HELLUVACOPTER

Georgia Institute of Technology Daniel Guggenheim School of Aerospace Engineering

35th Annual AHS Student Design Competition
Undergraduate Executive Summary

This design project was completed for credit in AE 4343, Rotorcraft Senior Design.

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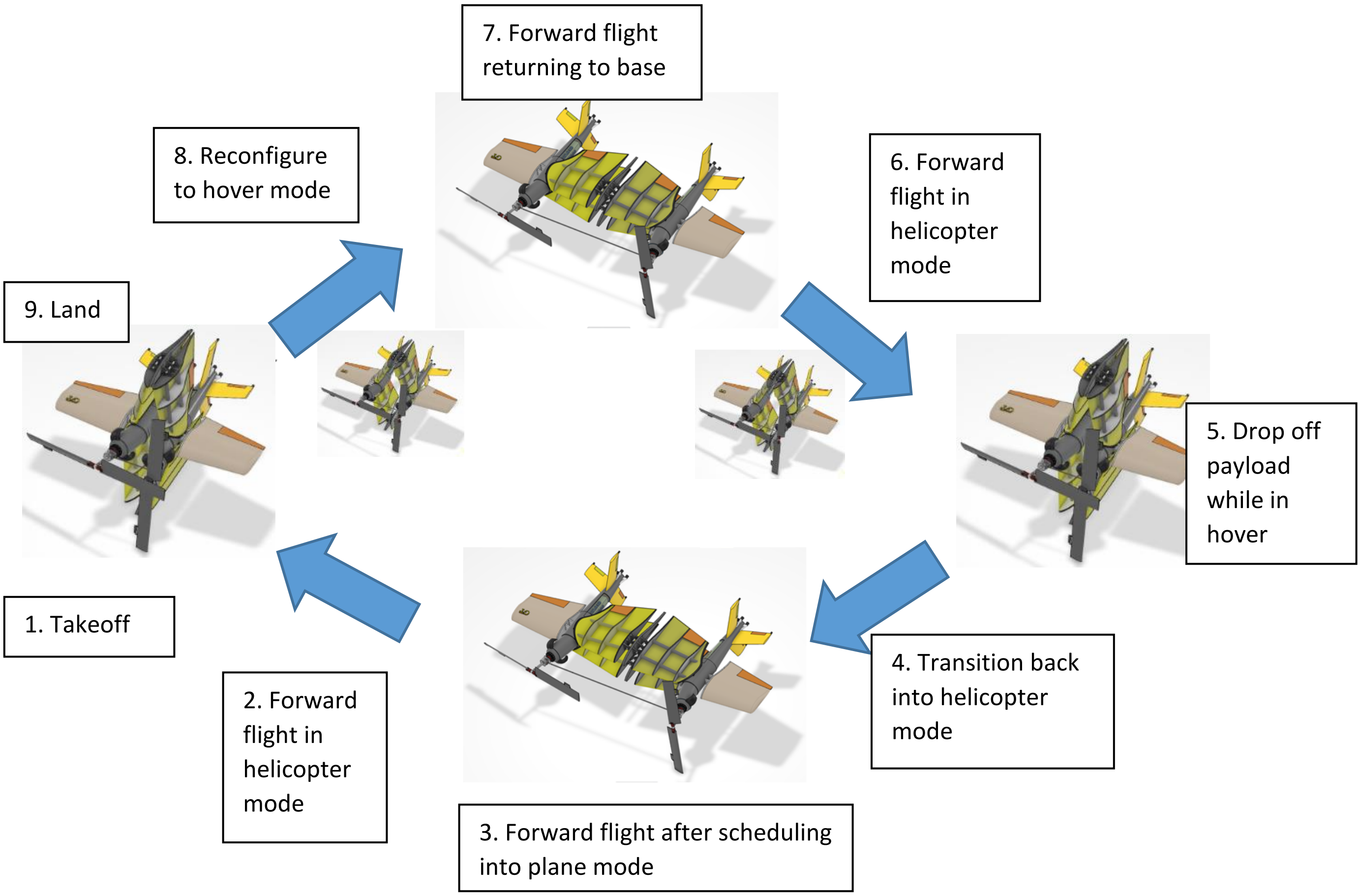
The Mission

Design a Group 3 size unmanned vertical takeoff and landing aircraft that achieves high speed forward flight and is efficient in hover through the use of novel reconfigurable propulsive and lifting devices.

Requirements

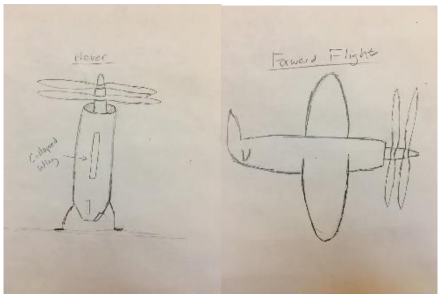
- Max takeoff weight shall be no more than 600 kgs.
- Vehicle shall be able to operate at 3000m.
- Maximum airspeed shall be at least 180 knots.
- Payload shall be at least 100 kgs.
- Maximum vehicle span shall be no more than 3m in hover configuration.

CONOPS

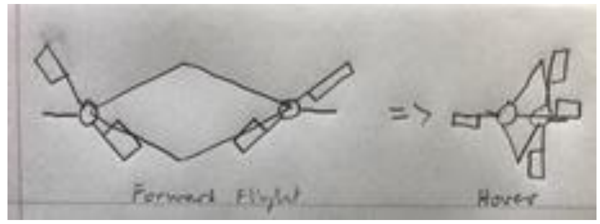


Concept Generation

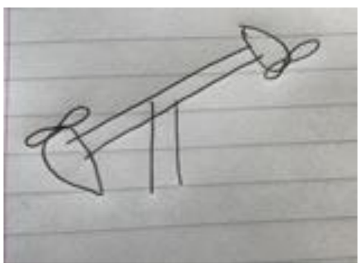
Alternatives we were considering



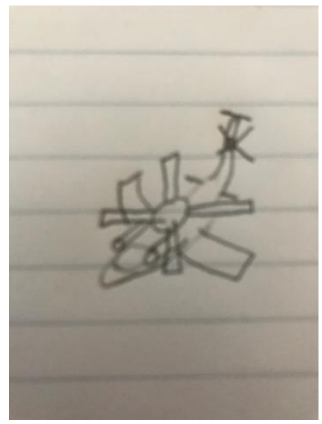
Coaxial Tailsitter



Shapeshifting Box wing

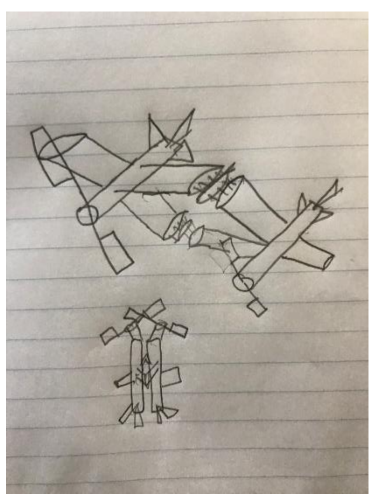


Tip Jet Propeller Rotor



X - Wing

Preliminary Drawings



Tradeoff

Prioritization

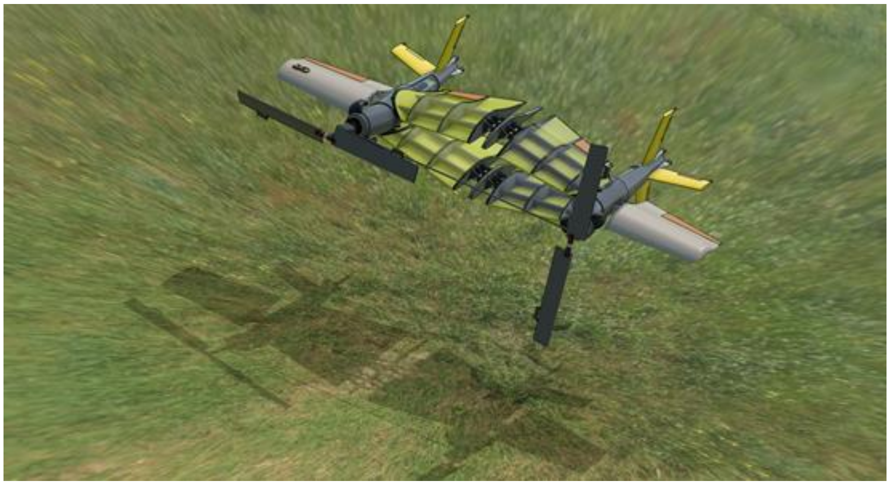
	Reconfig.	*Novelty*	*MTOW*	*Max Airspeed*	*Compactness*	*Hover Time*	*Cruise Range*	*Drag Area*	*Dash Speed*
Reconfig.	1.00	1.00	1.00	1.00	1.00	0.17	0.17	0.33	0.17
Novelty	1.00	1.00	1.00	0.33	9.00	0.33	0.33	0.33	0.33
MTOW	1.00	1.00	1.00	1.00	1.00	0.33	0.33	0.33	0.17
Max Airspeed	1.00	3.00	1.00	1.00	1.00	0.17	0.17	1.00	0.11
Compactness	1.00	0.11	1.00	1.00	1.00	0.17	0.33	1.00	0.17
Hover Time	6.00	3.00	3.00	6.00	6.00	1.00	1.00	3.00	0.33
Cruise Range	6.00	3.00	3.00	6.00	3.00	1.00	1.00	1.00	0.33
Drag Area	3.00	3.00	3.00	1.00	1.00	0.33	1.00	1.00	0.33
Dash Speed	6.00	3.00	6.00	9.00	6.00	3.00	3.00	3.00	1.00
Normalized	*18.65%*	*14.09%*	*13.06%*	*16.17%*	*21.45%*	*3.26%*	*4.04%*	*7.46%*	*1.81%*

QFD

	Weight	*Weight Empty Fraction*	*Propulsion Efficiency*	*Useful Specific Energy*	*Specific Power*	*FM*	*Disc Area*	*Flat Pate Area*	*Useful Wing Area*	*Hover Download*	*Transition Complexity*
Reconfig.	0.1865	2	1	2	0	0	0	2	3	1	3
Novelty	0.1409	1	1	1	1	1	1	1	1	1	3
MTOW	0.1306	3	3	3	2	3	3	1	2	3	3
Max Airspeed	0.1617	0	0	3	1	0	1	3	1	0	0
Compactness	0.2145	1	3	2	0	3	3	3	3	2	2
Hover Time	0.0326	3	3	3	3	3	3	0	0	3	0
Cruise Range	0.0404	3	3	3	3	0	2	3	3	0	0
Drag Area	0.0746	0	0	1	0	0	0	3	3	2	0
Dash Speed	0.0181	0	0	0	3	2	1	3	1	0	0

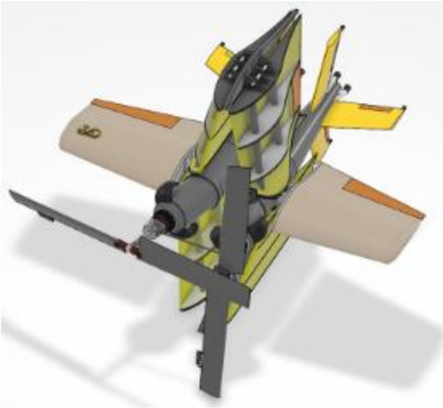
	Weight Empty Fraction	*Propulsion Efficiency*	*Useful Specific Energy*	*Specific Power*	*FM*	*Disc Area*	*Flat Plate Area*	*Useful Wing Area*	*Hover Download*	*Transition Complexity*
Total	1.34	1.58	2.11	0.78	1.27	1.52	2.12	2.11	1.40	1.80
Weight	8.35%	9.86%	13.18%	4.88%	7.94%	9.46%	13.21%	13.17%	8.70%	11.24%

Concept Design Summary

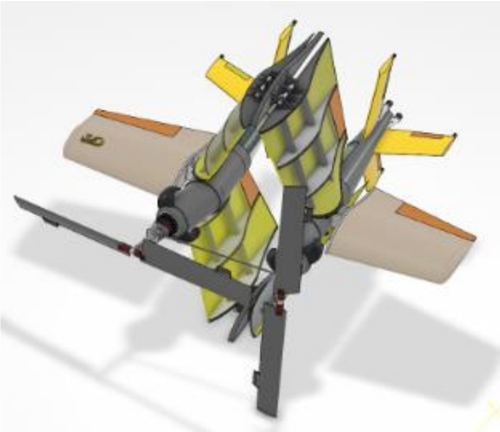


HELLUVACOPTER SPECIFICATIONS		
Dimensions		
Vehicle Span in Hover	3.0 m	9.84 ft.
Wingspan in Forward Flight	5.14 m	16.86 ft.
Wing Area	5.88 m^2	63.29 $ft.^2$
Aspect Ratio	4.5	
Powerplant		
2 X Stuttgart Engineering STV 130		
Engine Rating		
Maximum Continuous Power	112 kW	150 HP
Specific Fuel Consumption	0.36 kg/kW/hr.	0.58 lb./HP/hr.
Weight		
MTOW	600 kg	1322.77 lb.
Empty	334.5 kg	737.45 lb.
Payload	100 kg	220.46 lb.
Fuel	165.5 kg	364.87 lb.
Performance		
Hover Time @ SL 50%	2.2 hr.	
Hover Time @ 3000 m 50%	1.8 hr.	
Range @ SL	932 km	503 nm.
Range @ 3000 m	999 km	539 nm.
Dash Speed	403 km/hr.	216 kn.
Drag Area	0.47 m^2	5.1 $ft.^2$

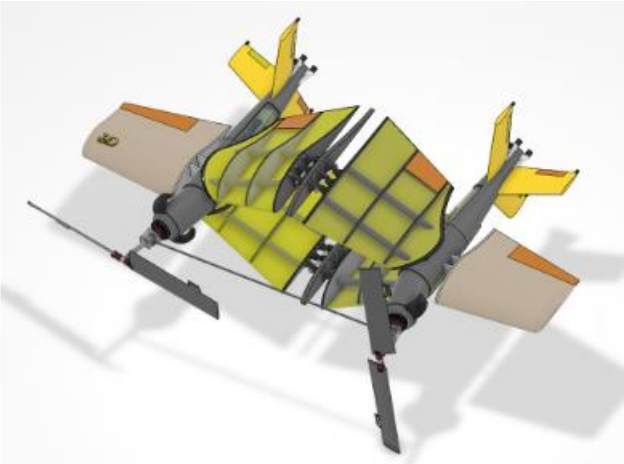
Reconfigurability



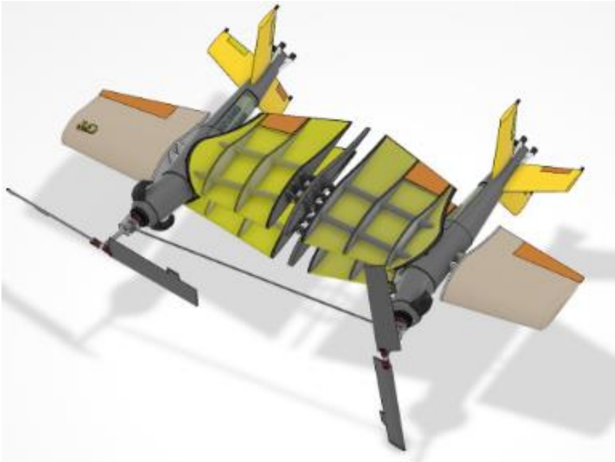
Hover configuration as seen in an isometric view.



Actuators used to open the aircraft in order to transition.



Aircraft is almost fully transitioned for forward flight.



Aircraft is in forward flight configuration as seen in an isometric view.

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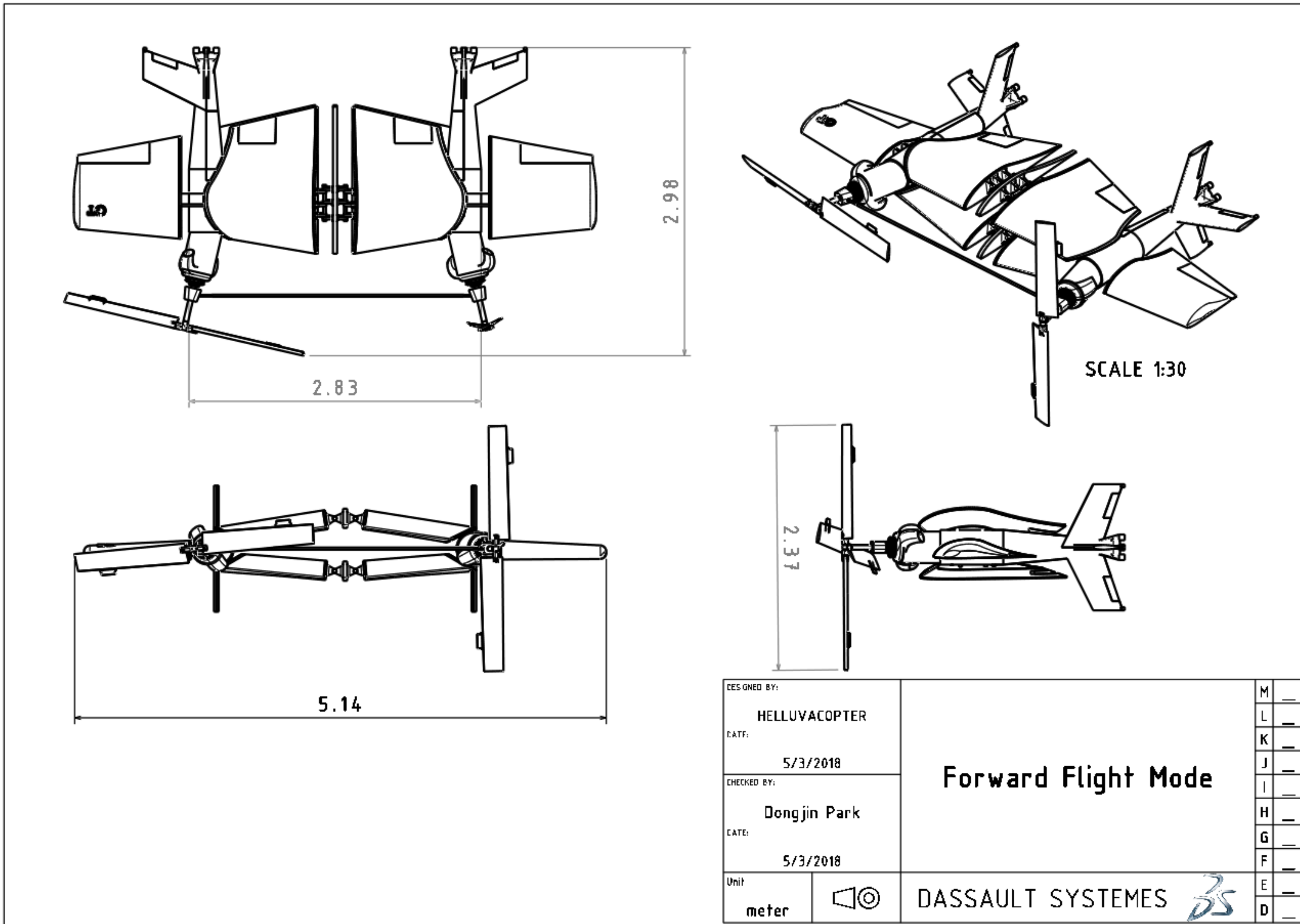
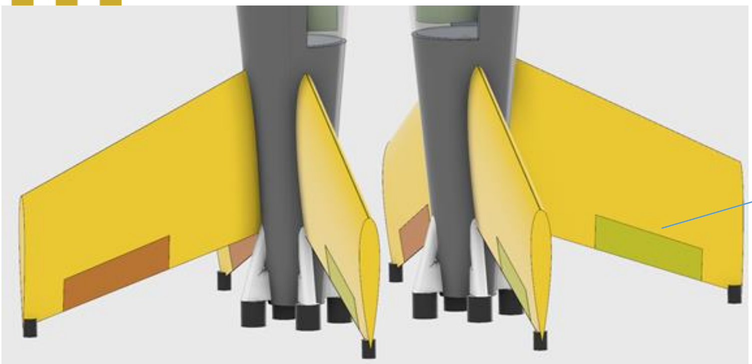
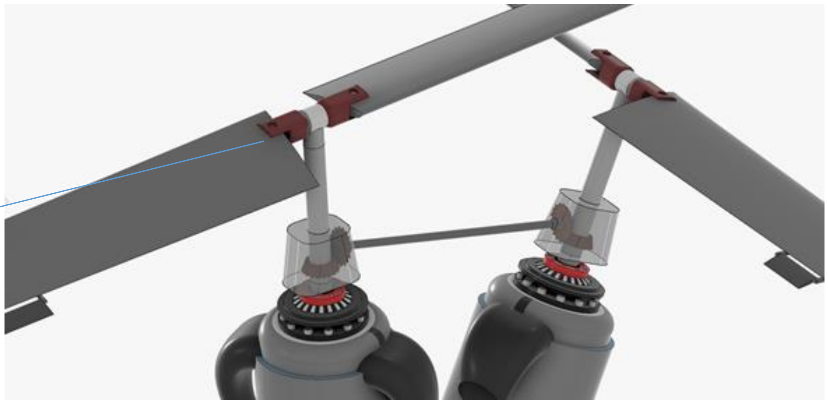

2.98
2.83
SCALE 1:30
5.14
2.37
DESIGNED BY:
HELLUVACOPTER
DATE:
5/3/2018
CHECKED BY:
Dongjin Park
DATE:
5/3/2018
Unit
meter
Forward Flight Mode
DASSAULT SYSTEMES
M L K J I H G F E D

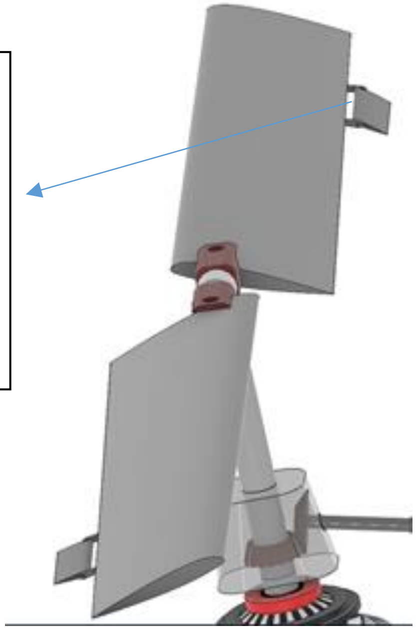


Elevator and Rudders are introduced in the landing gear as this aircraft is a tail sitter.

Rotor is using teetering hinge as is common among intermeshing rotors.



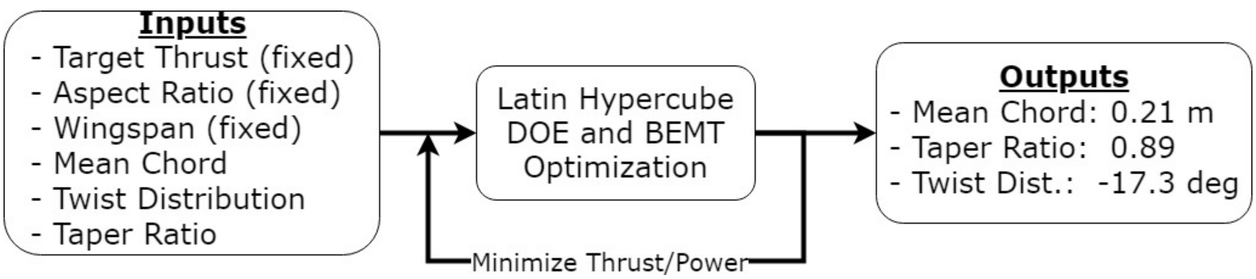
Rotor blades include servo flaps in order to minimize weight for hydraulic systems to change rotor pitch.



Sync-shaft is used in order to maintain intermeshing rotors and counter rotating rotors.

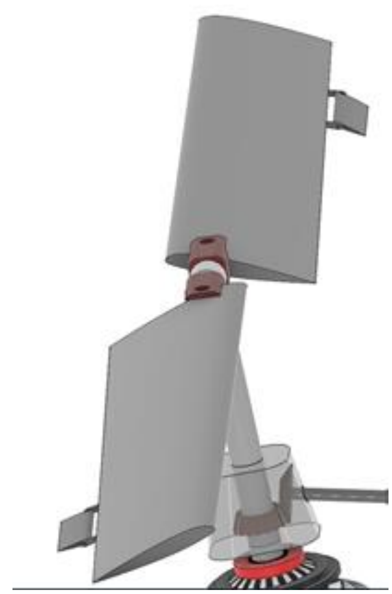
Optimized Rotors

Characteristic	Value
Radius (m)	1.1
Number of Blades	2
Mean Chord (m)	0.21
Taper Ratio	0.89
Blade Twist (°)	-17.3
Airfoil	NACA 23012
Tip Speed (m/s)	198

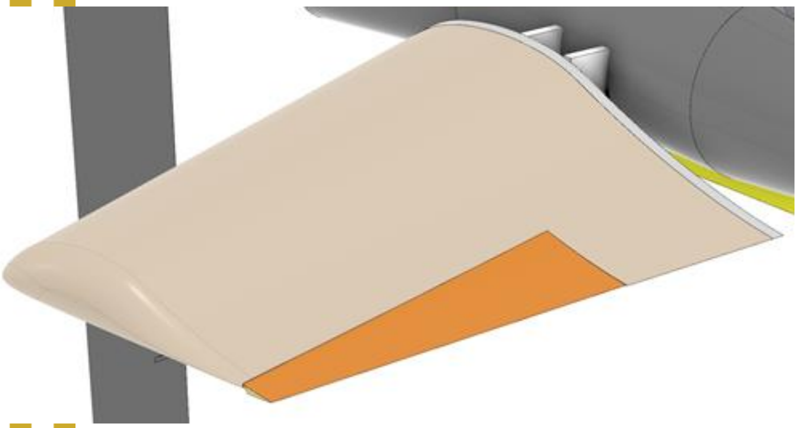


A Latin hypercube design of experiment was used along with combined blade element momentum theory in order to determine the optimal mean chord, taper, and twist.

The tip speed was set to 650 ft/s in order to minimize power required and still be able to produce the proper amount of thrust. A variable twist was used in order to optimize the inflow through the rotors as well as be a compromise for when the rotors act as propellers in forward flight.

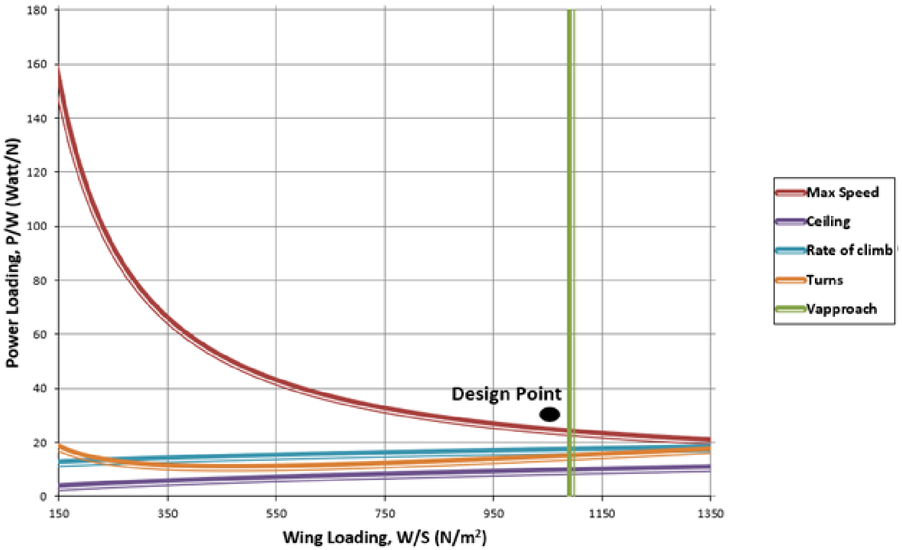


Body Wing Design

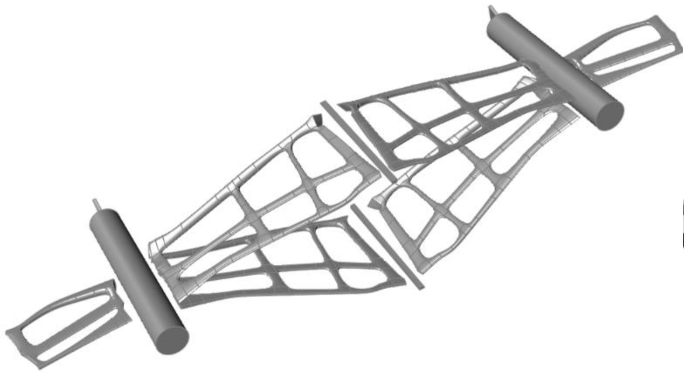


Dimension	Value
Aspect Ratio	4.5
Wing Area	5.88 m
Wing Span	5.14 m^2
Taper Ratio	0.84
Airfoil	Miley M06-13-128

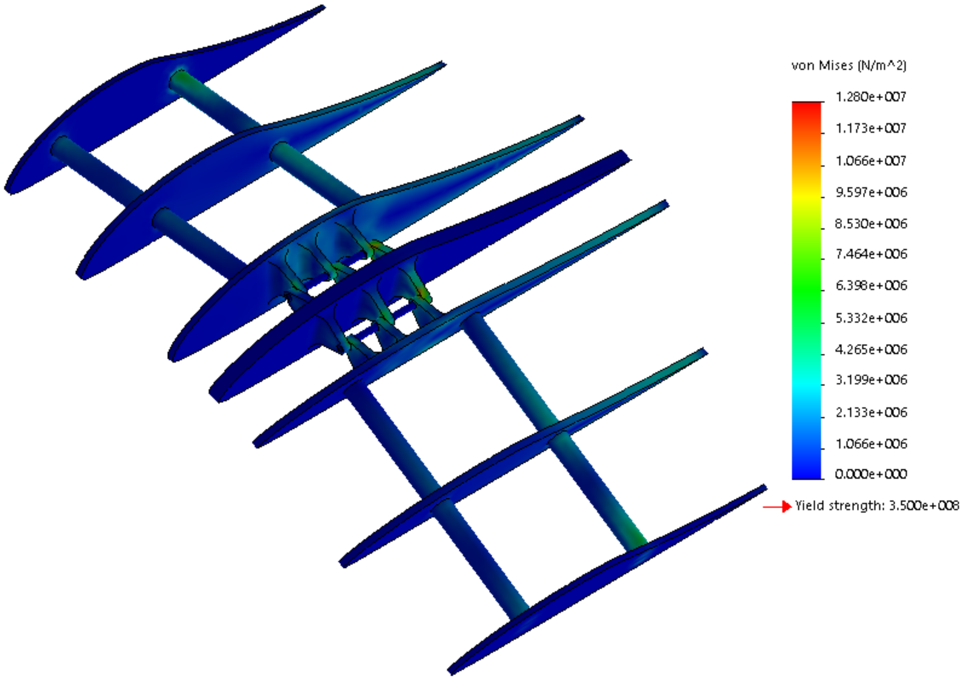
The body wing airfoil's design point was determined by comparing the power loading to the wing loading with the constraints of max speed, ceiling, rate of climb, turn, and Vapproach.



Structural Design



Finite Element Analysis was done with an applied load path in order to find the optimal internal structure required with spars and ribs. These were then formed into the internal structure seen to the right. A Von Mises contour plot was then created on this internal structure in order to see the yield strength of the structure.



Power plant Selection

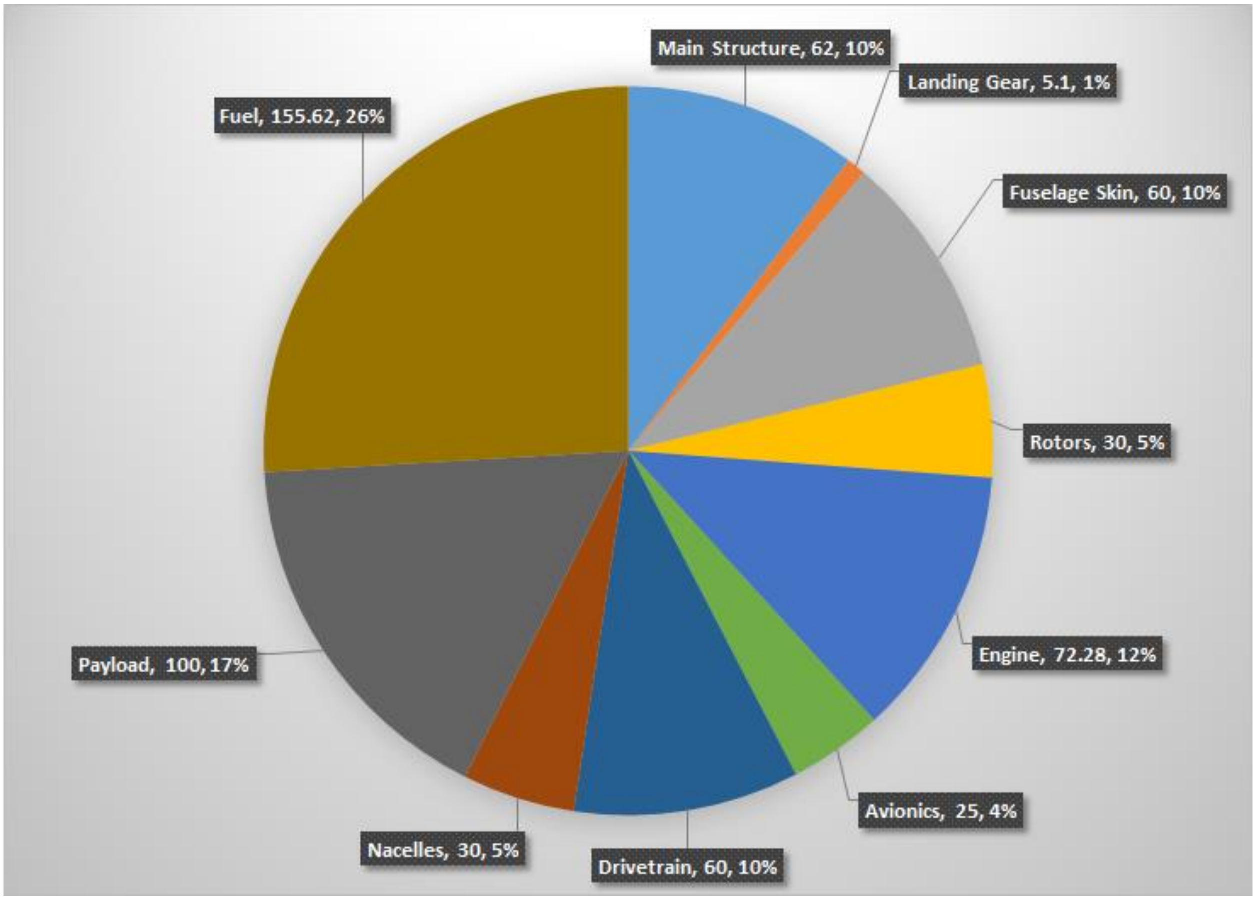
Base Model	Type	SFC (kg/kW/h)	Mass (kg)
Kawasaki 1043 cc	Gasoline Piston	0.34	63.9
STV - 130	Gasoline Turboprop	0.36	32.5
Rotax 915	Gasoline Piston	0.26	85.8
CD - 155	Diesel Piston	0.22	130.3

Engine	SFC (kg/kW/h)	Engine Mass Fraction	Est. Endurance (h)
Kawasaki 1043 cc	0.34	0.21	2.16
STV - 130	0.36	0.11	4.04
Rotax 915	0.26	0.29	1.81
CD - 155	0.22	0.43	-1.62

From this, we can see that the best engine is the STV-130 as it has the longest endurance compared to the alternative engines.

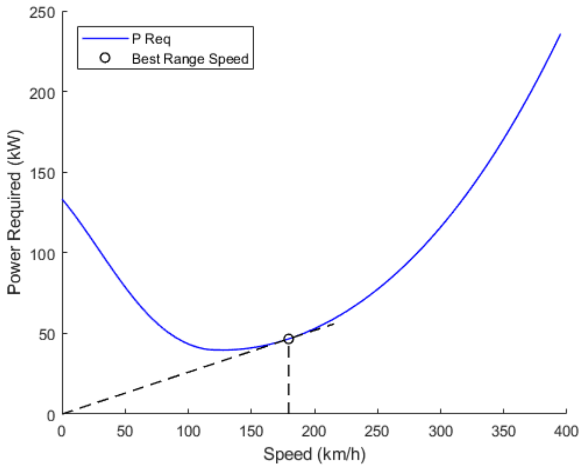
The selected engine spins very quickly due to its small size, the overall reduction ratio needed for the rotors is 23:1. While a high reduction ratio typically adds weight to the drive system, the corresponding low torque alleviates some of the pressure on the system and lessens the weight. Overall, the drive system weight was very small compared to that of the other options. This reduction ratio can be achieved with a two-stage planetary gear reduction at over 94% efficiency.

Weight Breakdown

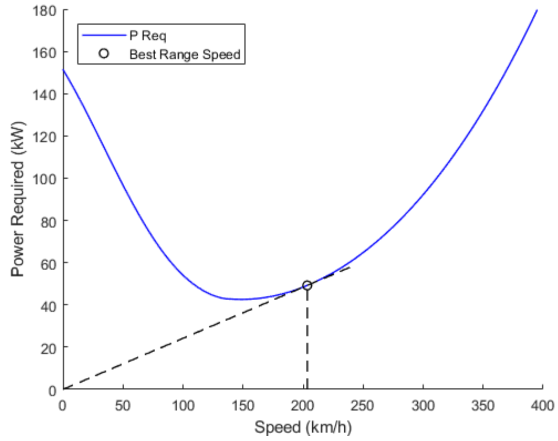


The goal was to minimize the empty weight fraction by reducing structural weight and engine weight along with the drivetrain. In doing so, we also lose on performance and in order to meet this. We used carbon fiber materials for the structure in order to keep the weight low as well as keeping the structure very strong. As can be seen, approximately 1/4th of our gross weight is fuel weight which allows us to have better range and endurance in hover at sea-level and 3000m.

Performance



The best range speed at sea-level.



The best range speed at 3000m.

Altitude	Range Speed (km/h)	Range w/ 50% Fuel (km)
Sea Level	179.6	932
3000 m	203.5	999

Altitude	Maximum Operating Power (kW)	Dash Speed (km/h)
Sea Level	250	403
3000 m	185	400

Specification	Metric	English
Hover Time @ SL with 50% Energy Consuption	2.2 h	2.2 h
Hover Time @ 3000 m with 50% Energy Consumption	1.8 h	1.8 h
Range @ Sea Level	932 km	503 nm.
Range @ 3000 m	999 km	539 nm.
Dash Speed @ Sea Level	403 km/h	218 kn.
Dash Speed @ 3000 m	400 km/h	216 kn.

The best range is higher at altitude as expected due to the lower amount of power required. Also, the constraining power requirement is the dash speed at sea-level.

The hover time at sea-level is higher than at altitude due to the lower power required to hover at sea-level.

Cost Analysis

Item	Cost (USD 2018)
Assembly	18,882
Main Structure	39,789
Landing Gear	2,648
Fuselage Skin	7,262
Rotors	21,948
Engine	26,826
Avionics	37,176
Drivetrain	13,734
Nacelles	9,348
Total	177,604

Each unit will have a production cost of $177,604 and are being made on a 20 year program. The margins are seen below where the company would be approximately $500 million USD in debt. However, after 13 years, the company would have recouped all losses and start profiting on every production unit sold.