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

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Motivation

FLEYE: micro UAV intended for safe aerial photography

- Study aerodynamics
- Increase generated thrust
- Optimize geometry

Use of CFD to test quickly different geometries

\[ \approx 20 \text{cm} \]
How to model the propeller?

Should be easy and fast

\[ \Delta p \]

Fan is modelized using \( \Delta p \)

\( \Delta p \) should be linked to blades characteristics:

- geometry: \( c, \beta, N \)
- aerodynamics: \( a, \alpha_{L0} \)

\( \Rightarrow \) Use Blade Element Theory
What is BET?

\[ dA = 2\pi r dr \]

\[ dT \approx N dL \]

\[ c_l = a \left( \beta - \frac{V_n}{\Omega r} - \alpha L_0 \right) \]

\[
\begin{align*}
\frac{dT}{dA} & \approx \frac{1}{2} c_l \rho N (\Omega r)^2 dS \\
\Delta p(r) &= \frac{dT}{dA} = \frac{\rho N ac}{4\pi} \left( [\beta - \alpha L_0] \Omega^2 r - V_n \Omega \right)
\end{align*}
\]
BET in OF framework

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

**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 $\alpha_{L0}$ constant along $r$
- $\beta (r)$ 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

![Graph showing relative pressure along the hub for different RPMs: 7000 RPM, 8000 RPM, and 9000 RPM. The graph plots Δp against ξ (dimensionless axial location). The data points and lines indicate the pressure distribution at various RPM values.]
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

\[ \Delta p(r) = \frac{\rho NaC}{4\pi} \left( [\beta - \alpha_{L0}] \Omega^2 r - V_n \Omega \right) \]

Zone near root of the propeller
- Low \( V_n \) due to incidence
- High \( \Delta p \) due to recirculation
\[ \Rightarrow \text{BET fails in this zone} \]
Conclusions

**BET leads to discrepancies**
- In recirculation zone
- With absolute thrust

**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