OLIWHOPER

EXECUTIVE SUMMARY

39TH Annual Student Design Competition

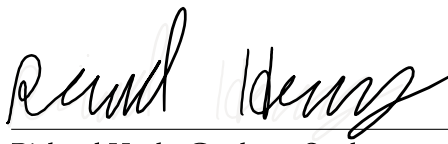
eVTOL Air Taxi for Passengers with Reduced Mobility (PRM)

Sponsored by BELL

RENSSELAER POLYTECHNIC INSTITUTE 1824

MOVE Center for Mobility with Vertical Lift at Rensselaer

Signature Page



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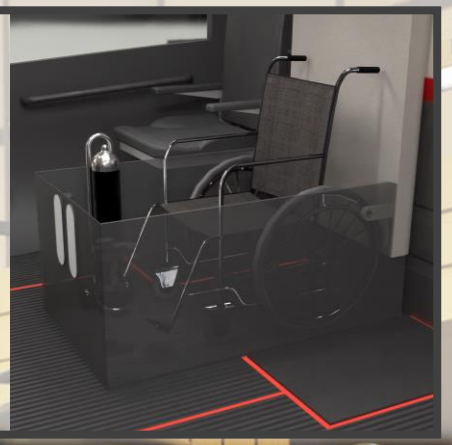
OLIWHOPER – Anyone, Anytime, Anywhere

Extendable Seats

Seats slide out of the cabin to give extra room for PRMs to sit

Cabin Storage

Passengers can keep medical equipment with them in the cabin



Cabin Accessibility

Folding seats and a spacious cabin make mobility easy within Oliwhoper

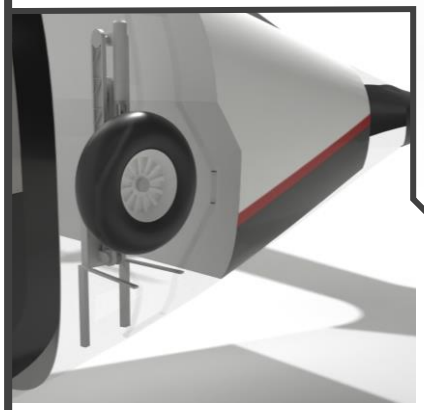
Audio and Visual Aids

Seat speakers and ground lighting help guide passengers to their seats

OLIWHOPER – Exceptional cruise and hover performance

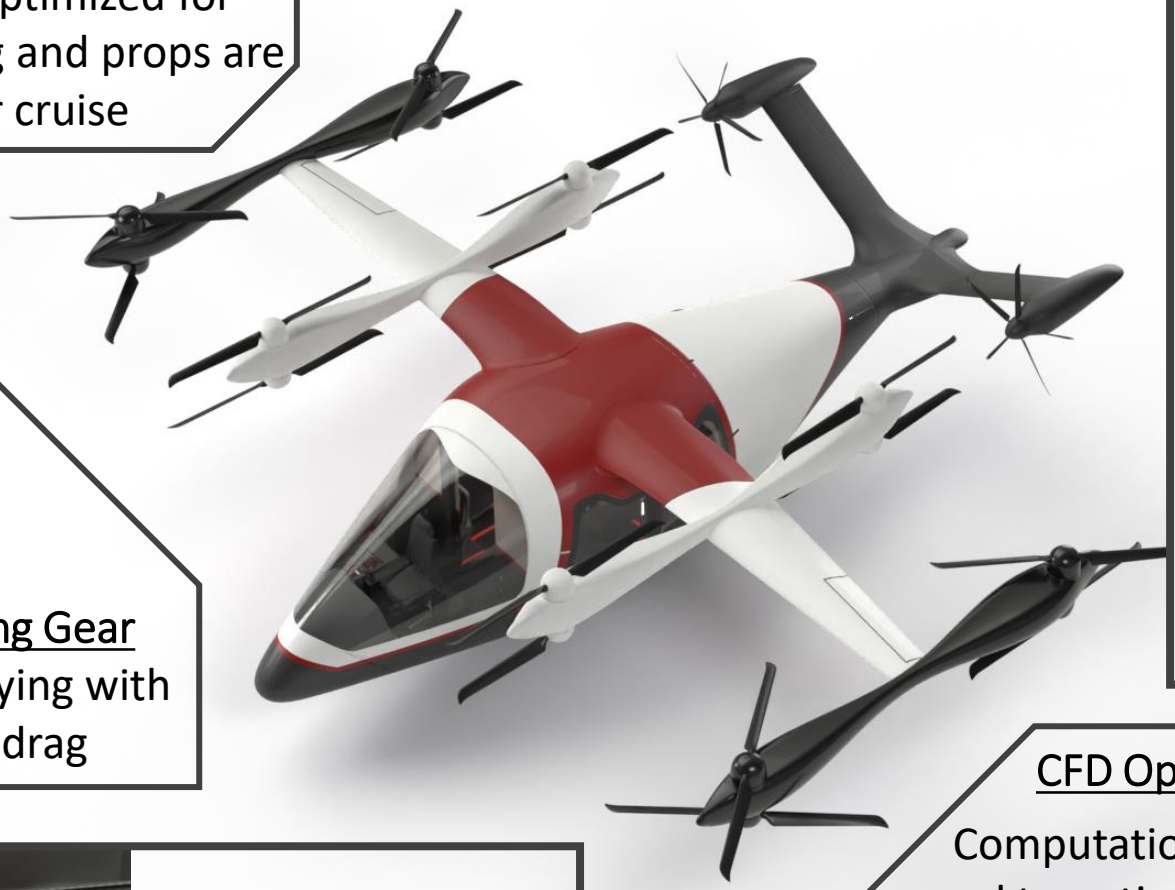
Lift + Cruise Configuration

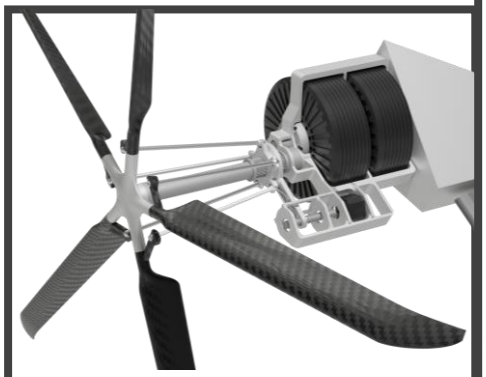
Lifting rotors are optimized for hover, while the wing and props are optimized for cruise



Retractable Landing Gear

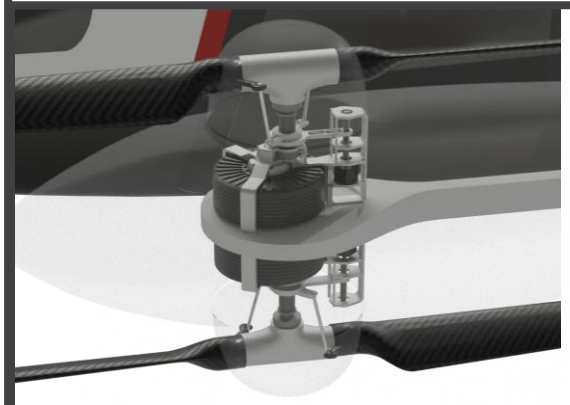
Enables ground taxying with minimal cruise drag





Tail Mounted Props

Keep blades up, away from ground personnel and augments yaw authority in cruise

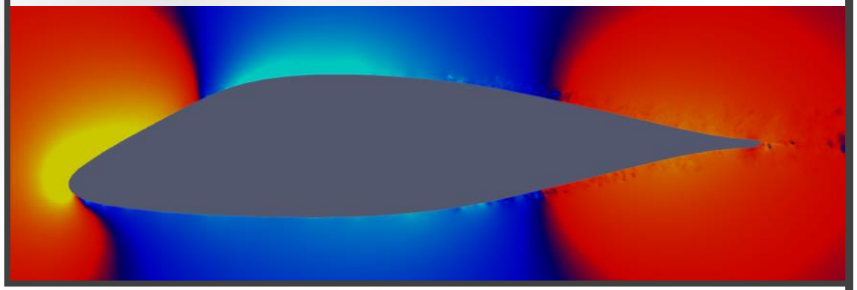


Coaxial Rotor Pair

Can stop aligned to the flow in cruise while providing a large disk area for hover

CFD Optimized Fuselage

Computational fluid dynamics is used to optimize the fuselage shape for minimum drag in cruise



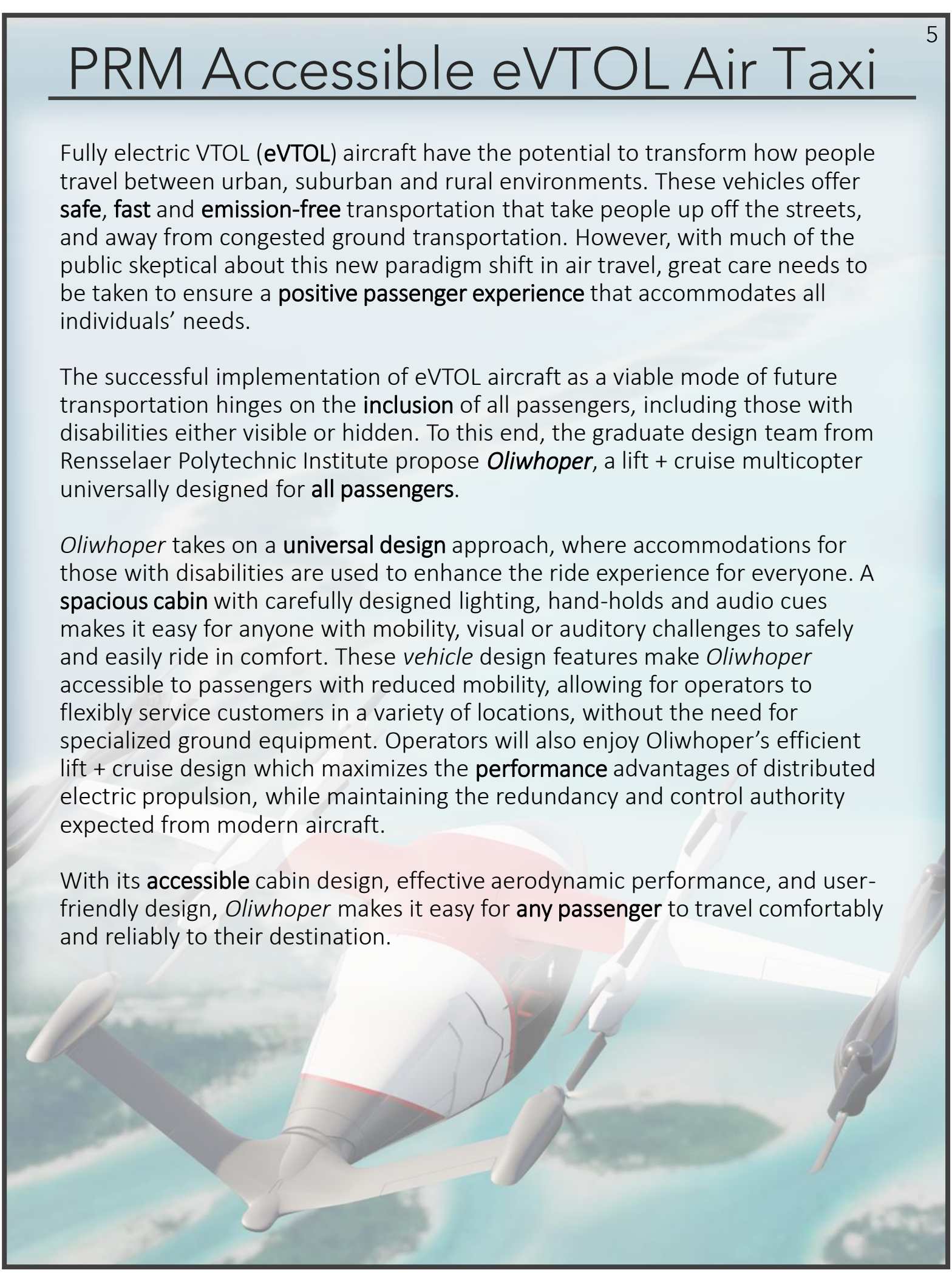
PRM Accessible eVTOL Air Taxi

Fully electric VTOL (**eVTOL**) aircraft have the potential to transform how people travel between urban, suburban and rural environments. These vehicles offer **safe**, **fast** and **emission-free** transportation that take people up off the streets, and away from congested ground transportation. However, with much of the public skeptical about this new paradigm shift in air travel, great care needs to be taken to ensure a **positive passenger experience** that accommodates all individuals' needs.

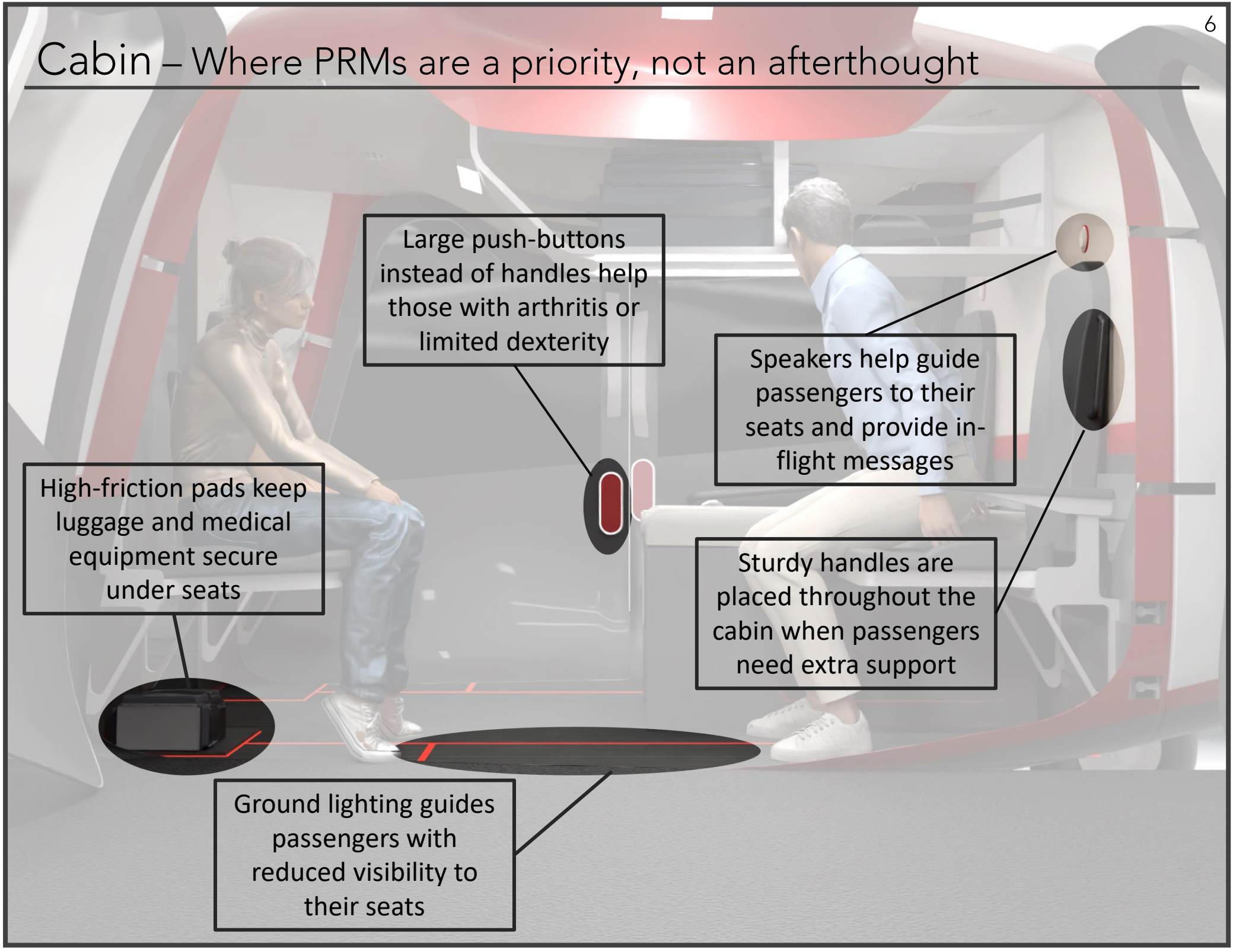
The successful implementation of eVTOL aircraft as a viable mode of future transportation hinges on the **inclusion** of all passengers, including those with disabilities either visible or hidden. To this end, the graduate design team from Rensselaer Polytechnic Institute propose ***Oliwhoper***, a lift + cruise multicopter universally designed for **all passengers**.

Oliwhoper takes on a **universal design** approach, where accommodations for those with disabilities are used to enhance the ride experience for everyone. A **spacious cabin** with carefully designed lighting, hand-holds and audio cues makes it easy for anyone with mobility, visual or auditory challenges to safely and easily ride in comfort. These *vehicle* design features make *Oliwhoper* accessible to passengers with reduced mobility, allowing for operators to flexibly service customers in a variety of locations, without the need for specialized ground equipment. Operators will also enjoy Oliwhoper's efficient lift + cruise design which maximizes the **performance** advantages of distributed electric propulsion, while maintaining the redundancy and control authority expected from modern aircraft.

With its **accessible** cabin design, effective aerodynamic performance, and user-friendly design, *Oliwhoper* makes it easy for **any passenger** to travel comfortably and reliably to their destination.

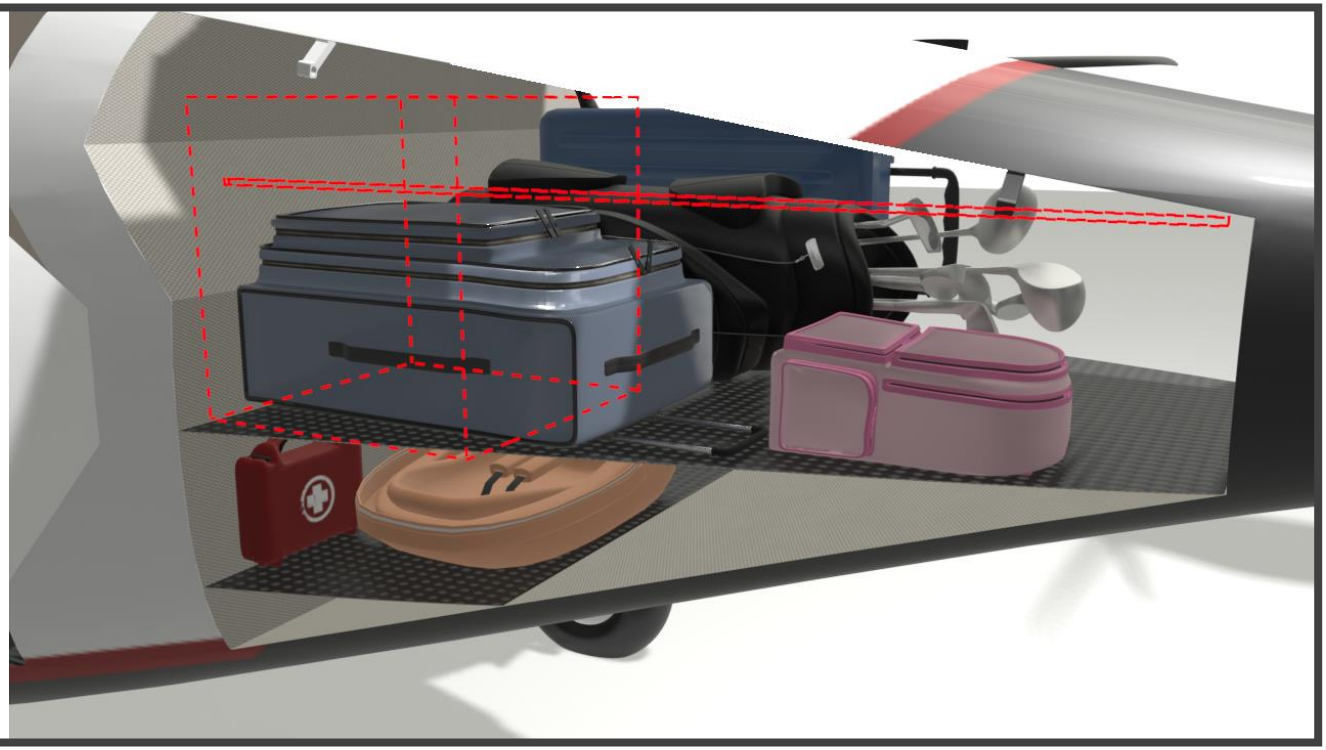


Cabin – Where PRMs are a priority, not an afterthought



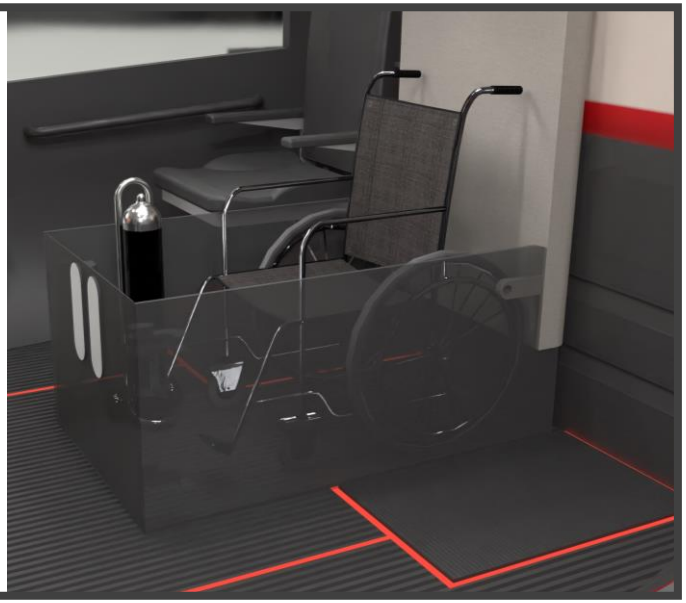
Luggage – Plenty of space for what needs to be brought along

- Rear luggage compartment fits luggage that's long or wide
- Lower bay can permanently store items like first aid kits and booster seats
- Gull-wing doors on either side make for easy luggage access



- Carry-on items can be stored in overhead bins
- Personal items can be stored under the seat

- Center console opens for extra storage in the cabin
- Sized to accommodate wheelchairs, walkers and other large medical equipment



Vehicle Configuration

Possible Configurations:




Lifting Rotors: 0 - 16

Propellers: 0 - 6

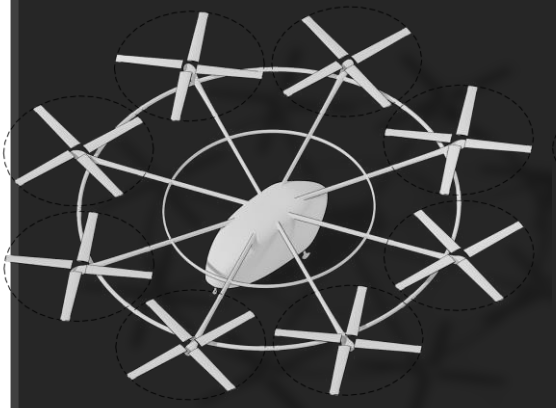
Tilt Rotors: 0 - 16

Main Wing Y/N

Over 1,500 configurations sized for the mission

Best performing configurations are selected for further study

Trade Space Investigation



Pure Multicopter	Lift + Cruise	Lift + Tilt
• 16 lifting rotors	• 8 lifting, 2 props	• 12 lifting, 2 tilt
• 60 kts cruise speed	• 150 kts cruise speed	• 200 kts cruise speed
• 6,700 lb GTOW	• 4,403 lb GTOW	• 5,894 lb GTOW

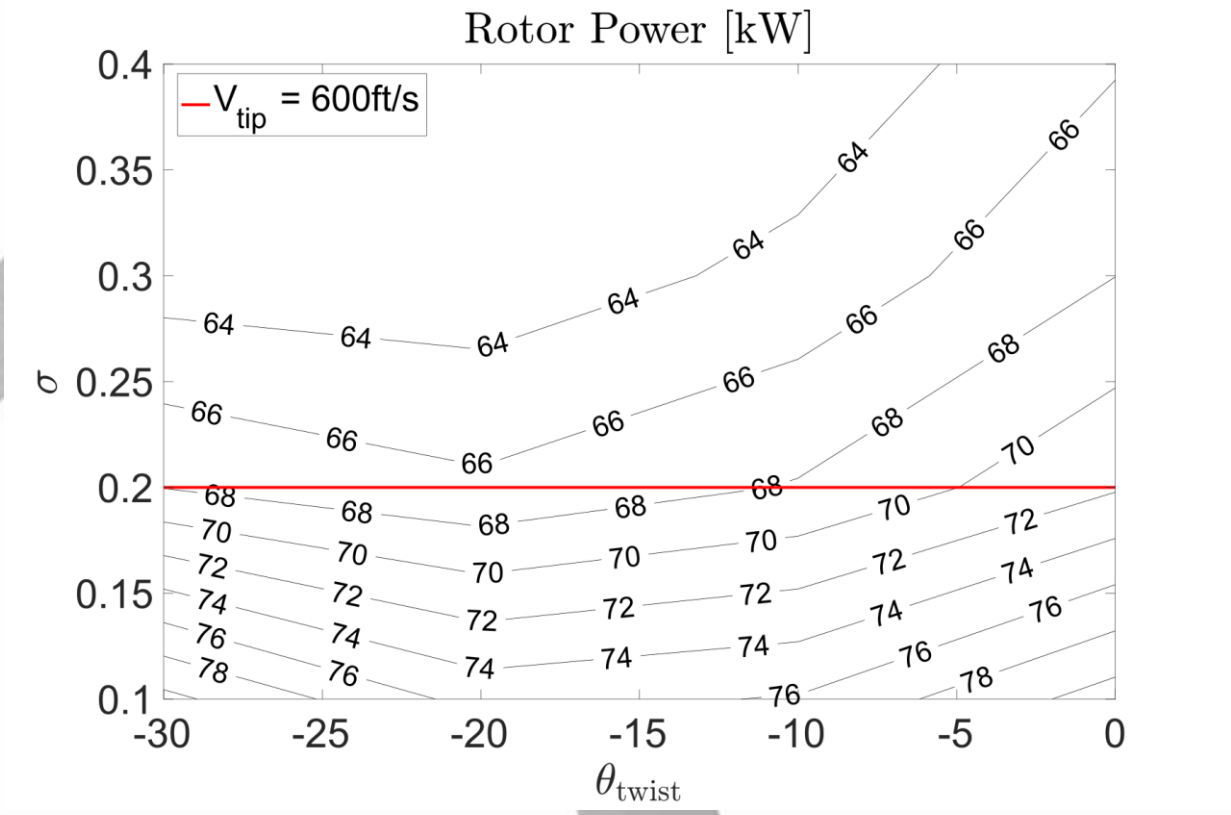
The Lift + Cruise configuration is chosen for its low mission energy, relatively short mission time and mechanical simplicity

Rotor & Propeller Design

The Lift + Cruise configuration allows for lifting rotors to be optimized for hover, and propellers to be optimized for cruise

Rotor solidity and twist are selected to minimize power while not exceeding the limit tip Mach number (M_{Tip} = 0.54)

Rotor power is evaluated in hover, cruise and axial flight using blade element theory with 10-state Peters-He dynamic inflow



Low rotor power is achieved via a high solidity, low tip speed design, thereby reducing profile power

Induced power is minimized by large disk area and low disk loading

Propeller efficiency achieved via a high twist rate

Motor Selection

EMRAX Motors with 1.6 Gear ratio supply 33 kW power MCP to each lifting rotor at 64 Nm torque

Air-cooled motors are lightweight and robust

Two motors per coax rotor pair adds redundancy and occupies a small footprint

EMRAX 228

HV-500

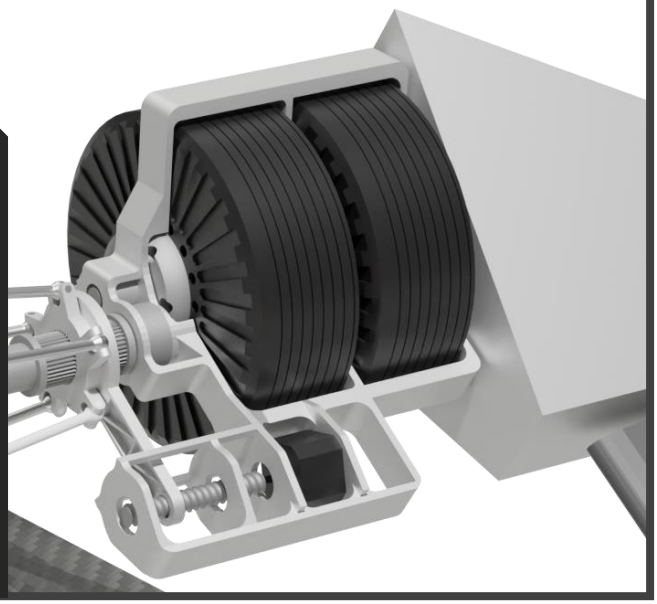
HV-500 motor controllers can operate at 800V with air cooling

Air cooling saves weight and reduces system complexity

Annular shafts allow for coaxial EMRAX 228s to supply 50 kW MCP at 96 Nm torque to the prop

Dual motors adds redundancy in case of motor out

Coaxial motors keeps fairing drag low



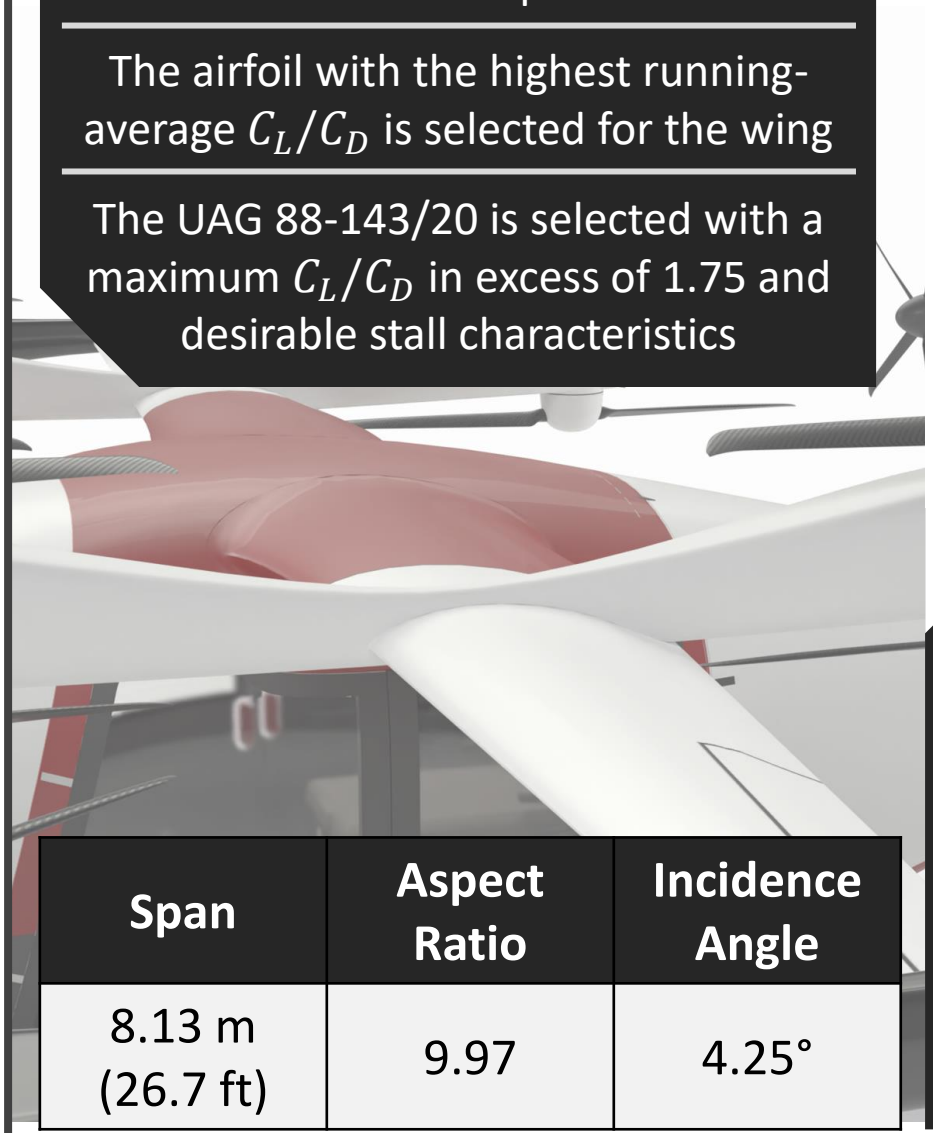
Wing – Optimized for low-drag cruise

Airfoil Selection

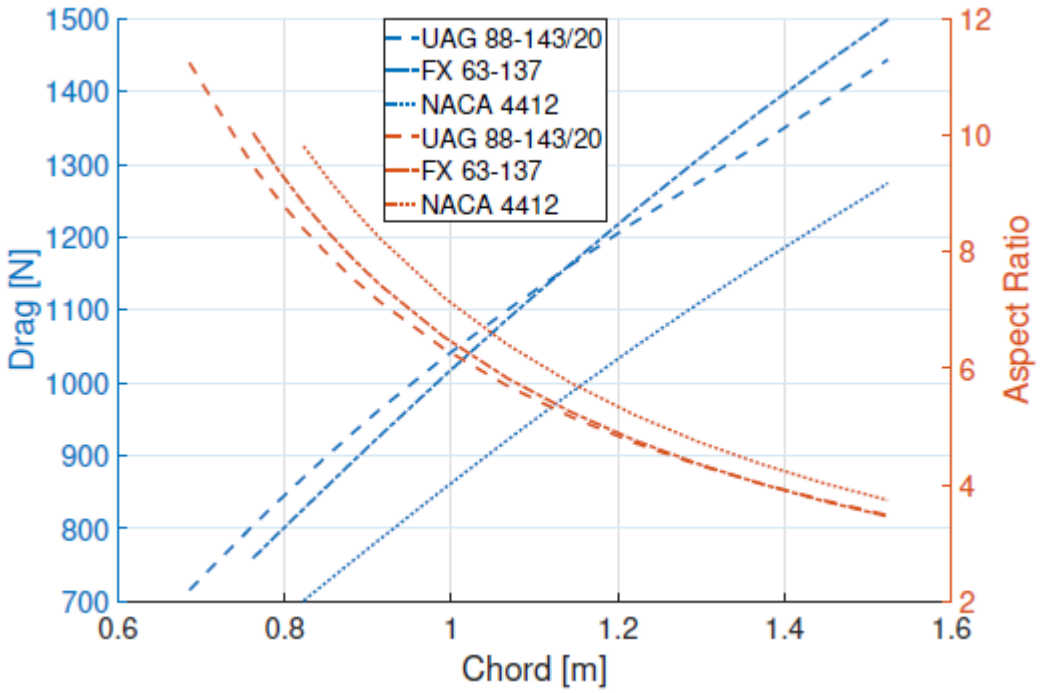
Xfoil is used to evaluate over 1,600 airfoil shapes

The airfoil with the highest running-average C_L/C_D is selected for the wing

The UAG 88-143/20 is selected with a maximum C_L/C_D in excess of 1.75 and desirable stall characteristics



Span	Aspect Ratio	Incidence Angle
8.13 m (26.7 ft)	9.97	4.25°



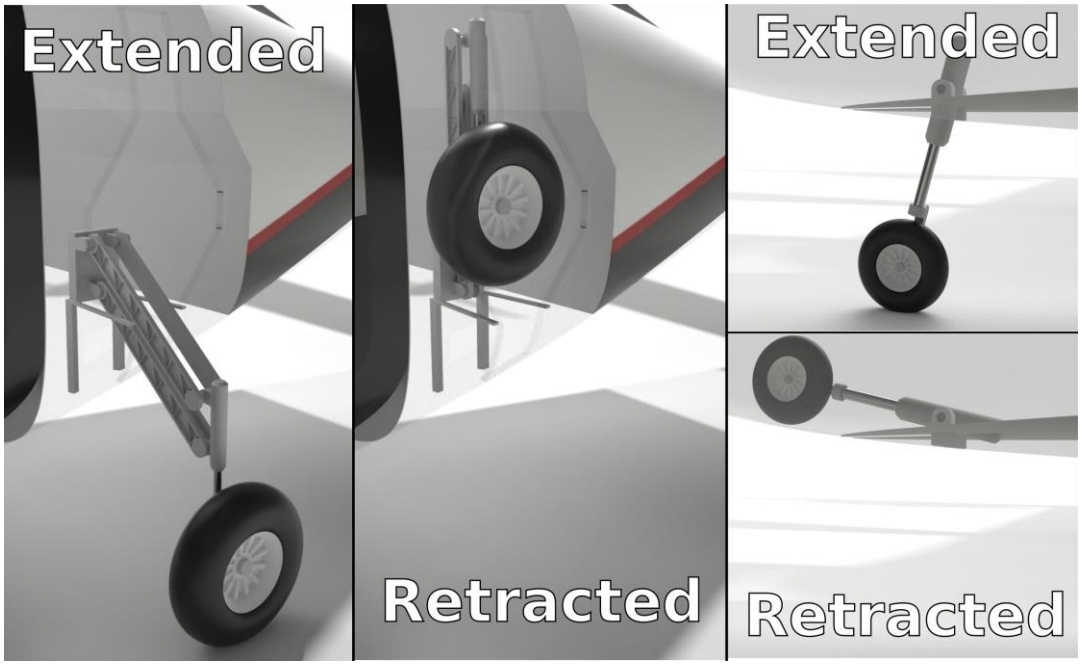
Wing Sizing

The wing planform is sized for minimum drag in cruise while meeting lift and structural constraints

Sufficient root airfoil thickness is ensured to accommodate a spar that can handle stress from the wing-mounted rotor thrust in hover

The wing span is constrained to extend out to the most outboard lifting rotor

Landing Gear



Retractable Landing Gear

Retraction mechanisms add an estimated 5.5 kg

This weight penalty saves over 230 N drag in cruise nominally incurred by a fixed landing gear

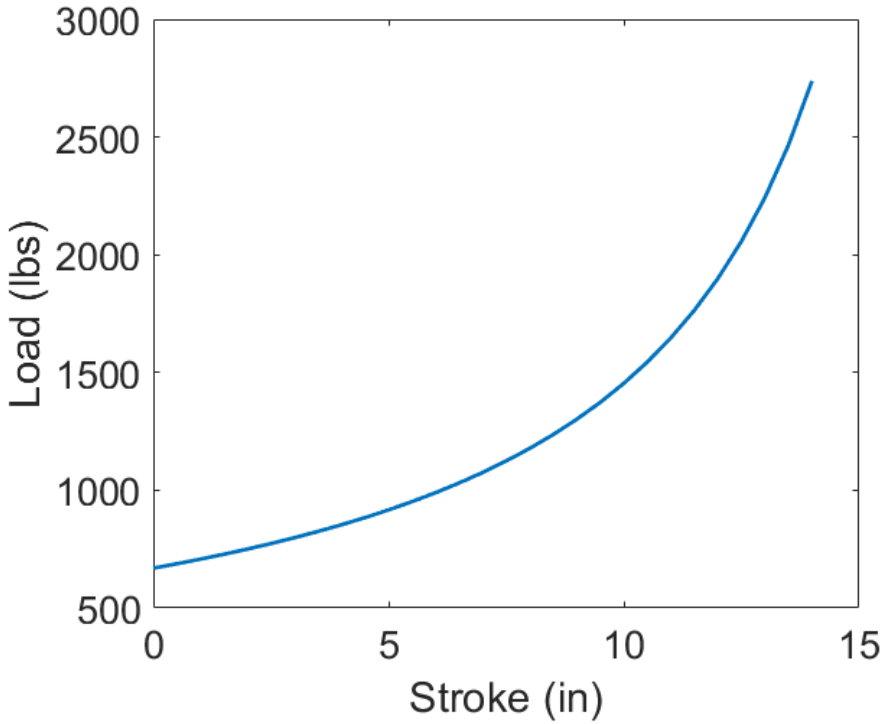
A 4-bar linkage stores aft landing gear compactly in the side of the fuselage

Shock Absorber Design

14 in. stroke length designed to arrest a 2 m/s (6.55 ft/s) descent at 2/3 GTOW

Oleo-pneumatic shocks used for their simple design and high efficiency

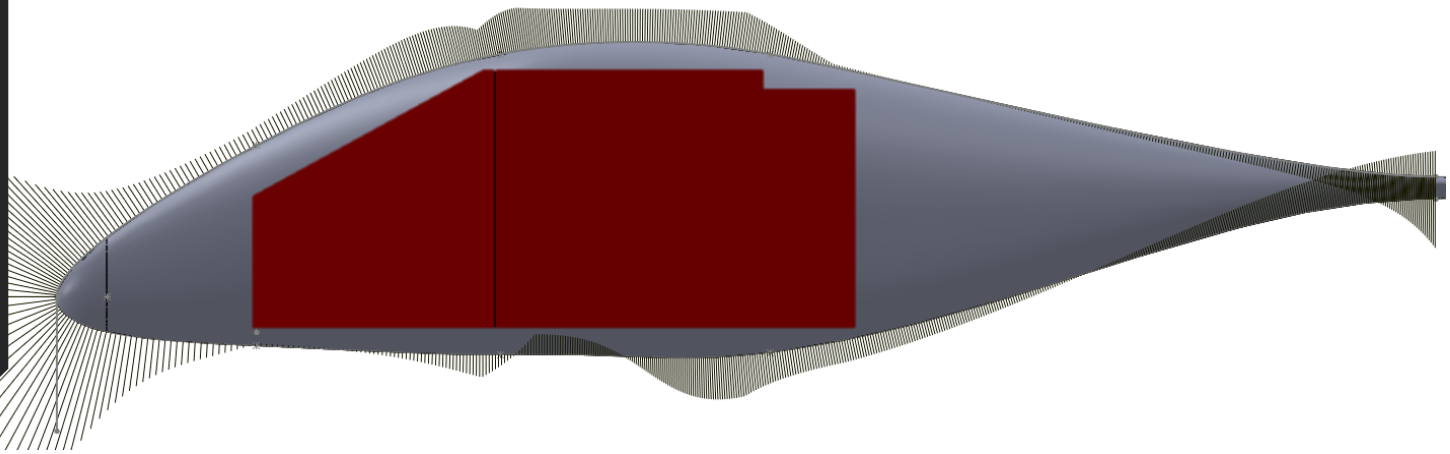
Compression ratios and piston areas are designed to accommodate the maximum loads incurred during landing

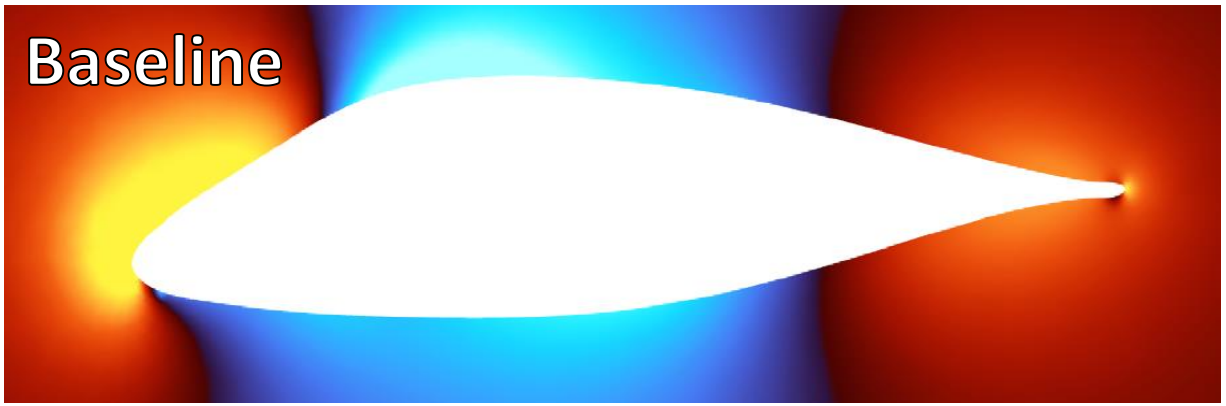


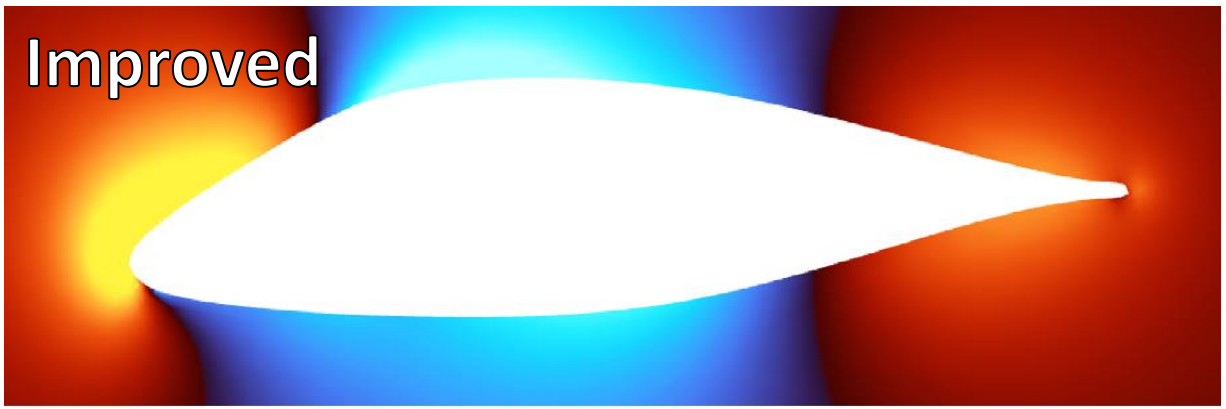
Fuselage Shape

Fuselage shape designed for minimum curvature around the cockpit and cabin

Low nose enhances cockpit visibility







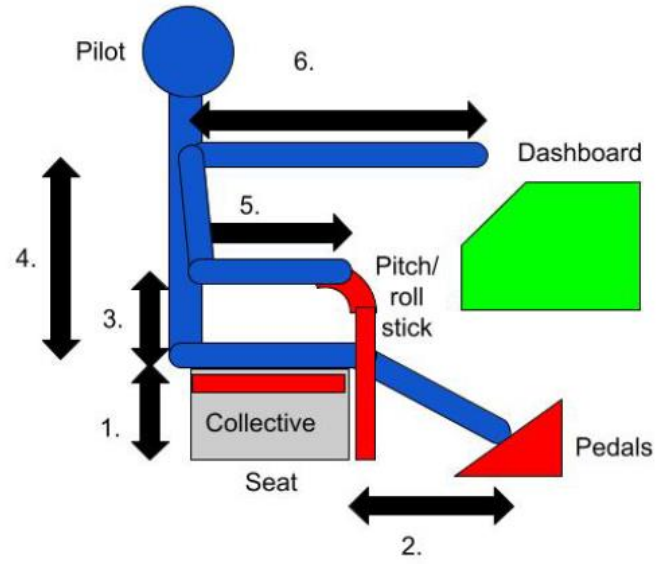
3D CFD used to analyze fuselage drag in cruise

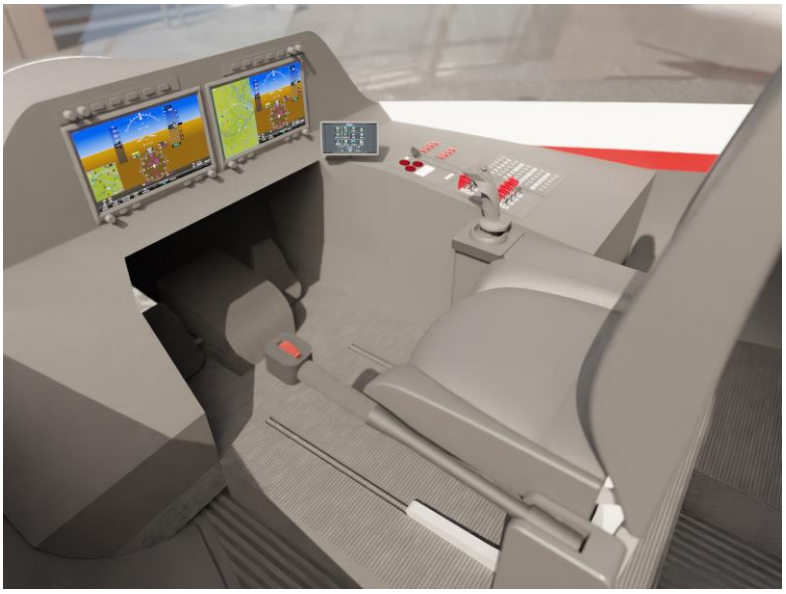
UltraFluidX with LES turbulence compared to Ansys Fluent RANS

Fluent is used to identify areas of high pressure drag and flow separation points

The fuselage shape is adjusted from the nominal to reduce fuselage pressure drag by 22.7% and total drag by 9.4%

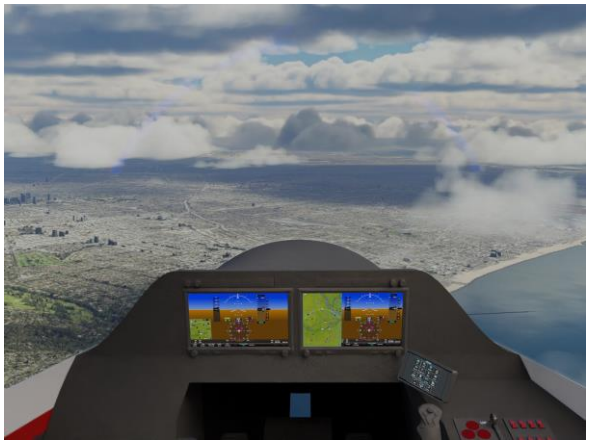
Cockpit

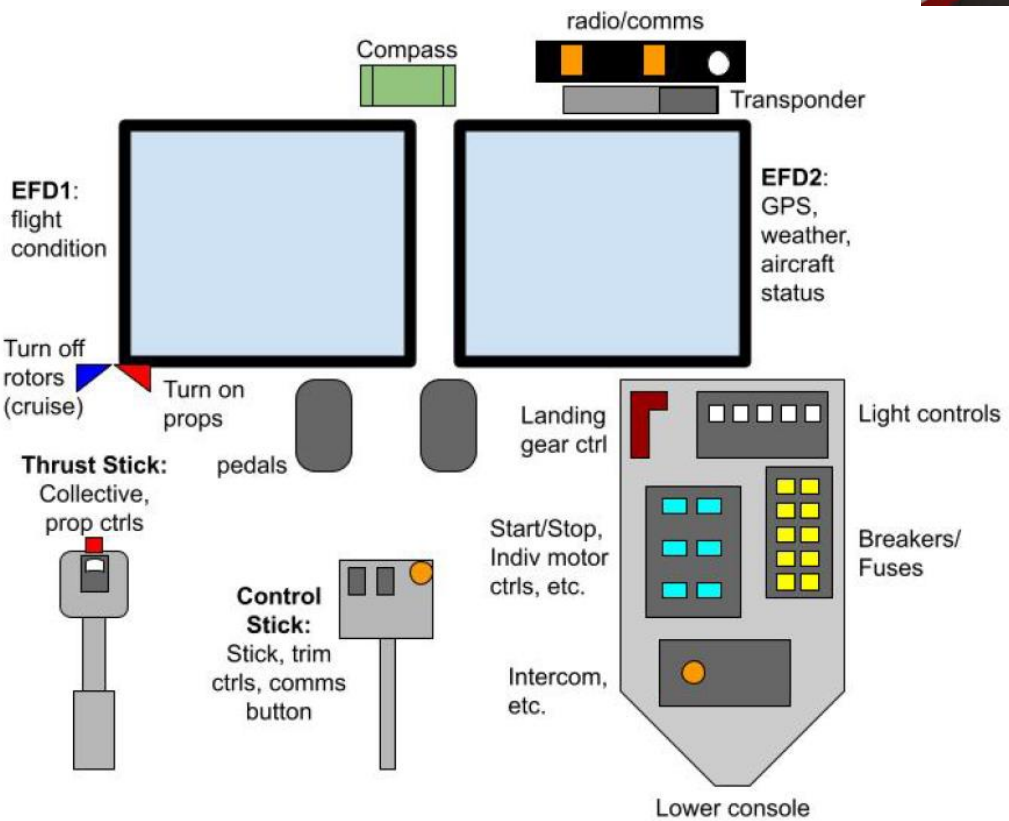




Sliding seat and adjustable controls keep everything within reach for tall and short pilots

Wide canopy gives excellent pilot visibility, enhancing situational awareness



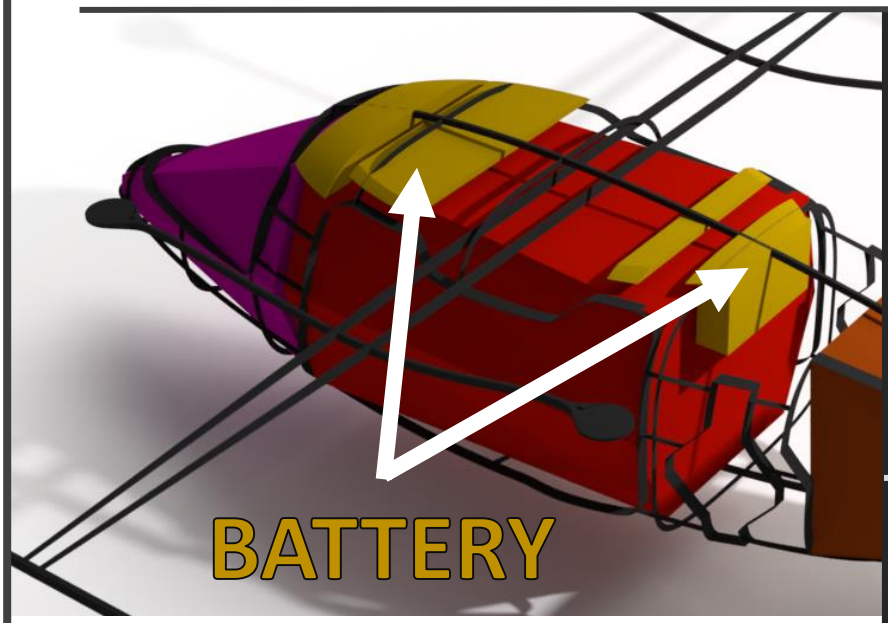


Slider on collective stick commands propeller thrust

Touch screen PFD and MFD make flight information easily visible

All controls meet 14 CFR Part 29 Requirements

Electrical

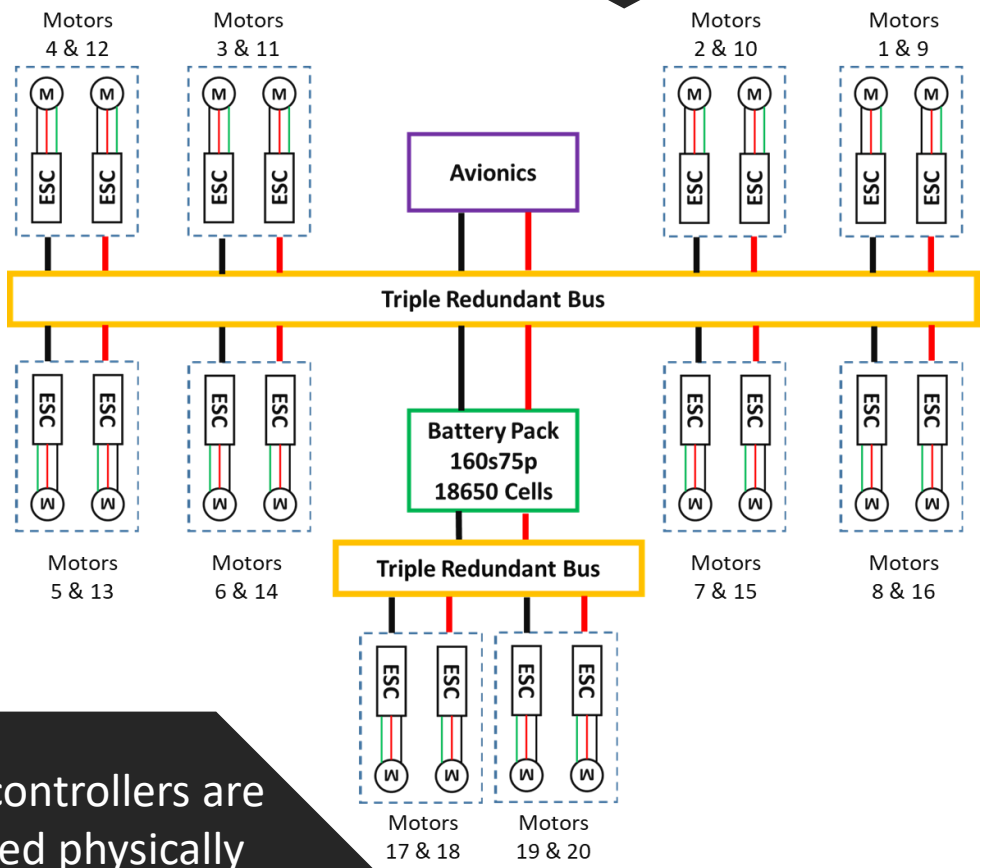


Battery

Stored high, near the wing in multiple sections

Proximity to the wing keeps wires short, minimizing electrical losses

High mounted battery keeps the CG close to the rotor plane, improving maneuverability



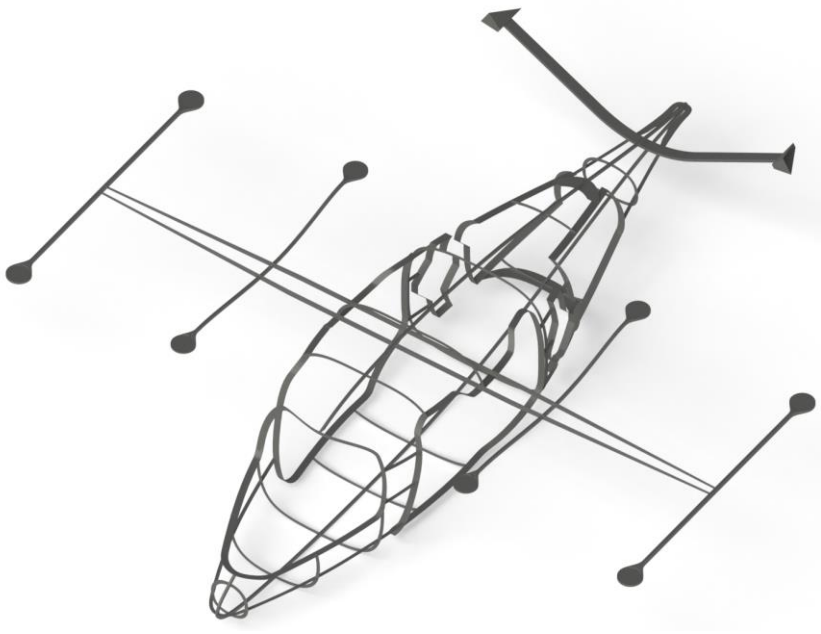
Triple redundant power bus between the battery and all motor controllers

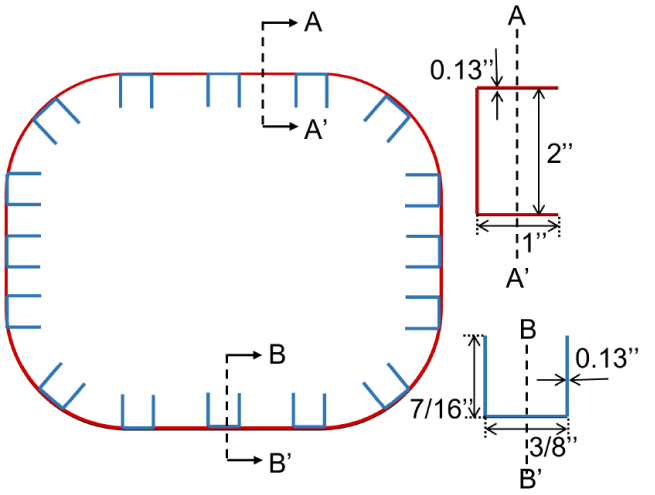
Motor controllers are mounted physically close to rotors to minimize electrical losses

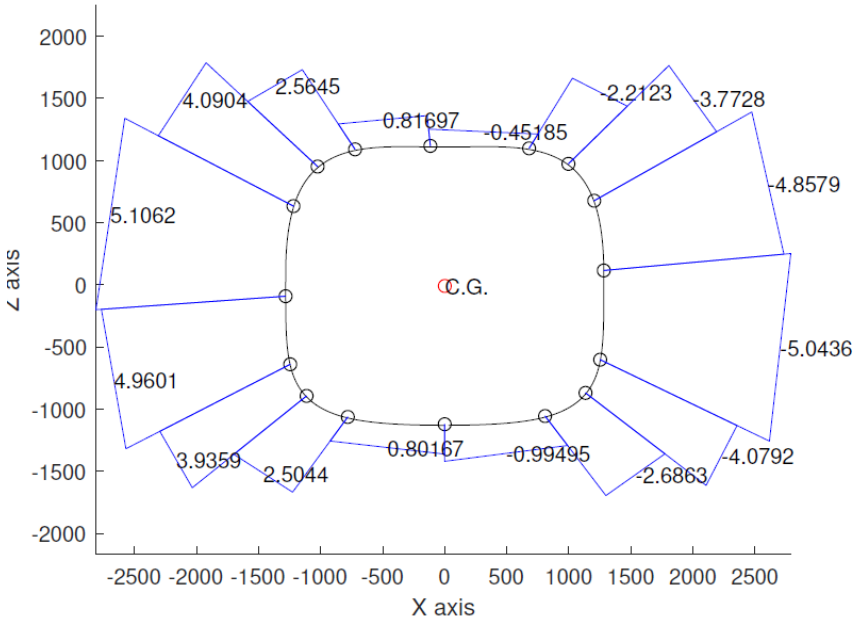
Structural

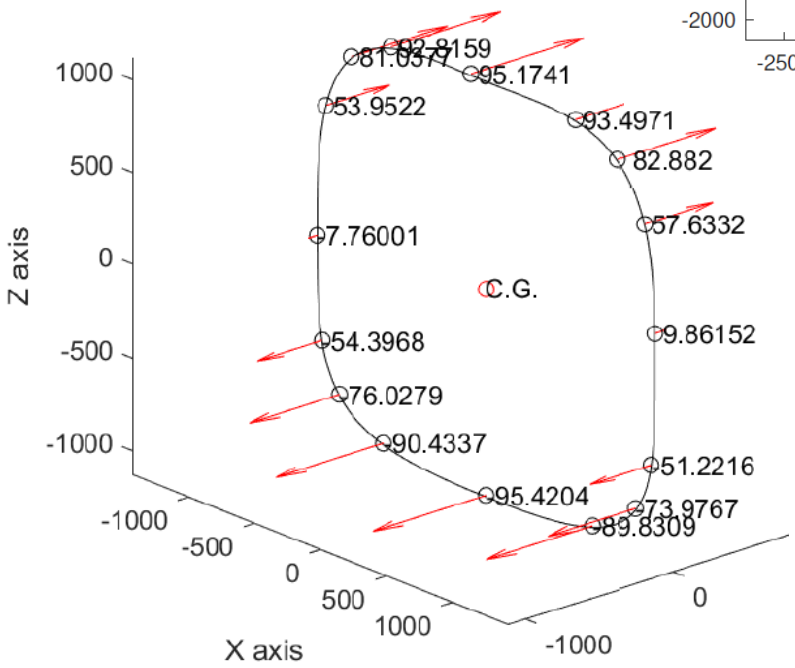
Stringers and ribs add rigidity to a carbon fiber skin

Rotor struts affix to the wing spar and propellers attach to the tail spar









Design envelopes are prepared based on 14 CFR part 25.337 with 19 maneuver and gust envelopes considered

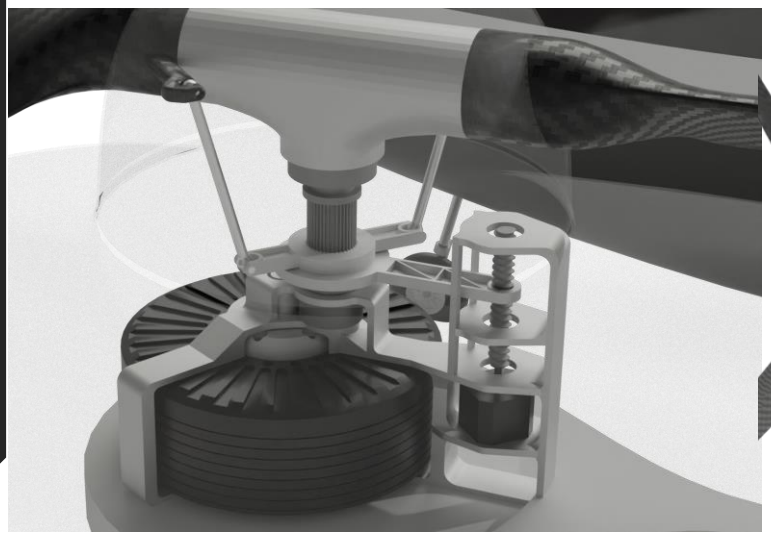
The stringers and skin are shown to withstand the stresses caused under limit loads with a 1.5 FOS

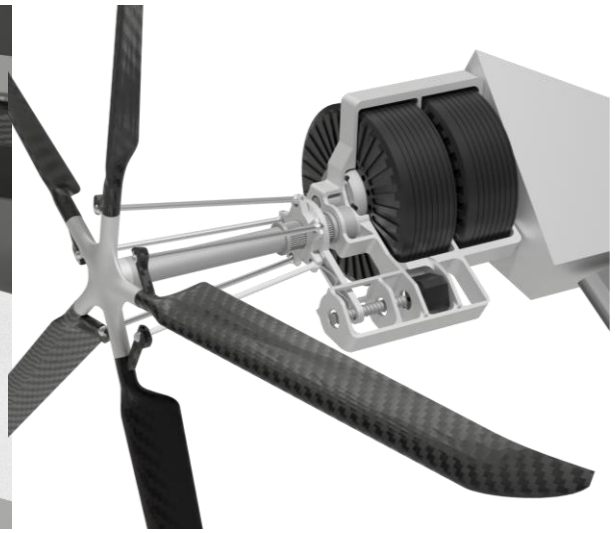
Controls

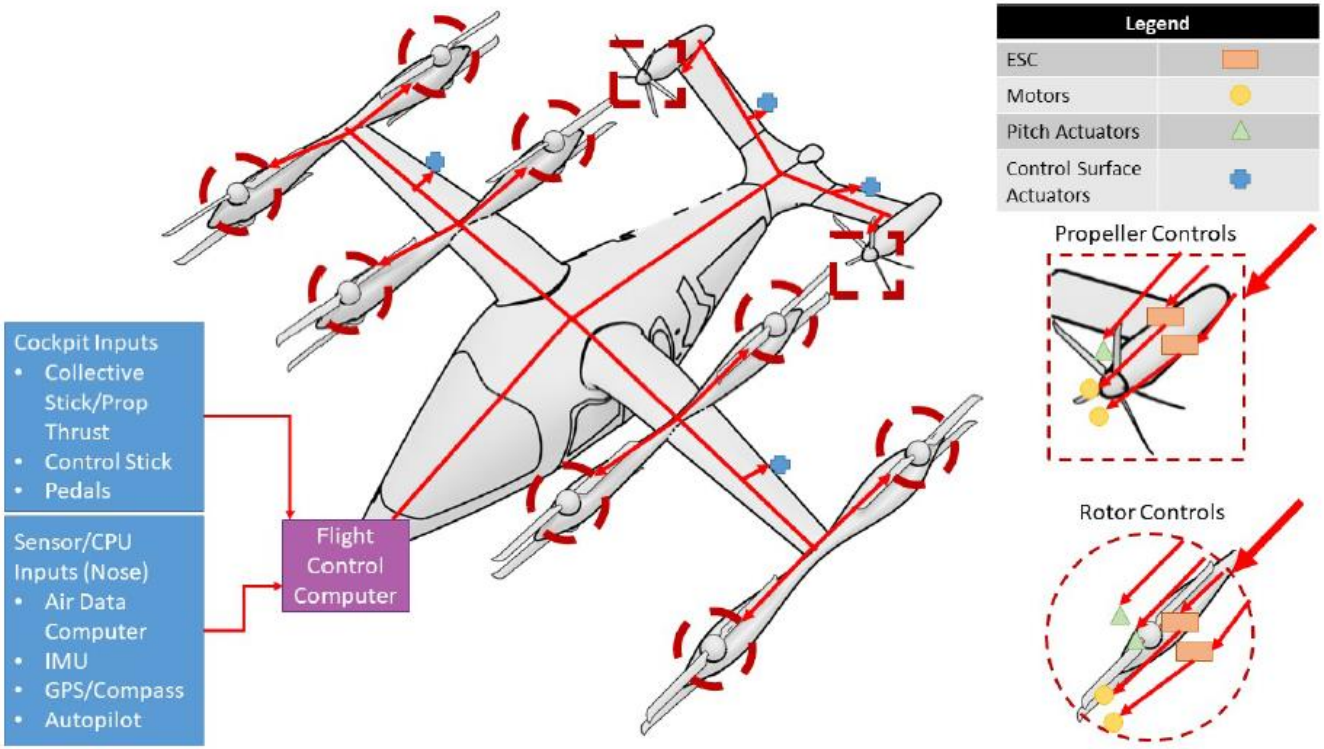
Variable blade pitch is needed to achieve adequate rotor response rates

Stepper motor driven ball screws alleviate the need for hydraulic actuators

Stepper motors are sized to reach 20°/s blade pitch rate





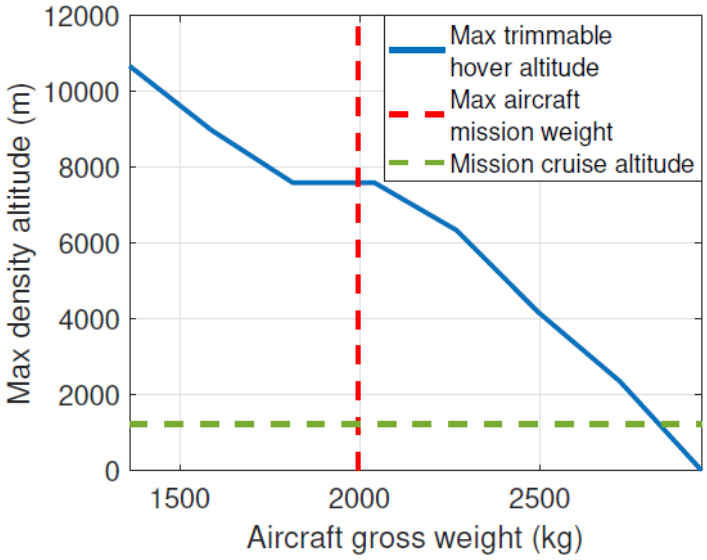


Ruddervator and ailerons are sized to meet 10° pitch and roll rate within 1.5s

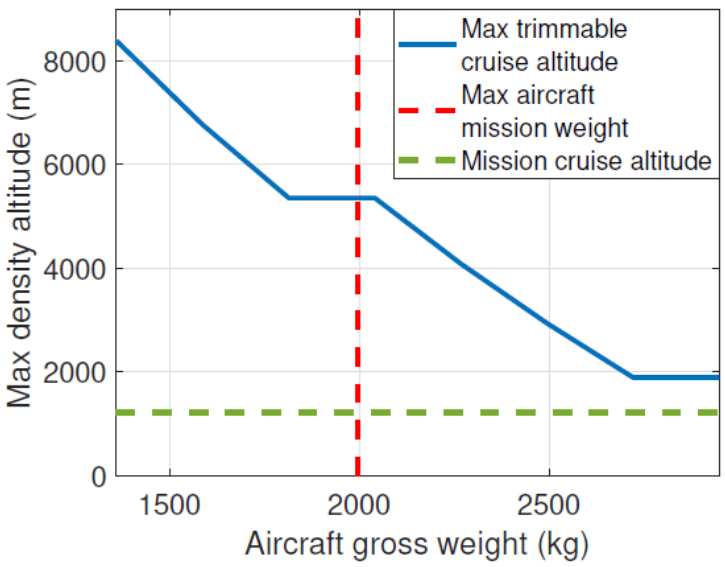
A flight control computer appropriately mixes the pilot inputs based on the flight state to command the control surfaces

Performance Analysis

Hover



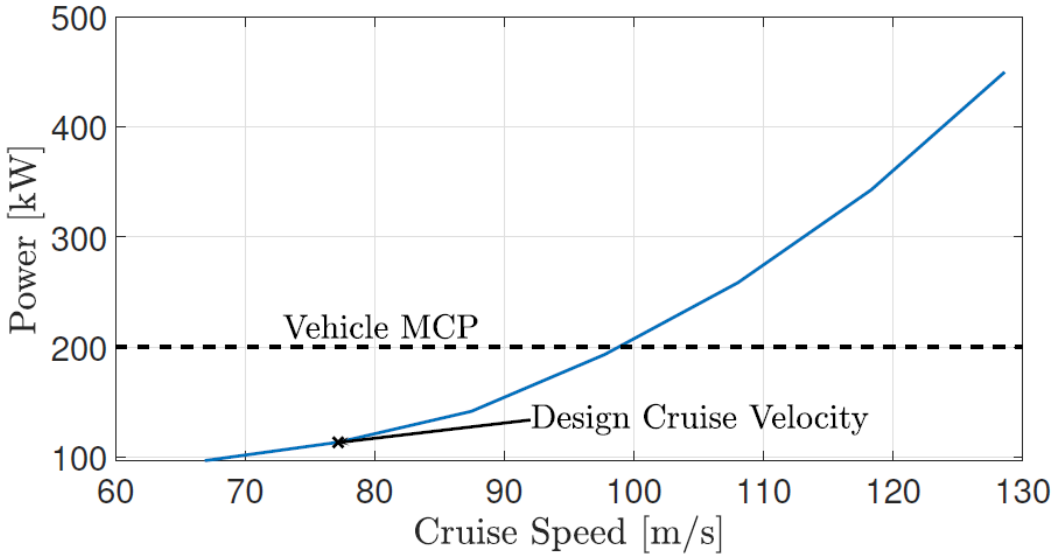
Cruise



Without air-breathing engines, max hover altitude is constrained by rotor stall

The maximum cruise altitude is constrained by wing stall

Oliwhoper's maximum operating altitudes exceed FL 164, well beyond the mission altitude



Oliwhoper can reach 97.75 m/s (190 kts) without exceeding the propeller MCP

At the designed 77 m/s (150 kt) cruise speed, each propeller draws 56 kW (75 hp)

Below 62 m/s (120 kt), lifting rotors augment wing lift

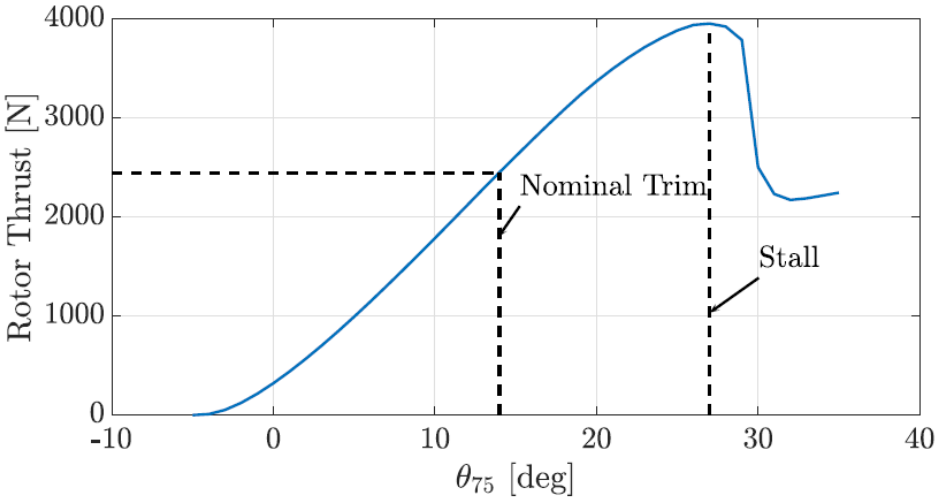
Maneuverability

Hover authority is evaluated in the most adverse wind condition (north-west)

Oliwhoper exceeds the agility requirements in all axes

Differential RPM is used to meet yaw authority requirements

Axis	Authority (rad/s^2)	Required Authority
Roll	7.92	0.175
Pitch	1.26	0.175
Yaw	0.175	0.175
Heave	7.83	2.45



An inverse model is used to determine the required flap deflections in cruse

Oliwhoper exceeds the agility requirements in roll and pitch

Differential prop RPM can be used to augment yaw authority in cruise

Axis	Flap Margin	Required Flap
Roll	20°	8.2°
Pitch	11.2°	10.8°
Yaw	11.2°	20.8°

Comfortable, Efficient, Capable

A **spacious** cabin with thoughtful seating, lighting and sound design make riding *Oliwhoper* **easy** for PRMs and able-bodied passengers alike

Oliwhoper's 8 x 2 Lift + Cruise configuration is carefully selected from over 1,500 designs to **efficiently** reach its destination using the **least energy** possible

Thorough performance, dynamics and structural **analysis** demonstrate Oliwhoper's high **performance** throughout the foreseeable flight envelope