CFD Simulation of a 3-Bladed Horizontal Axis Tidal Stream Turbine using RANS and LES


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Overview

1. Introduction
2. Methodology
3. RANS Results
4. RANS and LES comparison
5. Conclusions & Further work
Introduction

ReDAPT (Reliable Data Acquisition Platform for Tidal):

- Project designed to accelerate the tidal energy industry.
- Aim to inspire market confidence in tidal stream turbines (TST).
- Deployment of a full scale 1MW turbine at EMEC in the Orkneys.

This work:

- Using *Code_Saturne* to accurately predict loading on tidal turbines.
- Assess the influence of turbulence and waves on TSTs.
- Current results compare Reynolds Averaged Navier Stokes (RANS) model and Large Eddy Simulation (LES) against those for a laboratory scale turbine.
Introduction
Case overview

- 0.4 m radius, $R$, turbine pulled through a towing tank.
- Parametric study of force coefficients against tip-speed-ratio (TSR).

Photo reproduced from Bahaj et al. (2005).
EDF’s open-source CFD code, \textit{Code\_Saturne} (Archambeau et al., 2004), is used to simulate turbulent flow past a TST.

A sliding mesh method is developed in \textit{Code\_Saturne} to allow for the TST rotation.

Second order in space (central differencing).

First-order in time with $\Delta t \approx 1.5^\circ$ of rotation per time-step.

The $k - \omega$ SST RANS turbulence model is used to simulate the flow.

Results are also compared against an LES that is also been performed as part of this project.
Methodology

Sliding-mesh method

- Start in cell centre, $I$, with face-centre, $F$.
- $I$ is projected through $F$ to give a halo point, $H$.
- Search for, $J$, the nearest cell-centre to the halo-point.
- The face-centre value is given a Dirichlet condition with the value:

\[
\phi_F = \frac{1}{2}(\phi_I + \phi_H),
\]

Where:

\[
\phi_H = \phi_J + \left. \frac{\partial \phi}{\partial x} \right|_J (JH).
\]
Methodology

Meshing strategy

- Geometry built in two parts, inner turbine and outer domain.
- Block-structured approach with hanging nodes to control cell-count.
- \( \approx 2 \text{ million cells with } 15 < y^+ < 200 \) at the walls.
- LES mesh is wall refined with \( \approx 7.7 \text{ million cells.} \)
RANS Results
Flow-field

- Pressure iso-surfaces coloured by velocity are shown for the instantaneous flow-field for TSR = 6.
- Tip effects are clearly visible in the near wake whilst the mast creates main structures further down-stream.
Instantaneous velocity on centre-plane shows tip-effects and influence of mast on flow.
RANS Results

Force coefficients

- Effect of blades passing the mast is clear from instantaneous force coefficients.
- Power Spectral Density (PSD) analysis of the $C_P$ shows peaks at 3 and 6 times the blade rotation frequency ($f$).
RANS Results

Force coefficients

- $k - \omega$ SST predicts force curve against TSR although under predicted by approximately 10%.
- LES shows gain in precision matching experiments within 3% except for the lower values of TSR.
RANS and LES comparison

Flow structures

- Iso-Q $0.5 (\Omega_{ij} \Omega_{ij} - S_{ij} S_{ij})$ surfaces coloured by vorticity are shown for RANS and LES.
- LES maintains the tip vortices and captures structures in the wake better than RANS.
RANS and LES comparison
Pressure coefficients on the blades

- Mean pressure coefficients are shown on the blades at quarter length locations.
- Both RANS and LES predict similar behaviour although LES captures larger forces on pressure and suction surfaces.

\( k - \omega \) SST

LES
Conclusions & Further work

Conclusions:

- Sliding-mesh method successfully implemented in *Code_Saturne* to simulate a rotating TST.
- Flow features are captured well by RANS and LES.
- RANS under predicts the force coefficients whilst LES is far more accurate.
- Difference in calculations is near wall modelling and higher order time-scheme used by *Code_Saturne* for LES.

Further work:

- Wall refined RANS simulation to compare with experiments.
- Assess influence of waves on full scale MCT comparing with data from EMEC.
Acknowledgements

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**Sliding-mesh method**

**Implementation:** *Code_Saturne* Subroutines

- **Black** - Unchanged.
- **Red** - Modified.
- **Blue** - New.

- `findha` - Search for closest cell-centre to halo-point.
- `upcoef` - Updates Dirichlet values on interface.
Sliding-mesh method
Implementation: Pressure-Velocity Loop

- *Code_Saturne’s* existing pressure-velocity loop is enabled by setting NTERUP > 1.
- Loop used to ensure continuity over the interface.
- Modification to include the RANS subroutines.

```
tridim
  ↓
phyvar
  ↓
usclim
  ↓
navsto
  ↓
turb**
  ↓
phyvar
  → P-V Loop
```

References
# RANS and LES comparison

Comparison of numerical set-up

<table>
<thead>
<tr>
<th></th>
<th>RANS ($k-\omega$ SST)</th>
<th>LES</th>
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<tbody>
<tr>
<td><strong>Time-scheme</strong></td>
<td>1st order</td>
<td>2nd order</td>
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<tr>
<td><strong>Rotation per time-step</strong></td>
<td>1.5°</td>
<td>0.05°</td>
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<tr>
<td><strong>Space discretization</strong></td>
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<td><strong>Wall modelling</strong></td>
<td>Wall-functions</td>
<td>Wall refined</td>
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<tr>
<td><strong>Mesh size</strong></td>
<td>2.2 million</td>
<td>7.6 million</td>
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</tbody>
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