Verification of OpenFOAM to Simulate Tangential Vortex Intake for Civil Engineering Application

Eddy Y F Lau
Project Engineer
Water & Urban Development, Hong Kong

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Outline

1. Use of drop shaft in civil infrastructure
2. Design of tangential vortex intake
3. Verification of OpenFOAM to simulate tangential vortex intake
4. Conclusions

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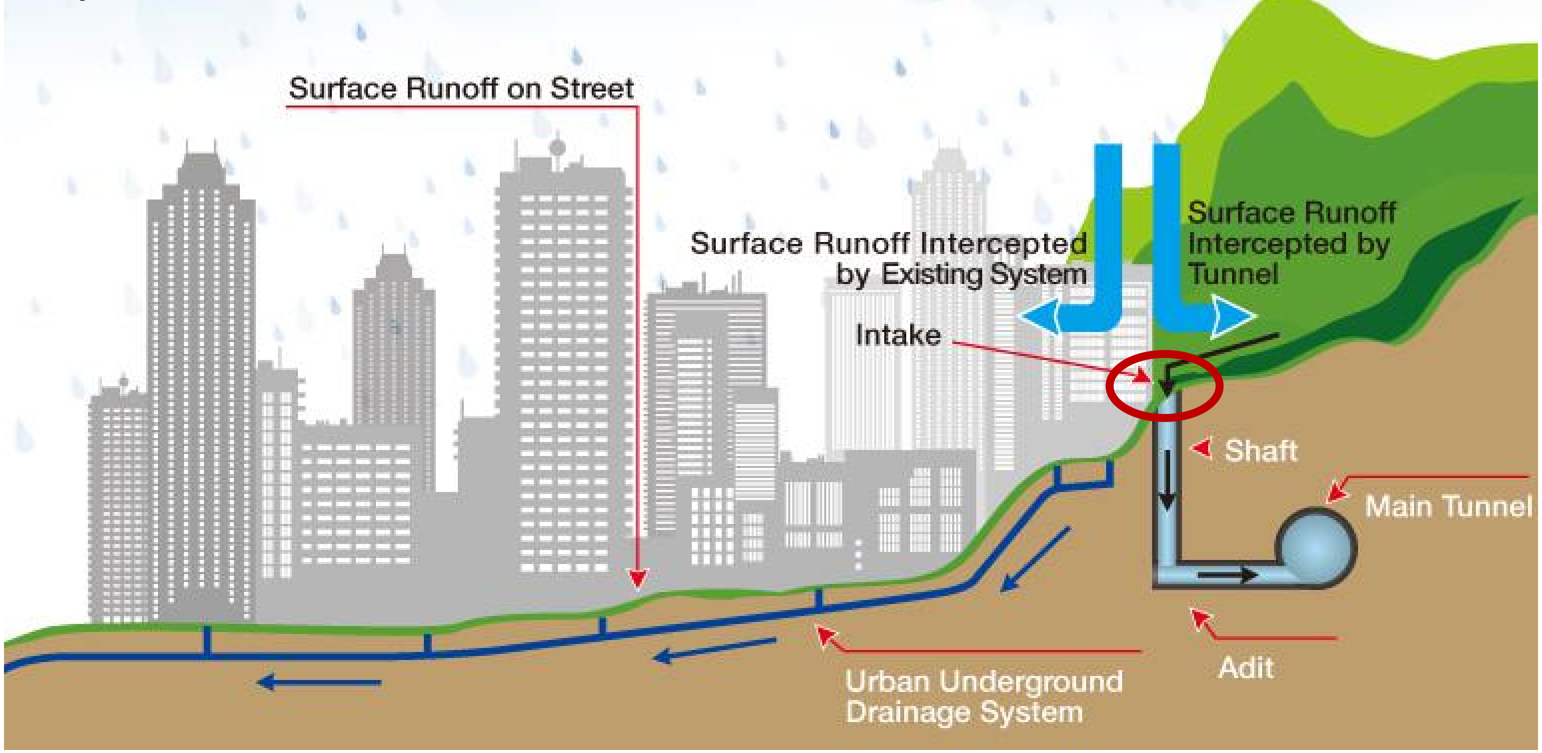
Use of drop shaft in civil infrastructure

- Flow with large drop in elevation is common in civil infrastructure
- Example: Intercepting surface runoff by drainage tunnel for flood protection



Source: *https://www.dsd.gov.hk/others/HKWDT/eng/background.html*

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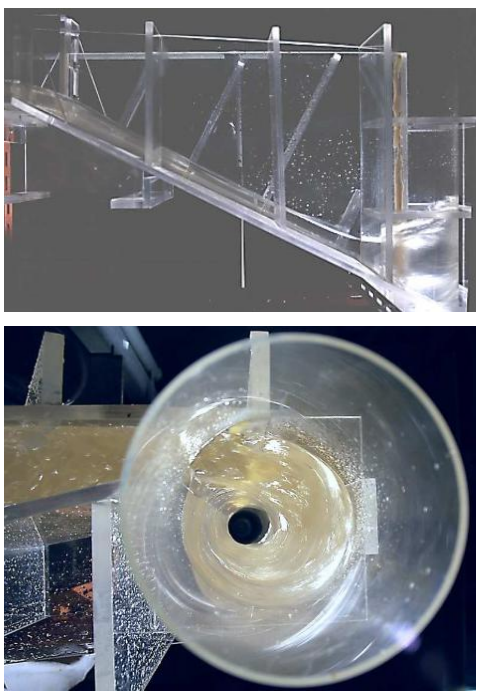
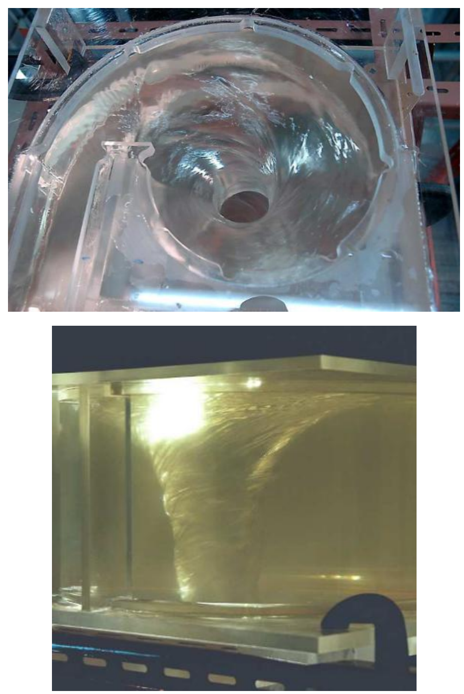
Use of drop shaft in civil infrastructure

Common types of drop shaft

- Vortex (Tangential, scroll, spiral)
- Plunging
- Cascade



Tangential intake



Scroll intake

Plunging intake

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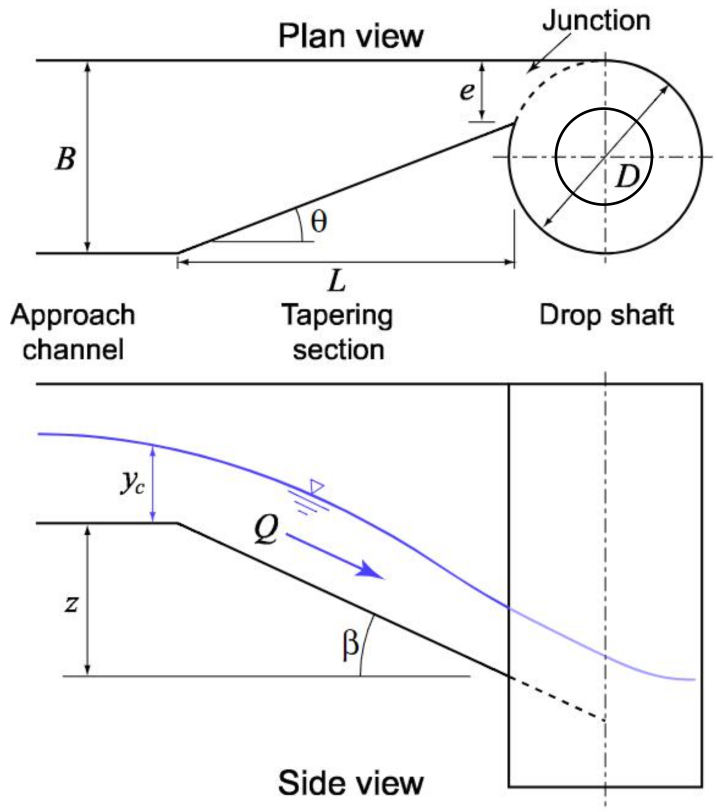
Design of tangential vortex intake

Key design criteria:

1. Head-discharge (Q-H) relationship
2. Minimum air core ratio

Design approaches:

1. CFD model
2. Physical model
3. Theoretical formula



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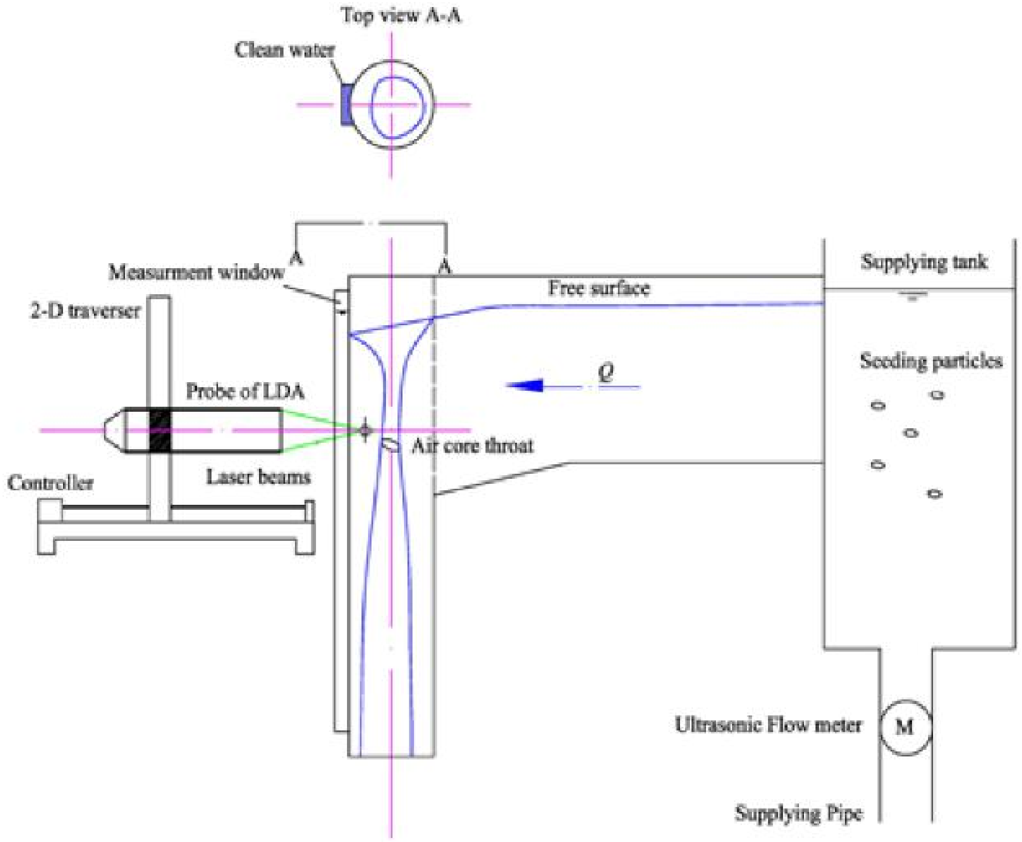
Design of tangential vortex intake

Challenges to design tangential vortex intake by CFD

1. Not common industrial practice
   → Engineers trust physical model
2. No known detailed study
   → In-depth verification work is not available
3. OpenFOAM
   → Commercial software, Flow-3D & ANSYS Fluent, are preferred

Verification of OpenFOAM to simulate tangential vortex intake

Detailed experimental study by Qiao et al. (2013)



Source: *Q.S. Qiao, J.H.W. Lee and K.M. Lam, "Steady Vortex Flow in Tangential Intake," IAHR World Congress Proceedings: 35th IAHR Congress, pp. 1254-1261, 2013*

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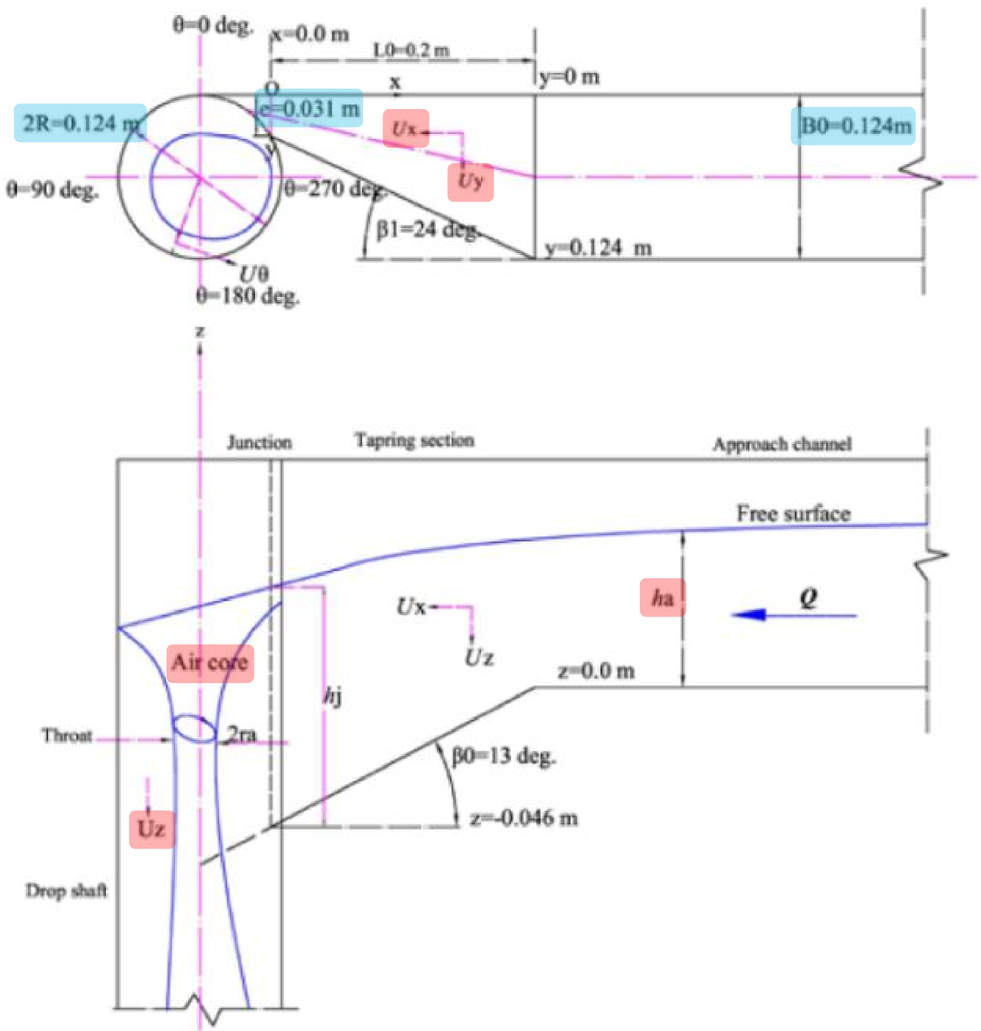
Verification of OpenFOAM to simulate tangential vortex intake

Geometric parameters and measured flow variables



Geometric parameters	Values
Shaft dia. & approach channel width	0.124m (1.86m for prototype)
Inflow junction width	0.031m (0.47m for prototype)

Measured flow variables	Values
Velocity	Ux, Uy, Uz
Depth	ha
Air core ratio	λ
Flow rate	2L/s to 10L/s ($1.7m^3/s$ to $8.7m^3/s$ for prototype)

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OpenFOAM settings

Parameters	Values
Version	OpenFOAM v4.1
Meshing	blockMesh & snappyHexMesh
Number of cells	1,485,577
Mesh size	0.01m (approach channel) 0.0025m (drop shaft)
Solver	interFoam
Turbulence model	kOmegaSST

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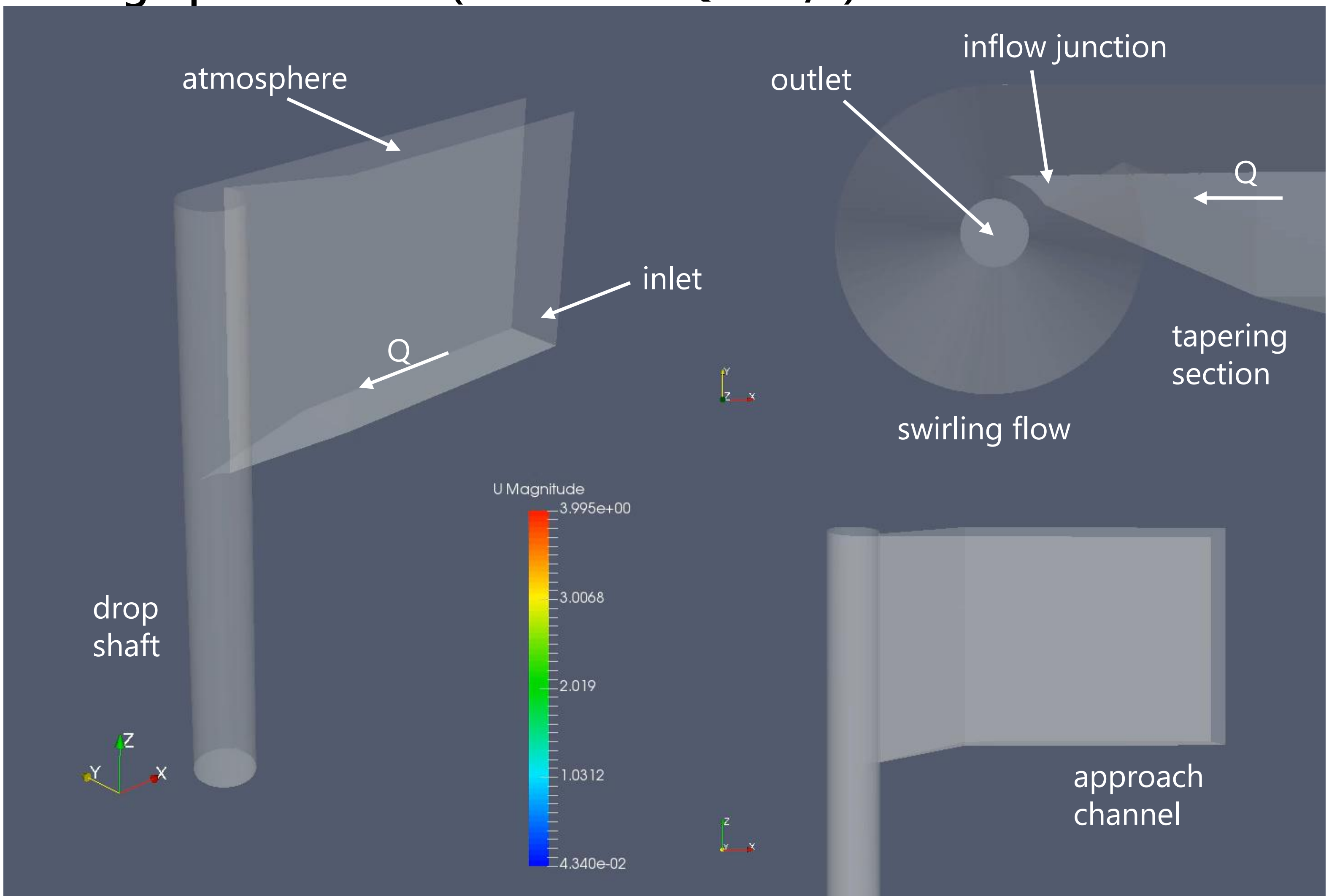
Setting up the model (Results of Q=10L/s)



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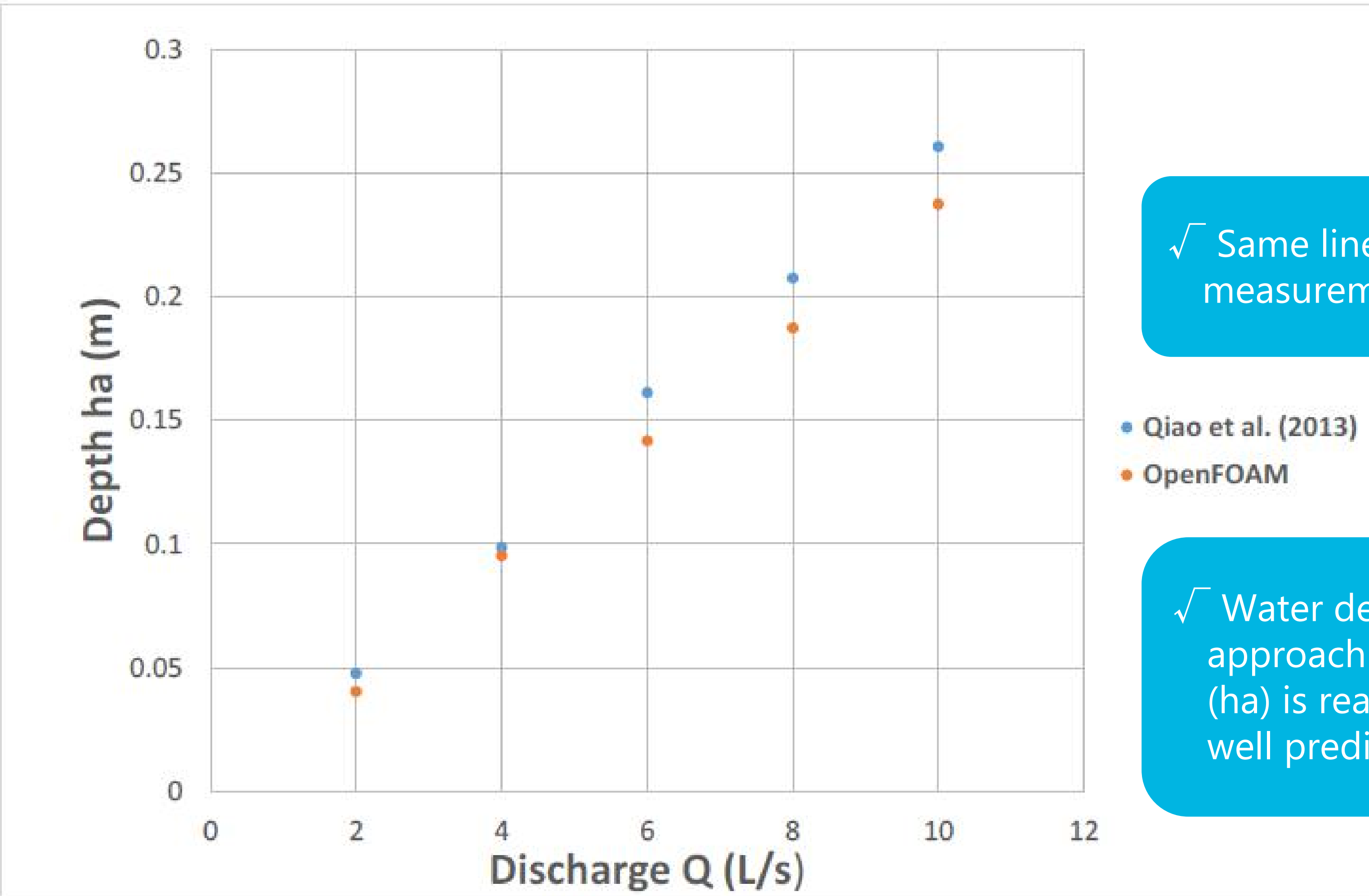
Comparison 1/4: Head discharge (Q-H) relation



- √ Same linear trend as measurement
- √ Water depth in approach channel (ha) is reasonably well predicted

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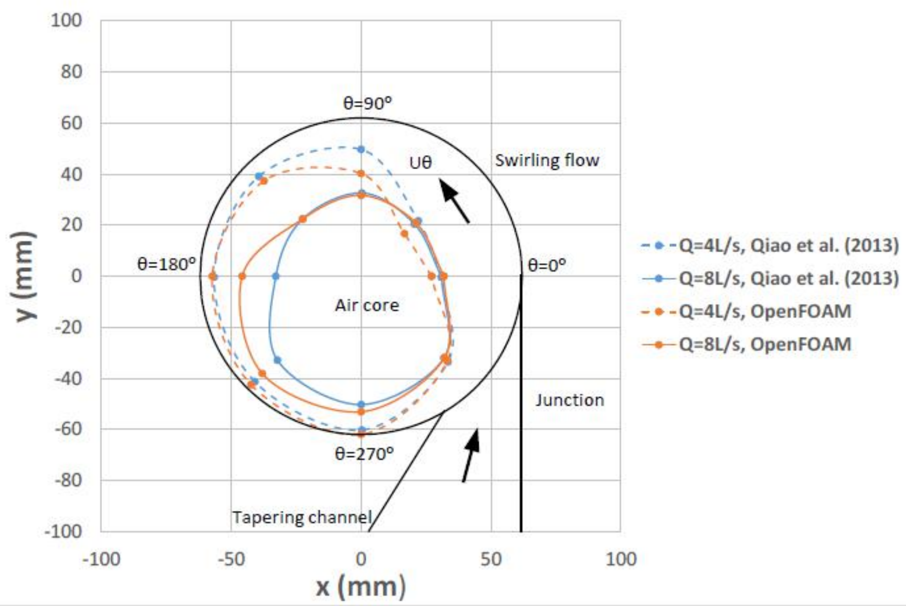
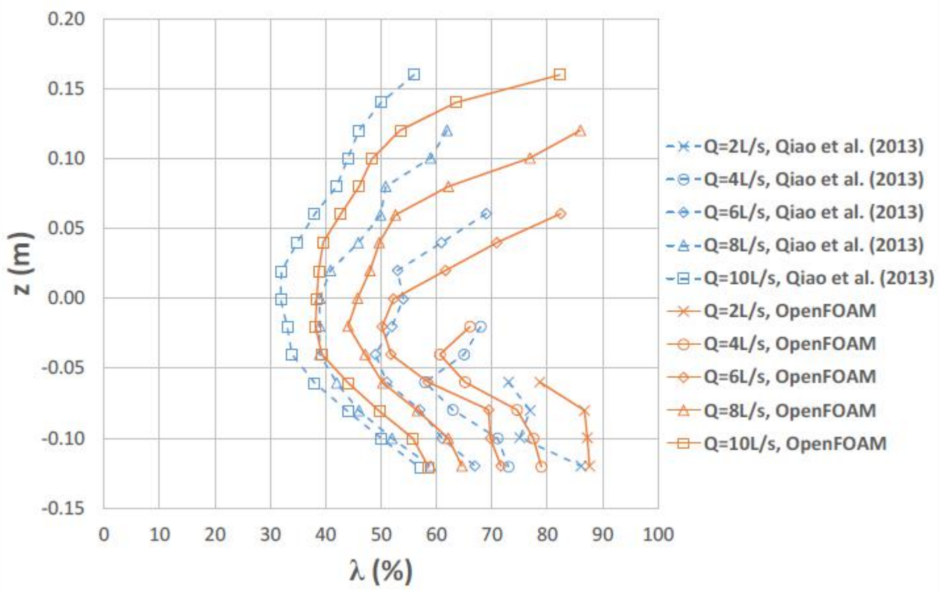
Comparison 2/4: Minimum air core ratio



Air core shape at z=-0.04m



Air core ratio

- √ D-shape air core
- √ Shape of simulated air core agrees reasonably well

- √ Trend consistent with measurements
- √ Minimum air core ratio (λ) predicted by OpenFOAM is reasonably accurate

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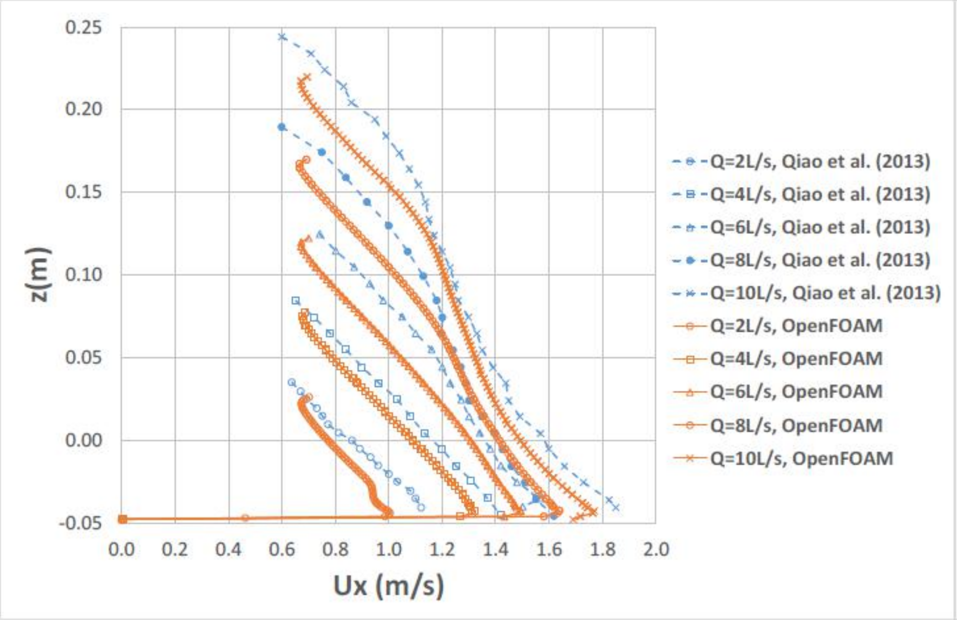
Comparison 3/4: Velocity distribution at inflow junction



Velocity distribution Ux at the junction (y=0.009m, x=0.0m)

√ Linear trend for Q=2 to 6L/s

√ Affected by swirling flow in drop shaft for Q=8 to 10L/s

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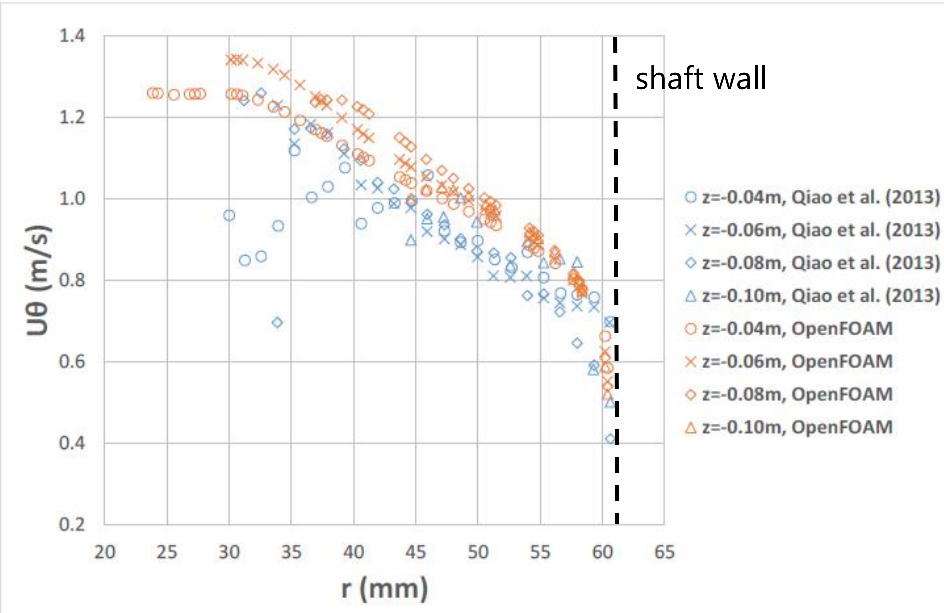
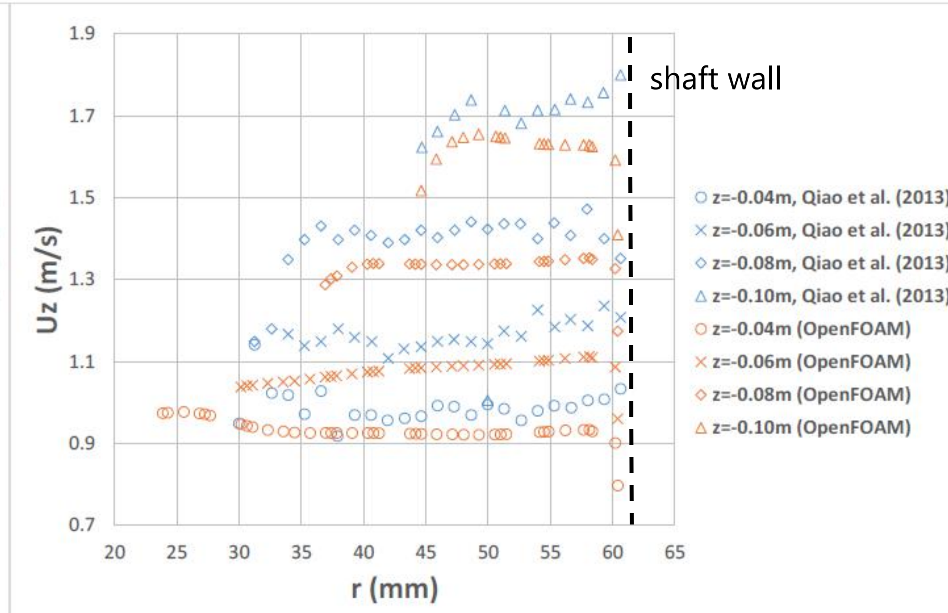
Comparison 4/4: Velocity distribution of swirling flow near to the throat





Tangential velocity U_θ of vortex flow (θ=45º for Q=4L/s)

Vertical velocity Uz of vortex flow (θ=45º for Q=4L/s)

- √ Inverse relationship between U_θ and r
- √ Velocity drops rapidly to zero at wall surface

- √ Uniform Uz in radial direction
- √ Good prediction of distribution of U_θ and Uz

Conclusions

- Detailed measurements by Qiao et al. (2013) provide solid basis to justify the use of OpenFOAM for civil engineering application
- Predicted key design criteria reasonably well
  1. Q-H relation
  2. Minimum air core ratio
- Revealed complex flow structures in the vortex flow
- Design tool for engineers
  → Supplement hydraulic physical model
  → Design complex hydraulic structures
- Research tool for academics
  → Gain insight into complex flow to develop better hydraulic theory

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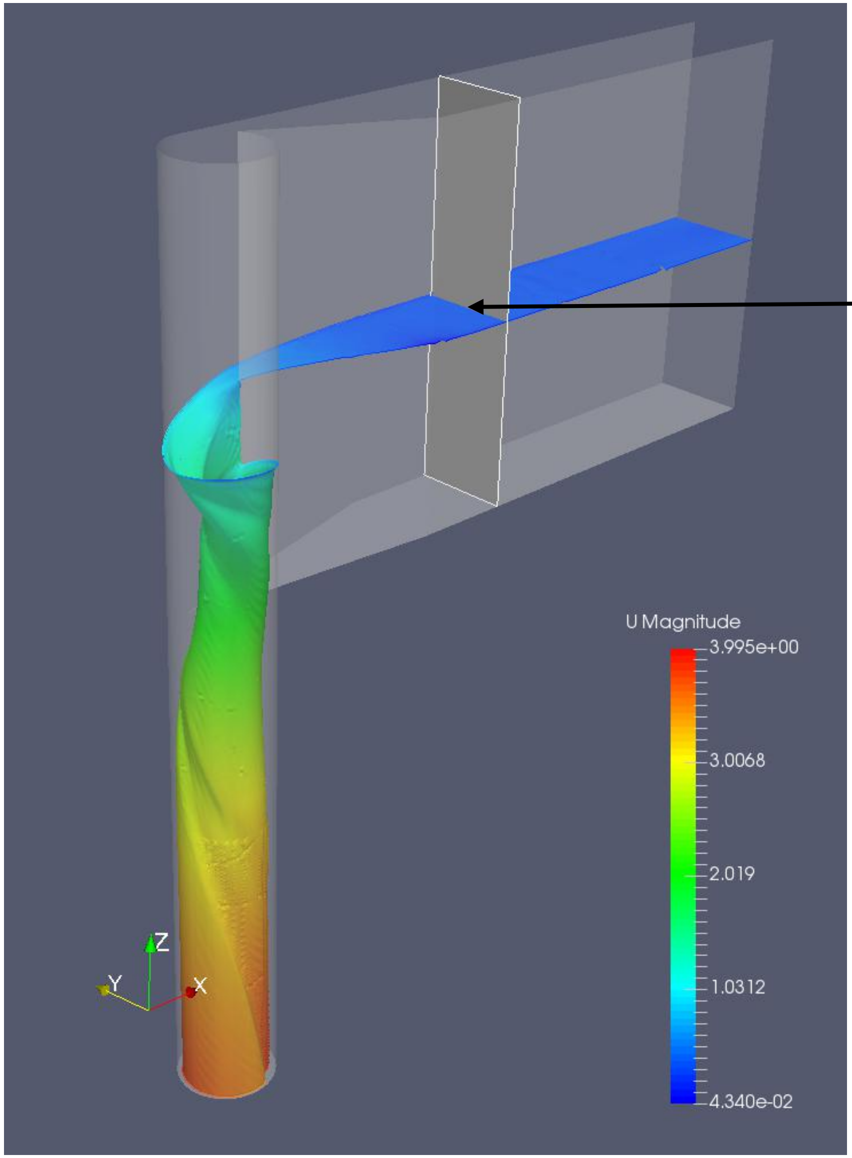
Head discharge (Q-H) relation (approach channel)



Verify depth at approach channel (ha)

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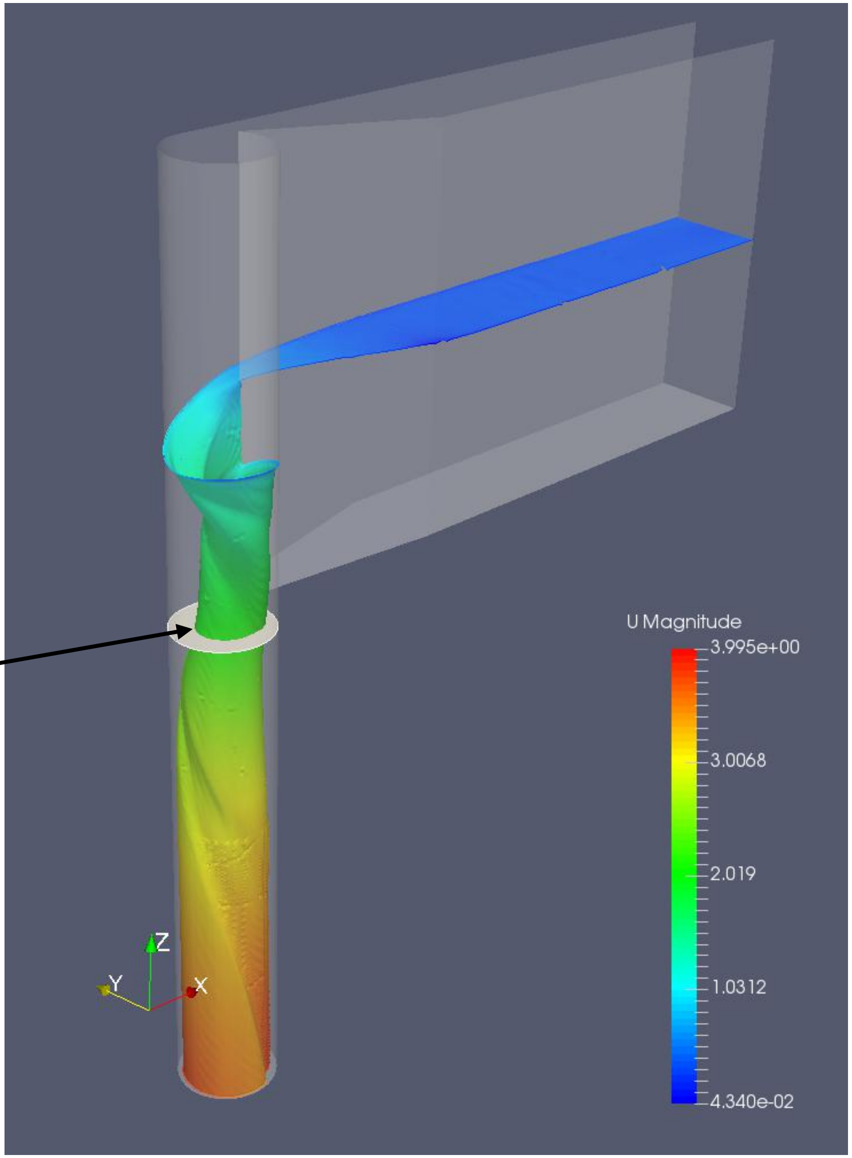
Minimum air core ratio (drop shaft)



Verify size of air core at z=-0.04m (bottom of inflow junction)

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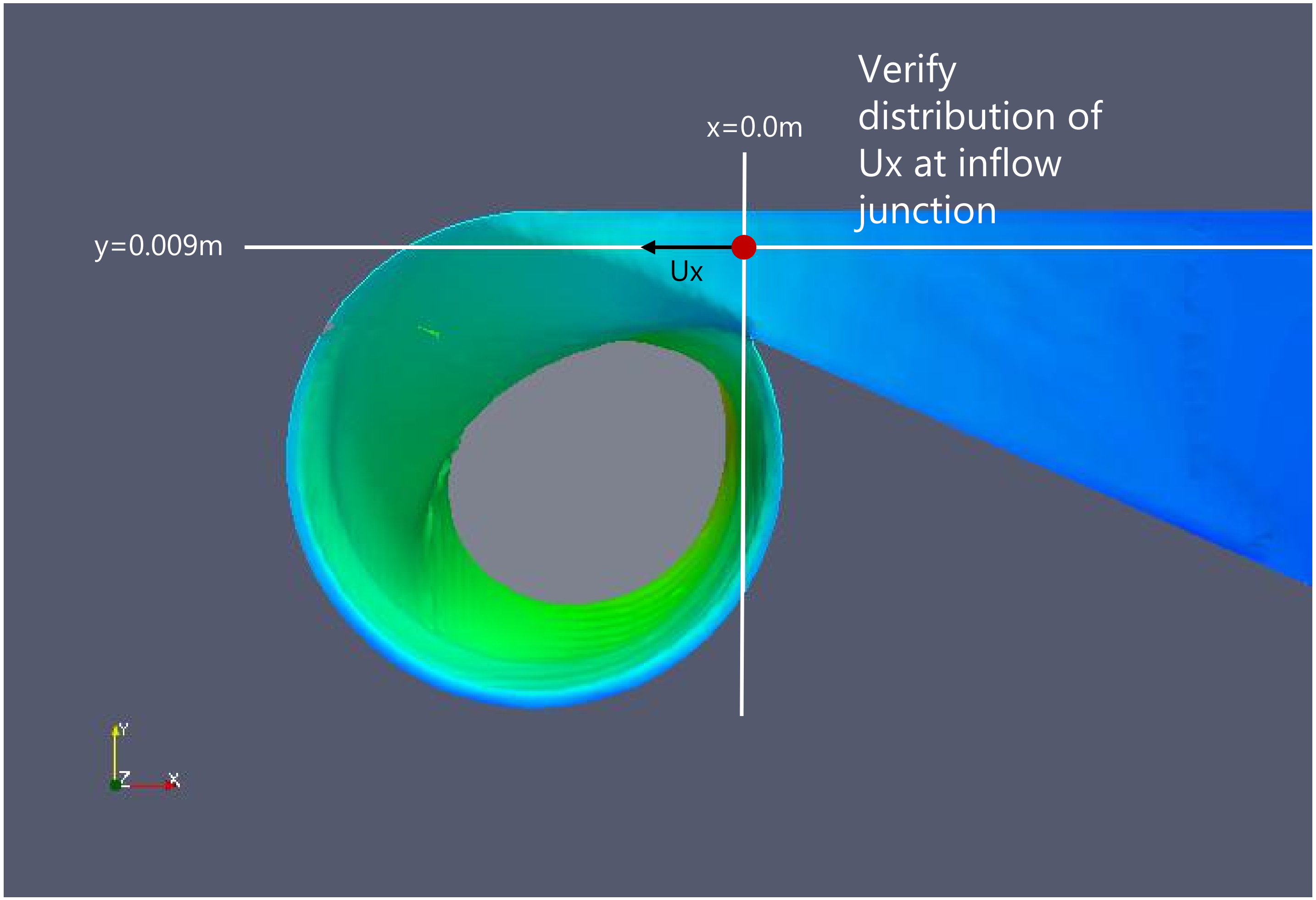
Velocity distribution at inflow junction



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Velocity distribution of swirling flow near to the throat