Implementation of the blade element theory to investigate the aerodynamic performance of a ducted fan UAV

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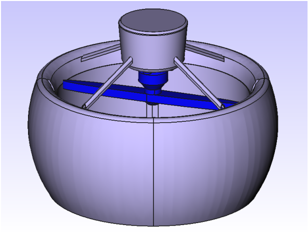
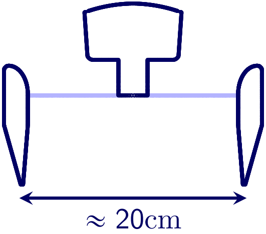
1st **Workshop of**
Belgian OpenFOAM users

Motivation

FLEYE: micro UAV intended for safe aerial photography





- Study aerodynamics
- Increase generated thrust
- Optimize geometry

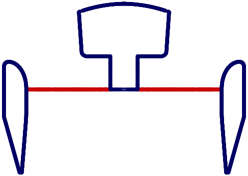
Use of CFD to test quickly different geometries

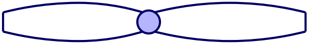
How to model the propeller ?

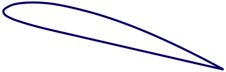
Should be easy and fast

$\Downarrow$

Fan is modelized using Δp







Δp should be linked to blades characteristics

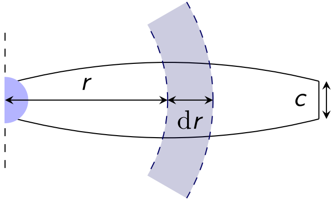
$\Rightarrow$ geometry: c, β, N

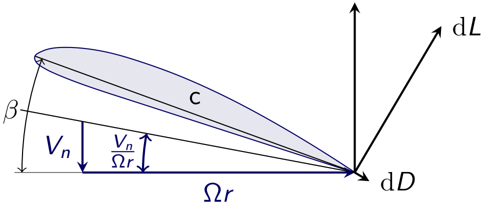
$\Rightarrow$ aerodynamics: a, α_{L_0}

$\Rightarrow$ **Use Blade Element Theory**

What is BET?

$$\mathrm{d}A = 2\pi r \mathrm{d}r$$





$$c_l = a\left(\beta - \frac{V_n}{\Omega r} - \alpha_{L_0}\right)$$

$$\begin{aligned} \mathrm{d}T &\approx \frac{1}{2} c_l \rho N \left(\Omega r\right)^2 \mathrm{d}S \\ \Delta p\left(r\right) &= \frac{\mathrm{d}T}{\mathrm{d}A} = \frac{\rho N a c}{4\pi}\left(\left[\beta - \alpha_{L_0}\right]\Omega^2 r - V_n \Omega\right) \end{aligned}$$

BET in OF framework

$$\Delta p\left(r\right) = \frac{\rho N a c}{4\pi}\left(\left[\beta - \alpha_{L_0}\right]\Omega^2 r - V_n \Omega\right)$$

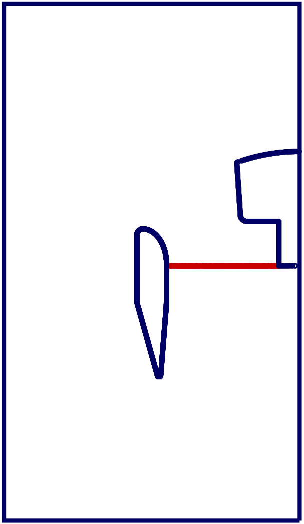
New boundary condition based on `fan`

⇒ Blade characteristics are input given as $\sum a_i r^i$

⇒ Normal velocity V_n is computed by the solver

⇒ $\Delta p = 0$ if negative or in recirculation

Modelization of the UAV



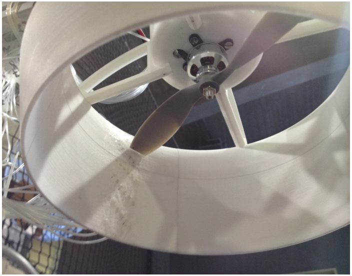
CFD model

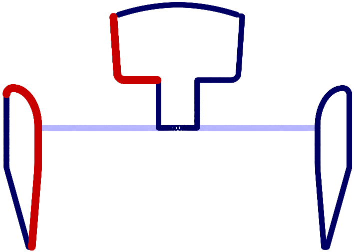
- Use of axisymmetry
- Steady solver `simpleFoam`
- Turbulence model $k-\omega$ SST

Model for propeller

- c, a and α_{L_0} constant along r
- $\beta\left(r\right)$ determined from pitch
- Different RPM are tested

Experimental setup



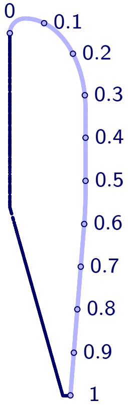


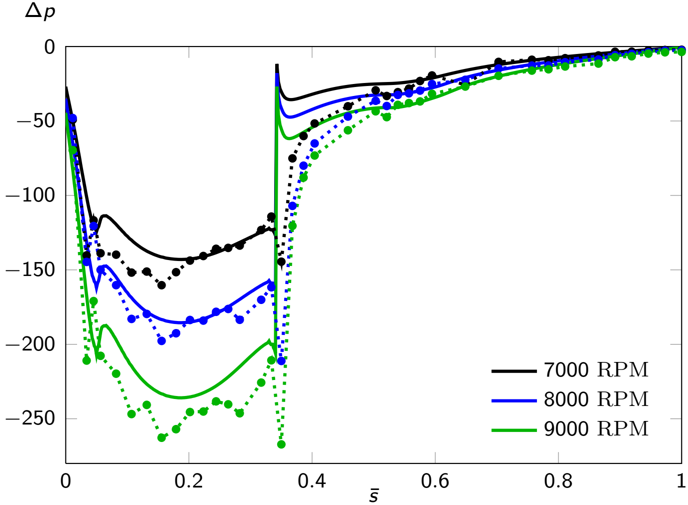
Validation of CFD

- Total forces
- Pressure along duct
- Pressure along hub

Comparison CFD-experiments

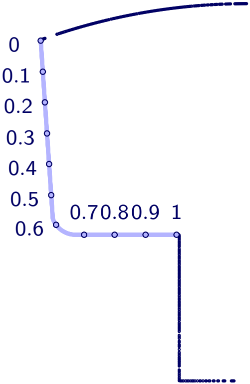
Relative pressure along the duct

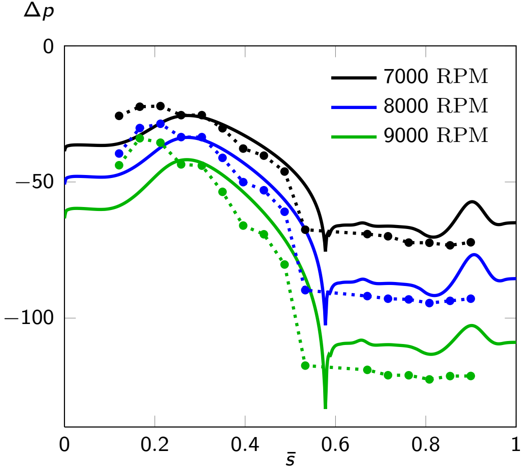




Comparison CFD-experiments

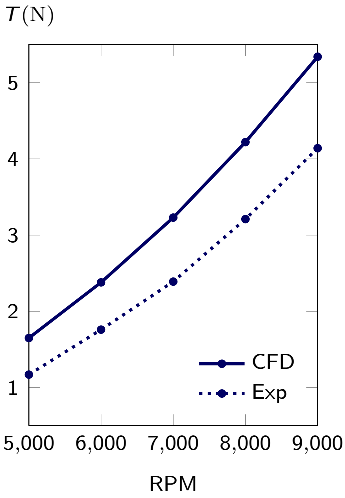
Relative pressure along the hub





Comparison CFD-experiments

Total thrust



Conclusions of validation

Pressure along the duct and hub

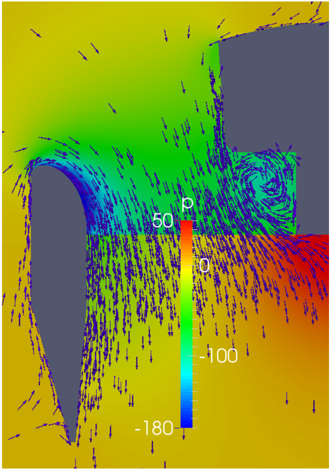
- Well approximated $< 15\%$
- Variation with RPM
- Discrepancies at tip clearance
- Differences near the motor

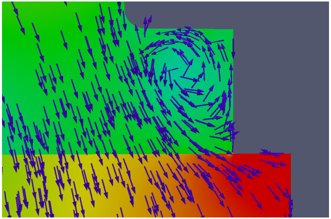
Total forces

- Variation with RPM
- Higher error $< 30\%$
- Should come from propeller

Comparison CFD-experiments

Model validity





$$\Delta p\left(r\right) = \frac{\rho Nac}{4\pi}\left(\left[\beta - \alpha_{L_0}\right]\Omega^2 r - V_n\Omega\right)$$

Zone near root of the propeller

- Low V_n due to incidence
- High Δp due to recirculation

$\Rightarrow$ **BET fails in this zone**

Conclusions

BET leads to discrepancies

- In recirculation zone
- With absolute thurst

However BET is able to

- Provide a good estimation of pressure
- Determine evolution of relative thrust with RPM

This implementation of BET enables

- **Fast simulations with physical parameters**
- **Optimization of the UAV geometry**