RMIT SKYHOOK ENGINEERS

Undergraduate Team

EXECUTIVE SUMMARY

36TH ANNUAL STUDENT DESIGN COMPETITION

EXTREME ALTITUDE MOUNTAIN RESCUE VEHICLE

Vertical Flight Society

AIRBUS

RMIT UNIVERSITY

RMIT SKYHOOK ENGINEERS

2019 Skyhook Engineers Team

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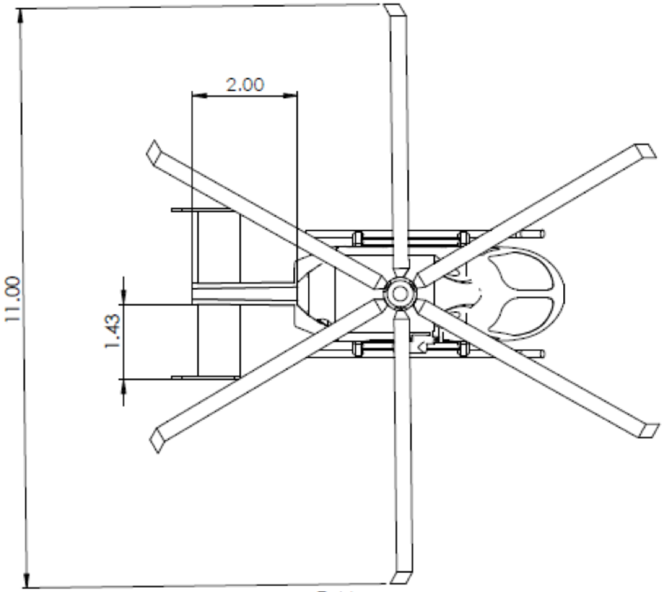
Consent and Request

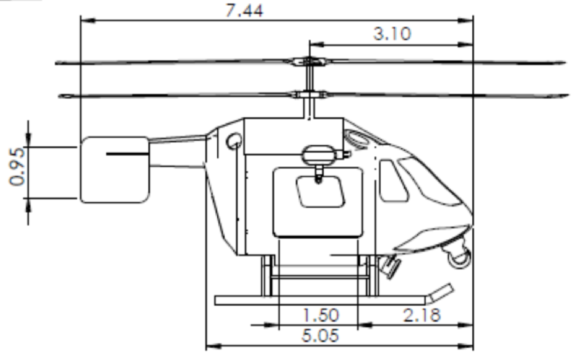
The RMIT Skyhook Engineers consent to publication of the Executive Summary on the Vertical Flight Society's website.Additionally, the RMIT Skyhook Engineers wish to receive feedback on their design.

DROP BEAR General Characteristics

Maximum take-off weight	$2{,}741.48\ kg$	$6043.93\ lbs$
Empty Weight	$1{,}956.48\ kg$	$4313.3\ lbs$
Useful Load fraction	$785\ kg$	$1730.63\ lbs$
Maximum cruise speed at sea level	$273.6\ km/h$	$147.7\ knots$
Hover ceiling	$9{,}327\ m$	$30{,}601\ ft$
Maximum range at sea level	$309.3\ km$	$167\ n\ miles$
Maximum Endurance at sea level	$2.53\ hours$	$2.53\ hours$

DROP BEAR Dimensions

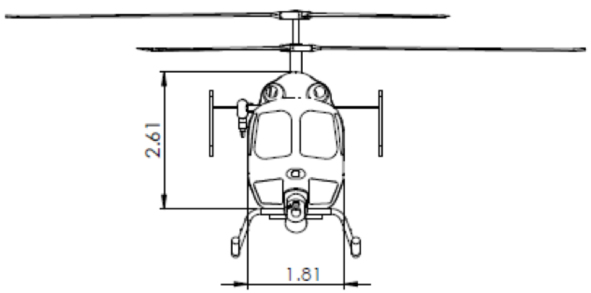




SCALE 1:80
MTOW 2,741.5 KG
Empty weight 1,956.48 KG

Hover cieling 9,327 M
Maximum range at sea level 309.3 KM
Maximum endurance at sea level 2.53 Hours

ALL DIMENSIONS ARE IN METRES



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:	DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING / REVISION
NAME / SIGNATURE / DATE			TITLE: RMIT SKYHOOK ENGINEERS - DROP BEAR SEARCH AND RESCUE HELICOPTER
DRAWN: RMIT UNDERGRADUATE TEAM			
CHK'D			
APPV'D			
MFG			
Q.A	MATERIAL:		DWG NO. FINAL / A3
	WEIGHT: 2741.5 KG		SCALE:1:100 / SHEET 1 OF 1

Top-down mission requirements

Þ The rotorcraft must complete the prescribed mission profile within 3 hours.

Þ The rotorcraft must be capable of extracting injured passengers in the worst-case scenario. Worst-case scenario is assumed to be unconsciousness.

Þ The rotorcraft must include a hoist system rated for 300 kg (662 lbs) with a minimum lifting load of 272.16 kg (600 lbs).

Þ The rotorcraft must include systems capable of surveying the ground and locating the injured passengers.

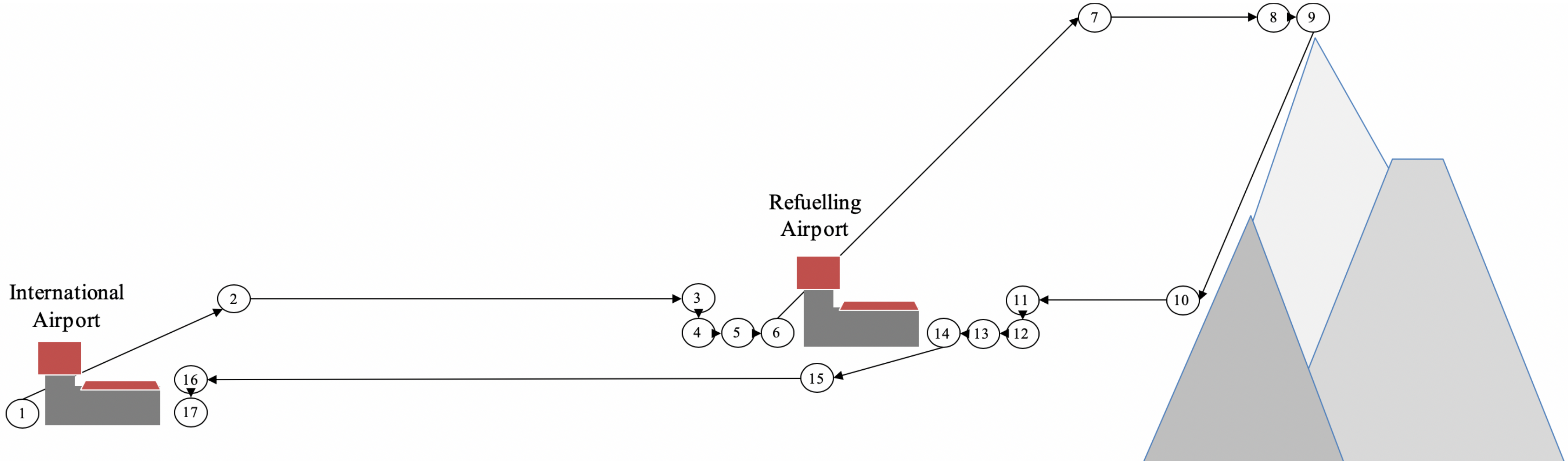
Þ The rotorcraft must be capable of maintaining heading in winds up to 74 km/h (40 knots) from any azimuth.

Þ The rotorcraft shall adhere to all FAA regulations and be certified for day and night IFR flight.

Þ All crew members must be capable of communicating with each other for the entirety of the mission.

RMIT SKYHOOK ENGINEERS

Mission Profile

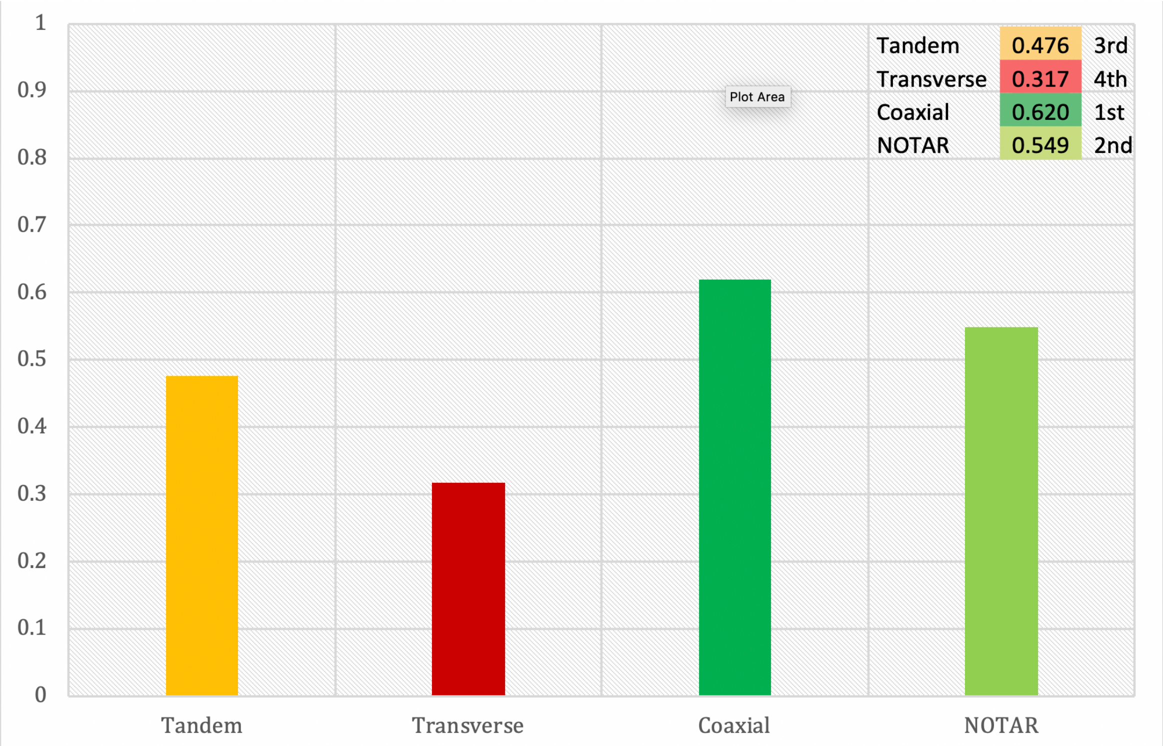


	START	2 min hover	Climb	Cruise	2 min hover	20 mins	2 min hover	Climb	Cruise	30 min hover
Phase Number	0	1	2	3	4	5	6	7	8	9
Altitude	1402	1402	1402-3780	3780	3780	3780	3780	3780-8870	8870	8870
Time [min]	0	2	2.62	35.6	2	20	2	5.75	4.69	30
Δx [m]	0	0	4718.25	130281.75	0	0	0	14483.74	13516.26	0
Δy [m]	0	~	2378	0	~	0	~	5090	0	~
Vx [m/s]	0	0	30	61	0	0	0	42	48	0
Vy [m/s]	0	0	15.12	0	0	0	0	14.76	0	0
e of attack [degrees]	0	90	26.75	0	90	0	90	19.36	0	0
Empty Weight	1939.37	1939.37	1939.37	1939.37	1939.37	1939.37	1939.37	1939.37	1939.37	1939.37
vailable Turboshaft [kW]	1343	1134	840.5	840.5	840.5	840.5	840.5	415.3	415.3	415.3
ilable Electric Engine [kW]	494	494	494	494	494	494	494	494	494	494
equired Turboshaft [kW]	0	673.3	840.5	812.8	720.5	0	720.5	415.3	415.3	415.3
uired Electric Engine [kW]	0	0	0	0	0	0	0	494	108.2	476.8
Fuel Weight [kg]	210	203.72	193.44	58.42	51.7	210	203.28	192.14	183.04	124.9
yload Weight [kg]	405	405	405	405	405	405	405	405	405	575
Current Weight	2554.37	2548.09	2537.81	2402.79	2396.07	2554.37	2547.65	2536.51	2527.41	2639.27

	Descent	Cruise	2 min hover	20 mins	2 min hover	Descent	Cruise	2 min hover	END
Phase Number	10	11	12	13	14	15	16	17	18
Altitude	8870-3780	3780	3780	3780	3780	3780-1402	1402	1402	1402
Time [min]	3.03	6.9	2	20	2	2.25	35.41	2	178.2533968
Δx [m]	2728.73	25271.27	0	0	0	5392.29	129607.71	0	0
Δy [m]	5090	0	~	0	~	2378	0	~	0
Vx [m/s]	15	61	0	0	0	40	61	0	0
Vy [m/s]	-27.98	0	0	0	0	-17.64	0	0	0
e of attack [degrees]	61.8	0	90	0	90	23.8	0	90	0
Empty Weight	1939.37	1939.37	1939.37	1939.37	1939.37	1939.37	1939.37	1939.37	1939.37
vailable Turboshaft [kW]	415.3	840.5	840.5	840.5	840.5	840.5	1134	1134	1134
ilable Electric Engine [kW]	494	494	494	494	494	494	494	494	494
equired Turboshaft [kW]	423.785	812.8	720.5	0	720.5	504.7	971.4	673.3	0
uired Electric Engine [kW]	328.815	0	0	0	0	0	0	0	0
Fuel Weight [kg]	118.9	92.71	85.99	210	203.28	197.99	37.46	31.18	31.18
yload Weight [kg]	575	575	575	575	575	575	575	575	150
Current Weight	2633.27	2607.08	2600.36	2724.37	2717.65	2712.36	2551.83	2545.55	2545.55

Rotor Configuration Trade-off Analysis

Results of rotor configuration evaluation



Weighting criteria

Weighting value [%]

Weight	8	Hover ceiling	17.5
Useful load	5	Hovering stability	17.5
Range	7.5	Vibration	15
Endurance	6.25	Year of production	6.25
Cruise Speed @ sea level	5	Number of aircraft manufactured	4
Cruise Speed @ altitude	0.5	Cost	7.5

Þ The highest scoring configuration is the Coaxial with a leading score of 0.62 compared to second place NOTAR at 0.55 and far succeeding Tandem with 0.48 and finally Transverse configuration with 0.32 points.

Þ Although there are mechanical complexities with the coaxial configuration it will be optimal and will require the use of the Prouty rotorcraft design method but modified for coaxial aircraft.

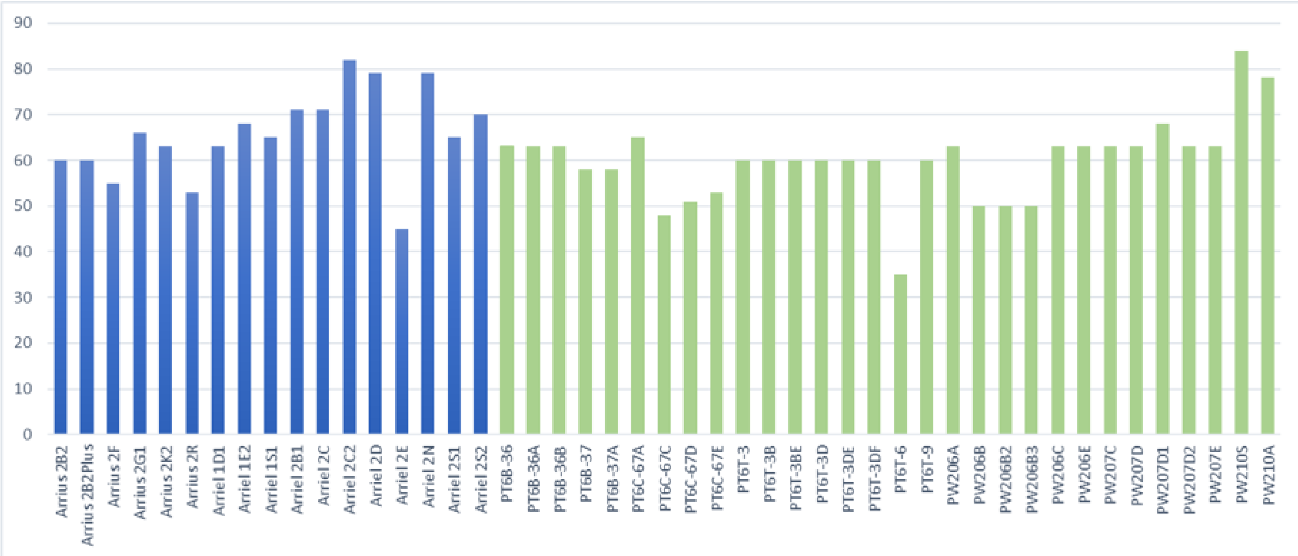
Rotor Configuration

Coaxial Rotor Configuration

Þ The Coaxial configuration has the contra rotating concentric two rotors on the same shaft and hence a zero-net torque for the system. Suitable for smaller cabins, proven design, improved hover stability, reduced roll tendencies. Disadvantages include mechanical complexities, high downwash velocities, poor forward cruise velocity, increased weight due to gearing, increased manufacturing and maintenance costs

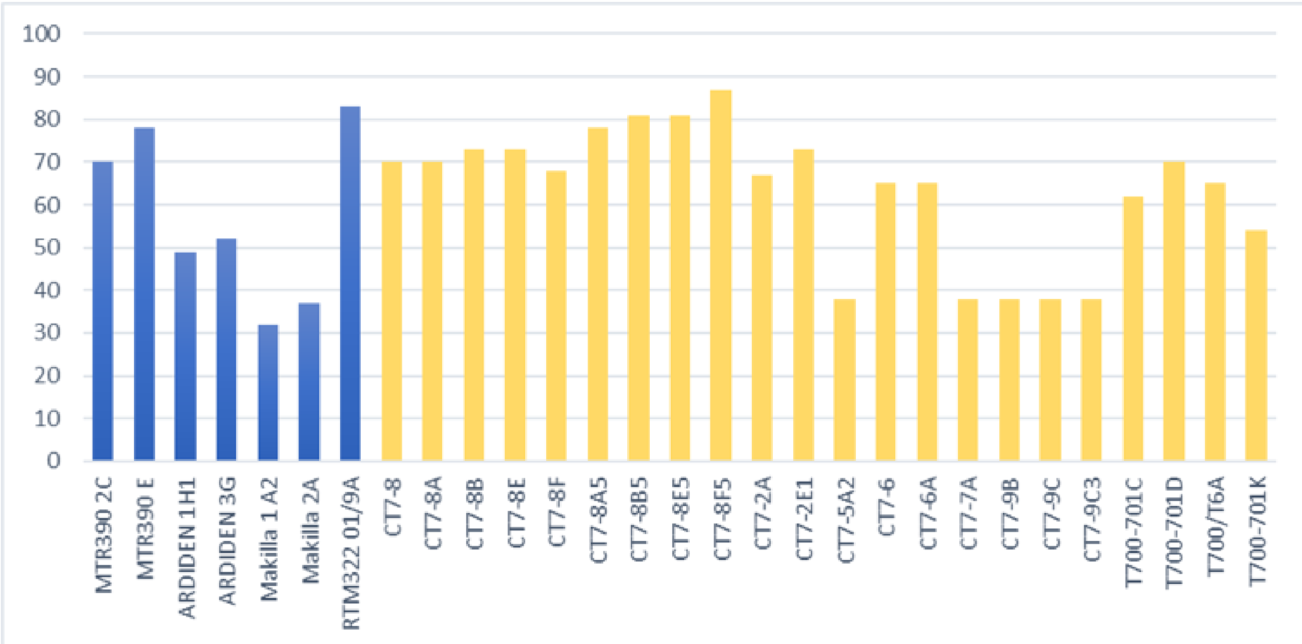
Turboshaft Engine Trade-off Analysis

Small turboshaft engine evaluation



- **The highest scoring small turboshafts are the PW210S, the Arriel 2C2, and the Arriel 2D and Arriel 2N. Of these engines, the Arriel 2N had the highest maximum continuous power and could meet our hover requirements when implemented in the hybrid propulsion package.**

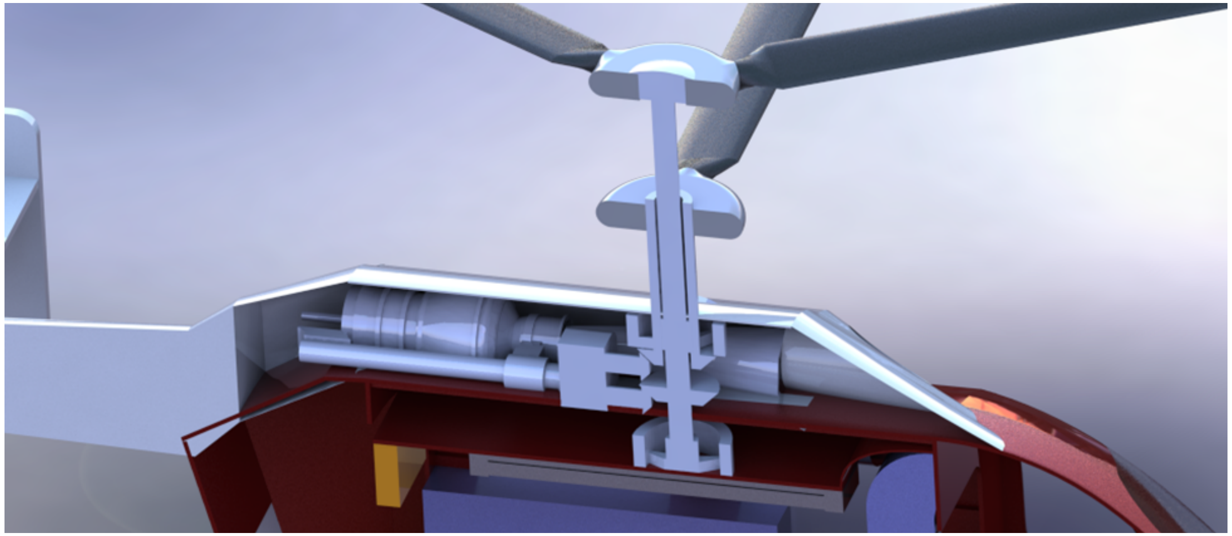
Large turboshaft engine evaluation

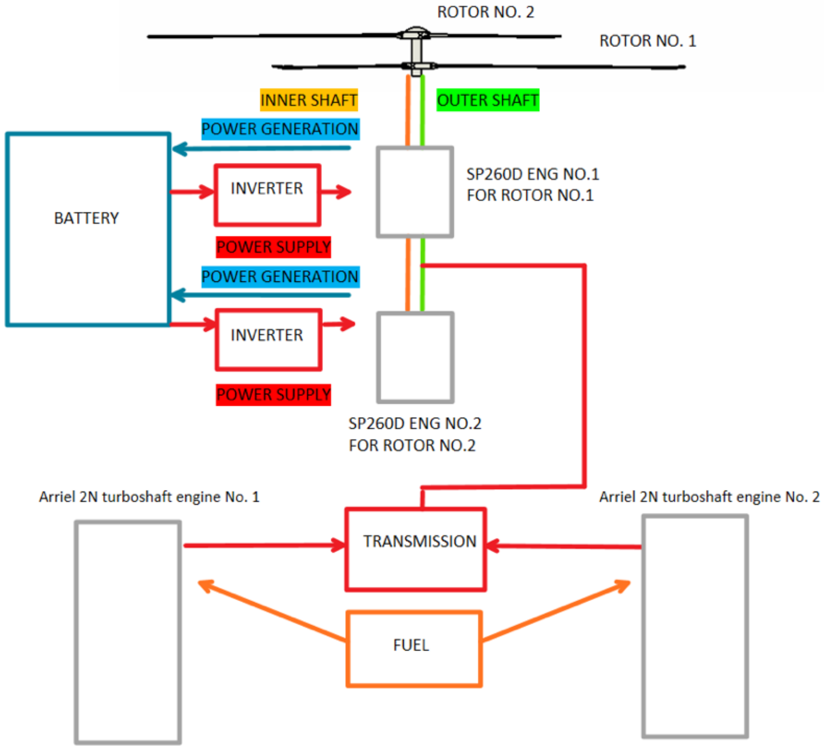


- **The highest scoring large engines are the CT7-8F5 and the RTM 322 01/9A. Both engines were tested in the turboshaft propulsion package, but neither could meet the hover requirements while maintaining a reasonable MTOW.**

Propulsion Configurations

Hybrid Propulsion Package





Þ For electric engine selection, the SP260D is selected since it was the only suitable electric engine currently available on the market for its specific attributes. Although not in service yet, legacy models have already been implemented in small fixed-wing aircraft such as the LE300, and the engine has a current TRL of 8.

Electric Powerplant Specifications

2 Siemens SP260D Electric Engines		**Manganese-Titanium (Lithium) Battery**	
Engine Weight	$100\ kg$	Battery Weight	$150\ kg$
Power Output (ideal)	$520\ kW$	Specific Energy	$140\ Wh/kg$
Motor Efficiency	95%	Battery Energy	$75.6\ MJ$
Power Output (real)	$494\ kW$	Battery Volume	$0.11\ m^3$
Maximum RPM	2500	Minimum Temperature	$-20°C$

Performance

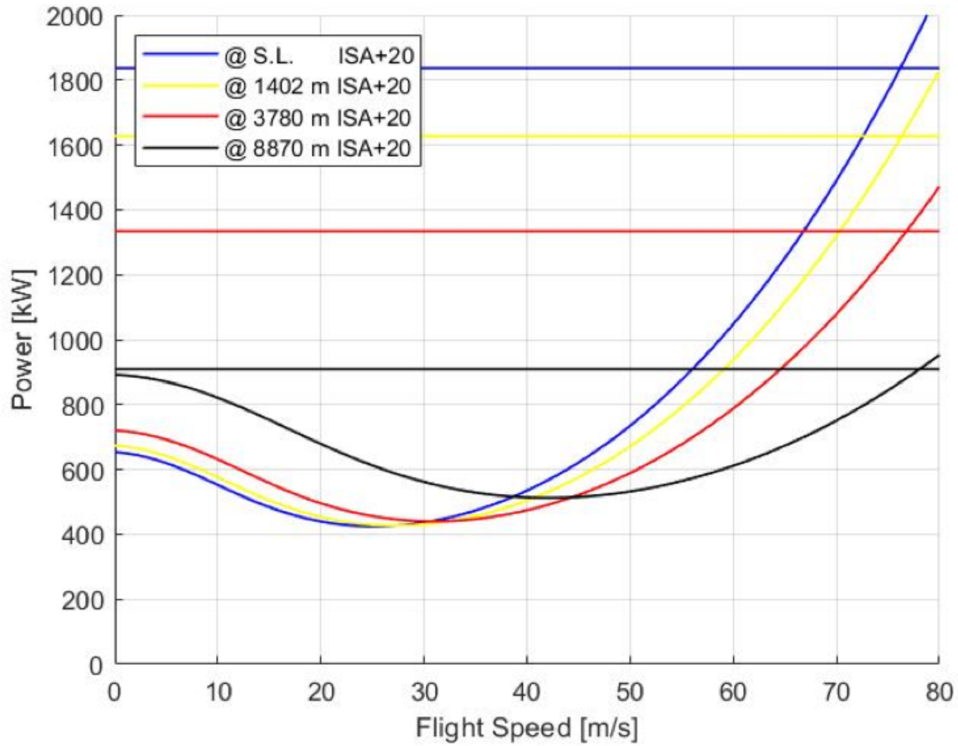
Power Available

- The power available is a mixture of turboshaft and electrical availability.

Power available for altitude

Altitude	Turboshaft Power	Electric Power	Power Available
Sea level	1,342.6 kW	494 kW	1,836.6 kW
1,402 m (4,600 ft)	1,133.9 kW	494 kW	1,627.9 kW
3,780 m (12,400 ft)	840.5 kW	494 kW	1,334.5 kW
8,870 m (29,100 ft)	415.3 kW	494 kW	909.3 kW

Power required for forward flight



Power required for hover

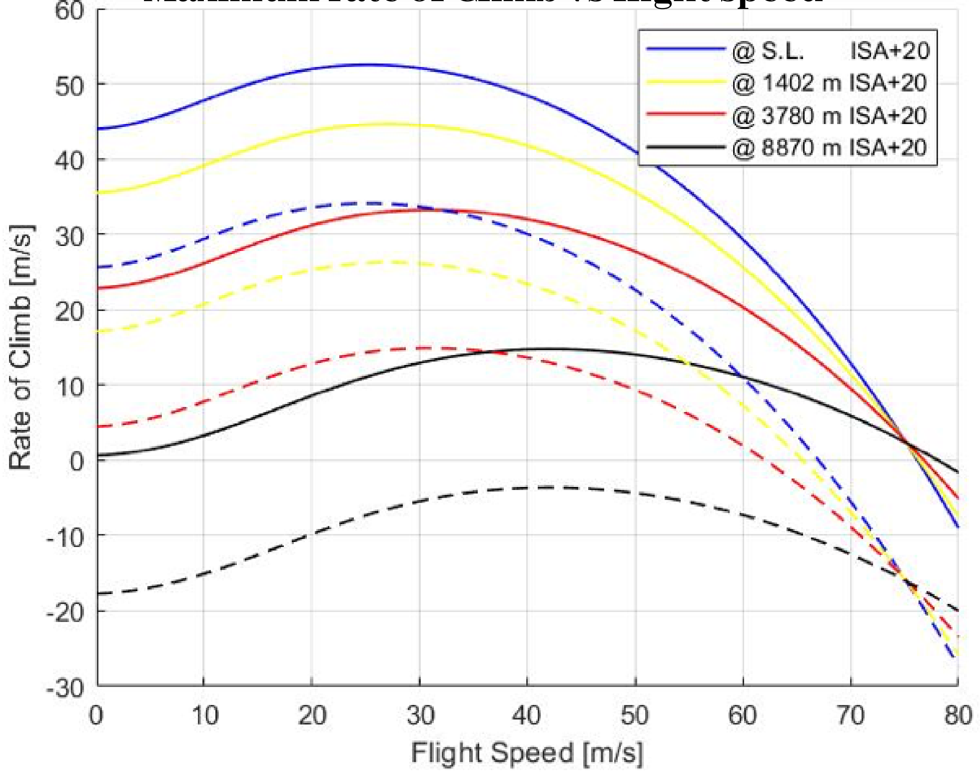
Altitude	Power required for hover
Sea level	653.5 kW
1,402 m (4,600 ft)	673.3 kW
3,780 m (12,400 ft)	720.5 kW
8,870 m (29,100 ft)	892.1 kW

Performance

Rate of Climb

- Due to the electrical engines , the rate of climb increases significantly and the helicopter becomes extremely responsive

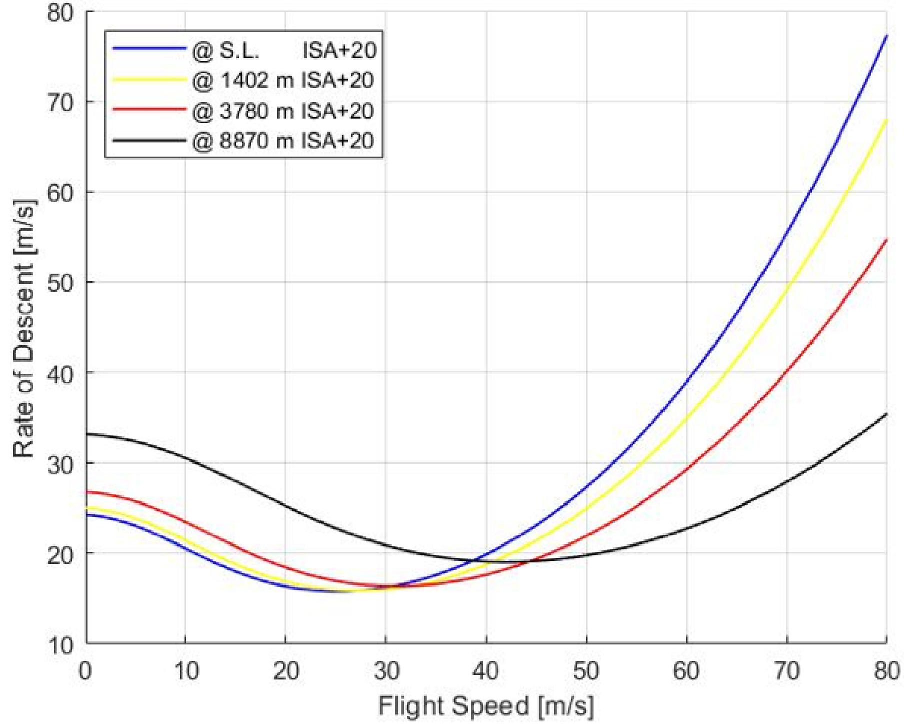
Maximum rate of Climb vs flight speed



Rate of Descent

- Maximum rate of descent occurs when no power is being supplied to the rotors, transitioning the helicopter into autorotation.

Maximum rate of descent vs flight speed



Performance

Range,Endurance, and Hover Ceiling

Þ The battery power of the helicopter provides 32.4% of the total range and 27% of the total endurance. If the battery weight was replaced with fuel, range and endurance would increase to 366.32 km and 3.17 hours respectively. Even though there is reduction in performance from using a hybrid propulsion package, this is necessary for meeting the strict hover requirements.

Flight characteristics for maximum range and endurance

	Range 309.28 km	Endurance 2.53 hours
Optimum Cruise speed	25 m/s	38 m/s
Average power at optimum cruise speed	407 kW	491 kW

Autorotation

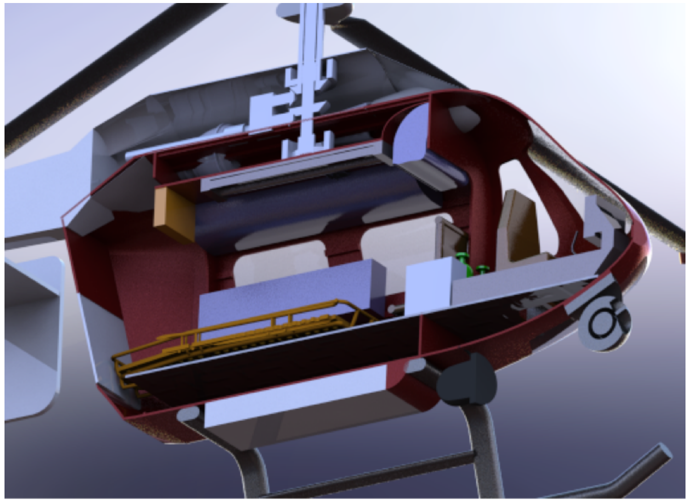
Þ Due to the large blade inertia and low disk loading, the helicopter is within the acceptable autorotation range for all key altitudes.

Autorotation index vs Altitude

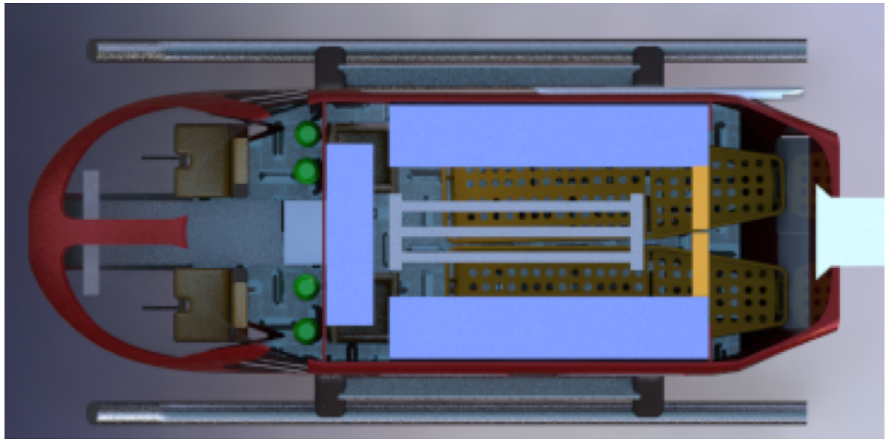
Altitude	Autorotative Index
Sea level	108.86
1,402 m (4,600 ft)	94.74
3,780 m (12,400 ft)	74.05
8,870 m (29,100 ft)	41.42

Structure and Cabin Architecture

Fuselage Section view



Internal cabin layout



Exposed fuselage view

- The fuselage was initially to be made boron-epoxy, however, evaluation of the helicopter's function shows the limitations it has stepping into other search and rescue environments.
- This fuselage uses a mixture of glass fibre and carbon fibre composites, which still meets the weight boundaries of a boron-epoxy fuselage.

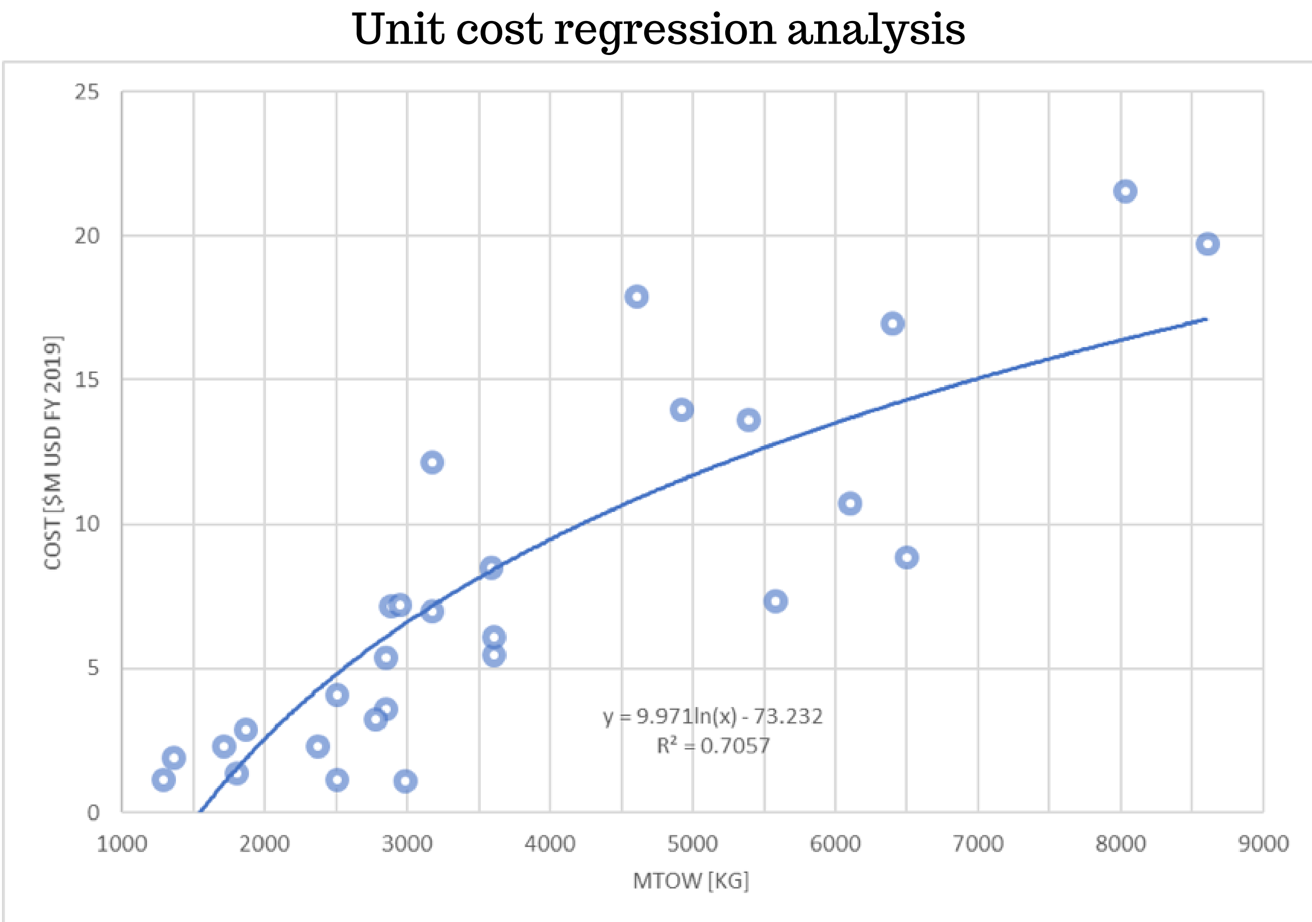
Weight Refinement

Component weights

System	Mass [kg]	Mass [lbs]
Main Rotor		
Rotor Blades	106.27	234.27
Rotor Hub	72.99	160.92
Structures		
Fuselage	183.58	404.72
Nacelles	37.78	83.29
Horizontal Stabiliser	25.43	56.06
Vertical Stabiliser	17.90	39.46
Landing gear	128.03	282.26
Furnishing	61.14	134.79
Manufacturing Variation	10.97	24.18
Power Production and Supply		
Turboshaft Engines	268	590.84
Fuel Weight	210	462.97
Electrical Engines	100	220.46
Batteries	150	330.69
Drivetrain	260.44	574.17
Flight Control Systems		
Avionics	68.04	150
Instruments	16.46	36.29
Systems Controls (Boosted)	1.35	2.98
Cockpit Systems	10.69	23.62
Electrical systems	201.06	443.25
Hydraulic Systems	17.40	38.36
Fuel Systems	5.09	11.22
Propulsion systems	44.99	99.18
Anti-Ice systems	43.86	96.70
Mission Systems		
Hoist (Goodrich 44316)	50	110.23
FLIR Camera (Safran Ultraforce 350-HD)	28	61.73
Crew Oxygen (4x MH Oxygen CFFC-048)	16	35.27
Searchlight (Spectrolab SX-16 Nightsun Enhanced)	31	68.34
Payload Weight		
Crew 1	85	187.39
Crew 2	85	187.39
Crew 3	85	187.39
Patient 1	85	187.39
Patient 2	85	187.39
Emergency medical Supplies	150	330.69
MTOW	2741.48	6043.93

Cost Breakdown

Þ **The development and unit costs are calculated using regression analysis. For unit costs, a Cost Estimating Relationship (CER) equation based on MTOW was developed. All data sourced for this regression model is sourced from Jane's, with selected helicopters listed in Appendix A. All costs are converted to $USD FY2019 using NASA's projected inflation factors .For our design, the unit cost is estimated at *$5.73 Million USD* per helicopter (FY2019). Note all masses used are in kg.**



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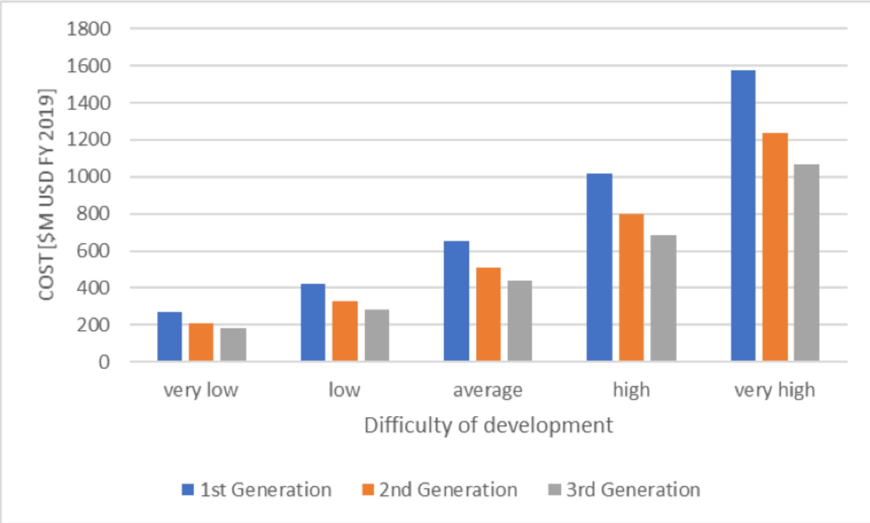
Cost Breakdown

Þ **Development costs were estimated using the Johnson Space Centre Advanced Mission Cost Model (AMCM). This is another regression model developed by NASA, which estimates development costs based on MTOW, quantity of units produced, generation of design, and other parameters**

Development costs vs difficulty of production and hardware development



Cost Breakdown vs manufacturer experience

Cost	Airbus (2nd Gen. model)	Experienced Manufacturer	New Manufacturer
Development	$327.57 Million	$420.65 Million	$1014.9 Million
Unit	$5.73 Million	$5.73 Million	$5.73 Million