

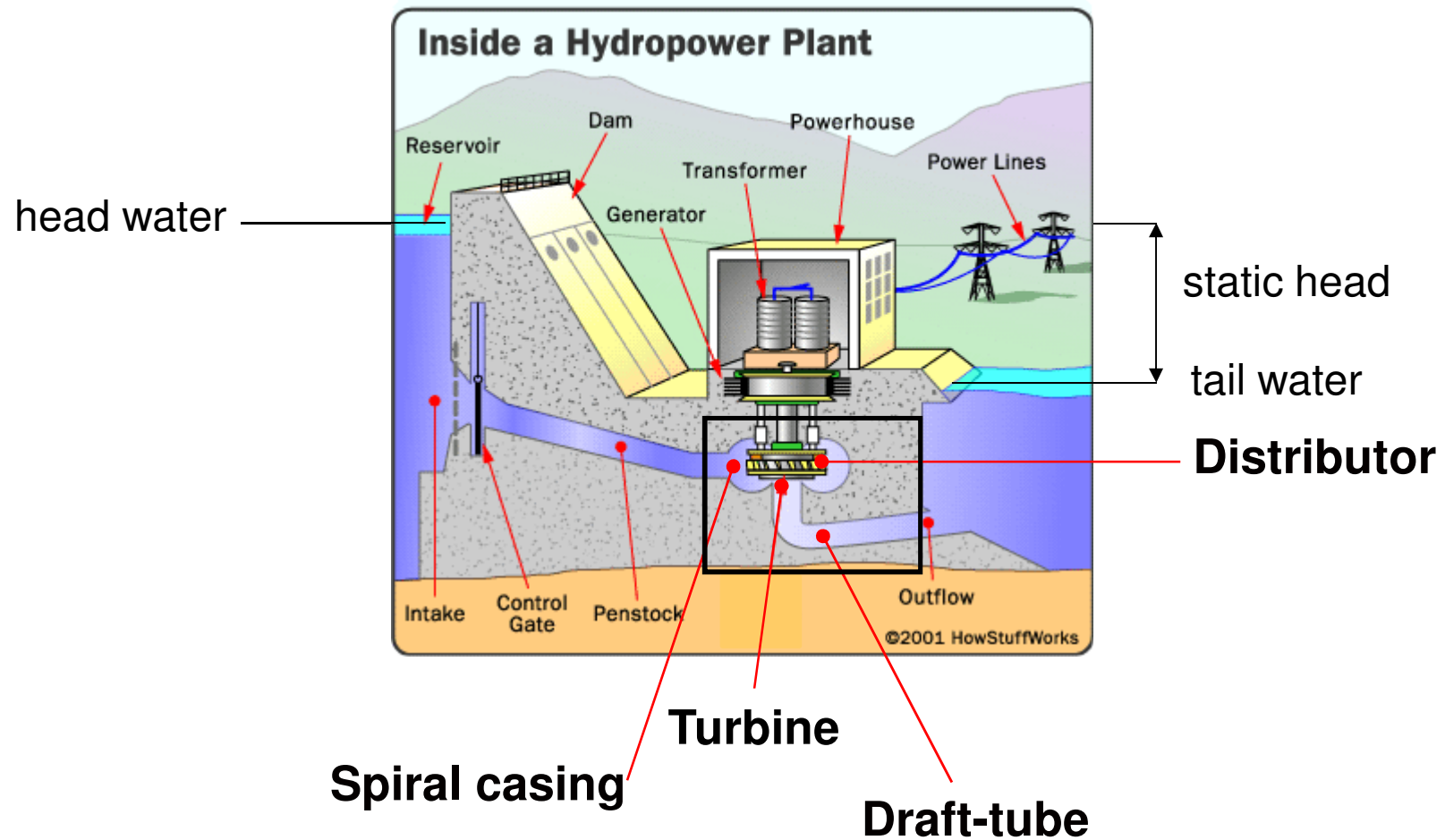


Mesh convergence study with foam-extend-3.1 for hydraulic turbine draft tube

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(École Polytechnique de Montréal)



Viscous flow simulations for hydraulic turbo-machinery design



- CFD commonly used by design engineers to evaluate losses in hydraulic components
- First step, create a valid mesh
- Accuracy of RANS flow solution: mesh size, Y_+ , expansion ratio, element skewness, orthogonality...
- Different good quality grids can yield quite different flow fields

- Draft-tube component
- Mesh convergence study:
 - parametric study:
 - Mesh resolution level
 - Skin thickness
 - Expansion factor
 - Maximum element size
 - Two test cases of draft-tube loss computation validated with experimental data

Computational Fluid Dynamic Setup

- Foam-extend-3.1
 - SimpleFoam solver
 - Standard RANS model
 - Two-equation k-epsilon turbulence closure model with wall functions
 - Advection scheme:
 - $\text{div}(\phi, U)$ Gauss linearUpwind Gauss linear
 - $\text{div}(\phi, k \text{ or } \epsilon)$ Gauss upwind
 - Convergence criterion: 1×10^{-5} on the residuals and on total pressure
 - Steady state
 - Outlet: average constant pressure=0 Pa.
 - Inlet:
 - Turbulence intensity=5%, length scale=0.0008216m
 - Nine synthetic axisymmetrical inlet swirling flow profiles

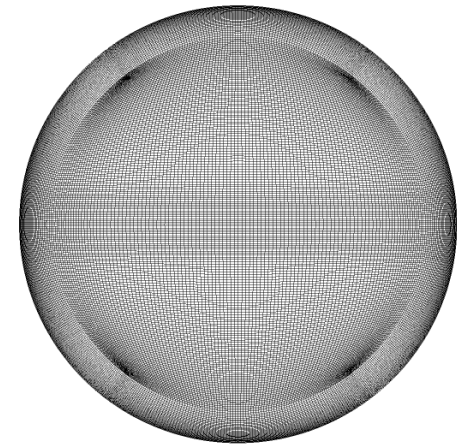
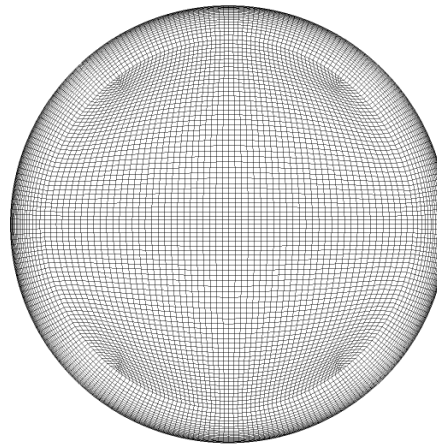
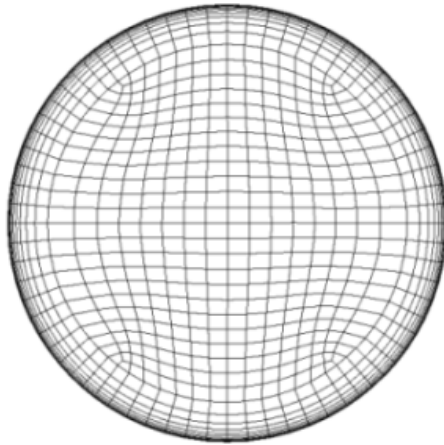
Computational Fluid Dynamic Setup

- Draft-tube losses
 - $(\Delta p_{tot})/0.5\rho V_{D_{inlet}}^2$
 - Normalized for imperial flow coefficient $Q_{11}=1$
 - Expressed in % of turbine head
- Target uncertainty of $\pm 0.5\%$ on draft-tube head losses

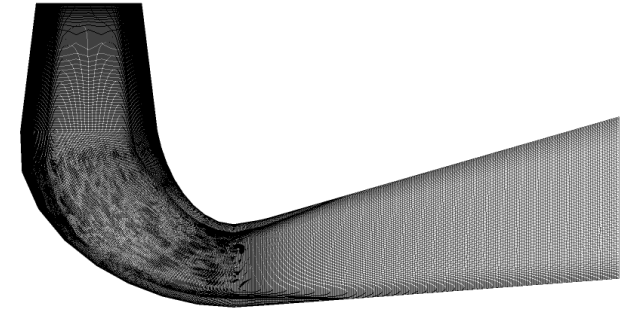
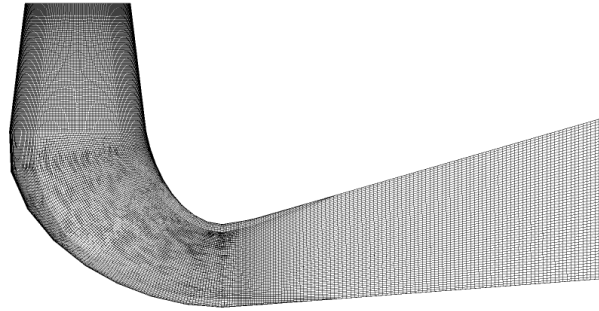
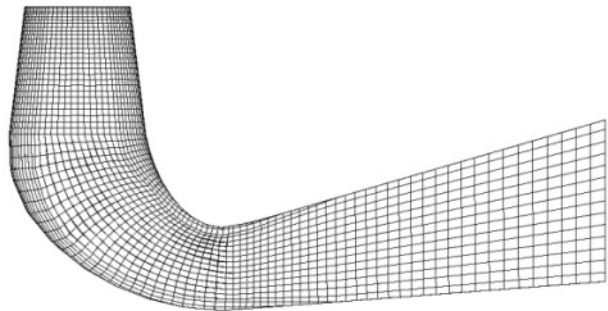
Parameter study on mesh convergence: Mesh resolution level

inlet

Resolution	0.02	0.05	0.1	0.2	0.5	1*	3	5
Vertices	0.15M	0.26M	0.45M	0.78M	1.76M	3.53M	12.29M	21.66M



Plane ZX

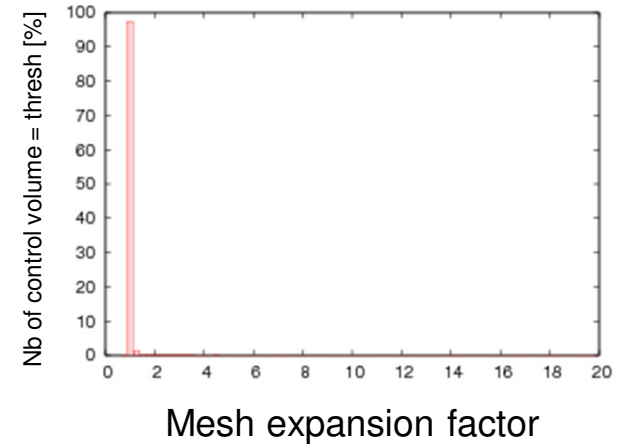
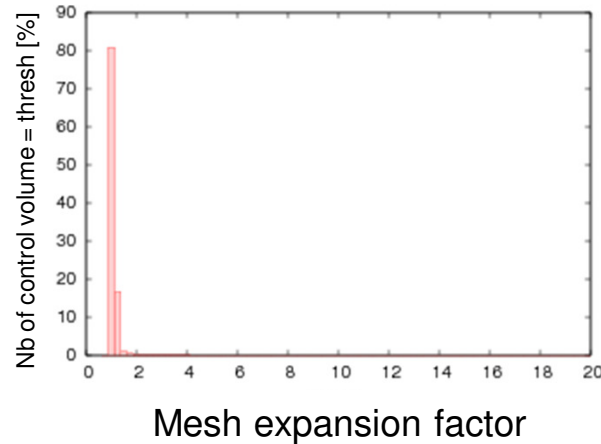
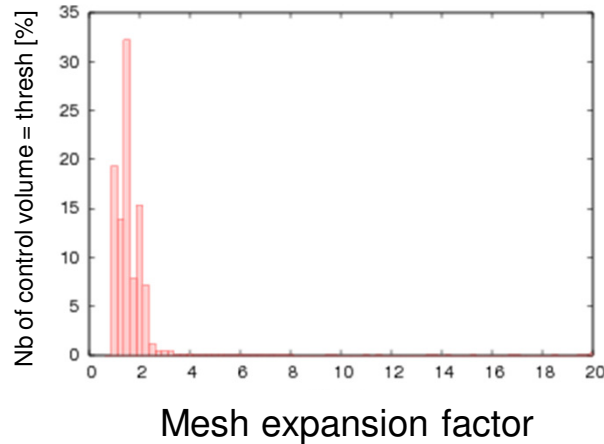
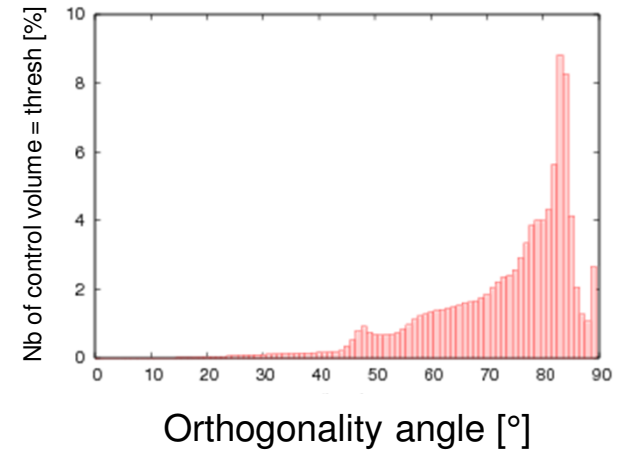
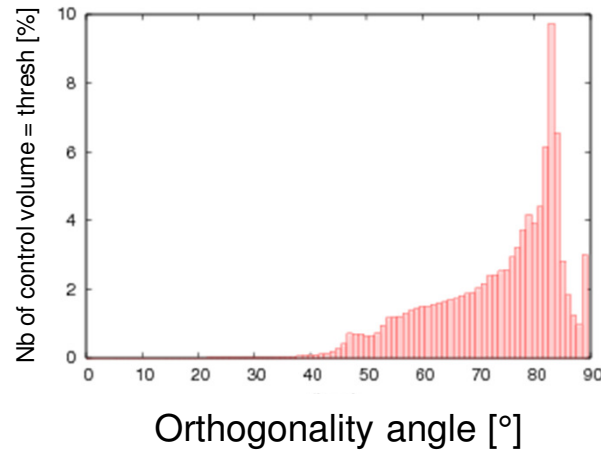
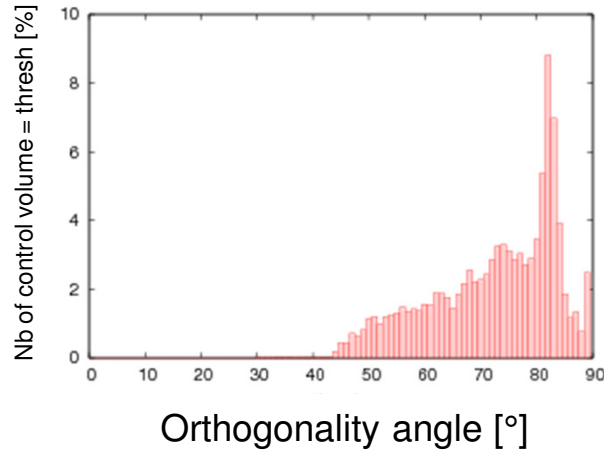


Mesh resolution 0.02

Mesh resolution 1.0

Mesh resolution 5.0

Parameter study on mesh convergence : Orthogonality angle and mesh expansion factor

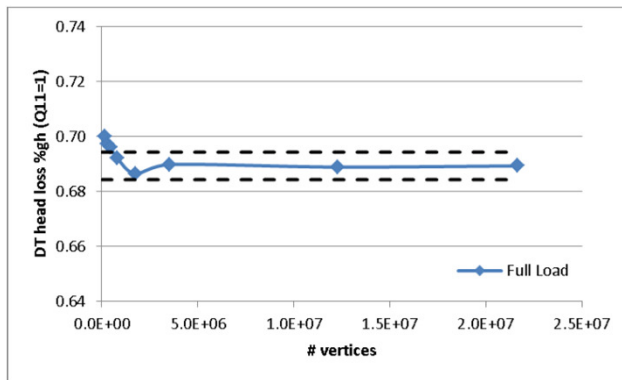
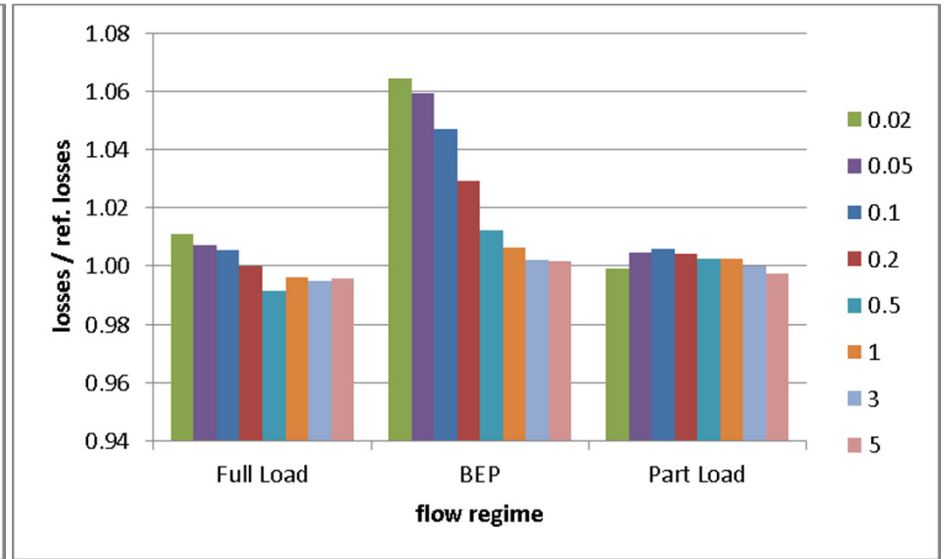
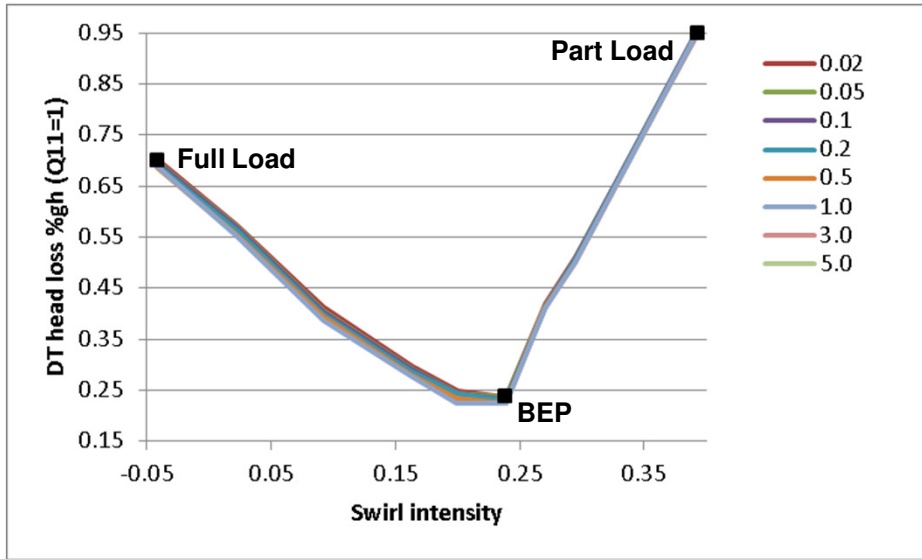


Mesh resolution 0.02

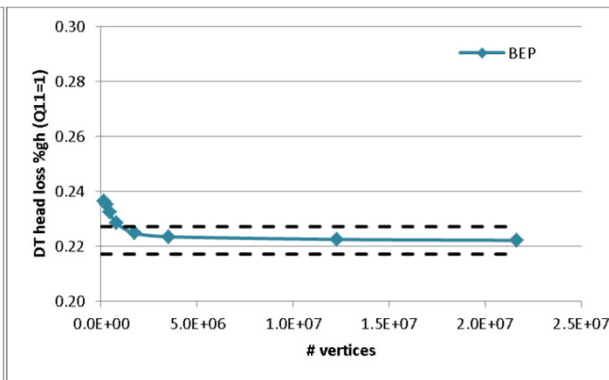
Mesh resolution 1.0

Mesh resolution 5.0

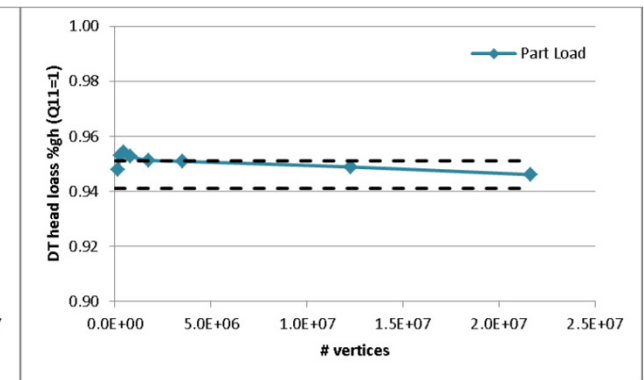
Parameter study on mesh convergence : Losses for dtA



Full load

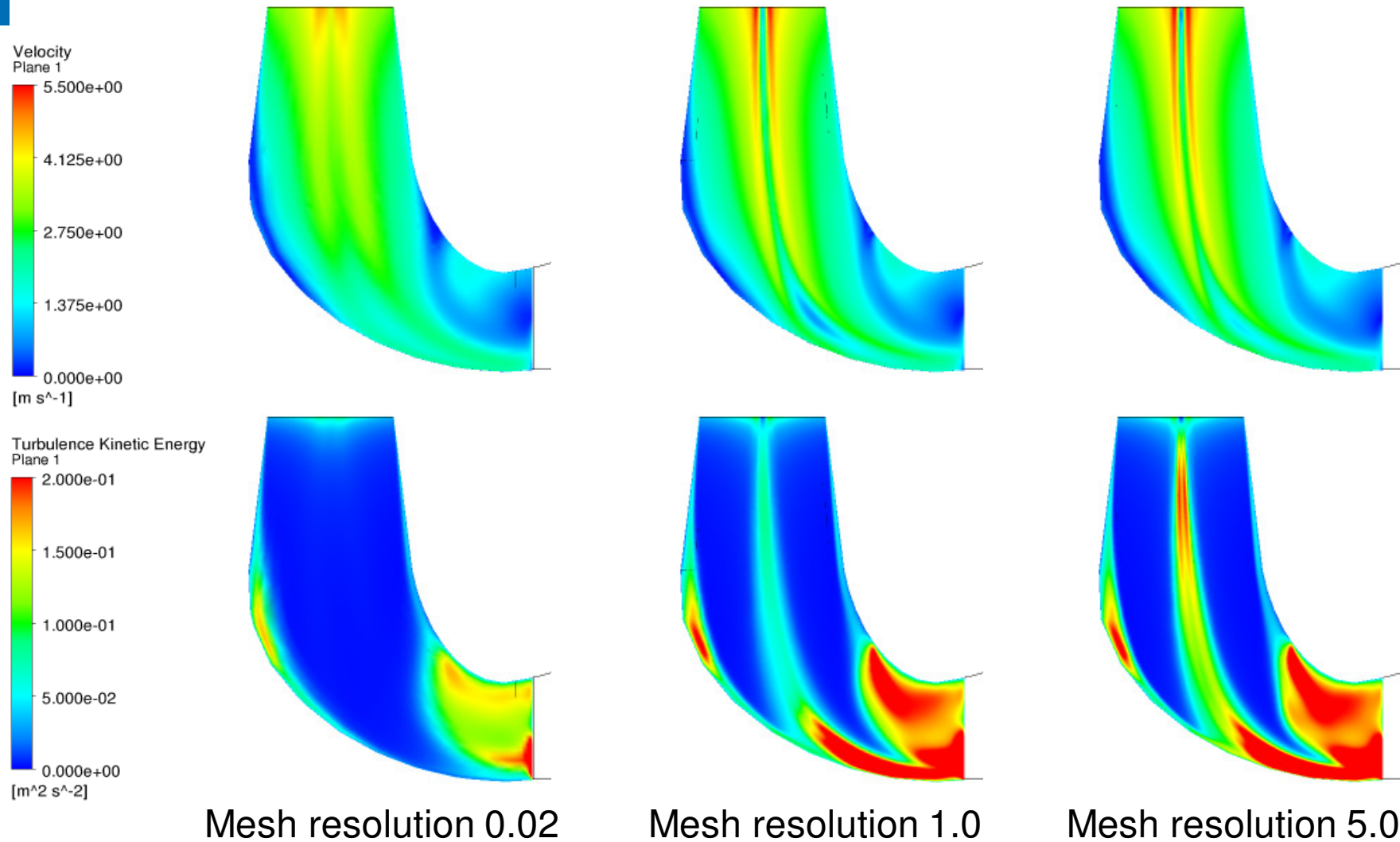


BEP



Part load

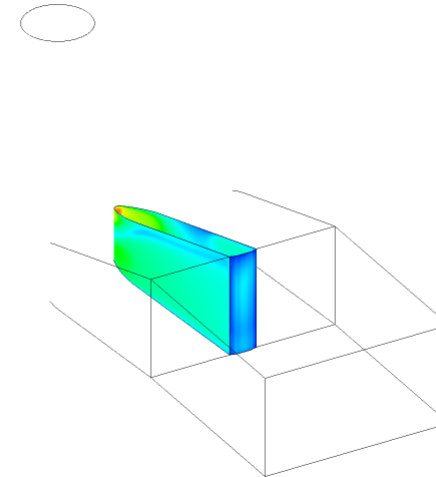
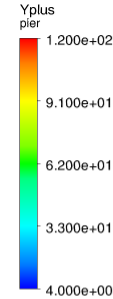
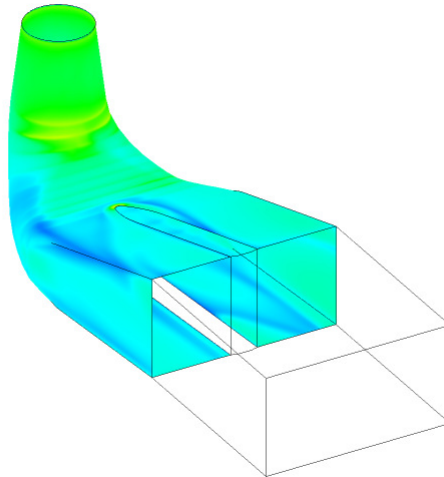
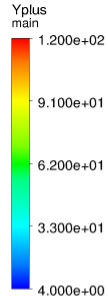
Parameter study on mesh convergence : Flow behavior at full load



Parameter study on mesh convergence: Y^+

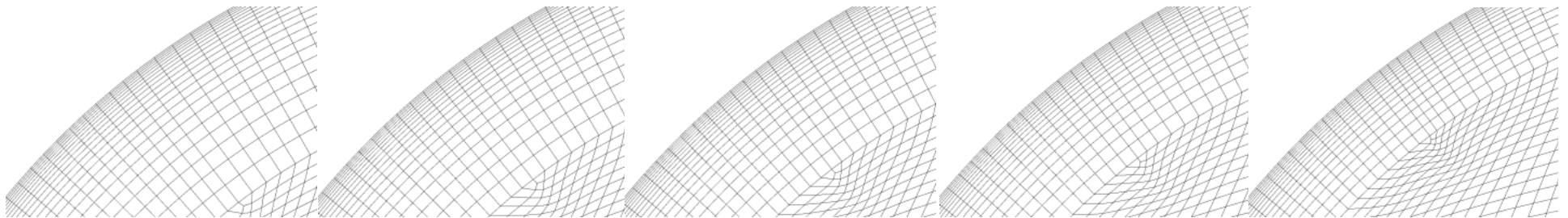
- Y^+ for BEP and different mesh resolution level
- Y^+ for mesh resolution level 5 and for 3 OP
- Mesh distribution be well controlled
- The Y^+ values within the recommended values (30-300) for computation using wall function

	draft-tube wall			pier wall				draft-tube wall			pier wall		
resolution	min	Ave	Max	min	ave	max	Resolution 5	min	Ave	Max	min	ave	max
0.02	4.6	42	75	3.5	39	91	Full Load	4.2	53	98	2.3	57	240
1.0	4.7	45	83	2.1	43	114	BEP	4.7	45	84	1.7	45	120
5.0	4.7	45	84	1.7	45	120	Part Load	6.4	63	116	2.1	61	209



Parameter study on mesh convergence : Skin thickness

Skin thickness	0.12	0.10	0.09*	0.08	0.06
Vertices	3.21M	3.34M	3.53M	3.43M	3.68M



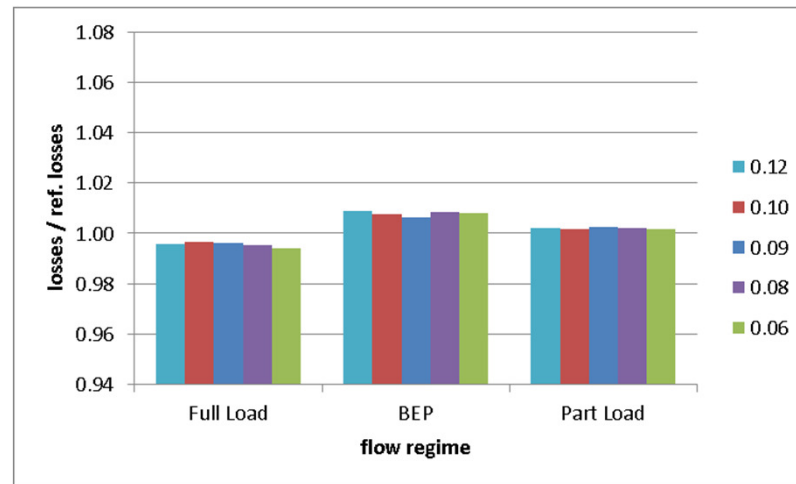
0.12

0.10

0.09

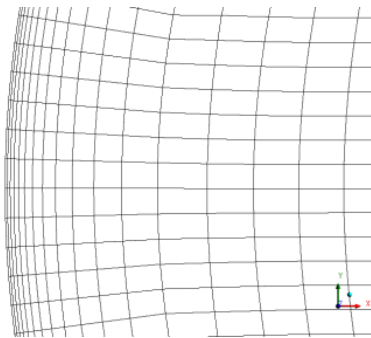
0.08

0.06

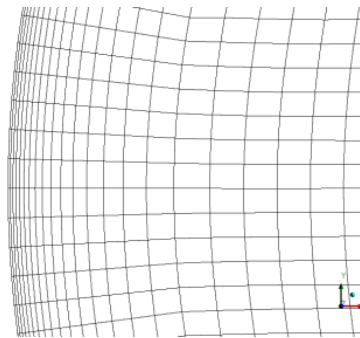


Parameter study on mesh convergence : Expansion factor

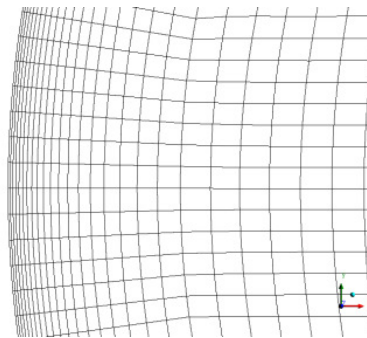
Expansion factor	1.30	1.20	1.15*	1.10	1.05
Vertices	2.15M	3.07M	3.53M	4.07M	5.65M



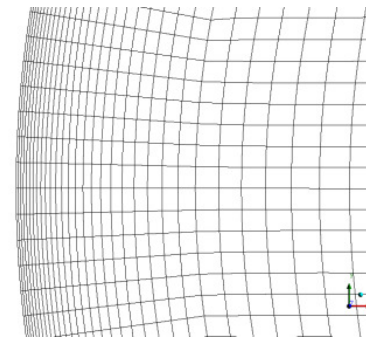
1.30



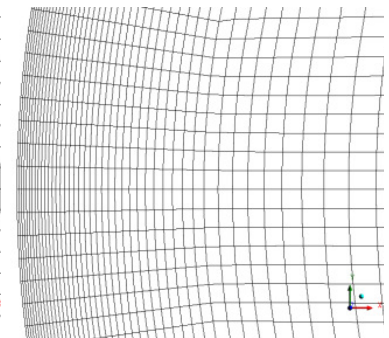
1.20



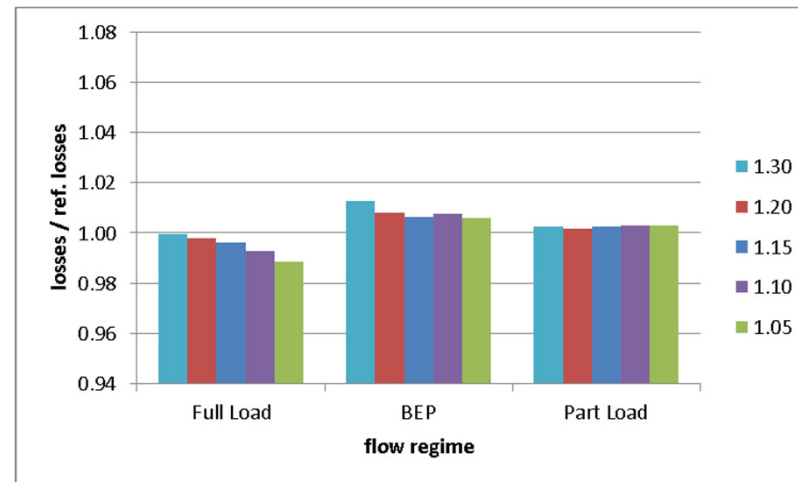
1.15



1.10

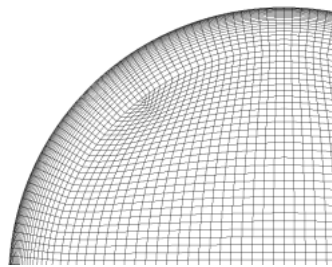


1.05

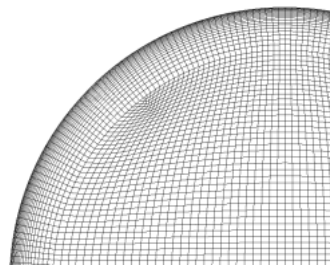


Parameter study on mesh convergence : Maximum element size

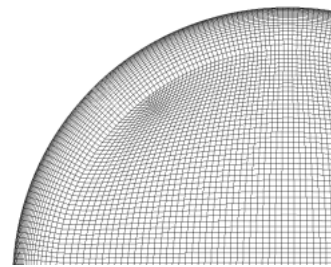
Max. Element Size	0.03	0.023*	0.015	0.01	0.005
Vertices	2.67M	3.53M	4.60M	5.82M	7.25M



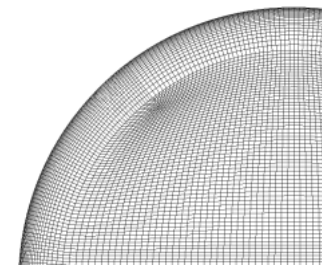
0.030



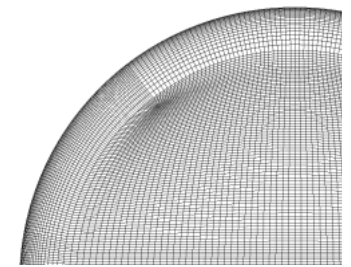
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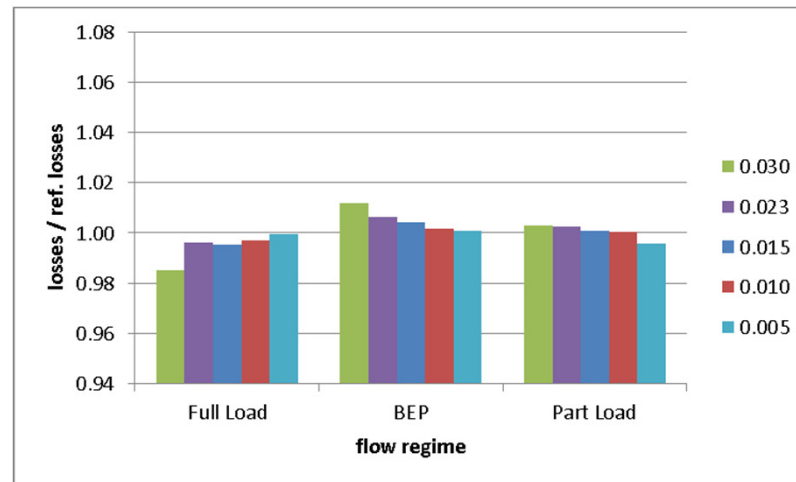
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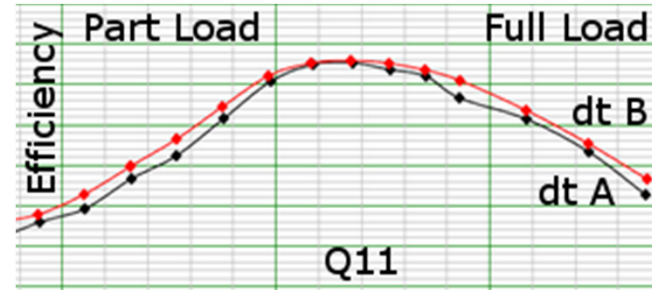
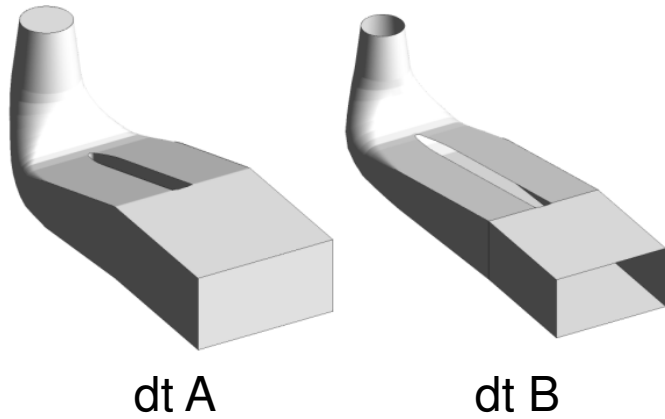
0.010



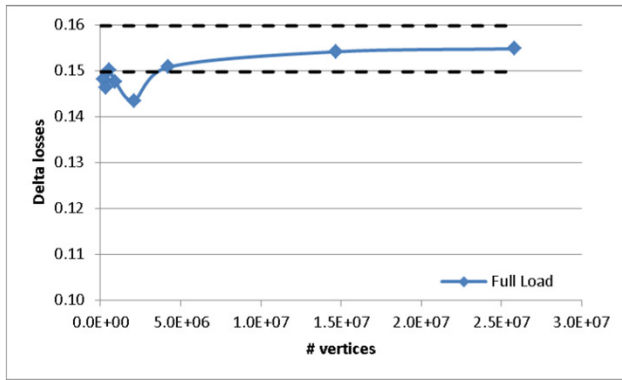
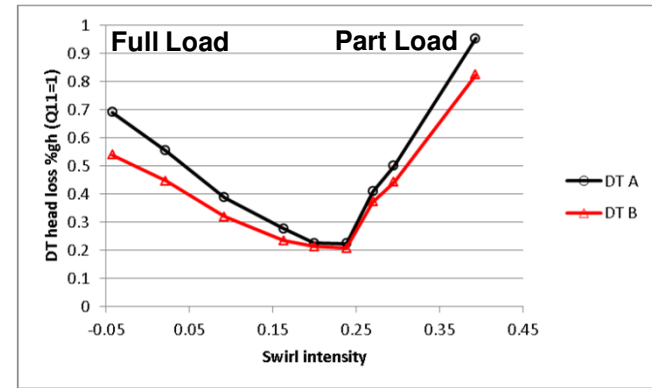
0.005



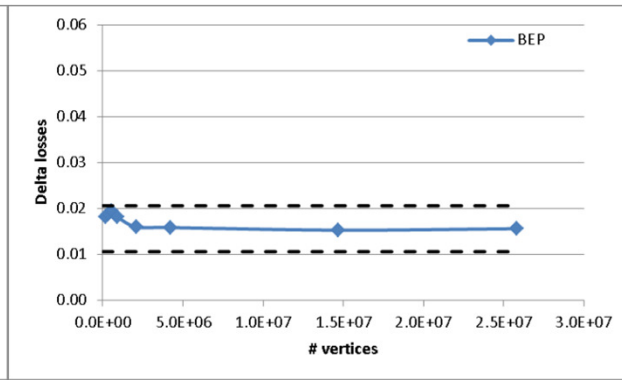
Case study: dt A and dt B



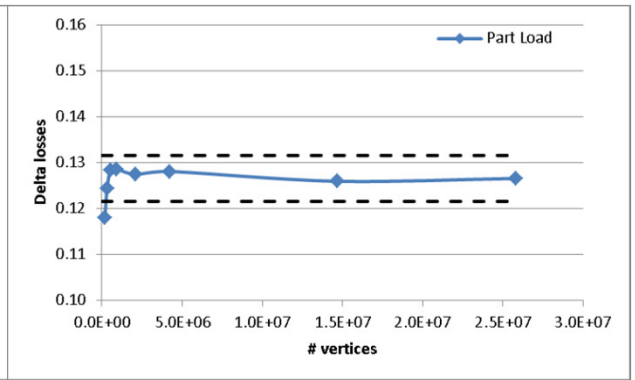
Experimental Data



Full load



BEP



Part load

Conclusions

- Mesh convergence study for turbulence flow in hydraulic turbine draft-tubes has been presented.
- Wide range of inlet swirling flows representing turbine operating conditions at model scale from part load to full load
- Parametric study:
 - mesh resolution level
 - skin thickness
 - mesh distance expansion factor from solid wall
 - maximum mesh size in core flow.
- Acceptable mesh convergence could be reached with mesh size beyond 4M vertices.
- Mesh convergence is reached for density greater than 1 for all conditions.
- The skin thickness factor has little effect on the draft-tube loss
- The element size factor in the core flow has some effects for full load and BEP, but less for part load conditions.
- The choice of the mesh expansion factor from solid wall is an important parameter for full load conditions. It has a small effect for BEP and part load for expansion factor smaller than 1.20.



Thank you for your attention

Previous work

- ✓ **Hydraulic turbine distributor simulation using OpenFOAM**
F. Guibault, C. Devals, J-F. Dubé, T.C. Vu and B. Nennemann,
5th OpenFOAM Workshop, Chalmers, Gothenburg, Sweden, 21-24 June, 2010
- ✓ **Draft Tube calculations using OpenFOAM and validation with FLINDT data**
C. Devals, Y. Zhang, F. Guibault, T.C. Vu and B. Nennemann,
6th OpenFOAM Workshop, PennState University, USA, 13-16 June, 2011
- ✓ **Hydraulic turbine spiral casing flow simulation using OpenFOAM**
C. Devals, F. Guibault and T.C. Vu
7th OpenFOAM Workshop, Darmstadt, Germany, 25-28 June 2012
- ✓ **Desynchronized guide vane torque prediction for CFD spiral casing flow simulation using OpenFOAM**
C. Devals, , F. Guibault and T.C. Vu
8th OpenFOAM Workshop, Jeju, Korea, 11-14 June 2013
- ✓ **Assessment of mesh characteristics for hydraulic component CFD simulations with OpenFOAM**
C. Devals, Y. Zhang, F. Guibault and T.C. Vu
9th OpenFOAM Workshop, Zagreb, Croatia, 23-26 June 2014
- ✓ **Evaluation of the Mixing Plane technology: application for distributor-runner channel**
C. Devals, Y. Zhang, J. Dompierre, F. Guibault, L. Mangani and T.C. Vu
10th OpenFOAM Workshop, Ann Arbor, USA, 29 June-02 July 2015