Aerodynamic design of a high solidity canted Vertical Axis Wind Turbine with OpenFOAM

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1/ Project Introduction
OpenFOAM interest for VAWT design

**D4Wind Project:**
- Walloon Region funds
- 1 SME, 1 university & 1 research center
- Task 1: Aerodynamics rotor design

**Vertical Axis Wind Turbines:**
- High & varying AOAs
- Highly unsteady flow, more complex than HAWT
- Difficulty to find accurate polar (dynamic stall)

**Strong interest in unsteady CFD:**
- Airfoils → static & dynamic polars
- Full rotor structure → arms, attachment... effects on performance & acoustic

Implicit Large Eddy Simulation
Cenaero in-house tool:
Argo DGM

Dynamic polars: CL for various TSR [3]
1/ Project Introduction
Presentation of the 2D validation case

Project steps:
- Validate CFD approach using OpenFOAM tools on 2D cases
- Compare 2D to 3D (straight blades)
- Study the canted effect
- Use developed methodology for D4Wind

Set-up:
- Meshing Gambit/ANSYS
- Transient, incompressible, unsteady flows with dynamic mesh: pimpleDyMFoam
- 2D URANS with turbulence models: \( k-\epsilon \) & \( k-\omega \) SST
- \( \Delta t \) as Courant number \( \leq 0.9 \)
- Naca0015, 0.420m chord, 2.8 rotor diameter, 0.1m axis diameter, no pitch

Experimental set-up for the straight (left VAWT) and canted (right) VAWT [1] (naca0015, chord 0.420m, rotor diameter 2.8m, height 2.9m)
Mesh specification:
- Unstructured triangular mesh
- Specification:
  - Domain: 14φ*21φ (φ=2.8m)
  - Rotating disk: 4φ
  - 2D mesh extruded
- Blades first cell as y+ ≤200
- Max aspect ratio 1.2

Operating conditions:
- Inlet velocity: U=10m/s
- Turbulence intensity 10%
- AMI rotation 30:140 RPM (Re 4:8e5)
2/ Modelling Approach

Mesh dependence study

- 50k nodes mesh chosen (vs. 150k in reference [2])
- Further analysis: 220k nodes

Simulations & ref. data [2] at TSR 1.32, U=10m/s, k-ω SST (k=1.5, ω=5.6), third revolution of blade n°2

<table>
<thead>
<tr>
<th>Nodes</th>
<th>Run time (3*360°)</th>
<th>Cp (exp:0.23)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20k</td>
<td>40 CPUh</td>
<td>0.09</td>
</tr>
<tr>
<td>50k</td>
<td>420 CPUh</td>
<td>0.20</td>
</tr>
<tr>
<td>110k</td>
<td>1200 CPUh</td>
<td>0.20</td>
</tr>
</tbody>
</table>
2/ Modelling Approach

Turbulence sensitivity study

Simulations at TSR 1.2, U=10m/s, 50knodes mesh, third revolution of blade n°2

- \( k \)- \( \omega \) SST chosen for the present study (as in reference [2])
- Turbulence level doesn’t alter much the results
3/ Result & Discussion

Vorticity TSR 1.32

TSR 1.32, \( U=10\, \text{m/s}, \, k-\omega \, \text{SST} \,(k=1.5, \, \omega=5.6) \) 50k nodes mesh
3/ Result & Discussion

Vorticity TSR 0.4

TSR 0.4, U=10m/s, k- ω SST (k=1.5, ω=5.6) 50k nodes mesh
4/ Results & Discussion

Thrust force coefficient variation with \( \theta \) for 4 TSR

Simulations at \( U=10\text{m/s}, \ k-\omega \text{ SST (}k=1.5, \ \omega=5.6\text{)}, \ \text{third revolution of blade n°2, 50k nodes mesh} \)
4/ Results & Discussion

Cp curve compared to reference numerical & experimental results

- 2D analysis shows good agreement with the reference
- Further analysis required in [1.5:2] TSR region
Conclusions:
• 2D comparison to benchmark shows very encouraging results
• Mesh 50k converges in reasonable time
• $k-\omega$ SST well adapted for VAWT highly separated flow

Perspectives:
• Mesh dependency & numerical schemes need to be further analysed
• Methodology to reduce computational time for 3D cases:
  • Change mesh: tetrahedral to hexahedral
  • Improve parallelisation approach
  • Steps with different numerical schemes
  • ...?
Thank you for your attention!

References:

Questions?

Comments?