Numerical computations of a tip vortex including gap with RANS and LES turbulence models

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HYDRONET 2 PROJECT

Multidisciplinary consortium

- Simulation of sand erosion
- Tip vortex Cavitation
- Instability of pump-turbine
- HydroPower design
- Plant monitoring

To improve the Design, Manufacturing and Operation of HydroPower Plants
**TIP VORTEX CAVITATION (TVC)**

**Problematic:**

- Tip vortex cavitation → severe erosion in axial turbines
- Accuracy of numerical approaches?

  - Origin: vortex roll up in the gap at the tip of the blades
  - Remedy (anti-cavitation lip): inefficient
  - Influence of gap width?
  - Scale up rules? (actual model tests not reliable)
NUMERICAL INVESTIGATION OF NON-CAVITATING VORTEX

Goal: An evaluation of the accuracy of the RANS computations compared to LES computations

Tools:
• Ansys CFX 14.0 commercial solver
• OpenFoam 2.1.0 and 2.2.0 open source solver
• Yales 2 solver 0.4.2 CNRS solver *(used for LES)*

Modelling:
• RANS k-ω SST + Wall Law
• LES dynamic Smagorinsky models + Wall Law
TEST CASES
(Experiment performed at the LMH cavitation tunnel)

Configurations: NACA 0009
- Incidence angle: \( \alpha = 10^\circ \)
- Inlet velocity: \( U_{\text{inlet}} \approx 10 \text{ m/s} \)
- Gap width: 2 mm and 10 mm
- Chord length: 0.1 m

Mesh:
- RANS: structural mesh with 6 millions of nodes
- LES: unstructural mesh with 24 millions of nodes
TIP VORTEX VISUALISATION (LES INSTANTANEOUS FIELD)

Iso surface of the Q-criterion

\[ Q = \frac{1}{2} (||\Omega||^2 - ||S||^2) \]

With:

- \( \Omega \): Rotation rate tensor
- \( S \): Strain rate tensor
TIP VORTEX VISUALISATION
(Mean field - Gap = 10 mm)

Iso surface of the Q-criterion

RANS (CFX)

LES (Yales 2)

RANS (OpenFOAM)
TIP VORTEX: DOWNSTREAM POSITION
(Mean field - Gap = 10 mm)

Axial vorticity $\Omega_x$ in a crosswise plane at $x = 0.15$ m (1 chord from the trailing edge)

LES (Yales 2)  RANS (CFX)  RANS (OpenFOAM)
TIP VORTEX GENERATION: 
(RANS vs LES)

Axial vorticity $\Omega_x$ in a plan y-z along the blade

RANS (OpenFOAM)  
LES (Yales 2)

Gap = 10 mm
TIP VORTEX TRAJECTORY:
(Gap 10 mm)

Vortex core position downstream the blade
TIP VORTEX TRAJECTORY:
(Gap 10 mm)

Vortex core position downstream the blade
TIP VORTEX VISUALISATION: 
(INFLUENCE OF THE GAP WIDTH)

Iso surface of the Q-criterion

Gap = 10 mm

Gap = 2 mm

RANS (OpenFOAM)
TIP VORTEX GENERATION:
(INFLUENCE OF THE GAP WIDTH)

Axial vorticity $\Omega_x$ in a plan y-z along the blade

Gap = 10 mm  
Gap = 2 mm

RANS (OpenFOAM)
TIP VORTEX TRAJECTORY: (INFLUENCE OF THE GAP WIDTH)

Vortex core position downstream the blade

RANS (OpenFOAM)
TIP VORTEX TRAJECTORY:
(INFLUENCE OF THE GAP WIDTH)

Vortex core position downstream the blade

RANS (OpenFOAM)
OUTLOOK

- TO COMPARE COMPUTATIONS WITH EXPERIMENTS
- TO PERFORM CAVITATING TIP VORTEX

Void fraction visualisation
THANK YOU FOR YOUR ATTENTION

OpenFOAM

Yales 2

Experiment

Vertical velocity component $V$ (m/s) in a crosswise plan at $\frac{1}{2}$ chord downstream the trailing edge
Trajectoire du tourbillon dans le plan x-y

vorticité axiale

x (m)

y (m)

0.09 0.1 0.11 0.12 0.13 0.14 0.15 0.16

0 0.005 0.01 0.015 0.02 0.025 0.03 0.035

EXPE
OF Pimple 2M
OF Pimple 6M
OF Pimple 18-6M
CFX 6M
Yales WallLaw
Trajectoire du tourbillon dans le plan x-z

vorticité axiale

\[ x (m) \]

\[ z (m) \]

- **EXPE**
- OF Pimple 2M
- OF Pimple 6M
- OF Pimple 18-6M
- CFX 6M
- Yales WallLaw
Mesh 2.8
millions of nodes