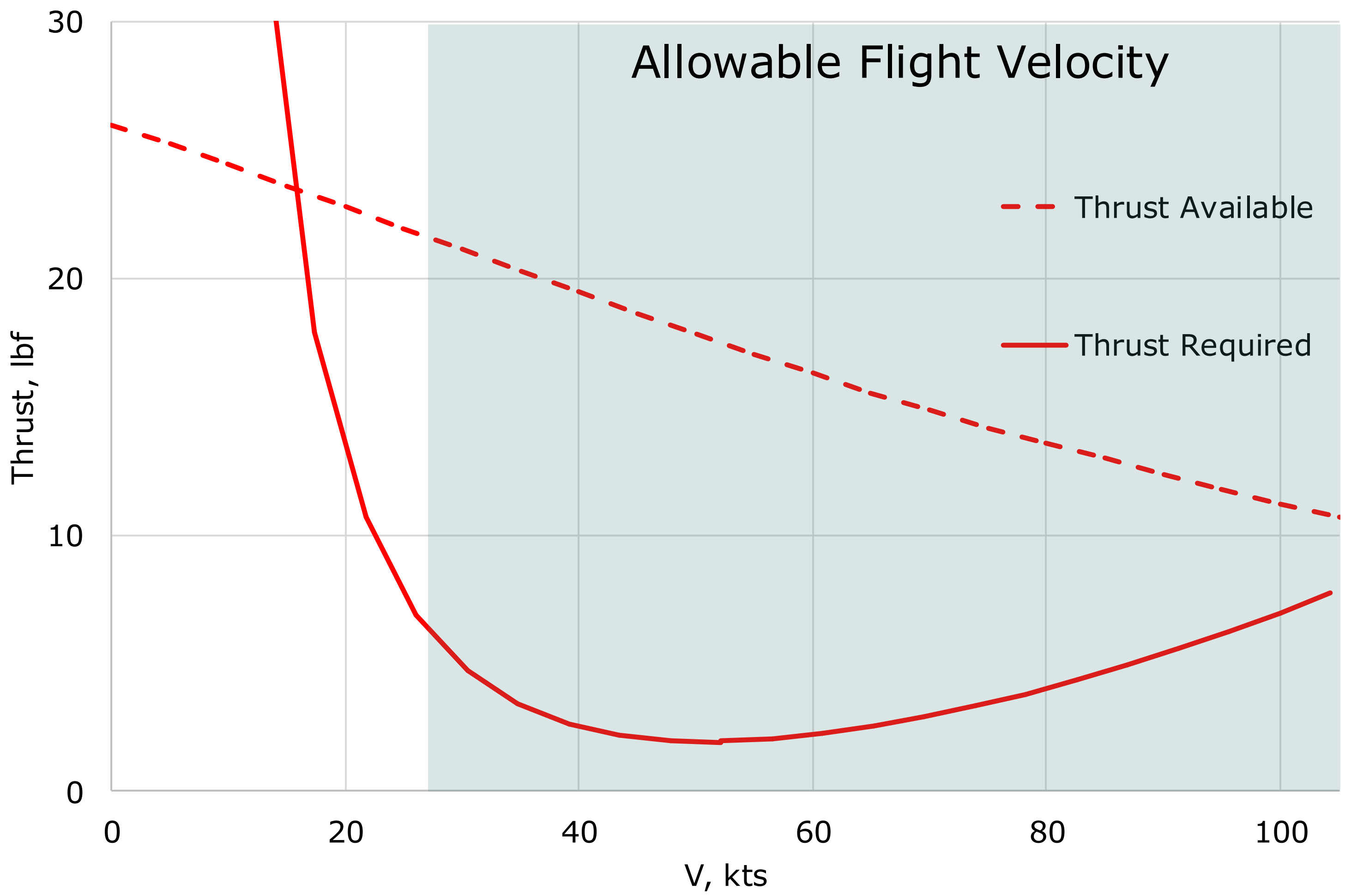


Selected Propellers Allow for Flight at 100-kts

- 18-in diameter propellers with 12-in pitch are sufficient to meet cruise speed requirement of 100-knts
- At 10,000-RPM at 100-kts, generate 9.74-lbf of thrust, greater than the 7.72-lbf of drag generated

Propulsion Configuration Produces Excess Thrust at All Flight Speeds

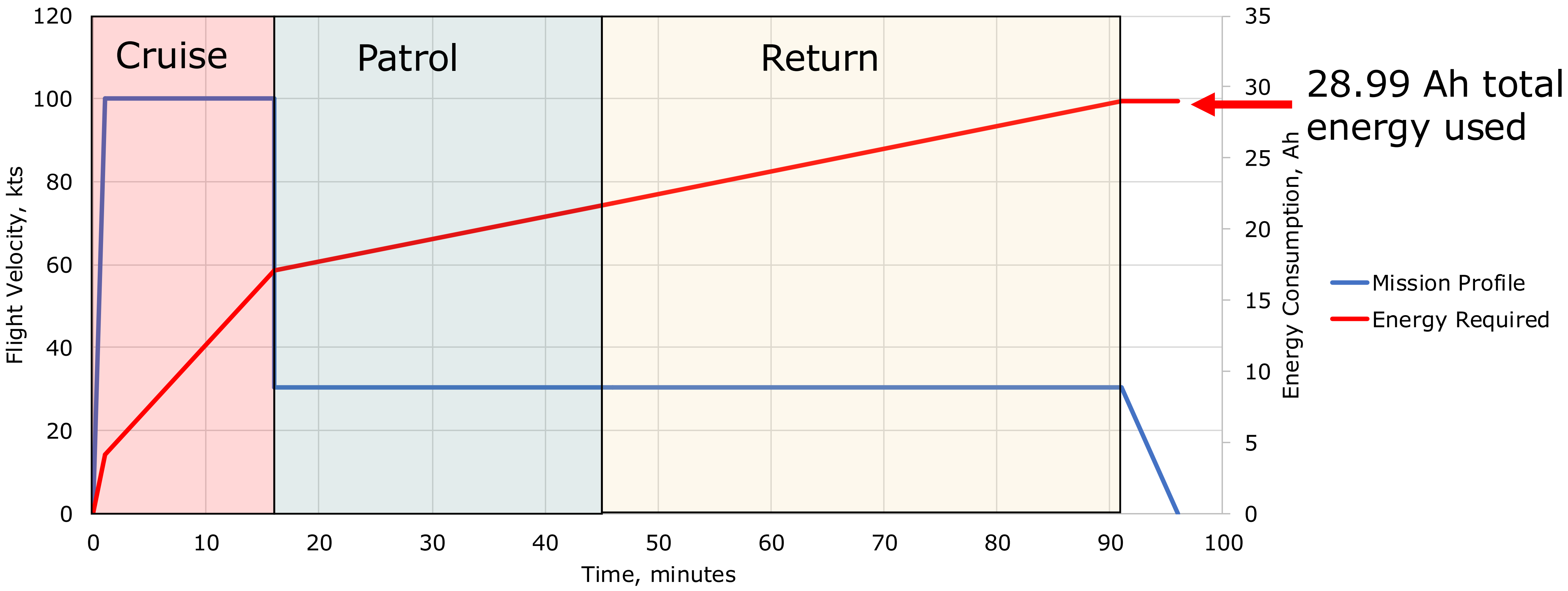
- Net thrust generated from 17-100 kts
- Takeoff speed limited by aerodynamics, not propulsion



Propulsion Configuration Meets Performance Requirements

Parameter	Requirement	Design
Motors	N/A	2x Sunnysky X4125 V3 480-kV
Propeller Protection	Avoid damage from wire or net recovery	Propellers behind wing
Minimum Service Interval	>3 months	Unlimited with battery trickle charging
Propulsive Power	≥5,500 W	5,500 W
Motor Max RPM	10,000 RPM	10,500 RPM
Minimum Thrust	7.72 lbf @ 100 kts	9.74 lbf @ 100 kts
Maximum cruise speed	100 kts	108 kts

Energy Required Primarily Driven by Cruise Phase Speed



Selected Battery Configuration Provides Sufficient Energy

Parameter	Specification
Energy Required	28.99 Ah
Total Energy	30 Ah
Energy Margin	3.50%

Battery Configuration Meets Performance Requirements

Parameter	Requirement	Design
Minimum Endurance	90 minutes	3.5% margin for 90-minute mission
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

Launch and Recovery

Design Requirements Drive Launch & Recovery System Selection

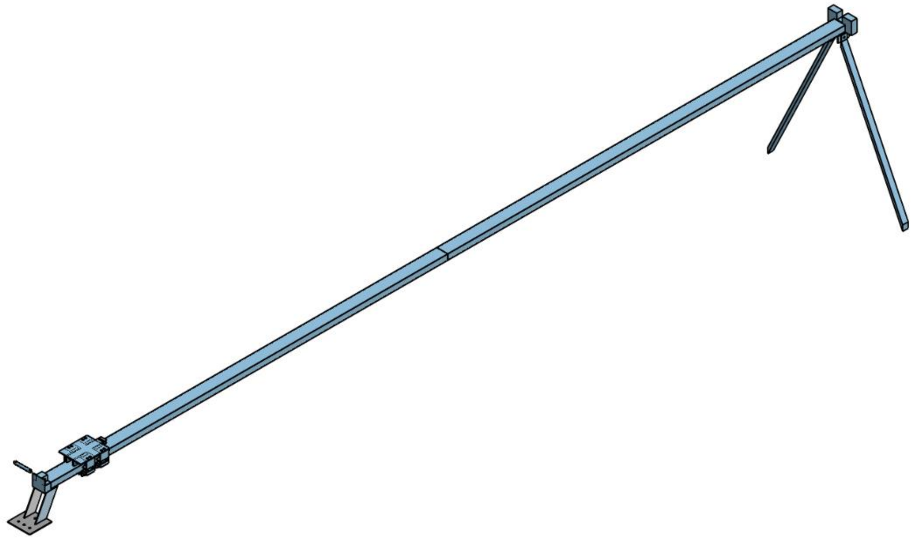
Parameter	Requirement
Maximum Load Factor	3.5 g
Aircraft Weight	**35-lb**
Launch Platform Size	**4 ft x 4 ft platform**
User Input	**Autonomous**
Launch Energy	**>975 ft-lbs**
Aircraft Takeoff Speed	45 ft/s

Elastic Launch System Best Fits Project Needs

Elastic Launch System

- Silicone rubber cables
- Launch cart on linear rail

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

Cable Recovery System

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

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 Test Article

Fabrication of Flight Test Article is Not Identical to Design

Propulsion

- Lower capacity battery(6 Cell 10000mAh Lipo)
- Lower pitch propellers(18x10 Propellers)

Structures

- Lifting surfaces vacuum formed fiberglass incased foam
- Fuselage molded with fiberglass/honeycomb

Flight Test Article will be Constructed to Validate Final Design

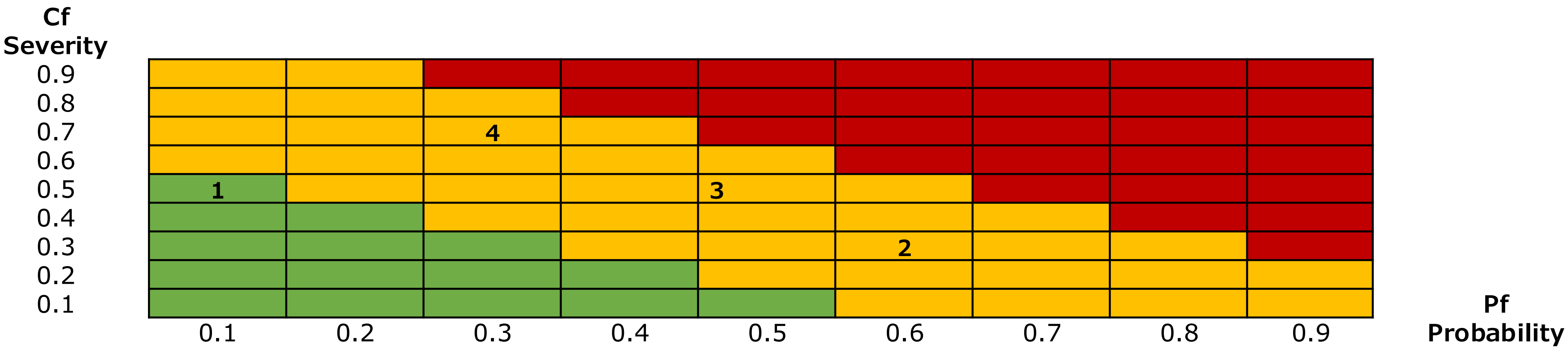
- Extrapolate endurance time and top speed
- Confirm take off distance and catapult functionality
- Demonstrate payload deployment mechanism

Flight Test Article Risks

- Complex fuselage design causing fabrication delays
- Vacuum forming fiberglass over foam may deform airfoil profile
- Belly landing may cause irreversible damage to fuselage and propellers
- Budget and Supply Chain when sourcing parts

Risk Assessment & Budget

Risk Assessment



1. Business closure/supply chain issues prevent FTA construction
2. Catapult does not work as intended; conventional take-off necessary
3. Damage to flight test article before testing is complete
4. Piloting inexperience results in airframe loss in high wind conditions

Risk Mitigation

Risk 1: Supply Chain Issues

- Most parts required for the FTA have already been acquired
- No specialty parts have been specified with limited availability

Risk 2: Conventional Take-Off

- Design has sufficient power to fly with additional drag from landing gear
- Design can be retrofitted with main gear under the wing and in the nose if necessary
- Preliminary FTA verified conventional take-off is possible

Risk Mitigation Continued

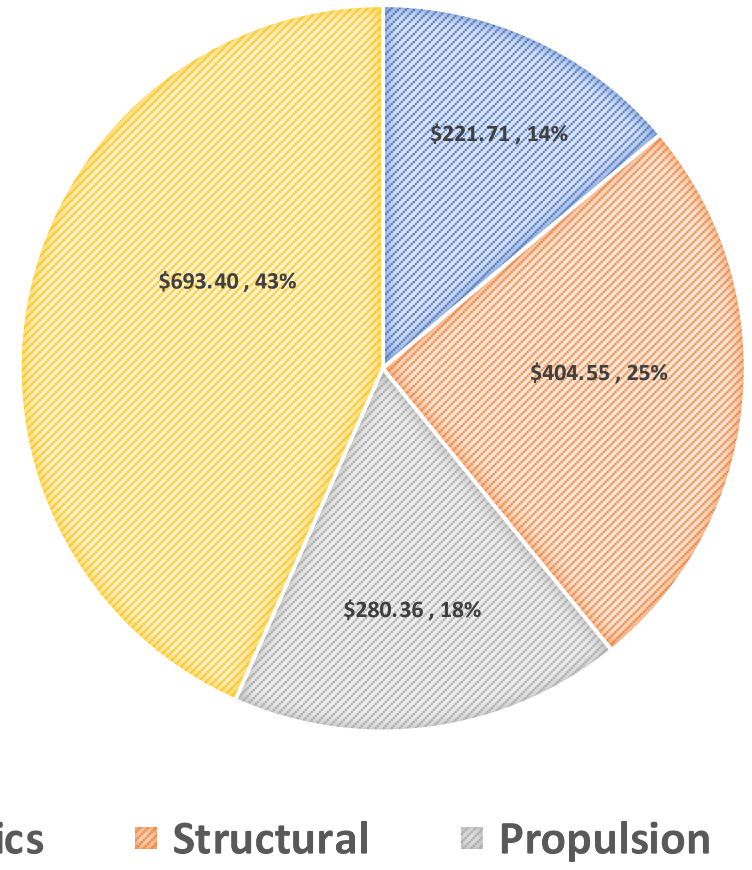
Risk 3: Damage to Flight Test Article

- Recovery will use a net to minimize landing damage
- Aircraft will be reinforced with Kevlar at wingtips, nose, tail to accommodate belly landing
- Additional propellers will be ordered so that a breakage will not interfere with testing

Risk 4: Test Flight Wind Conditions

- Testing will be scheduled for days with low wind
- Aircraft implements a flight controller for active stability

Project Calypso is Meeting Requirements and Predicts to Deliver On-Budget



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	100-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-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	31.25-lb

Calypso Team Recommends to Move to Detail Fabrication Phase

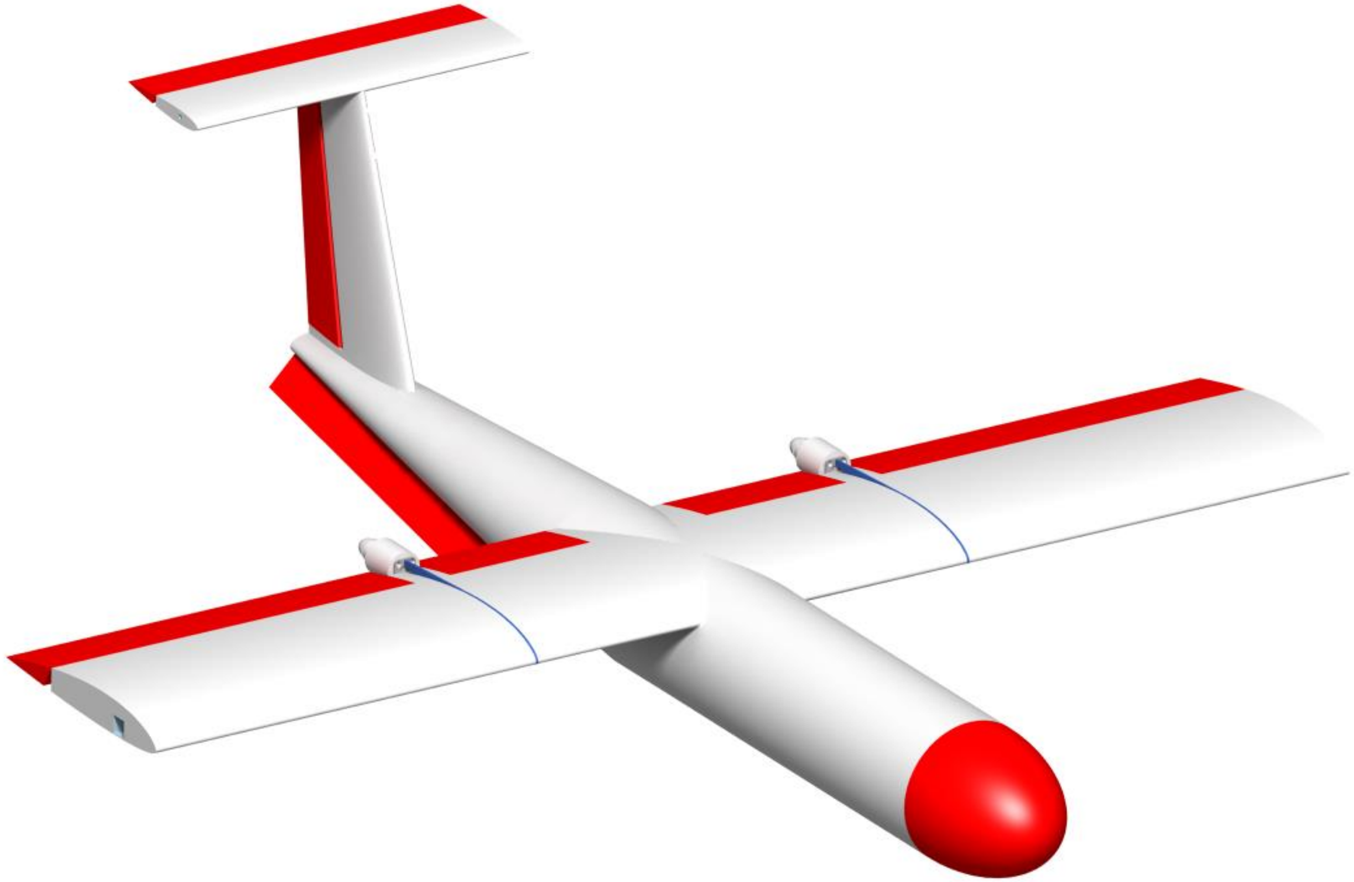
Design satisfies critical design requirements

Wind tunnel testing has verified design features

Construction of detail flight test article can begin

- Final validation of aerodynamics and flight performance
- In-field testing of raft deployment

Questions?

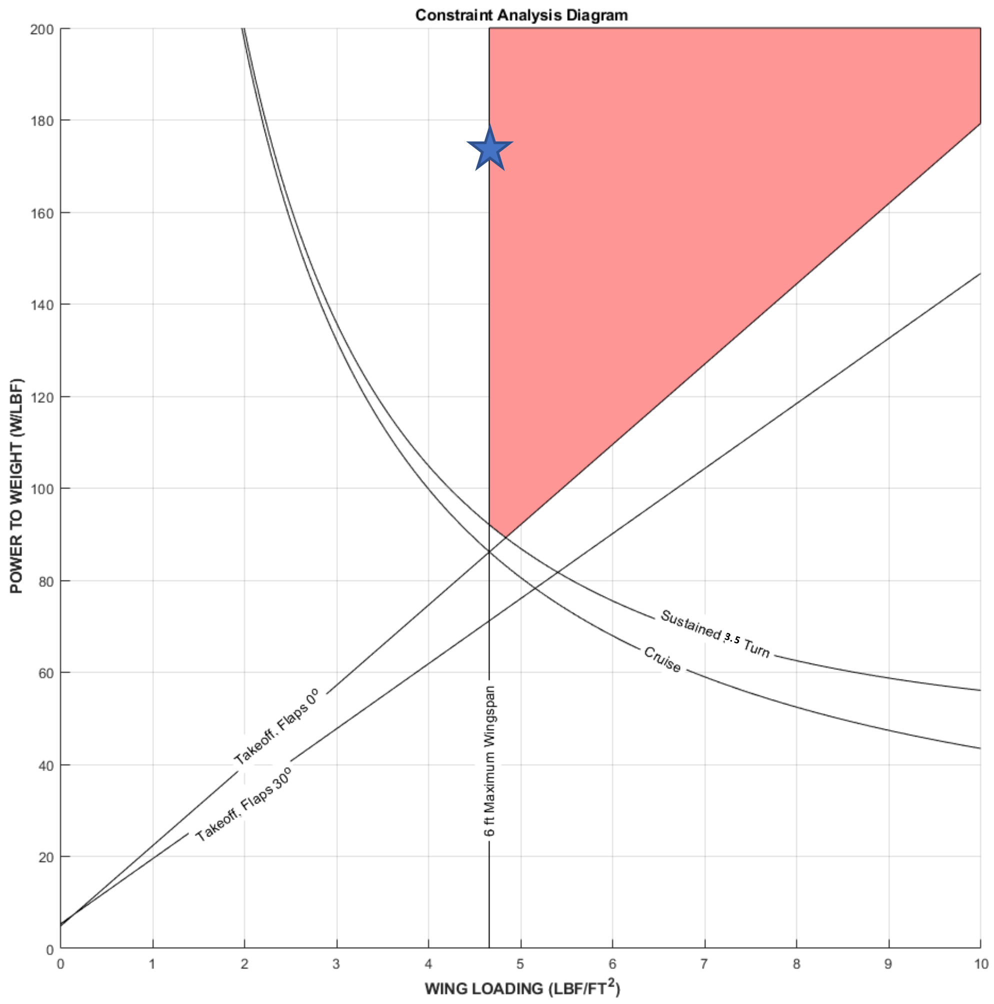


Appendix

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	

Calypso

Wing Configuration Trade Study Tables

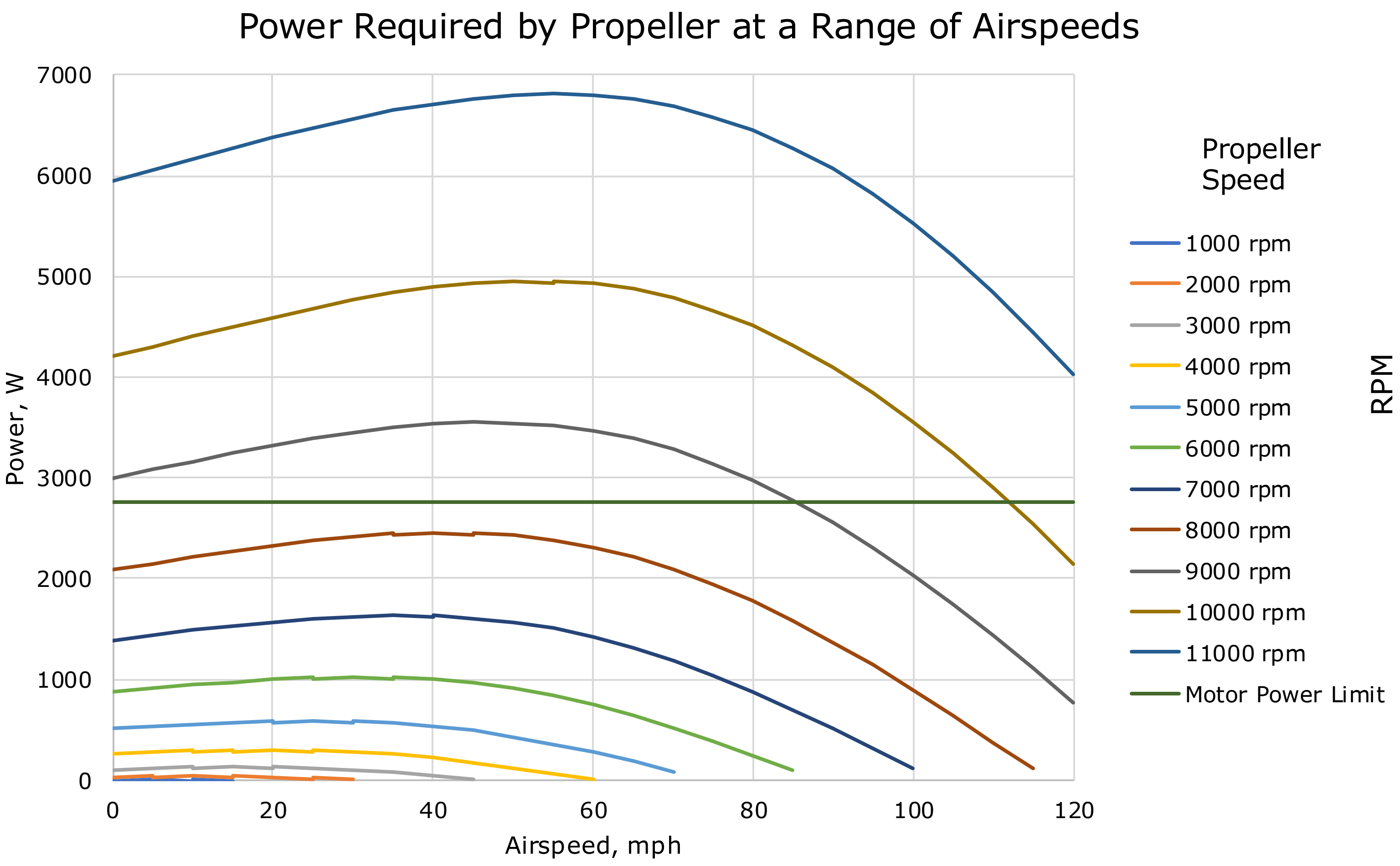
Wing Configuration						
	Regtangular	Tapered Straight	Sweptwing (low speed)	Elliptical	Rear Wing Canards	Score Factor
Stablity	5	3	3	4	2	4
Lift	4	4	4	3	4	4
Drag	1	4	3	4	3	3
Manueverability	3	3	2	3	3	3
Fabrication	4	4	2	1	3	2
Structural Weight	2	3	3	3	3	2
Totals:	60	63	53	57	54	

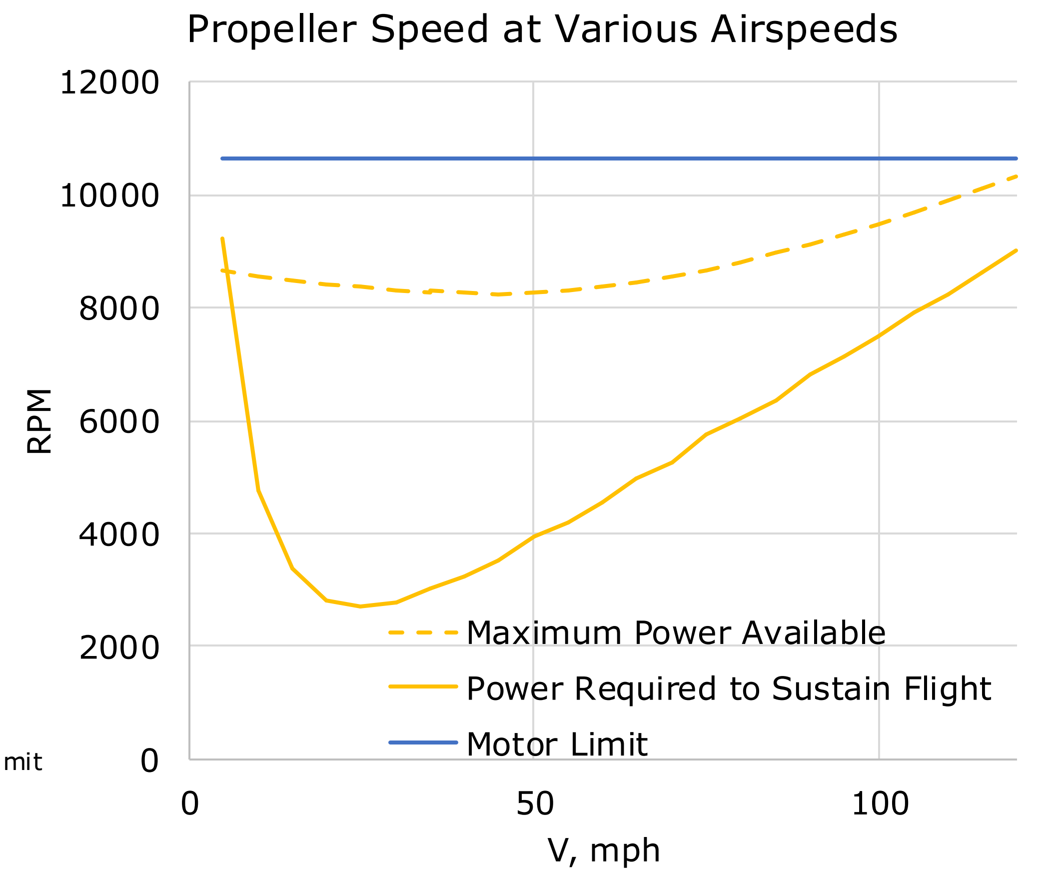
Wing Location				
	High	Mid	Low	Score Factor
Roll and Stablity	4	4	3	4
Tail Interference	3	3	4	2
Manueverability	3	4	4	2
Cruise	3	2	3	2
Payload	4	2	4	3
Stall Characteristics	4	5	3	4
Totals:	62	60	58	

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





Calypso

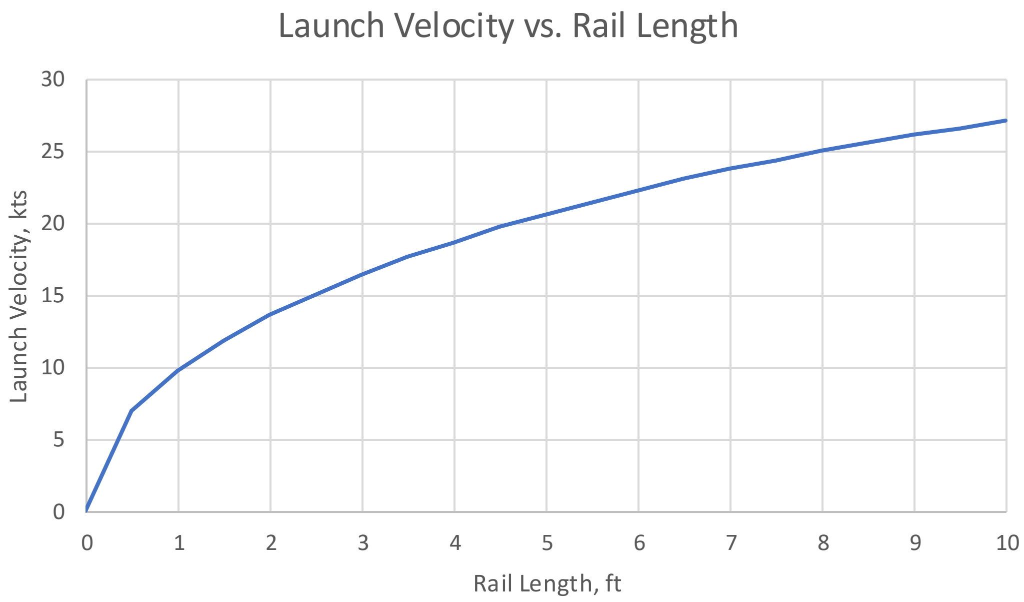
Catapult Performance

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

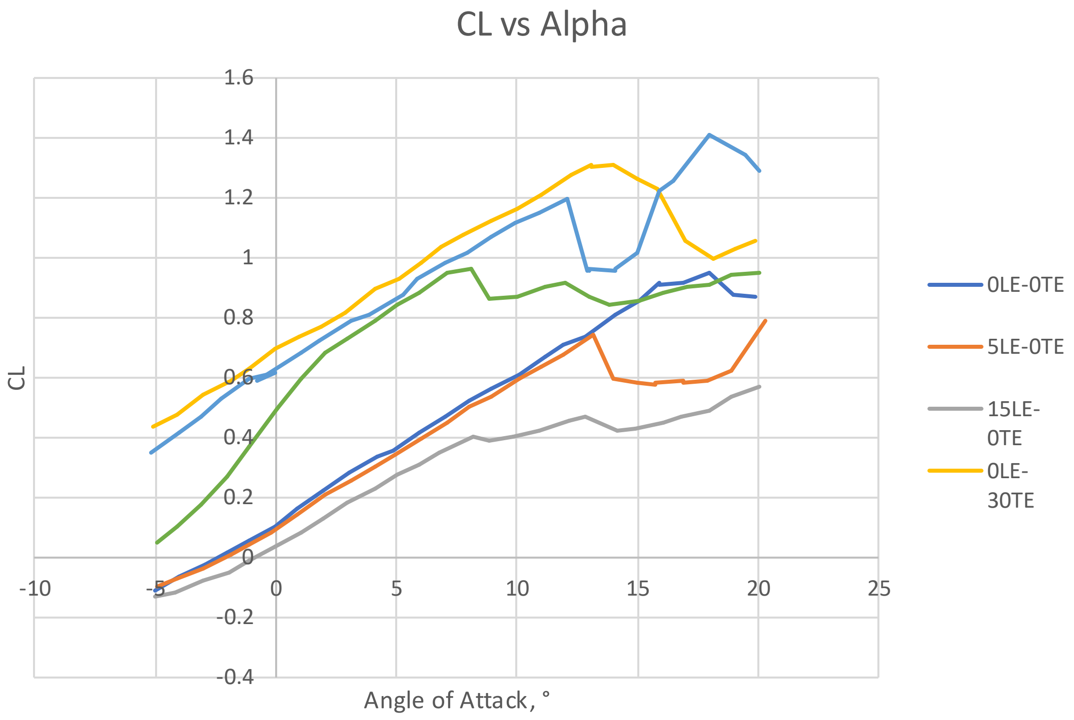
Launch Velocity: 27.1 kts

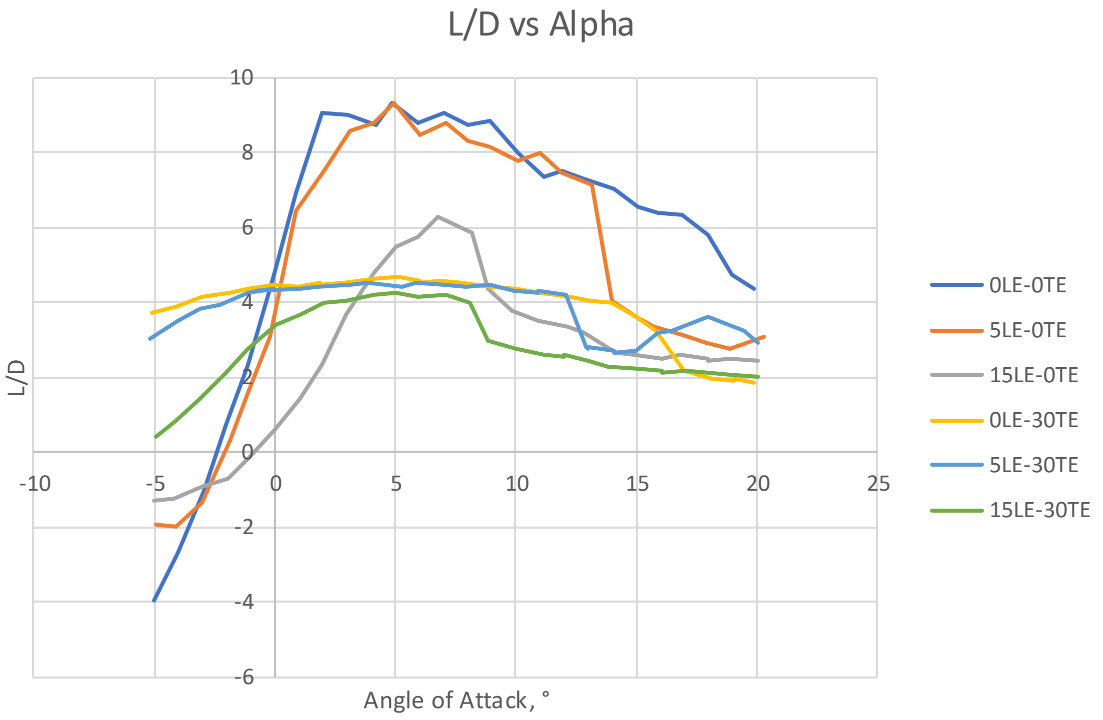
Avg g-load: 3.3

Maximum Energy: 975 lbf-ft



Wind Tunnel Test Data – Mechanized Wing





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40-41	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
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Figure References

Slide #	Item	Source
5	Render Background	Link
7	MH-65 Dolphin Helicopter	Link
18	Uncharted Supply Co. Rapid Raft Outdoors	Link
25	Pixhawk 4 Flight Controller	Link
26	Commtact MDLS Radio Communications	Link
31	Wire Recovery of Boeing ScanEagle	Link
47	APC 18x12e Propeller	Link
51	Liperiair 30,000 mAh Battery	Link