Undergraduate Design Team
University of Maryland - College Park

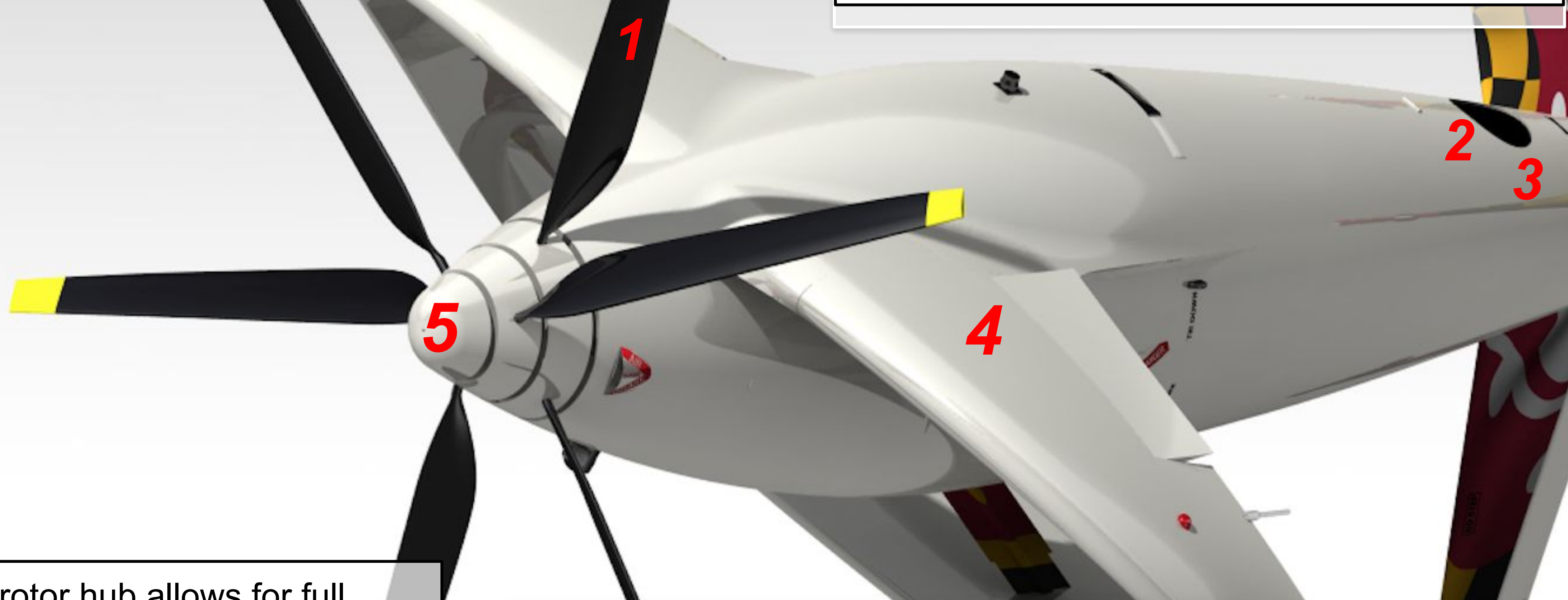
35th Annual American Helicopter Society
International Student Design Competition 2018

Kwatee Conceptual Design

Sponsored by The United States Army Research Laboratory

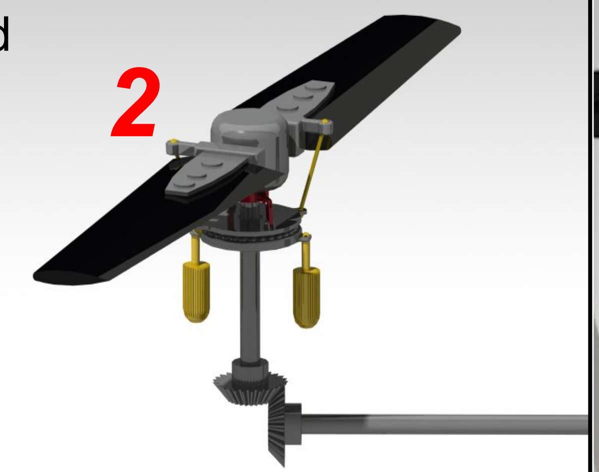
UNIVERSITY OF
MARYLAND

Kwatee Overview



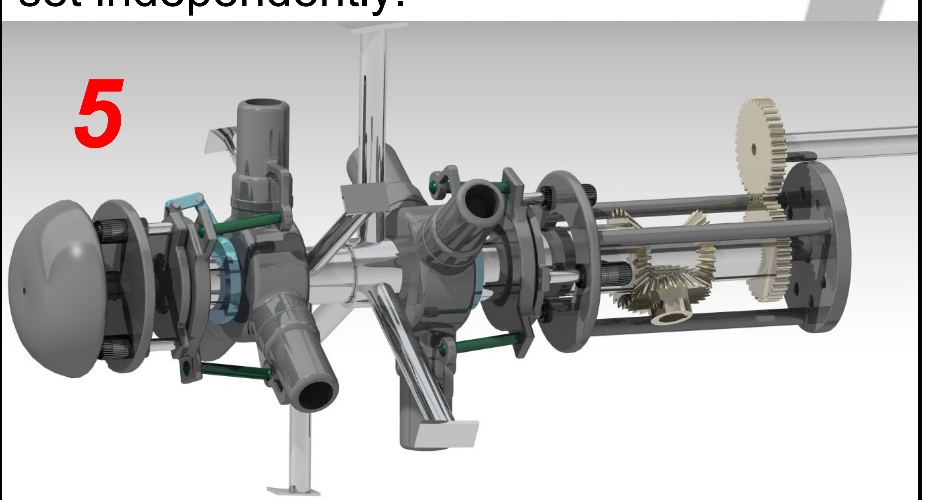
Six SC1095 blades are optimized to reach a balance of hover and axial flight performance.

Bidirectional ducted fan in the tail section allows for a complete thrust reversal to aid in transition between flight modes.



Rotating shroud reduces drag in axial flight and shields the fan assembly from elements.

Rigid coaxial rotor hub allows for full cyclic and collective control for each rotor set independently.



Design Highlights:

Max Dash Speed: **421 km/h**

Max Range @ 50% fuel: **515 km**

Max Endurance @ 50% fuel: **2.73 hours**

MTOW: **531 kg**

A unique variable incidence box wing reduces transition duration while canceling pitching moment from induced flow.

Introduction

In response to the 35th Annual AHS International Student Design Competition Request for Proposal, the University of Maryland Undergraduate Team presents *Kwatee*, a novel reconfigurable VTOL capable of fast forward flight.

In the spirit of RFP's desire for reconfigurability and the US Army's long standing tradition of drawing names from Native American culture our design is named after the cheerfully optimistic Native American God of transformation, *Kwatee*.

Design Capabilities

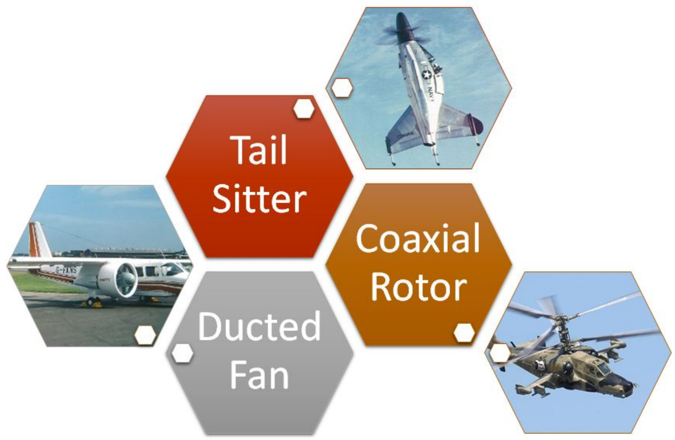
Kwatee is a coaxial proprotor tail sitter configuration utilizing a novel variable incidence boxwing and a bidirectional ducted fan, all in a vehicle weighing 532.6 kg, well within the American Helicopter Society's RFP limits. Two flight modes endow *Kwatee* with hover capability for navigating a megacity environment and forward flight capability with maximum dash speed of 426 km/h (230 knots) exceeding the RFP requirement.

Design Highlights

- Novel variable incidence box wing
- Bidirectional ducted fan
- A multi mission capable platform
- Fast forward flight at 426 (230 knots)
- Extended range of 354 km (440 miles)
- Prolonged endurance of 4.1 hours

Analytical Hierarchy Process (AHP)

Design Drivers	Design Driver Weights	Final Considered Configurations
18 initial design drivers, using the Analytical Hierarchy Process, were narrowed down to 8 final design drivers.	Design drivers were compared in pairs and weighted relative to each other using the AHP.	The final 3 considered configurations were then selected for further investigation.



RFP Requirement	Design Solution
Max Size of 3mx3m in hover	Utilized a box wing and coaxial proprotor in tailsitter configuration capable of producing more lift in a smaller span
Reconfigurable	Novel variable incidence box wing and ducted tail fan enables smooth transition between hover and forward flight modes
Efficient Hover	Coaxial rotor allows for maximum disk area and no tail rotor, resulting in lower disc loading and high power loading
Fast Forward Flight	Loweight fuel-efficient twin turboshaft engine, along with low induced and profile drag from box wing and fuselage with excellent fineness ratio.
Unmanned vehicle	Advanced avionics package allows for fully autonomous missions

Kwatee

As stated in the RFP the vehicle will need to possess the capability to navigate a megacity environment and high speed flight of a fixed-wing aircraft. A benchmark was made using two popular civilian aircraft: the Robinson R22 (helicopter) and the Piper PA-28 Cherokee (fixed wing).

	RFP	R22	PA-28	***Kwatee***
Maximum Gross Takeoff Weight (MTOW)	600 kg (1300 lbs)	635 kg	975 kg	**533 kg (1172 lbs)**
Operating Altitude standard atmosphere	3,000 m (9,900 ft)	4,267 m	4,267 m	**3,000 m (9,900 ft)**
Maximum Airspeed (V_{max})	335 km/h (180 knots) or greater	188.9 km/h	227.8 km/h	**425 km/h (230 knots)**
Payload	100 kg (220 lbs) or greater	218 kg	430 kg	**100 kg (220 lbs)**
Maximum Vehicle Span (in hover)	3 m (9.8 ft) (9.8 ft)	7.67 m	9.2 m	**3 m (9.8 ft)**

RFP states the design is a Group 3 UAS. Even with the footprint restriction and the weighing less than a comparable helicopter and fixed wing aircraft, Kwatee surpassed the other aircrafts in nearly all categories.

Each proposal is compared on four performance metrics. Kwatee, even compared to larger aircraft, is still a capable vehicle.

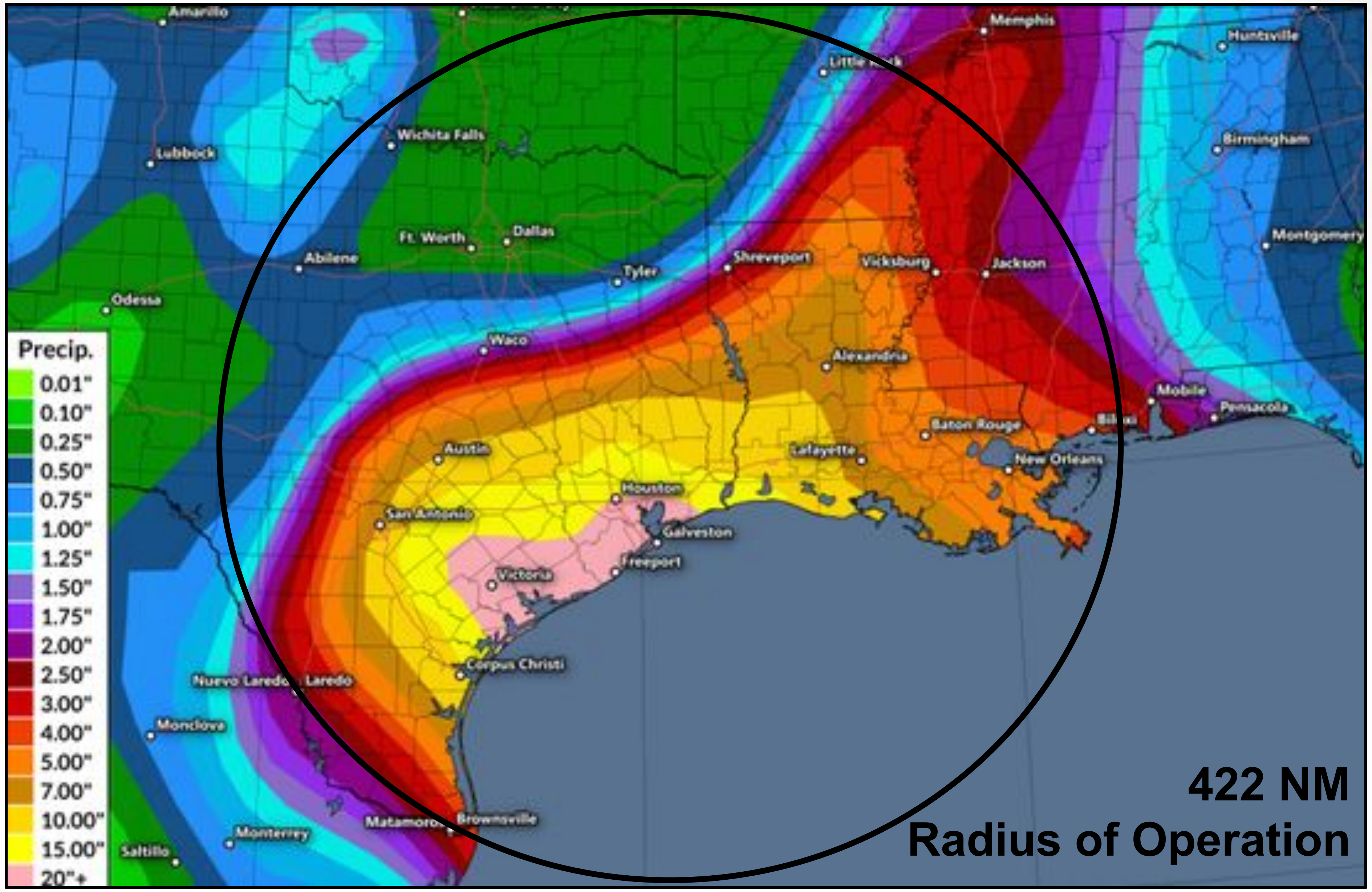
	R22	PA-28	***Kwatee***
Endurance	2 hours	2.5 hours	**SLS: 1.74 hours 3000 m: 1.45 hours**
Cruise Range	193 km (104.3 NM)	475 km (256.3 NM)	**SLS: 510 km (281 nm) 3,000 m: 515 km (278 NM)**
Dash speed (V_{max})	188.9 km/h	227.8 km/h	**SLS: 389 km/h 3000 m: 425 km/h**
Estimated Drag Area	0.8 m^2	0.77 m^2	**0.16 m^2**

Missions:

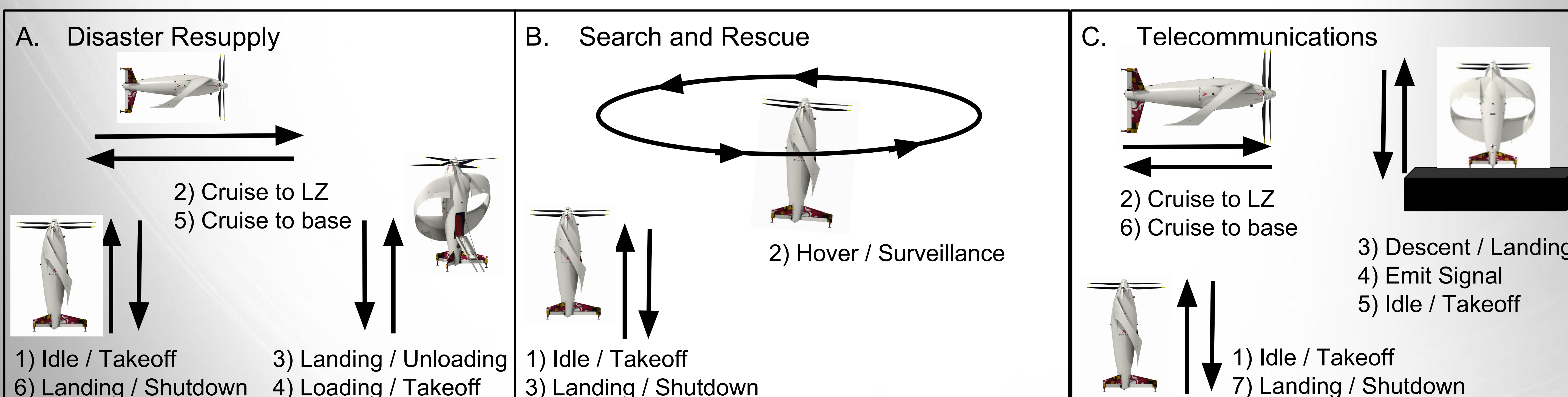
A. Disaster Resupply:
- Will consist of delivering medical supplies, emergency rations, and water to victims of natural disasters.

B. Search and Rescue:
- Will contain robust avionics capable of thermal and IR sight for locating civilians in distress.

C. Telecommunications:
- Will consists of a long range antenna capable of delivering wireless signal to a largely affected area.



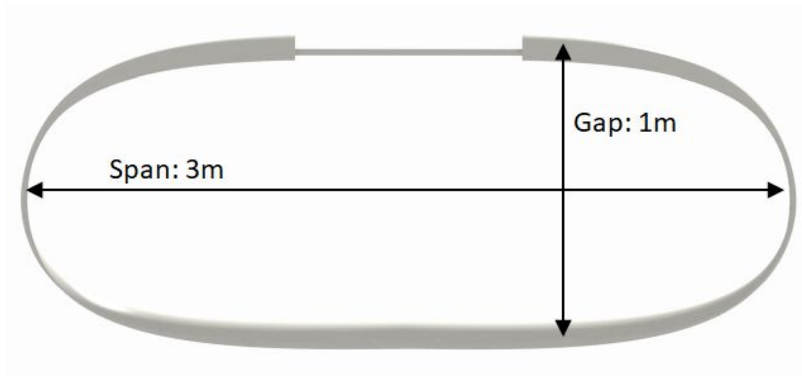
Houston, Texas that depicts levels of precipitation experienced during hurricane Harvey (2017). The large circle indicates the area that the *Kwatee* could provide assistance to after the storm.



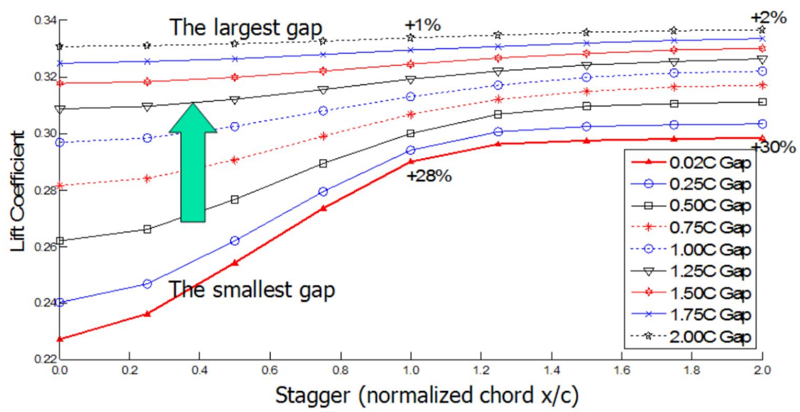
Box Wing

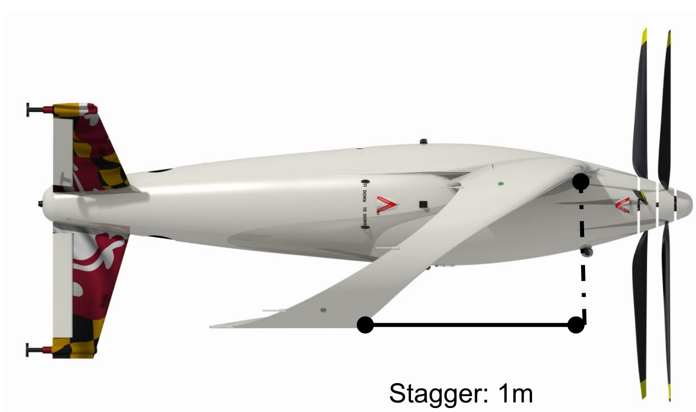
Due to span restriction, a box wing was chosen as the main lifting device in forward flight mode.

- Box wing generates more lift than similarly spanned monowings
- Endplates reduce wingtip vortex effects, increasing overall span efficiency of the system from <1.0 to 1.46
- Box wing is structurally stiffer than conventional designs, allowing for a higher aspect ratio for the individual wings
- The stagger and gap are selected to give maximum lift efficiency within *Kwatee's* footprint limitations



Box Wing Specifications
Airfoil: Wortmann FX 63-137
Chord: 1 m (root), .55 m (tip)

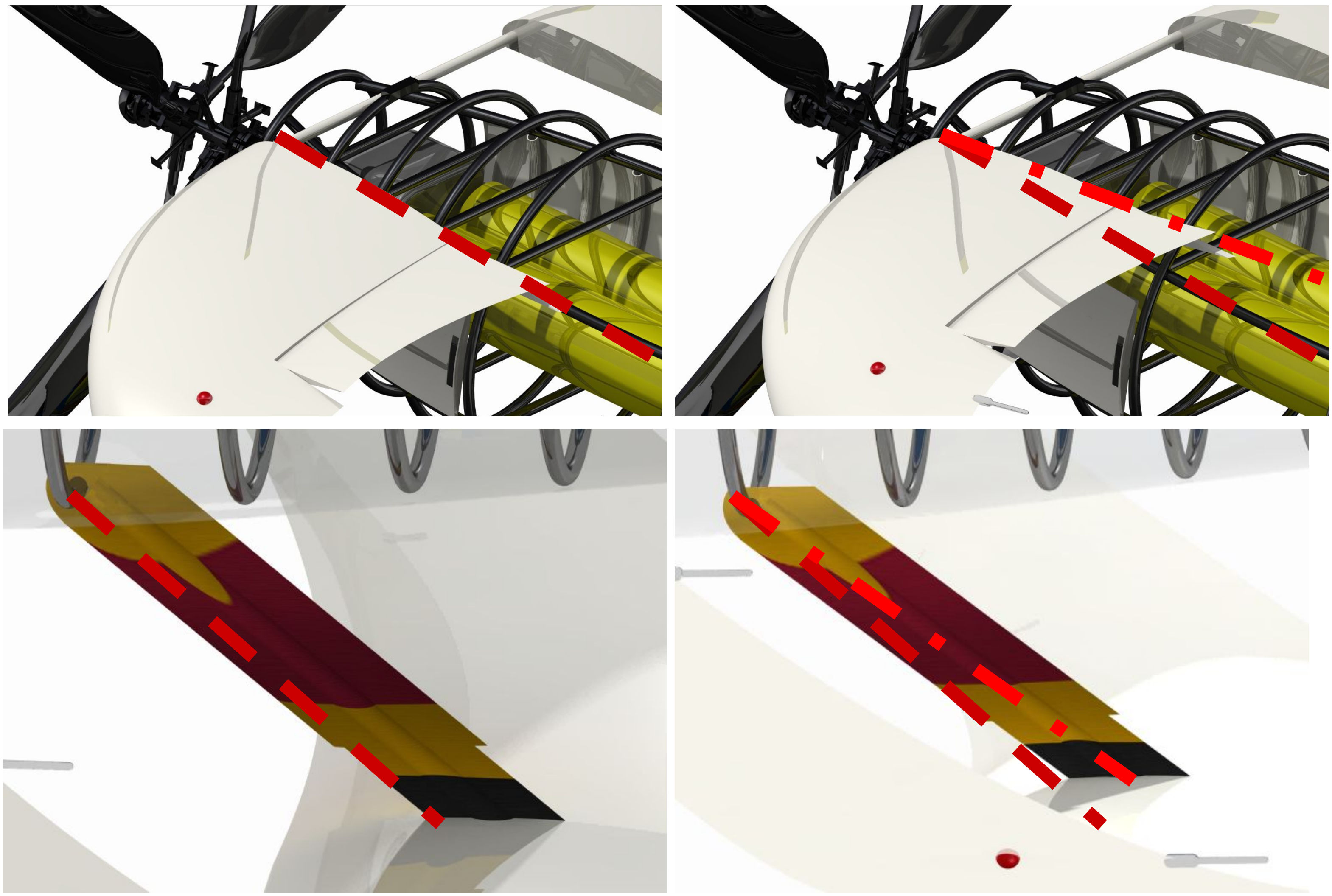




Reconfigurable Wing: Variable Incidence

A variable incidence wing is implemented to:

- Reduce required power for transition maneuvers
- To increase gust resistance while in hover
- Keep *Kwatee* controllable through its continuous-ascent transition

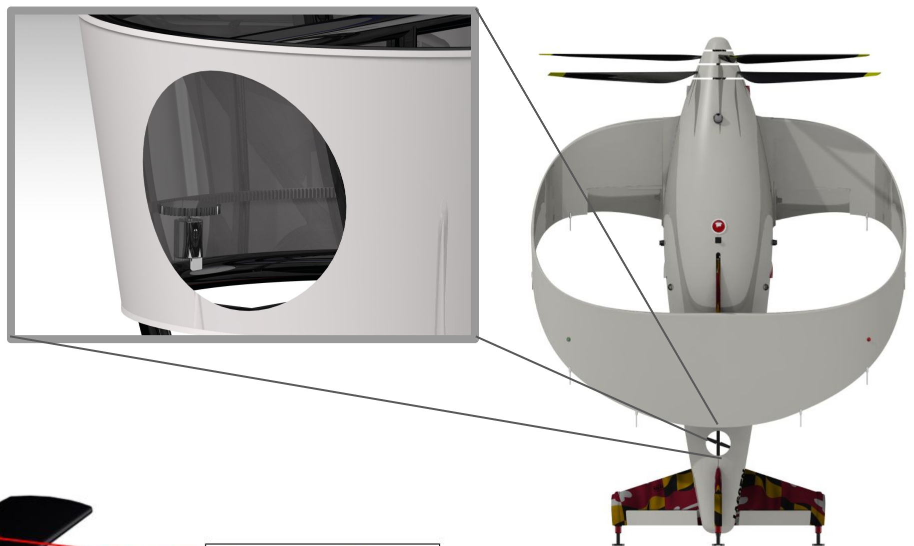


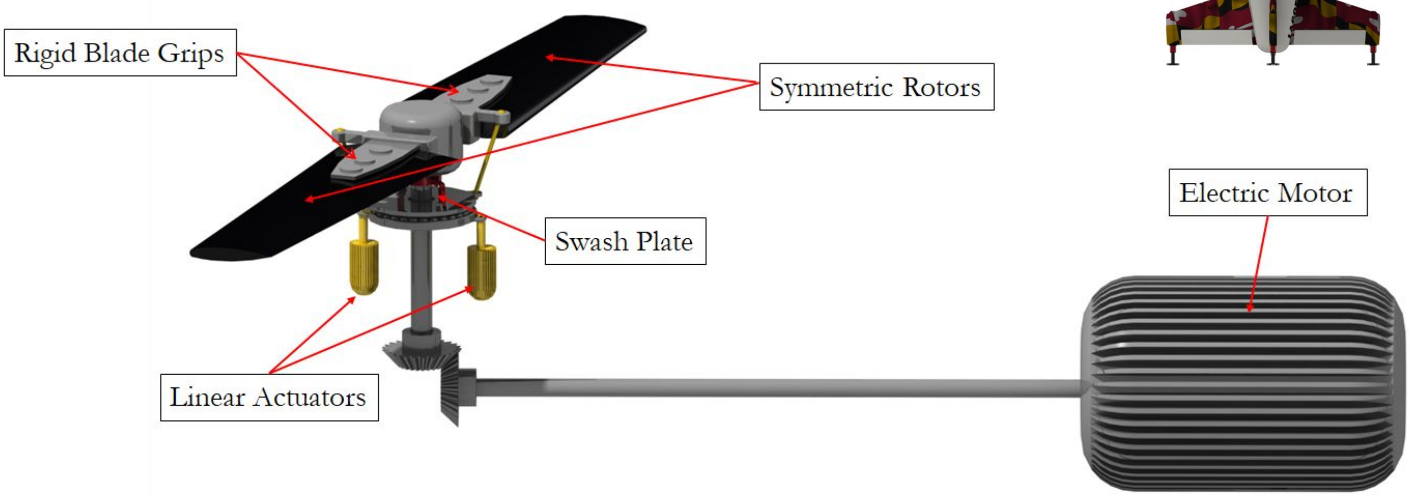
The two images on the left depict the wing and the strut that connects the bottom wing to the fuselage in their static position. The wing is pitched down 5° in the images to the right with the dotted red line depicting the change in wing incidence.

Bidirectional Ducted Fan

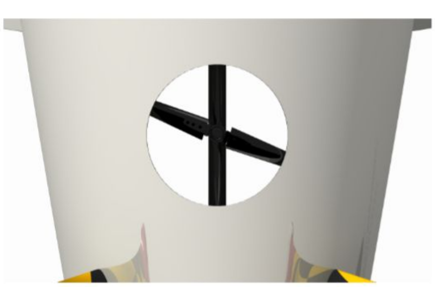
The Bidirectional ducted fan:

- Aids in the transition maneuver.
- Reduces the power required in transition.
- Has a collective control range of -14° to 14° to provide bidirectional thrust.

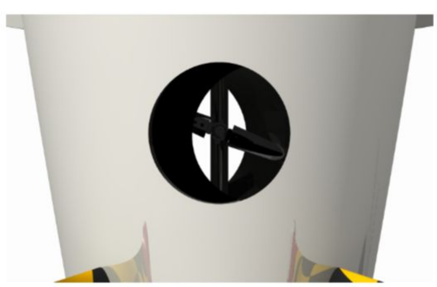




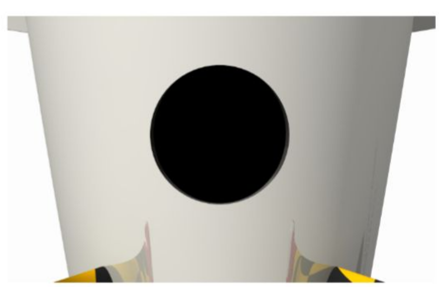
Fan is shrouded in forward flight to eliminate unnecessary drag. When *Kwatee* is on the ground the shroud can be closed to protect the fan assembly from the elements.



Open Shroud



Partially Closed

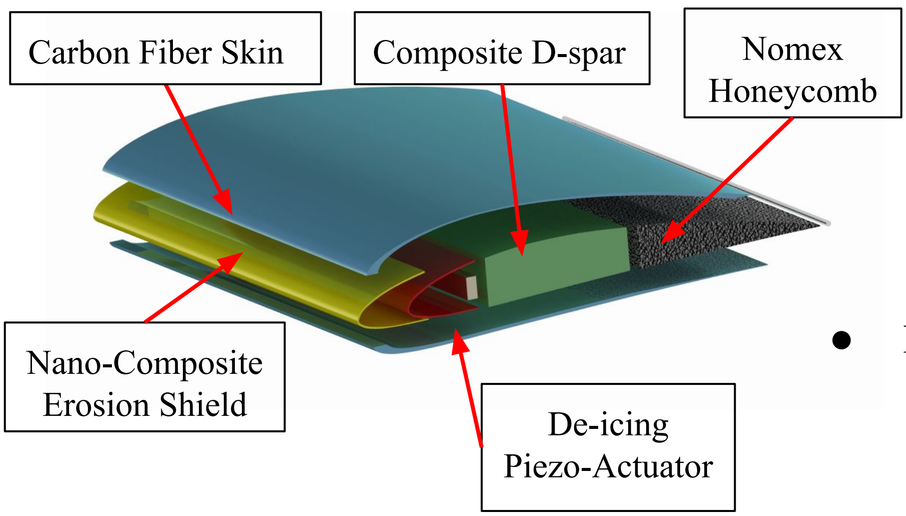


Closed

Rotor Blades

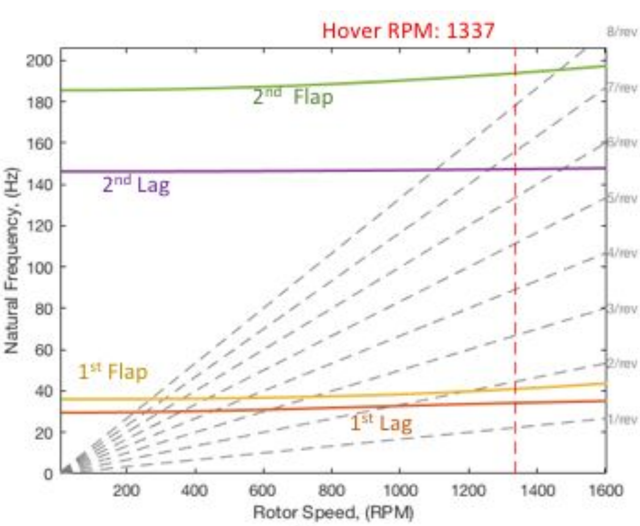
Kwatee's blades have been designed to optimize the compromise between hover and propulsive efficiencies through an extensive parametric sweep of *7,700* airfoils, taper and twist rates.

- Composite rotor blades
  - Graphite-Epoxy D spar
  - Carbon Fiber Skin : high specific strength
  - Nomex honeycomb: minimize weight.

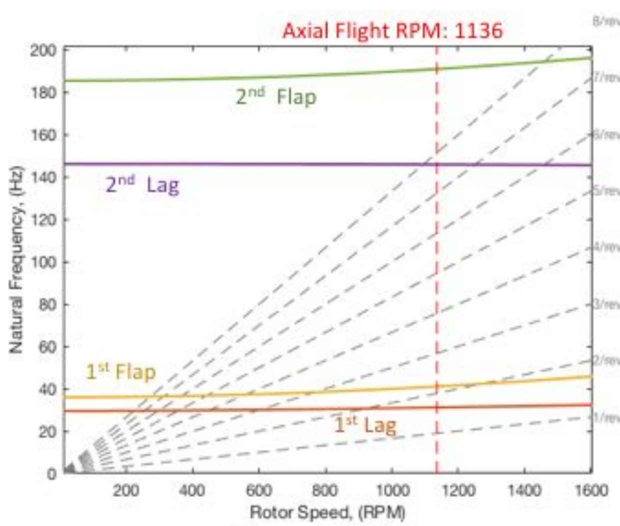


Rotor Performance Characteristics	
Figure of Merit	**0.782**
Propulsive Efficiency	**0.793**
Disk Loading	833 N/m^2 (17.4 lb/ft^2)
Power Loading	33.3 N/kW (10.1 lb/hp)
Hover Tip Mach Number	0.640

- Fan plots for Hover and Forward Flight
  - **1.53/rev 1st flap freq.**
  - Ensures no Blade Strike



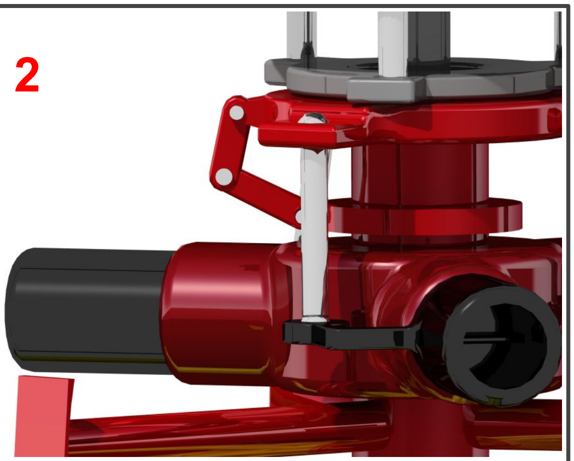
Hover



Forward Flight

Coaxial Hub

6 independently controlled actuators control full collective and cyclic settings

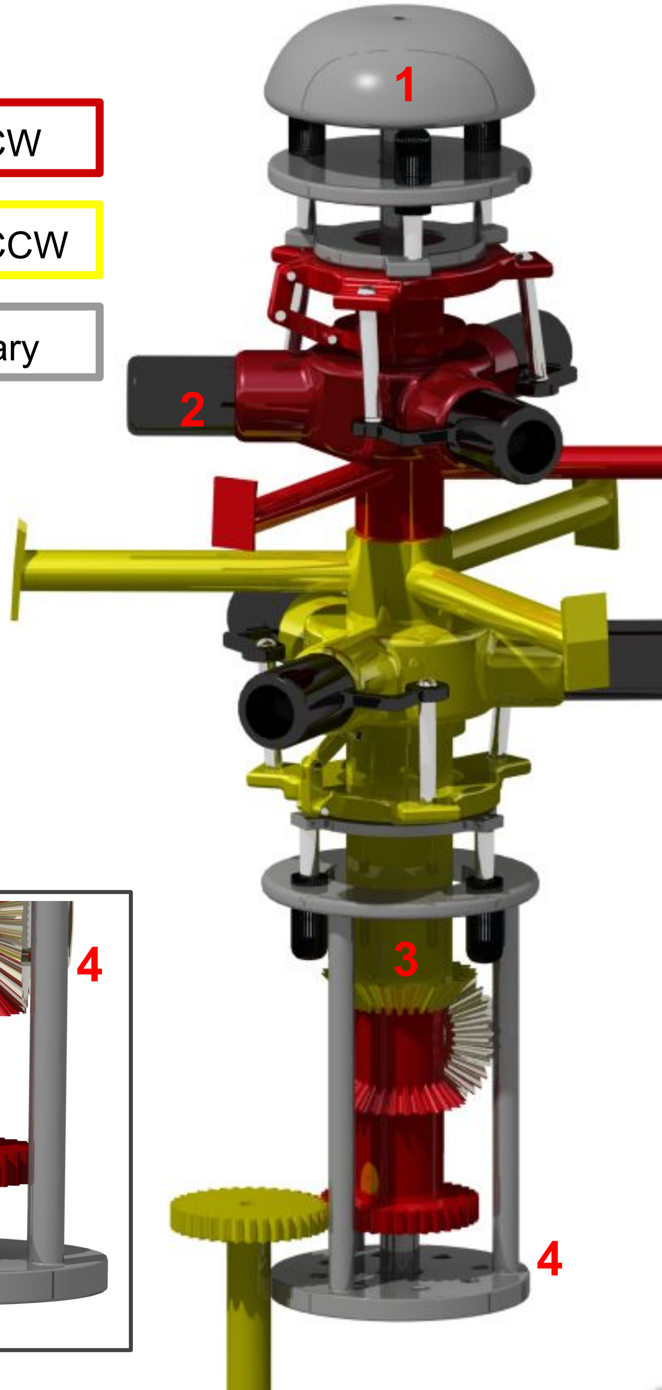


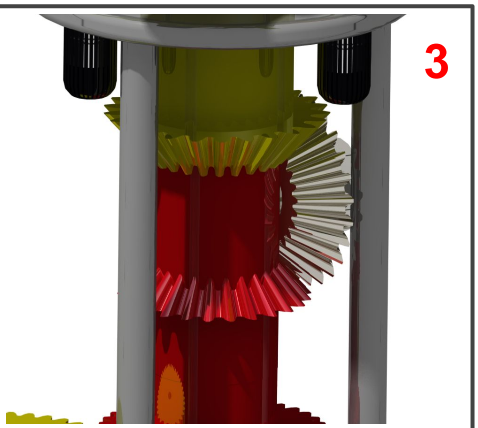
Blade grips take advantage of centrifugal forces to grip composite rotor blades

Rotates CW

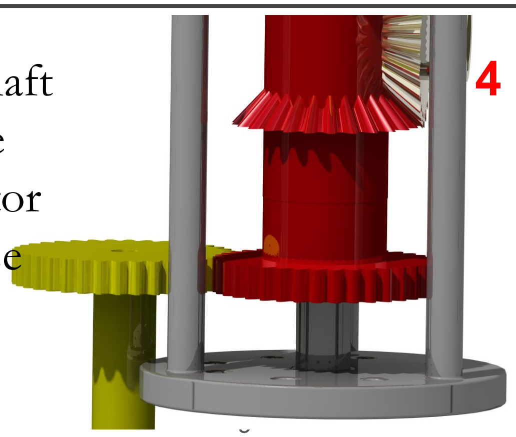
Rotates CCW

Stationary





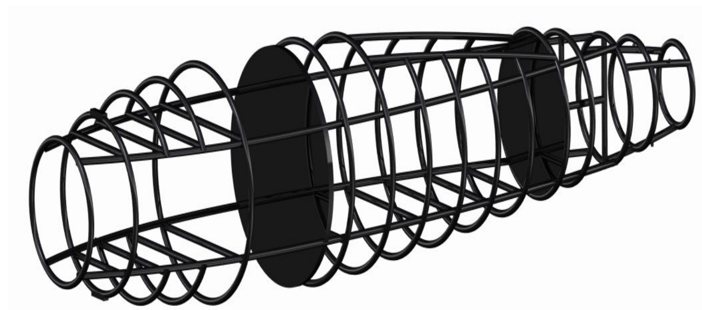
Gearbox uses bevel gear system to reverse direction of rotation

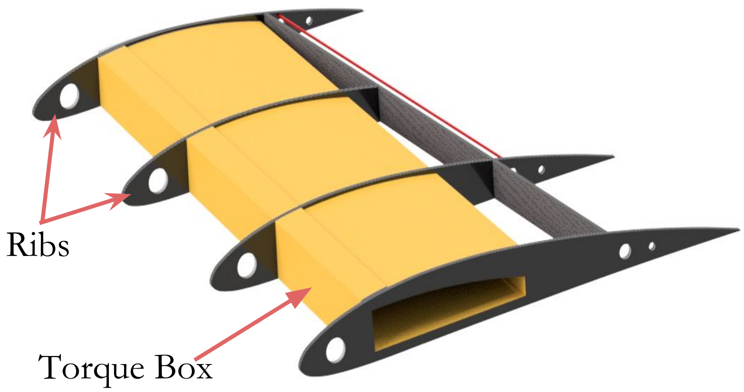


A structural shaft connecting the base of the rotor hub to the nose portion of the hub

Lightweight Airframe

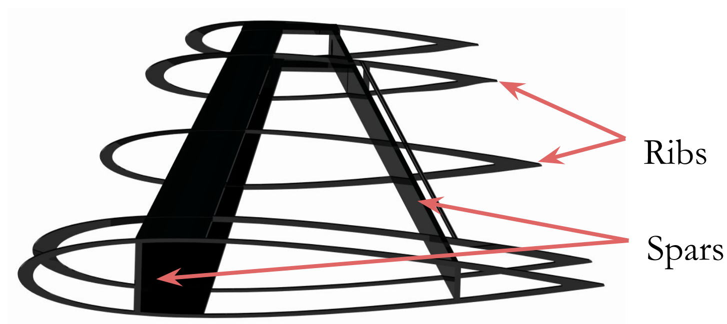
Kwatee's semi-monocoque airframe consists of strategically placed bulkheads, longerons, stringers and load bearing skin. Vehicle components are positioned to achieve short load paths.

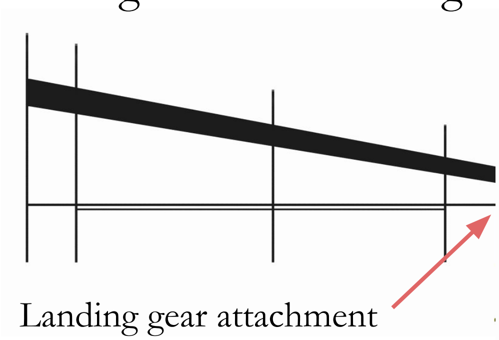




The box wing is optimized for high bending stiffness needed during forward flight. The graphite-epoxy wing is composed of torque box, ribs and skin.

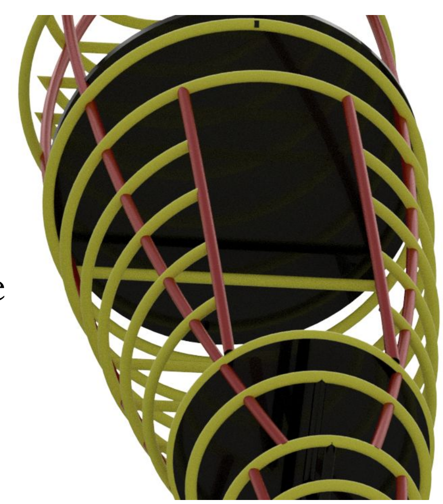
The internal structure of the fins consist of ribs and two angled spars that ensure a smooth transfer of the landing loads to the longerons.



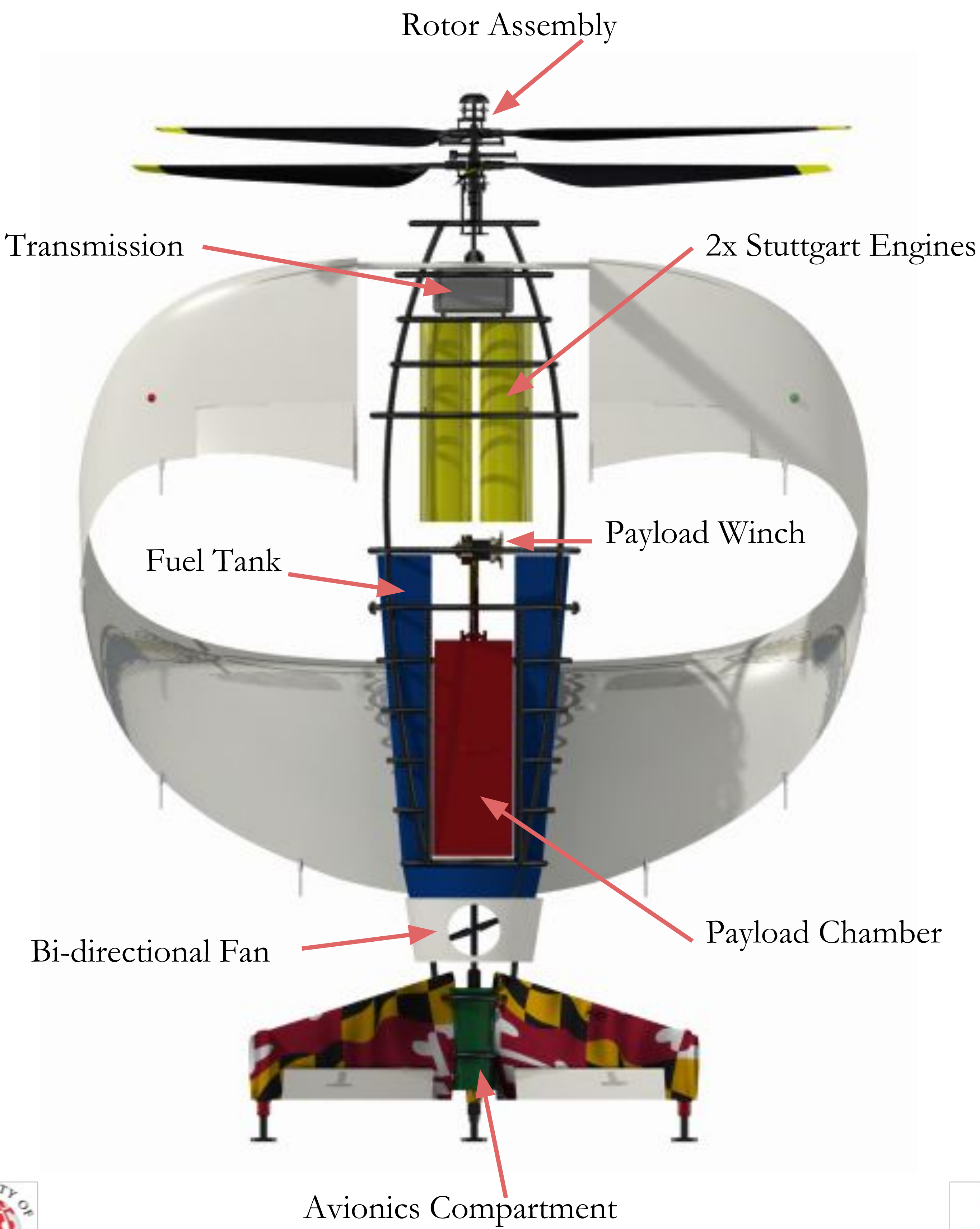


The sealed oleo-pneumatic landing gear is attached to the leading edge spar of the tail fin.

Door frames are created around the payload door and engine bay doors to improve structural integrity



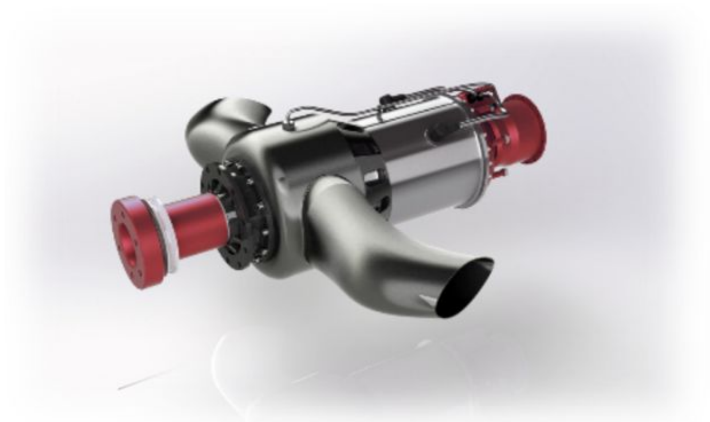
Kwatee's Internal Layout



Kwatee Powerplant

Kwatee utilizes a Stuttgart STV130 twin turboshaft propulsion system with a total output of 260 hp.

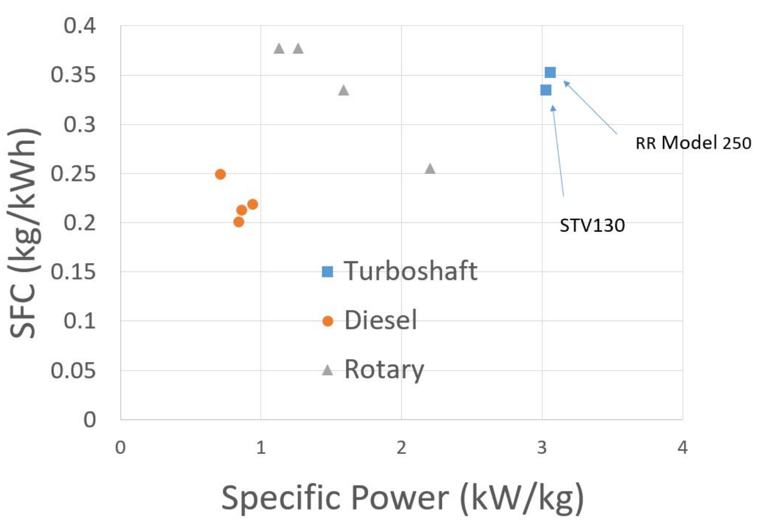
- Operates at both horizontal and vertical orientations at all altitudes
- Flight test proven reliability and superior specific power and size
- Power is transmitted through a built-in reduction gearbox
- Cooled and lubricated by a dry sump lubrication system and radiator



Stuttgart STV-130

Comparing the Stuttgart (*Kwatee's* powerplant) and the Rolls Royce Model 250

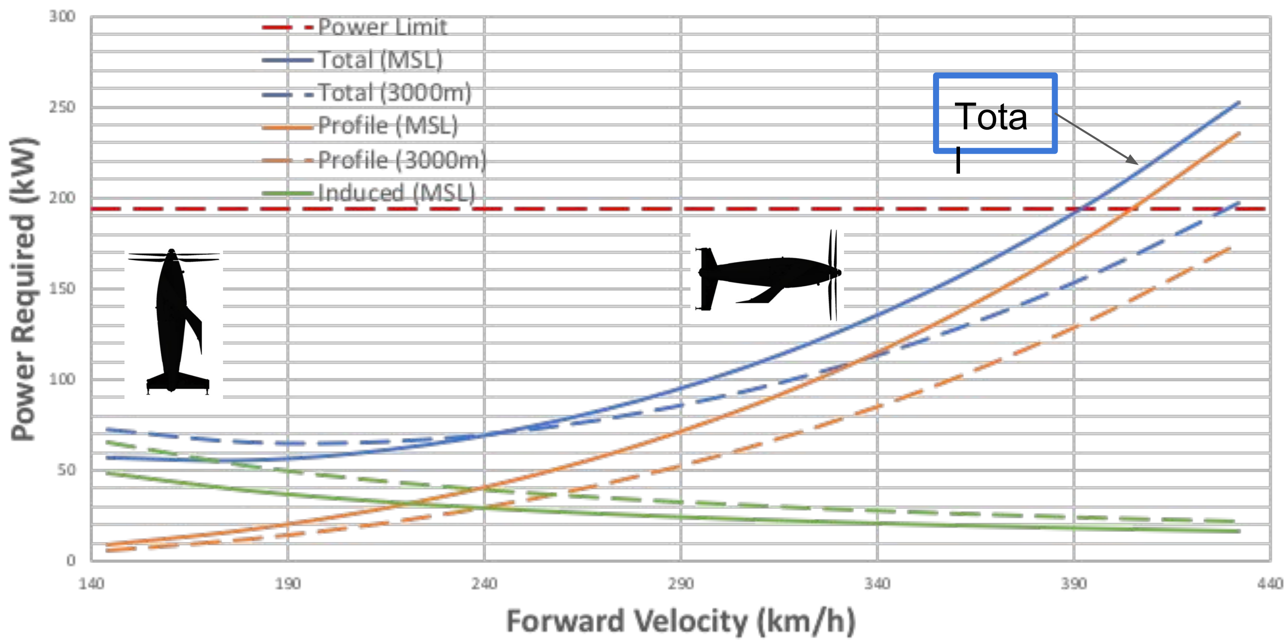
	Stuttgart STV130 Turboshaft	**Rolls Royce Model 250-C20J Turboshaft**
Power (each)	**97 kW**	313 kW
Power/Weight	**3.03 kW/kg**	3.05 kW/kg
Sfc	**0.33 kg/kWh**	0.37 kg/kWh
Number of Engines	**2**	1



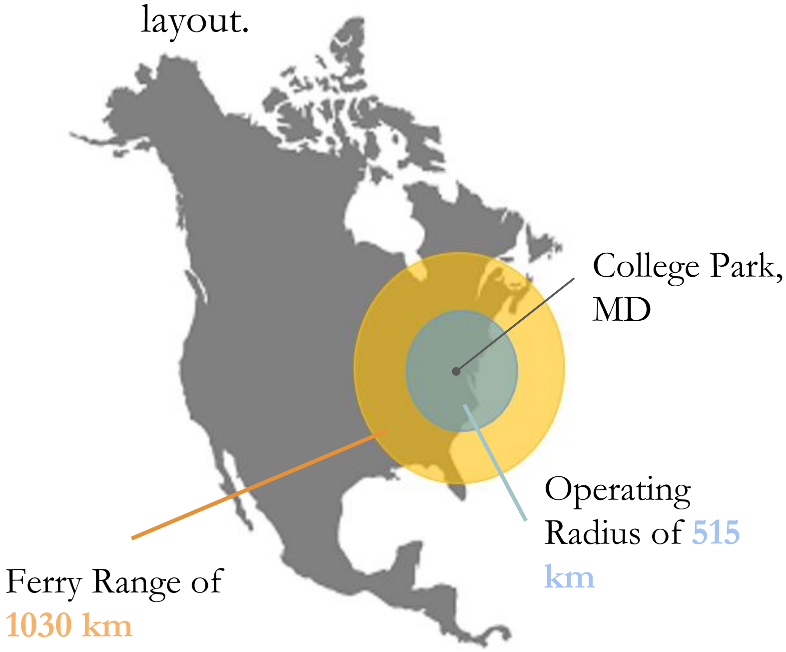
Comparison of Rotary, Diesel, and Turboshaft engines

Kwatee Performance

Kwatee is capable of operating efficiently in both hover and forward flight configurations for a wide range of altitudes due to the low drag profile.



- Efficient hover, high dash speeds, and efficient cruise achieved through optimized enhanced blade geometry, highly streamlined fuselage and optimized box wing layout.



Vehicle Range and Endurance			
HOVER	Endurance Sea Level		**1.74 hr**
	Endurance 3000 m		**1.45 hr**
FORWARD	Max Range (50% fuel)		**515 km**
	Max Endurance (50% fuel)		**2.73 hr**
	Velocity	Best Range	**73 m/s**
		Best Endurance	**49 m/s**
		Maximum	**118 m/s**

Avionics Suite-State of the Art

Imaging Systems

- BOSON 320 Thermal Sensors

- Vision CM202 Gimbaled Camera

Flight Control and Autonomy

- TSI 634000 Pitot Static and Temperature Sensor
- Puck VLP-16 LIDAR Sensor

Supporting Equipment

- Engine Performance Sensors
  - TE Connectivity Ni1000SOT

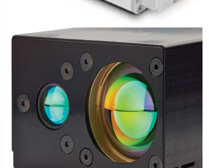
  - Eaton DCCS50-100

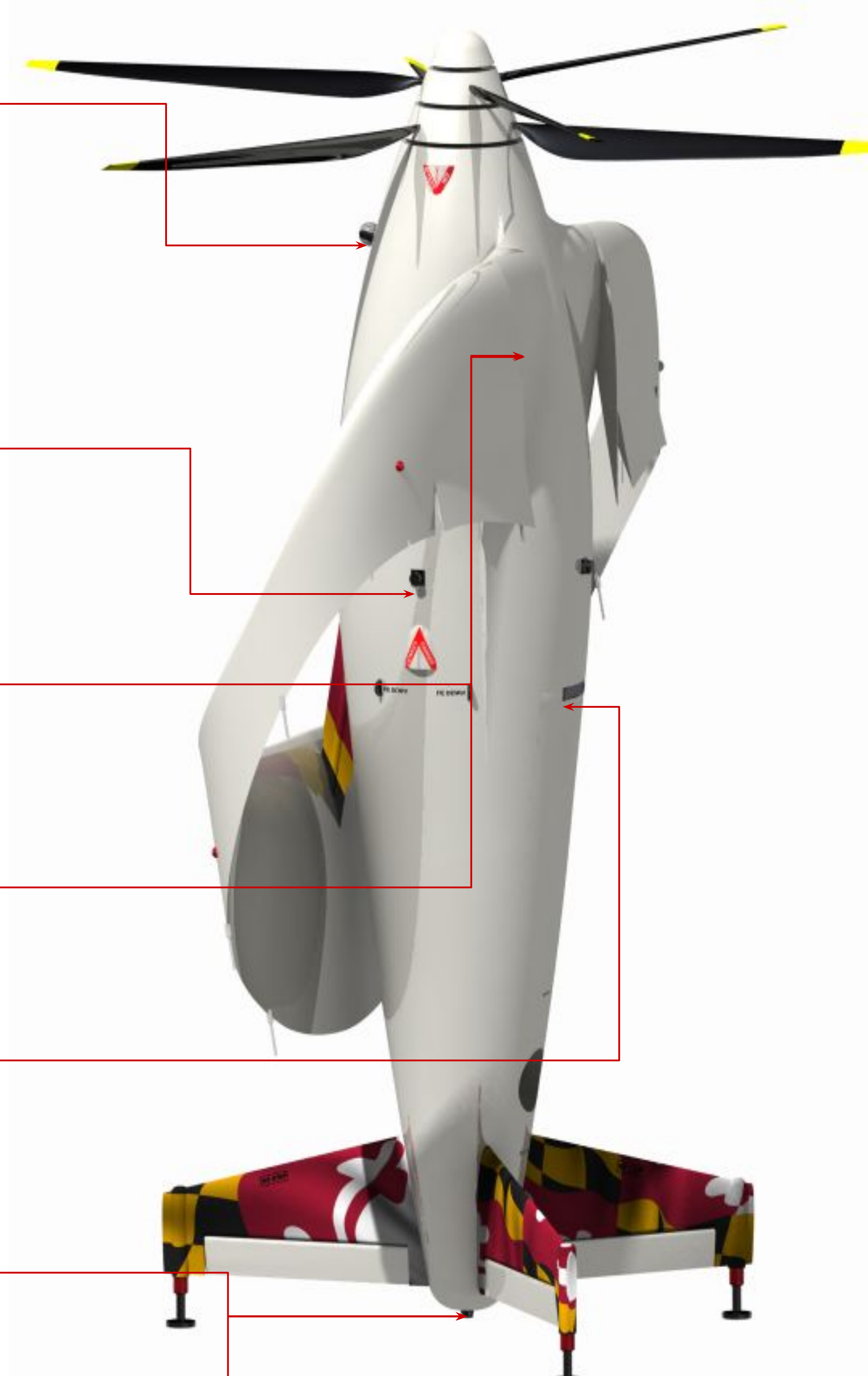
- Rigid 36762 Micro Switch

Take-Off and Landing systems

- GRA 55 Radar Altimeter

- FLIR MLR-4K LIDAR Range Finder





Avionics Compartment

Flight Control

- Piccolo II- Flight Module/Autopilot and IMU

Flight Navigation and Communication

- NovAtel's OEM GNSS Transmitter/ Receiver

- Trimble Force 524D

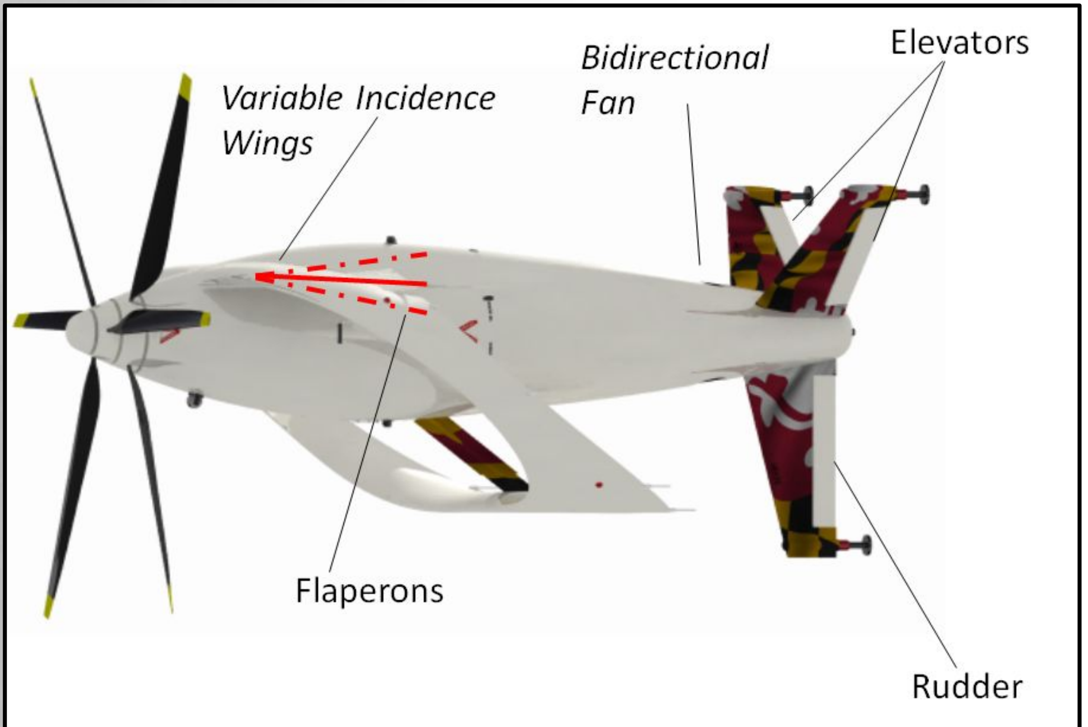
- UAV Navigation PSY90081 Radio Datalink
- AC-27 SATCOM Datalink and Antenna

Supporting Equipment

- Primary 12 Volt Lithium-Ion Battery

- Sparton LPC-500 Processor/ Storage

Flight Control and Transition

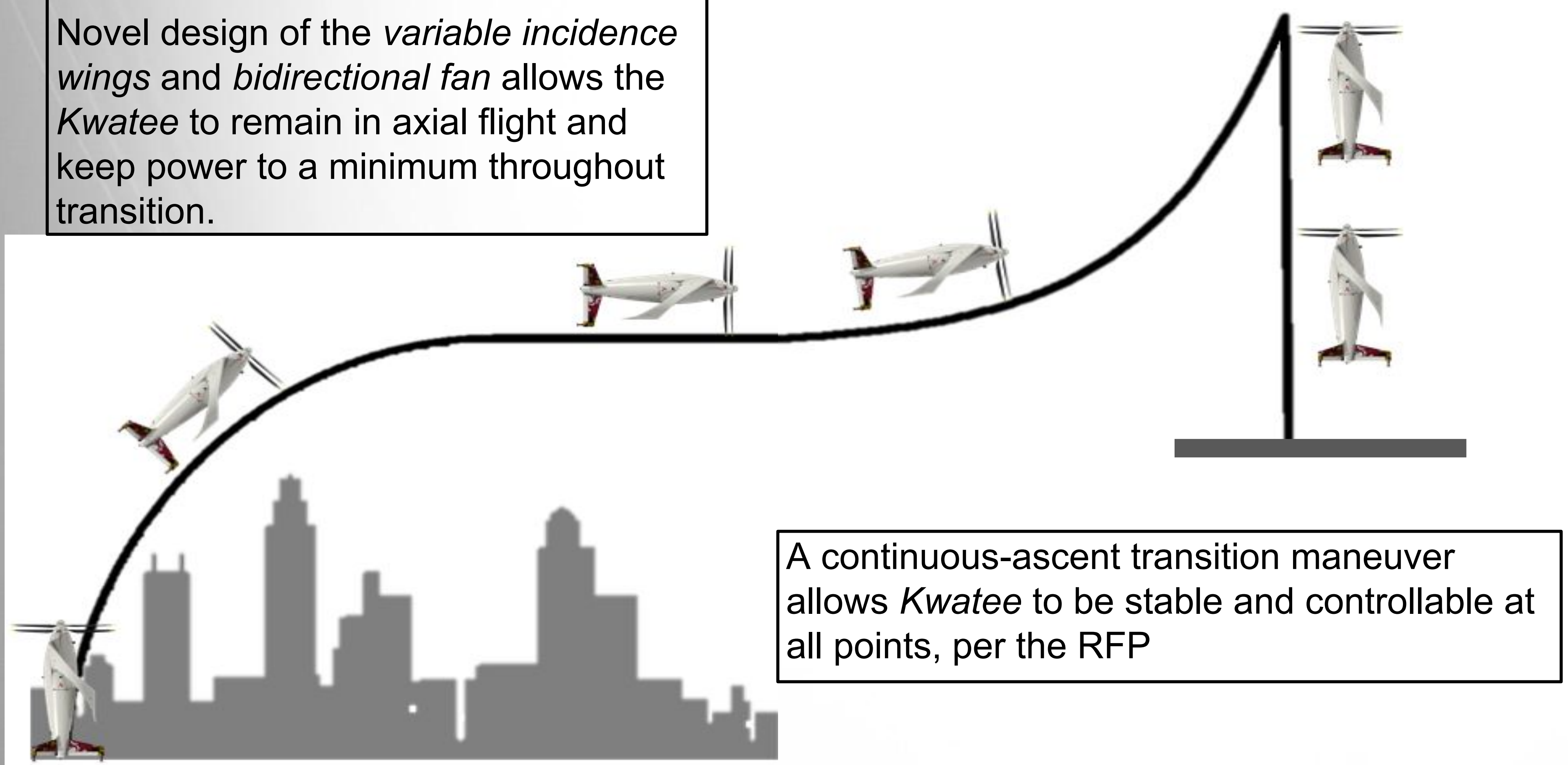


Forward flight control mechanisms

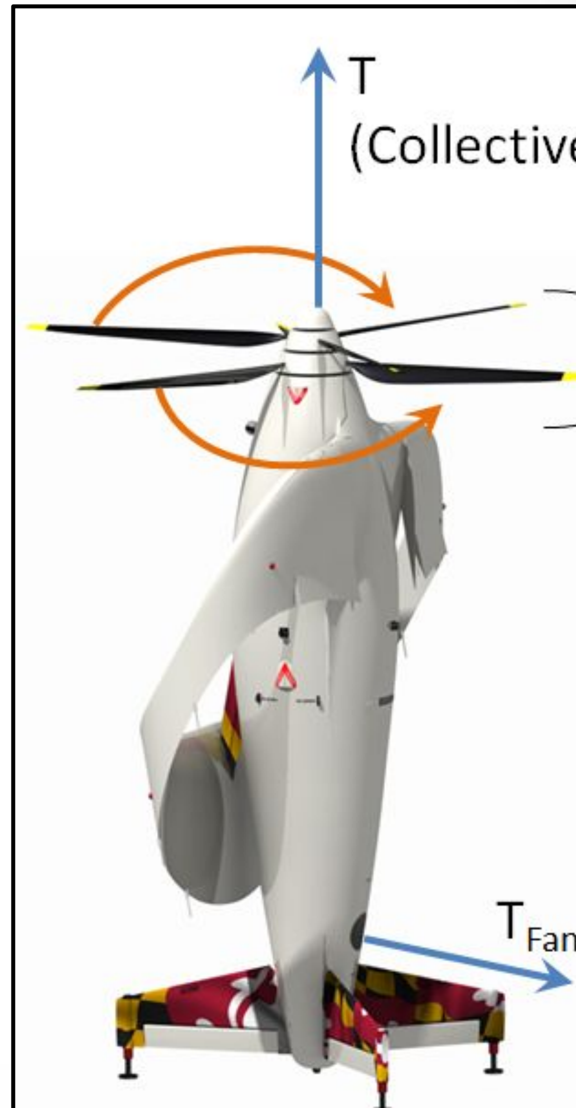
Novel design of the *variable incidence wings* and *bidirectional fan* allows the *Kwatee* to remain in axial flight and keep power to a minimum throughout transition.

	Pitch	Roll	Yaw
Hover	Cyclic	Cyclic	Differential torque of coaxial-proprotors
Forward Flight	Elevators	Flaperons	Rudder

Kwatee's controls scheme and surfaces used to maneuver depends on which flight mode it is in



A continuous-ascent transition maneuver allows *Kwatee* to be stable and controllable at all points, per the RFP



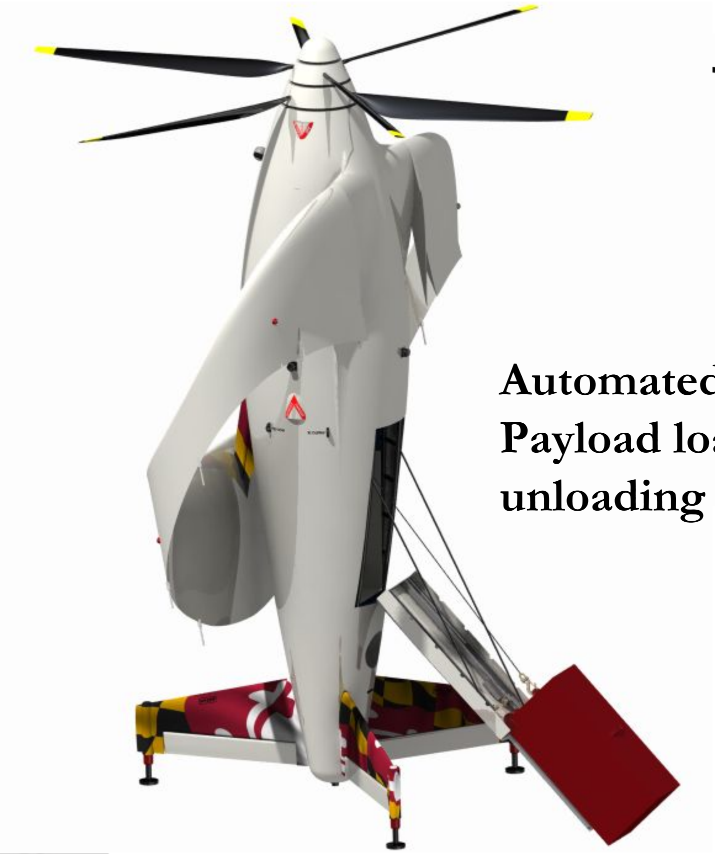
Hover free body diagram and control mechanisms

Concept of Operations

Kwatee is a group 3 VTOL autonomous aircraft capable of reaching a max speed of 118 m/s (230 knots) and maneuvering within tight spaces found in an urban canyon environment. This versatility allows *Kwatee* to complete a variety of missions in a number of environments.

Kwatee's concept of operations is as follows:

- Install flight plan
- Preflight check, boot electronics, close payload door (all autonomously)
- Begin vertical flight, transition to forward flight, fly to target
- Reverse transition to hover, land and unload payload or perform other specified mission objectives, prepare to return
- Return home, land, and shutdown.



Automated Payload loading/ unloading

Engine panels open up for complete access during maintenance

Cost and Weight Breakdown

Component	Weight (kg)	% Empty Weight	X_{CG} (m)	Cost (USD)
Fuselage	50.48	15.23	0.0	$42,000
Wing	57.5	17.36	0.02	$30,000
Rotor Assembly	33.2	10.02	1.68	$74,500
Landing Gear	3.12	0.94	-2.20	$12,300
Payload Door	28.89	8.72	-0.83	$8,000
Fan	4.31	1.3	-1.65	$500
Fins	26.22	7.91	-1.85	$3,500
Control Surfaces	8.53	2.57	-0.12	(Within Wing and Fins)
Propulsion	102.49	30.93	0.63	$162,440
Avionics	16.63	5.02	-1.96	$23,120

Empty Weight	*331.37*
Fuel	*100*
Payload	*100*
Total	***531.37***
Max	***600.00***

Kwatee is designed to be an affordable option at a cost of **$496,400** per unit

Kwatee's lightweight structure and design was developed to ensure flexibility in both payload range and fuel amount (additional fuel tank locations are available), allowing for expanded mission capabilities.

Upper weight limit additions:
150 kg of fuel total + 115 kg payload = GTOW of 596 lb

Empty Weight Fraction: 0.624

Summary

Kwatee, the University of Maryland's response to the RFP for the 2017-2018 AHS Student Design Competition, combines the hover and low speed efficiency of a helicopter with fast forward flight efficiency of a fixed wing into one versatile multi mission capable platform.

- Novel variable incidence boxwing to obtain optimal angle of attack
- Bidirectional ducted fan for efficient transition between flight modes
- Efficient hover capability for navigating megacities
- Maximum dash speed of 426 kph (230 knots), faster than comparable sized fixed wing aircraft
- Versatile multi mission capable platform adept for many roles
- Extended range of 354 km (440 miles) enable *Kwatee* to cover a large service area
- Prolonged endurance 4.2 hours for prolonged search and rescue missions