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

J. Decaix & C. Münch-Alligné, HES SO Valais, Sion, Switzerland
G. Balarac, LEGI, Grenoble, France

HYDRONET 2 PROJECT

Multidisciplinary consortium

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

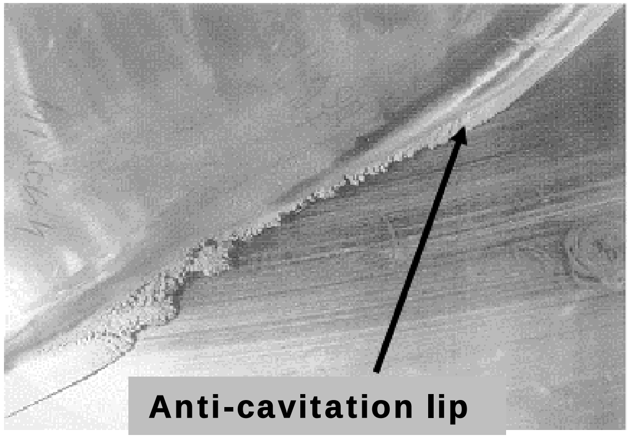
To improve the Design, Manufacturing and Operation of HydroPower Plants

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:

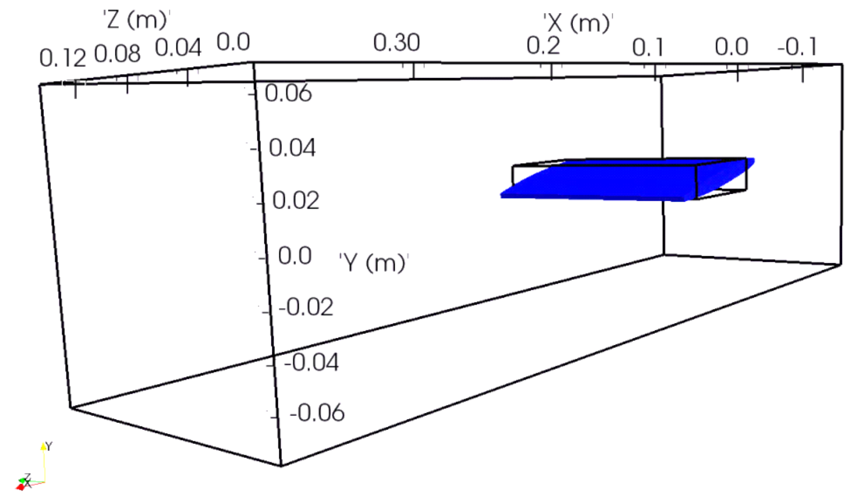
- RANS k-ω SST + Wall Law
- LES dynamic Smagorinsky models + Wall Law

TEST CASES

(Experiment performed at the LMH cavitation tunnel)

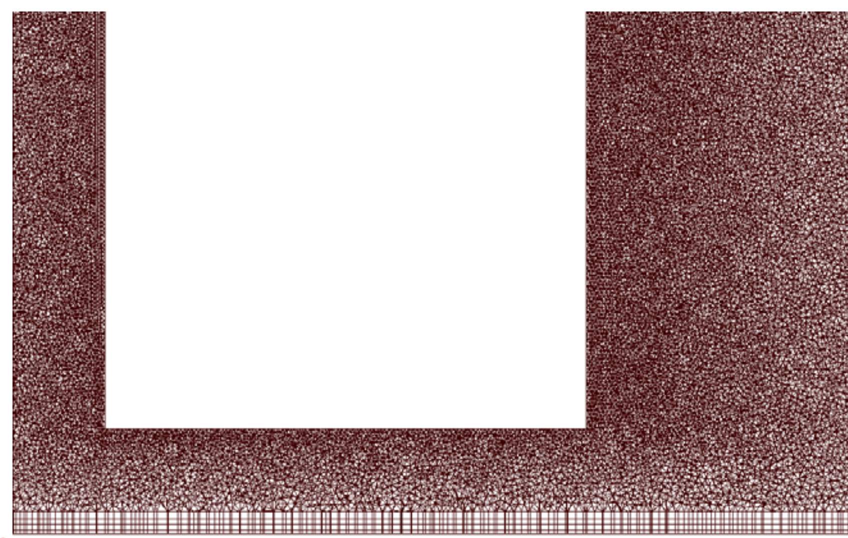
Configurations: NACA 0009

- Incidence angle: α = 10°
- Inlet velocity: $U_{inlet} \approx 10$ 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



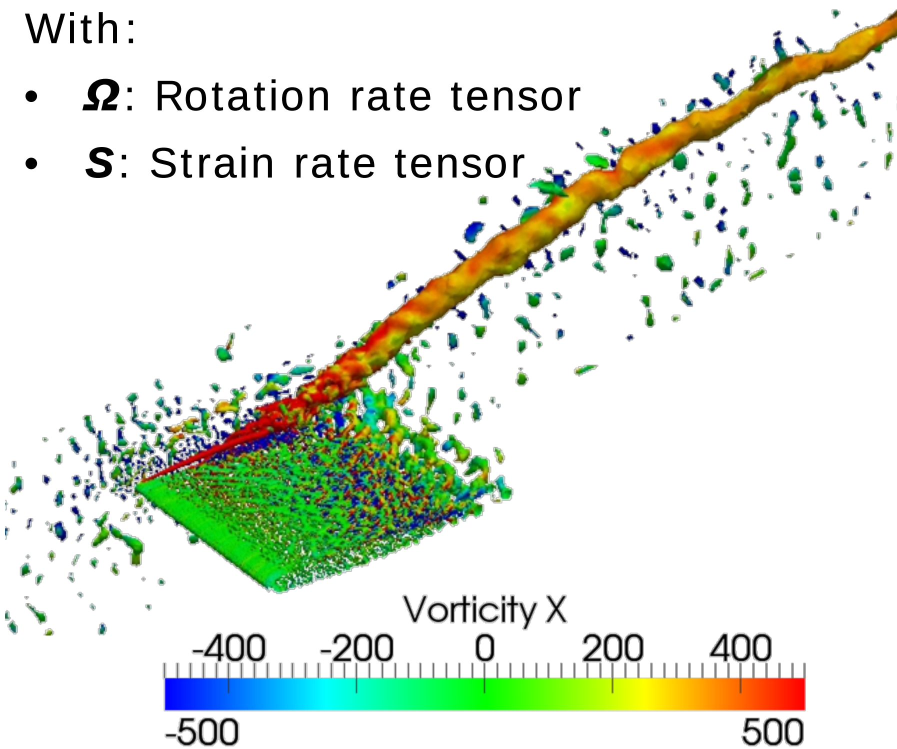
TIP VORTEX VISUALISATION
(LES INSTANTANEOUS FIELD)

Iso surface of the Q-criterion

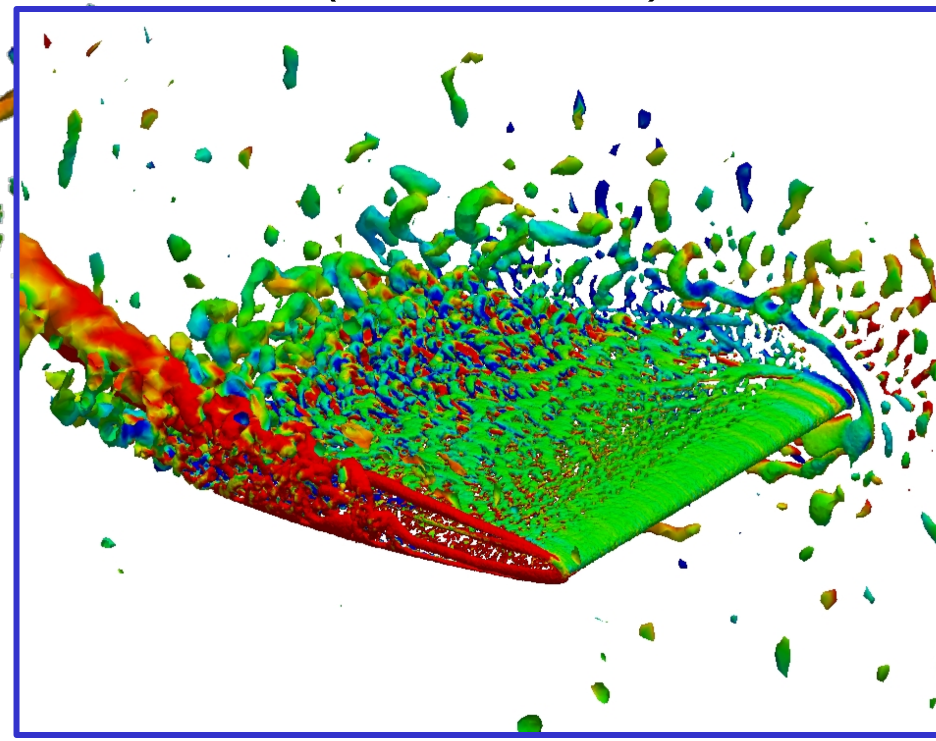
$$Q = 1/2\,(||\Omega||^2 - ||S||^2)$$

With:

- Ω: Rotation rate tensor
- S: Strain rate tensor



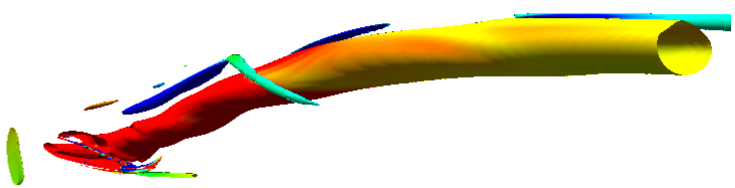
Zoom (reverse view)



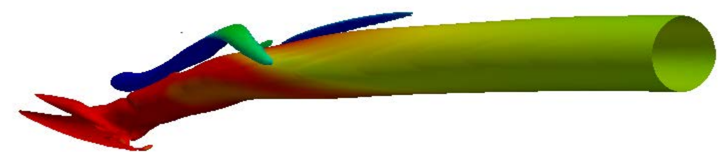
TIP VORTEX VISUALISATION

(Mean field - Gap = 10 mm)

Iso surface of the Q-criterion

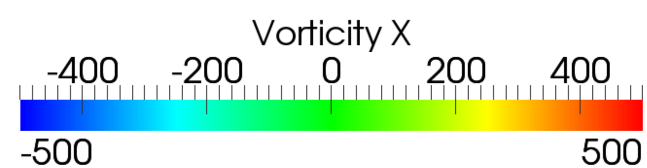


RANS (CFX)



RANS (OpenFOAM)

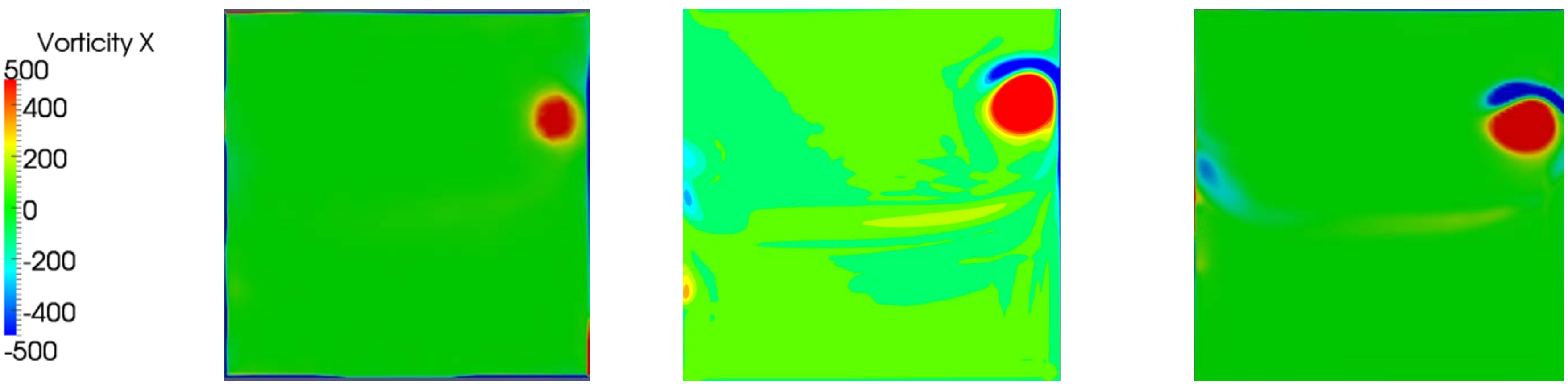
LES (Yales 2)



TIP VORTEX: DOWNSTREAM POSITION

(Mean field - Gap = 10 mm)

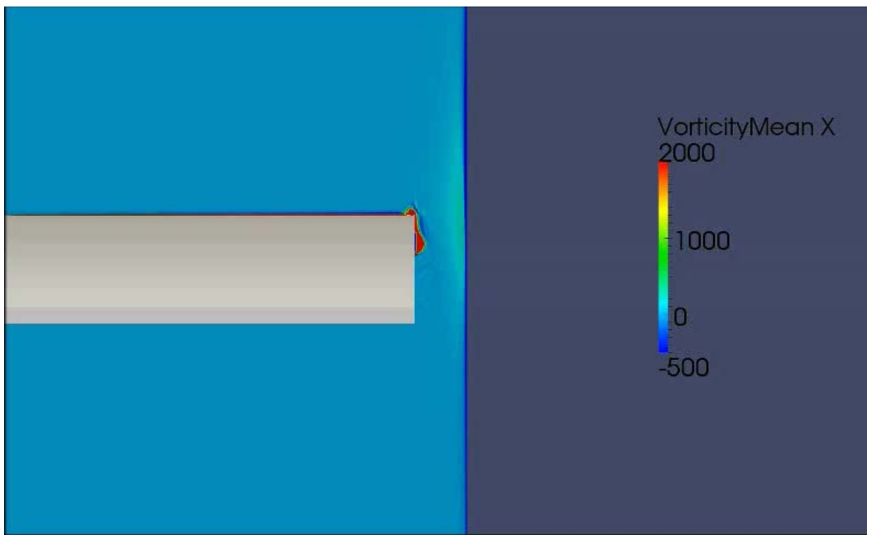
Axial vorticity Ω_x in a crosswise plane at x = 0.15 m (1 chord from the trailing edge)



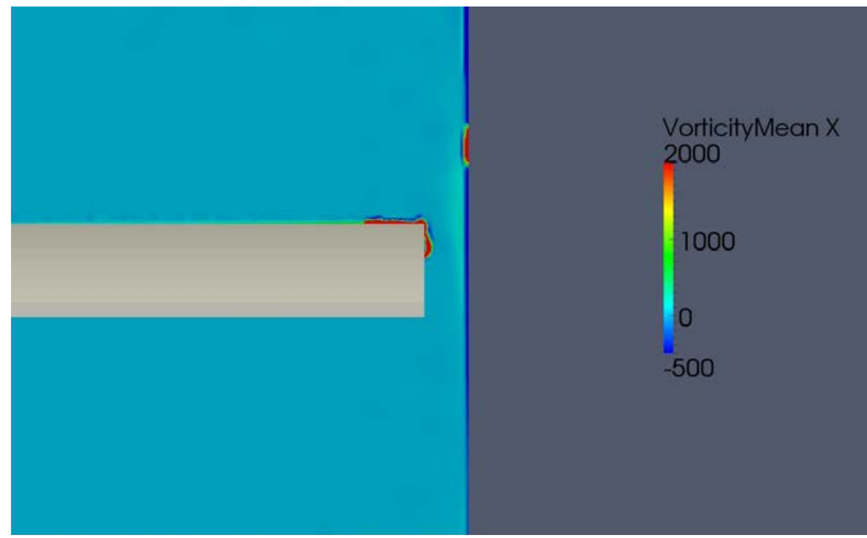
LES (Yales 2) **RANS (CFX)** **RANS (OpenFOAM)**

TIP VORTEX GENERATION:
(RANS vs LES)

Axial vorticity Ω_x in a plan y-z along the blade



RANS (OpenFOAM)

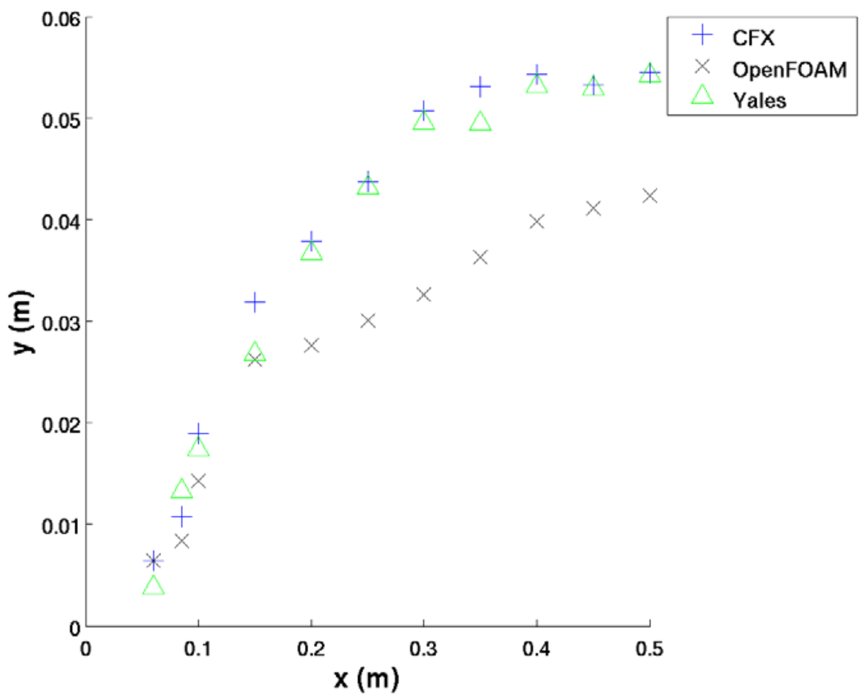


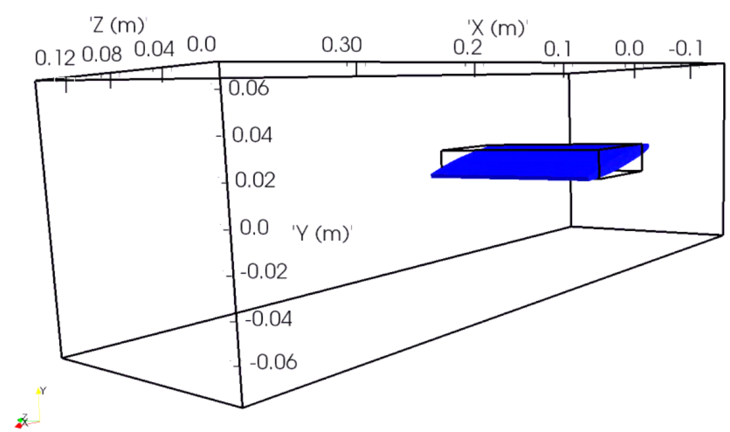
LES (Yales 2)

Gap = 10 mm

TIP VORTEX TRAJECTORY:
(Gap 10 mm)

Vortex core position downstream the blade





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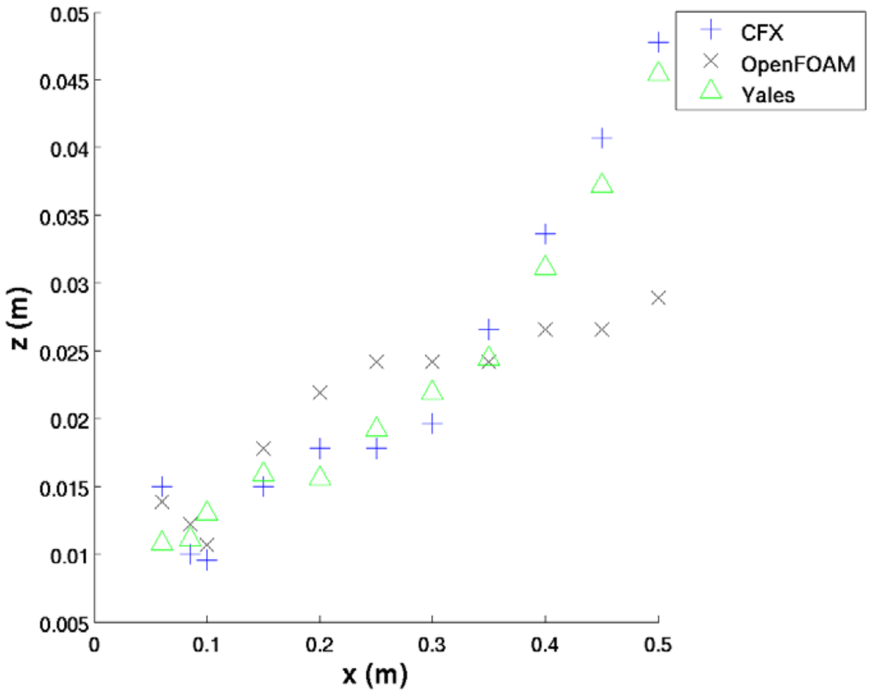
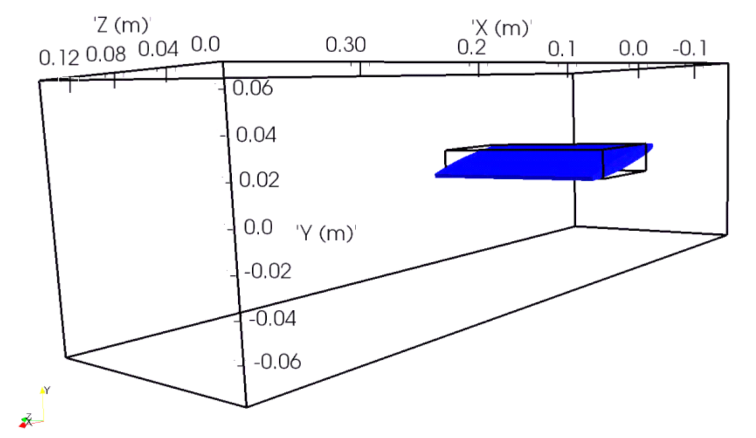
(Gap 10 mm)

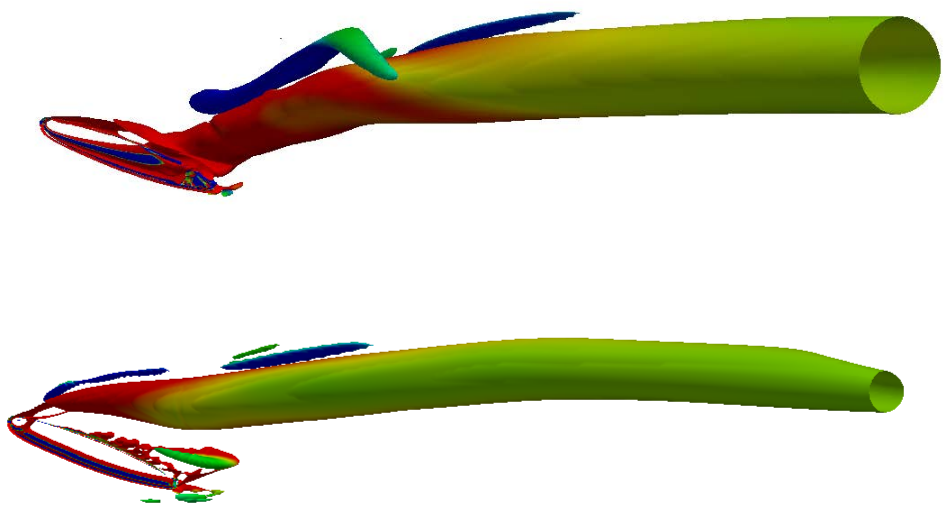
Vortex core position downstream the blade





TIP VORTEX VISUALISATION :
(INFLUENCE OF THE GAP WIDTH)

Iso surface of the Q-criterion



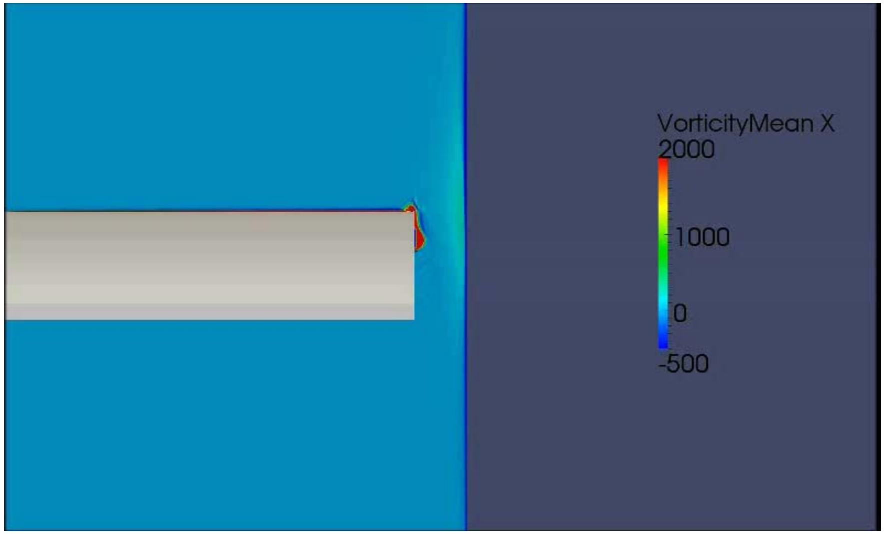
Gap = 10 mm

Gap = 2 mm

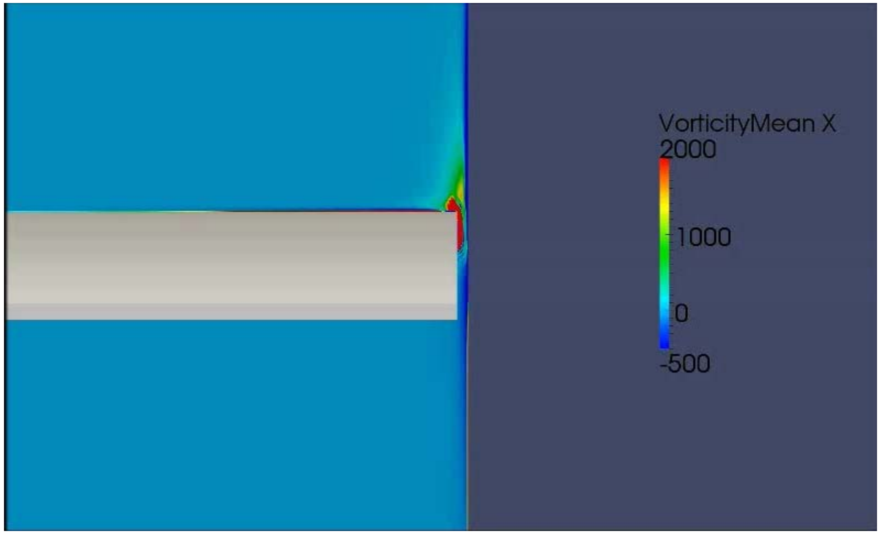
RANS (OpenFOAM)

TIP VORTEX GENERATION:
(INFLUENCE OF THE GAP WIDTH)

Axial vorticity Ω_x in a plan y-z along the blade



Gap = 10 mm

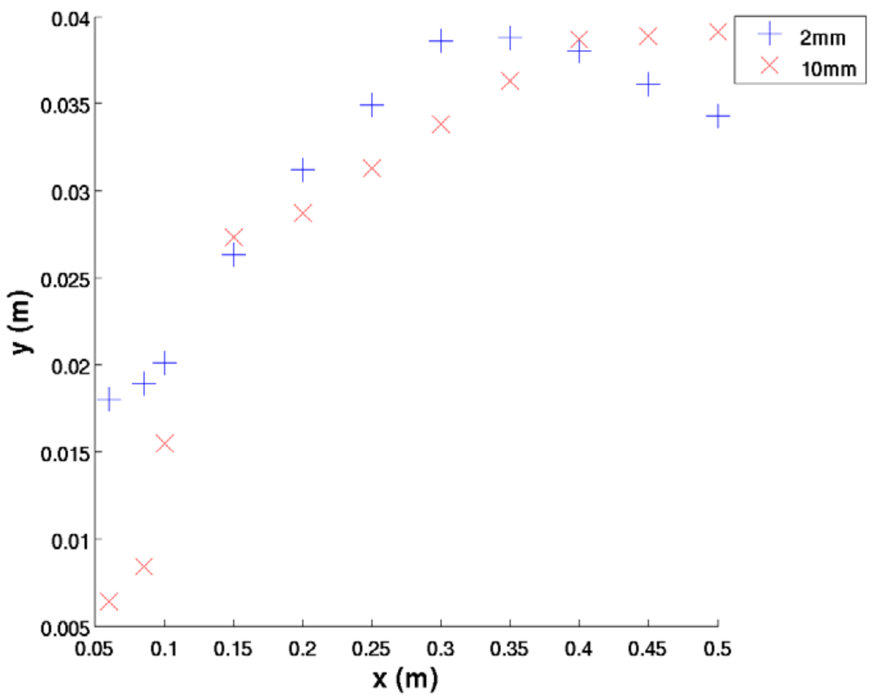


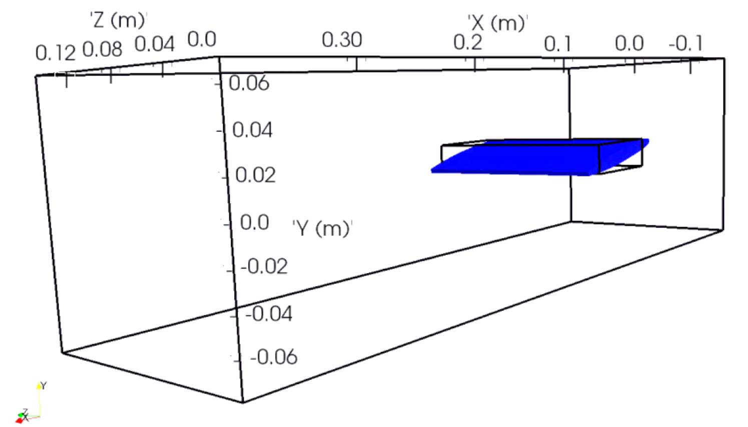
Gap = 2 mm

RANS (OpenFOAM)

TIP VORTEX TRAJECTORY:
(INFLUENCE OF THE GAP WIDTH)

Vortex core position downstream the blade





RANS (OpenFOAM)

TIP VORTEX TRAJECTORY:
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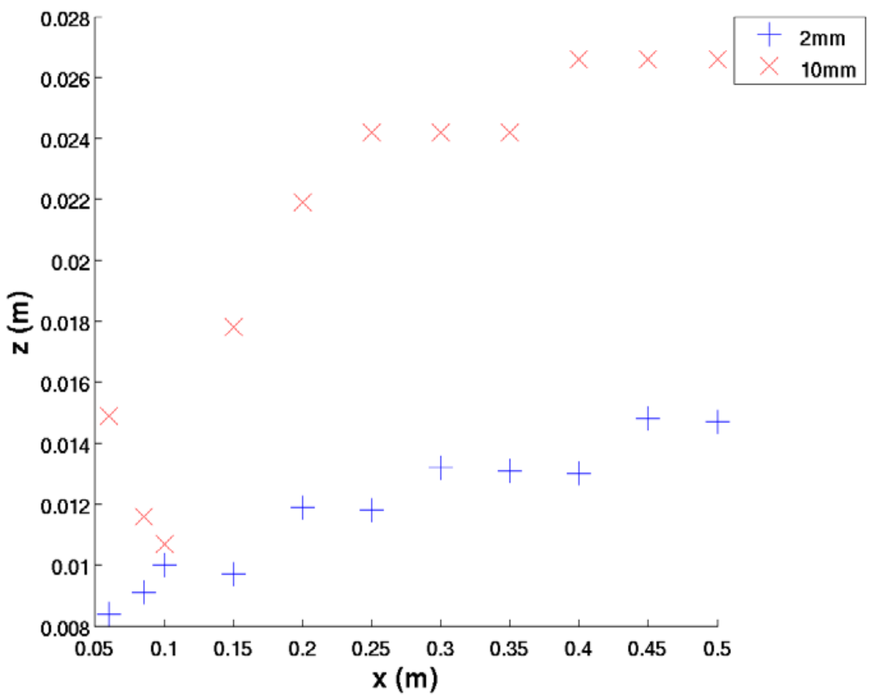
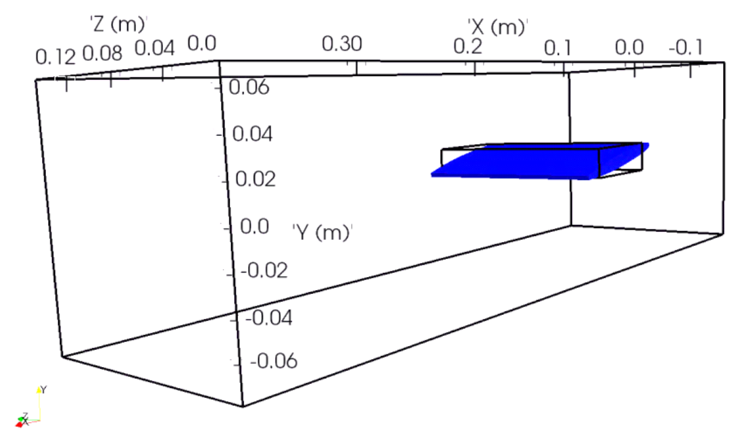
Vortex core position downstream the blade

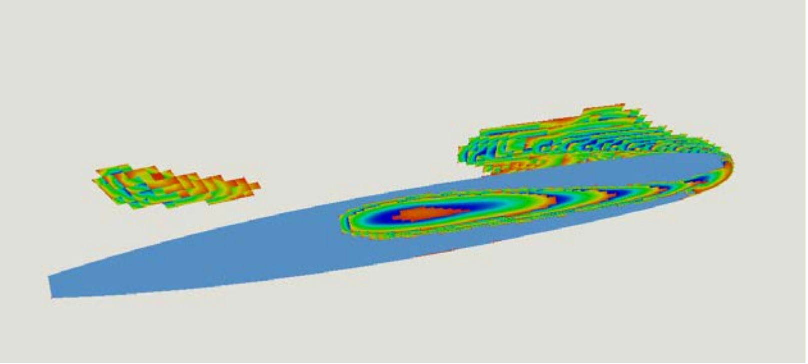




RANS (OpenFOAM)

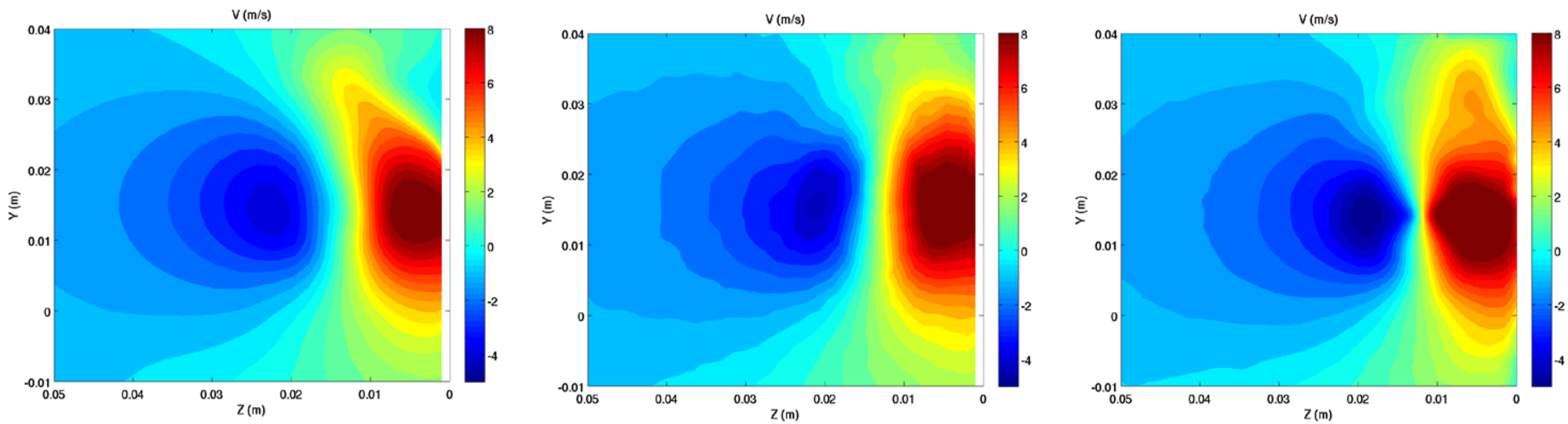
OUTLOOK

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



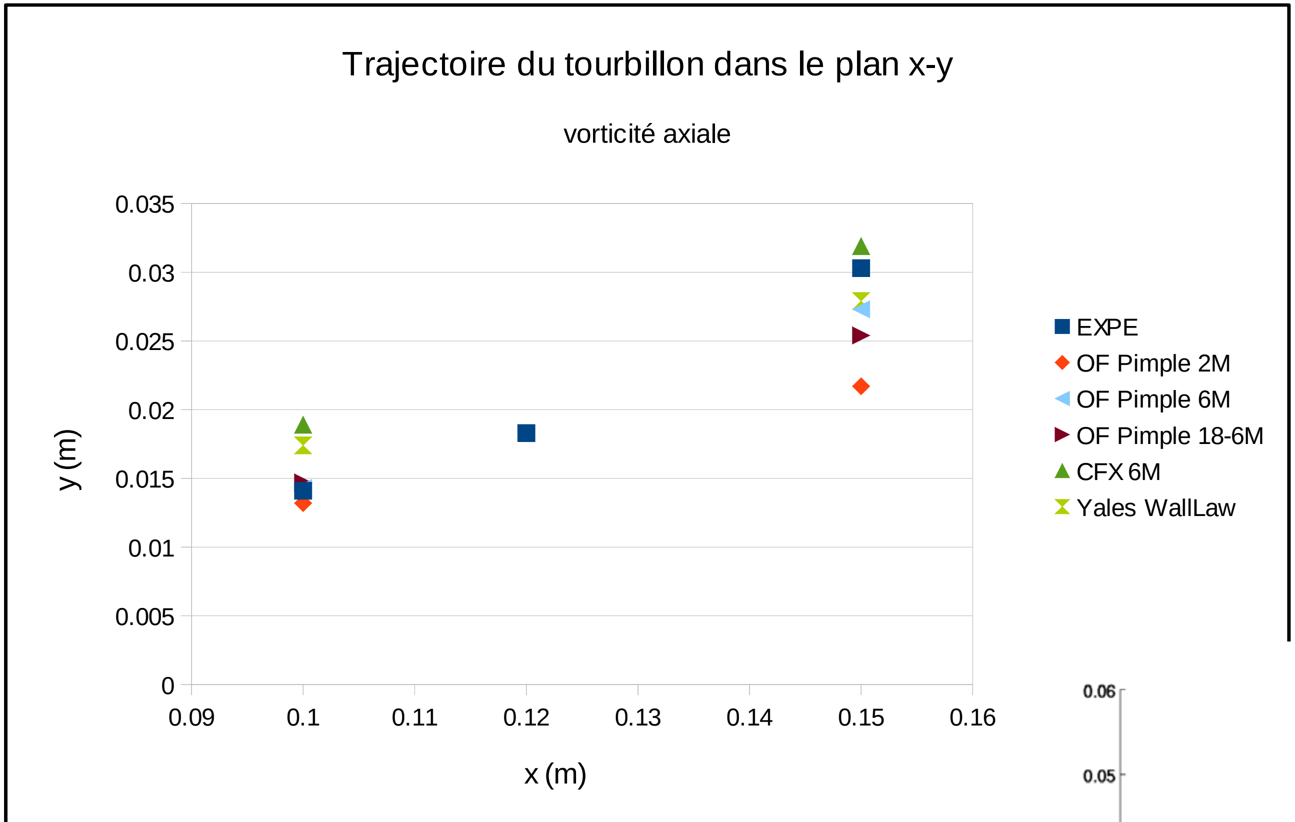
Void fraction visualisation

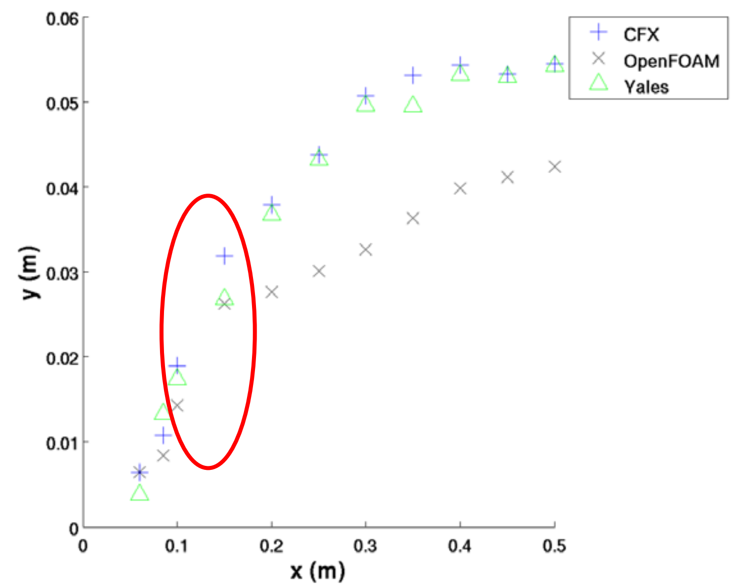
THANK YOU FOR YOUR ATTENTION

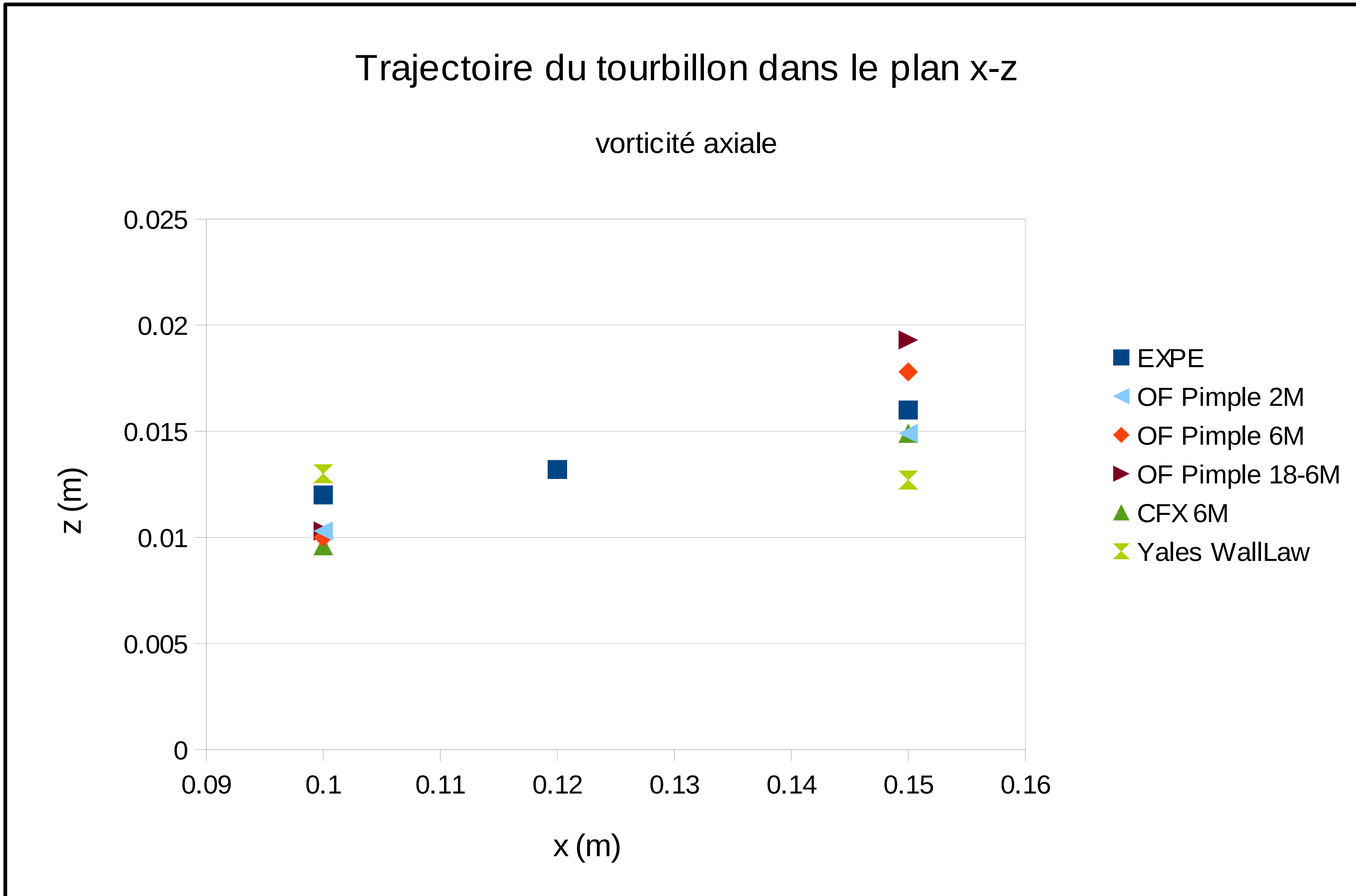


OpenFOAM **Yales 2** **Experiment**

Vertical velocity component V (m/s) in a crosswise plan at ½ chord dowstream the trailing edge


Trajectoire du tourbillon dans le plan x-y
vorticité axiale
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
y (m)
0.09
0.1
0.11
0.12
0.13
0.14
0.15
0.16
x (m)
EXPE
OF Pimple 2M
OF Pimple 6M
OF Pimple 18-6M
CFX 6M
Yales WallLaw


0.06
0.05
0.04
0.03
0.02
0.01
0
y (m)
0
0.1
0.2
0.3
0.4
0.5
x (m)
CFX
OpenFOAM
Yales


Trajectoire du tourbillon dans le plan x-z
vorticité axiale
z (m)
0.025
0.02
0.015
0.01
0.005
0
x (m)
0.09
0.1
0.11
0.12
0.13
0.14
0.15
0.16
EXPE
OF Pimple 2M
OF Pimple 6M
OF Pimple 18-6M
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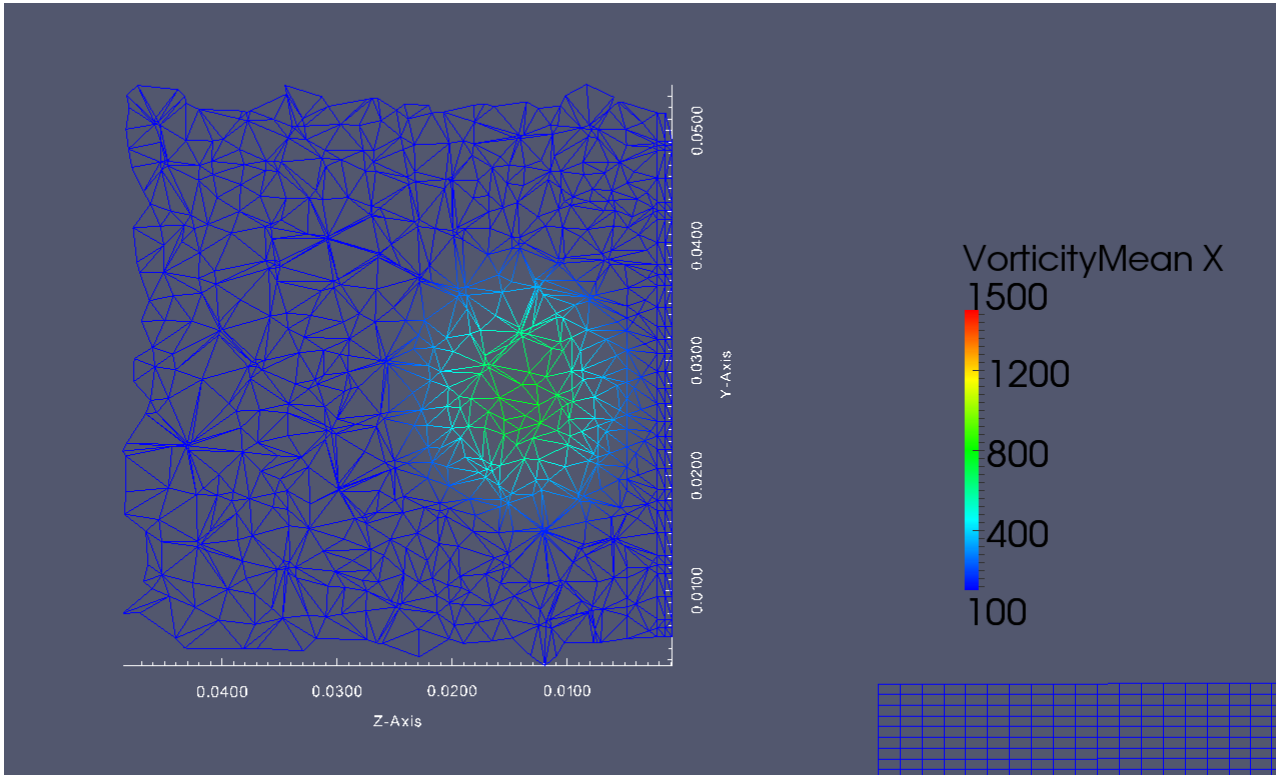

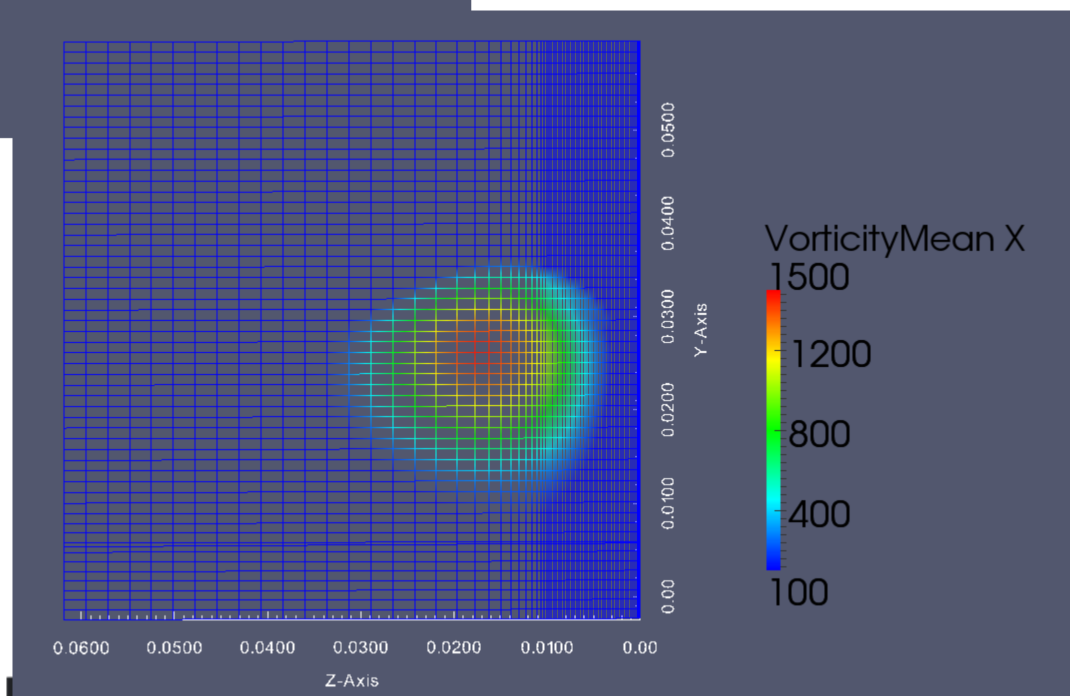

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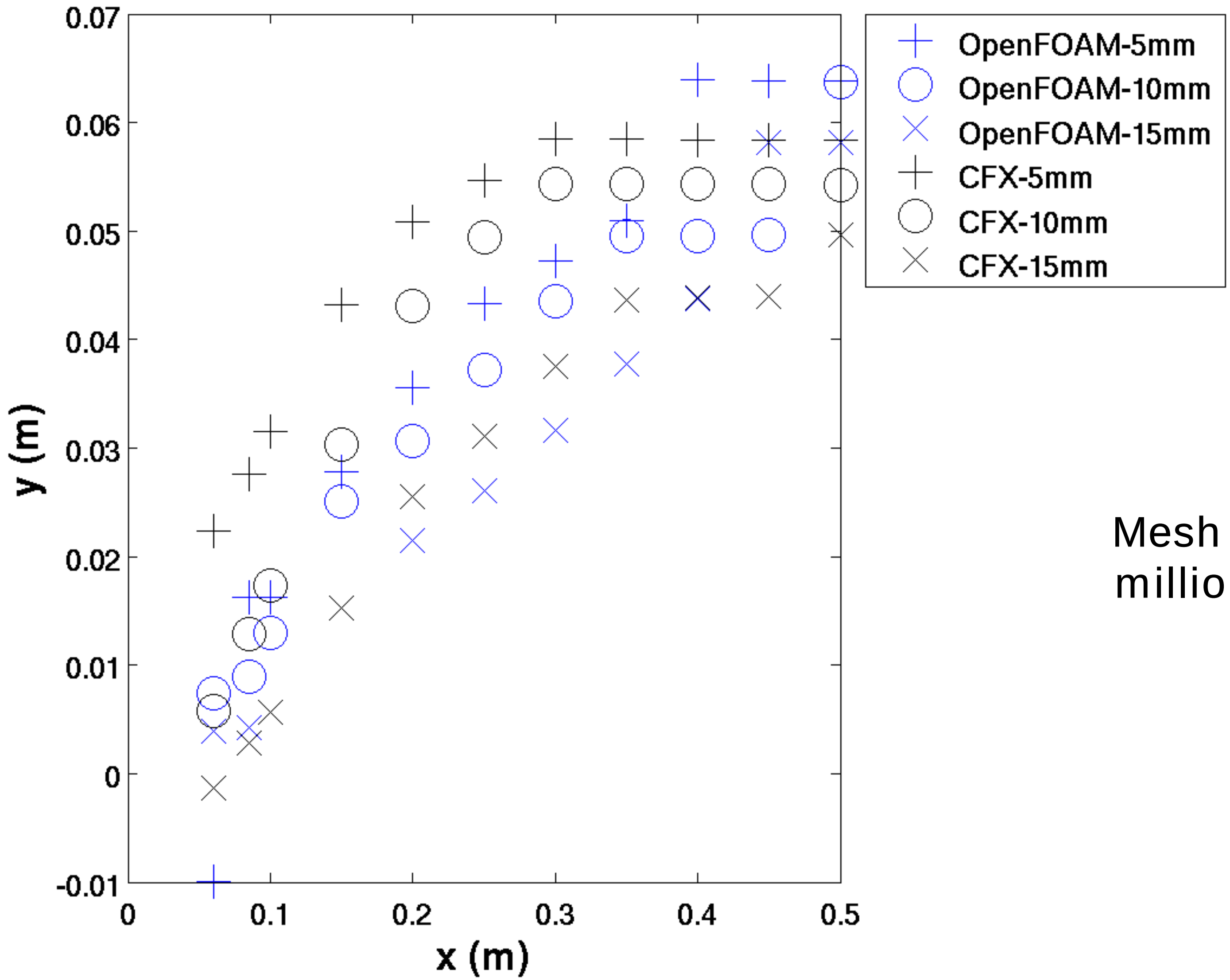

Mesh 2.8 millions of nodes