Aerodynamic Fact Check of eVTOLs

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Overview

• What is DEP and what can it do for you?

• Literature review and set goal

• Simulation setup

• Case studies
  • Coaxial-Quadro-Copter
  • Duo-Tilt-Wing Octo-Copter

• Comparing Configurations

• Summary & Conclusions
What is DEP?

- DEP (distributed electric propulsion)
  - Allows to produce thrust virtually anywhere
    - Allows for more efficient wings in compound configurations
    - Up to 10% observed in the literature [10]
  - Electric motors can change their speed rapidly
    - No need for pitch control
    - Blades may operate at their best Figure of Merit
    - Pitching moment constraints strongly reduced
Literature review and set goal

• Current aerodynamic studies rely on either

  • Wake models with either panel methods and/or blade element theory
    • Wake models and panel methods assume inviscid, incompressible, irrotational flow
    • Blade element theory utilizes tabled 2D airfoil data

  • CFD simulations that simplify the propellers/rotors to avoid meshing it
    • Often steady state is computed
    • No statement about the propellers possible

• Recent Examples: Fischer and Ortun [10], Droandi et al [11]

• This study investigates to specific configurations with resolved propellers with CFD and analyzes the effect of removing propellers
Case Studies

- Model abstraction
- No affiliation with the manufactures!
- Guestimations about missing values

**eHang 184**

- Coax – quad

**A³ Vahana**

- Octo – tilt
Simulation setup

- FLOWer 4
  - Laminar/turbulent transition based empirical models
  - Chimera
  - 6th order Pade Filter in background mesh

- Two level grid setup
  - Parametric in-house grid generator G³
  - 2nd level for parametric sweeps
  - 1st level for validation (only coax-quad)

- All simulations are *unsteady*! (hover with 15 revs)
- Forward flight as half model

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Coax-quad meshes

<table>
<thead>
<tr>
<th>Component</th>
<th>Fine</th>
<th>Coarse</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blade</td>
<td>5.6e4</td>
<td>7.0e3</td>
</tr>
<tr>
<td>Fuselage</td>
<td>5.1e4</td>
<td>6.4e3</td>
</tr>
<tr>
<td>Background (forward flight/hover)</td>
<td>9.2e6 / 1.8e7</td>
<td>1.1e6 / 2.3e6</td>
</tr>
<tr>
<td>Total:</td>
<td>1.1e7 / 2.3e7</td>
<td>1.4e6 / 2.9e6</td>
</tr>
</tbody>
</table>
Coax-Quad Results
Coax-Quad in Hover – Coax vs Single Propeller

- Coaxial rotor surpasses single rotor
- Trend well captured on both mesh resolutions
Coax-Quad in Hover – Coax vs Single Propeller

- Coaxial rotor is a compact efficient solution
- Two (isolated) rotors would be the most efficient configuration
- A single rotor can still lift the vehicle (emergency)!
Coax-Quad in Forward flight (100 km/h)

<table>
<thead>
<tr>
<th>Mesh Type</th>
<th>Pitch (°)</th>
<th>RPM</th>
<th>Req. power (kW)</th>
<th>Pitching moment (Nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse</td>
<td>-8.7°</td>
<td>2030</td>
<td>35.8</td>
<td>+9.4</td>
</tr>
<tr>
<td>Fine</td>
<td>-9.0°</td>
<td>2150</td>
<td>41.1</td>
<td>+9.3</td>
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</table>
Octo-Tilt Results
Octo-Tilt-Wing in hover – 4 vs 8 Propellers

- Pitch control has a varying Figure of Merit over thrust
- RPM control has almost constant Figure of Merit (Re & Mach effects)
Octo-Tilt-Wing in hover – 4 vs 8 Propellers

- A mild preference for multiple rotors observed
- The wing acts as a stator, thus higher efficiency with wing
- Despite an additional blade and different planform, similar performance to single quad rotor
Octo-Tilt-Wing in forward flight (175 km/h)

Investigated a two and four component trim for the lateral motion
Octo-Tilt-Wing in forward flight (175 km/h)

- Many trim scenarios imaginable!
- Slight octo-tilt configuration slightly favored
- Some uncertainty remains (up to 0.6 kW)
Comparison and Summary
Comparing Configurations

<table>
<thead>
<tr>
<th>Mass:</th>
<th>360 kg</th>
<th>725 kg</th>
<th>575 kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diagonal:</td>
<td>5.6 m</td>
<td>8.5 m</td>
<td>7.3 m</td>
</tr>
</tbody>
</table>

Electrified helicopter with 7AD rotor

The heaviest and largest machine has the greatest range, still all of them are single seaters!
Summary

• CFD investigation with resolved propellers of a coaxial-quadrocopter and a octo-tilt-wing configuration

• Coaxial rotors are more efficient on same projected disc area

• Hover efficiency can be increased with a wing (stator effect)

• Tilt configuration is more efficient with eight instead of four propellers

• Heaviest machine has greatest range

• High aerodynamic efficiency is “easily” obtained, success of eVTOLs is determined elsewhere
  • Safety
  • Acoustics
  • Economics
Backup
Coax Quad in Hover

At the design thrust the difference in required power between the fine and coarse mesh is up to 4 %

Transition lines
upper rotor, suction side

Fine mesh solutions have deteriorated performance due to less laminar regions!
Coax Quad – forward flight (100 km/h)

• The horizontal and vertical force are trimmed

• Built surrogate model from six coarse mesh simulations with different RPM / tilt angles

• Optimizer determined final trim

• Checked with fine mesh simulation