Fully Resolved Wind Turbine Simulation with OpenFOAM

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Purpose Investigate the performance of a diffuser augmented wind turbine

Outline Validate the current results against experimental data. Study the power extraction performance of the bare wind turbine at different tip speed ratios. Investigate the improvement in performance with various types of diffusers.

Computing system: SQUID General

(v60823) Purpose CPU nodes

node-hour	6000 node-hour
memory used	10000 GB
parallelize	380 nodes

Results

1.1 Geometry model

Here is the model of wind turbine, mainly including:

- tower
- nacelle
- hub
- support structure
- blade
- diffuser

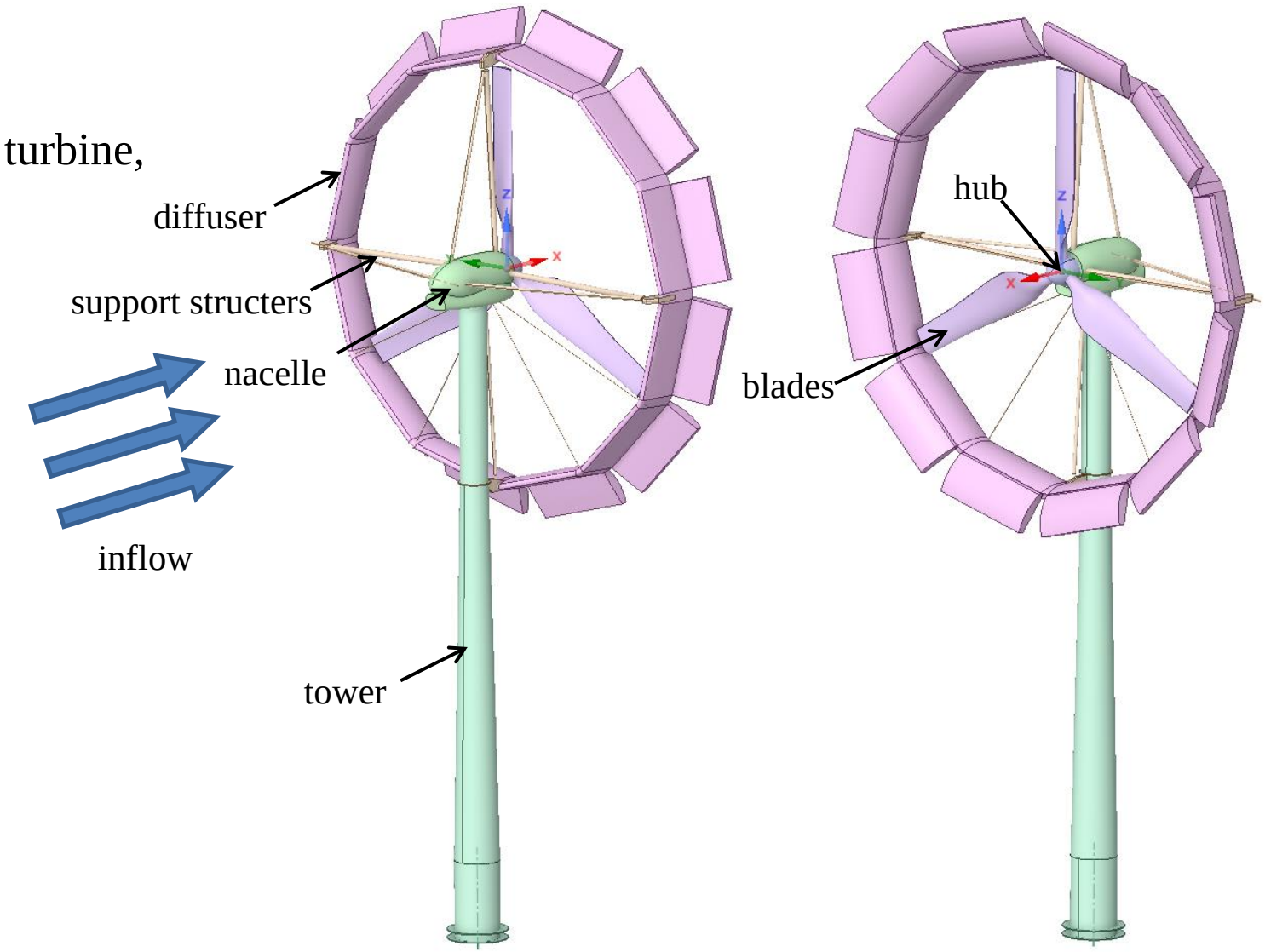


Fig. 1 Schematic of wind turbine model

Results

1.1 Geometry model

- To simulate the wind turbine, it needs to simplify the geometry model, shown in the right figure.
- In this study, the support structures, nacelle and hub are disregarded.
- It helps the simplification of mesh generation process and reduces the time cost of simulation.

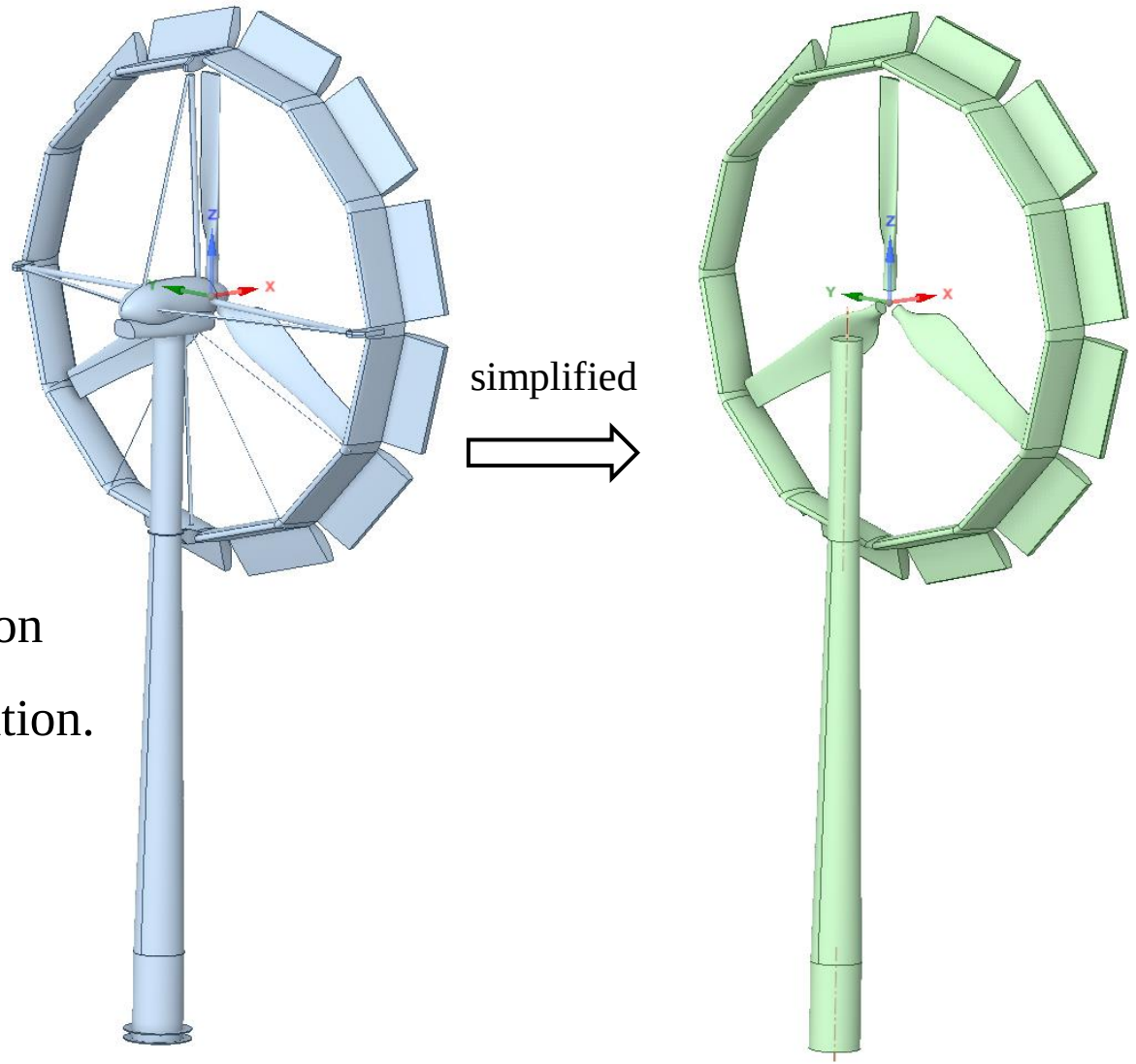
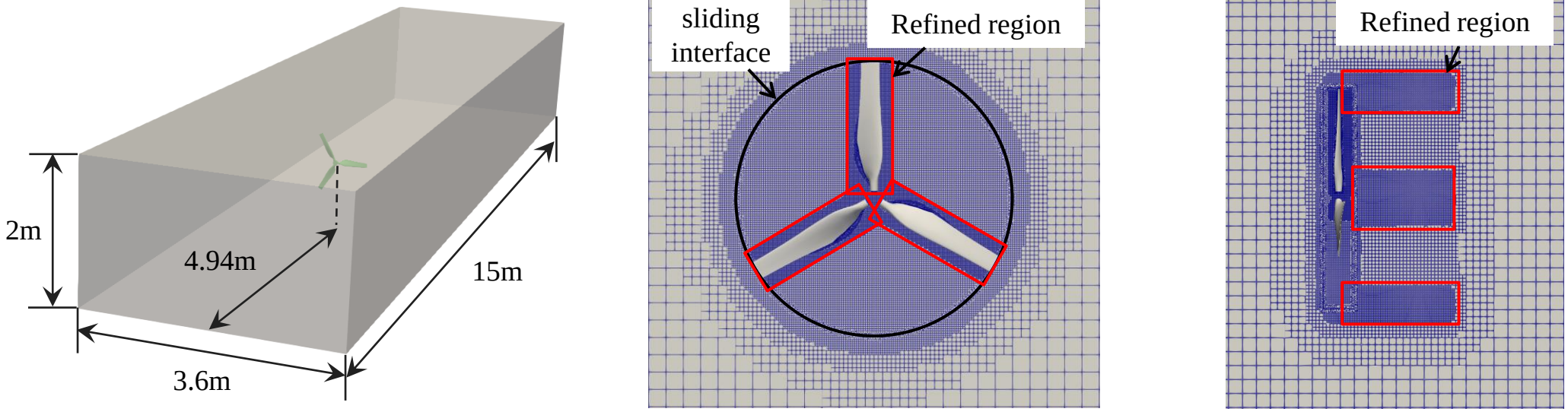


Fig. 2 Simplification of wind turbine model

Results

1.2 Generate the mesh of the wind turbine

- The mesh around the blades has been refined to improve accuracy in the results.
- The mesh in the downstream region has been refined to capture the wake characteristics more accurately.



(a) Simulation domain

(b) Slice by *x* axis

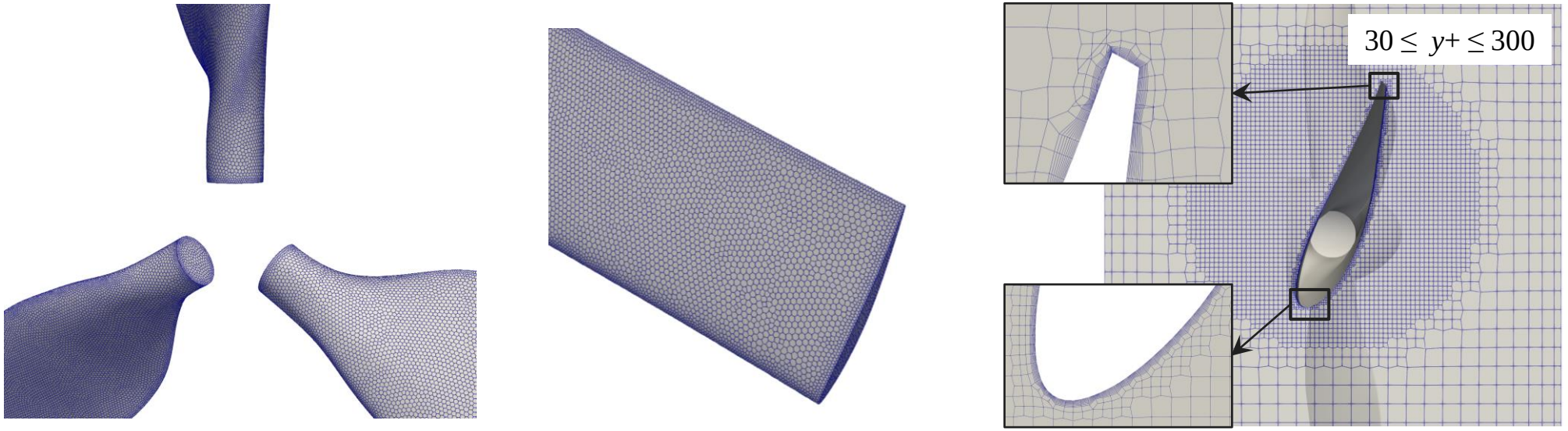
(c) Slice by *y* axis

Fig. 3 Schematic of the simulation mesh

Results

1.2 Generate the mesh of the wind turbine

- Here, it shows the mesh details around the root and tip region of the blades.



(a) Root of the blades

(b) Tip of the blade

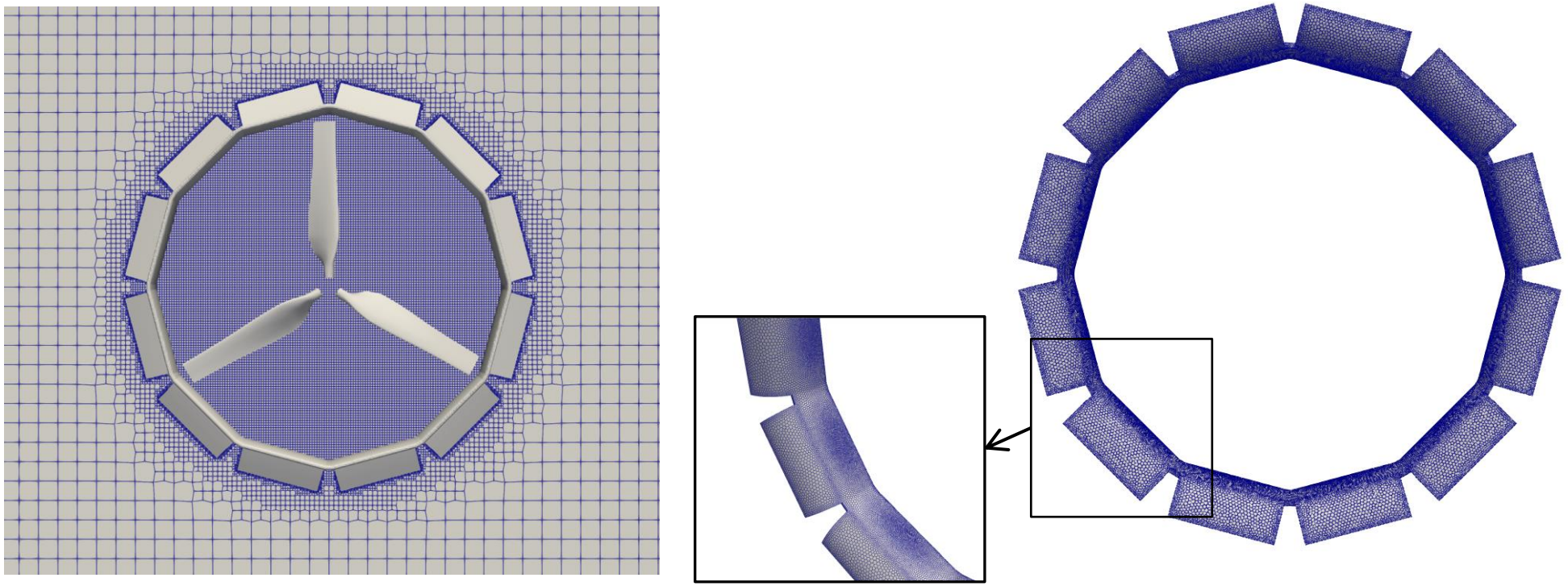
(c) Local mesh of the blade

Fig. 4 Details of the simulation mesh

Results

1.2 Generate the mesh of the wind turbine

- The mesh with the diffuser is shown below:



(a) Slice by *x* axis

(b) Mesh details of the diffuser

Fig. 5 Mesh of wind turbine with the diffuser

Results

2.1 Mesh convergence verification

- Simulation results with three different mesh resolutions:

- The simulation results are simulated by different mesh resolutions (Coarse, medium and fine) with different node numbers on foil surface and *y*+.
- The medium mesh reaches a relatively good result, and it is conducted in the following calculations.

Table 1 Comparisons of power coefficient C_P between different mesh resolutions

Mesh	Grids	λ	*Tr* (Nm)	*Cp*
Coarse	1,490,000	4.2	0.66	0.31
Medium	2,630,000	4.2	0.69	0.33
Fine	3,490,000	4.2	0.70	0.34

Results

2.2 Validation with NREL (National Renewable Energy Lab) experiment

Table 2 Parameters of experiment

Conditions	**unit**	**Values**
Radius	m	5.029
Wind speed	m/s	5-25
Test section	m	24.4 x 36.6
Rotational speed	rpm	72
Grids	cells	2, 797, 371
Processors		38

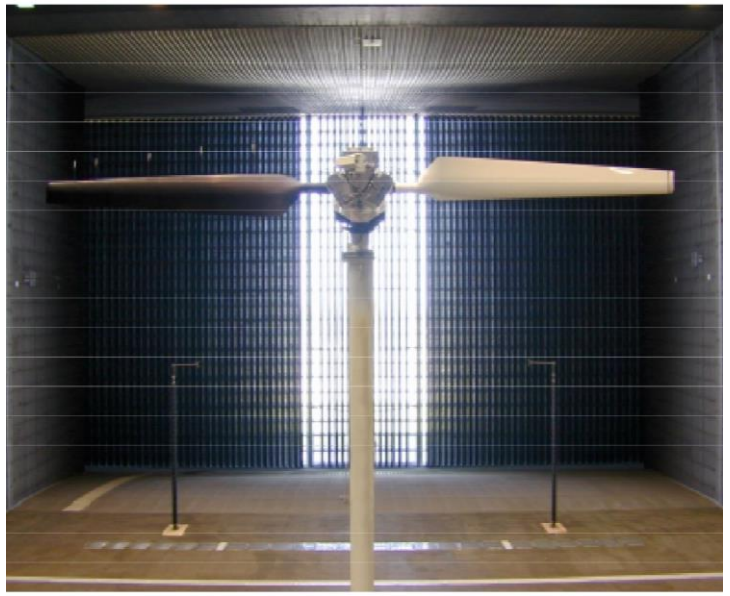


Fig. 6 NREL phase IV wind turbine

Results

2.2 Validation with NREL (National Renewable Energy Lab) experiment

- The present results demonstrate strong agreement with the experimental and numerical data across various inflow velocities.

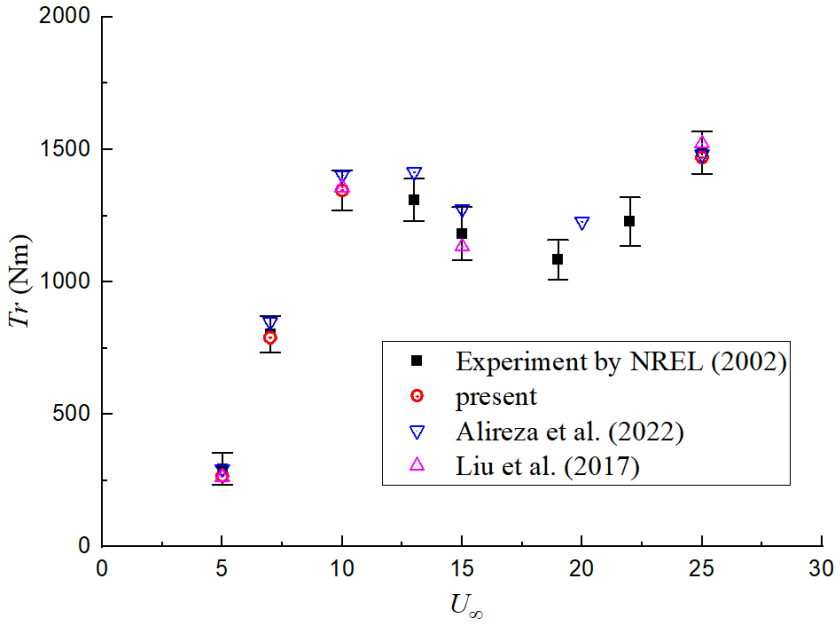


Fig. 7 Comparisons of experimental and simulation results

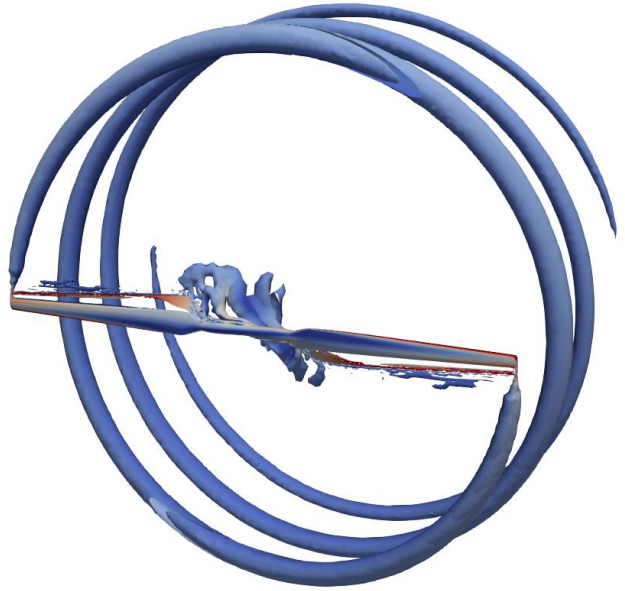
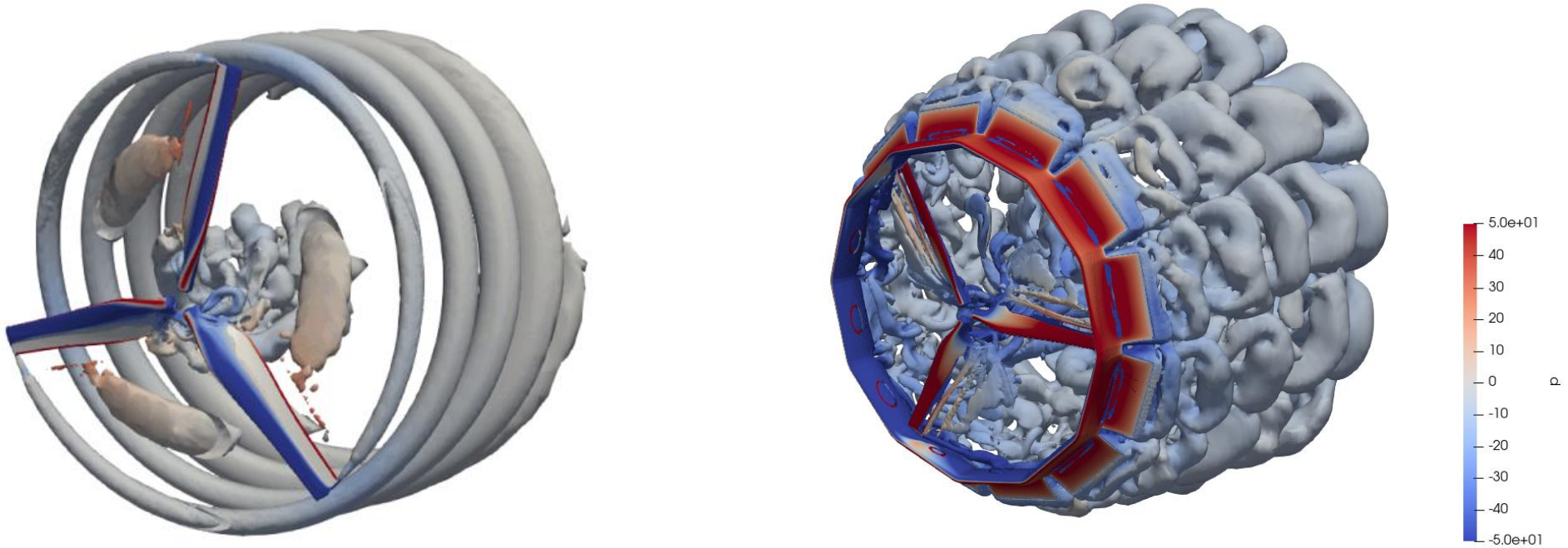


Fig. 8 Wake topology by *Q*-Criterion, colored by velocity (U = 5m/s)

Results

3.1 Present results of the wind turbine

- The torque will initially increase, then decrease, and eventually stabilize at a steady level.



(a) Bare (b) With diffuser

Fig. 9 Wake topology by Q-Criterion, colored by pressure

Results

3.1 Present results of the wind turbine

- The maximum power coefficient C_p reaches about 0.774 at $\lambda = 3.6$ with an increase of 70.9% compared with the bare wind turbine.
- For the bare wind turbine, the simulation results exceed the experimental findings by an average of 10%.

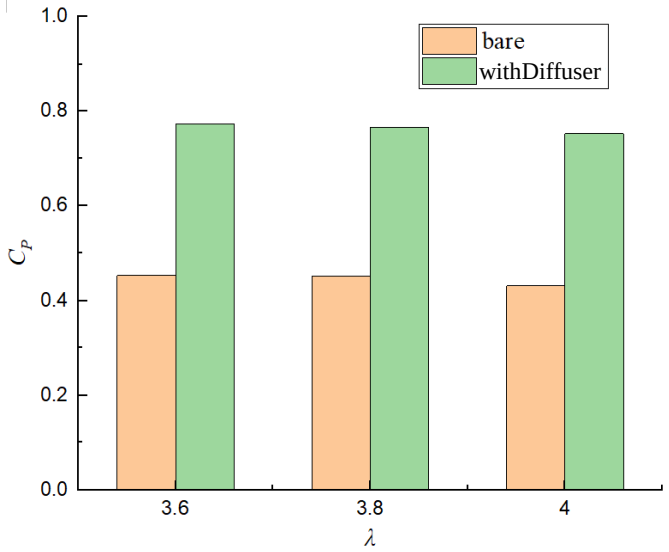


Fig. 10 Comparisons of power coefficient C_P

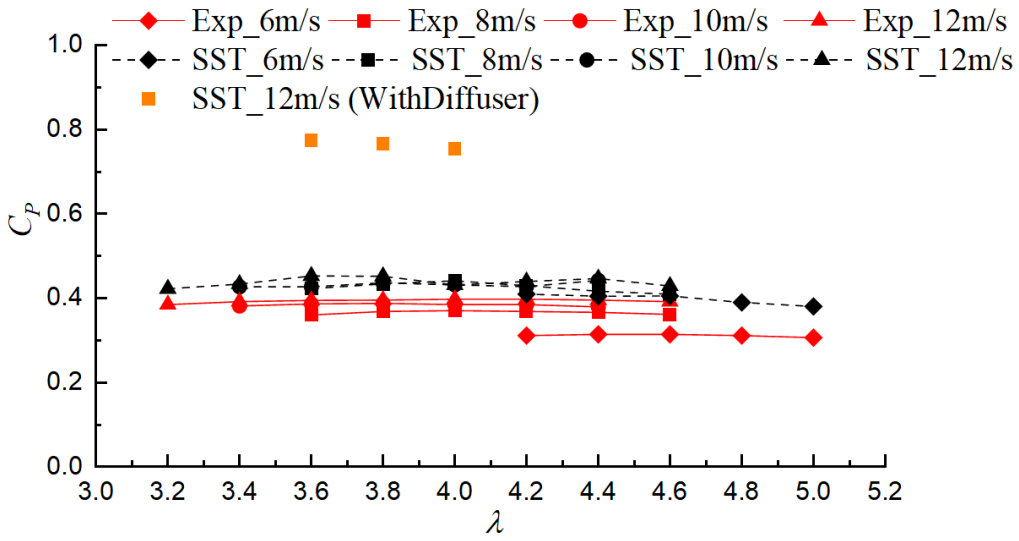


Fig. 11 Comparisons of power coefficient C_P between OpenFOAM and experimental results

Results

3.1 Present results of the wind turbine

- Compare the result (added a tower) with present result (without a tower)

Table 3 Parameters of the case

Conditions	**unit**	**Values**
Wind speed	m/s	12
Test section	m	3.6 x 2.0
Tip-speed ratio		3.6
Grids	cells	5, 979, 096
Processors		38
Calulated time	hours	120
Simulation time	period	5.5

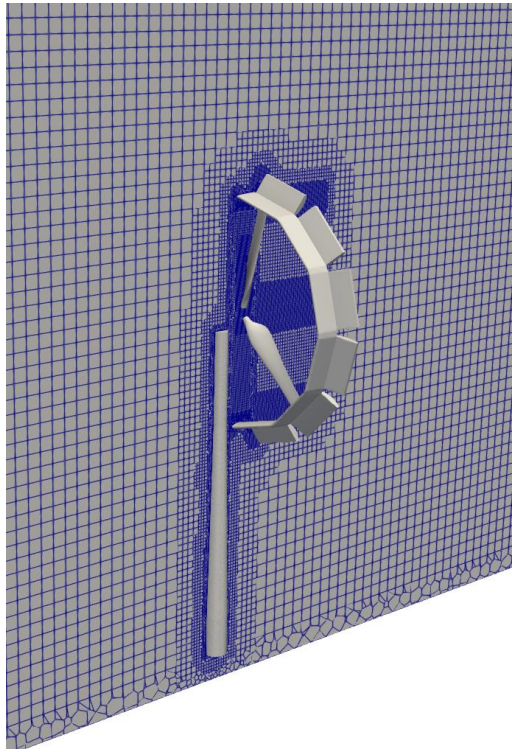


Fig. 12 Mesh of wind turbine with a tower

Results

3.1 Present results of the wind turbine

- Compare the result (added a tower) with present result (without a tower)

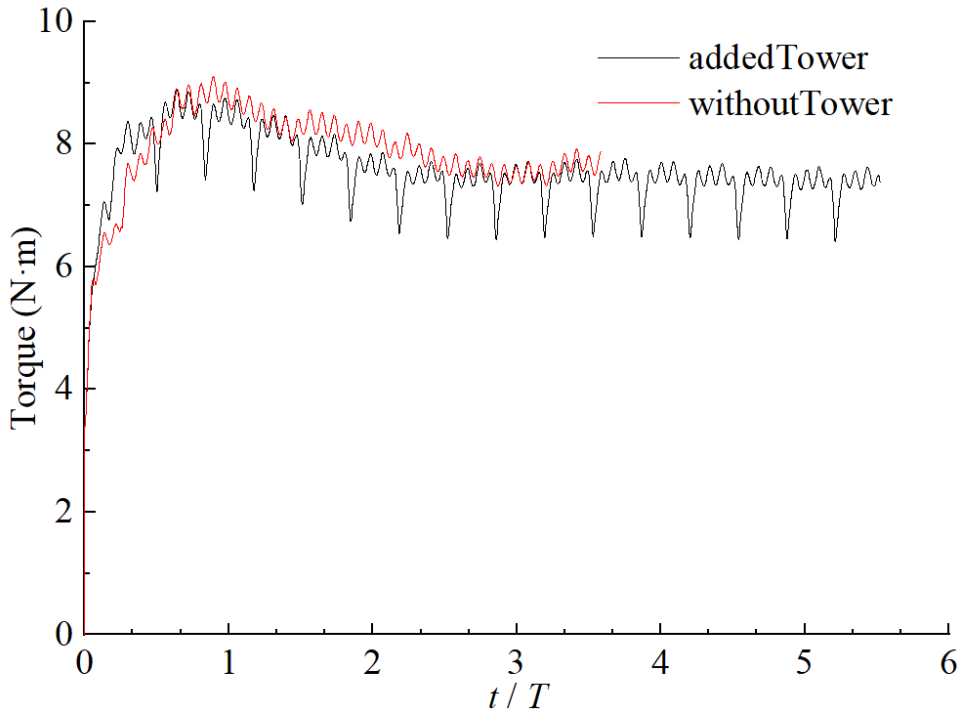


Fig. 13 Torque Tr vs time (Simulation result)

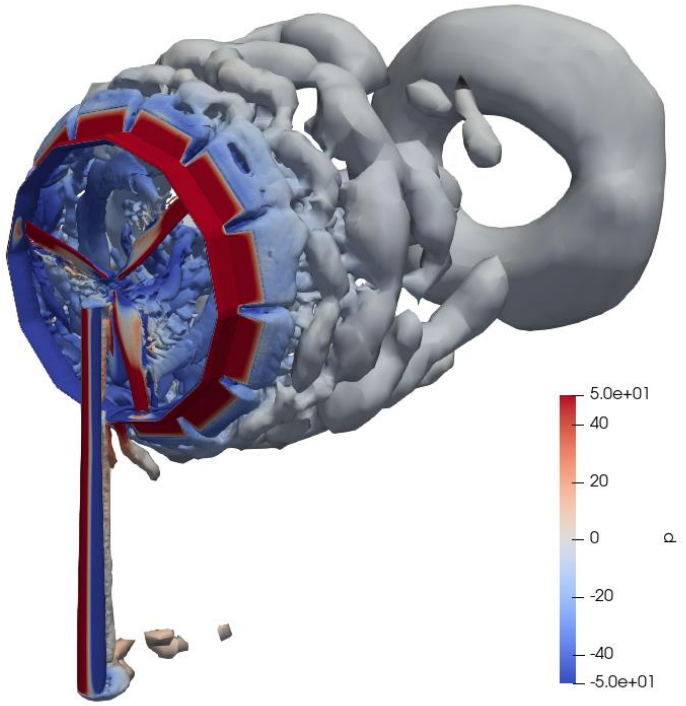


Fig. 14 Simulation result (t / T = 4.2, Q =30)

Results

3.2 Present results of the wind turbine (new type)

- Drag coefficient C_d for the diffuser 3AD000TC200 is calculated (Full size, D_{rotor} = 21.12 m)
- The maximum value for rotor is reached at λ = 4.2, $C_d = F_D / (0.5 \bullet \rho \bullet U^2 A_{rotor}) = 1.094$
- The maximum value for diffuser is reached at λ = 4.2, $C_d = F_D / (0.5 \bullet \rho \bullet U^2 A_{rotor}) = 0.422$

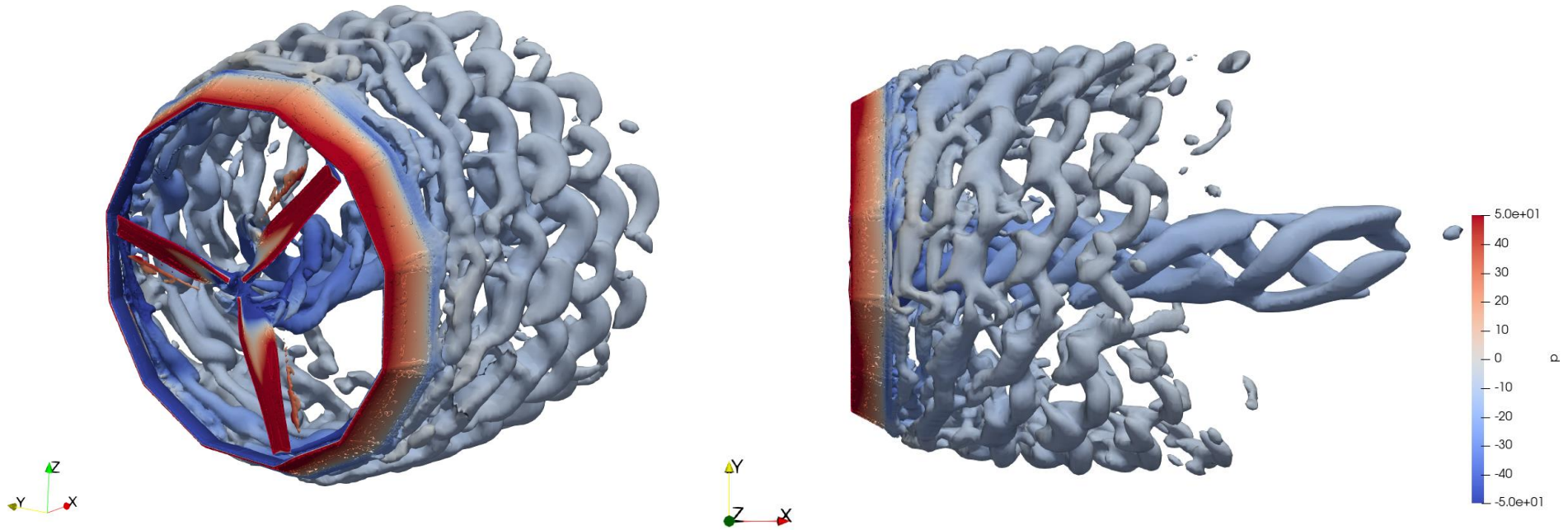


Fig .15 Wake topology by λ_2-Criterion, colored by pressure

Results

3.2 Present results of the wind turbine (two rotors)

- The case 3AD000TC200, λ = 4.2 has been calulated by two models, namely $k\omega$-SST and LES (SA-DES) models.
- Two results $C_{P\text{-SST}}$ = 0.814, $C_{P\text{-SADES}}$ = 0.786 (for SST, is higher about 3.4%).

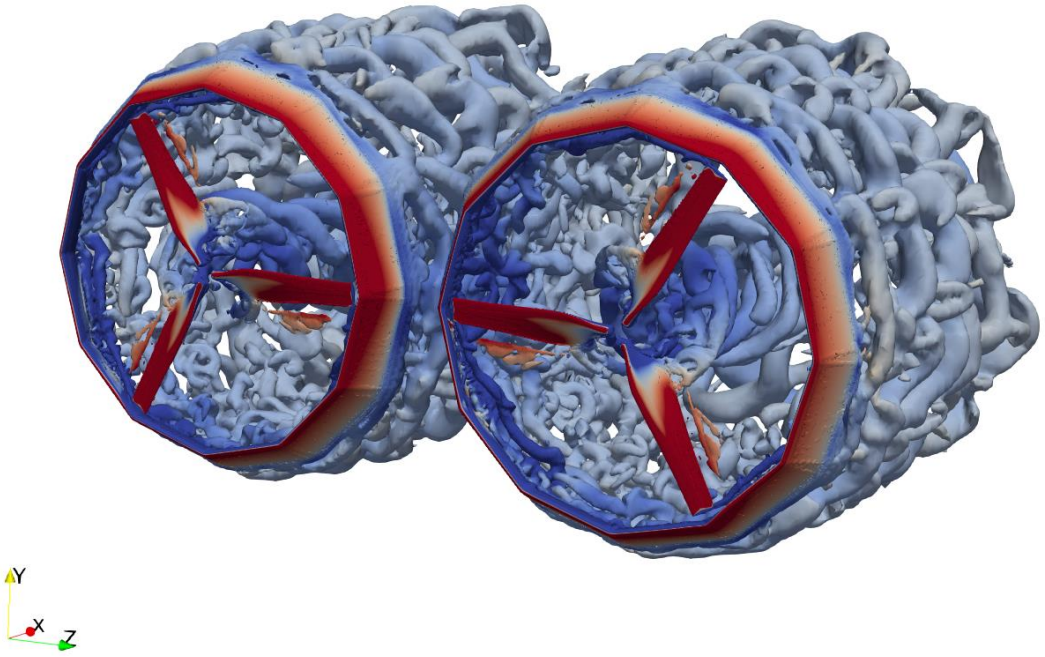


Fig. 16 Wake topology by λ_2-Criterion, colored by pressure ($k\omega$-SST)

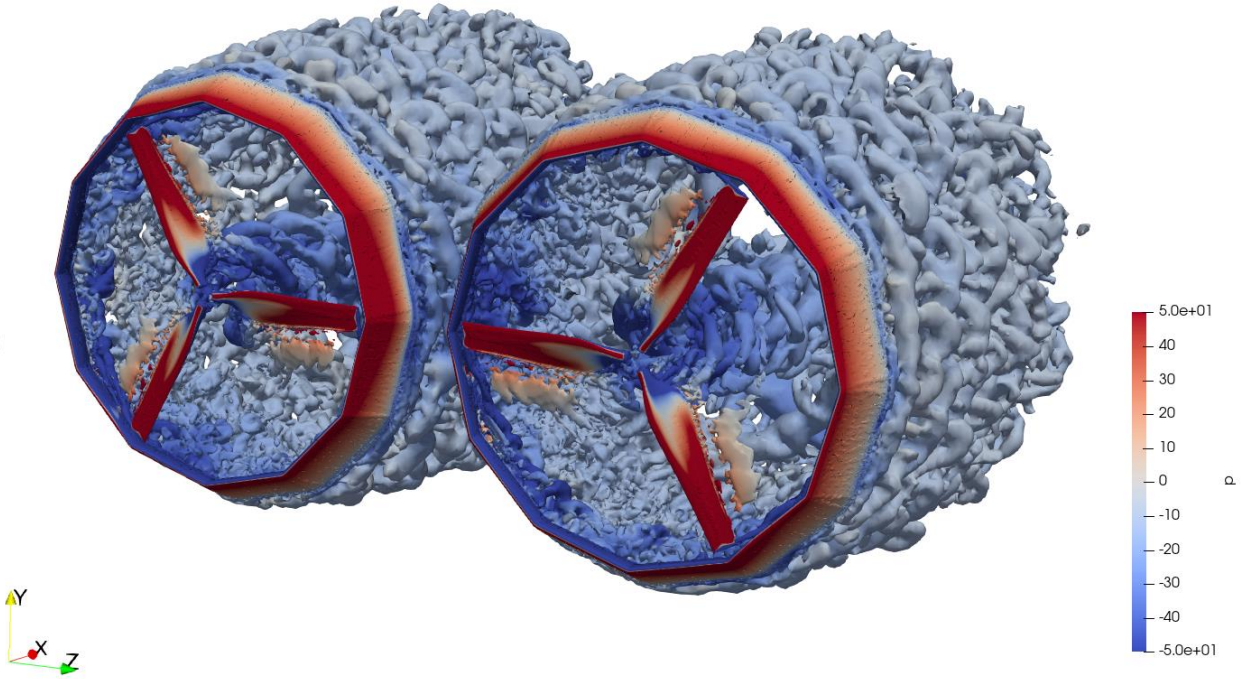


Fig. 17 Wake topology by λ_2-Criterion, colored by pressure (SA-DES)

Summary

1. For a bare wind turbine, the power coeffcient CP can reach up to about 0.42.
2. The maximum power coefficient Cp reaches about 0.774 at λ = 3.6 with an increase of 70.9% compared with the bare wind turbine.
3. Due to the tower shadow effect, the power loss is estimated to be approximately 3%.
4. For two rotors configuration, the increase is about 11.7% for 3AD at λ = 4.0, compared to a single turbine with diffuser.