Aerodynamic Fact Check of eVTOLs

Gunther Wilke

DLR AS-HEL

21. DGLR-Fachsymposium der STAB

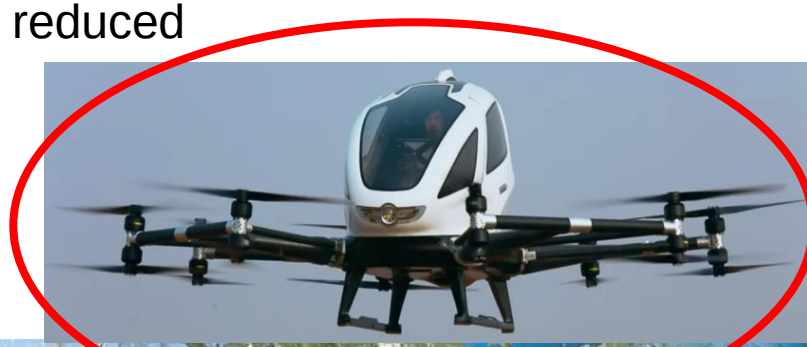
DLR

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

eHang 184

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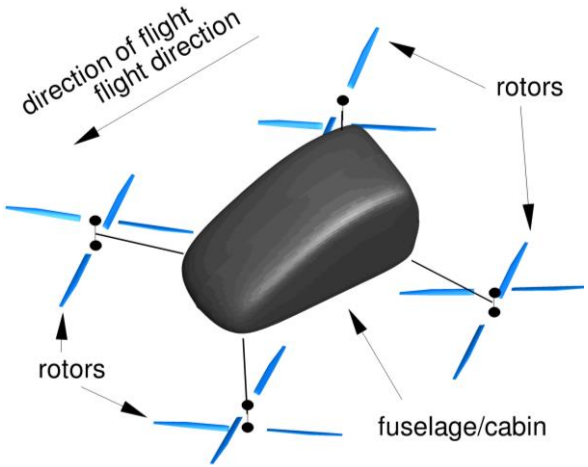
coax – quad



A^3 Vahana

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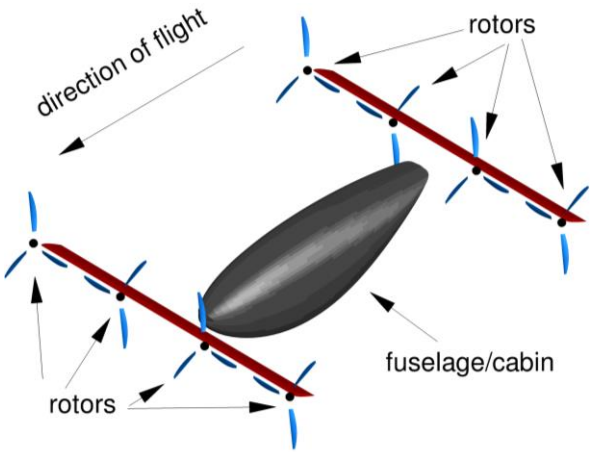
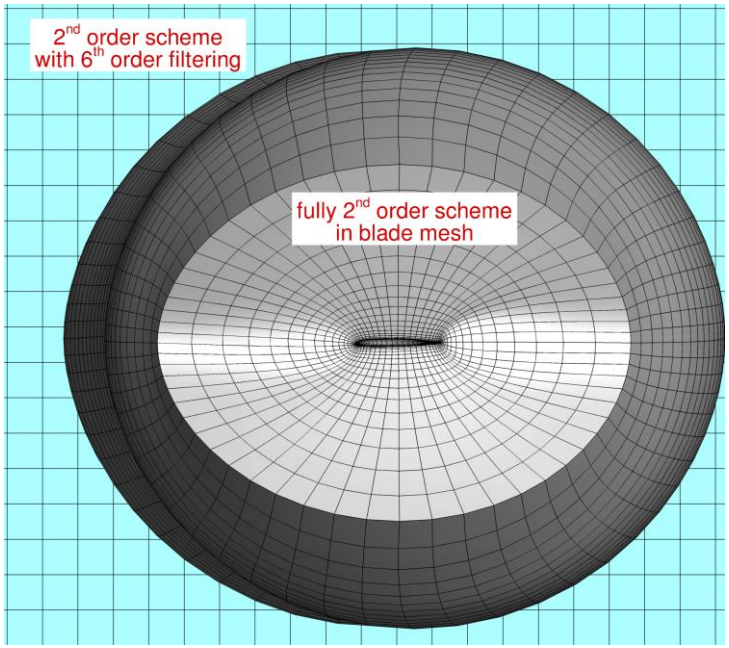
octo – tilt



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

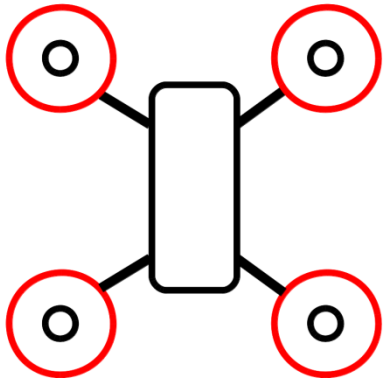
Simulation setup

- 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 G^3
  - 2nd level for parametric sweeps
  - 1st level for validation (only coax-quad)
- All simulations are <u>unsteady</u>! (hover with 15 revs)
- Forward flight as half model



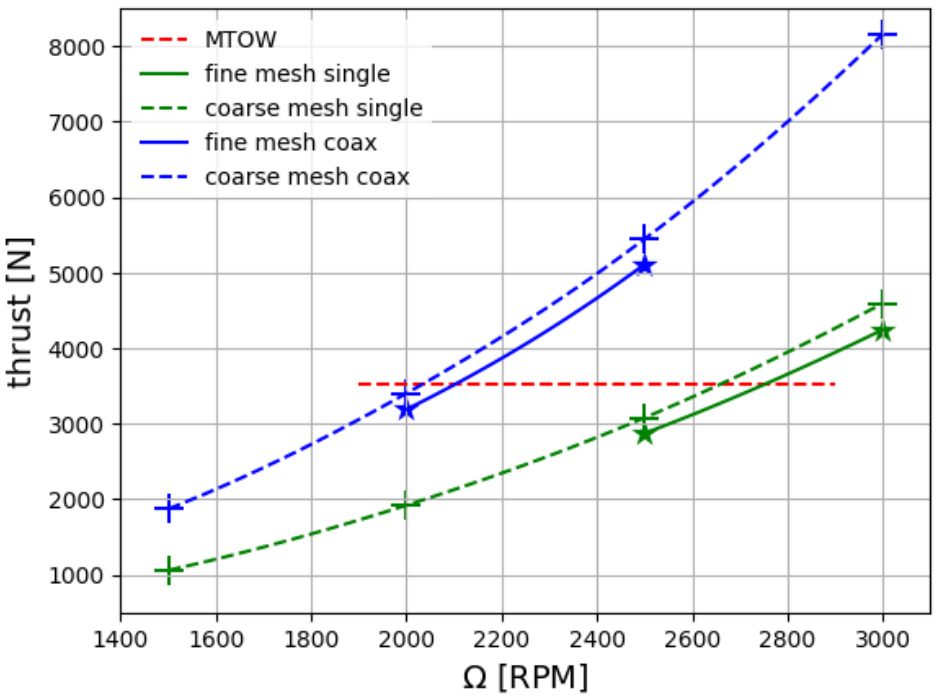
Coax-quad meshes

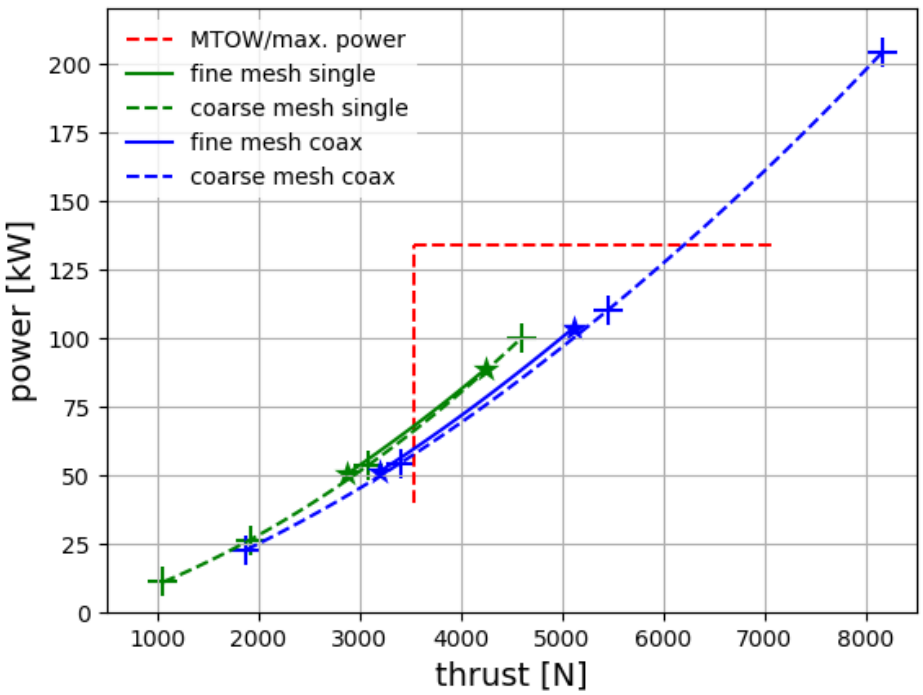
Component	Fine	Coarse
Blade	5.6e4	7.0e3
Fuselage	5.1e4	6.4e3
Background (forward flight/hover)	9.2e6 / 1.8e7	1.1e6 / 2.3e6
Total:	1.1e7 / 2.3e7	1.4e6 / 2.9e6



Coax-Quad Results

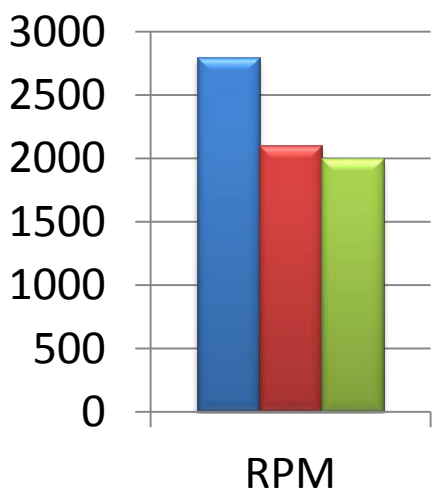
Coax-Quad in Hover – Coax vs Single Propeller

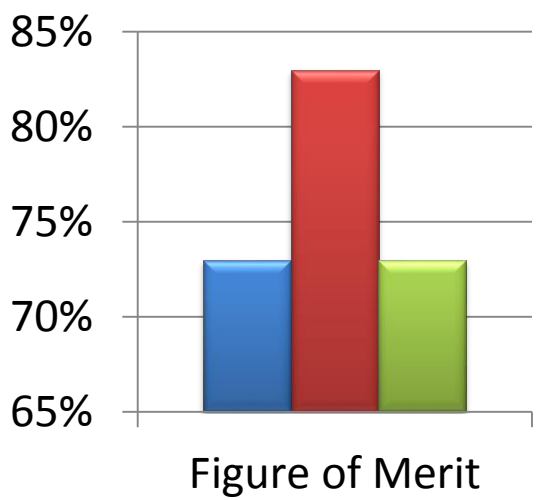


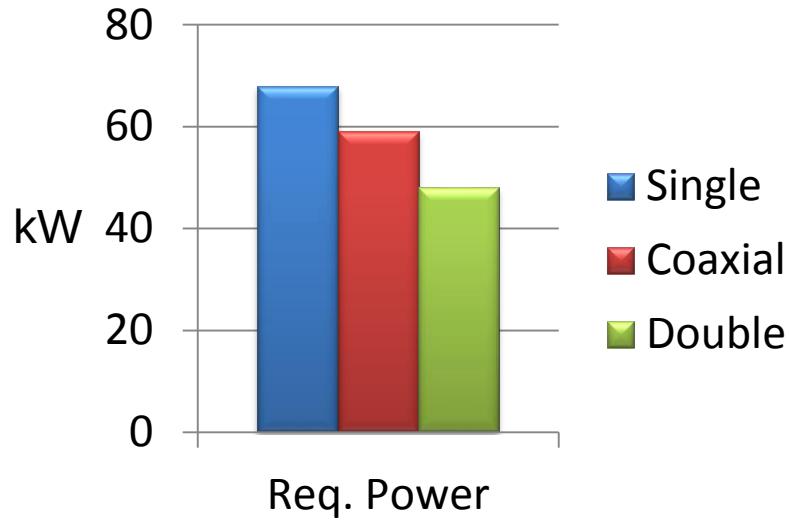


- Coaxial rotor surpasses single rotor
- Trend well captured on both mesh resolutions

Coax-Quad in Hover – Coax vs Single Propeller

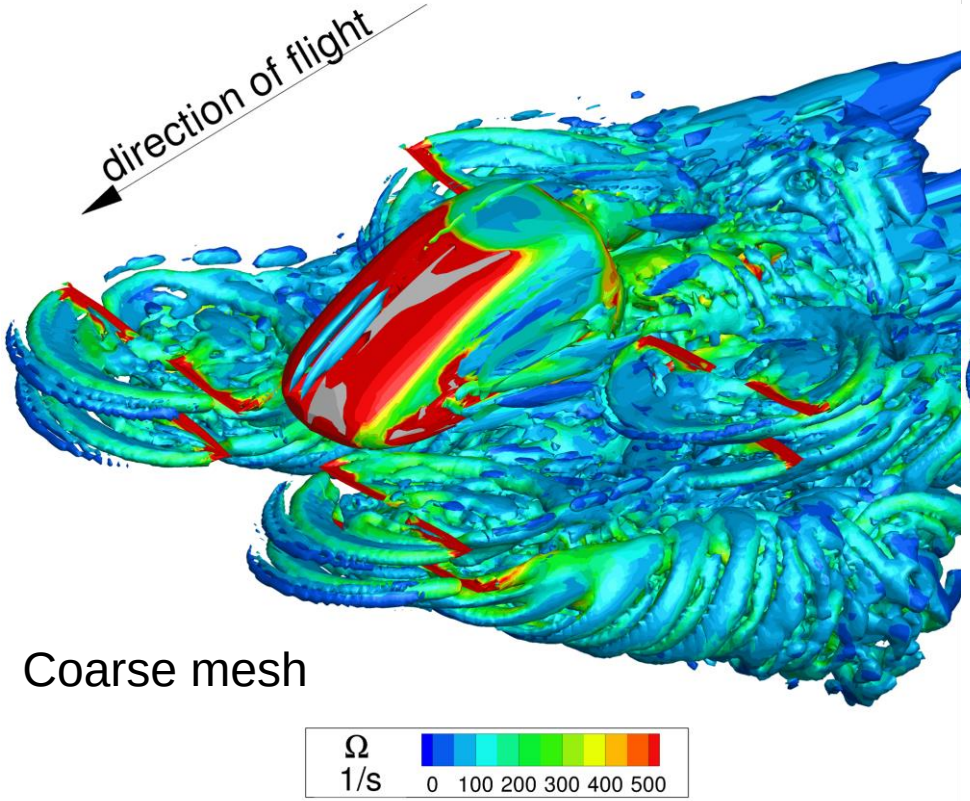




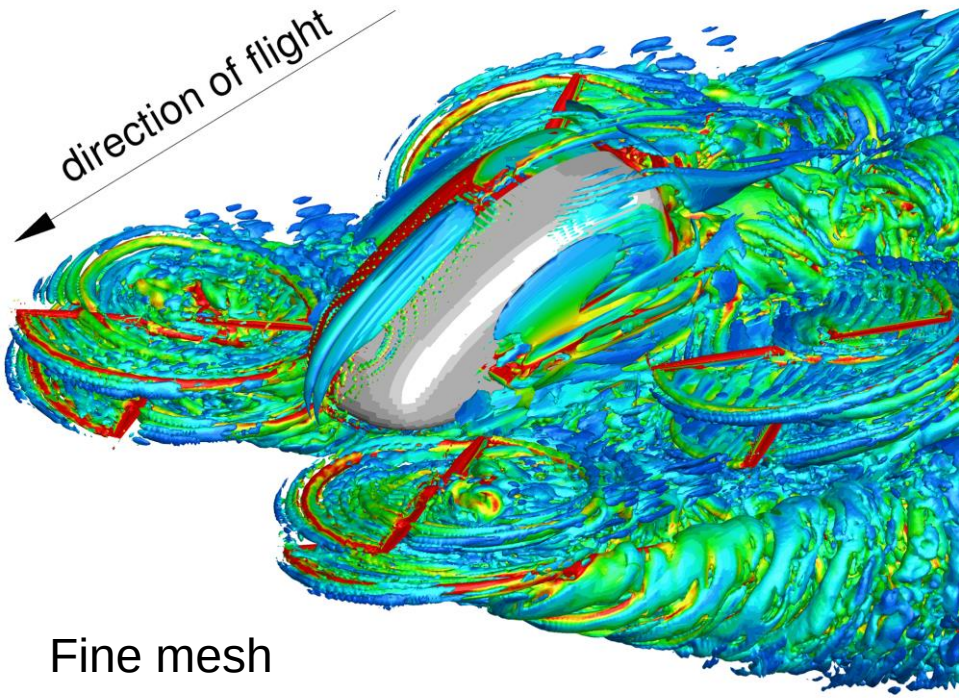


- Coaxial rotor is a compact efficient solution
- Two (isolated) rotors would be the most efficient configuration
- A single rotor can still lift the vehicle (emergency) !

Coax-Quad in Forward flight (100 km/h)



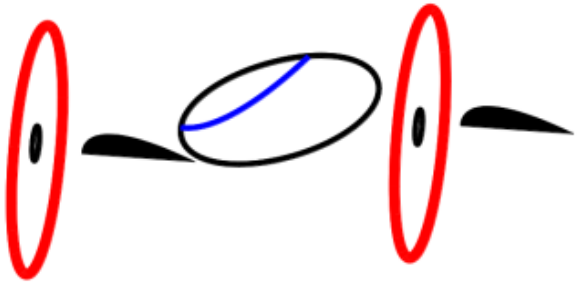
Coarse mesh



Fine mesh

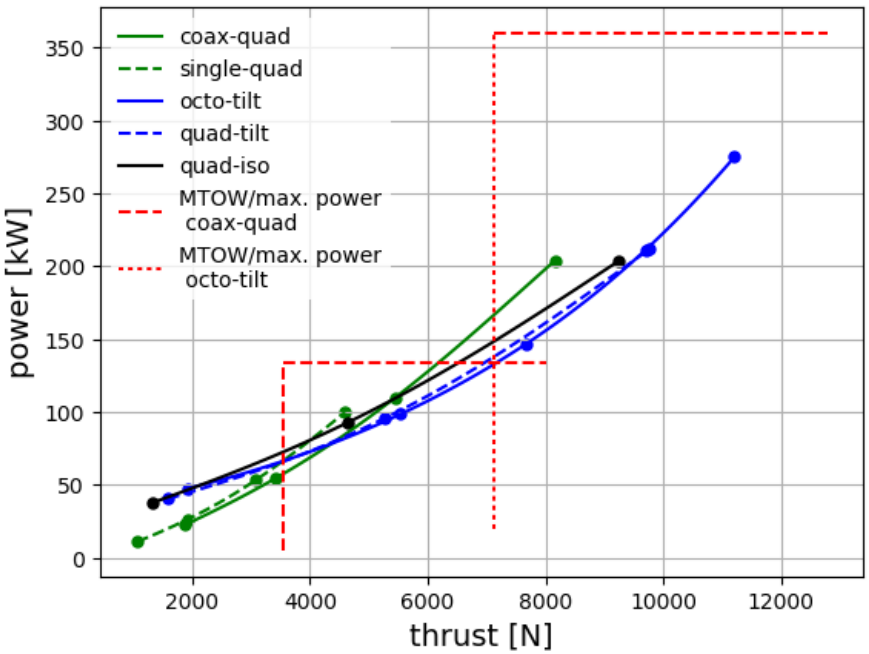
	Pitch	RPM	Req. power	Pitching moment
Coarse	-8.7°	2030	35.8 kW	+9.4 Nm
Fine	-9.0°	2150	41.1 kW	+9.3 Nm

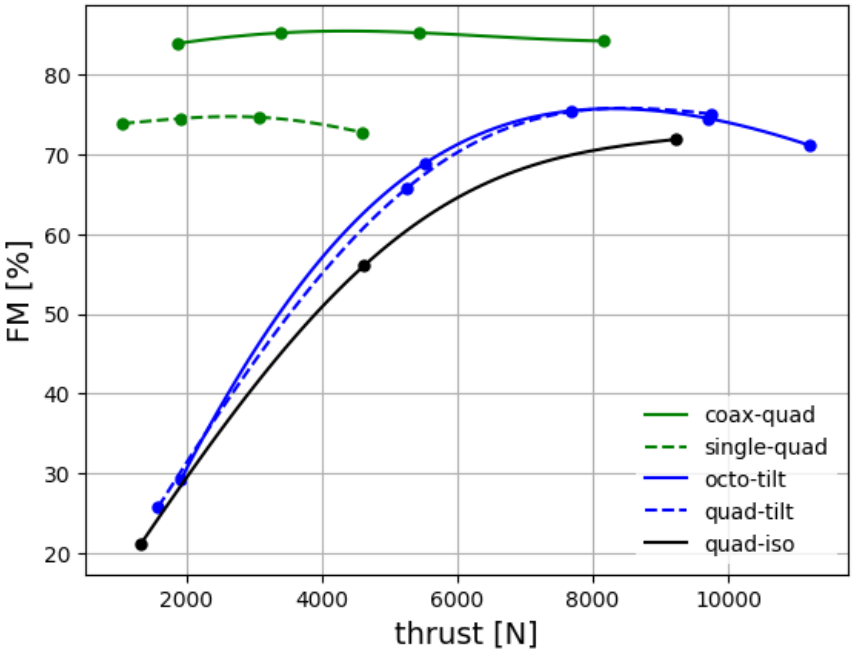
DLR



Octo-Tilt Results

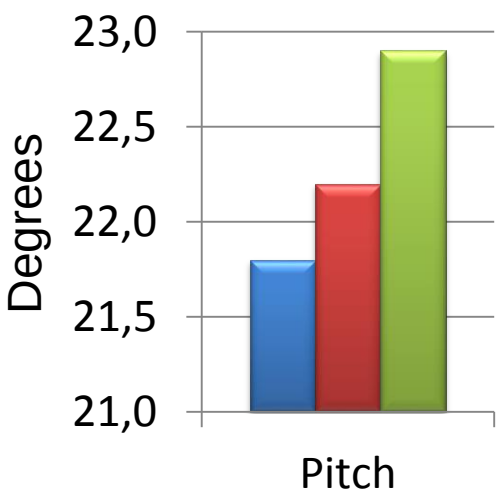
Octo-Tilt-Wing in hover – 4 vs 8 Propellers

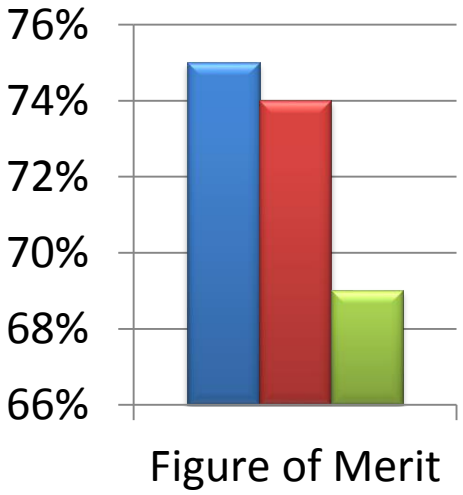


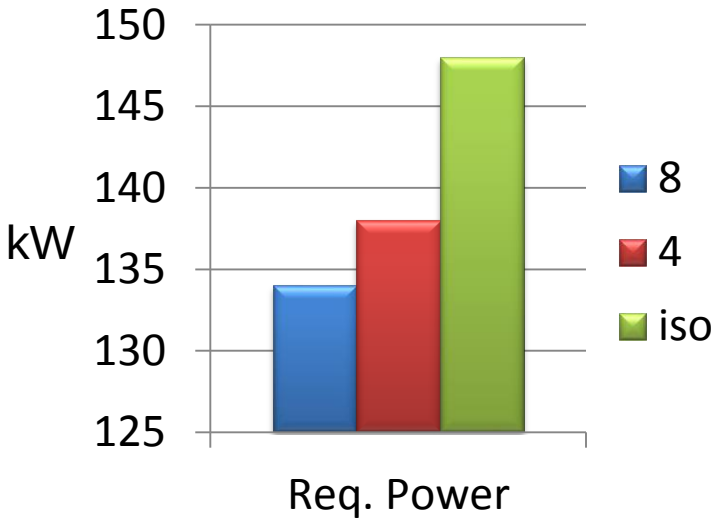


- Pitch control has a varying Figure of Merit over thrust
- RPM control has almost constant Figure of Merit (Re & Mach effects)

Octo-Tilt-Wing in hover – 4 vs 8 Propellers

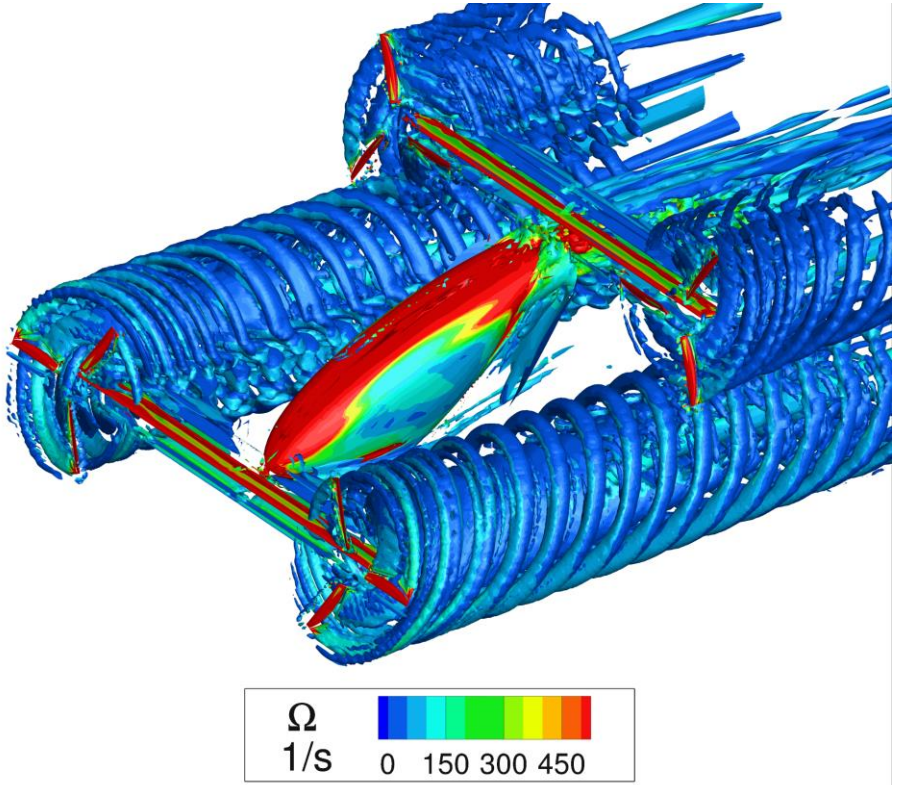




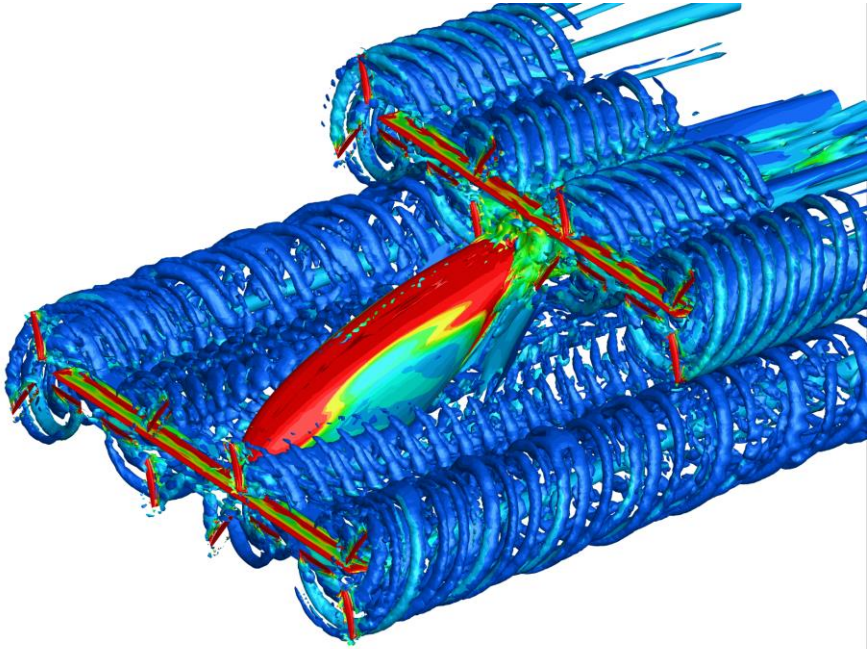


- A mild preference for multiple rotors observed
- The wing acts as a stator, thus higher efficiency with wing
- Despite an additional blade and different planform, similar performance to single quad rotor

Octo-Tilt-Wing in forward flight (175 km/h)



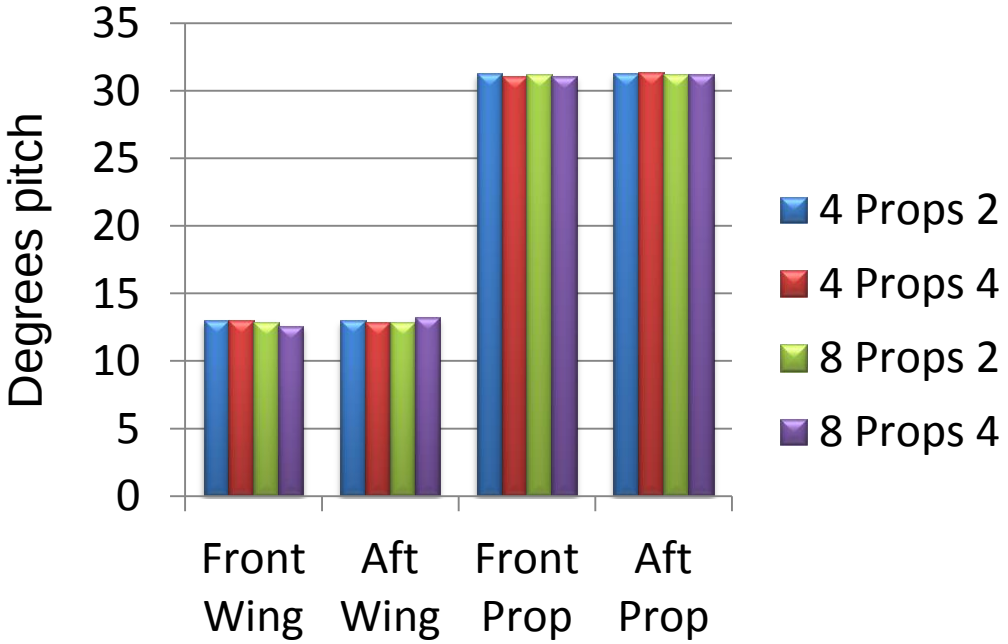
Quad-tilt

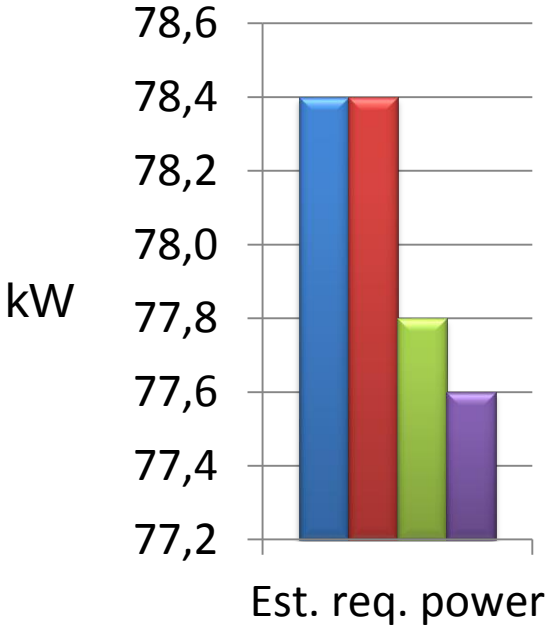


Octo-tilt

Investigated a two and four component trim for the lateral motion

Octo-Tilt-Wing in forward flight (175 km/h)

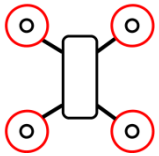


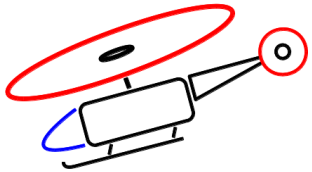


- Many trim scenarios imaginable!
- Slight octo-tilt configuration slightly favored
- Some uncertainty remains (up to 0.6 kW)

Comparison and Summary

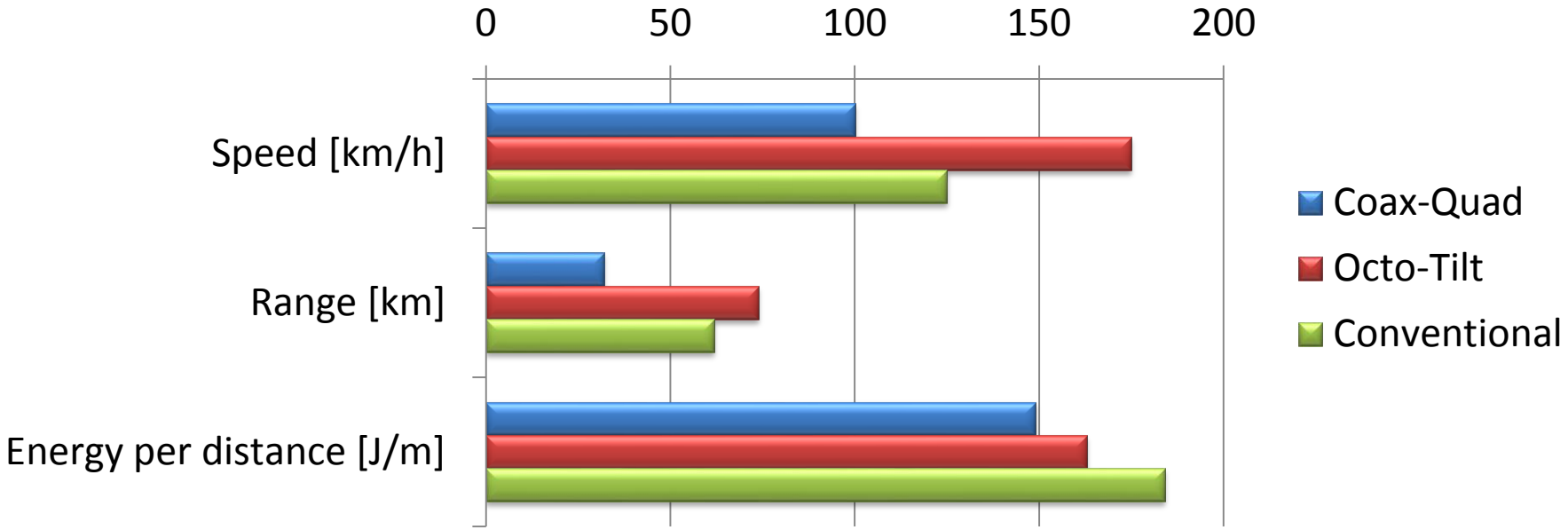
Comparing Configurations





Electrified helicopter with 7AD rotor

Mass :	360 kg	725 kg	575 kg
Diagonal:	5.6 m	8.5 m	7.3 m



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

Summary

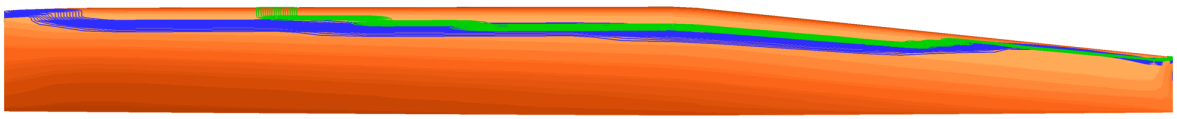
- CFD investigation with resolved propellers of a coaxial-quadrocopter and a octo-tilt-wing configuration
- Coaxial rotors are more efficient on same projected disc area
- Hover efficiency can be increased with a wing (stator effect)
- Tilt configuration is more efficient with eight instead of four propellers
- 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
Coarse

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