Project Calypso

Design Concept Review

Team Introduction

Joshua Carver
Program Manager

Ryan Lundell
Airframe Lead

Jacob McMillin
Integration Lead

Caleb Lynch
Systems Engineer

Anthony Mclevsky
Avionics Engineer

Khaled Alhammadi
Propulsion Engineer

Tyler Phillips
Structures Engineer

Marcello Montes
Aerodynamics Engineer

Presentation Objectives

Introduce aircraft use case & mission

- Identify design-driving mission requirements

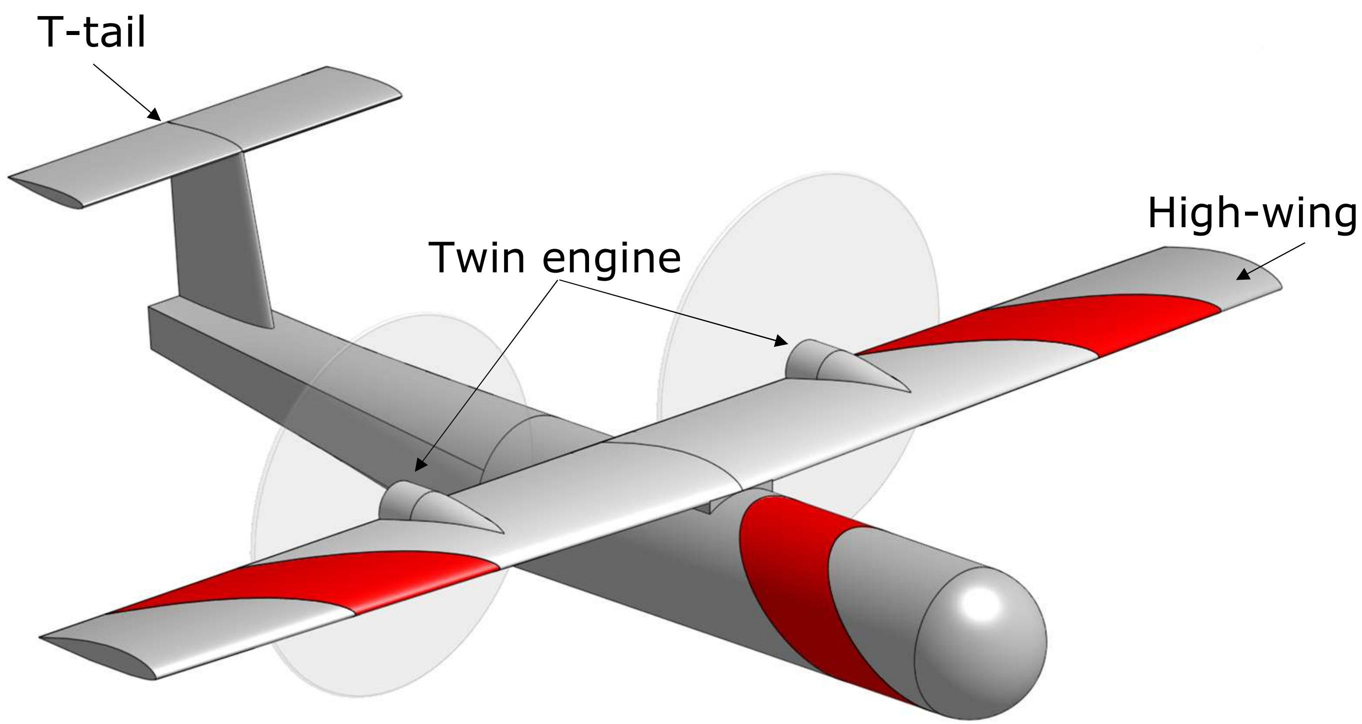
Compare three separate aircraft concepts

- Recommend two preferred designs

Compare & select design features

- Derived from requirements for wing, tail, propulsion, payloads, etc.

Design Overview

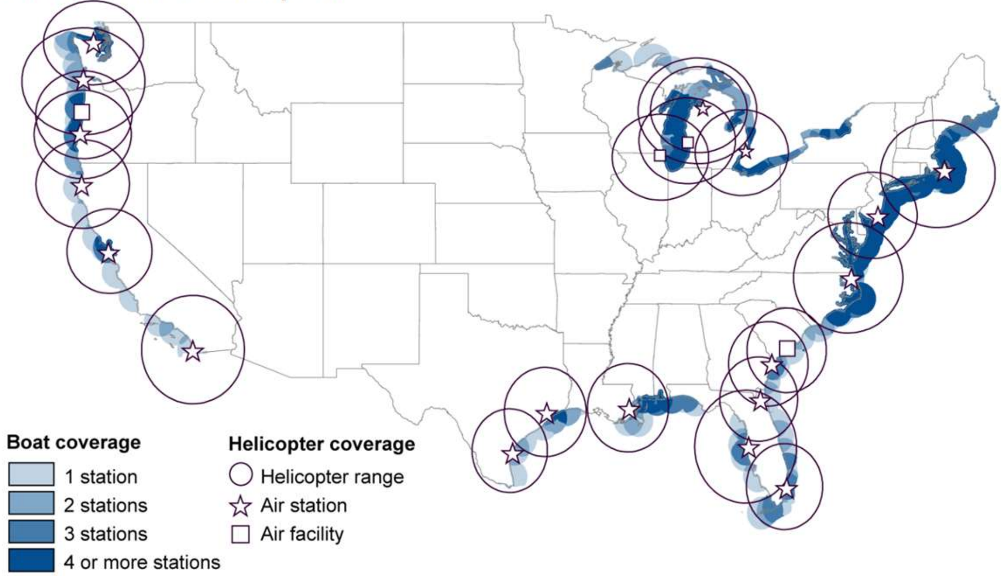


Concept and Requirements

Maritime Search & Rescue (SAR) Response Needs to Improve

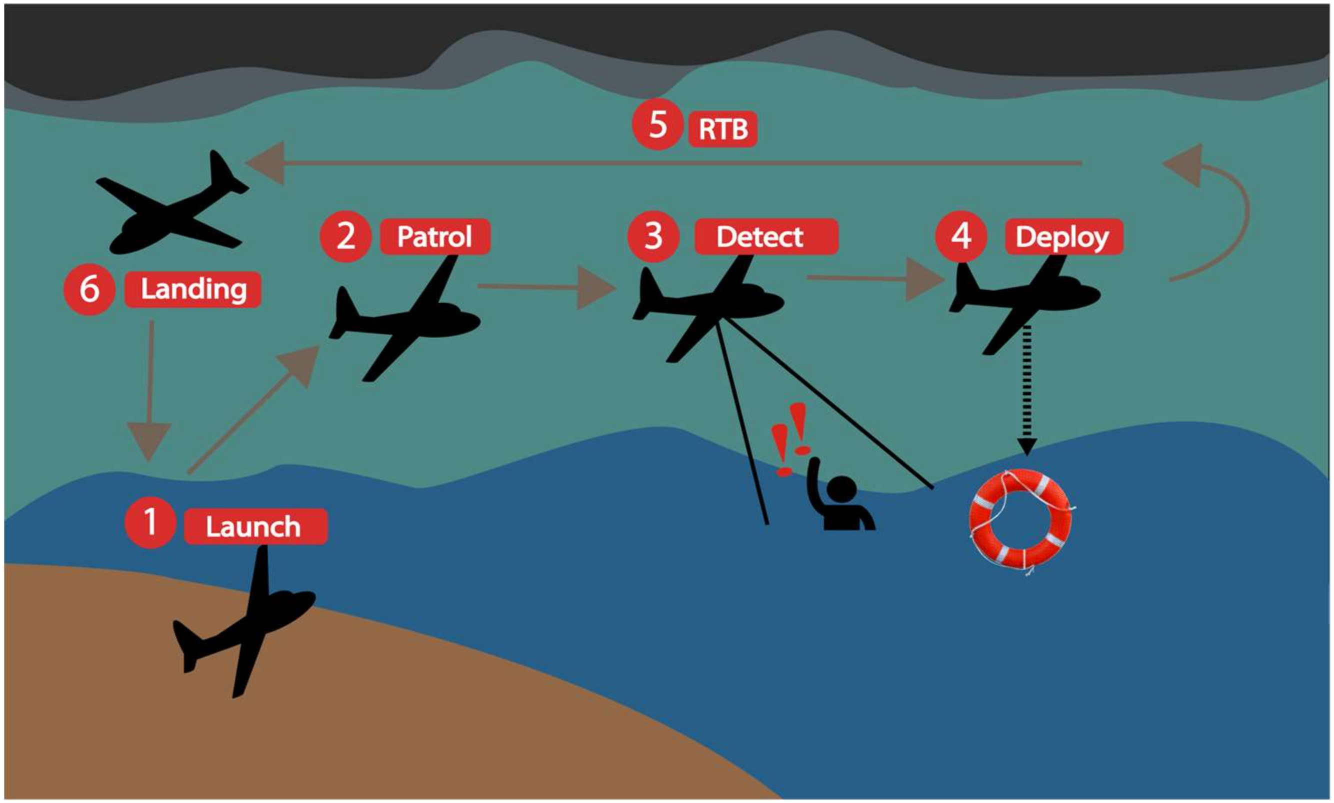
- In FY2017, 32% of lives lost were after Coast Guard notification[1]
- Deployment of rapid-response aircraft will buy time for the Coast Guard to rescue victims

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

Rapid-Response Search Plan



Design-Driving Requirements

Operational Radius	**20 mi**
Takeoff/Landing Distance	**Vertical/Catapult Launched**
Payload	**4 lb sensor gimbal Specified life raft**
Dash Speed	100 kts
Minimum Loiter Time	30 min
Standby Time	3 months
Maximum Takeoff Weight	25 lb
Environmental	Withstand maritime environment Fly in Beaufort Level 7 Conditions (28-33 kts)
Operational	Autonomous takeoff, landing, and transit to search point

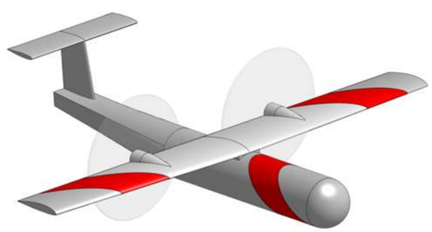
Manned Platforms Not Suited to Rapid-Response Search*

- Infrastructure for takeoff and landing
- Regular maintenance
- Large crews
- Operator risk[5]

*Sourced from [2][3][4]

Calypso Exceeds Capabilities of Other Unmanned Aircraft

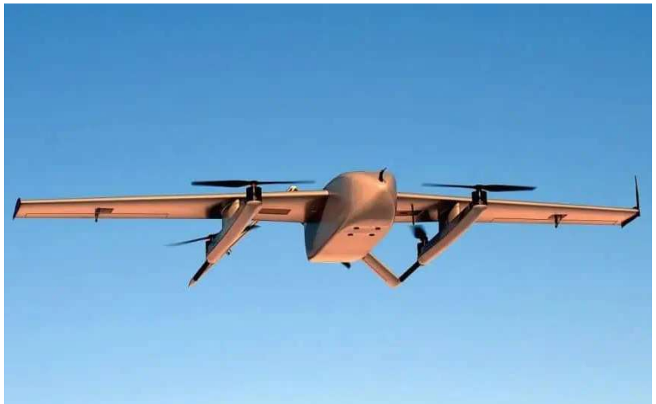
	Calypso	UAVISION Spyro [6]	Boeing ScanEagle [7]
Operational Radius	20 mi	7.5 mi	600 mi
Dash Speed	**100 kts**	30 kts	80 kts
Endurance	1 hr	1 hr	18 hr
Max Takeoff Weight	25 lb	26 lb	58 lb
Payload Capacity	10 lb	15 lb	10 lb*



*No payload accommodations for life raft or preserver

Concept & Configuration Selection

High-Level Concepts Considered



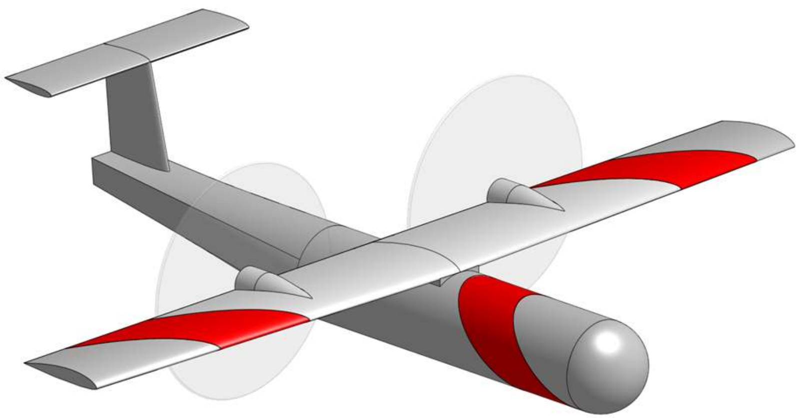
4+1 Vertical Takeoff & Landing (VTOL)

Tail-sitter Vertical Takeoff & Landing (VTOL)

Catapult Launched Conventional (CATOBAR)

Conventional Configuration Outperforms Alternatives

- Simplified controls & stability
- Larger payload capacity
- Smaller drag profile
- Higher cruising speeds



Sensitivity Analysis

Design driving sensitivities

1. Endurance: 6.65 lb per hour flight time
2. Range: 3.99 lb per 60 miles of flight
3. Payload Weight: 2.49 lb take-off weight per 1 lb of payload

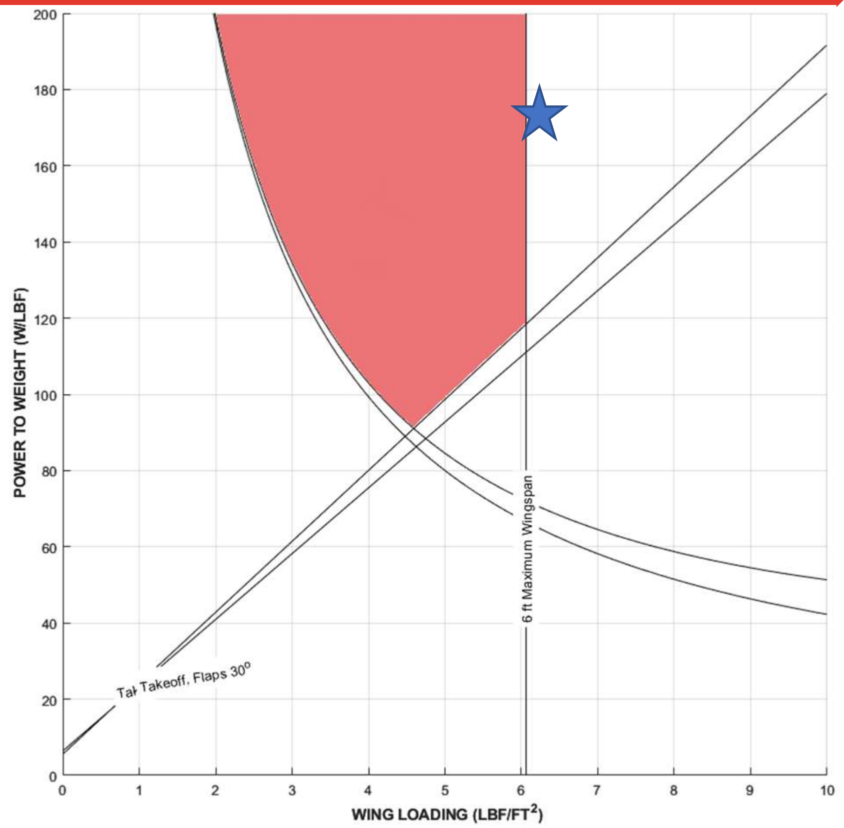
Prioritize minimizing structural & payload weight to allow for increasing range & endurance

Design Point Allows for Excess Performance

Weight Fractions
- 40% Payload
- 30% Structural
- 30% Propulsion

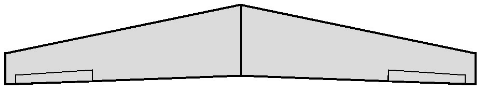
Minimum power needed
- 120 W/lbf @6ft wingspan

Power Selected
- 175 W/lbf @ 6ft wingspan
- 45% excess power

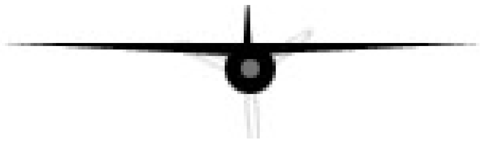


Tapered High Wing Configuration Preferred

Tapered Wing
- Manufacturing
- Mounting control surfaces
- Lift & stability

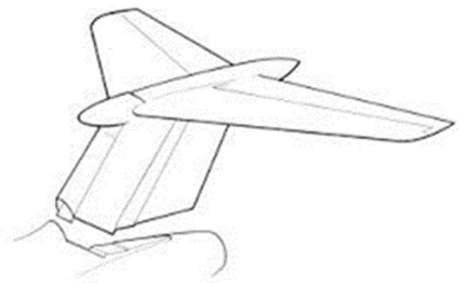


High Wing
- Payload space
- Structural integrity
- Roll characteristics



T-tail Configuration Selected

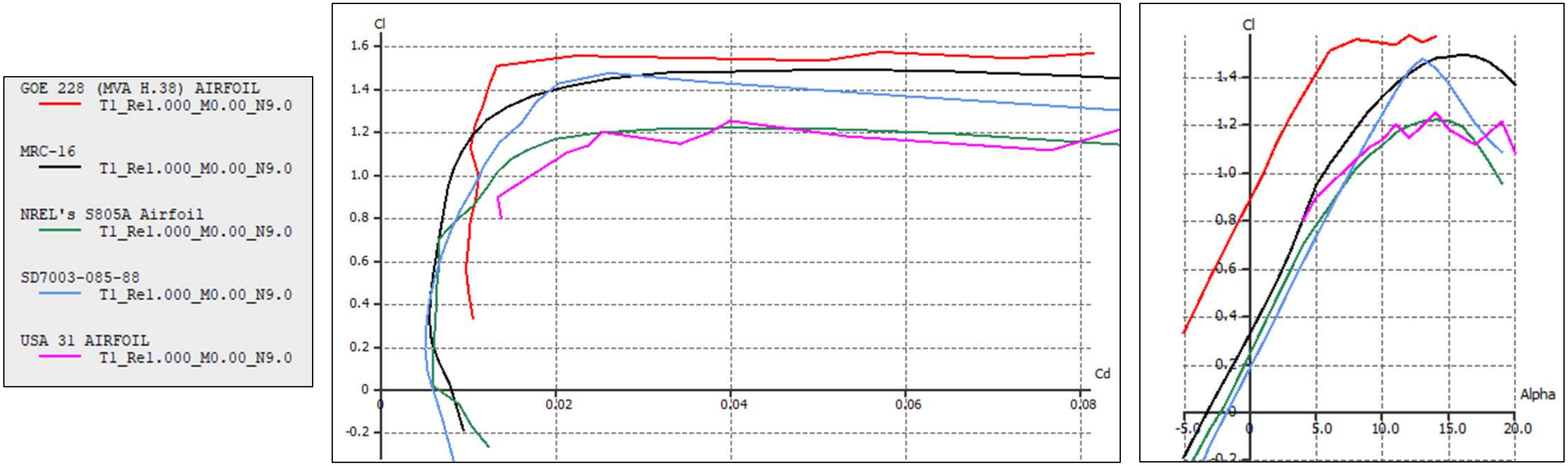
T-Tail
- Better control
- Less prop interference
- Ease of future modification



Conventional Tail
- Structural strength
- Control surface actuator mounting

Aerodynamic Design

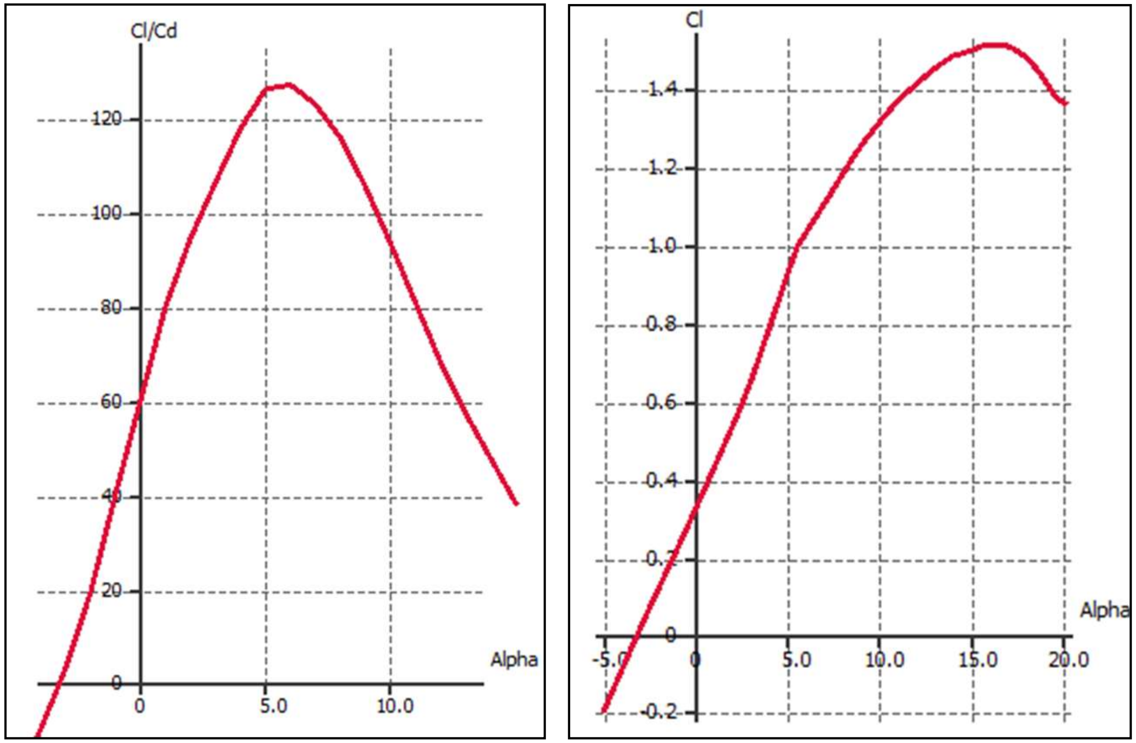
MRC-16 Chosen for Balanced Lift vs Drag & Post-Stall Performance



Airfoil performance tested at 1,000,000 Re

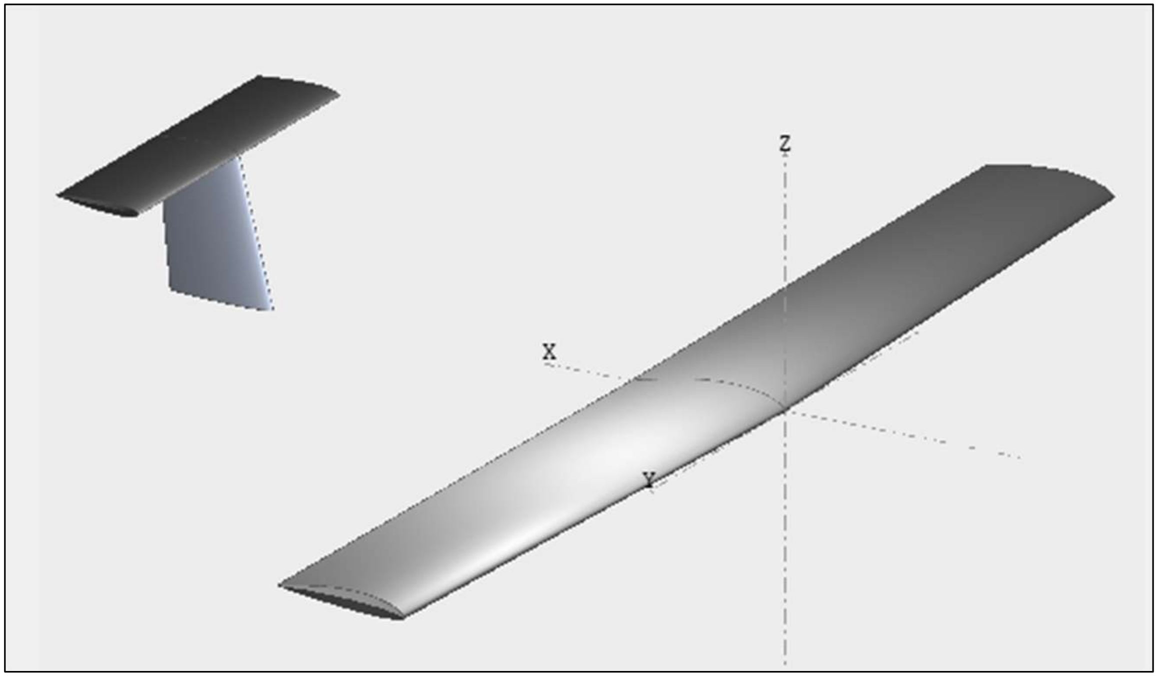
MRC-16 Airfoil Performance

2-D Direct foil design



Airfoil tests at Re = 1,150,000 (V_{dash})

Configured Aircraft Design



Tested aircraft configuration

Wing Area	594 in^2
Wingspan	72 in
Root Chord	9 in
Aspect Ratio	8.73
Taper Ratio	0.83

Aircraft is Statically & Dynamically Stable

Variable	Value
C_L Max	1.4 , 14° AoA
C_L/C_D Max	30 , 4° AoA
C_M Curve	Negative gradient
C_D Min	0.01

Test Type	Stability	F_1 (damped nat. freq.)	ζ (damping ratio)
SPPO	Stable	3.19	0.283
Phugoid	Stable	0.03	0.056
Roll Mode	Stable	~	~
Dutch Roll	Stable	1.43	0.060
Spiral Mode	Unstable	~	~

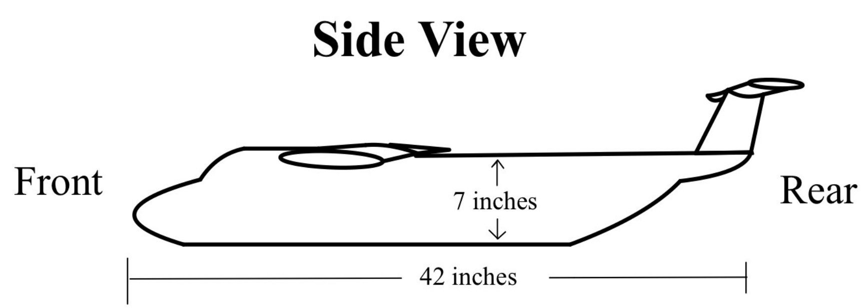
Fuselage Size Driven by Life Raft

- 7″ to 8″ diameter
- Length of 42″ to 46″ long for a fineness ratio close to 6
- Fineness ratio of 6 allows for minimum drag
- Allows internal fuselage clearance for life raft payload

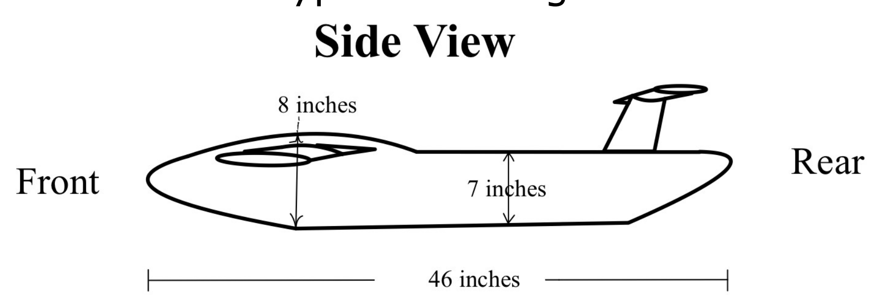
Fuselage Designs Allow for Payload Bay Flexibility

- Interchangeable fuselages for future payload delivery methods
- Type A & Type B fuselage designs have very similar aerodynamic stability

Type A Fuselage



Type B Fuselage



Propulsion Design

Motor Comparison

Electric

Pros:
- High efficiency
- Longer lifespan
- High reliability

Cons:
- More complicated
- Battery limitation

Gas

Pros:
- Higher energy & power densities
- Long flight time

Cons:
- Not self-starting
- High acoustic & thermal signatures
- Hygroscopic fuel

Glow

Pros:
- fuel efficient
- Has highest speed

Cons:
- Not self-starting
- Tune & maintenance
- Hygroscopic fuel

Motor Selection

- SunnySky X5320 Brushless Motors

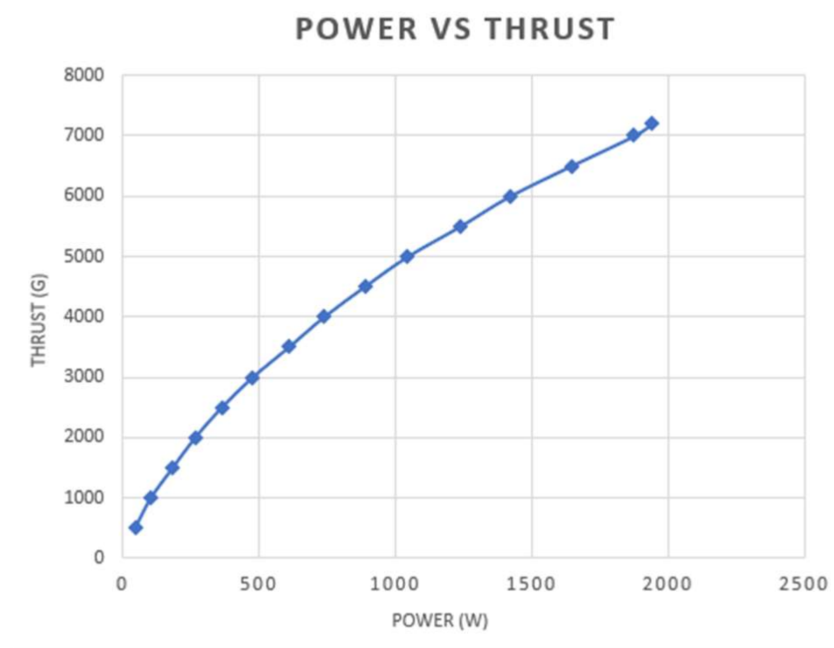
- Aircraft will have 2 Motors

- Power requirements

175 W/lbf for both motors

Prop Selection

- Prop diameter by Prop pitch 18"x10"
- High pitch to get to speed desired
- Manufacturer Recommended prop
- Allows for 1.27 thrust-to-weight ratio



Life Raft & Deployment

Off-the-Shelf (OTS) Rafts Not Satisfactory

	ThrowRaft Survivor [8]	Uncharted Supply Rapid Raft [9]	Winslow RescueRaft [10]
Buoyancy, lb	100	400	800
Weight, lb	2.8	3.8	16
Packed Dimensions, in	12x2.5x9	15x5Ø	8x14x16
Deployed Dimensions, in	48x42x4	72x33x12	72x72x18

Modified OTS Raft Meets Needs

- "Modified Rapid Raft"
  - Added ballast bags & CO_2 inflator
- 400 lb buoyancy
- 5 lb weight
- 15"x5.25"Ø packed dimensions

Two Payload Deployment Systems (PDS) Designed

Bomb Bay Type

Pros:

- Smaller size
- Light Weight

Cons:

- Complex (18 Parts)
- Requires modification to raft

Ejector Type

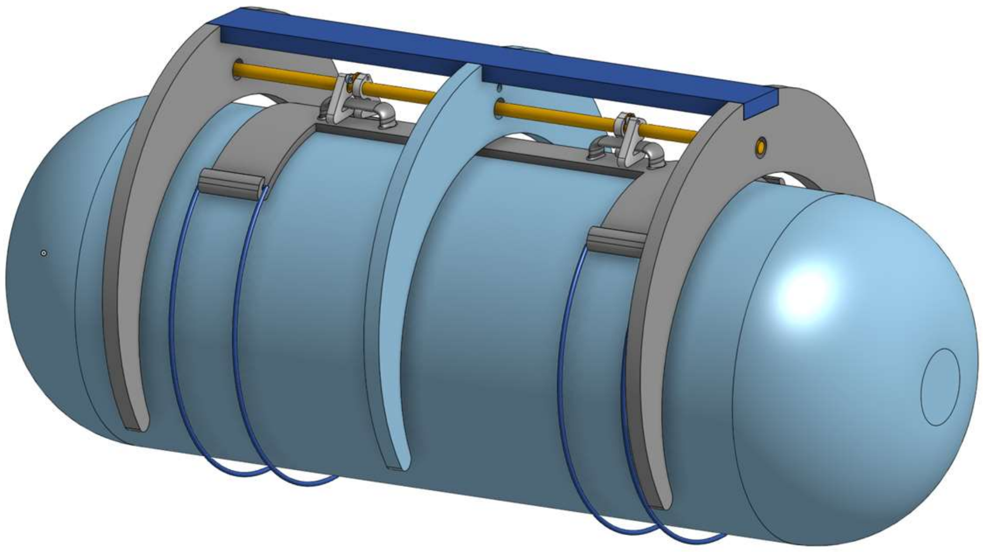
Pros:

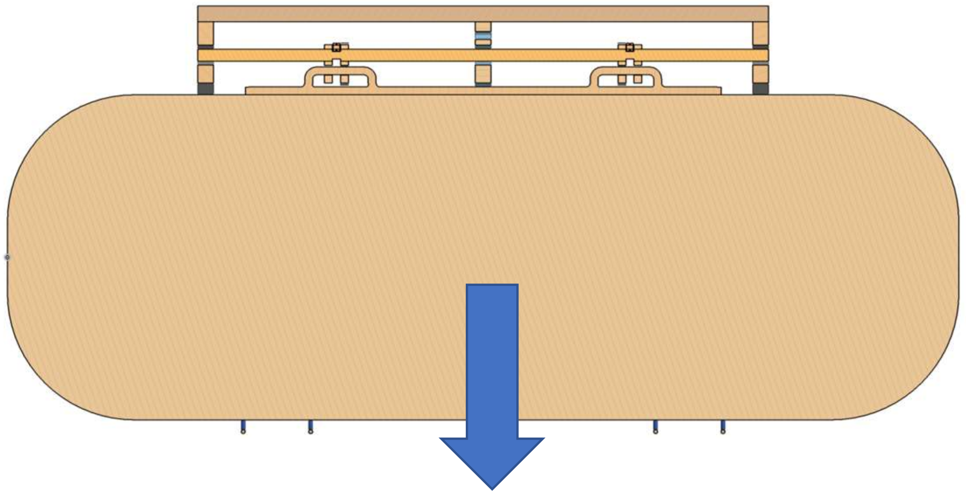
- Simple (5 Parts)
- Robust

Cons:

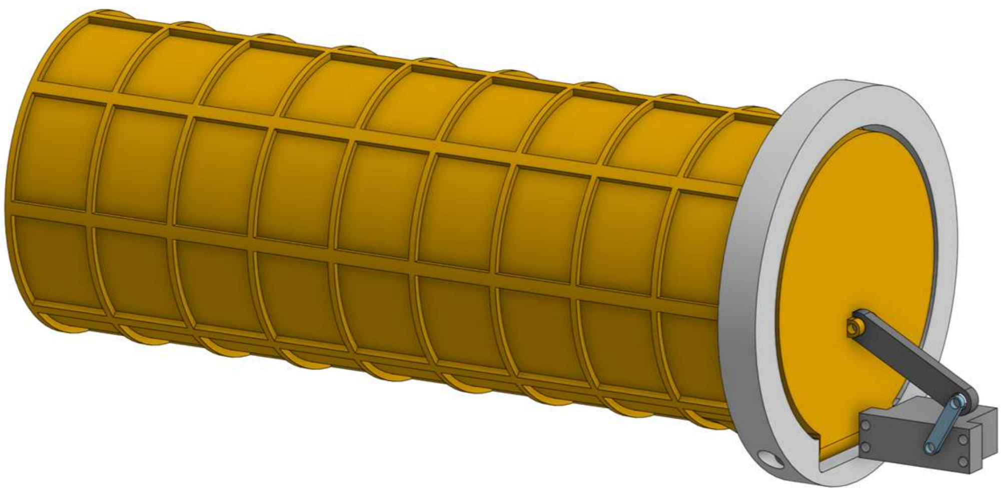
- Heavier than Bomb Bay Type
- Larger than Bomb Bay Type

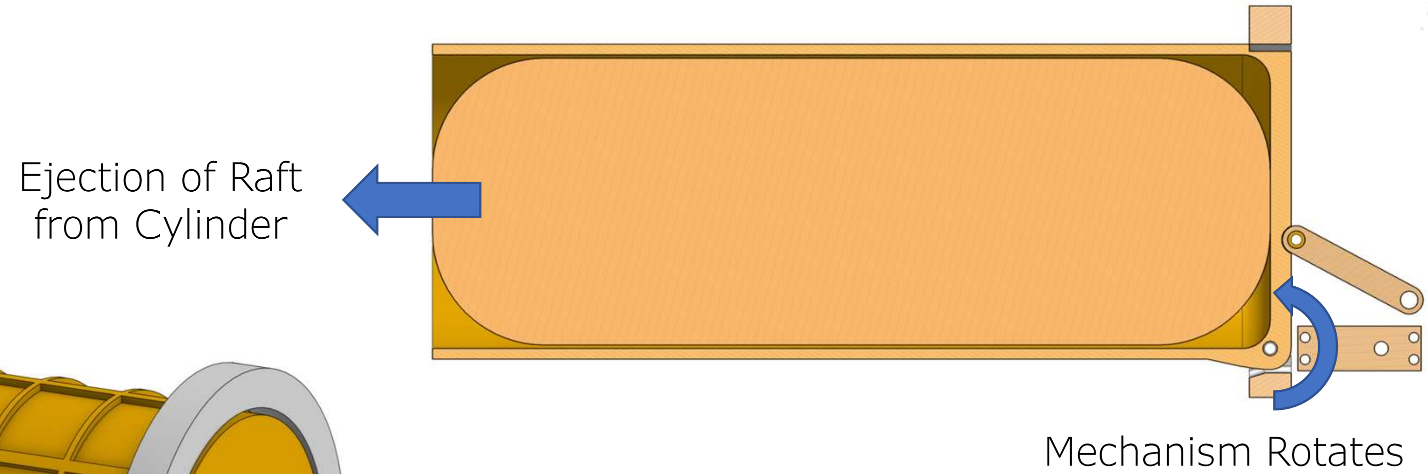
Bomb Bay Type is Smaller





Ejector Type is Simpler





Communications & Flight Control

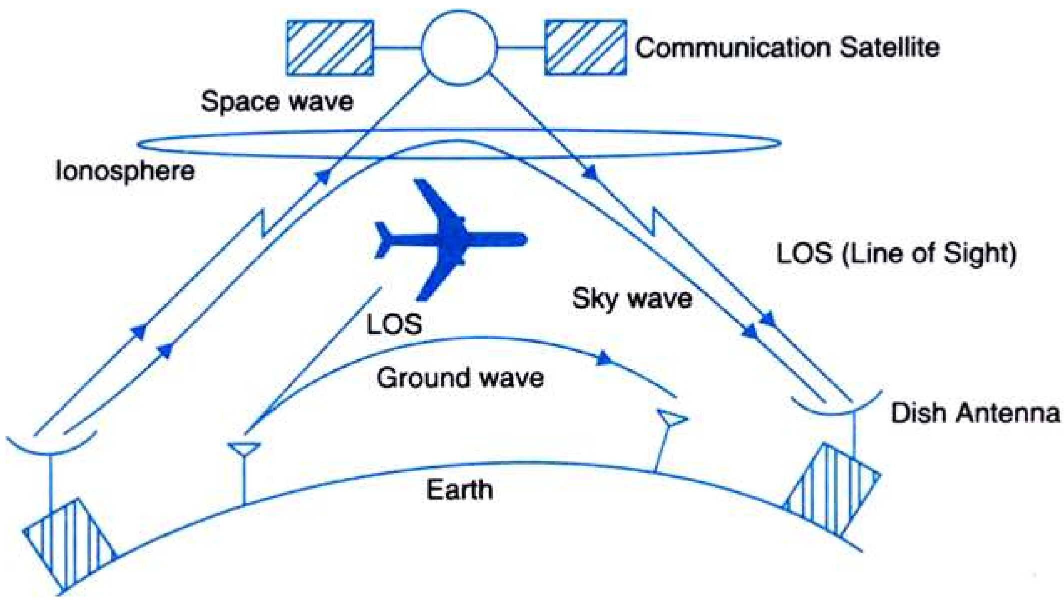
Communication Categories

Satellite

- Good Range
- Used for trans-oceanic flights

LOS Radio

- Good Bandwidth
- Used with high altitude long endurance UAVs.



Commtact MDLS Selected

Radio	Type	Weight (g)	Range KM	Bandwidth
Commtact MDLS (1)	Radio	100	40	Excellent
Commtact IDLS MK-II	Radio	2,500	250	Excellent
AKSON C-BAND DLS	Radio	< 3,000	200	Good
COBHAM AVIATOR UAV 200 (2)	Satellite	1,450	3760	Poor

1

2

Pixhawk 4 Selected

Component	Price USD	I/O ports	Notes
Pixhawk 4 (1)	190.00	16	Newer, better Documentation.
Pixhawk 4 mini	159.00	8	Inexpensive, older, harder to source.
CUAV Pixhawk V6X	519.00	16	Expensive, more features than necessary.


1

Sensing Capabilities Necessitated by Pixhawk Integration

- Global Positioning System (GPS)
- 3D Gyroscopes
- Inertial Navigation System (INS)
- Pitot-Static Probe & Sensor

Launch & Recovery Systems

3 Typical Launch Systems Available

Elastic System (ELS) –

Elastic bands, short rail, lightweight

Pneumatic System (PLS) -

Compressed air & cables, large scale, heavyweight

Ballistic System (BLS) -

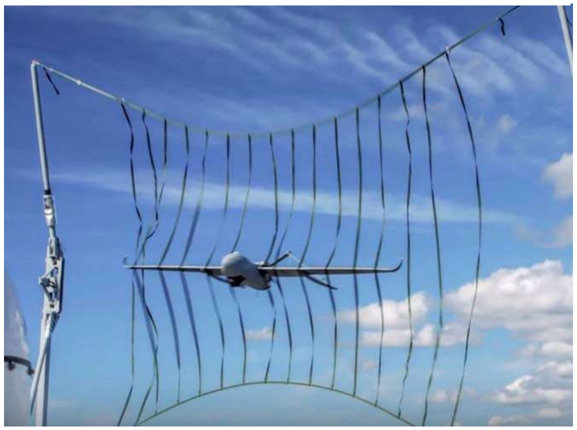
Rockets on short rail, sustained thrust, high speed

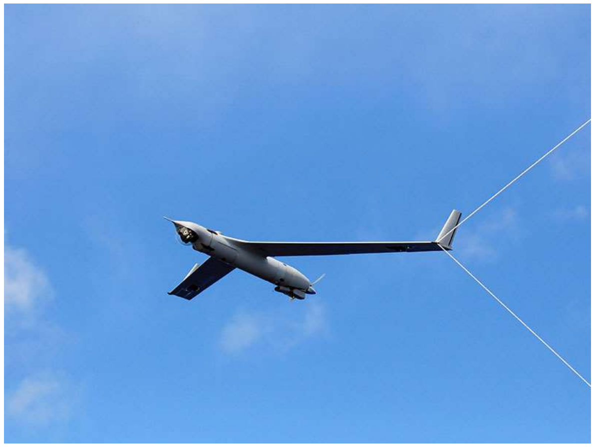
Project Will Use Elastic Launch System

- Integrated flexibility for multiple airframes & mission profiles
- High acceleration at low cost & size

3 Typical Recovery Systems Available

Net System (NRS) – Large margin for error, entangles airframe to stop





Cable System (CRS) - Low margin for error, one or both wings catch cable

Parachute System (PRS)- Low accuracy, impacts airframe fuselage design, last resort

Project Will Use Cable Recovery System

- Integrated flexibility for multiple airframes & mission profiles
- High accuracy with an entirely passive system & minimal impact on the airframe

Conclusions & Recommendations

Recommended Design

CATOBAR Conventional

- Superior performance in cruise
- 4-by-1 fallback using aerodynamic commonality

Twin engine, electric

- Necessary performance for take-off & cruise
- Lighter than gasoline engine, eliminates fuel concerns

Pusher-prop arrangement

- Less likely to be damaged on recovery

T-tail & high-wing design

- Superior stability & take-off performance

What Are Our Next Milestones?

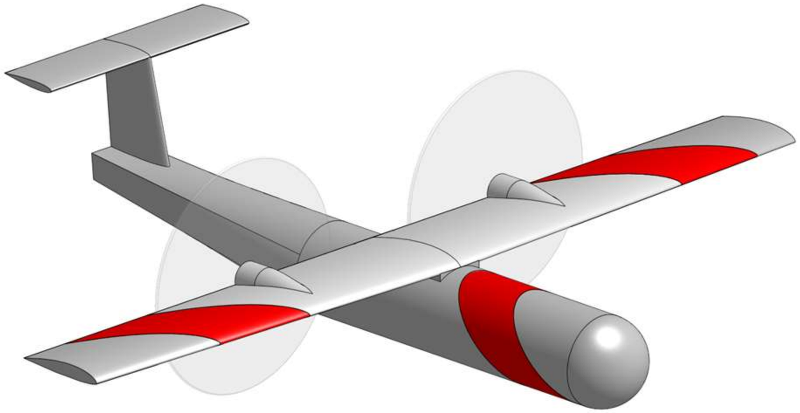
Creation of scale glider before design freeze (March 27th)

- Verify aerodynamic estimates
- Evaluate airframe control response
- Fabrication experience

Testing of launch mechanisms before FRR (April 7th)

- Determine acceptable launch performance
- Collaborate with other Capstone teams to consolidate catapult design
- Collect launch data & compare with predictions

Questions?



Appendix

Sensitivity Analysis

Parameter	Sensitivity
Payload Weight	2.475 lb/lb
Empty Weight	1.900 lb/lb
Range	0.066 lb/mi
Endurance	6.645 lb/hr
L/D	-0.199 lb

Initial Parameters	
L/D	20
Range	60 mi
Payload Weight	10 lb
MTOW	25 lb
C_P	10.736 lb/hp/hr

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	

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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	

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Aircraft Testing

Wing Span	72.00	in
Area	594.00	in²
Projected Span	72.00	in
Projected Area	594.00	in²
Mean Geom. Chord	8.25	in
Mean Aero Chord	8.27	in
Aspect ratio	8.73	
Taper Ratio	0.83	
Root to Tip Sweep	1.79	°

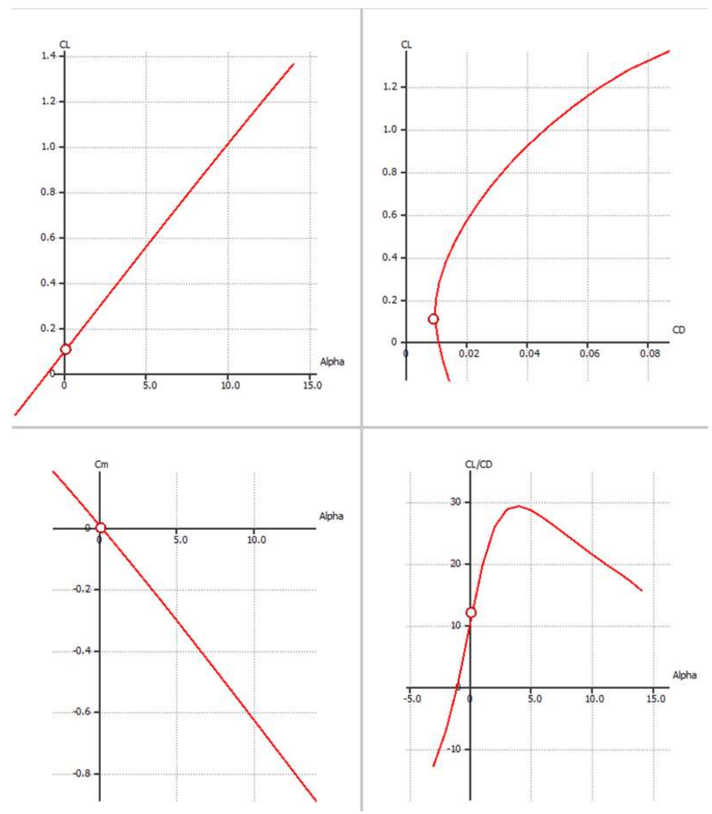
Wing

Wing Span	20.40	in
Area	97.92	in²
Projected Span	20.40	in
Projected Area	97.92	in²
Mean Geom. Chord	4.80	in
Mean Aero Chord	4.80	in
Aspect ratio	4.25	
Taper Ratio	1.00	
Root to Tip Sweep	0.00	°

Elevator

Wing Span	16.00	in
Area	43.20	in²
Projected Span	16.00	in
Projected Area	43.20	in²
Mean Geom. Chord	5.40	in
Mean Aero Chord	5.42	in
Aspect ratio	5.93	
Taper Ratio	0.80	
Root to Tip Sweep	12.00	°

Tail



Aircraft Testing Inertias

Weight	Mass (lb)	X (in)	Y (in)	Z (in)
L Motor	1	9	-6	0
R Motor	1	9	6	0
Gimbal	4	-18	0	-3.5
Batteries	4	-12	0	-3.5
Electronics	1	-12	0	-3.5
Fuselage (empty)	2	0	0	-3.5
Life Raft system	6	0	0	-3.5

Propeller-Motor Data

Prop(inch)	Voltage(V)	Amps(A)	Thrust(gf)	Watts(W)	Efficiency(g/W)	Load temperature in 100% throttle
18*10	22.2	2.1	500	46.62	10.72501073	95℃
		4.7	1000	104.34	9.584052137	
		8.3	1500	184.26	8.140670791	
		12	2000	266.4	7.507507508	
		16.4	2500	364.08	6.86662272	
		21.5	3000	477.3	6.285355123	
		27.5	3500	610.5	5.733005733	
		33.3	4000	739.26	5.410816222	
		40	4500	888	5.067567568	
		47.1	5000	1045.62	4.781851916	
		55.8	5500	1238.76	4.439923795	
		64	6000	1420.8	4.222972973	
		74.1	6500	1645.02	3.951319741	
		84.5	7000	1875.9	3.731542193	
		87.5	7200	1942.5	3.706563707	

Launch System Comparison

Design Considerations	ELS	PLS	BLS
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 Considerations	NRS	CRS	PRS
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

References

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http://www.charlesriverrc.org/articles/design/donstackhouse_conventionalvsvtail.htm.

[16] "Comparative analysis of aerodynamic characteristics of rectangular and ..." Available:

https://www.researchgate.net/publication/344160569_Comparative_Analysis_of_Aerodynamic_Characteristics_of_Rectangular_and_Curved_Leading_Edge_Wing_Planforms.

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Figure References

Slide #	Item	Source
6	USCG Coverage Map	Link
9	MH-65 Dolphin Helicopter	Link
10	UAVision Spyro Drone	Link
10	Boeing/Insitu ScanEagle In Flight	Link
12	Hybrid Drone	Link
12	Heurobotics Tail-Sitter Drone	Link
12	Boeing/Insitu ScanEagle On Catapult	Link
26	Electric Motor	Link
26	Gas Motor	Link
26	Glow Motor	Link

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27	SunnySky X5320 Motor	Link
30	ThrowRaft Survivor Life Raft	Link
30	Uncharted Supply Co. Rapid Raft	Link
30	Winslow Marine Super Light RescueRaft	Link
31	Uncharted Supply Co. Rapid Raft Outdoors	Link
36	LOS vs Satellite	Link
37	Commtact MDLS Radio Communications	Link
37	Cobham Aviator AUV 200 SATCOM	Link
38	Pixhawk 4 Flight Controller	Link
41	Detachable Light Catapult	Link

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42	Robonic KONTIO Pneumatic Catapult	Link
42	BQM-167 During Rocket Propelled Launch	Link
44	Wire Recovery of Boeing ScanEagle	Link
45	Aerosonde Mark 4.7 Net Recovery	Link
45	Wire Recovery of Boeing ScanEagle	Link
45	Practice Drone Recovered with Parachute	Link