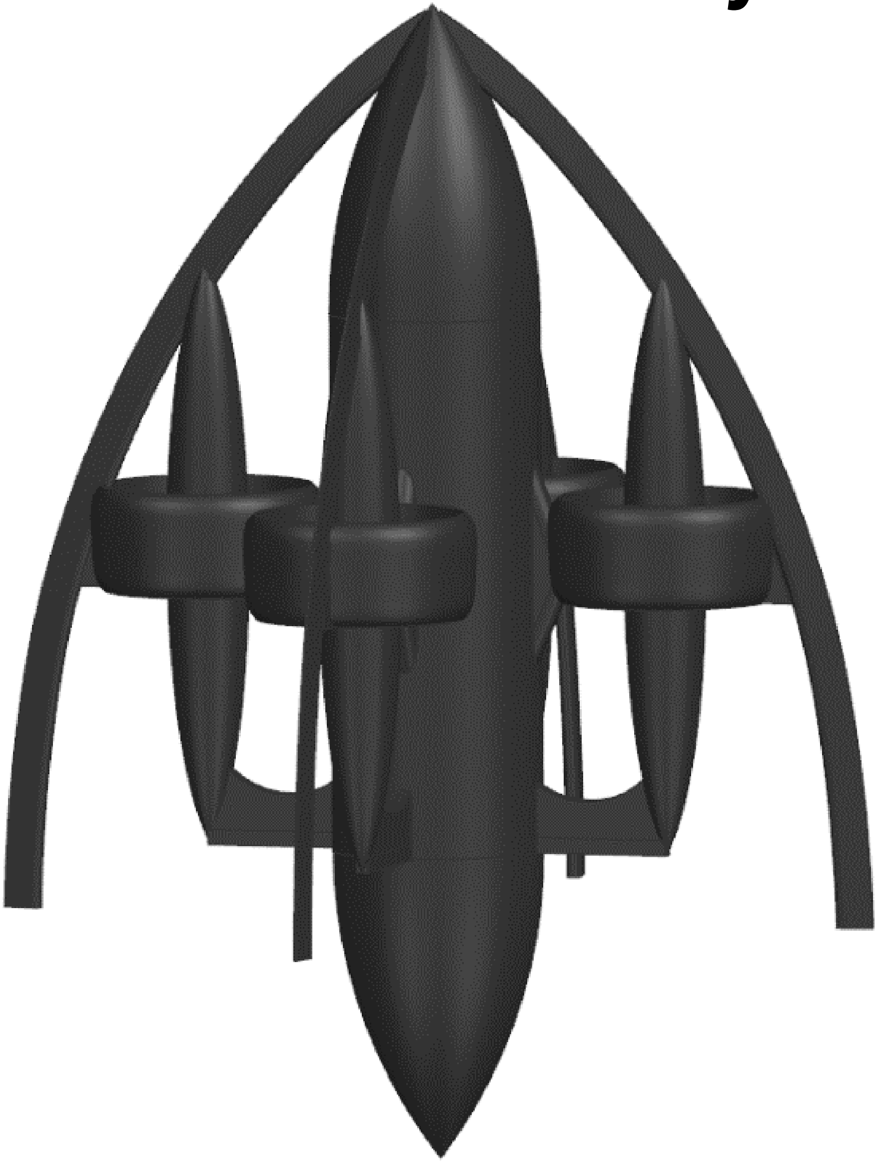
Asklepios:
Executive Summary



University of Kansas Undergraduate Team

38th Annual Student Design Competition

VFS 2025 UAV for Medical Equipment Distribution

Sponsored By Boeing

The University of Kansas Undergraduate <u>Team QuadRockets</u>

Zachary Schwab

Mason Denneler

Micaela Crispin

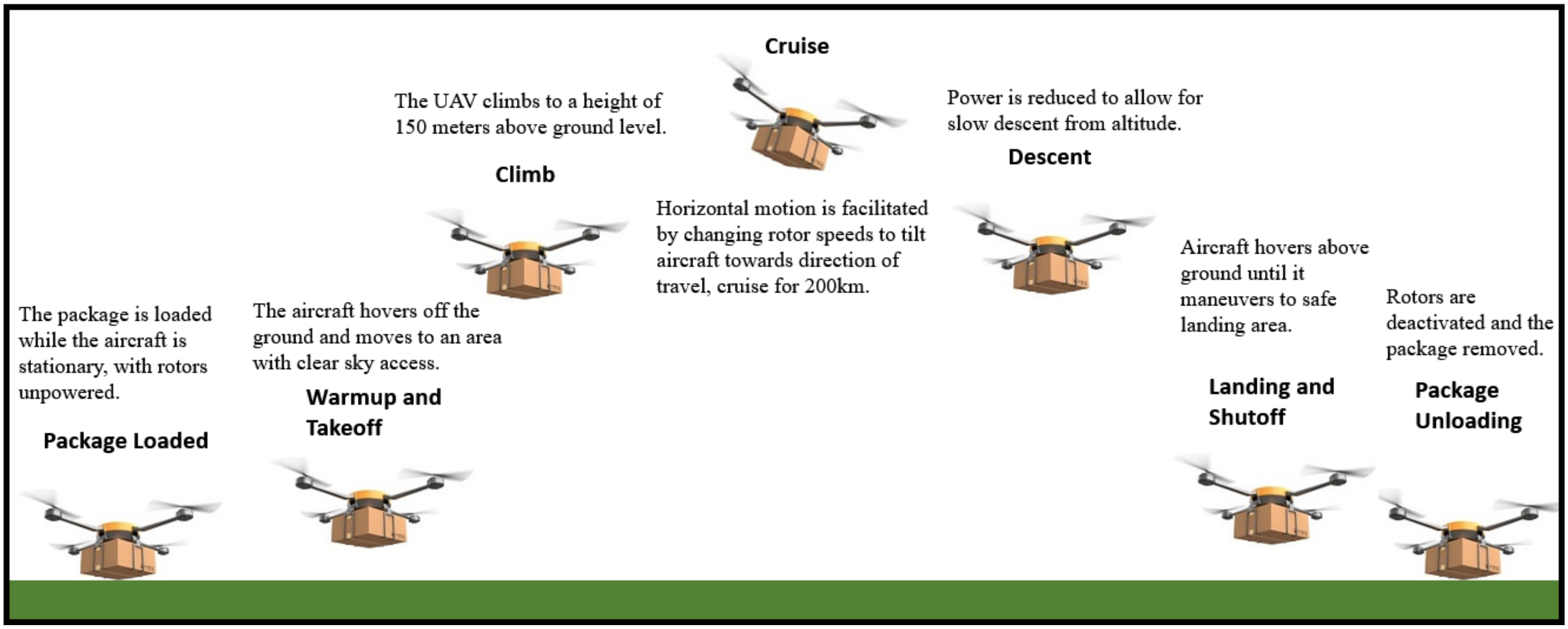
Instructed By: Dr. Ron Barrett

Professor of Aerospace Engineering

Director of the Adaptive Aerostructures and Aircraft Design Laboratories

Introduction (To VTOL Aircraft)

Popular package delivery concepts typically feature four or more top mounted rotors that efficiently lift the aircraft with the smallest amount of power. However, this design suffers from low horizontal travel speeds. The tilt body design allows the entire body of the aircraft to transition into lateral flight once the desired elevation is reached. This concept makes the most sense for vertical takeoff and landing aircraft that must also travel long distances quickly.



Package Loaded

The package is loaded while the aircraft is stationary, with rotors unpowered.

Warmup and Takeoff

The aircraft hovers off the ground and moves to an area with clear sky access.

Climb

The UAV climbs to a height of 150 meters above ground level.

Cruise

Horizontal motion is facilitated by changing rotor speeds to tilt aircraft towards direction of travel, cruise for 200km.

Descent

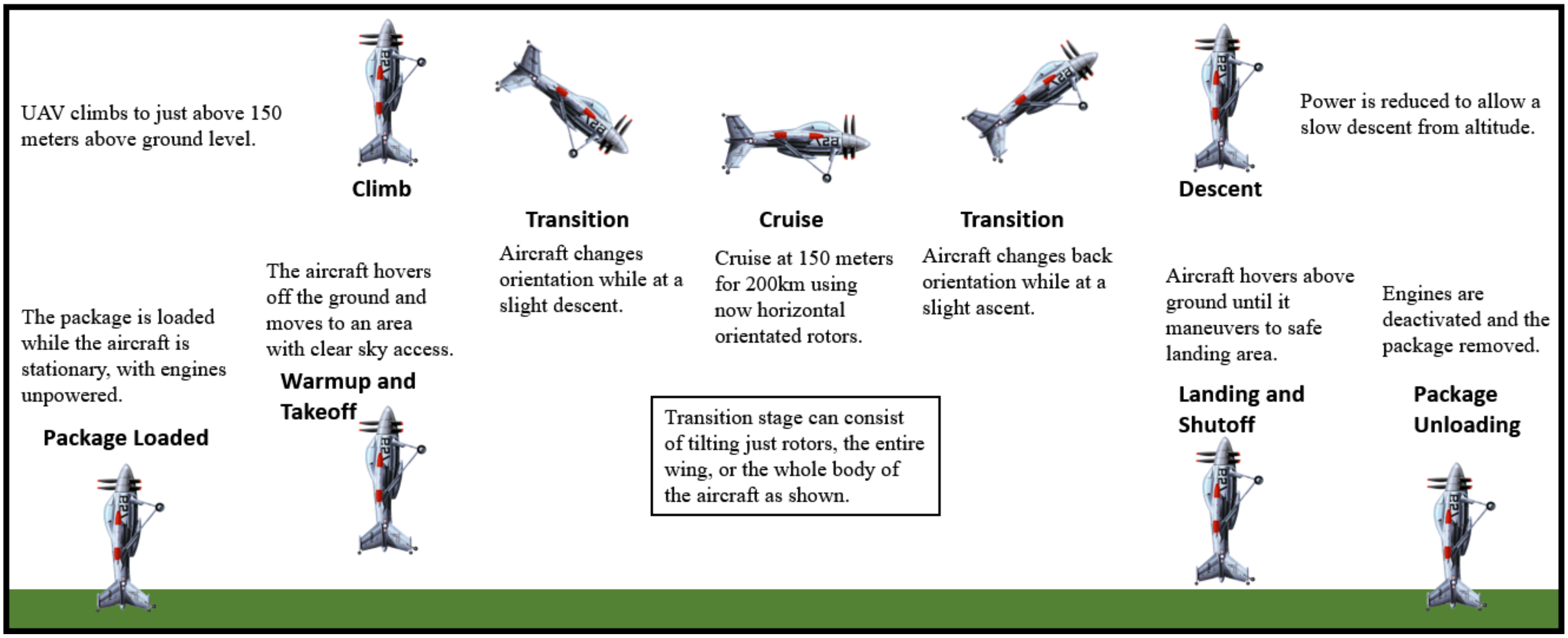
Power is reduced to allow for slow descent from altitude.

Landing and Shutoff

Aircraft hovers above ground until it maneuvers to safe landing area.

Package Unloading

Rotors are deactivated and the package removed.



Package Loaded

The package is loaded while the aircraft is stationary, with engines unpowered.

Warmup and Takeoff

The aircraft hovers off the ground and moves to an area with clear sky access.

Climb

UAV climbs to just above 150 meters above ground level.

Transition

Aircraft changes orientation while at a slight descent.

Cruise

Cruise at 150 meters for 200km using now horizontal orientated rotors.

Transition

Aircraft changes back orientation while at a slight ascent.

Descent

Power is reduced to allow a slow descent from altitude.

Landing and Shutoff

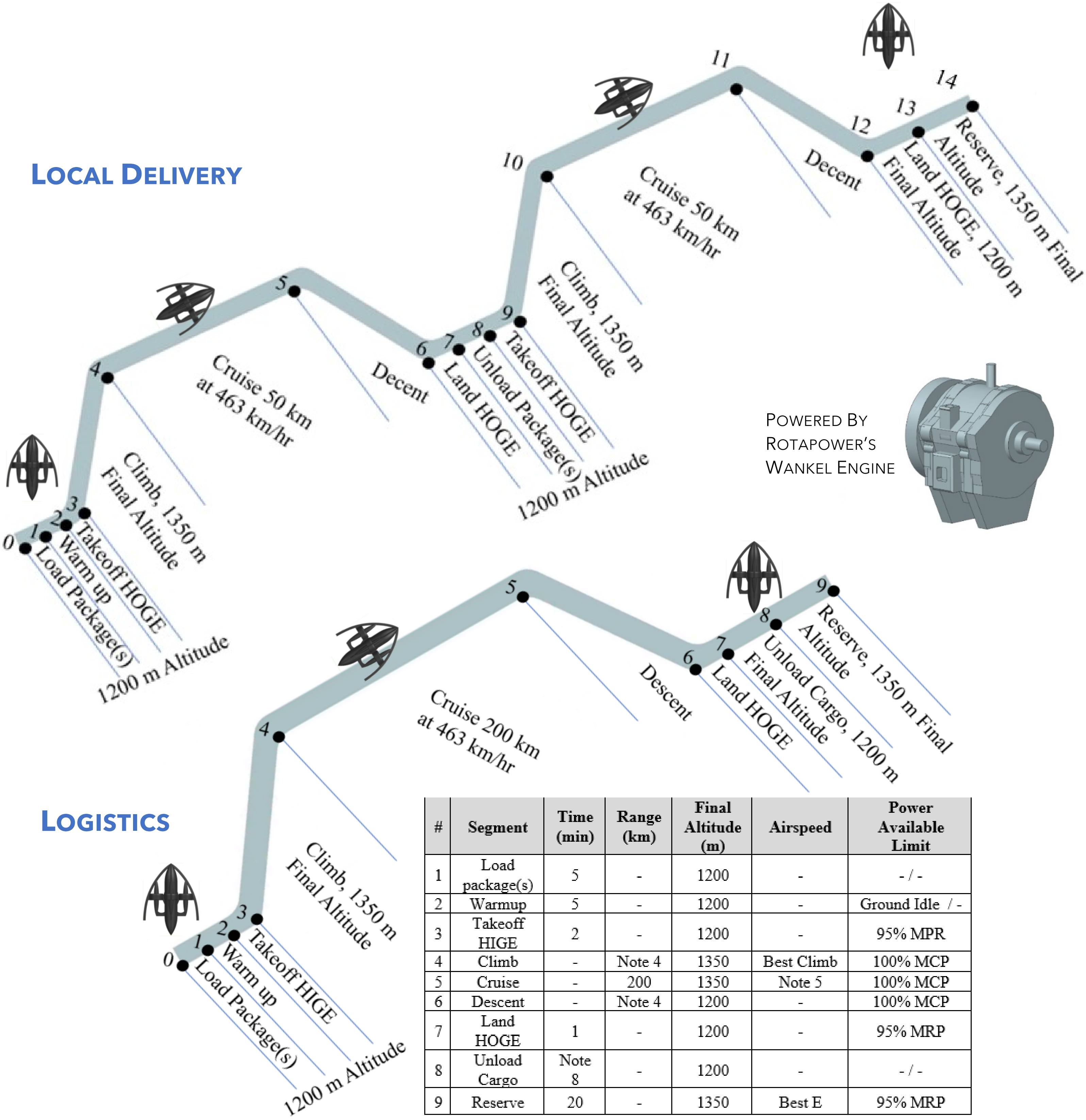
Aircraft hovers above ground until it maneuvers to safe landing area.

Package Unloading

Engines are deactivated and the package removed.

Transition stage can consist of tilting just rotors, the entire wing, or the whole body of the aircraft as shown.

Mission Profiles



LOCAL DELIVERY

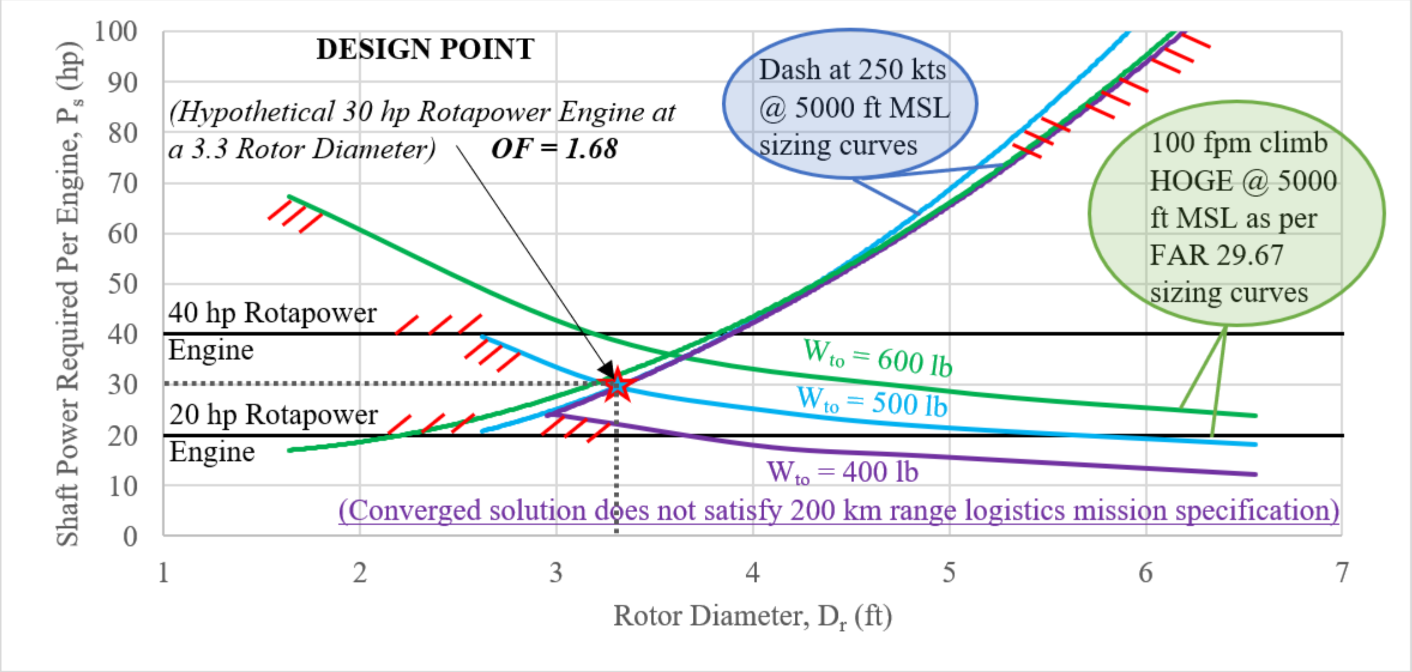
POWERED BY ROTAPOWER'S WANKEL ENGINE

LOGISTICS

#	Segment	Time (min)	Range (km)	Final Altitude (m)	Airspeed	Power Available Limit
1	Load package(s)	5	-	1200	-	- / -
2	Warmup	5	-	1200	-	Ground Idle / -
3	Takeoff HIGE	2	-	1200	-	95% MPR
4	Climb	-	Note 4	1350	Best Climb	100% MCP
5	Cruise	-	200	1350	Note 5	100% MCP
6	Descent	-	Note 4	1200	-	100% MCP
7	Land HOGE	1	-	1200	-	95% MRP
8	Unload Cargo	Note 8	-	1200	-	- / -
9	Reserve	20	-	1350	Best E	95% MRP

Rotor BEMT Sizing

Using general relationships between rotor diameter and aircraft characteristics derived from the xq-138, estimates for parasite drag, wing area, wetted area, dash lift and drag coefficients, and finally the required thrust needed in dash can be estimated used for calculating BEMT code results. From the BEMT results a sizing chart has been produced to size the rotor blades and required power per engine.

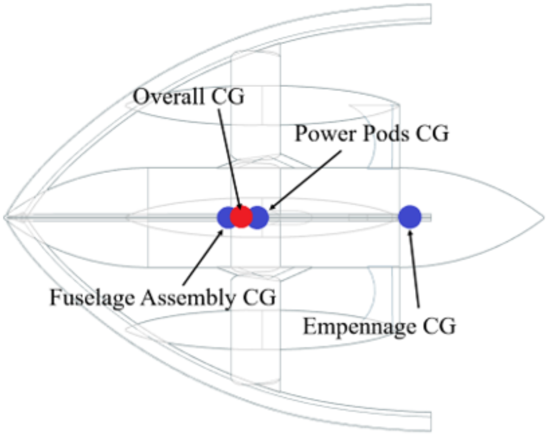


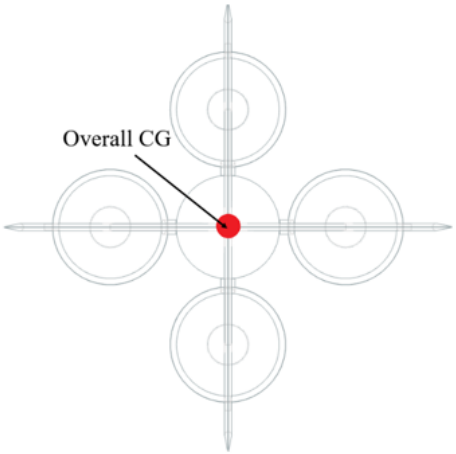
Blade Element Momentum Theory Results at ideal design point (NACA 0012 Rotor Blade Airfoil)

Flight Condition	Blade Diameter (ft)	Rotor Speed (RPM)	Root Cord (in)	Taper Ratio	θ_0 (deg)	θ_1 (deg)	θ_{tw} (deg)	θ*r^exp (deg)	# of blades	Thrust (lb)	P_{shaft} (hp)	Propeller Efficiency	Figure of Merit	Thrust Coefficient (C_T)	Pressure Coefficient (C_P)
250 kt Dash at 5000 ft	3.3	2302	1.37	0.9	44.6	65	-45	-0.49	2	35.8	29.9	91.70%	7%	0.0083	0.0078
10 kt Hover at 5000 ft	3.3	4500	1.37	0.9	-15.8	65	-45	-0.49	2	125	29.8	12.90%	45.8	0.012	0.0021

Weight and Balance

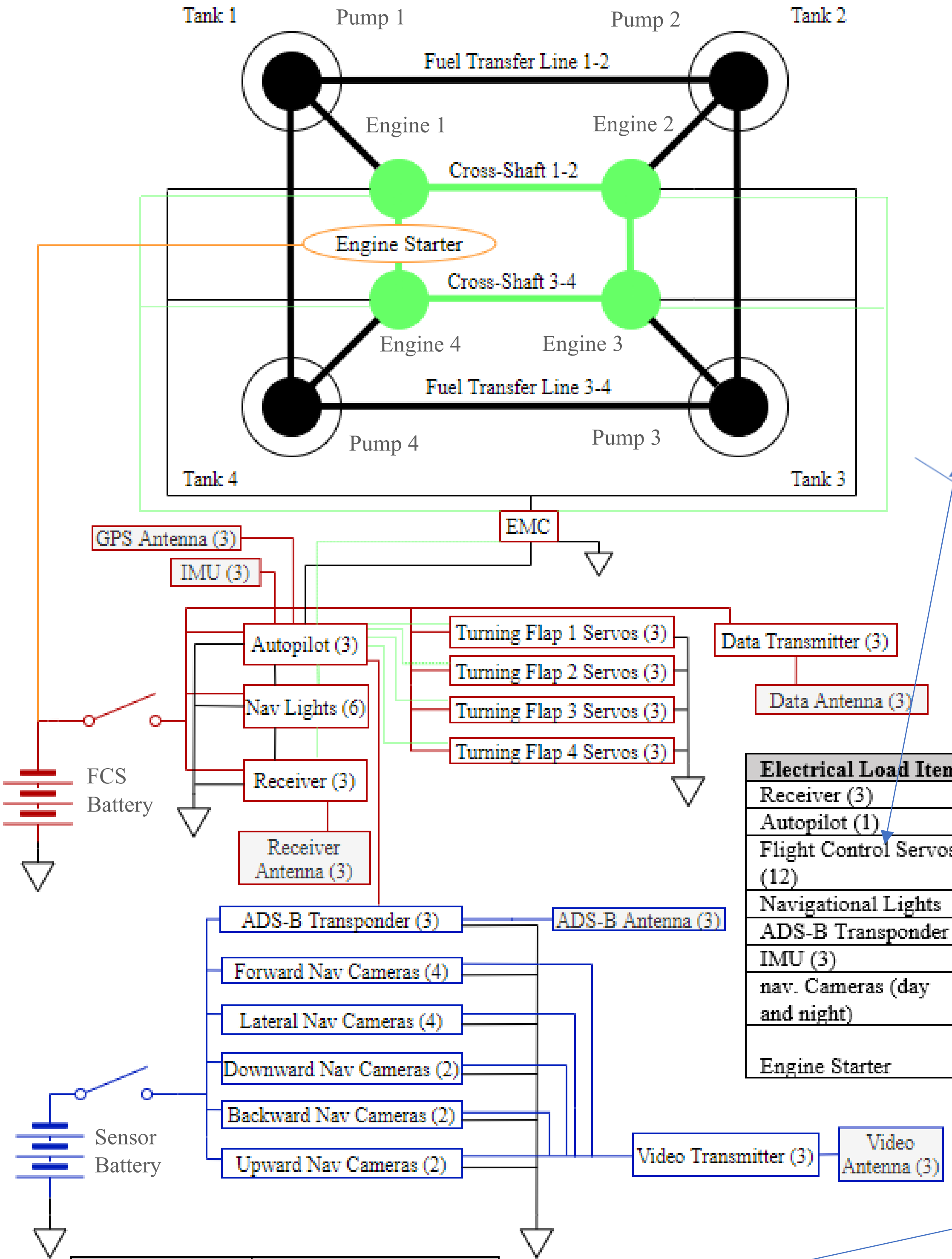
	Weight (kg)	FS (cm)	X_cg (cm)	W*X (kg*cm)	Z_cg (cm)	W*Z (kg*cm)
Fuselage & Rotor Guards (4)	30	320	220	6600	0	0
Muffler Hard Points	6	340	240	1400	0	0
Turning Flaps (4)	4	550	450	1800	0	0
Turning Flap Servos (12)	4.4	545	445	2000	0	0
Undercarriage	12	520	420	5000	0	0
Fasteners and Frames	2	360	260	520	0	0
Servo X-Frames	3.1	400	300	930	0	0
Elec. and Mech. Connections	1.1	320	220	240	0	0
RotaPower Engines (4)	56.7	340	240	14000	0	0
Starter	1.2	345	245	290	0	0
Fuel	27.2	345	245	6700	0	0
Trapped Fuel and Oil	0.5	340	240	120	0	0
Fuel Tanks and Lines	4	345	245	980	0	0
Muffler	7.5	340	240	1800	0	0
Rotors (4)	3.6	335	235	850	0	0
IMU/Magnetometer (3)	0.5	160	60	30	0	0
Autopilot	0.3	180	80	20	0	0
Autopilot mount	0.2	185	85	20	0	0
Receivers (3)	0.8	260	160	130	0	0
Navigation Lights	0.2	280	180	40	0	0
ADS-Transponder (3)	0.2	190	90	20	0	0
FCS Battery	2.5	210	110	280	0	0
Sensor Battery	1.5	210	110	170	0	0
Navigation Cameras	0.6	200	100	60	0	0
Primary Payload	50	340	240	12000	0	0
CG Positioning System	6.7	330	230	1500	0	0

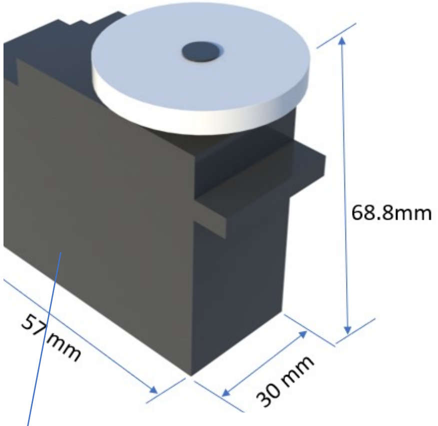


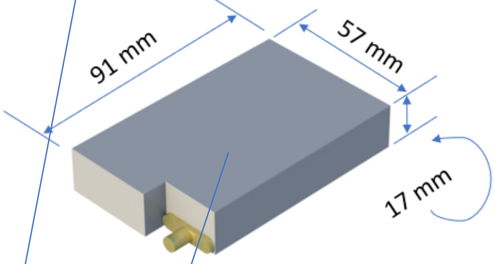


TRIPLY REDUNDANT CONFIGURATION SHOWN

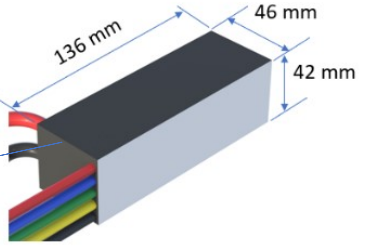
Sensors and Coms







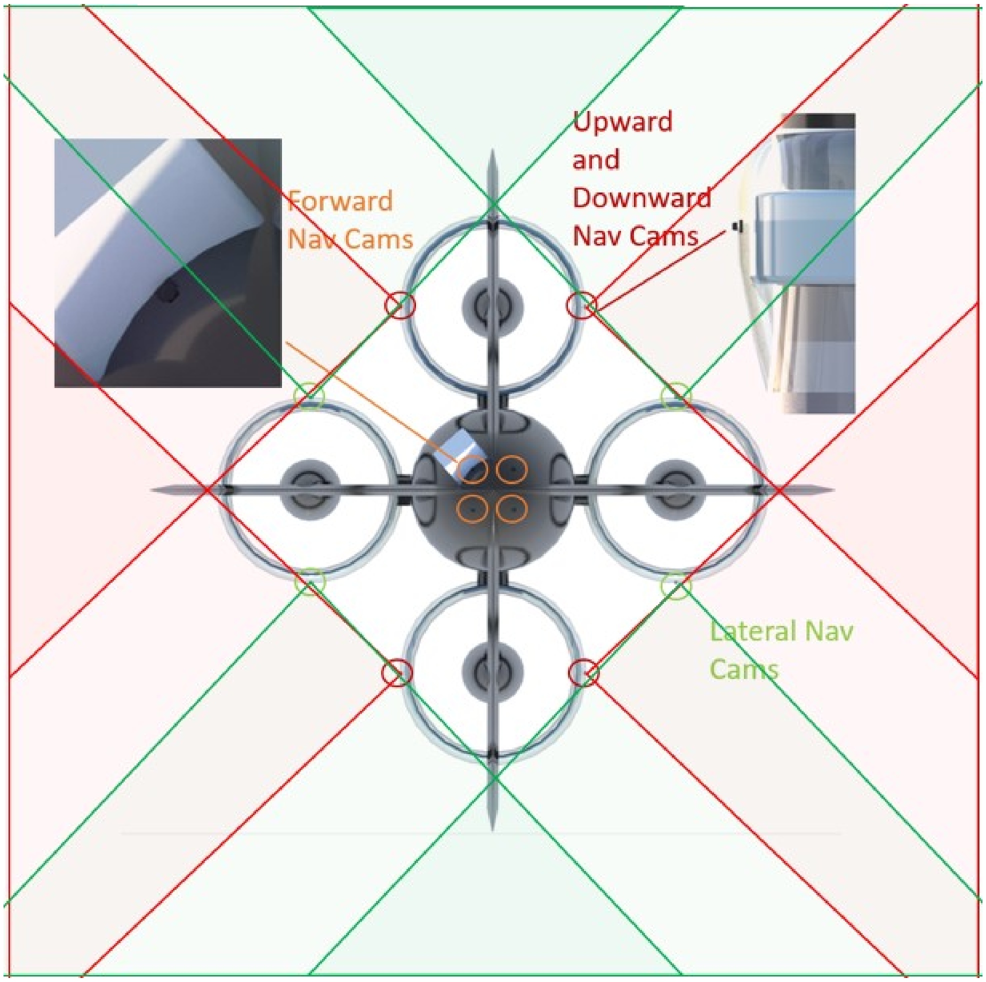
Electrical Load Item	Market Name
Receiver (3)	FrSky X8R
Autopilot (1)	MP21283X Triple Redundant
Flight Control Servos (12)	Hitec RCD® HRC32805S
Navigational Lights	elechawk LED Light Strip
ADS-B Transponder	PING-200SR
IMU (3)	MOTUS
nav. Cameras (day and night)	MS5000S
Engine Starter	1.4 kw high torque starter motors for early models



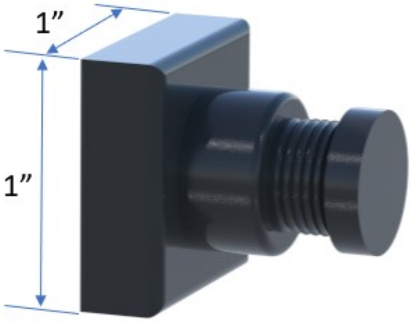
Battery Type	Market Name
Flight Control System (FCS) Battery	TATTU 7000mAh 4s 25c Lipo Battery
Sensor Battery	Lumenier 205mAh

Sensors and Coms, Cont.

Stereoscopic fields of view



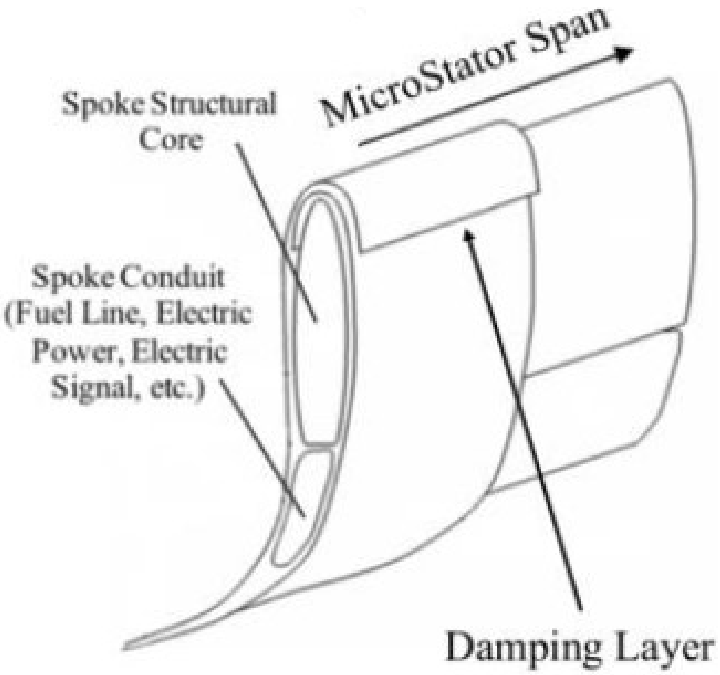
Stereoscopic Vision for Collision Avoidance



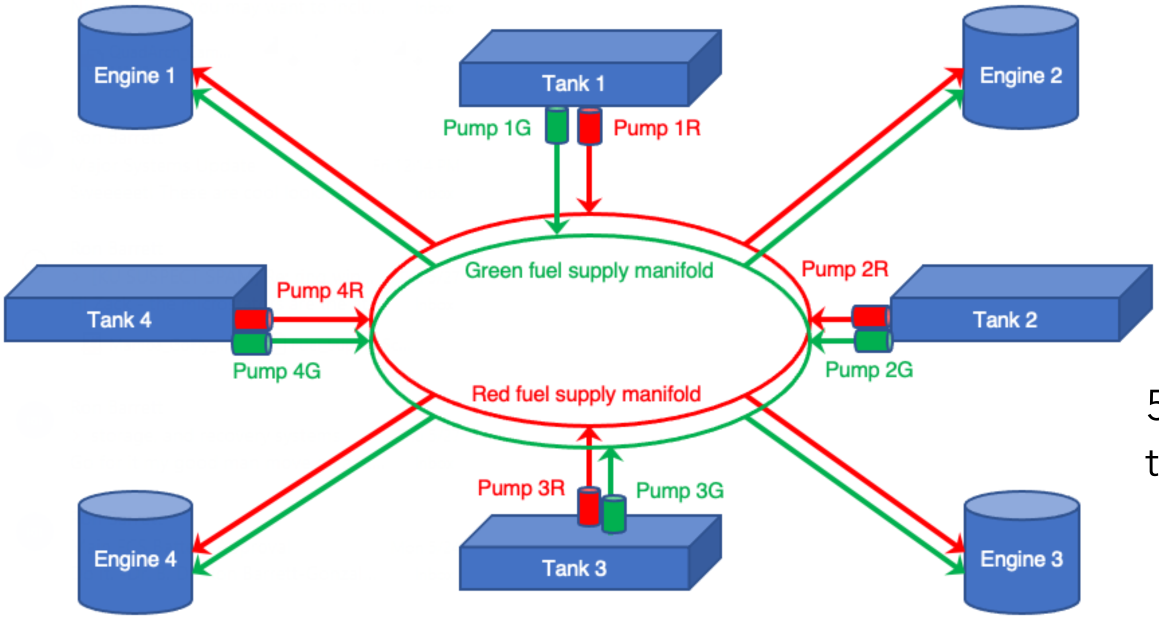
Nested Backwards Vision Cameras Strategically Placed in the Wire-Strike Guard/Duct Fairing

Major Systems

MicroStators (Figure taken from Mamba GoFly Report) deliver fuel and electric signals to engine.

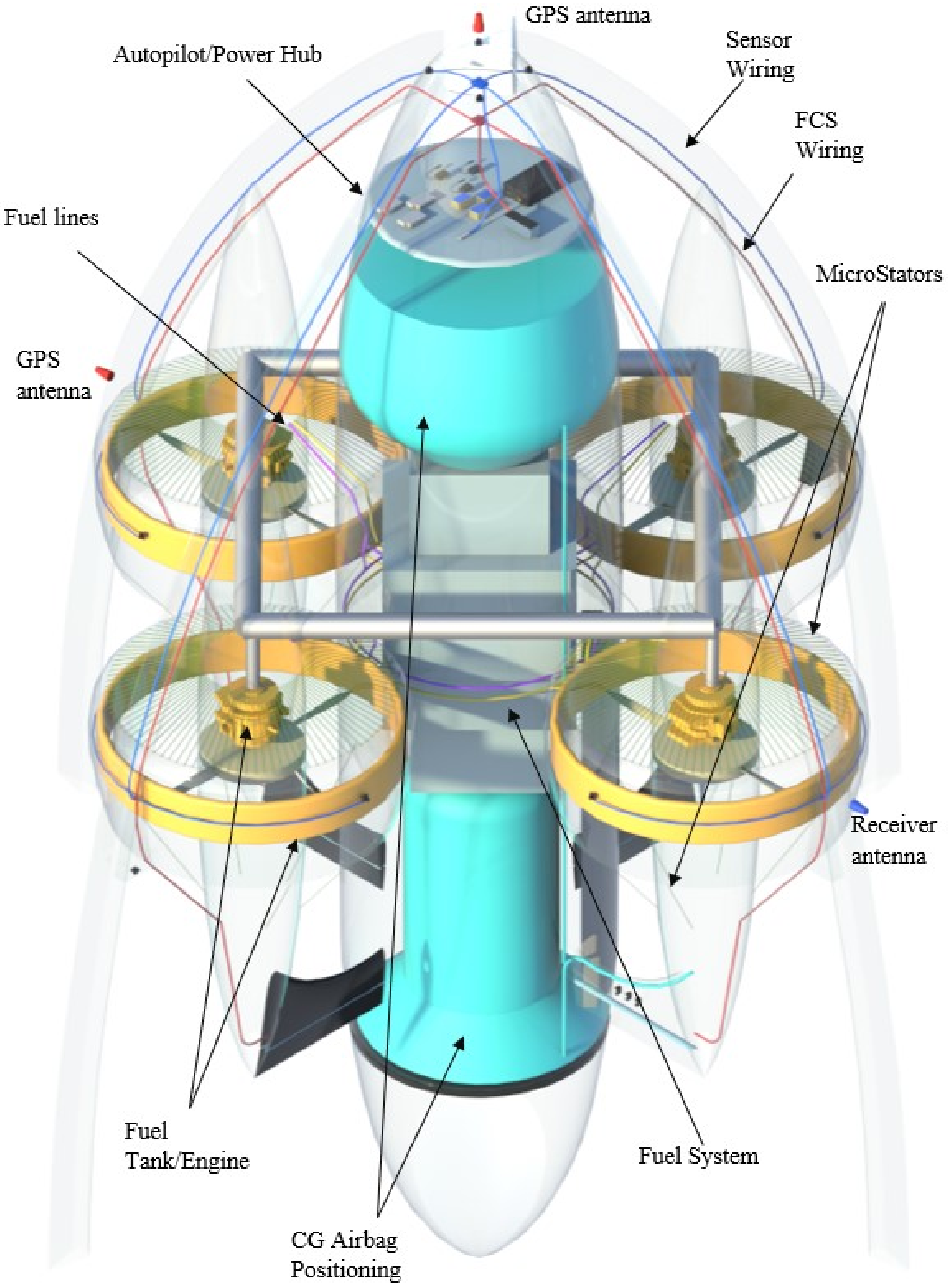


Doubly Redundant Internal Fuel System Concept



5.2 gal fuel tanks

Major Systems, Cont.



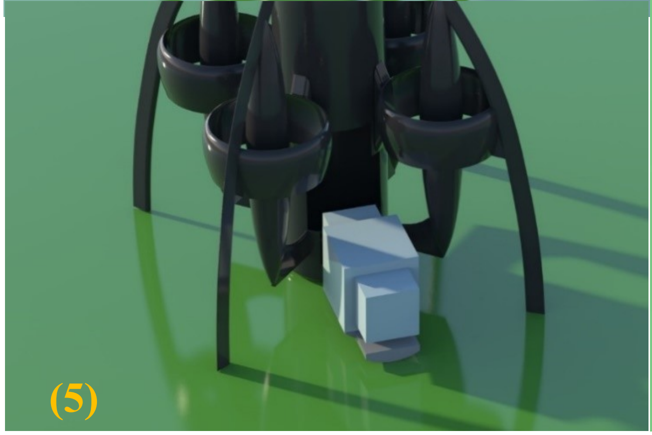
Payload Egress/Ingress Concept


(1)


(2)


(3)

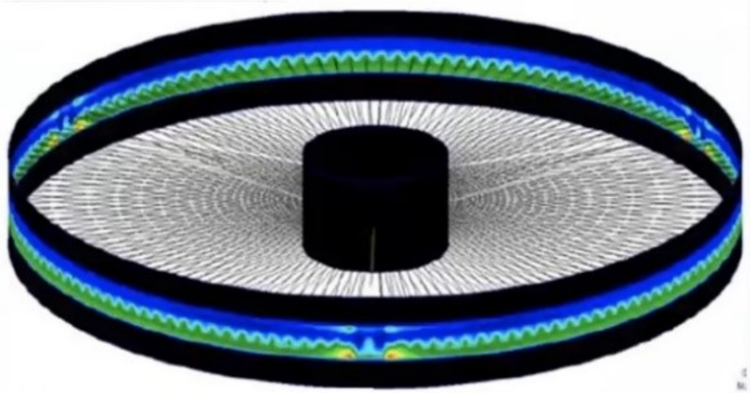

(4)

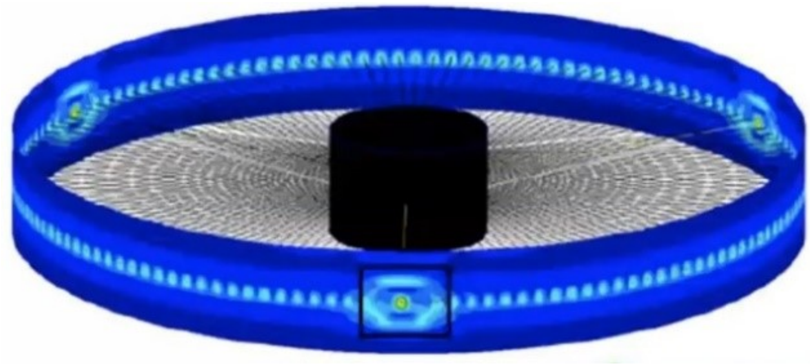

(5)

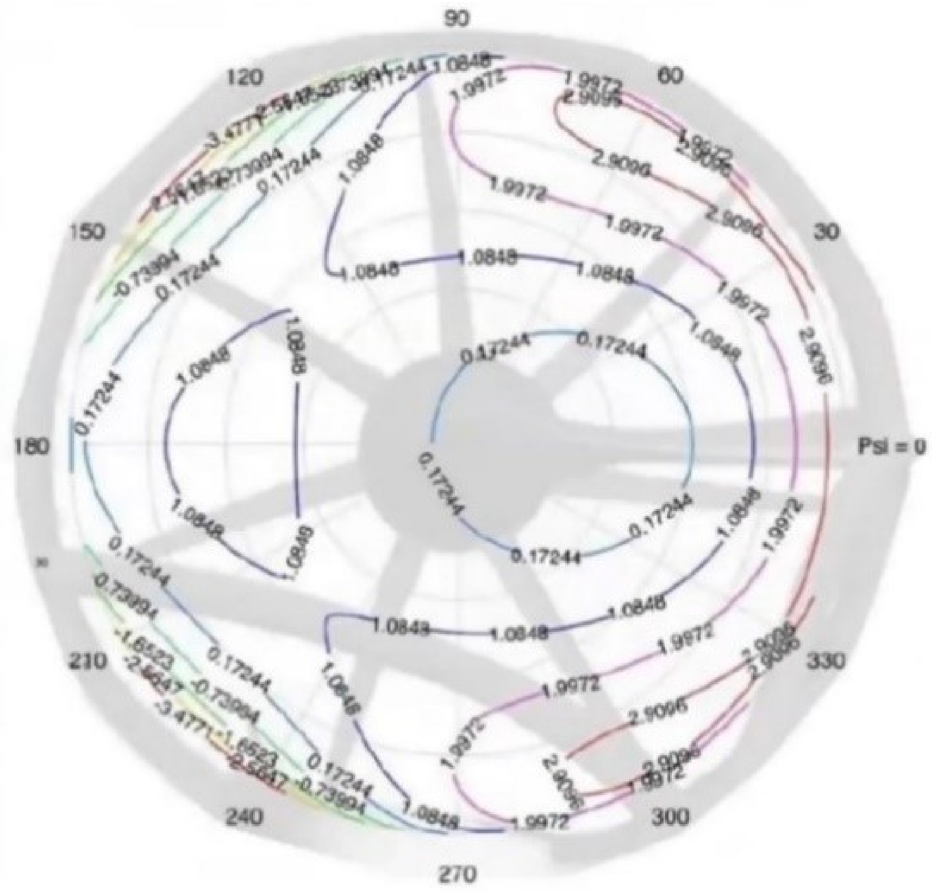

(6)

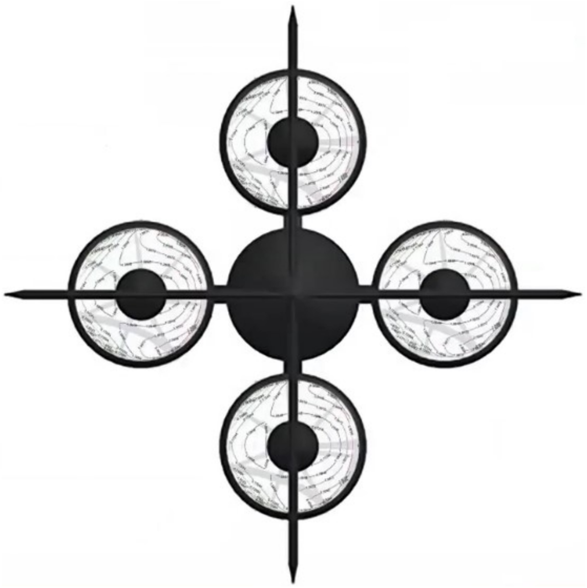
Safety

- MicroStators/Ducted fans protect body parts from fan blades
- Proven Safe by Mamba GoFly CFD and FEM Design Analysis
- Wire-strike guards for added protection in urban areas









Cost Analysis

To estimate the total life cycle cost and the cost per individual unit, the method detailed by Roskam in Aircraft Design: Part VIII Chapters 3 and 4 will be used. By simply imputing the ampere weight and the max speed the aircraft will travel at, an estimate for total aircraft costs can be found.

Variable	Assumption
Airframe Engineering and Design Cost (pg. 22-28)	
W_{ampr}	121 lbs: 24.7% of the XQ-138 based on weight fractions
V_{max}	250 kts: dash speed from V-n diagrams
N_{rdte}	5 aircraft: 1 structural, 1 ground vibration test, 1 hover test, 2 transition test
F_{diff}	1.5: convertible aircraft of this kind have been made before
F_{cad}	1
R_{er1990}	$62: Roskam pt. VIII Fig. 3.3
CEF_{1990}	140: Roskam pt. VIII Fig 2.7
CEF_{2020}	250: Roskam pt. VIII Fig. 2.7
Development Support and Testing Cost (pg. 29)	
$CEF=CEF_{2020}$	250
Flight Test Airplanes Cost (pg. 29-33)	
N_e	4: four ducted fan engines
N_{st}	2: one for static and one for crash test
N_p	0
C_{er}	$35,000: Mamba GoFly used the same engines only with 40 hp rather than 30 hp. The cost of each of these was $45,000. Scaling based on the hp, the approximate cost per engine will be $35,000
C_{pr}	0
$C_{avionics}$	$350,000: based on Mamba Go Fly numbers
$R_{m,r1990}$	$34/hr: Roskam pt. VIII Fig. 3.4
F_{mat}	2: using advanced composites
N_{rr}	8: Assuming around 100 aircraft can be produced per year
$R_{t,r1990}$	$44/hr: Roskam pg. VII Fig. 3.5
Flight Test Operations Cost (pg. 34)	
F_{obs}	1: No stealth requirements
F_{space}	2: Factor added in to account for the increased airspace needed to flight test the aircraft for safety reasons
Test and Simulation Facilities Cost (pg. 35)	
F_{tsf}	0: No extra facilities needed
RDTE Profit (pg. 35)	
$F_{pro,r}$	0: Assuming non-profit for liability reasons
Cost to Finance the RDTE Phases (pg. 36)	
$F_{fin,r}$	0.05: Assuming 5% interest rate

Cost Analysis, Cont.

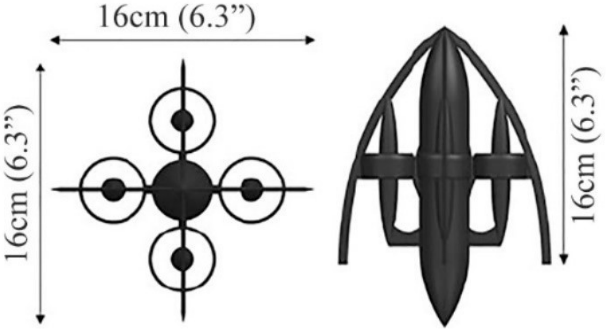
Variable	Calculated Value	Eqn. #, pg. #
Airframe Engineering and Design Cost (pg. 22-28)		
$MHR_{aed,r}$	16160 hrs	3.2, 24
R_{er}	$111/hr	3.6, 28
$C_{aed,r}$	$178,900	3.3, 24
Development Support and Testing Cost (pg. 29)		
$C_{dst,r}$	$12,210,000	3.7, 29
Flight Test Airplanes Cost (pg. 29-33)		
$C_{(e+a),r}$	$1,470,000	3.9, 30
$MHR_{man,r}$	$70,450	3.11, 31
$R_{m,r}$	$60.70	
$C_{man,r}$	$4,277,000	3.10, 31
$C_{mat,r}$	$57,470,000	3.12, 31
$MHR_{tool,r}$	51350 hrs	3.14, 33
$R_{t,r}$	$78.60	
$C_{tool,r}$	$4,035,000	3.13, 33
$C_{qc,r}$	$556,000	3.15, 33
$C_{fta,r}$	$67,810,000	3.8, 29
Flight Test Operations Cost (pg. 34)		
$C_{fto,r}$	$1,926,000	3.16, 34
Test and Simulation Facilities Cost (pg. 35)		
$C_{tsf,r}$	$0	3.17, 35
RDTE Profit (pg. 35)		
$C_{pro,r}$	$0	3.18, 35
Cost to Finance the RDTE Phases (pg. 36)		
$C_{fin,r}$	$4,187,000	3.19, 36
CRDTE		
CRDTE	$87,920,000	3.1, 21

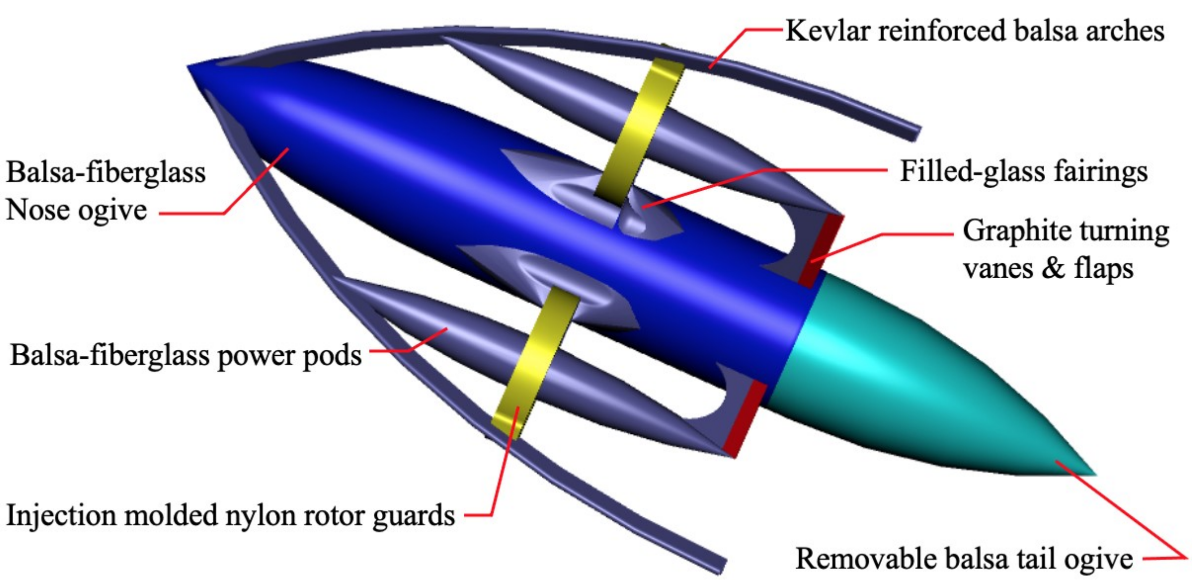
- The cost of research and development is $87,920,000

A production run of 200 aircraft with a 6% cost of financing + 10% profit at the break-even point would lead to an acquisition cost of: $510k/aircraft. The cost of operation ≈ $280/hr. Assuming a 1,000 hour aircraft, this indicates a life cycle cost (LCC) of $510k + 1,000hrs * $280/hr = $790k/aircraft.

Test Model

The 1/27 scale Asklepios

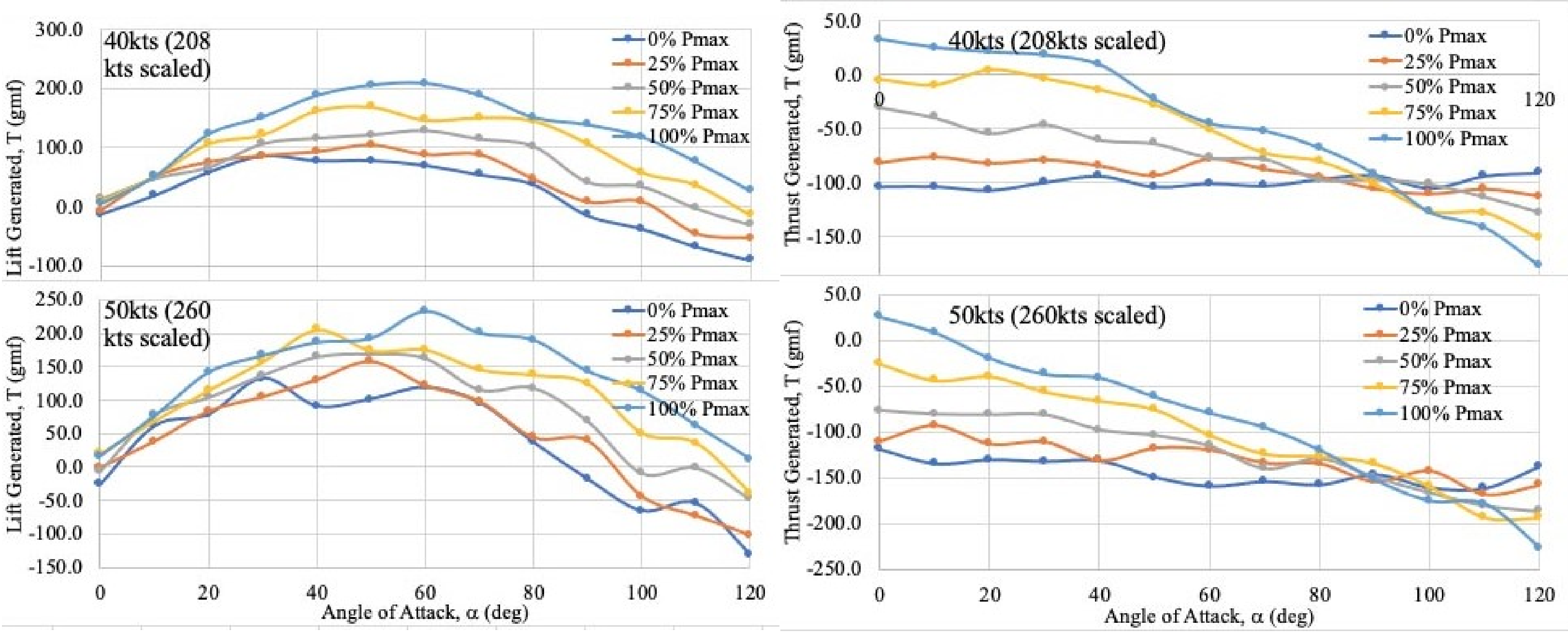


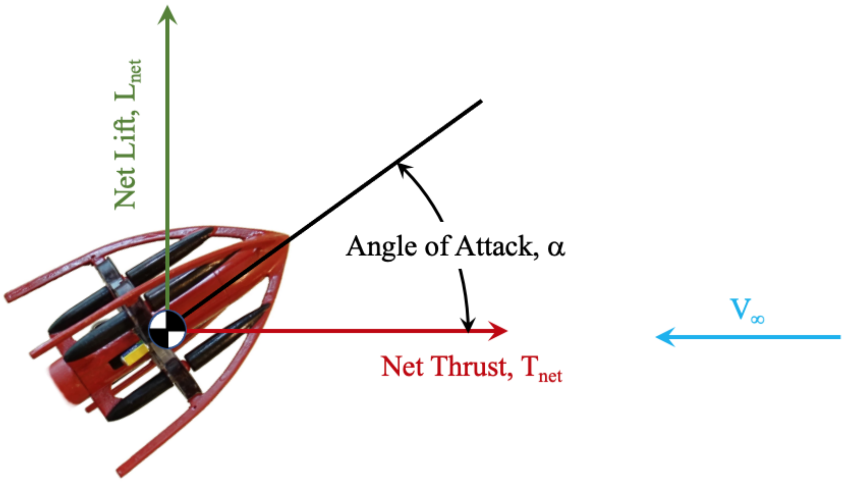


Test Model Wind Tunnel Testing

Wind Tunnel Test Matrix

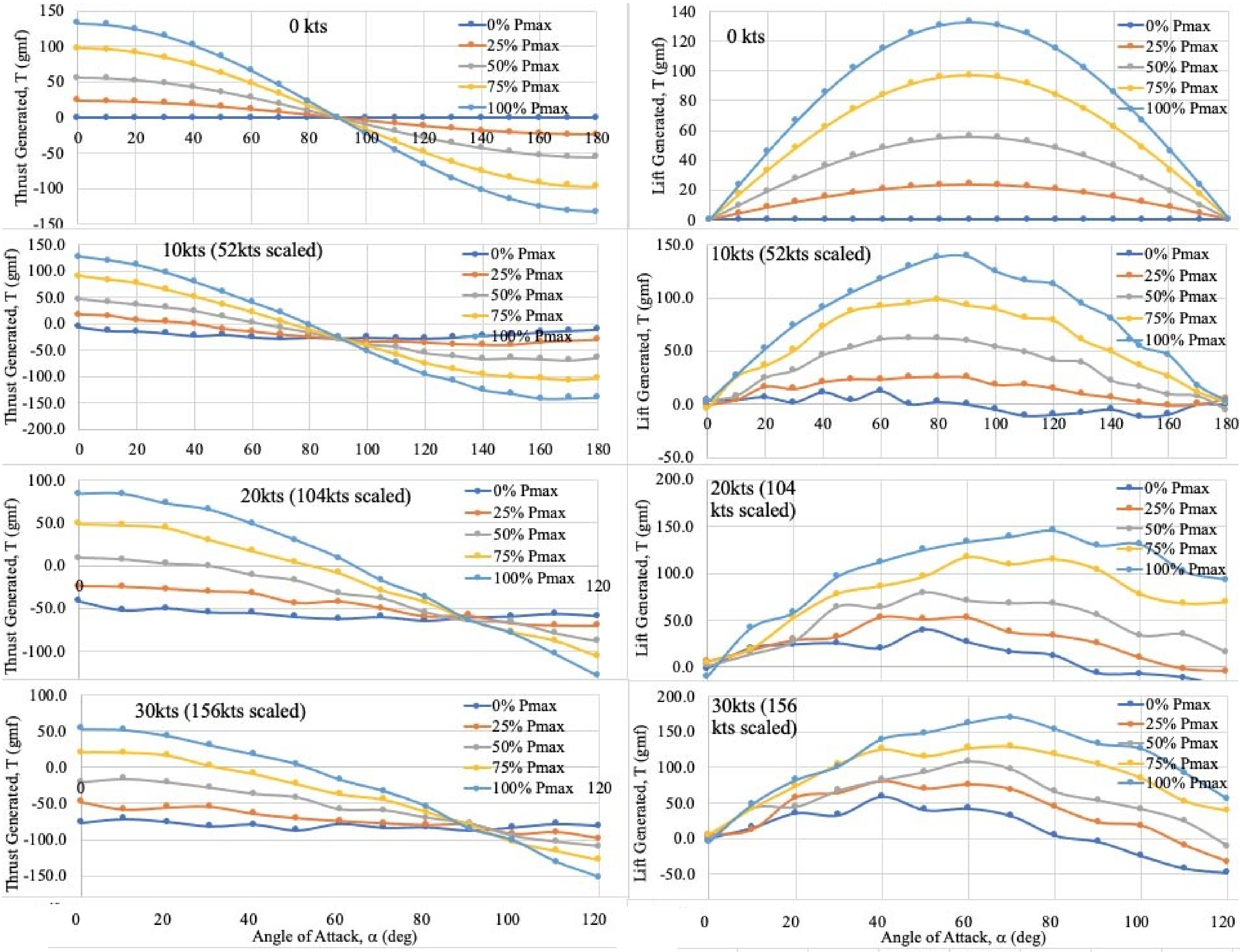
	Minimum	Maximum	Increment
Angle of Attack	0°	180°	10°
Tunnel Speed	0kts	50kts	10kts
Power Setting	0% Pmax	100% Pmax	25% Pmax





Test Model Wind Tunnel Testing, Cont.

Wind tunnel testing shows full transition capability being maintained through 50kts under 1g flight (which equates to a Froude-scaled speed of 260kts) under full power at just over 10 deg. angle of attack.



Flight and Wire-Strike Testing

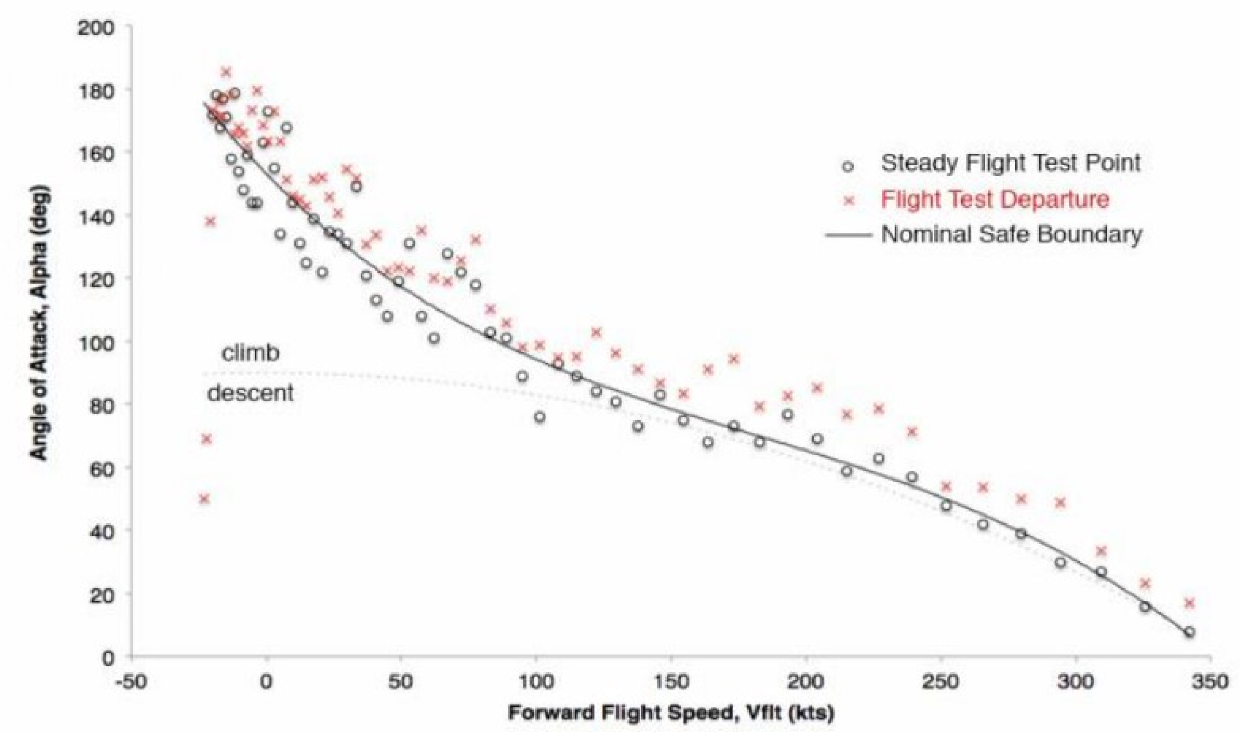
Drones Operating below 500 ft must be qualified for wire strike.
They have and will continue to strike wires at an alarming rate no matter how good their wire detection or avoidance systems are. What is more is that they must do so safely with neither wire break nor crash.
-Wes Ryan, Chief, FAA Small Aircraft Directorate 2018

https://vimeo.com/557298319

https://vimeo.com/557352330

Transition Testing

The model flight test aircraft achieved full transition four times during flight test prior to the submission of this report. Two forms of transition entry were tried, both worked, i.) Hover-climb, then dive to entry, ii.) Hover-climb direct entry. One technique was used for transition back from high-speed flight to hover-mode flight: Zoom climb to burn off airspeed, then back down slowly. This was the only method that has been shown to safely work for fully convertible aircraft as shown below.



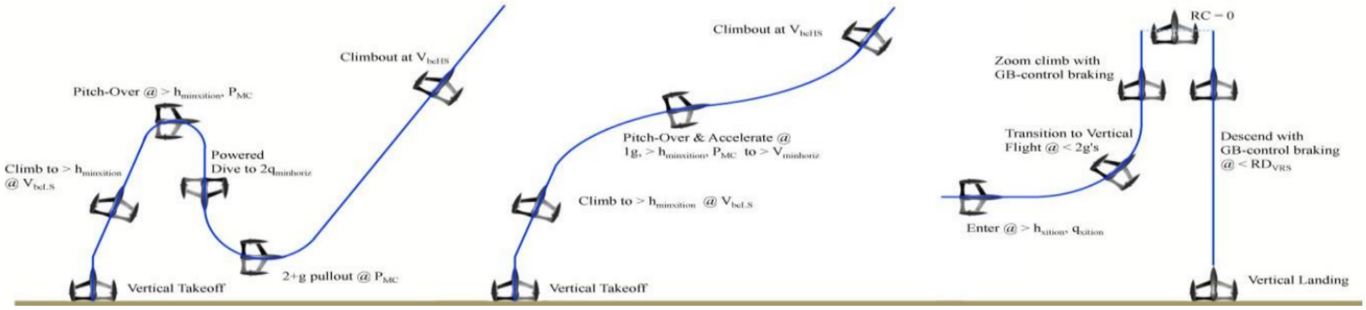


Fig. XX6.4 Two High Speed Conversion Entry Transitions Used, One Exit Transition

Conclusion

The RFP called for a design that could safely and efficiently carry a 50kg load to emergency sites up to 200km away quickly and autonomously. As of 2021, there is currently no extant aircraft that could fulfill this purpose well as the market for UAVs is split between extremely light weight package delivery concepts and large urban air taxis. Because of this, a new aircraft was designed from scratch for this report using and building off concepts of previous successful aircraft.

The converged solution was a convertible body-tilt aircraft that can reach the maximum FAA allowable travel speed of 250 kts, can travel over 700 nmi in ferry flights, and has numerous safety measures that limit any kind of danger of the public being exposed to the aircraft. Additionally, the design was built as a 1/27th scale model and shown to perform well in wind tunnel and freeflight tests.

Regards – Team QuadRockets