METALTAIL

35th Annual AHS Student Design Competition

A Reconfigurable VTOL Aircraft

Sponsored by United States Army Research Laboratory

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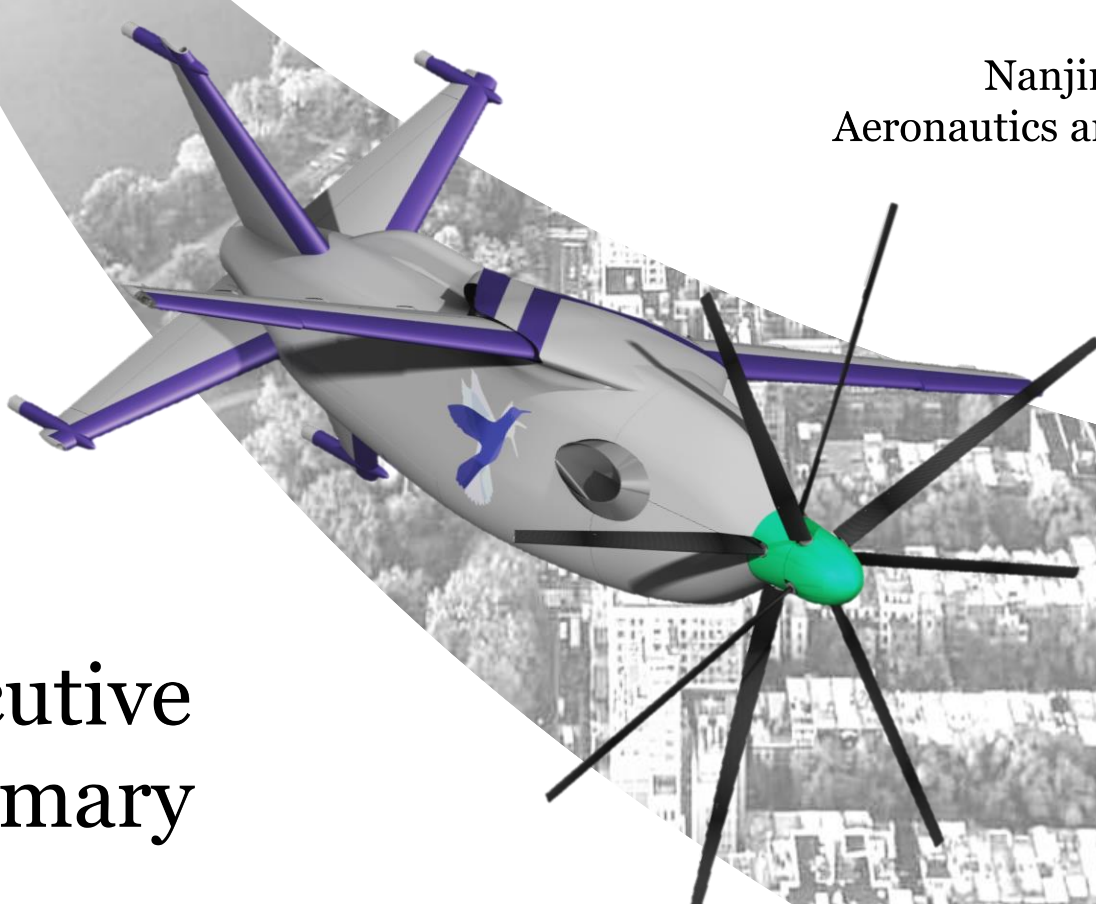

Executive Summary

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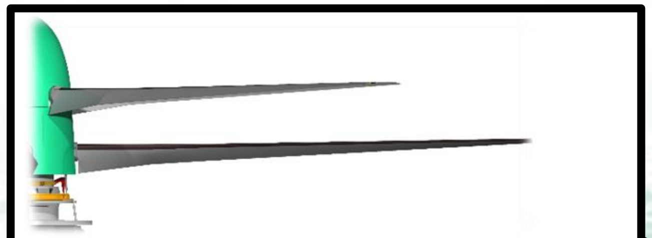
Metaltail: Reconfigured for the Future

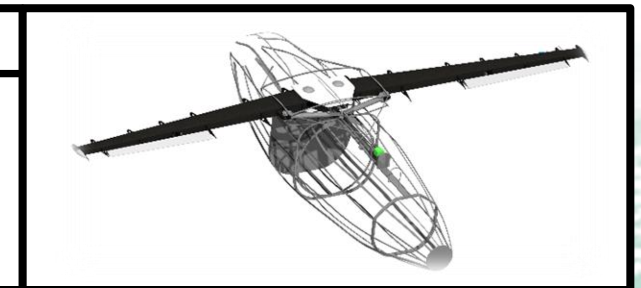


Tailored Proprotor Design

Common point design between rotors and propellers provides efficient performance for both hover and forward flight.

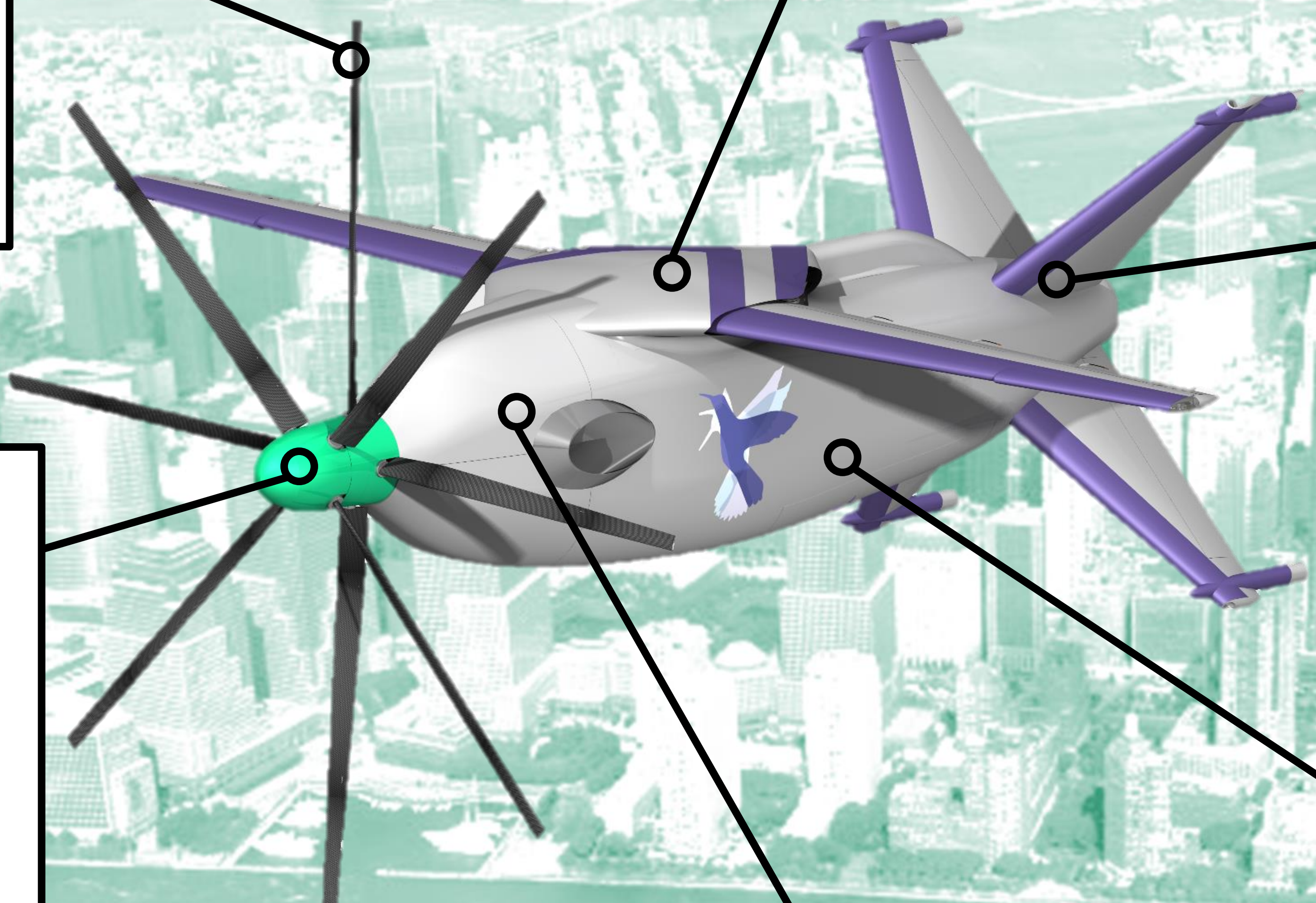
Swing Wing Mechanism

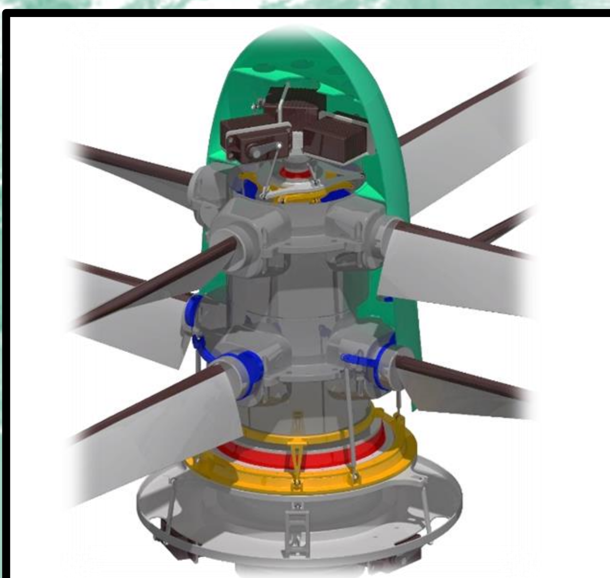
Novel execution of sweeping wings reconfigures past problems into present-day solutions.



Tailsitter Configuration

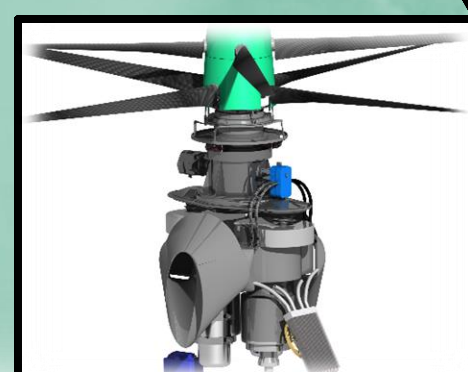
An X-tail titanium frame ensures structural integrity for bearing landing loads.





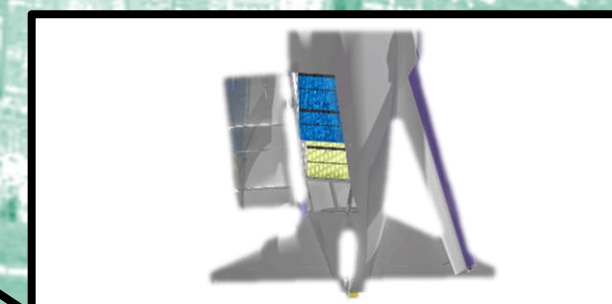
Innovative Hingeless Hub

Unique swashplate mounting method results in compact hub with shorter control rods.



State-of-the-Art Engines

Two advanced turboshaft diesel engines deliver unprecedented power for exceptional performance.



Modular Payload Bay

Large compartment and modular rack offers flexibility for assortment of payload packages.

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Metaltail: Pushing the Envelope

High in the montane forests of Ecuador, a steady hum of activity can be heard as Tyrian Metaltail hummingbirds skirt around the flora, pollinating the habitat. Using their high visual acuity, these small creatures can recognize a wide variety of colors and detect the slightest of motions. Coupled with their agile wing movements, they are able to precisely hover in place while in complex and dynamic environments.

Inspired by these small but impressive flyers, *Metaltail* is a **fully autonomous, high-speed, reconfigurable** aircraft designed by the University of Maryland in response to the 35th Annual AHS Student Design Competition Request for Proposal (RFP) sponsored by the United States Army Research Laboratory (ARL).

Developed as a Group 3 Unmanned Aerial Vehicle (UAV), *Metaltail* is an autonomous **coaxial-proprotor swing-wing tailsitter** that, like the high-altitude hummingbirds of Ecuador, leverages visual sensory information and adjustable wing geometry to **maneuver in megacity environments**.

With **powerful, lightweight, state-of-the-art turboshaft engines**, and **sleek aerodynamic design** pushing the forward flight envelope at this scale, *Metaltail* endeavors to change the world by delivering critical emergency supplies while circumventing the barriers typically faced by current operating vehicles.

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Mission: Mending Hearts

Eight-year-old Charlie was born with a critical congenital heart defect (CHD). Years of treatments at Children's National Medical Center in Washington D.C. had been ineffective, so she was added to the national waiting list for organ transplants.

A year later, Charlie's family is notified that a viable heart is available and will be transported from NYU Medical Center, a straight distance of 330 km. A heart is only viable for 4-6 hours so the method of transportation is not a small consideration.

Typical Transportation:

EMS automobile: 4+ hours
EMS helicopter: 65 minutes
EMS Fixed-wing: 40+ minutes, dependent on transfer
Metaltail: 42 minutes exactly

With a speed of 471 km/h at max continuous power, it can cover 330 km point-to-point in a blistering 42 minutes. Metaltail outshines the competition by being faster, cheaper, and quicker than all other options, ensuring that time-critical needs are met with time to spare.

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Enabling Rapid Response

In the United States, 8,000 individual deaths occur every year because organs are not donated in time. Emergency Medical Services (EMS) typically use rotorcraft for transport up to a range of 320 km. Maryland State Police EMS rotorcraft, such as the AgustaWestland AW-139, cruise at 300 km/h, covering 320 km in 64 minutes.

Metaltail can traverse the same distance in 41 minutes, traveling at 471 km/h at maximum continuous power, a **36% reduction** in time.

At velocity for best range, 311 km/h, *Metaltail* has an operational range of 1240 km on full fuel, carrying 100 kg of payload at 3000 meters altitude, and an extended range of 1700 km by trading 30 kg of payload for 30 kg more fuel.

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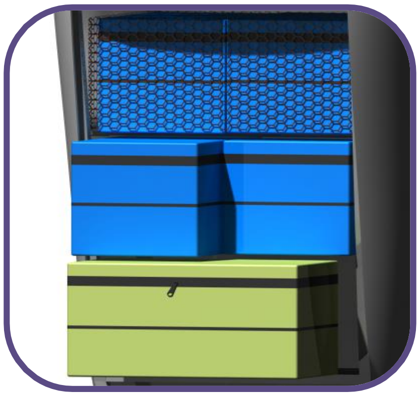
Multi-Mission Capability



Package Delivery

- Reconfigurable shelving system provides modular payload capacity
- Cargo nets secured to L-tracks provide secure transport and convenient access
- Medical supply delivery setup (pictured) includes four 8-liter blood/organ coolers and additional medical supply storage

Maritime Search and Rescue

- Forward flight performance allows for large search radius
- Additional fuel tank and gimbal with powerful sensor suite augment surveillance capacity
- Offshore coordination of multiple vehicles ensures more coverage in less time

Communications Relay

- Efficient hover and forward flight mean either loiter or station keeping are options
- Advanced avionics suite guarantee operational capability regardless of environment

Megacity Firefighting

- Circumvents congested terrestrial traffic, provides access to tall structures
- Thermal sensor suite for identifying personnel and critical fire targets
- Launch equipment for distributing fire suppression generator capsules

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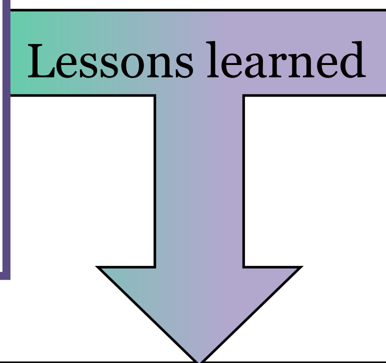
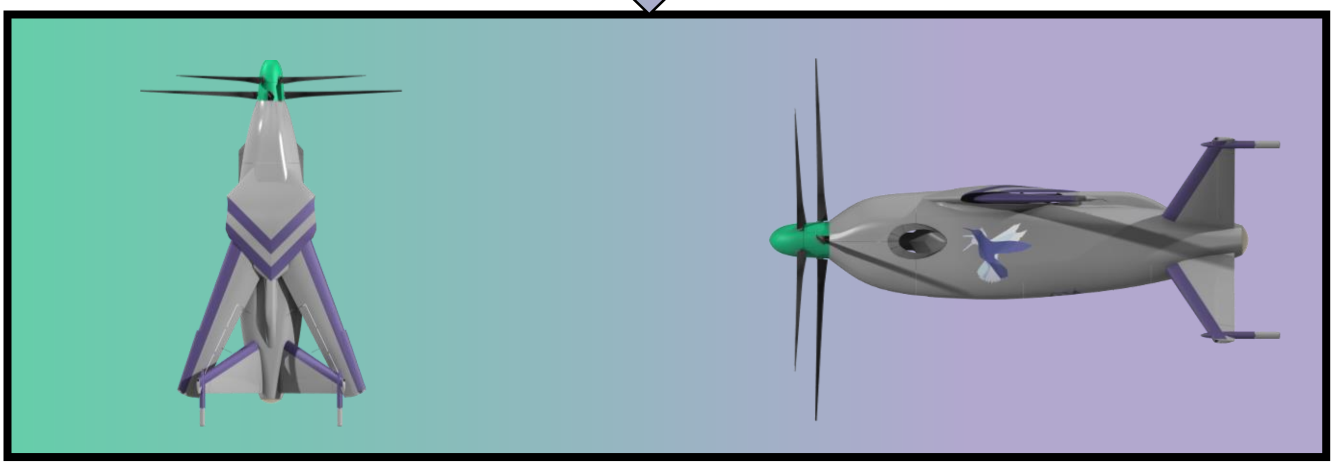
Vehicle Configuration

A **Group 3** aircraft operating in **megacity operations**, confined to **3 by 3 meter square,** capable of achieving **high-speed flight**.

VTOL

Fixed wing





Metaltail - **Advanced Swing Wing Coaxial Tailsitter**

Rotor and fixed wing technology at its best. Compact. Safe. Efficient.

Downwash velocity is lower than other rotor configurations confined to the same 3 x 3 meter square area, reducing the wind speed affecting ground personnel

The disk loading is much lower, translating into an efficient hovering vehicle.

Download penalty of the fuselage in conventional helicopters is greatly mitigated with the slender frame now oriented in the same direction as the flow.

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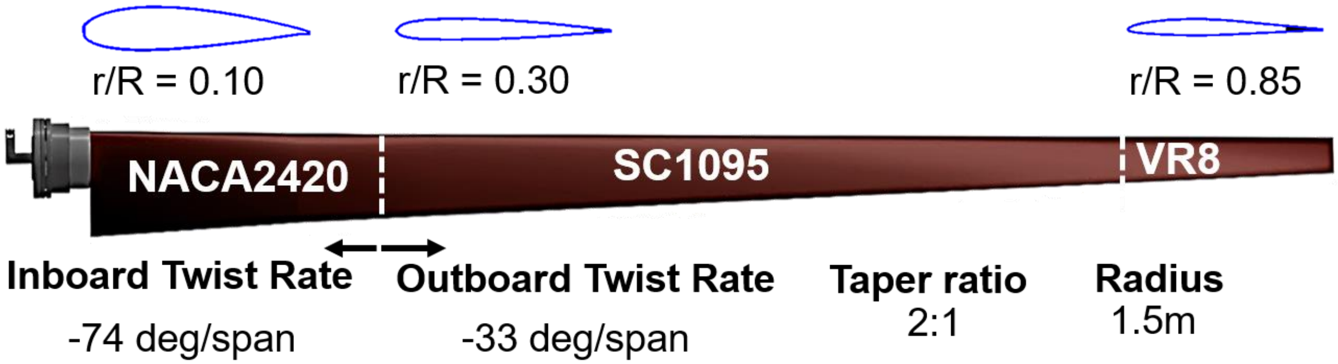
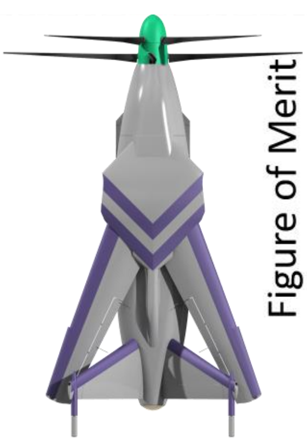
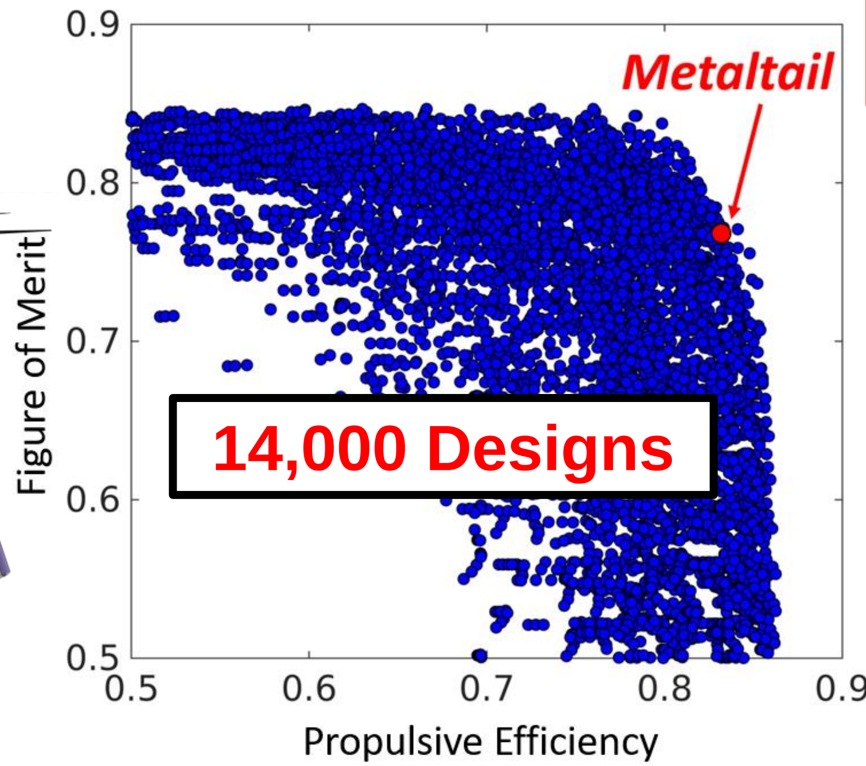
Proprotor Aerodynamic Design

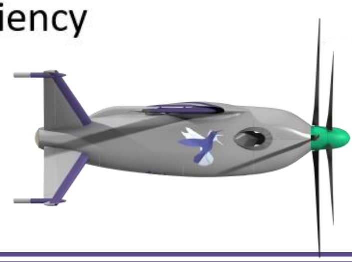


- **14,000 designs** were considered in hover and cruise.
- **2D CFD** was performed to obtain airfoil tables for **15 airfoils**
- Combination of **78 twist rates** were investigated
- Geometric parameters of the rotor were varied to obtain **exceptional high-speed** and **hovering efficiency**.
- Designs analyzed using **advanced BEMT** and **FVM** methods

$$FM = 0.768$$
$$\eta_p = 0.832$$







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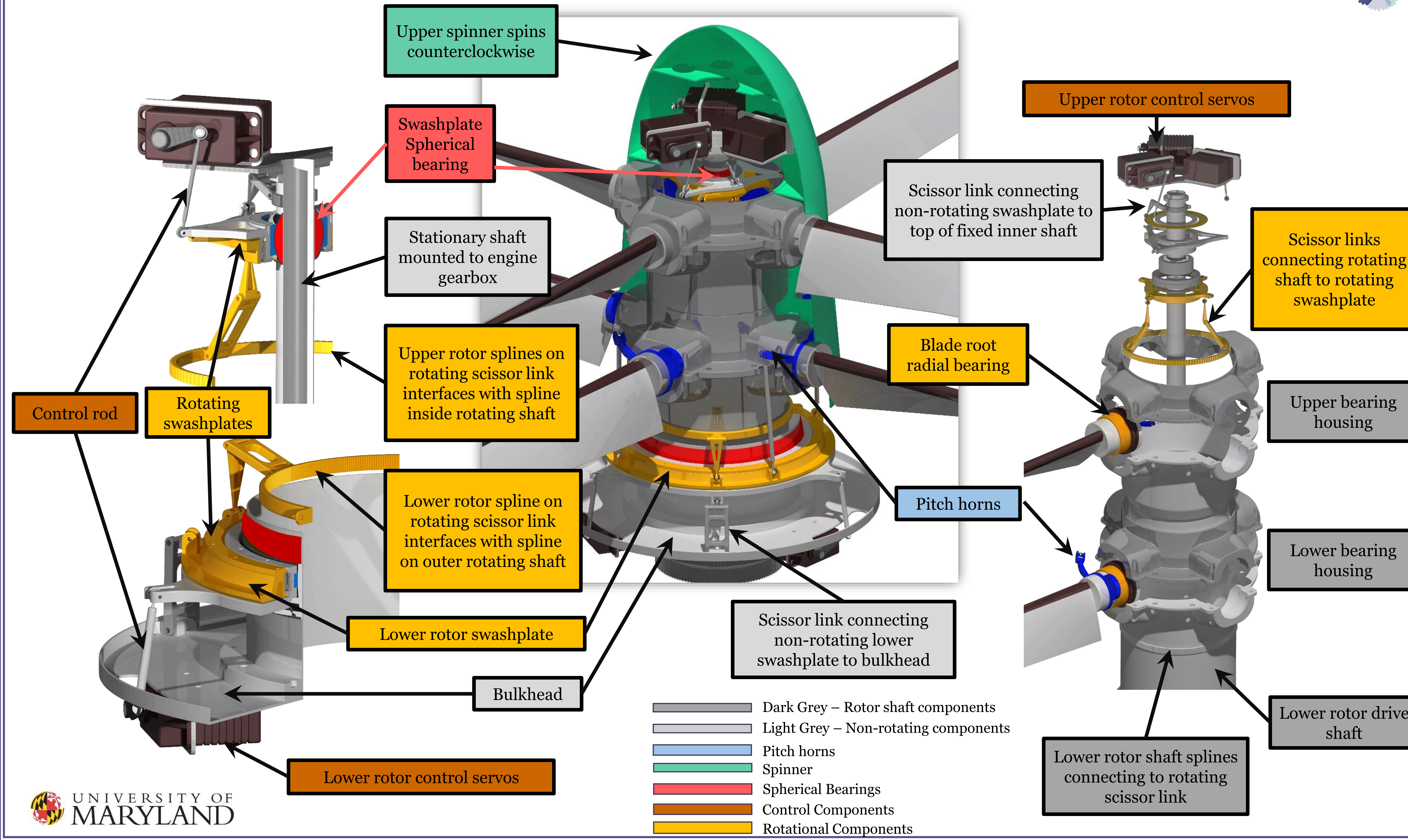
Hub Design: Hidden Internal Swashplate Mechanism (HISM)



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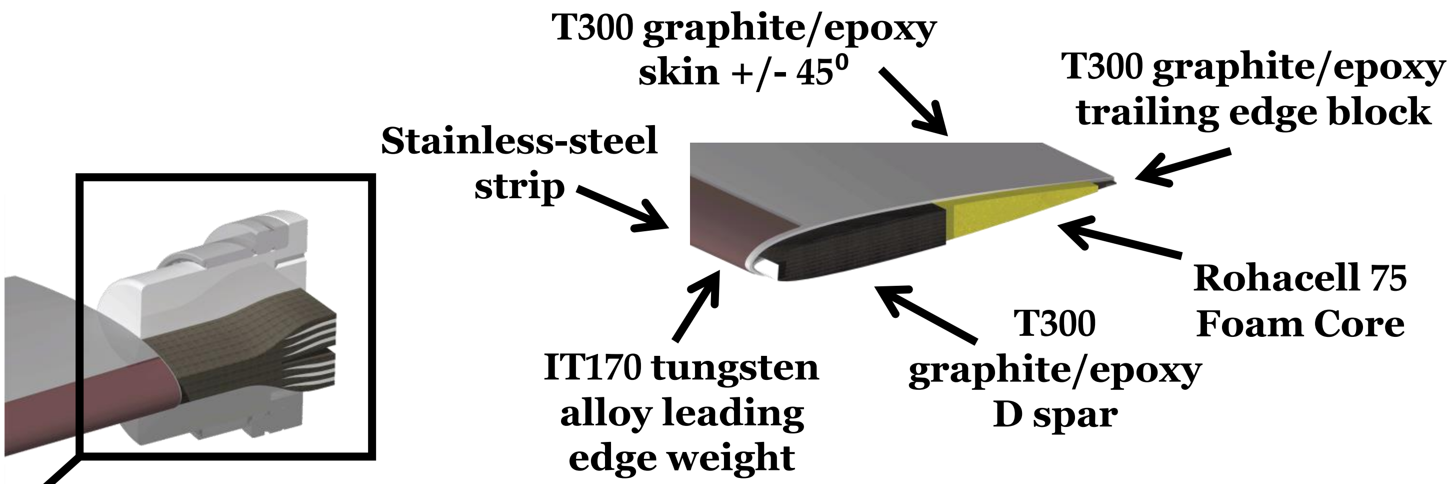
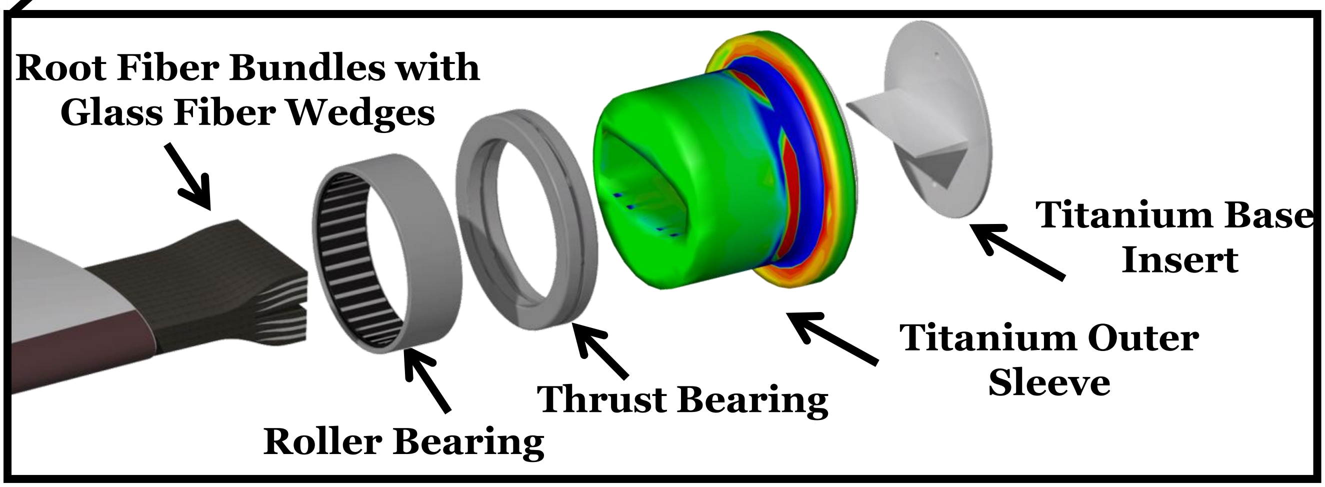
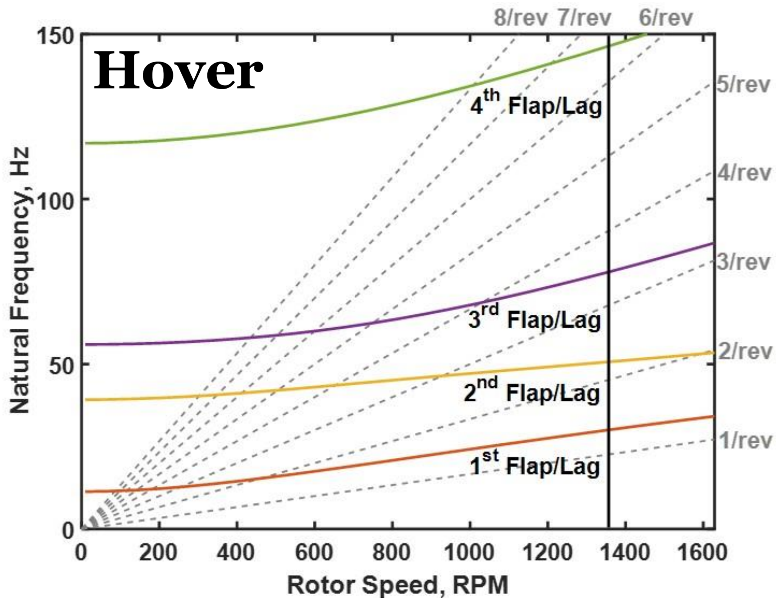
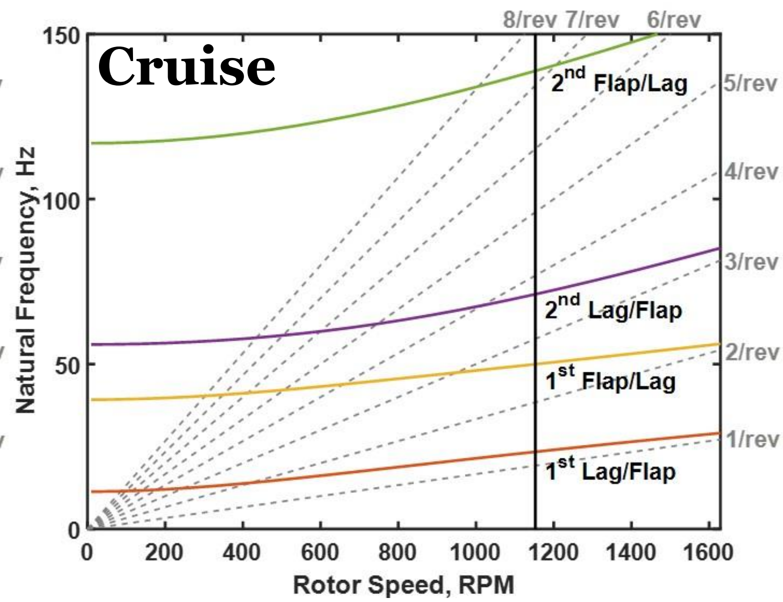
Blade Structural Design

- **Stiff rotor blades** eliminate the risk of blade strike
- **Novel**, **compact** root wedge design implemented for *Metaltail* blades









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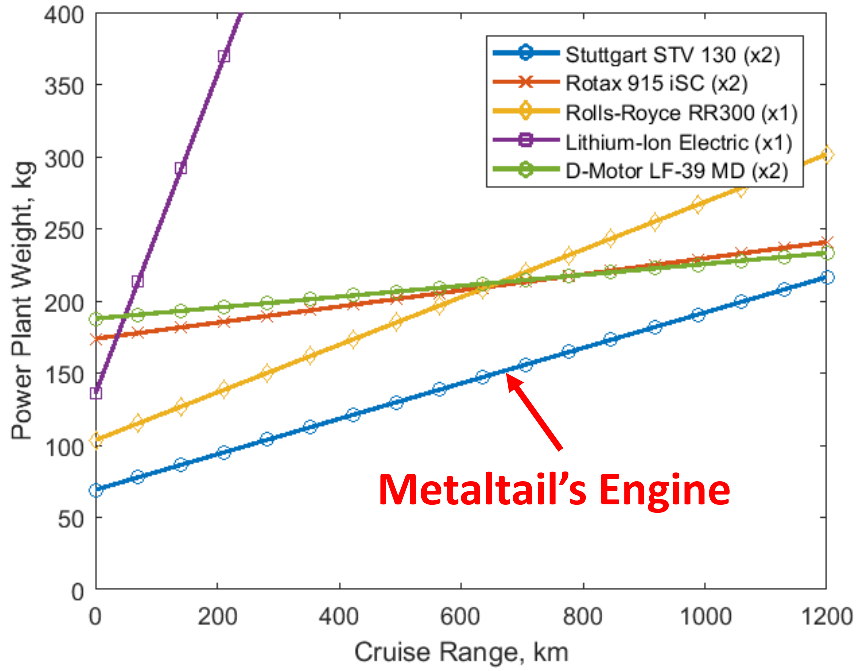
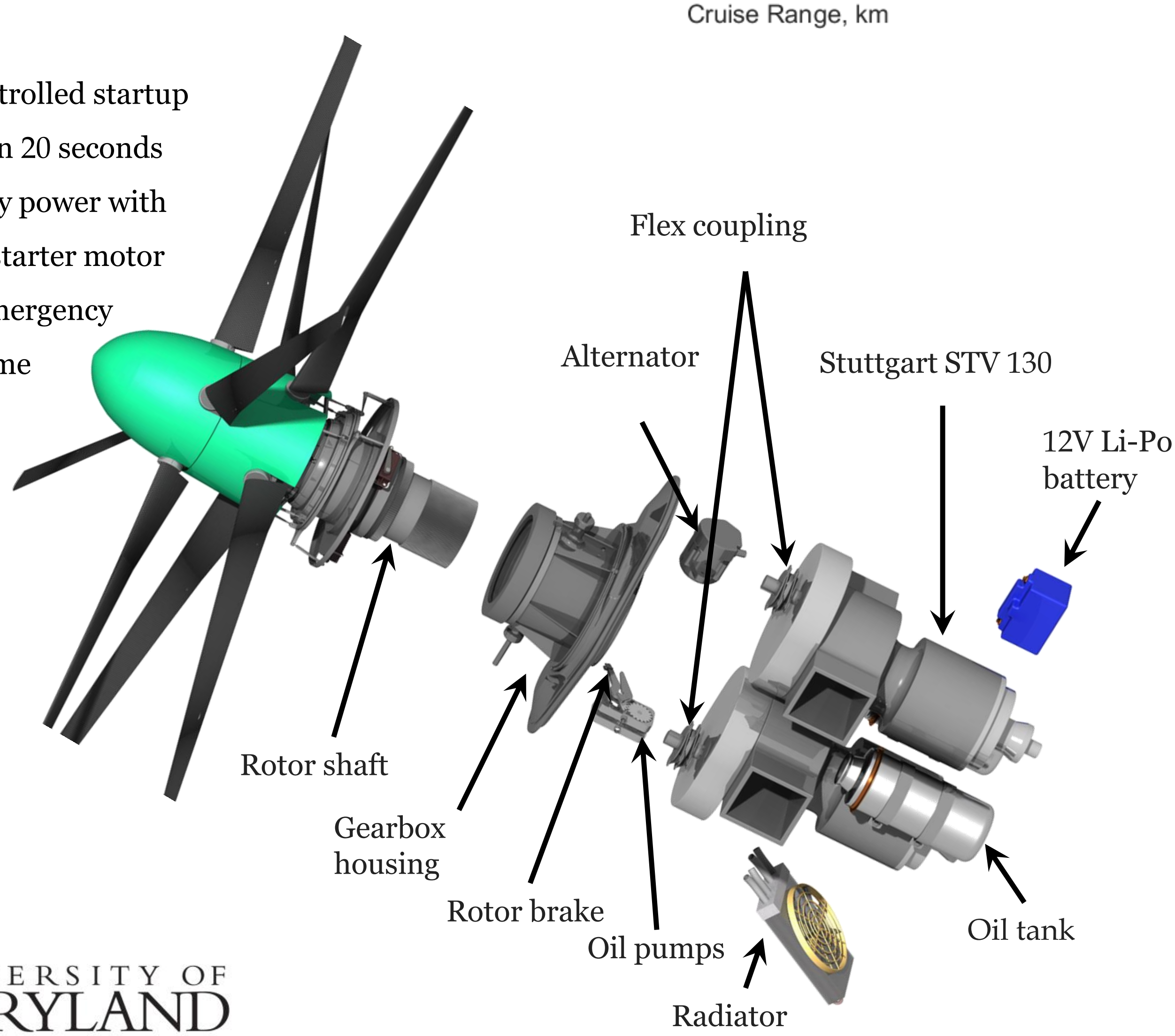
1st Flap – 1.33 /rev Hover

Powerplant

Two Stuttgart STV 130 turboshaft engines power the coaxial rotor.

- STV 130 has the lowest specific fuel consumption (SFC) at predicted cruise and hover power settings.
- Free turbine recuperated turboshaft engine with a single-stage compressor and single-stage power turbine.
- Free turbine-powered drive shaft allows the rotor to stop with the engines at idle for safe ground operations.
- Engine-controlled startup completes in 20 seconds from battery power with integrated starter motor reducing emergency response time





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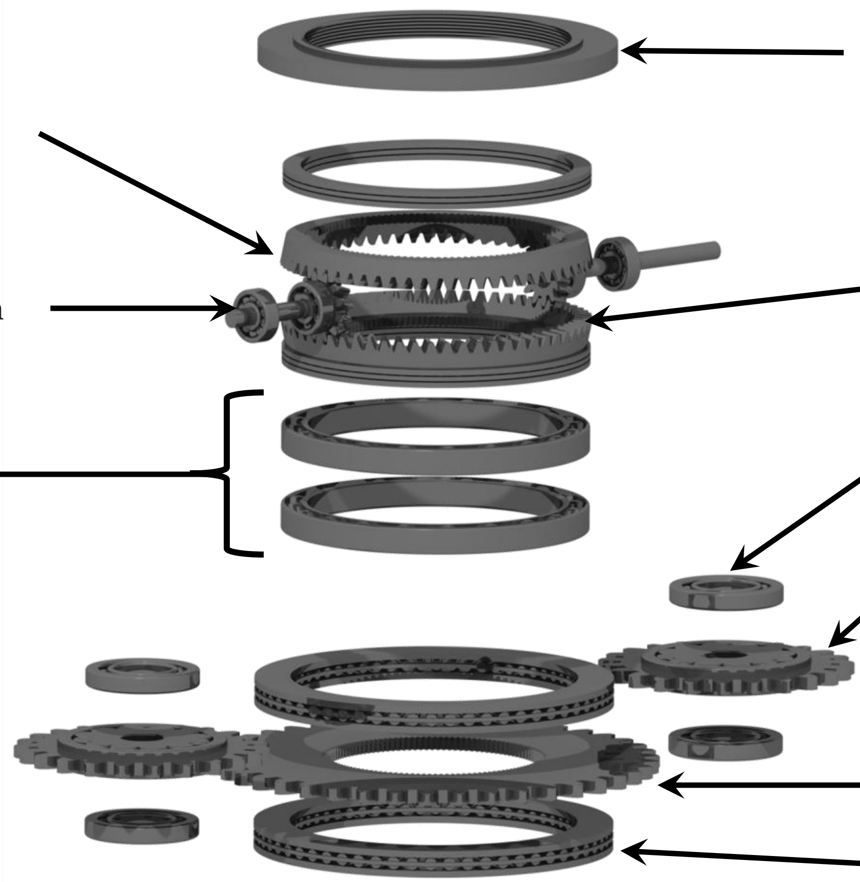
Transmission Design

Dual-input spur gear reduction module with a split-bevel coaxial drive module to allow the motor and rotor to operate at the most efficient rotational speeds with a 1.826:1 reduction ratio.

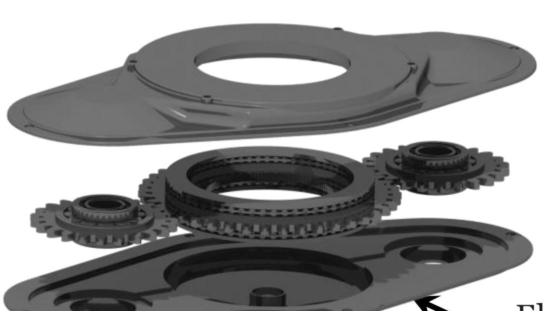


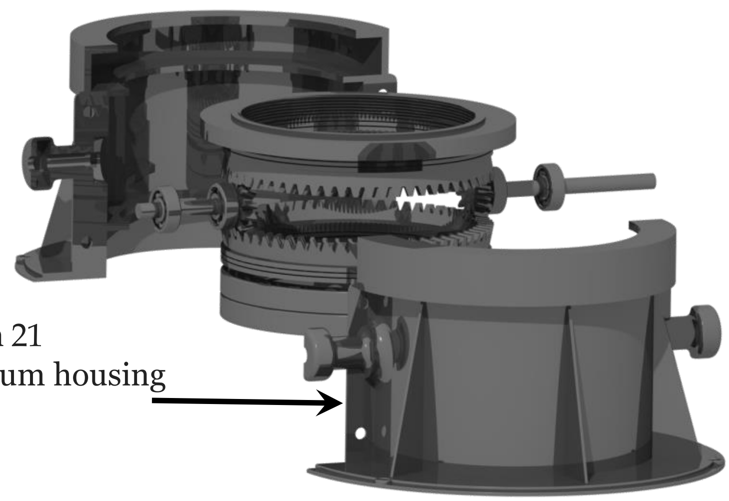
Dual-Input, Spur-Gear Reduction Module

Input over-running clutch to allow OEI operations for increased safety and reliability.

Split-Bevel, Coaxial Drive Module

Spiral bevel gears for reduced transmission noise and increased reliability and safety. Simplistic coaxial configuration for increased reliability.





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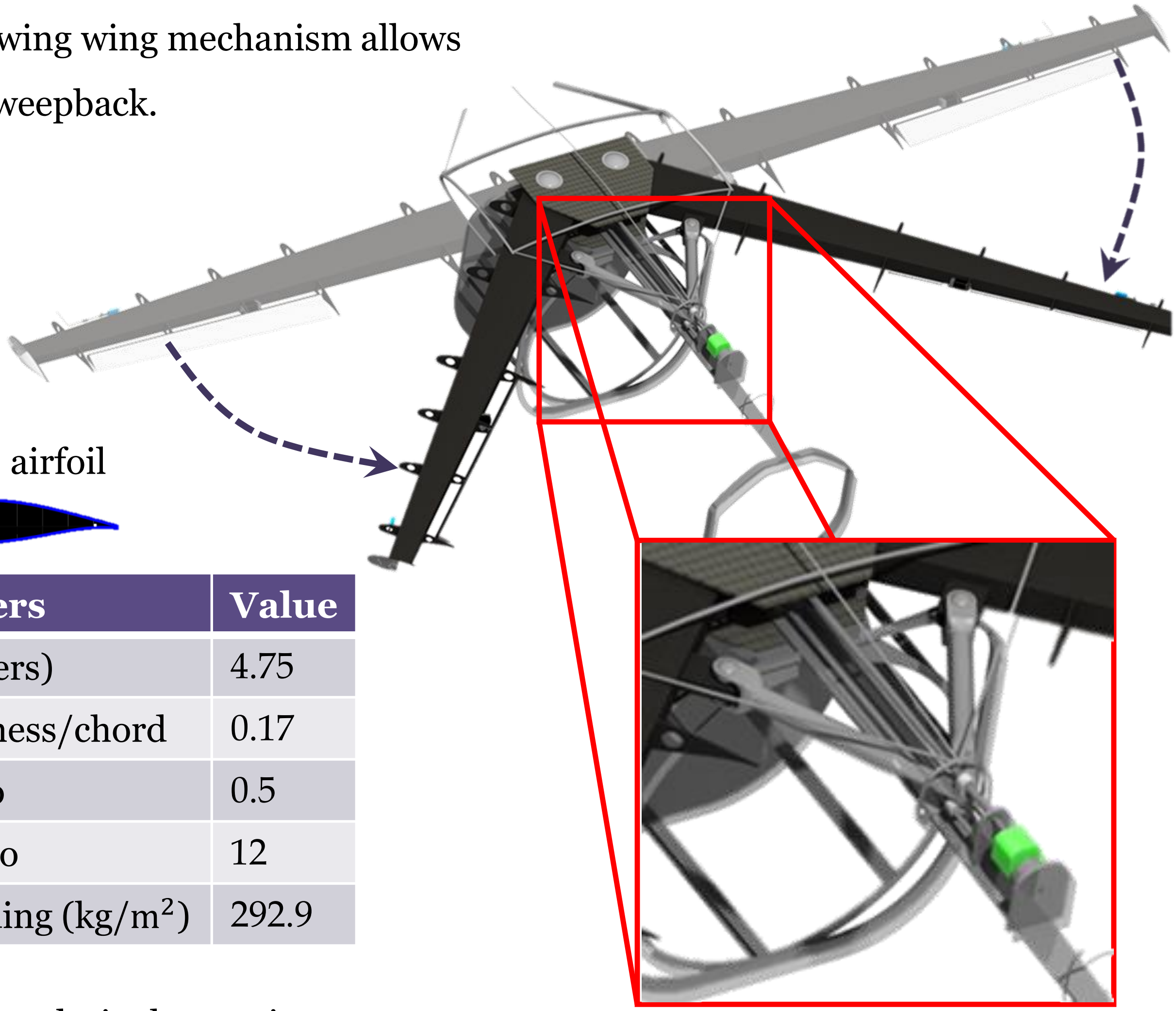
Swing Wing Design

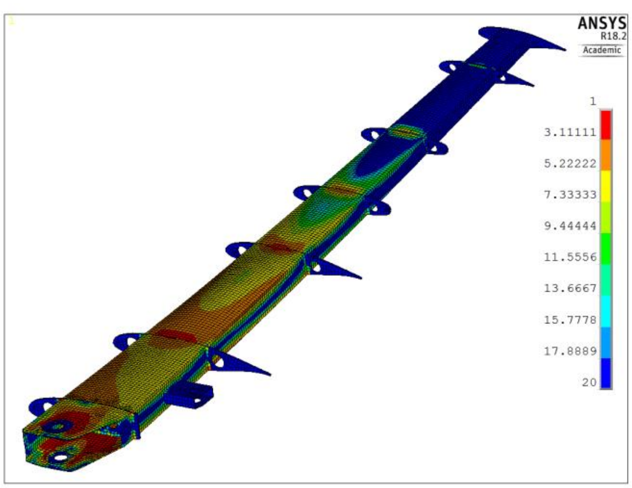
Design of swing wing mechanism allows for 66° of sweepback.



GA(W)-1 airfoil

Parameters	Value
Span (meters)	4.75
Max thickness/chord	0.17
Taper ratio	0.5
Aspect ratio	12
Wing Loading (kg/m^2)	292.9

Static load analysis shows wing spar has factor of safety of 1.5 when under a 3.5g load.



The swing wing mechanism is a motorized lead screw capable of fully sweeping the wing in under 8.5 seconds.

- Self-locking lead screw
- Rotation Speed: >8 degrees/second
- Buckling load factor of safety: 5
- Transition during maneuvers
- Mechanism Weight: <5 kg
- Screw Diameter: 16mm

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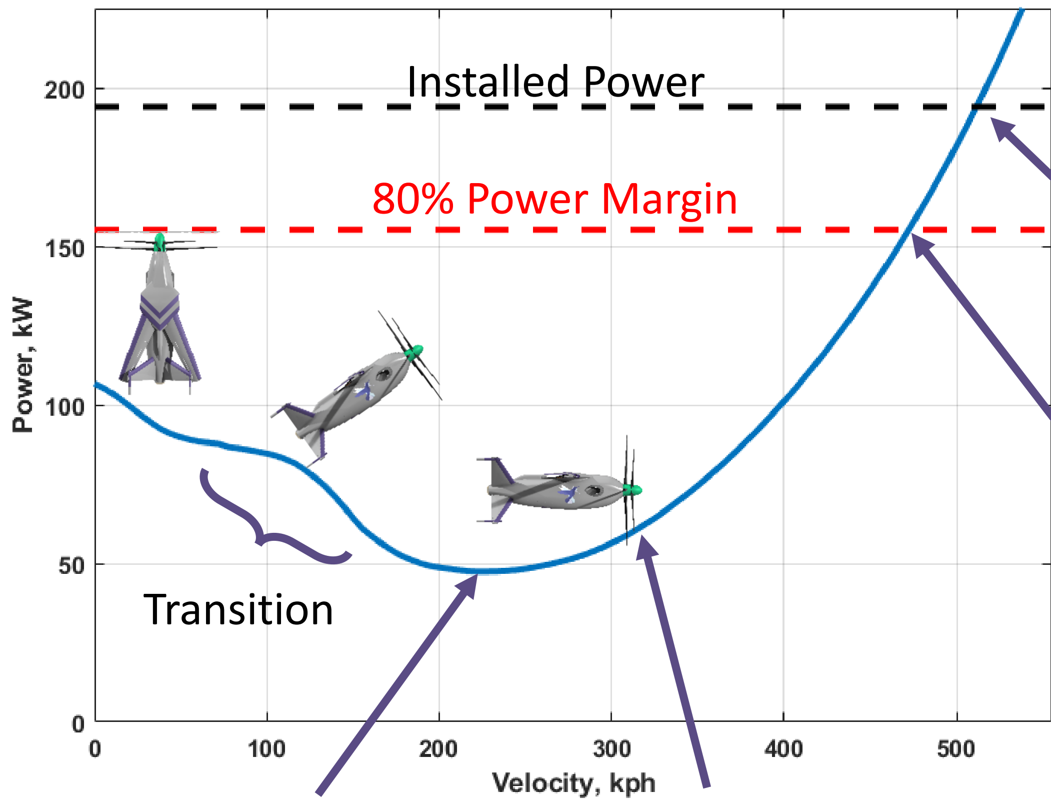
Vehicle Performance: Faster, Higher, Farther



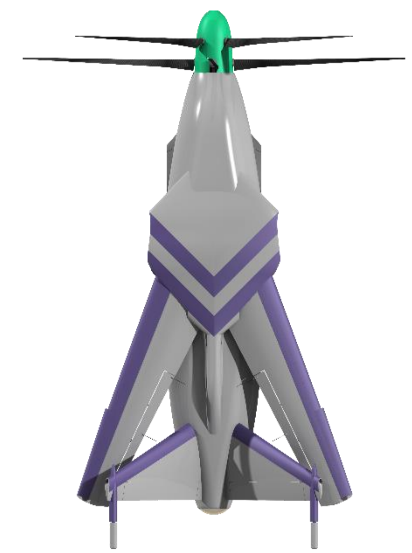
Dash speed
$V_{max} = 511kph$

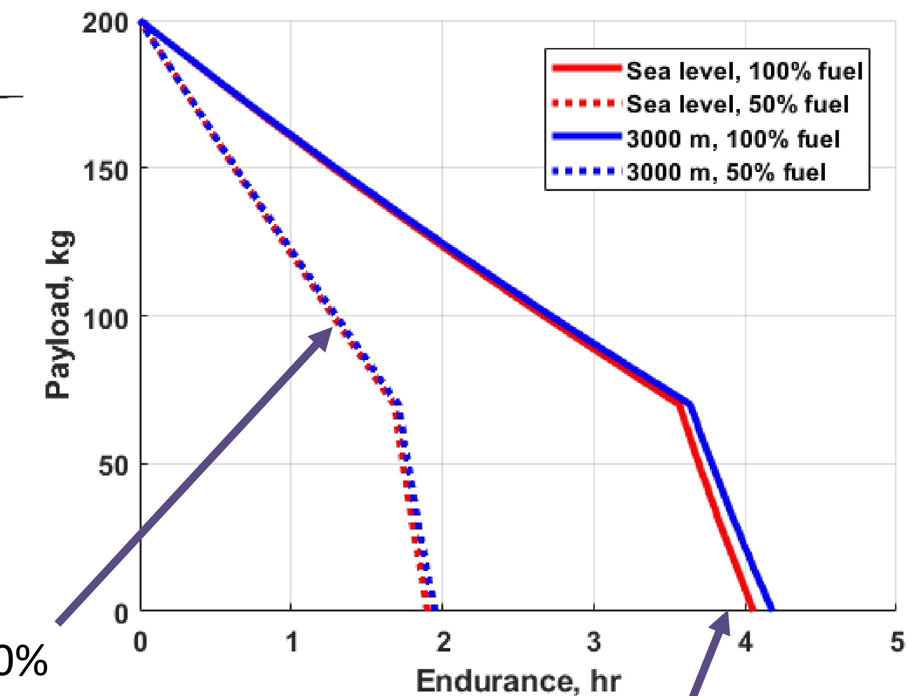
Max sustained speed
$V_{cr,max} = 471kph$

Best endurance
$V_{BE} = 222kph$

Most efficient cruise
$V_{BR} = 311kph$

Efficient in Hover…

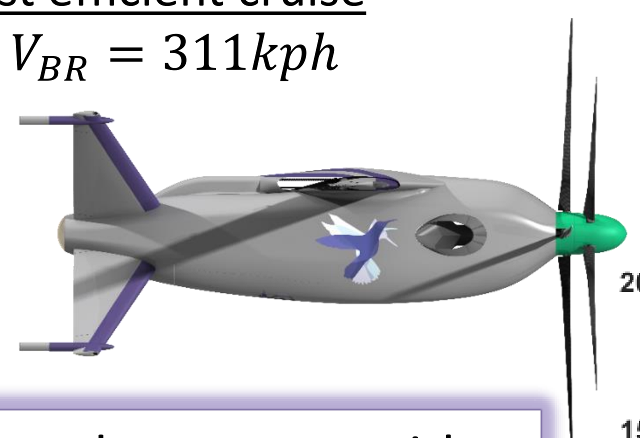




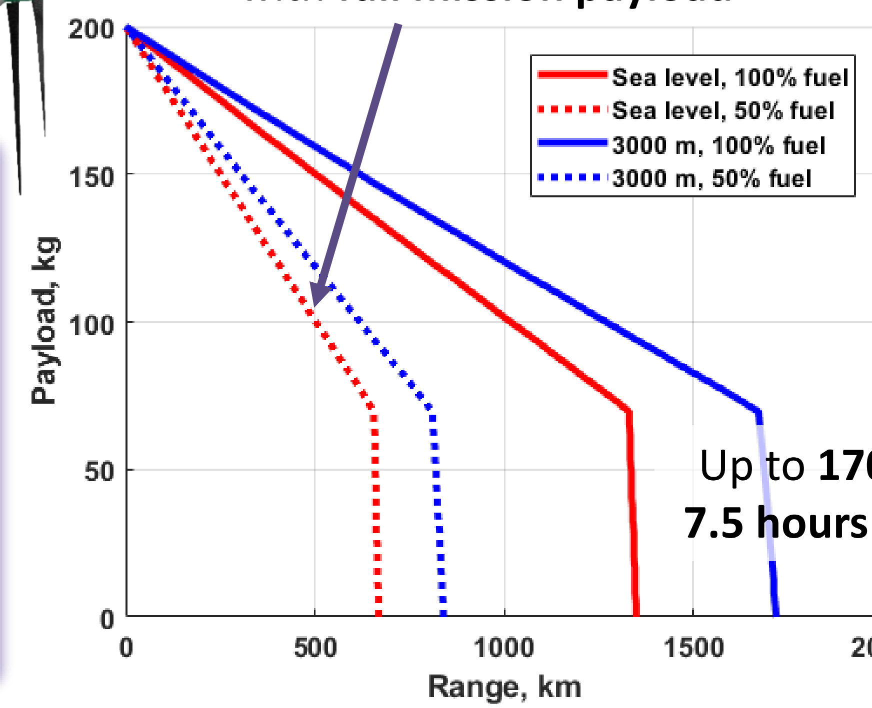
80 minutes hover using 50% fuel with **full mission payload**

Up to **4 hours** hover endurance

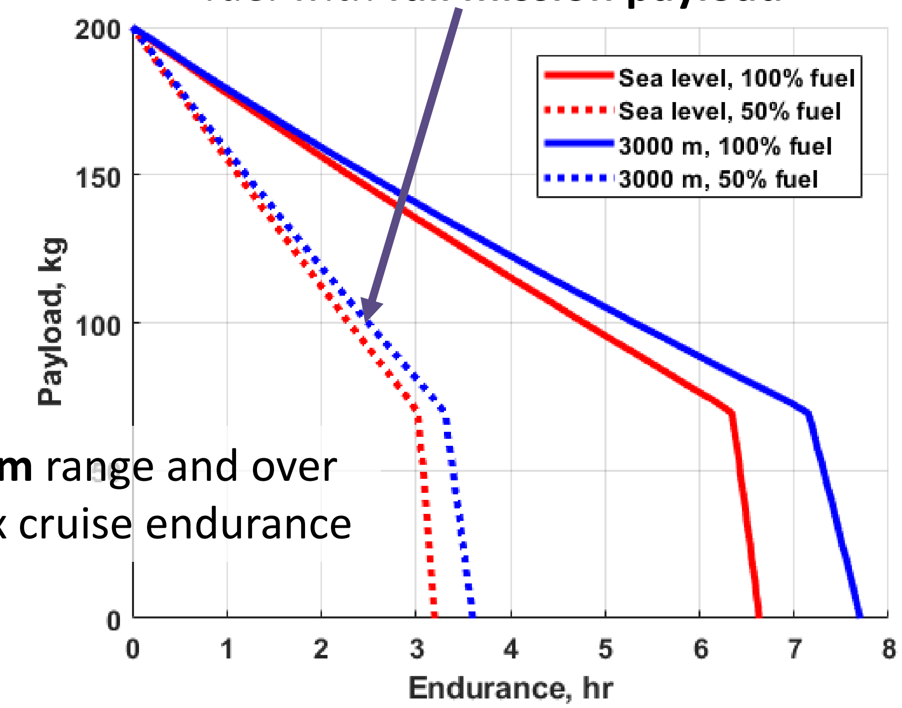
…and in Cruise



>500 km range using 50% fuel with **full mission payload**



2.5 hours endurance using 50% fuel with **full mission payload**



Up to **1700 km** range and over **7.5 hours** max cruise endurance

Metaltail combines an advanced proprotor with a highly streamlined fuselage:

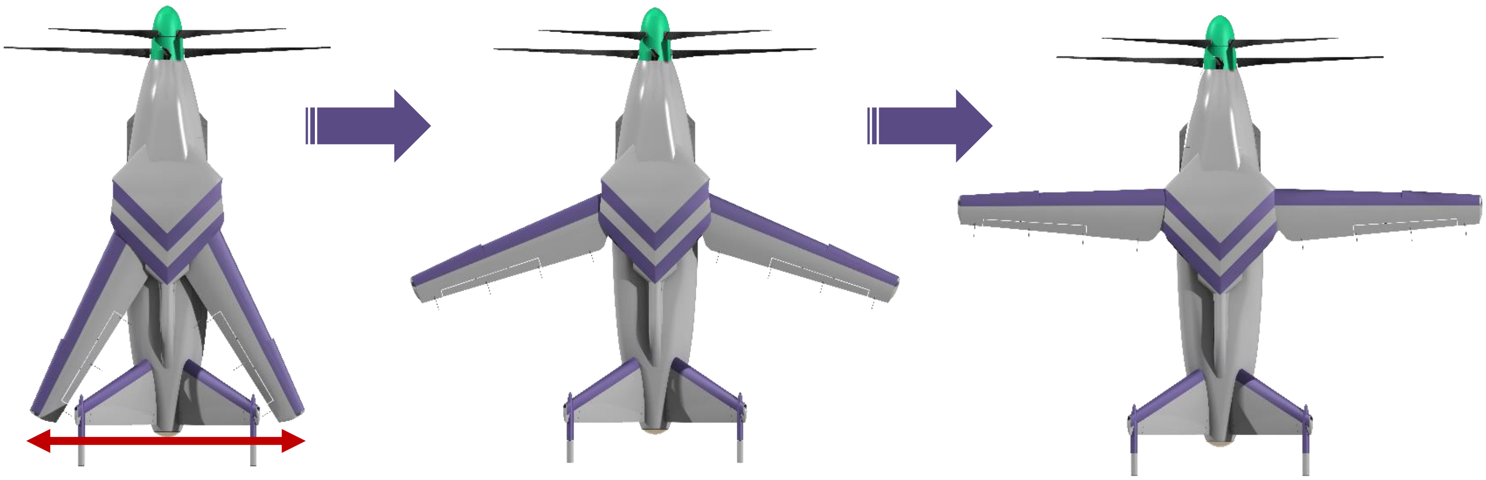
- As efficient as a **helicopter in hover**
- **Faster** than any current fixed-wing aircraft of similar size
- Up to **12 km/kg** fuel economy for long range and low operational cost

Transition

Hover
minimum span

Transition
reduce control loads

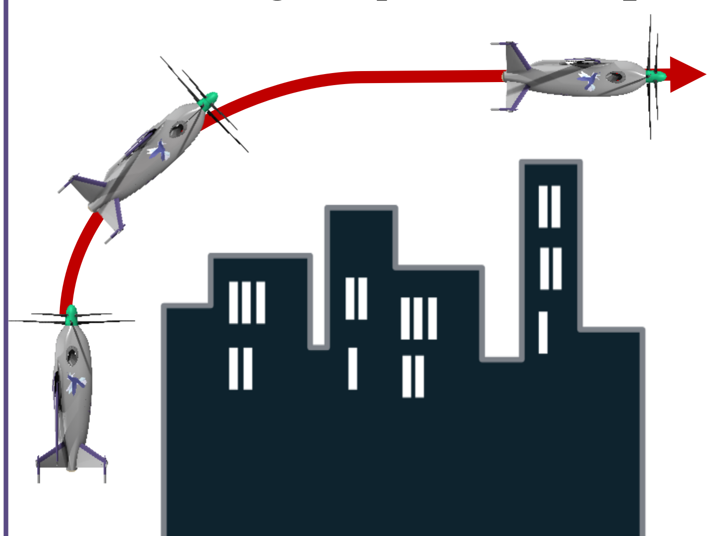
Forward Flight
aerodynamic efficiency



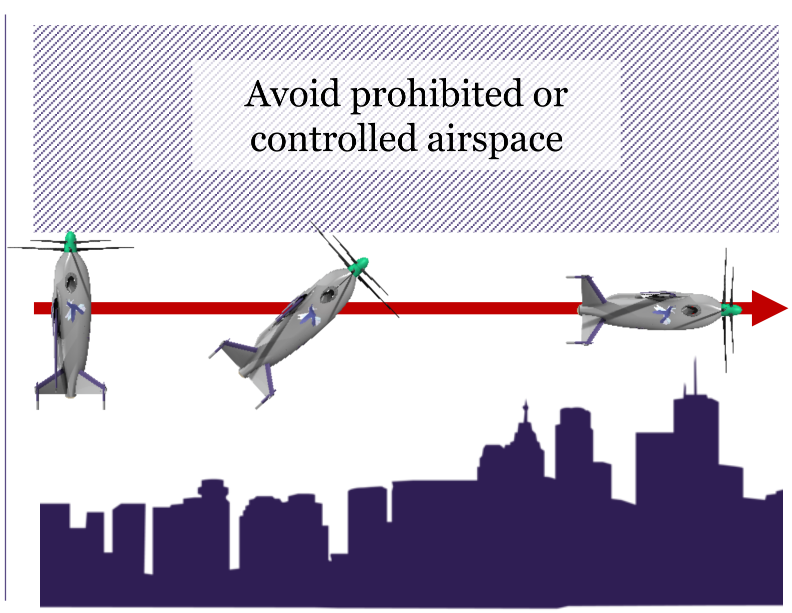
Metaltail's unique wing sweep mechanism enables high performance in both VTOL and forward flight modes:

- Transition using only aerodynamic controls—**reduces rotor power**
- Use movement of center of pressure to trim vehicle dynamically
- **Compact** in hover, without compromising **cruise efficiency**
- Only **42 sec** to transition and accelerate from hover to cruise speed

Wing sweep allows **multiple maneuvers** possible based on mission:



- Clear obstructions quickly
- Very small control inputs



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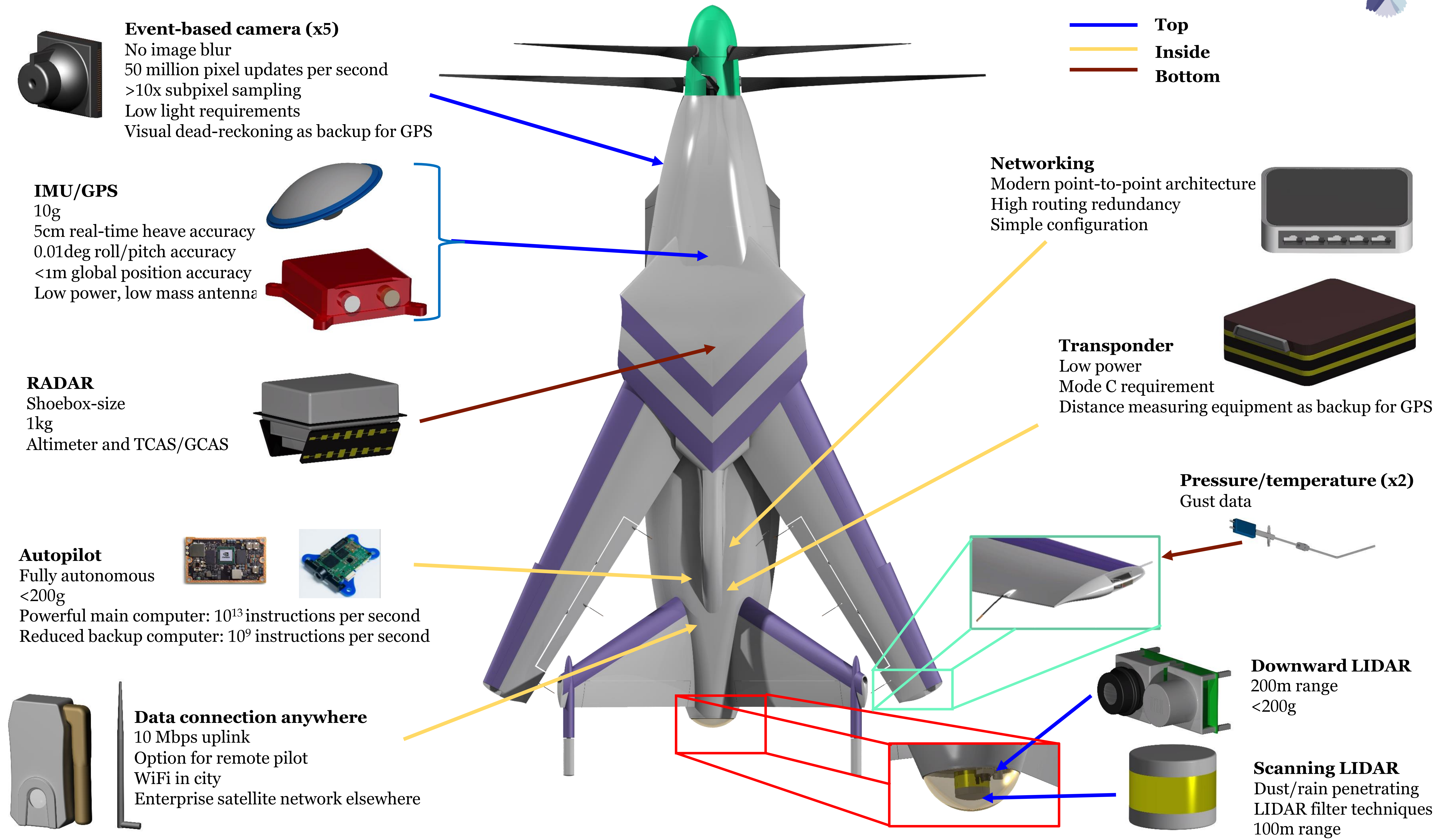
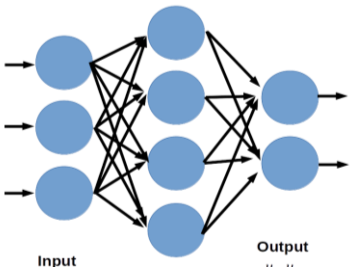
Avionics: State of the Future

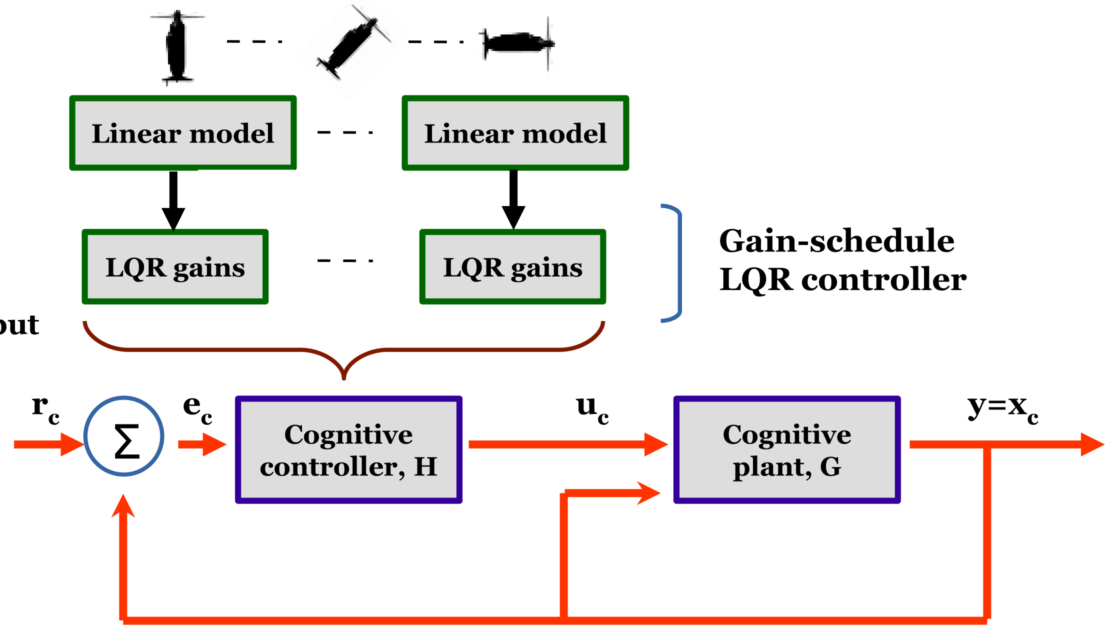


Cognitive Controller



G: Predict vehicle response

H: Determine actuator output



Analytical:

$$H_i \to \hat{u} - u_{LQR} = e$$

$$H_{i+1} = H_i - \frac{\delta u}{\delta H_i} e$$

Flight:

$$G_i \to \hat{y} - y_{KF,i+1} = r$$

$$H_i \to \hat{u} - R(r)$$

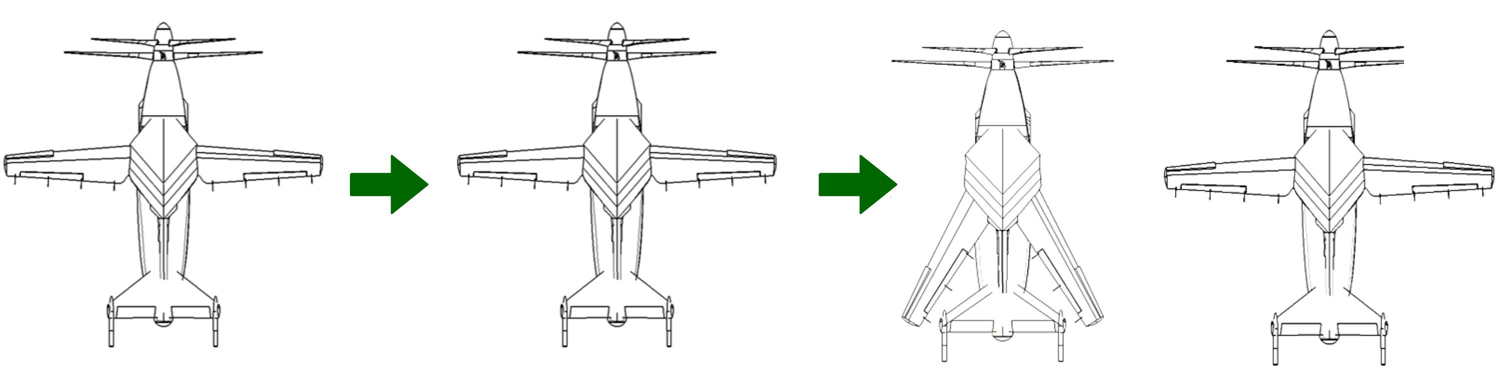
$$G_{i+1} = G_i + \frac{\delta y}{\delta G_i} r$$

State-of-art neuromorphic design

Simple to regress to reliable controller or revert to prior controller state

Tunable, simple to change heuristic for controller characteristics

Proven optimality for a given heuristic



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Learn full-vehicle model robust to stochastic effects

Assured Autonomous Navigation

Bird's eye view

Cognition in real-world conditions

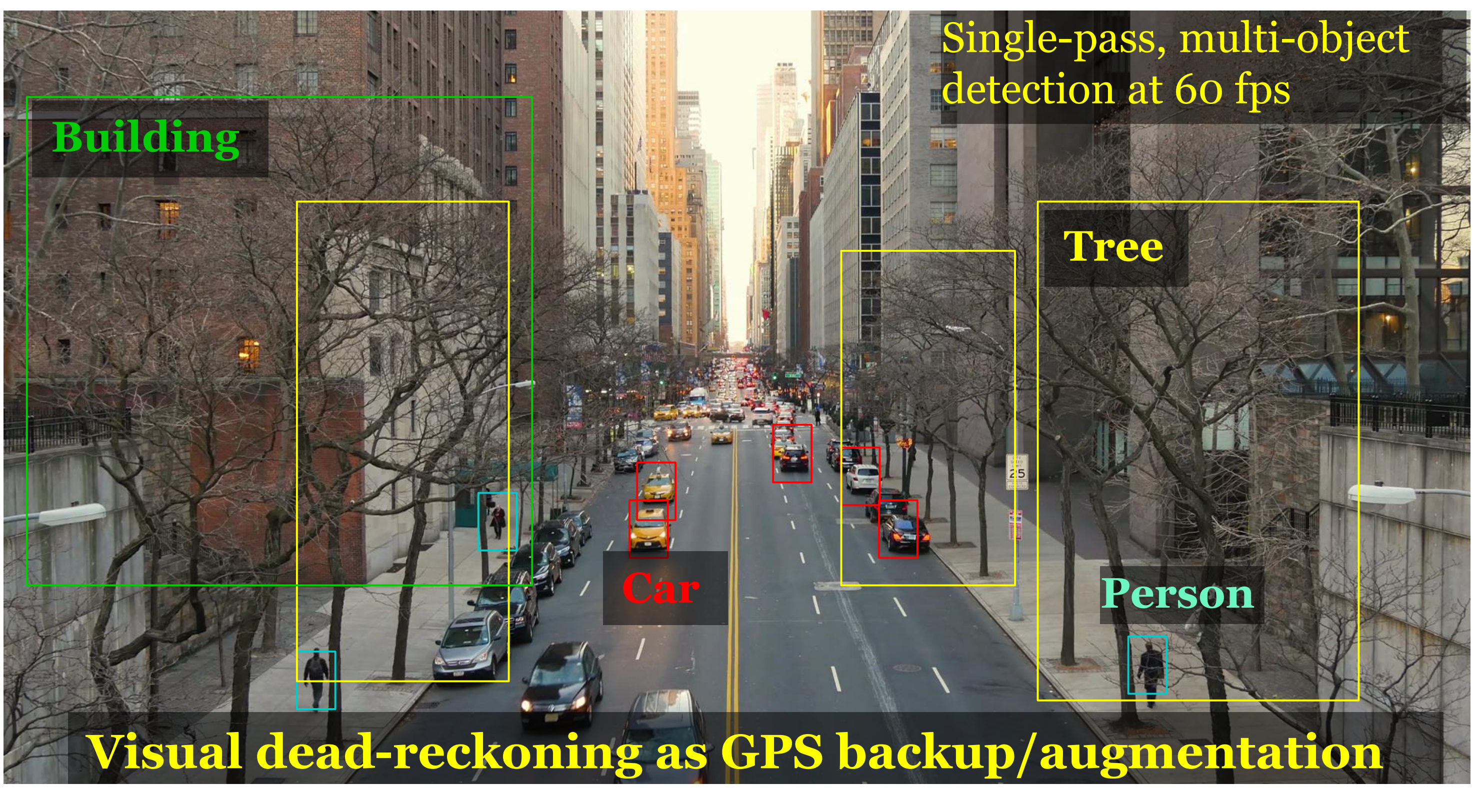
Instantaneous decision-making

Minimal memory requirement

Context-sensitive to vehicle state, disturbance, and noise

Fast convergence to global optimal path via asynchronous training

Camera view



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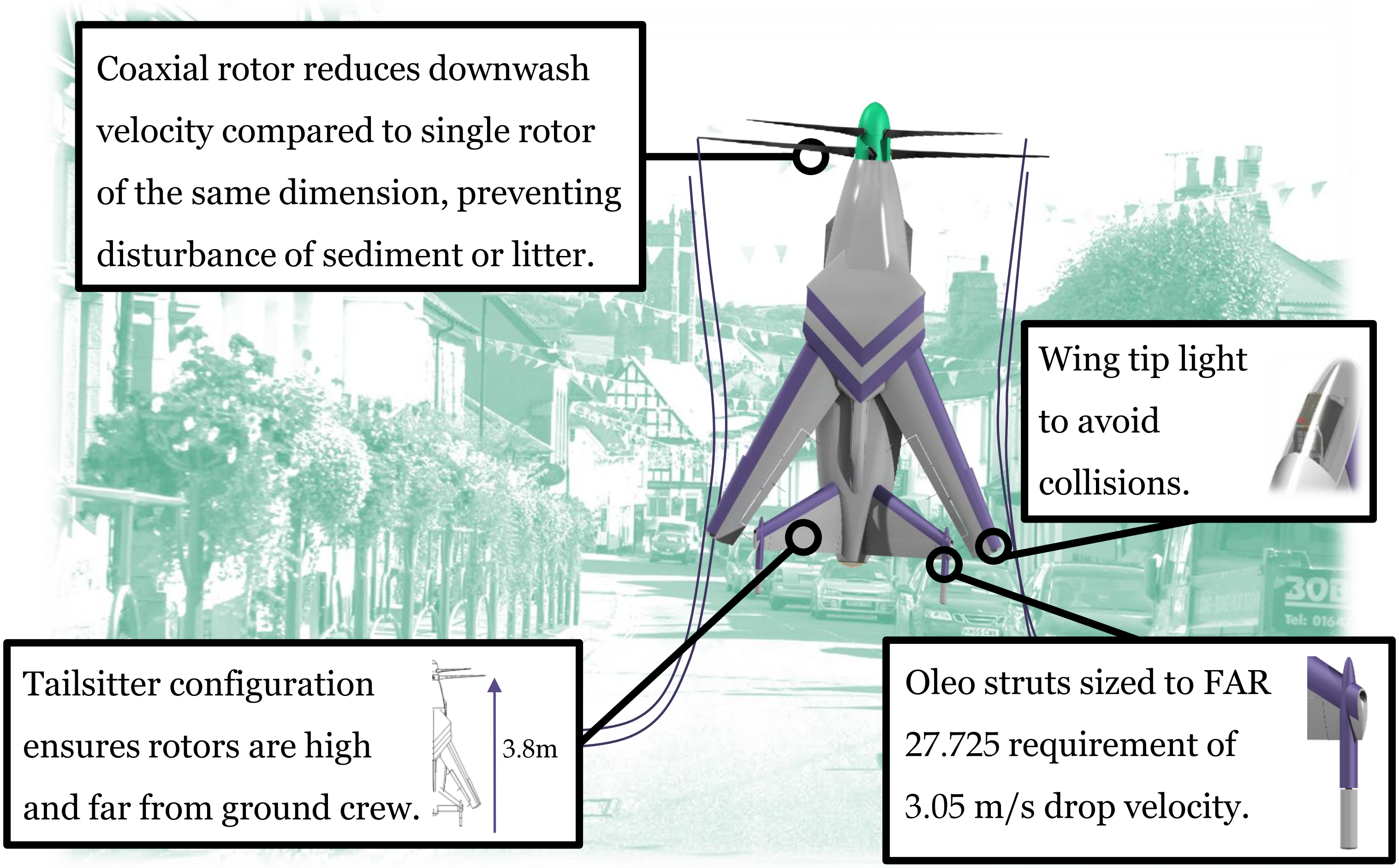
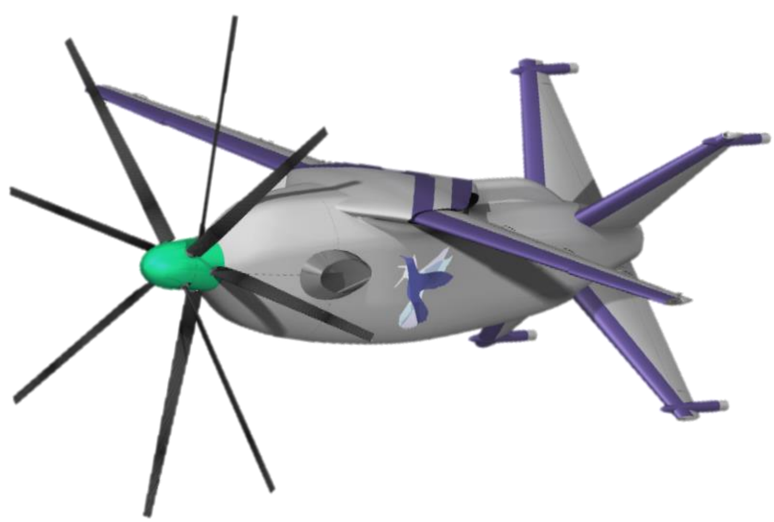
Safety Driven Design

Standard Urban Operation



In flight failures:

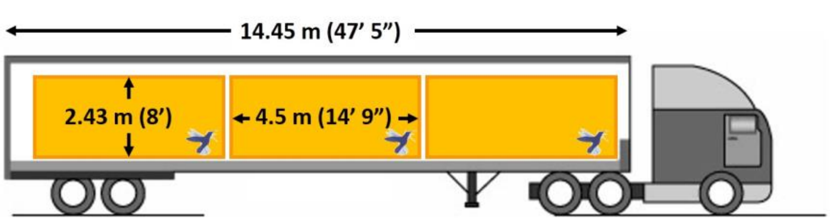
- Metaltail's two 97 kW engines provides One Engine Inoperable (OEI) capability
- Back up power sustains control surface operability to maneuver Metaltail in a glide to a remote area

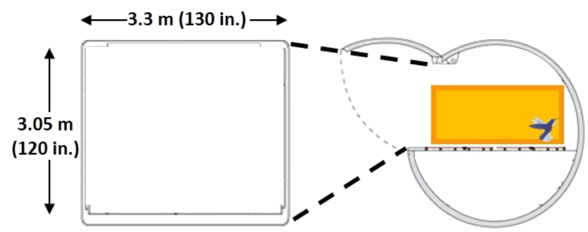


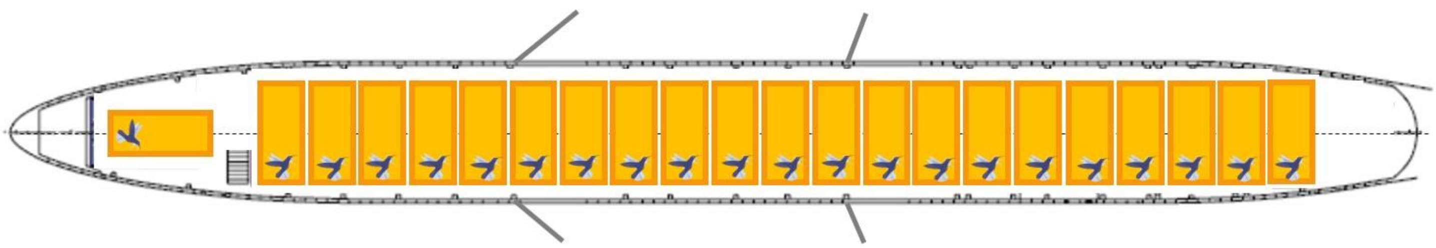
Concept of Operations

Metaltail comes fully assembled, shipped in a custom shipping crate, 2.43 x 2.43 x 4.5 meters. Three crates fit end to end in a standard 15 meter dry van semi-trailer. Twenty-two crates can fit in a B747-8F main cargo hold for mass emergency deployment to disaster relief sites.

Metaltails are mission ready out of the box.



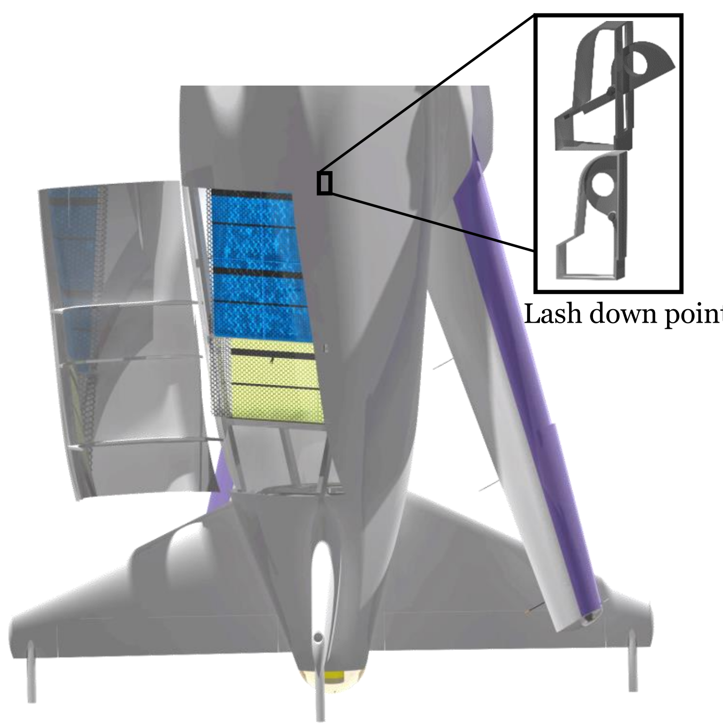




Metaltail's payload volume is 0.2 cubic meters, double the minimum required volume of the RFP.

Metaltail's payload rack can be removed and replaced with other custom racks with mission-specific equipment.

Spring-loaded lash down points assist in anchoring during ground ops and remain flush to skin during flight operation.



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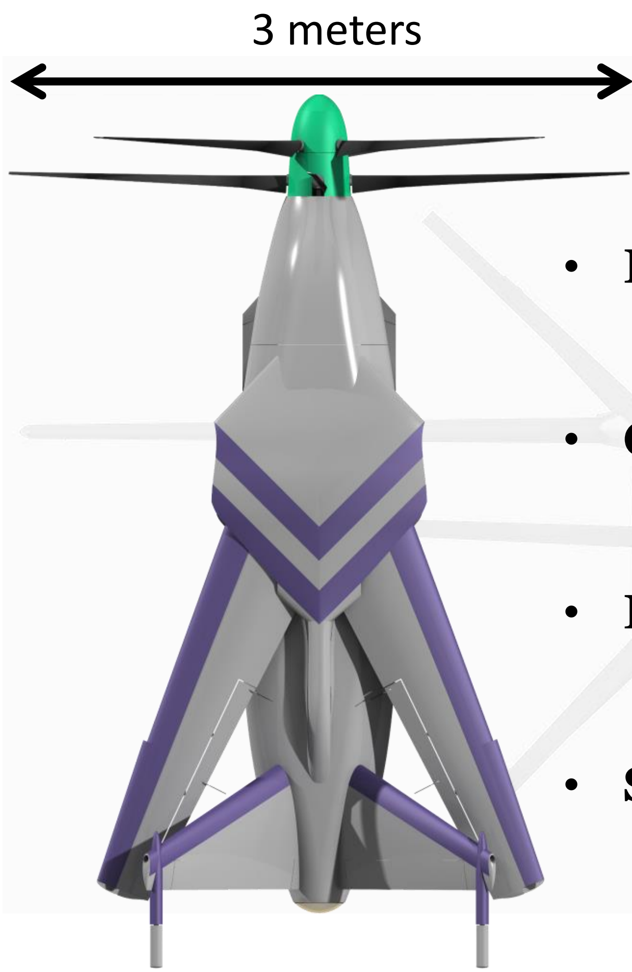
Metaltail Performance Metrics

Metrics	Conditions	*Metaltail* Value
Hover Time, hours (using 50% fuel)	SLS	1.28
	3000 m	1.30
Cruise Range, km (at V_{BR} using 50% fuel)	SLS	502
	3000 m	619
Dash Speed, km/h (V_{max})	SLS	454
	3000 m	511
Drag Area, m² (at V_{max})	SLS	0.1303
	3000 m	0.1306



- **Reconfigurable**
  - Novel swing wing design allows efficient hover and forward flight
- **Compact**
  - Fits in a 3 meter by 3 meter square
- **Efficient** in hover and forward-flight
  - Figure of Merit of 0.768
  - Propulsive Efficiency of 0.832
- **Safe**
  - Autonomous assurance
  - Ground clearance

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