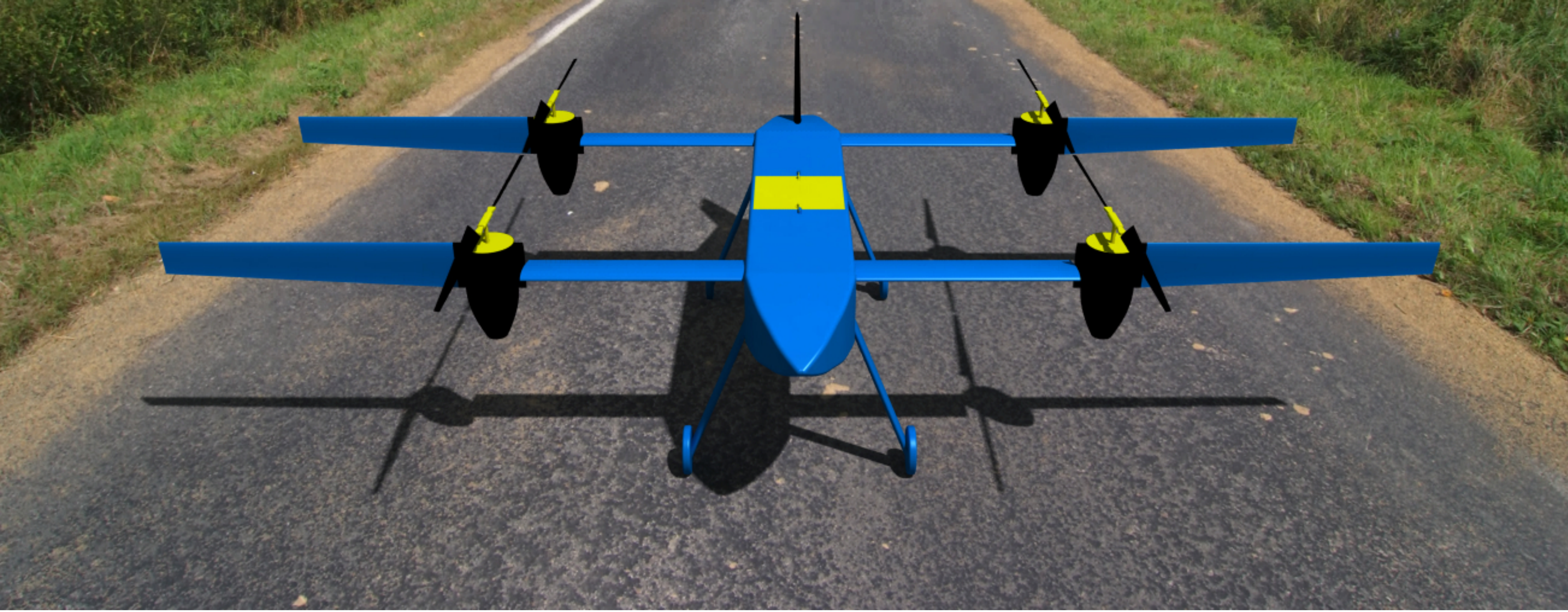


High Aspect Ratio Electric Tandem Concept (HARETC)

32nd ahs international student design competition

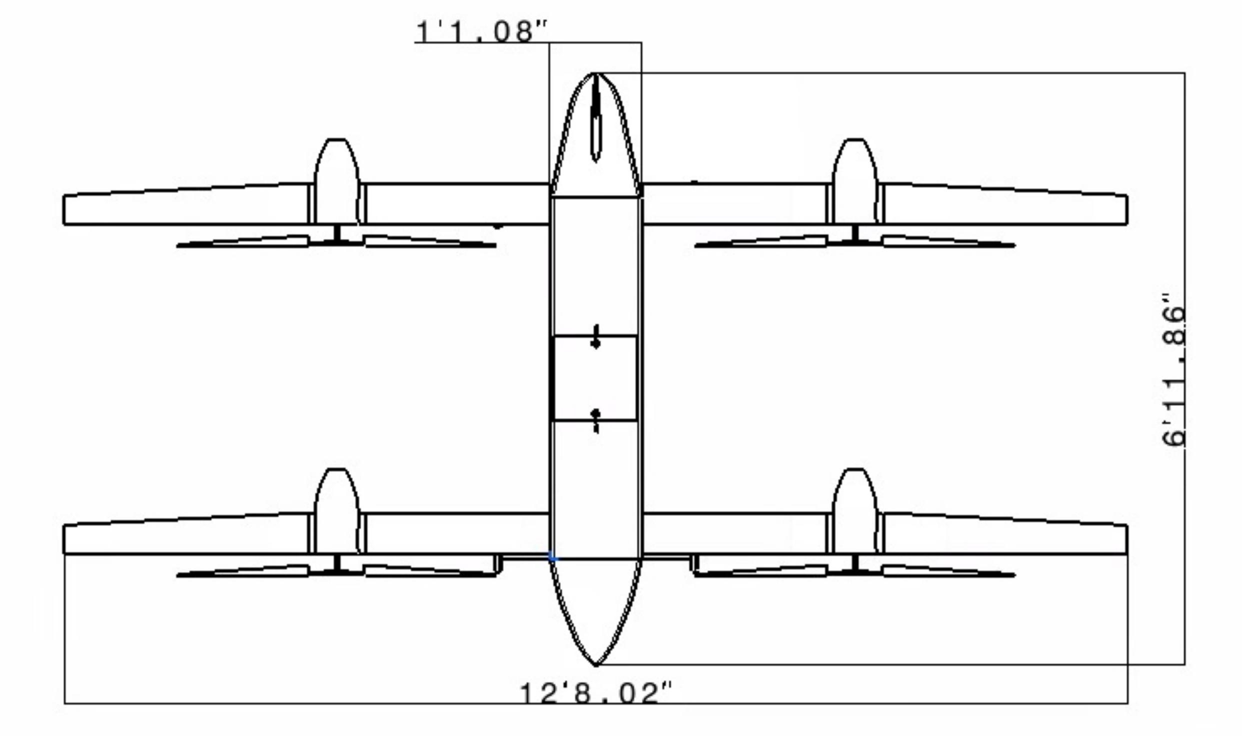
Georgia Institute of Technology

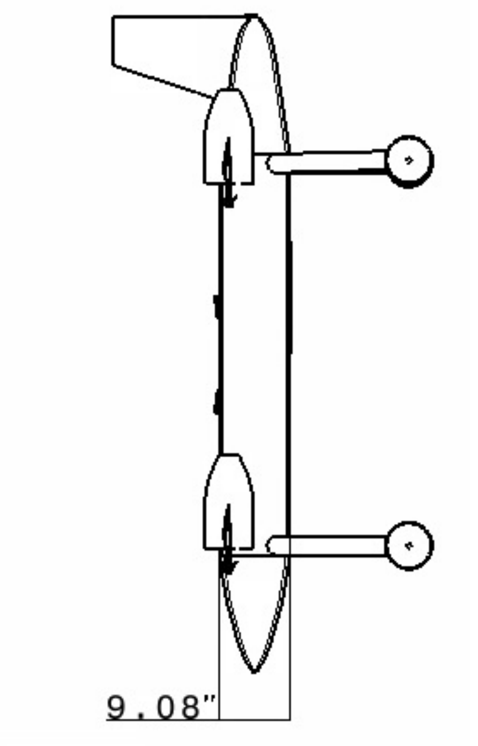
Middle East Technical University

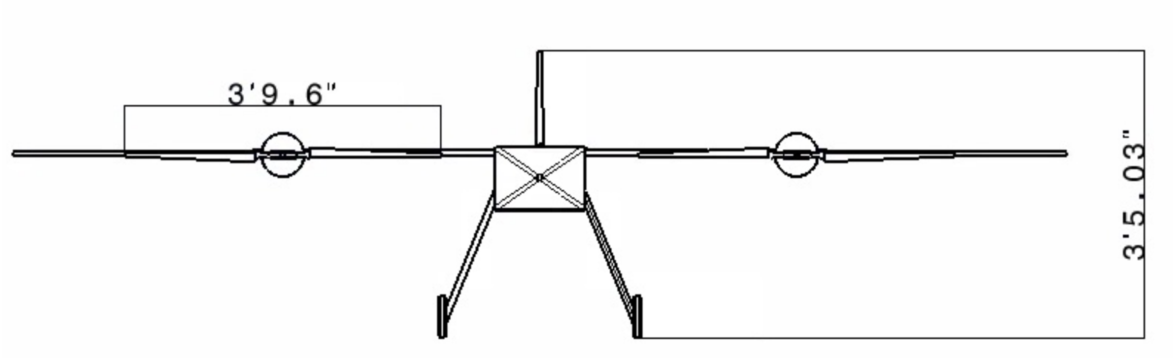
BOEING

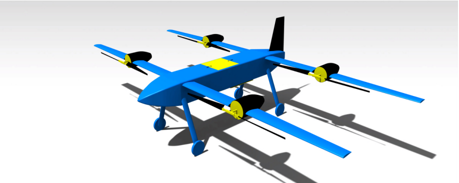
AHS INTERNATIONAL

Vehicle Three View

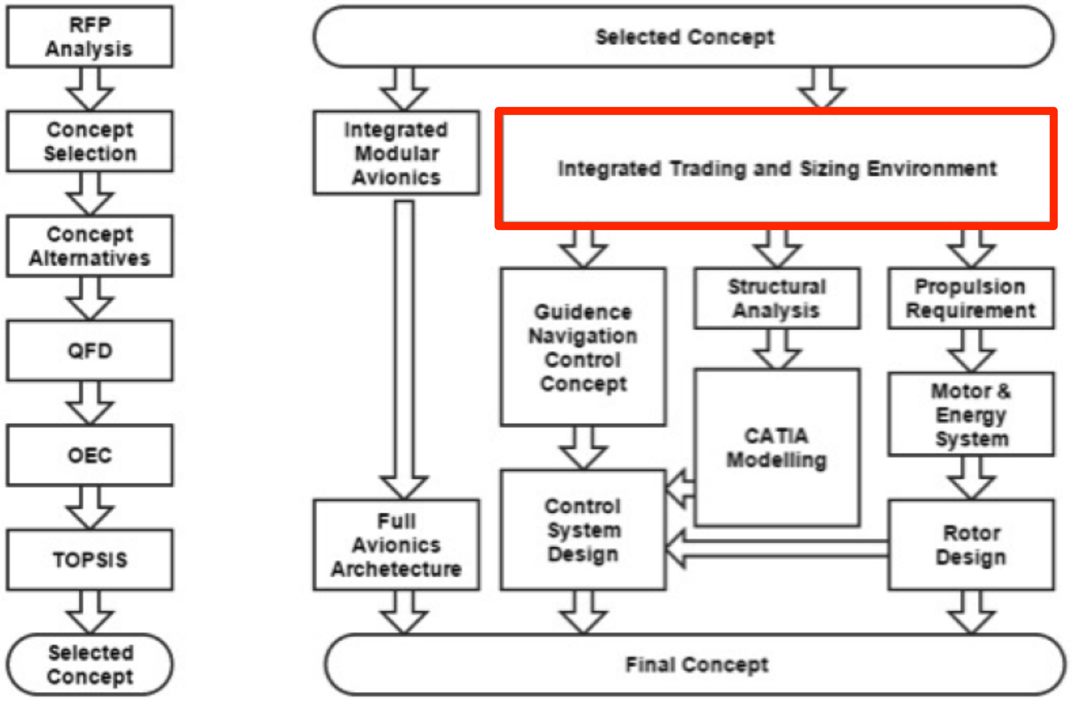


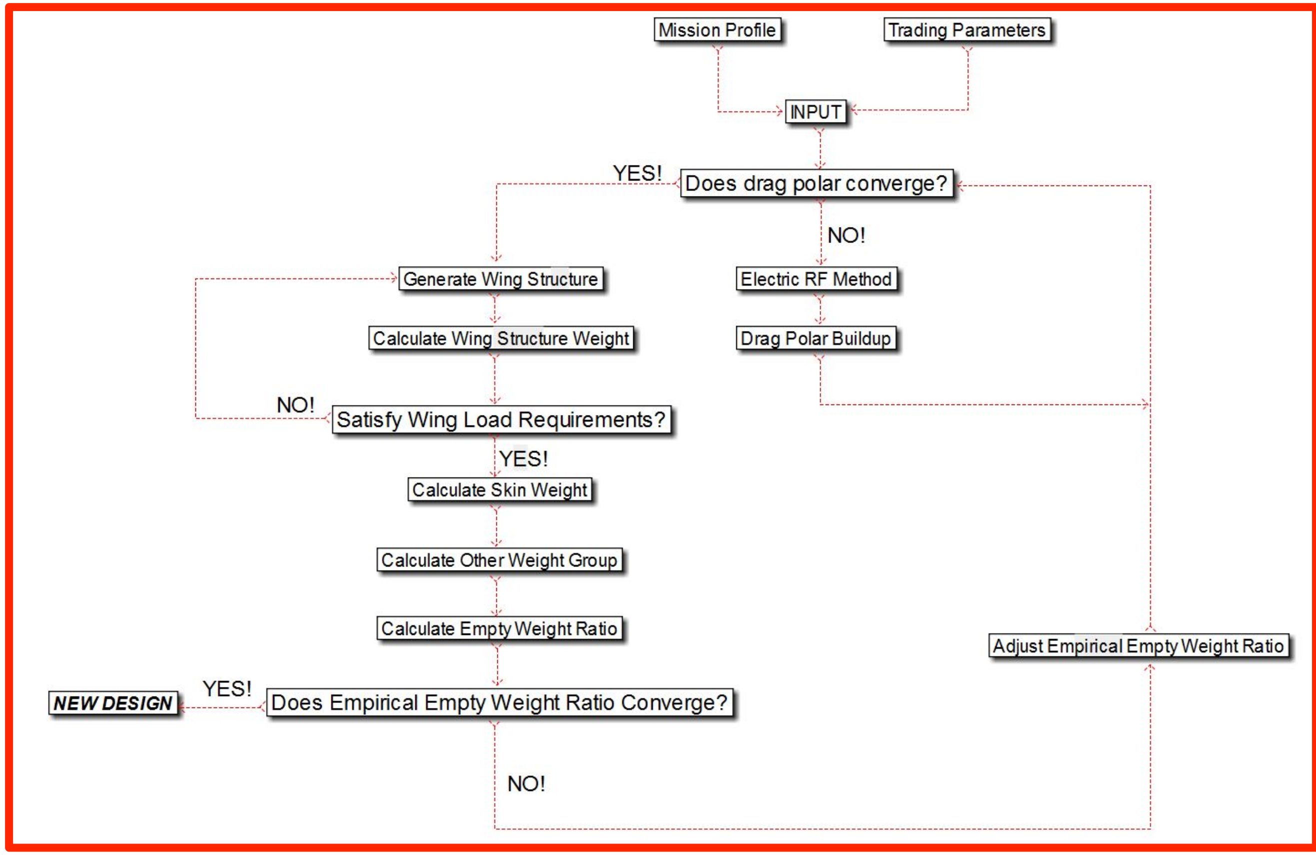


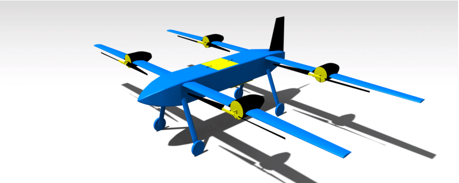




Design Process

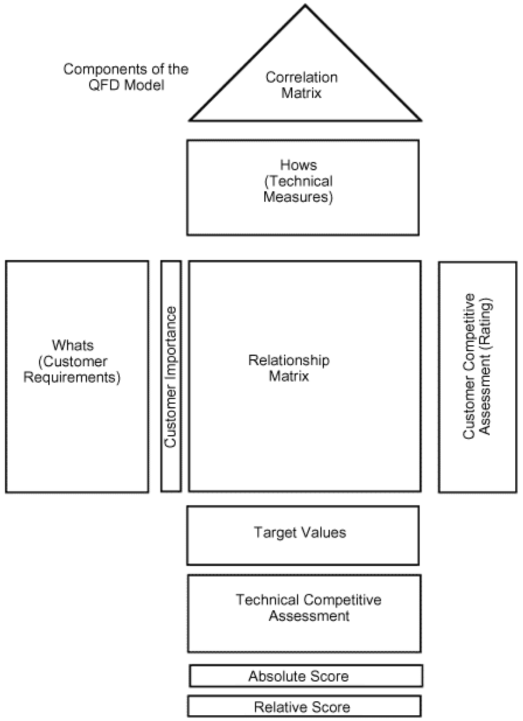


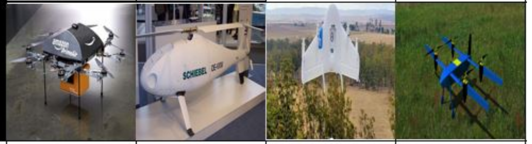




Customized integrated trading and sizing environment (ITSE) code set allows team members from multiple disciplines to work in parallel.

Concept Selection

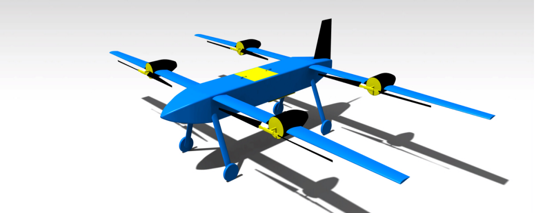


	Unweighted			
	Baseline	Alternate 1	Alternate 2	Alternate 3
	Amazon Prime	Schiebel Camcopter	Google Wing	HARETC
				
Cruise Velocity	DATUM	1	1	1
Airframe Weight	DATUM	0	-1	0
Turn Around Time	DATUM	0	0	0
Noise	DATUM	1	0	0
Cruise Efficiency	DATUM	0	1	1
Hover Efficiency	DATUM	0	0	0
Loading Time	DATUM	1	0	1
Mean Time to Failure	DATUM	0	-1	0
Maintenance	DATUM	0	-1	0
Safety	DATUM	0	1	1
Control Robustness	DATUM	0	0	0
DOC	DATUM	0	0	0
Manufacturing	DATUM	0	-1	0
Reliability	DATUM	0	0	0
Emissions	DATUM	-1	0	0
Total	0	2	-1	4

Selection Criteria	Weight	Selection Criteria	Weight
Cruise Velocity	7.55%	Maintenance Cost	5.66%
Airframe Weight	6.60%	Safety	4.72%
Turn-around Time	9.43%	Control Robustness	8.49%
Noise	2.83%	Direct Operating Cost	9.43%
Cruise Efficiency	4.72%	Manufacture Cost	9.43%
Hover Efficiency	4.72%	Reliability	7.55%
Loading Time	9.43%	Emissions	4.72%
Mean Time to Failure	4.72%		

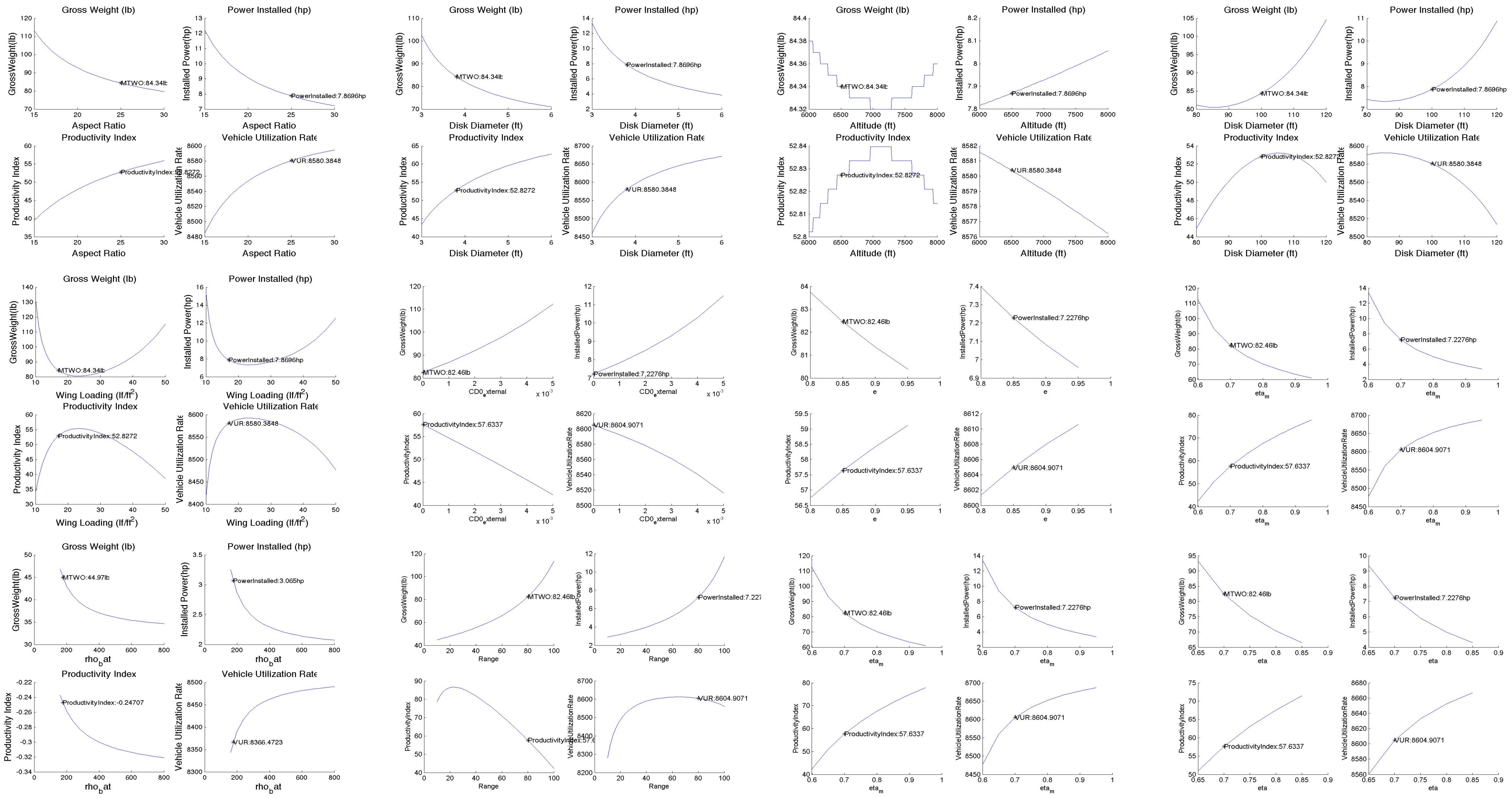
Amazon Prime	0.393
Schiebel Camcopter	0.657
Google Wing	0.435
HARETC	0.811

Quality Function Deployment → **Pugh Matrix** → **Technique for Order of Preference by Similarity to Ideal Solution(TOPSIS)**

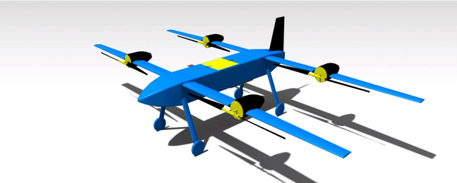


HARETC fulfills customer needs, is technically feasible, and is the best option out of four similar concepts.

Design Trade Studies



Parameter	Value
Aspect ratio	25
Wing loading (lb/sq.ft)	17
External CD0	0
Oswald Efficiency	0.9
Battery power density (Wh/kg)	176
Operational Radius (mile)	37.5
Rotor Overal Efficiency	0.7
Rotor diameter (ft)	3.8
Payload (lb)	15
Cruise speed (mph)	100
Motor Efficiency	0.7
Number of blades	2
Motor power density (hp/lb)	1.0
Cruise Altitude (ft)	6500
Crud Drag Multiplier	1.3
Vehicle Hover time in minutes	6

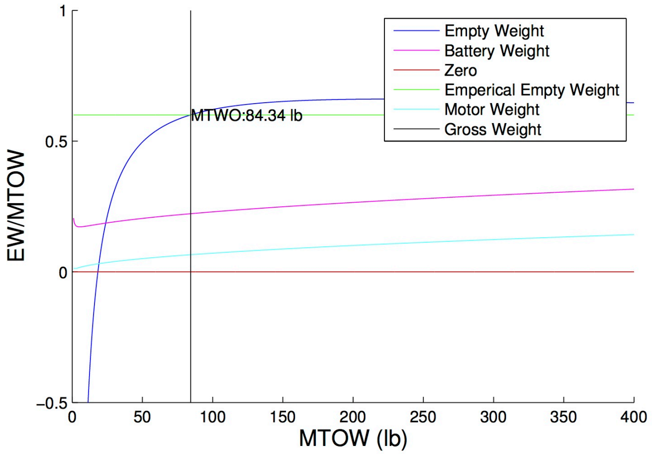


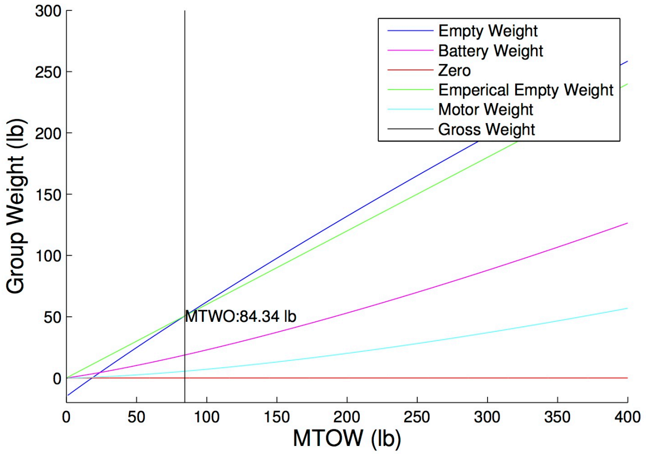
Detailed trade study on important parameters to identify the best design point.

Weight Sizing

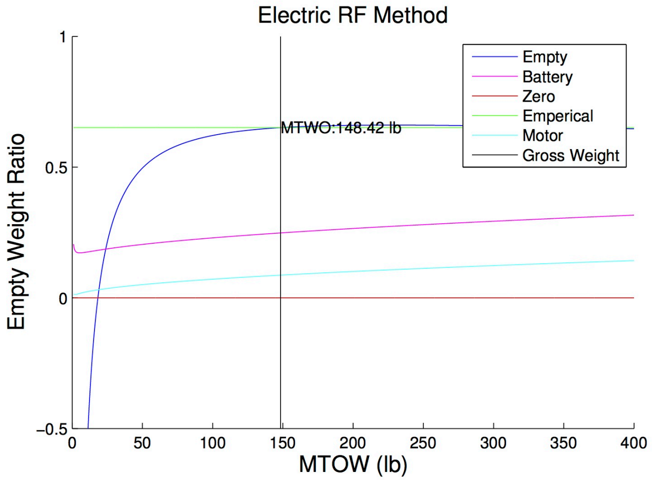
Georgia Tech

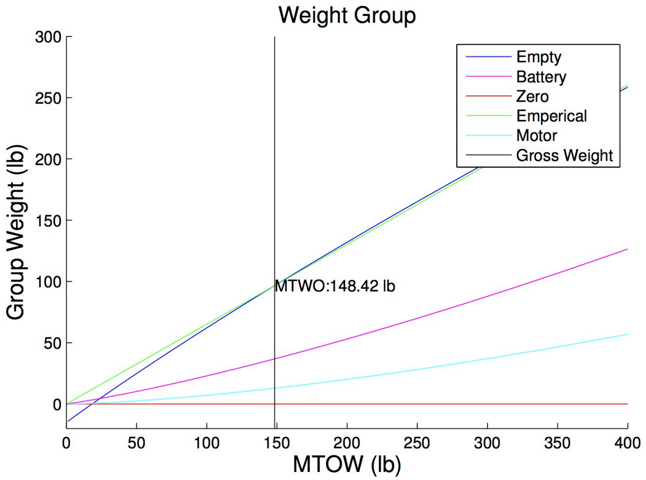
	Weight (lb)	Fraction
Payload weight	15.000	0.178
Motor Weight	7.870	0.093
Battery Weight	18.736	0.222
Structural Weight	42.735	0.507
Gross Weight	84.340	1.000

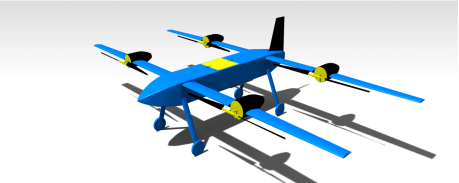




	Weight (lb)	Fraction
Payload weight	15.000	0.101
Motor Weight	18.371	0.124
Battery Weight	36.819	0.248
Structural Weight	78.229	0.527
Gross Weight	148.420	1.000



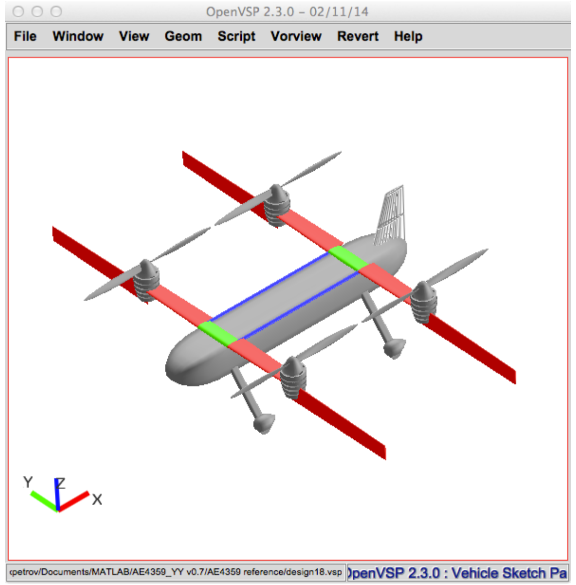




A custom electric RF method is used to size full electric VTOL. First weight sizing result (top) is based on mission profile. The second weight sizing result (bottom) is based on empty weight build up.

HARETC

Center of Gravity

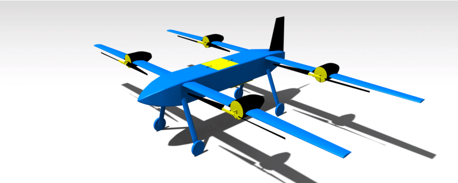


Name	Weight (lb)	x Loc. (ft)	y Loc. (ft)	z Loc. (ft)
Fuselage	15.74	3.50	0.00	0.00
Left front rotor	3.98	0.75	2.50	0.45
Right front rotor	3.98	0.75	-2.50	0.45
Left rear rotor	3.98	4.65	2.50	0.45
Right rear rotor	3.98	4.65	-2.50	0.45
Left front nacelle	0.17	0.92	2.50	0.45
Right front nacelle	0.17	0.92	-2.50	0.45
Left rear nacelle	0.17	4.82	2.50	0.45
Right rear nacelle	0.17	4.82	-2.50	0.45
Front wing	7.37	1.55	0.00	0.40
Rear wing	7.37	5.45	0.00	0.40
Tail	3.54	6.00	0.00	0.00
Parachute	11.50	5.50	0.00	0.20
Avionics	3.45	0.50	0.00	0.00
Front gear	3.45	1.45	0.00	-0.50
Rear gear	3.45	5.35	0.00	-0.50
Misc	5.75	3.50	0.00	0.00
Front battery	36.82	2.17	0.00	0.20
Rear battery	0.00	4.63	0.00	0.20
Left front motor	4.59	0.92	2.50	0.45
Right front motor	4.59	0.92	-2.50	0.45
Left rear motor	4.59	4.82	2.50	0.45
Right rear motor	4.59	4.82	-2.50	0.45
Payload	15.00	3.40	0.00	0.20
Total	148.41			

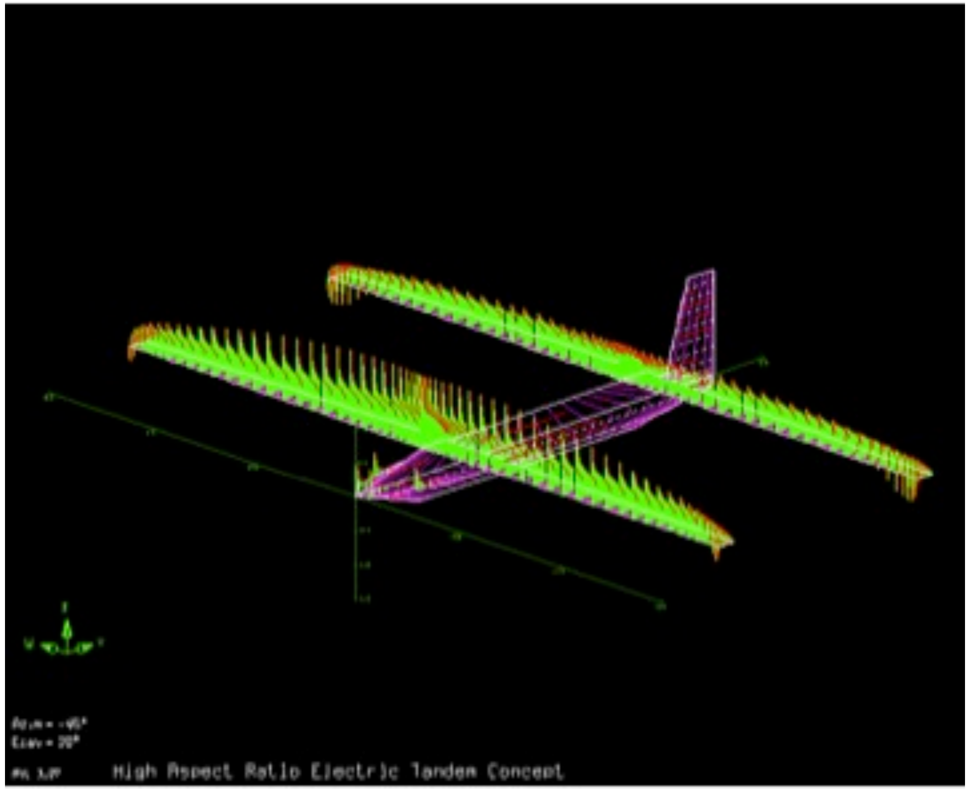
	MTOW	x Loc.	y Loc.	z Loc.
CG Loc.	MTOW	x Loc.	y Loc.	z Loc.
With Payload	148.414	3.132	0.000	0.208
Without Payload	133.414	3.102	0.000	0.209

VSP model & component position → **Component weight** → **Center of gravity**

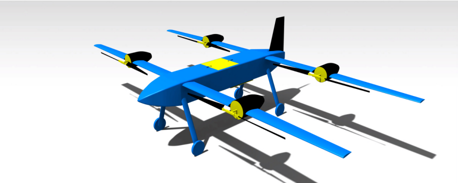
A CAD based detailed weight and CG analysis enables the calculation of the center of gravity of the vehicle.



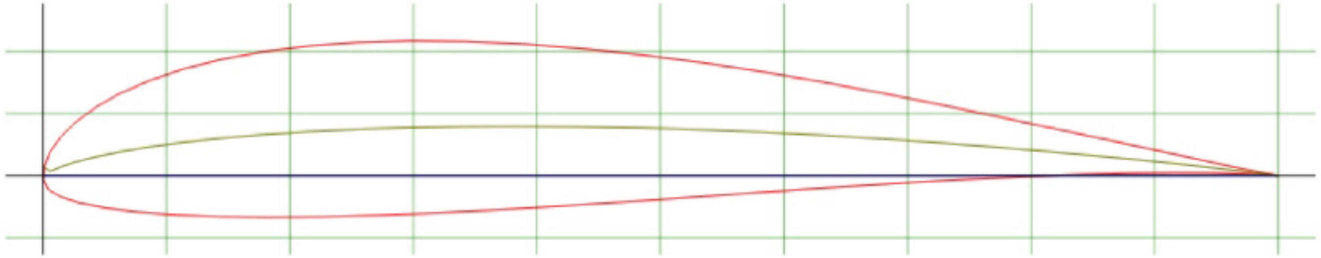
Neutral Point Estimation



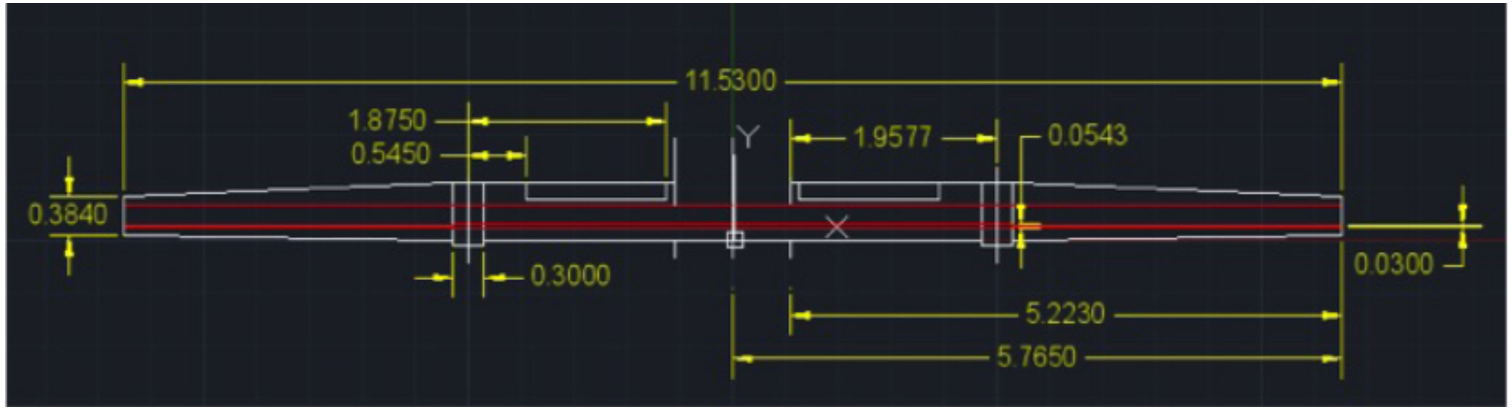
Athena Vortex Lattice (AVL) software is used to estimate the Neutral Point. The program indicates the N.P. is located 3.14 ft behind the nose of the aircraft. The aircraft is statically stable with/without payload.



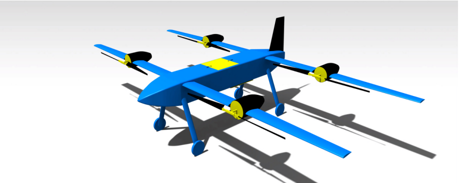
Airfoil Selection and Wing Design



SD7062 Airfoil.
High L/D and High stall angle of attack.

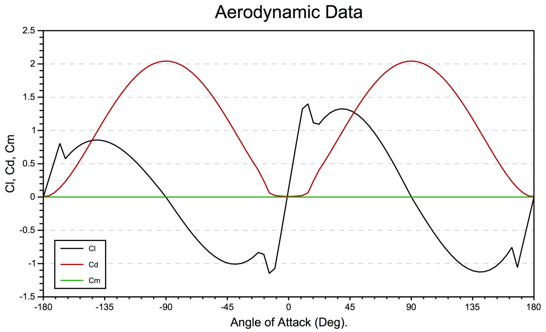


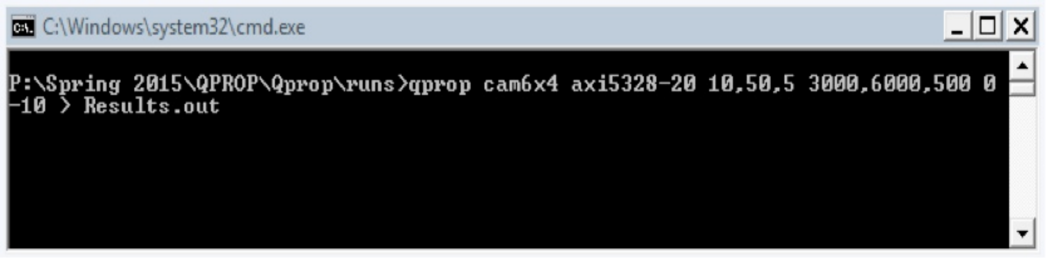
Red lines indicate wing spar location.

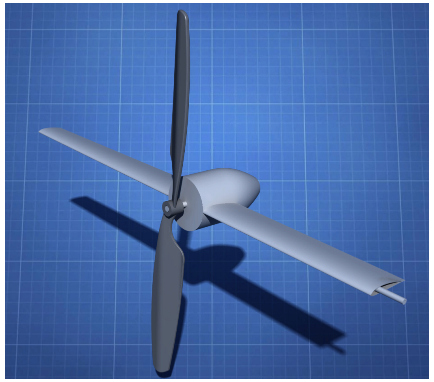


Parameter	Value
Span	10.447ft
Reference chord	1.097ft
Aspect ratio	25
Inboard wing taper	1
Outboard wing taper	0.7
Front wing incidence	2 deg
Rear wing incidence	1 deg
Front inboard wing twist	0 deg
Rear inboard wing twist	0 deg
Front outboard wing twist	-1.5 deg
Rear outboard wing twist	-1.5 deg

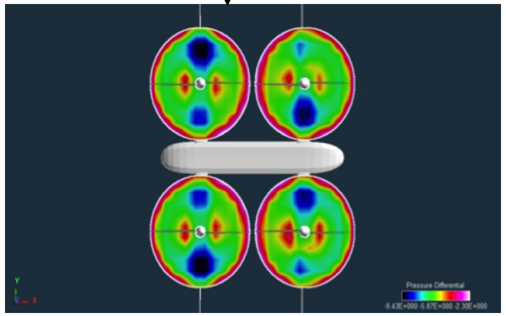
Rotor Design





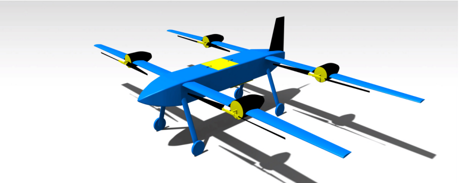


Airfoil analysis using XFLR → **Combined motor and rotor analysis using QPROP(cruise)/BEMT(hover)** → **CATIA V6**



CFD analysis using RotCFD → **3D print the blade and hardware validation** → **Final Result**

Parameter	Value
Root Chord Length	2 inches
Taper Ratio	0.3
Fixed Pitch	0 degrees
Tip Angle of Attack	6 degrees
Root Angle of Attack	45 degrees
Blade Radius	1.9 feet
Number of Blades	2

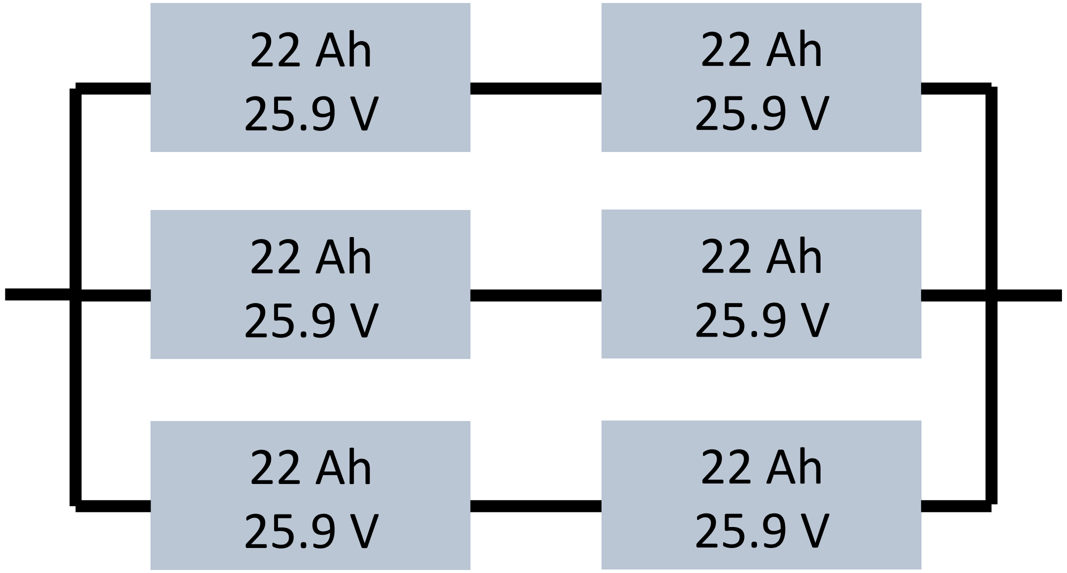


An iterative, multilevel process yields a rotor design that excels in both cruise and hover

Georgia Tech

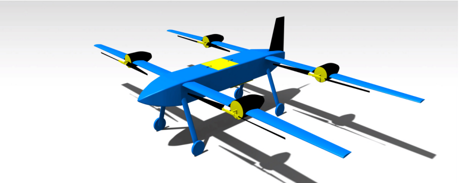
HARETC

Battery Pack

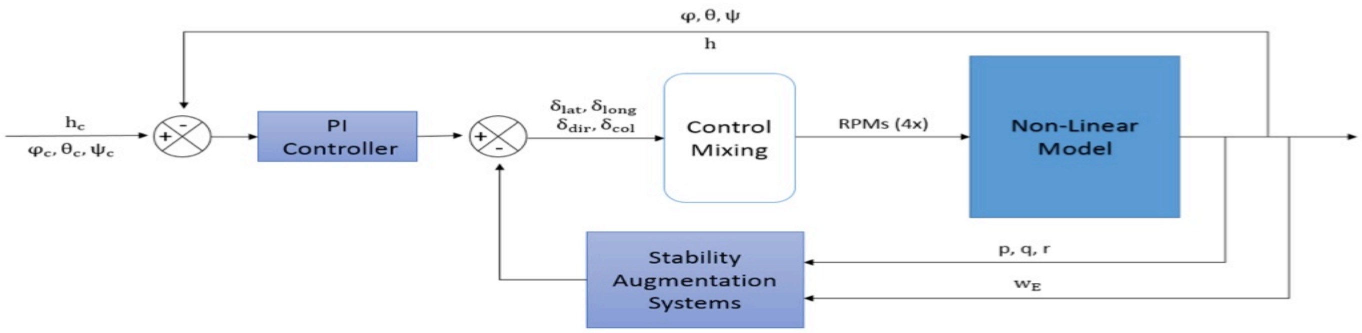


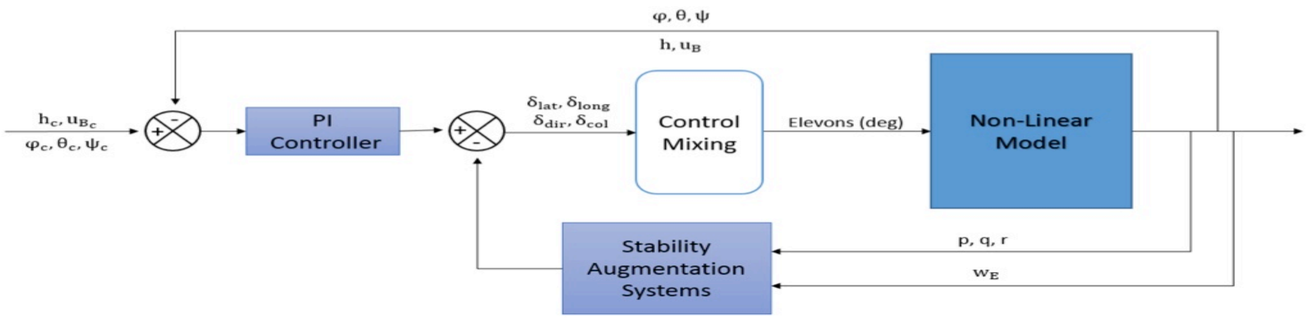
Parameter	Value
Capacity	66 Ah
Voltage	51.8 V
Rating	40C
Cells in each battery	7
Dimensions	$6.96inch \times 11.66inch \times 6.32inch$
Weight	36 lb
Specific energy	189.3 Watt-hour/Kilogram

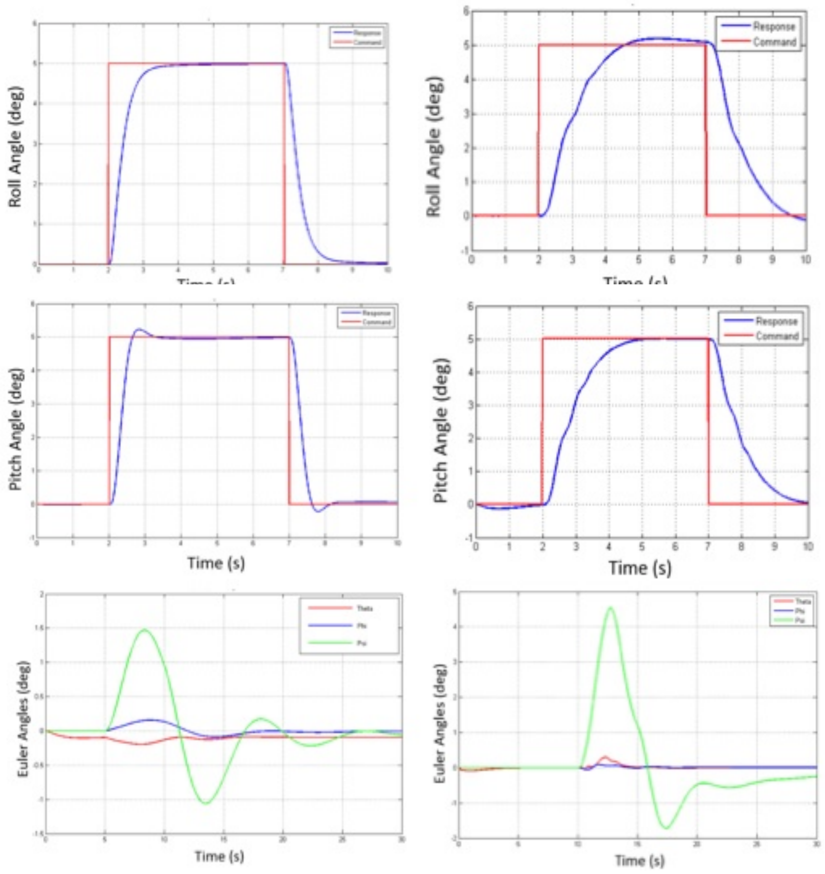
A series-parallel LiPo battery pack provides enough power and redundancy to power the vehicle.

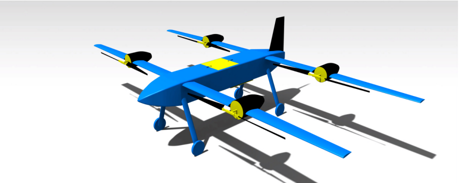


Guidance, Navigation, and Control









A non-linear 6 degrees of freedom (DOF) system is designed to model vehicle dynamics. Simulation shows good attitude tracking and gust response.

HARETC

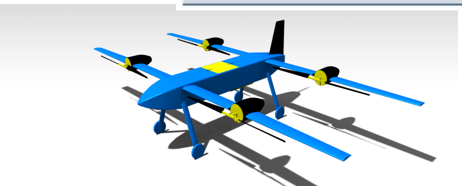
Hover and Cruise Control Gains

	Roll Rate (p) Gains	Pitch Rate (q) Gains	Yaw Rate (r) Gains	Vertical Speed (h) Gains	
	Kp_p	Kp_q	Kp_r	Kp_h	Ki_h
Hover (0 mph)	10	20	10	-20	-15
Cruise (113 mph)	0.6	0.35	0.3	0.7	0.1

	Altitude (ft)	Forward Velocity (mph)	Collective Angle (deg)	Right Front RPM	Left Front RPM	Left Aft RPM	Right Aft RPM	Roll Angle (deg)	Pitch Angle (deg)	Yaw Angle (deg)	Right Front Elevon (deg)	Left Front Elevon (deg)	Left Aft Elevon (deg)	Right Aft Elevon (deg)
Hover	6010	0	12	1989	1989	1618	1618	0	-0,18	0	0	0	0	0
Cruise 1	6480	80	12	2858	2858	2858	2858	0	5.35	0	1.01	1.01	-1.01	-1.01
Cruise 2	6480	120	12	4238	4238	4238	4238	0	-0.71	0	-0.13	-0.13	0.13	0.13
Cruise 3	6480	140	12	4931	4931	4931	4931	0	-1.96	0	-0.33	-0.33	0.33	0.33

	Roll Angle (ϕ) Gains		Pitch Angle (θ) Gains		Altitude (h) Gains		Velocity (u) Gains	
	Kp_ϕ	Ki_ϕ	Kp_θ	Ki_θ	Kp_h	Ki_h	Kp_u	Ki_u
Hover (0 mph)	50	0.1	28	3.1	-10	-5	-	-
Cruise (113 mph)	2	0.3	1.6	0.2	0.09	0.02	10	6

In cruise, the main logic for controlling the attitude rate depends on control surface deflections. All elevons are used for pitching and rolling and the rudder is utilized for yawing. On the other hand, in hover the differential RPMs are used excluding the elevons. In this case, total thrust is kept constant during all RPM changes and yaw motion is controlled by varying cross rotors RPMs.



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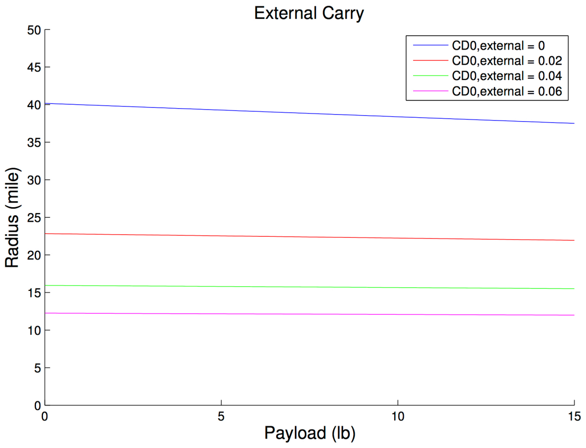
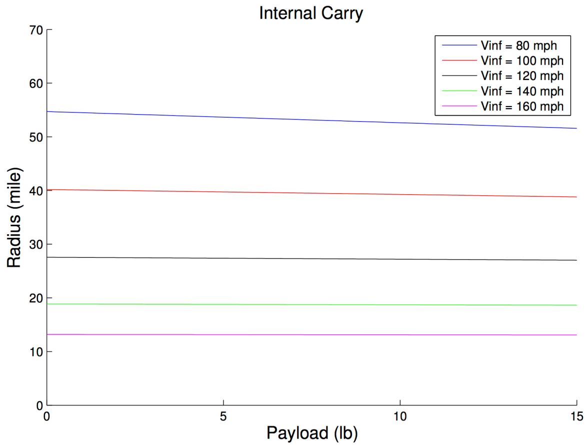
HARETC

Performance



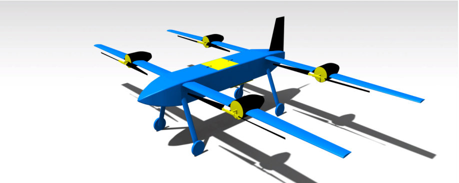


Range Payload diagram(top)

HARETC is a highly flexible vehicle, capable of carrying packages both inside and outside, flying at different velocity. HARETC is able to perform up to 2 standard 10 mi. x 13 lb mission with 1 time battery charge.

Airspeed (mph)	External drag	Power (hp)	Thrust(lb)	Motor efficiency	Rotor efficiency	Range (mile)
80	0	1.0595	4.9665	0.94922	0.59945	103.1603
100	0	1.3791	5.1715	0.95019	0.6091	77.6046
120	0	1.9546	6.108	0.95404	0.64732	54.0274
140	0	2.8122	7.5325	0.95861	0.69206	37.2703
160	0	3.9865	9.3431	0.96294	0.73401	26.1823
80	0.06	2.5648	12.022	0.9675	0.77821	41.3091
100	0.06	4.319	16.1958	0.972	0.82201	24.2521
120	0.06	7.0347	21.9831	0.97528	0.85461	14.8161
140	0.06	10.8793	29.1402	0.97716	0.8747	9.5586
160	0.06	16.0283	37.5654	0.97816	0.88742	6.4806

Typical Mission Table



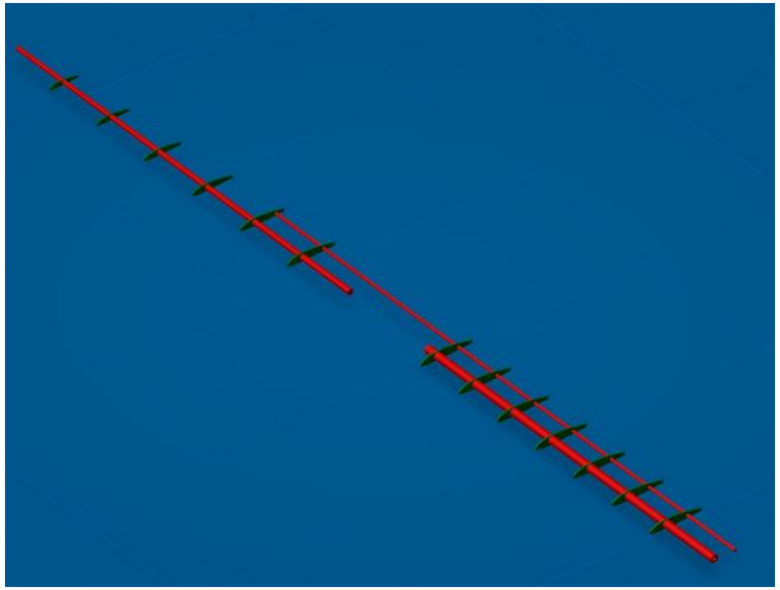
Time	First Package	Time	Second Package
00:00	Vehicle lands at central hub	19:00	Vehicle lands at central warehouse
00:30	Remove used battery	19:00	Use the same battery
01:00	Install new battery	19:00	Use the same battery
01:30	Upload mission waypoint	19:30	Upload mission waypoint
02:00	Load cargo	20:00	Load cargo
02:30	Pre-flight Checklist	20:30	Pre-flight Checklist
03:00	System self-diagnostics	21:00	System self-diagnostics
03:30	Takeoff	21:30	Takeoff
09:30	Reach destination	27:30	Reach destination
10:30	Land at destination	28:30	Land at destination
11:30	Unload cargo	29:30	Unload cargo
12:00	Takeoff	30:00	Takeoff
18:00	Reach hub	36:00	Takeoff
19:00	Land at central hub	37:00	Vehicle lands at central hub

Mission Time Table

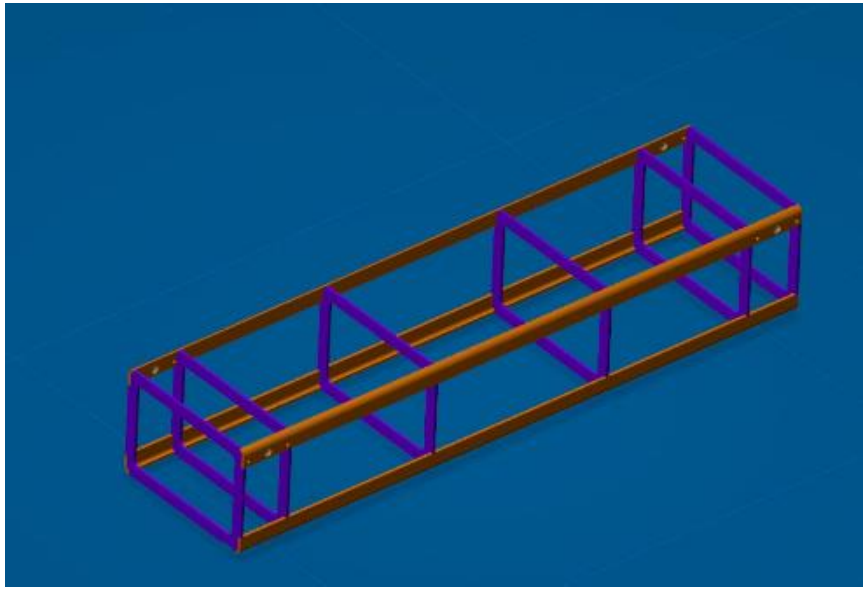
Georgia Tech

HARETC

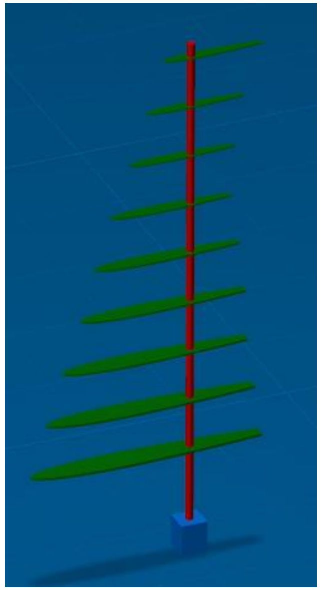
Structural Design



Wing Structure



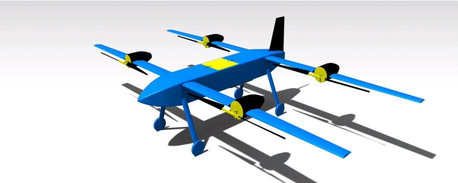
Fuselage Structure



Vertical Tail Structure

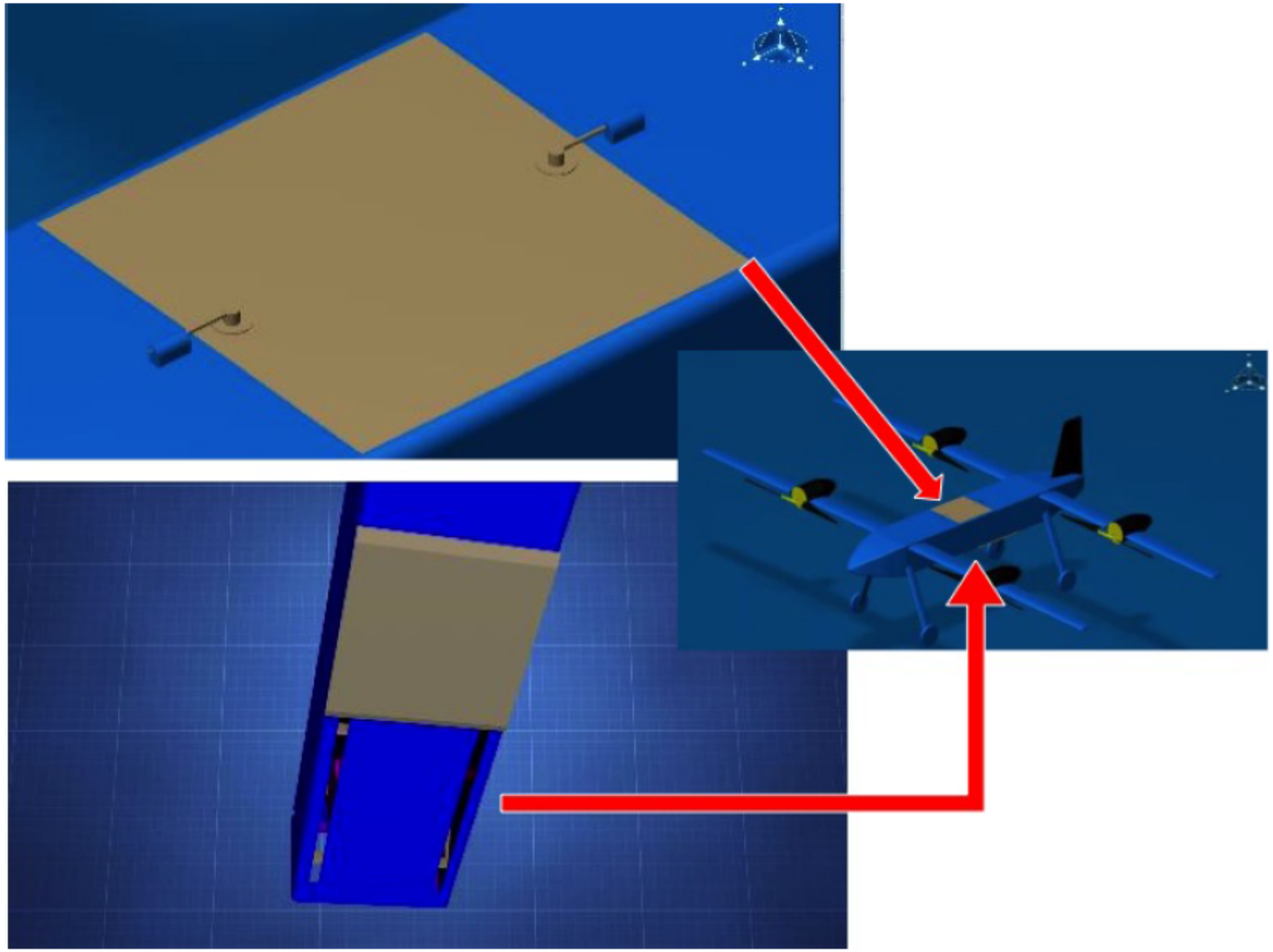
Each structure is composed of a diverse group of materials to achieve optimum strength while minimizing weight. The designs produce maximum performance with minimal compromise.

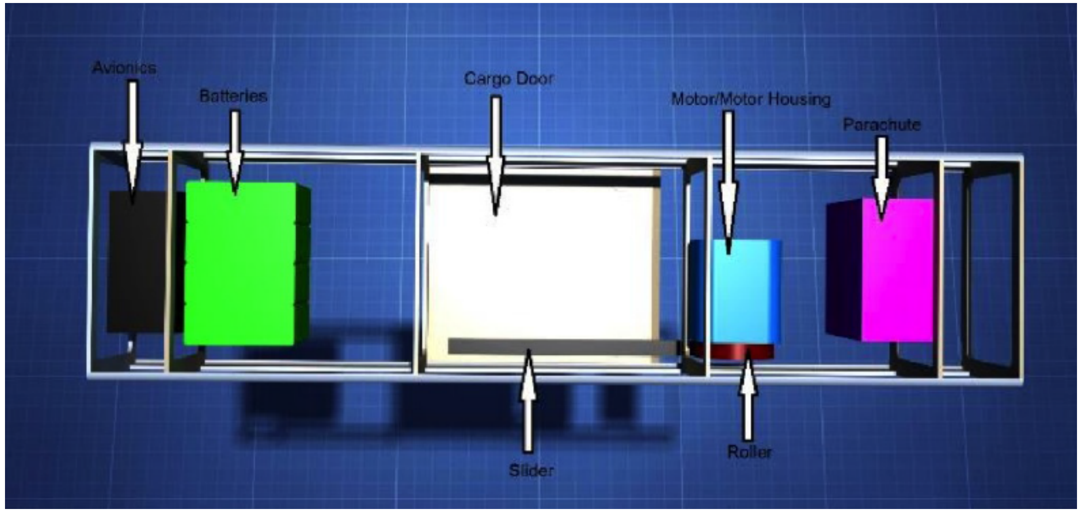
Parameter	Value		
Material	Density (lb/in3)	Elastic Modulus (ksi)	Yield Strength (psi)
Aluminum 2024-T6	0.1000	10,500	50,000
Aluminum 6061-T6	0.0975	10,000	40,000
Aluminum 7075-T6	0.1020	10,400	73,000
Carbon Fiber (unidirectional)	0.0254	26,000	170,000
E-Glass Epoxy	.0693	6,200	105,000
Polypropylene	.0324	210	1,200
S-Glass Epoxy	.0649	5,720	120,000
Steel AISI 1045	0.2778	29,700	86,670
Titanium Ti-6Al-4V	0.1600	16,500	128,000



Vehicle Layout and Cargo Logistics

Georgia Tech





Cargo is loaded into vehicle through manual door on top of vehicle. Cargo is unloaded through automatic sliding doors on bottom of vehicle.

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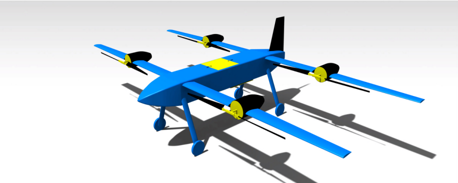
Cost Analysis

Total Manufacture Cost

Type	Cost
Structure	$ 275.00
Wing	$ 525.00
Landing Gear	$ 530.00
Blades X 4	$ 340.00
Controls	$ 325.00
Labor Pay	$ 800.00
Battery	$ 1,850.00
Motor	$ 4,500.00
Avionics	$ 290.00
electrical Components	$ 300.00
Instruments	$ 200.00
Rough Order Magnitude Adjustment at 10%	$ 1000.00
Total Manufacturing Cost	$ 10,935.00



Total Non-recurring Cost

TypeCost	Expenses
Engineering	
Design	$28600
Flight Test	$60000
Component Test	$20600
Systems Engineering/ Project Management	$35000
Total Engineering	$144200
Manufacturing Engineering	
Planning, Loft, Other	$30600
Project Management	$75000
Total Manufacturing Engineering	$105600
Tooling	
Tool Make	$78300
Outside Tooling	$24200
Total Tooling	$102500
Manufacturing	
Software	$71500
Flight Test	$18700
Component Test	$90000
Total Manufacturing	$180200
Logistics	$114200
Rough Order Magnitude Adjustment at 10%	$64670
General & Administrative Cost at 10%	$64670
Total Cost without Profit	$776040
Profit at 15%	$116406.05
Grand Total	$892446

Recurring Cost

Table 24: Total Direct Expenses

TypeCost	Expenses
Direct Mission Costs (no labor)	$15.00
General and Administrative	$350.00
Insurance	$25.00
Depreciation	$143.00
Total Direct Expenses	$533.00

Table 25: Staff Expenses

TypeCost	Expenses
Training Expenses	$600.00
Flight Technicians	$450.00
Engineering and Marketing	$150.00
Total Staff Expense	$1,200.00

Table 26: Direct Operating Cost (1 year 1 vehicle)

TypeCost	Expenses
Batteries X 6 (every 20 days)	$2,100.00
Blades	$910.00
Tooling	$350.00
Direct Operating Cost	$3,360.00

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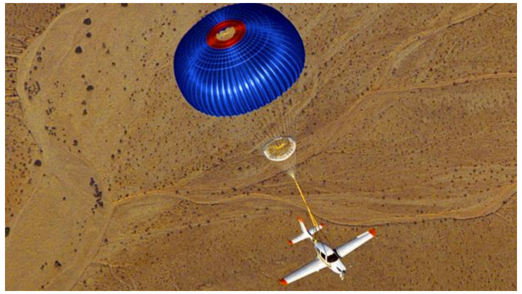
Reliability & Safety



Parachute

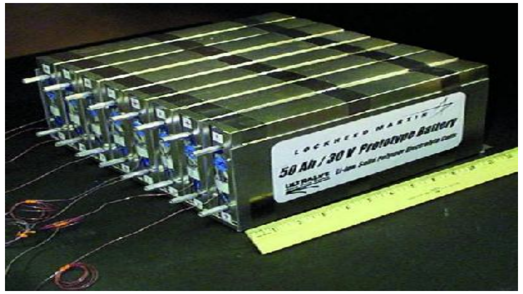
$$Probability\ of\ vehicle\ loss = A^X + B^Y + C^Z + D^N + E^M = 1.879E-7$$

Vehicle reliability study calculation based on Boeing report.

Gliding

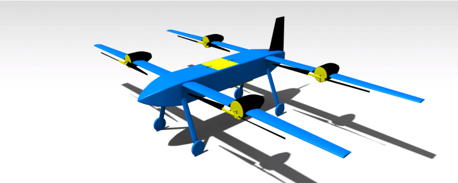
$$\frac{P(F)}{hr} = \frac{P(Inc)}{hr} \times A_{exp} \times \rho \times P(F|Exp)$$

$$\frac{P(F)}{hr} = 1.879E-7 \times 45ft^2 \times 7.24e-6people/ft^2 \times 25\% = 1.5304455e-11$$



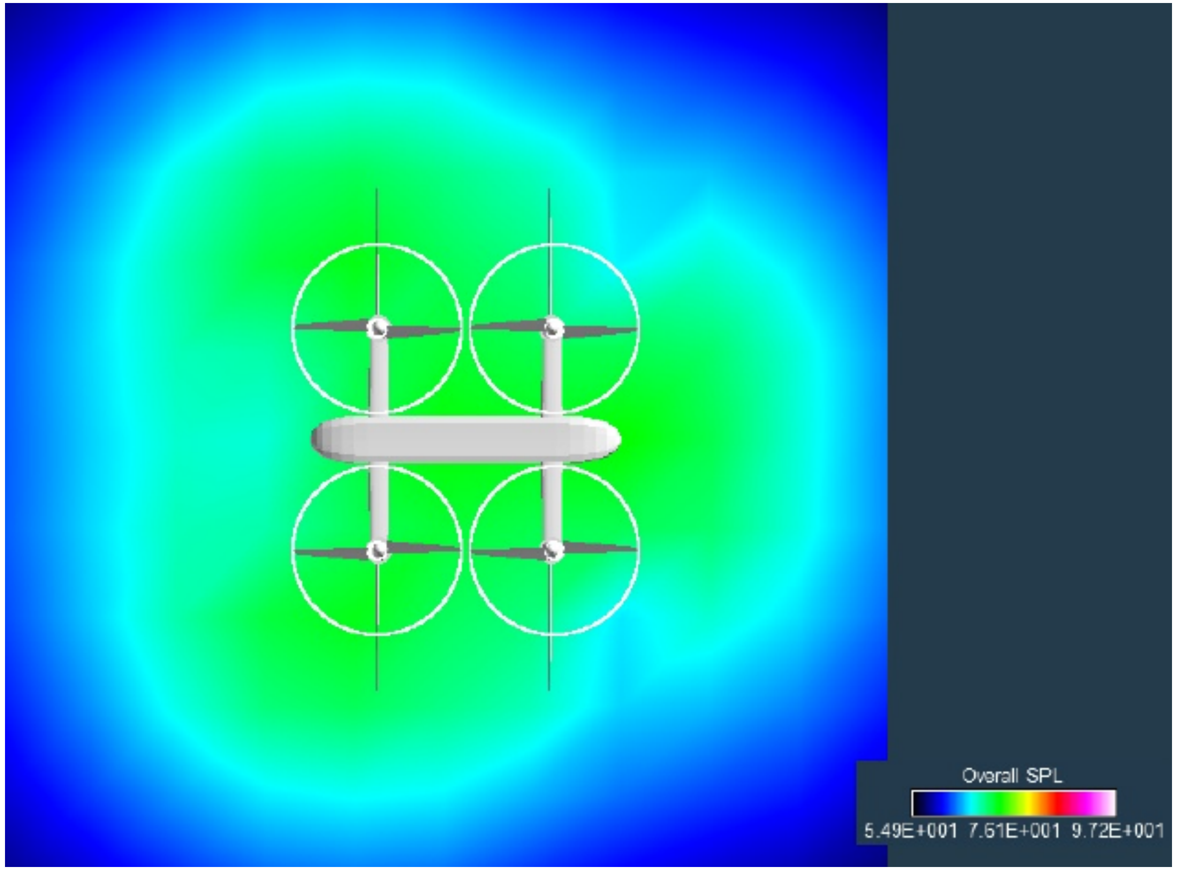
Emergency power

Vehicle level of safety and the probability of fatal ground collision are estimated using a MIT study.

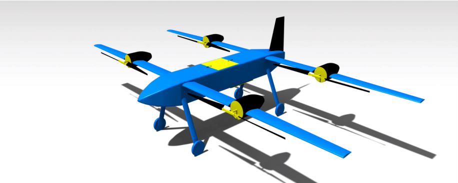


Triple redundancy, triple safety

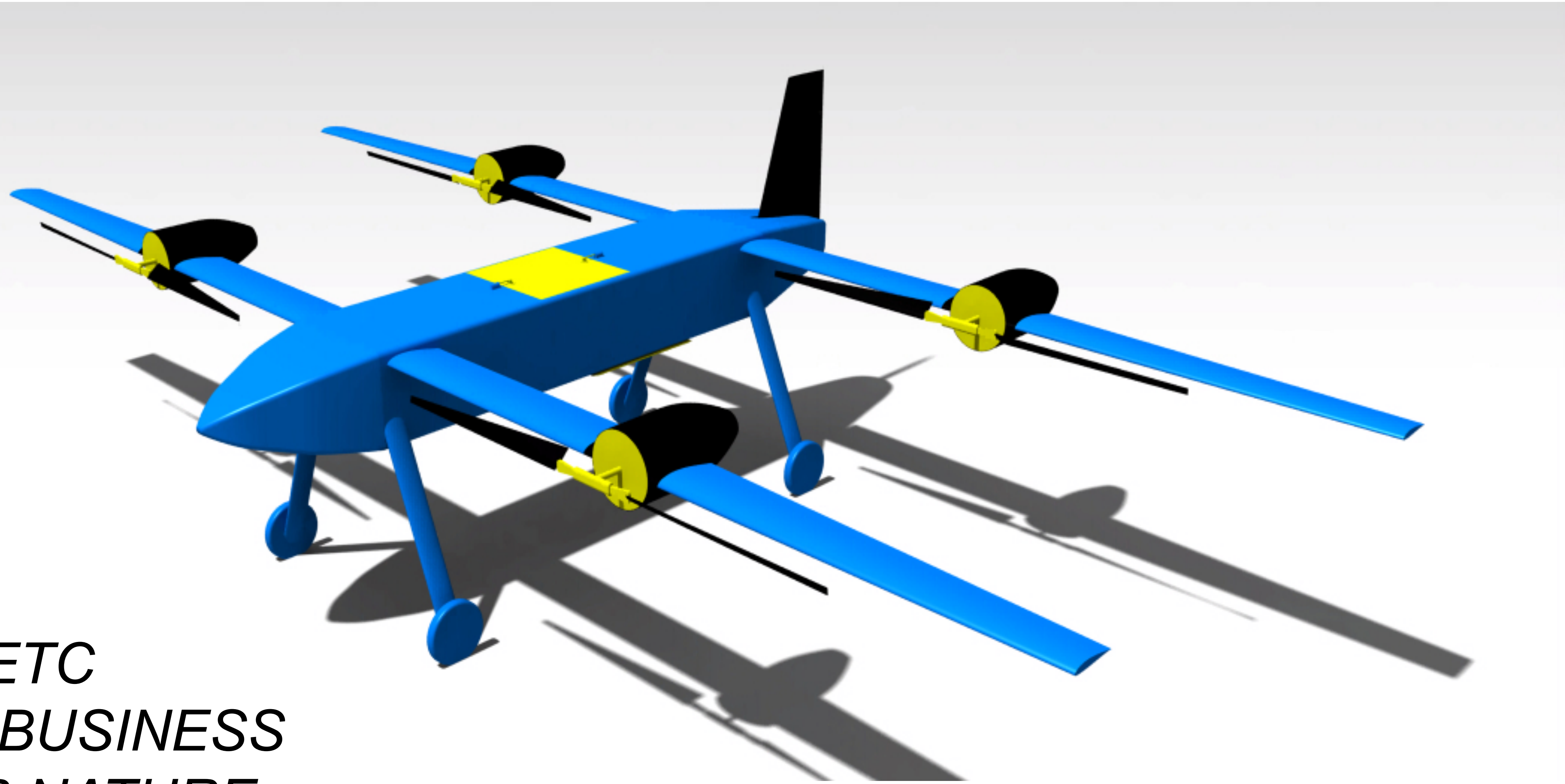
Noise and Emissions



HARETC noise profile is in full compliance with 14 CFR Part 150



HARETC Noise Contour obtained from RotCFD.(10 ft AGL, maximum thrust)



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