EXECUTIVE SUMMARY

39TH Annual Student Design Competition

eVTOL Air Taxi for Passengers with Reduced Mobility (PRM)

Sponsored by MOVE Center for Mobility with Vertical Lift at Rensselaer
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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 taxiing 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.
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.
High-friction pads keep luggage and medical equipment secure under seats.

Large push-buttons instead of handles help those with arthritis or limited dexterity.

Speakers help guide passengers to their seats and provide in-flight messages.

Sturdy handles are placed throughout the cabin when passengers need extra support.

Ground lighting guides passengers with reduced visibility to their seats.
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
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**
  - 16 lifting rotors
  - 60 kts cruise speed
  - 6,700 lb GTOW

- **Lift + Cruise**
  - 8 lifting, 2 props
  - 150 kts cruise speed
  - 4,403 lb GTOW

- **Lift + Tilt**
  - 12 lifting, 2 tilt
  - 200 kts cruise speed
  - 5,894 lb GTOW

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

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

<table>
<thead>
<tr>
<th>Span</th>
<th>Aspect Ratio</th>
<th>Incidence Angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.13 m (26.7 ft)</td>
<td>9.97</td>
<td>4.25°</td>
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</table>
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

![Graph showing load vs. stroke]
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%
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
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.
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.

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

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)

<table>
<thead>
<tr>
<th>Axis</th>
<th>Authority ($rad/s^2$)</th>
<th>Required Authority</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roll</td>
<td>7.92</td>
<td>0.175</td>
</tr>
<tr>
<td>Pitch</td>
<td>1.26</td>
<td>0.175</td>
</tr>
<tr>
<td>Yaw</td>
<td>0.175</td>
<td>0.175</td>
</tr>
<tr>
<td>Heave</td>
<td>7.83</td>
<td>2.45</td>
</tr>
</tbody>
</table>

Oliwhoper exceeds the agility requirements in all axes

Differential RPM is used to meet yaw authority requirements

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

Oliwhoper exceeds the agility requirements in roll and pitch

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

<table>
<thead>
<tr>
<th>Axis</th>
<th>Flap Margin</th>
<th>Required Flap</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roll</td>
<td>20°</td>
<td>8.2°</td>
</tr>
<tr>
<td>Pitch</td>
<td>11.2°</td>
<td>10.8°</td>
</tr>
<tr>
<td>Yaw</td>
<td>11.2°</td>
<td>20.8°</td>
</tr>
</tbody>
</table>
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.