DEVELOPMENT OF A METHODOLOGY FOR THE NUMERICAL SIMULATION OF TIDAL TURBINES

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Introduction

- NREL Phase VI turbine.
- Single Moving Reference Frame (SRF)
- Virtual Blade Model (VBM)
- Actuator Disk Model (ADM)
- Main focus is the far wake of the turbine.

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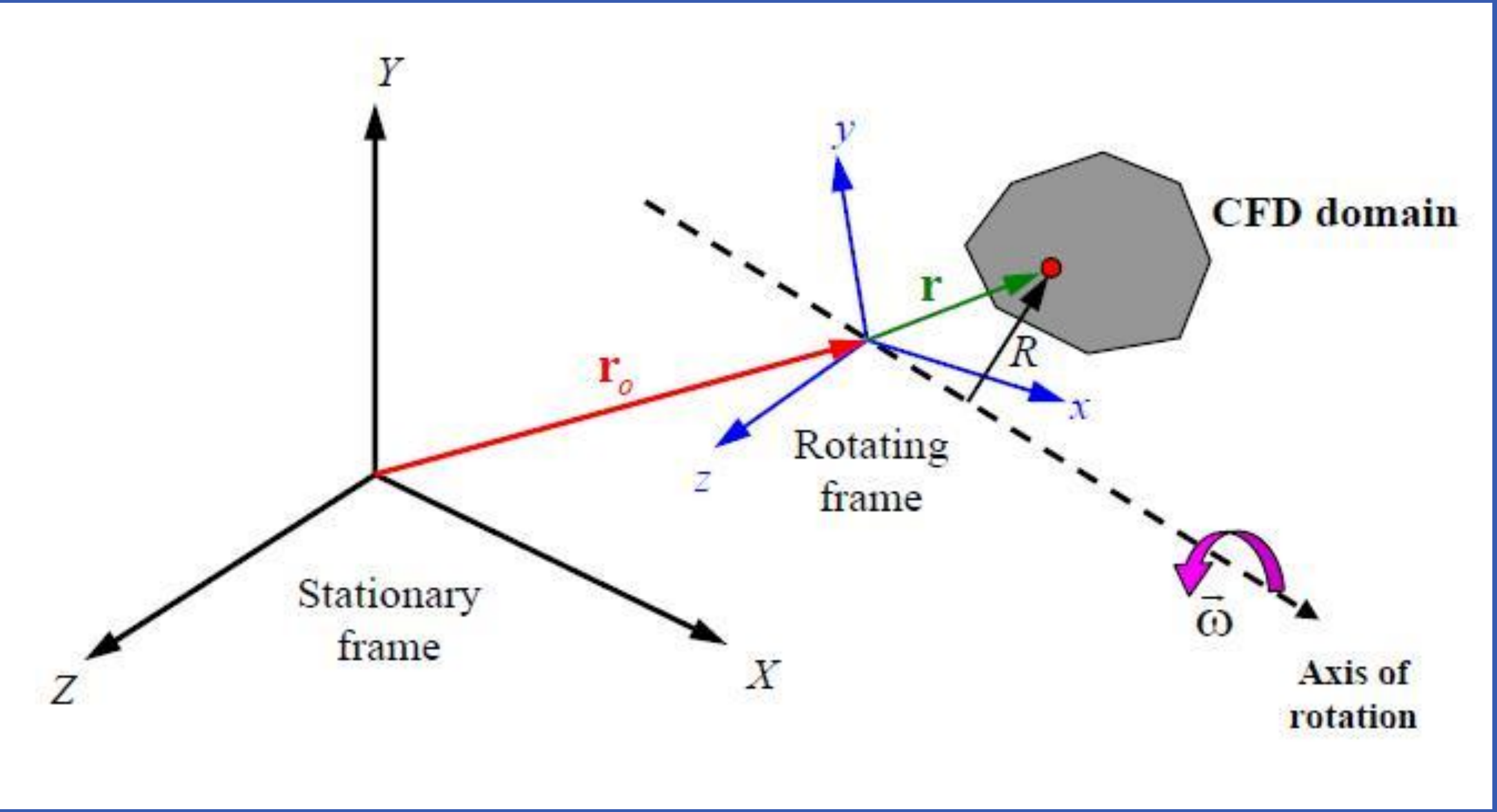
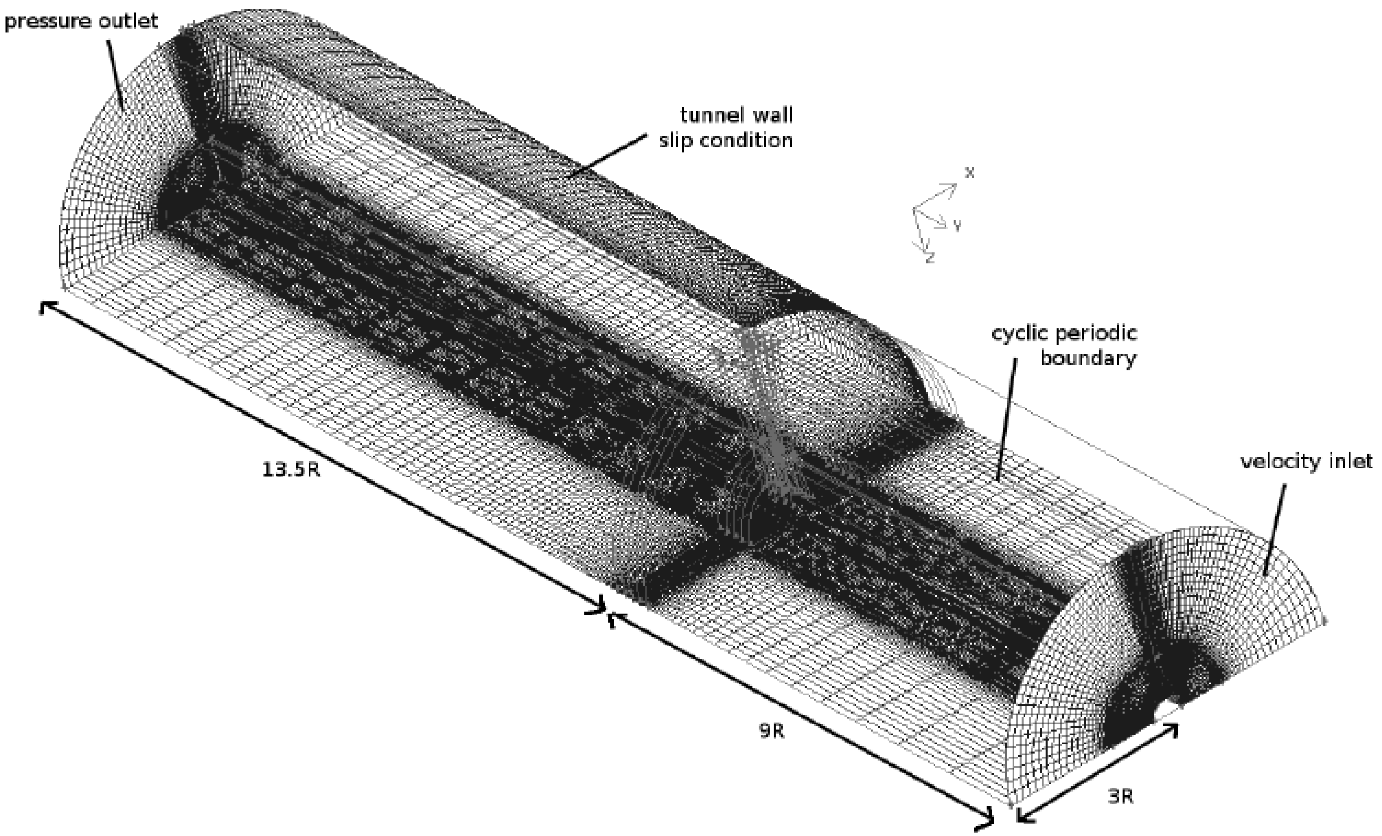
Single Moving Reference Frame

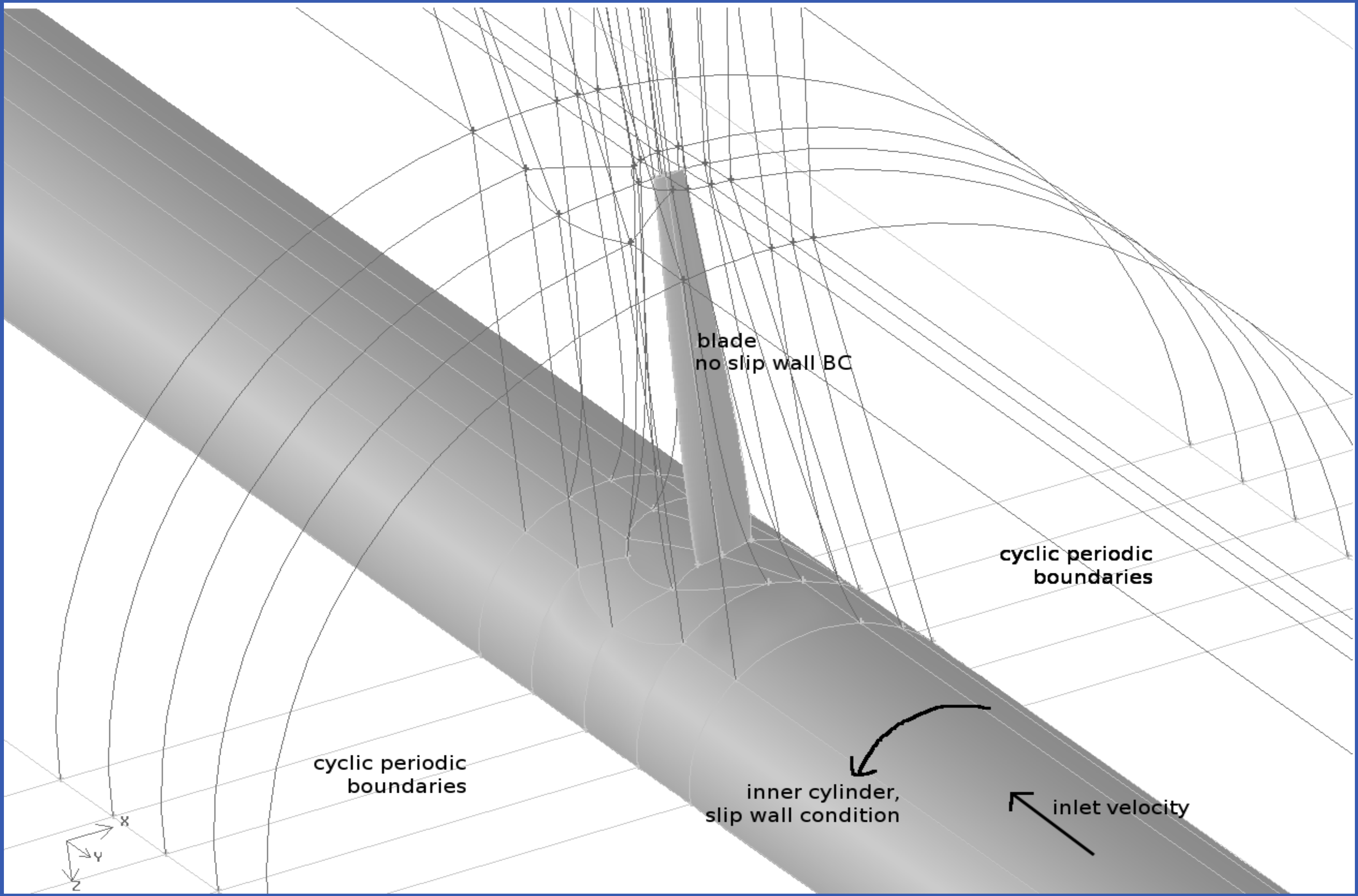
SRF is a model to simulate rotating flows with axisymmetric boundary conditions in a simplified environment.



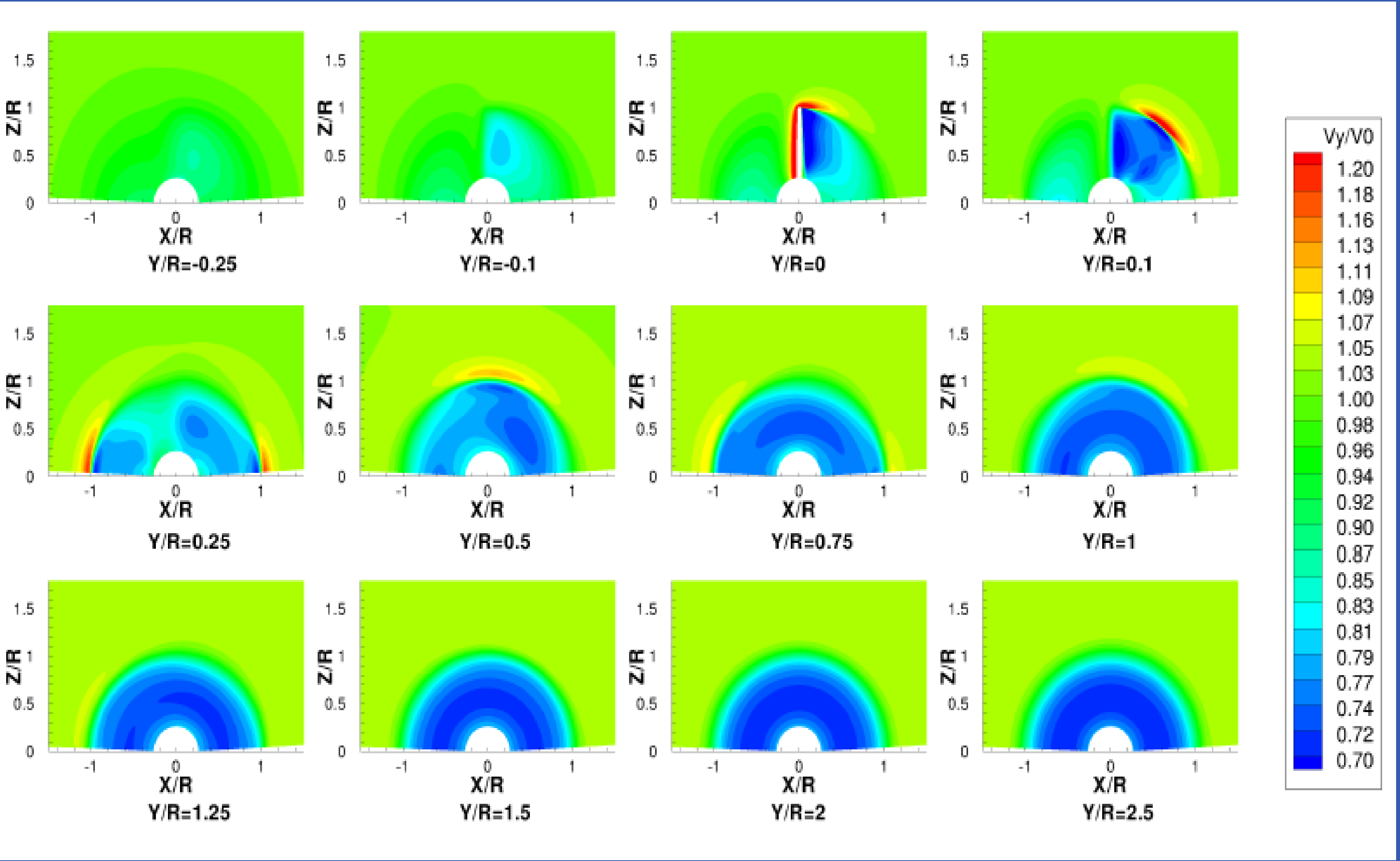
Single Moving Reference Frame (SRF)



Single Moving Reference Frame (SRF)



Results from SRF



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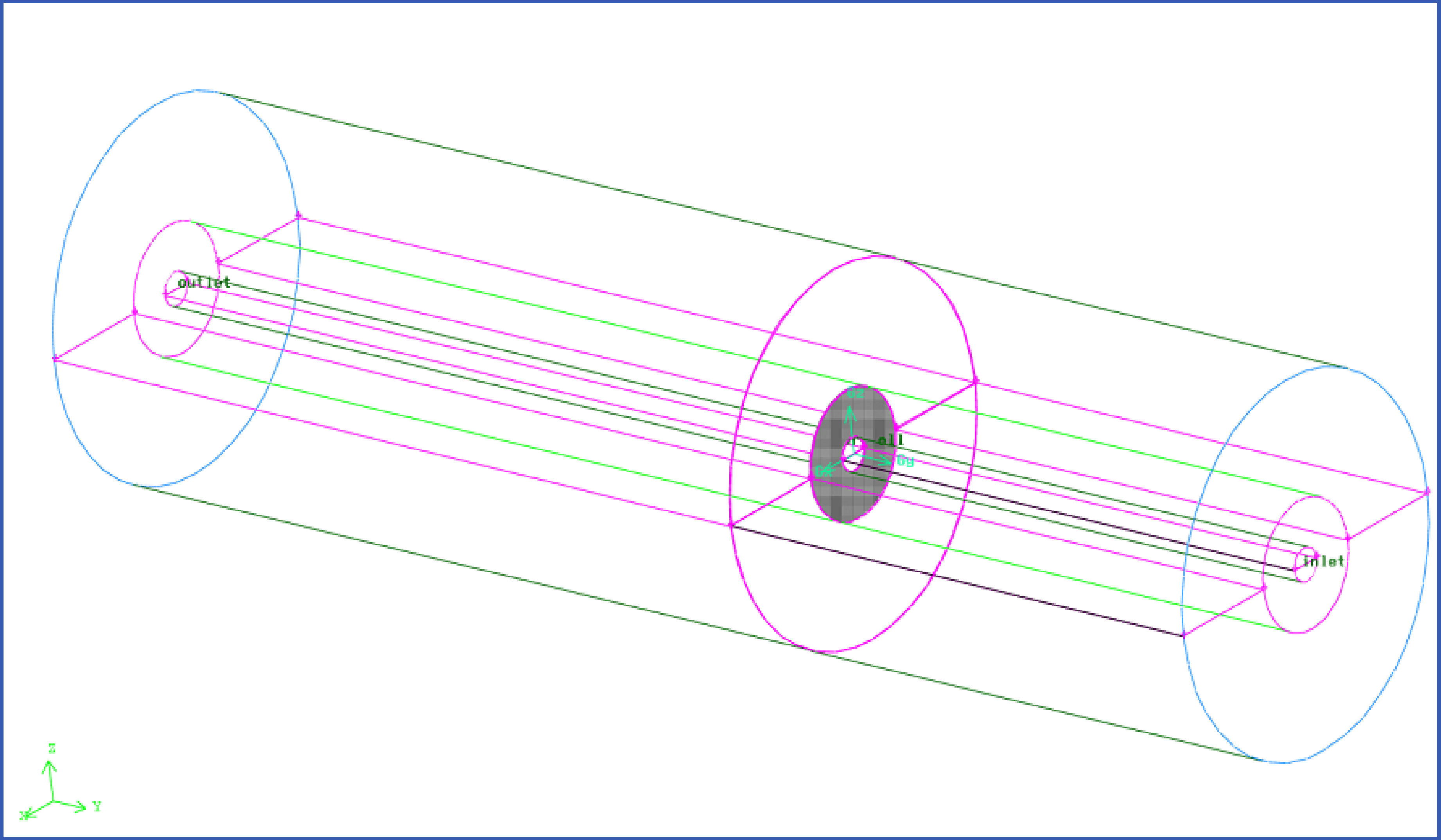
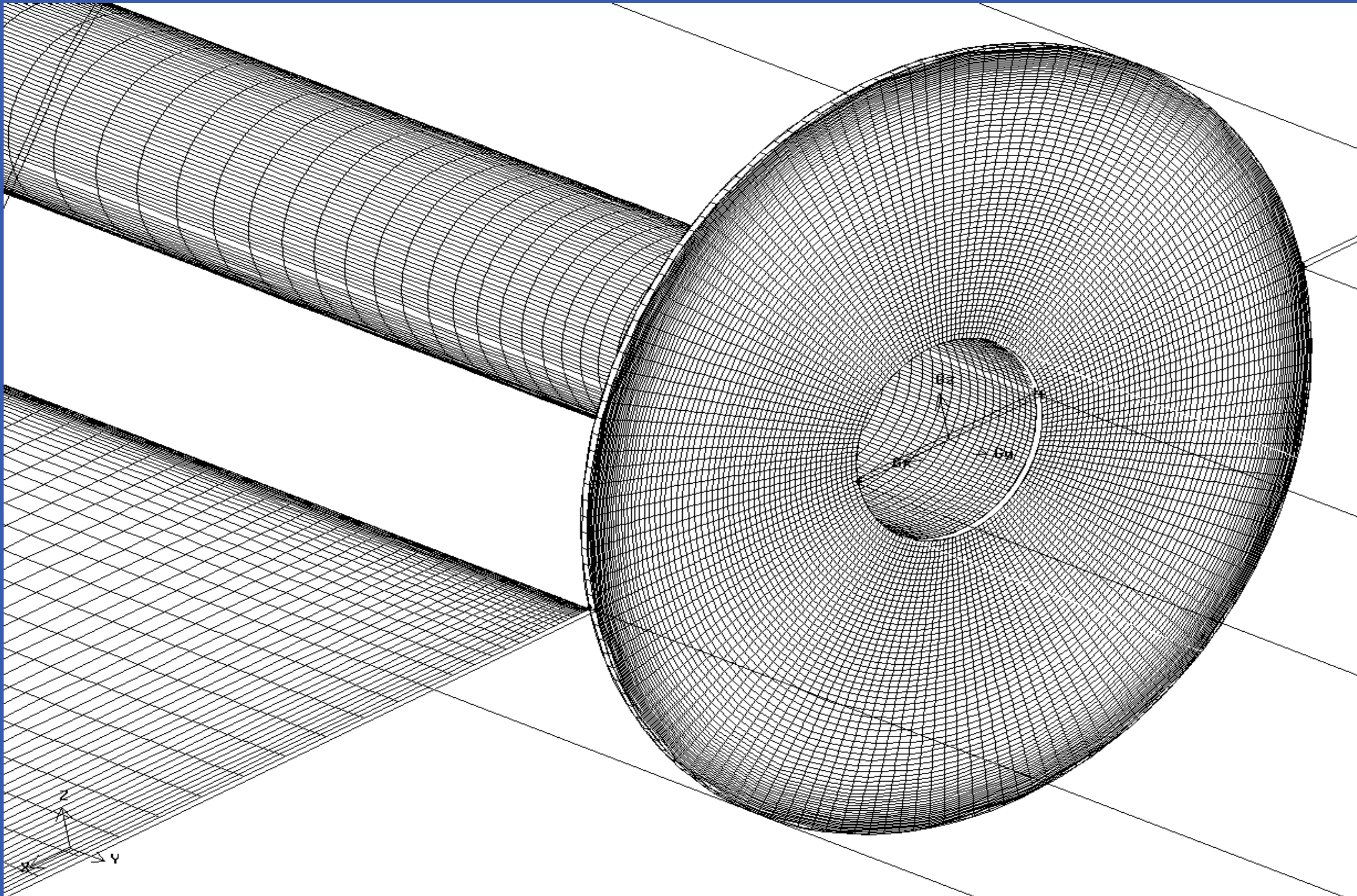
Virtual Blade Model (VBM)

- In this model the geometry of the blades and the flow around the blades are not resolved.
- Thus, the blades are accounted for, without actually being present (Blades are Virtual).
- This technique models the rotor through source terms in the momentum equation.

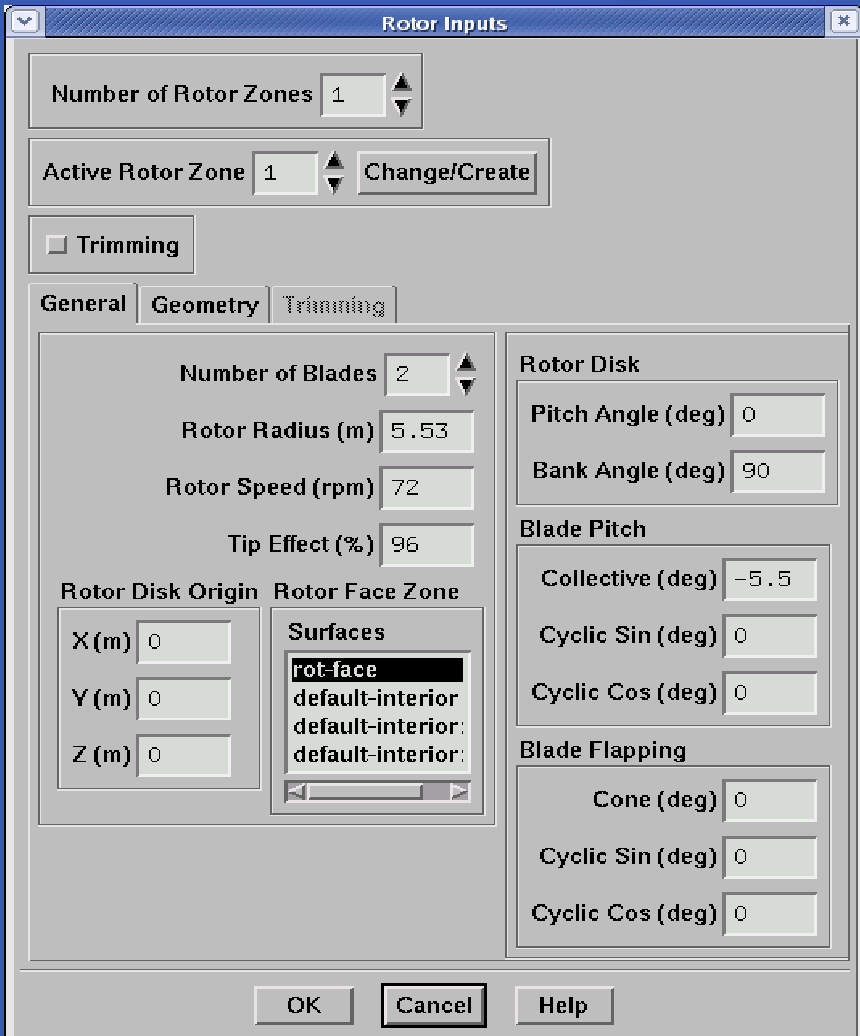
VBM Mesh

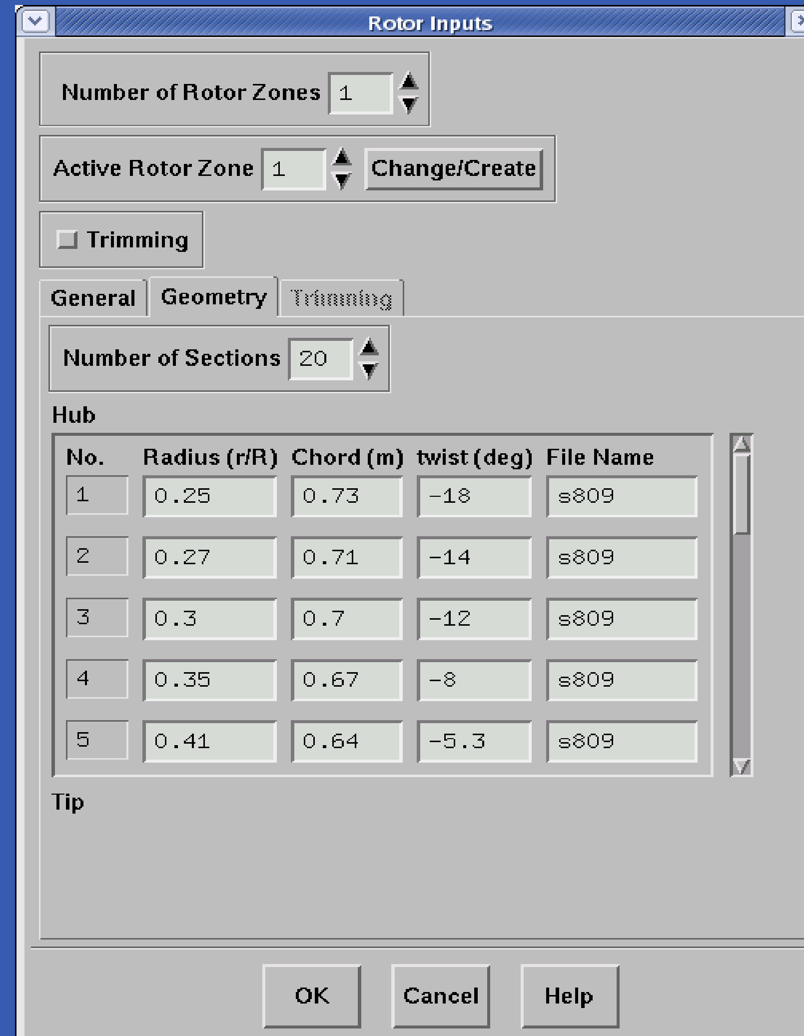


VBM Mesh



Inputs for VBM





- Plus a table of lift and drag coefficient as a function of Angle of Attack (AOA).

VBM Iteration Procedure

1. The source term is unknown at the beginning.
2. The initial velocity field is used to obtain a local AOA, Mach and Reynolds number.
3. Based on AOA, lift and drag coefficient will be interpolated from the look-up table.
4. The lift and drag forces will be calculated as fallow:

$$f_{L,D} = C_{L,D}(\alpha, Ma, Re) * c\left(\frac{r}{R}\right) * \frac{\rho . u_{tot}^2}{2}$$

5. New sources and then new velocity is calculated.
6. The iteration will repeated till convergence.

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Actuator Disk Model (ADM)

- Turbine is modeled as a homogeneous disk.
- The disk evenly spreads out the blades effect.
- The disk supports a pressure difference, but not an axial velocity difference.
- "Porous Disk"
- Two coefficients for modeling a Porous media.
- The coefficients were evaluated based on the Actuator Disk Theory and results from VBM.

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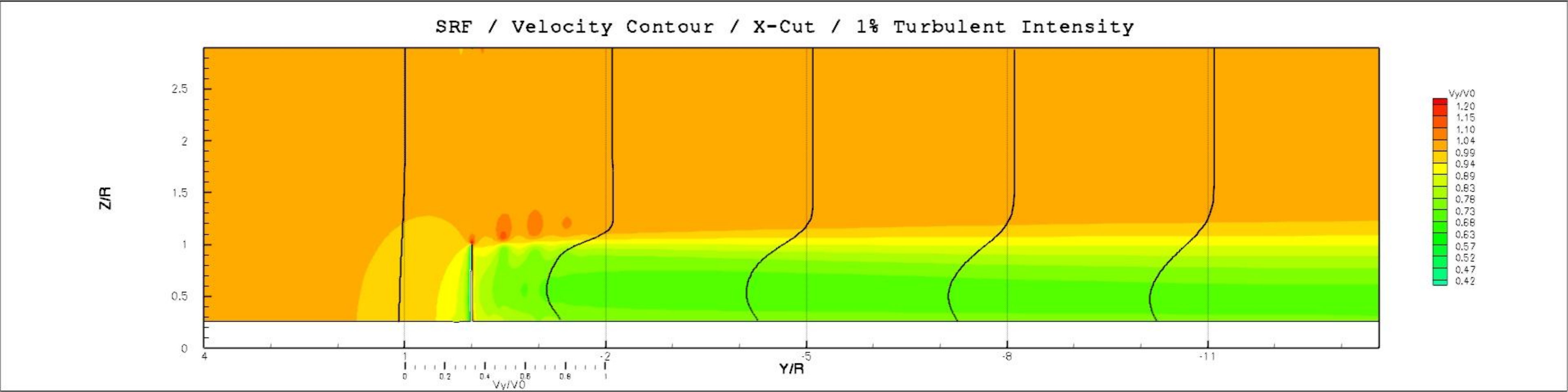
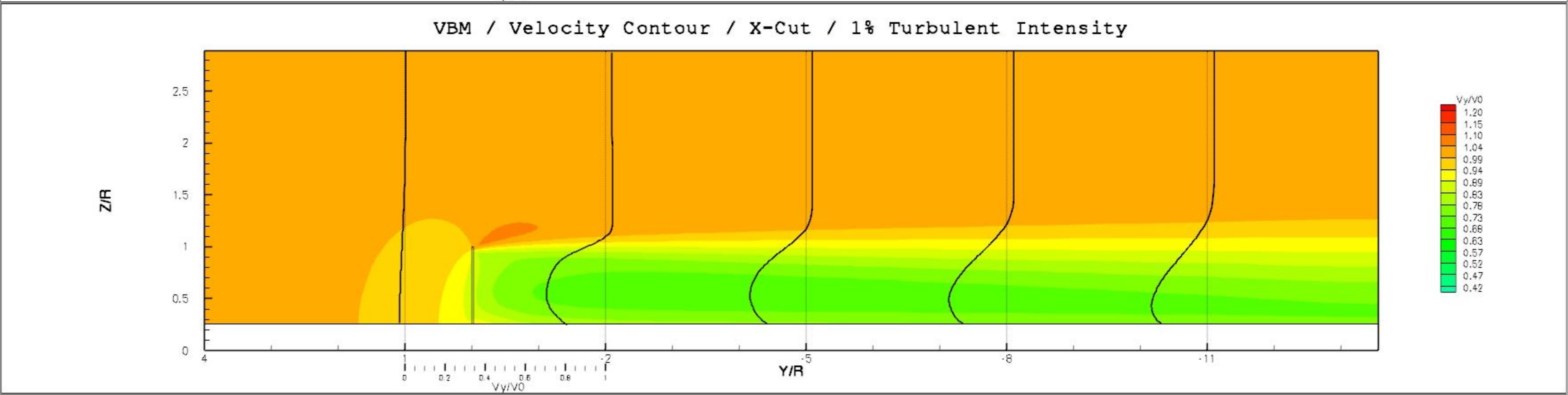


SRF / Velocity Contour / X-Cut / 1% Turbulent Intensity
Z/R
Y/R
Vy/V0
0 0.5 1 1.5 2 2.5
4 1 -2 -5 -8 -11
0 0.2 0.4 0.6 0.8 1
Vy/V0
1.20 1.15 1.10 1.04 0.99 0.94 0.89 0.83 0.78 0.73 0.68 0.63 0.57 0.52 0.47 0.42



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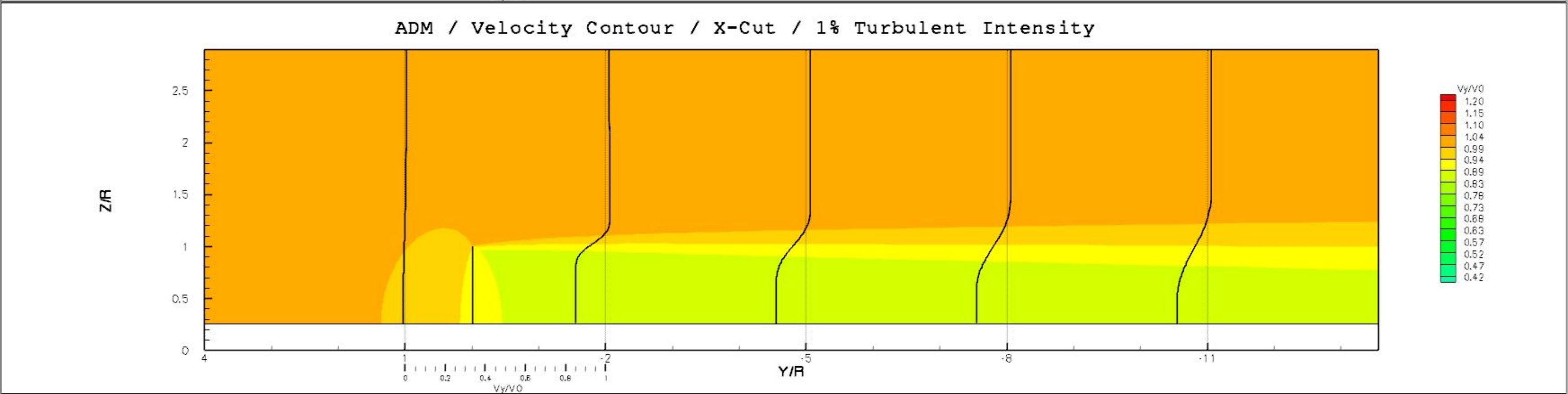
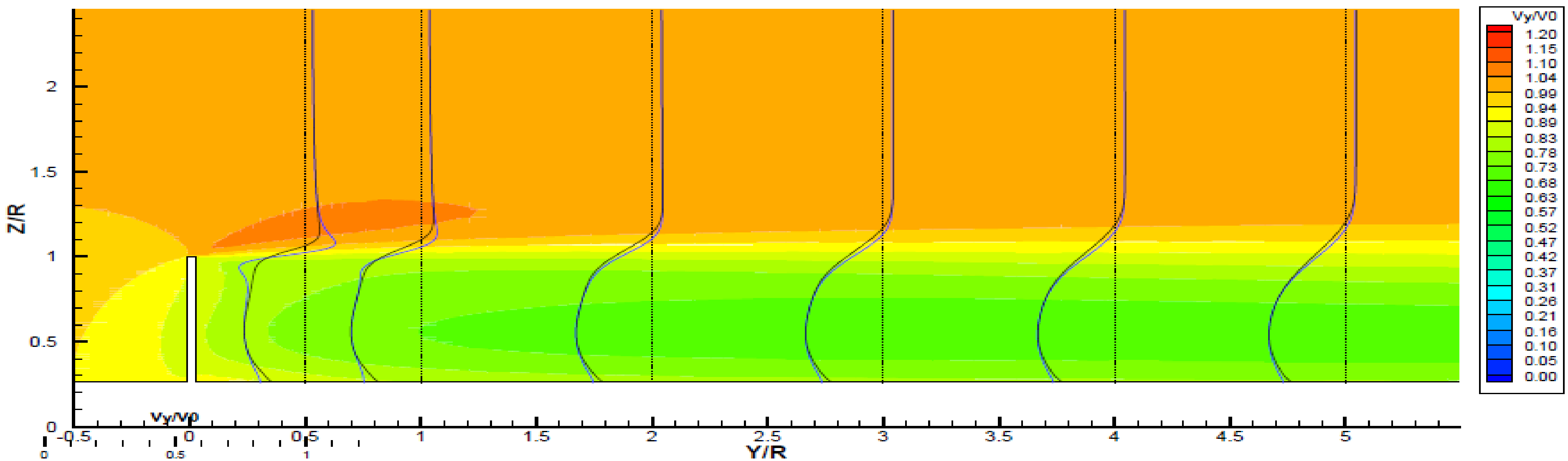


ADM / Velocity Contour / X-Cut / 1% Turbulent Intensity
Z/R
Y/R
Vy/V0
0 0.5 1 1.5 2 2.5
4 1 -2 -5 -8 -11
0 0.2 0.4 0.6 0.8 1
Vy/V0
1.20 1.15 1.10 1.04 0.99 0.94 0.89 0.83 0.78 0.73 0.68 0.63 0.57 0.52 0.47 0.42

SRF vs. VBM



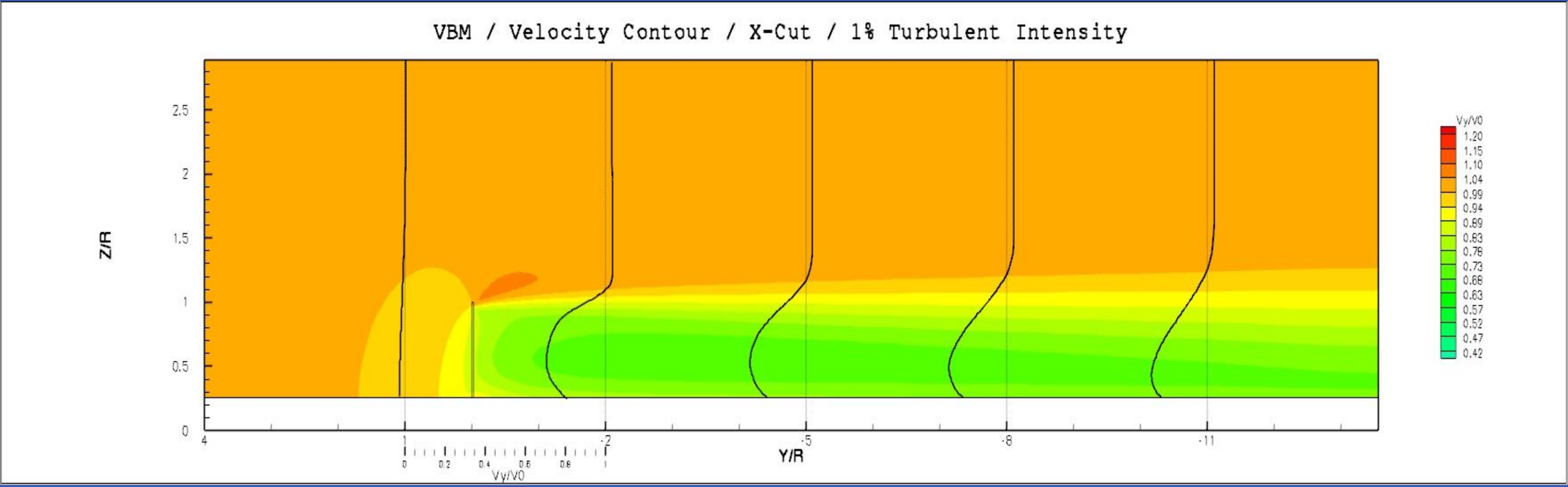
Model	Number of Mesh Element [mil.]	Number of Iterations	Calculated Power [Watt]
SRF	5.10	12000	5200
VBM	1.65	2500	5400

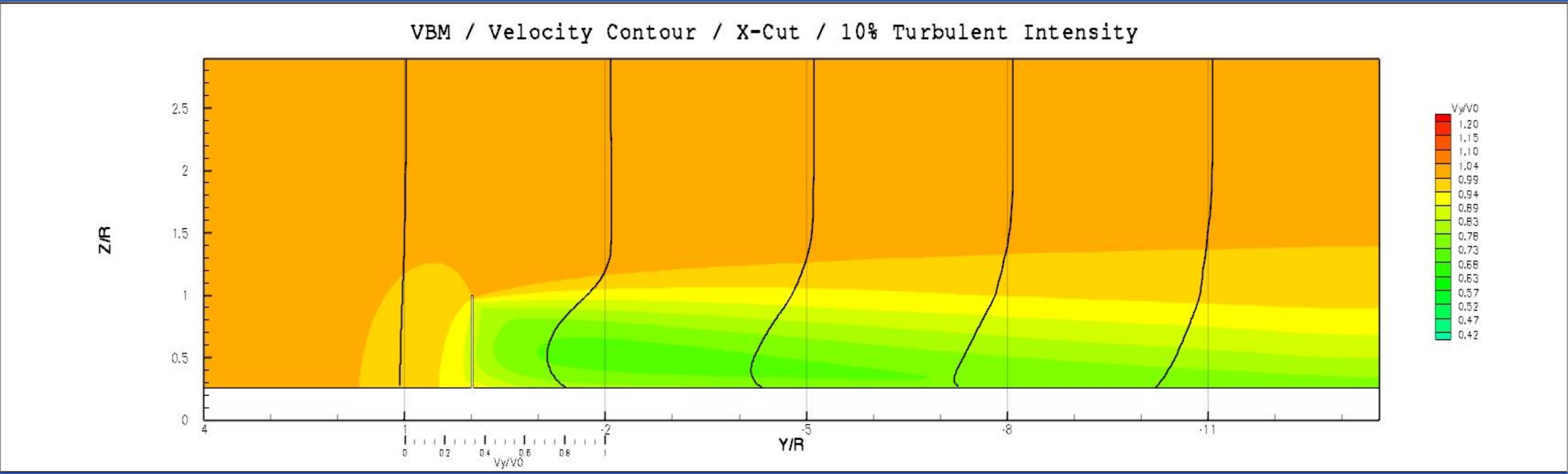
Changing Turbulent Intensity (TI)

- Turbulent Intensity for the first set of simulation was 1% based on NREL test conditions in the AMES wind tunnel.

- To have more realistic simulations, the background turbulence intensity was changed to 10%.

VBM 1% TI vs. VBM 10% TI



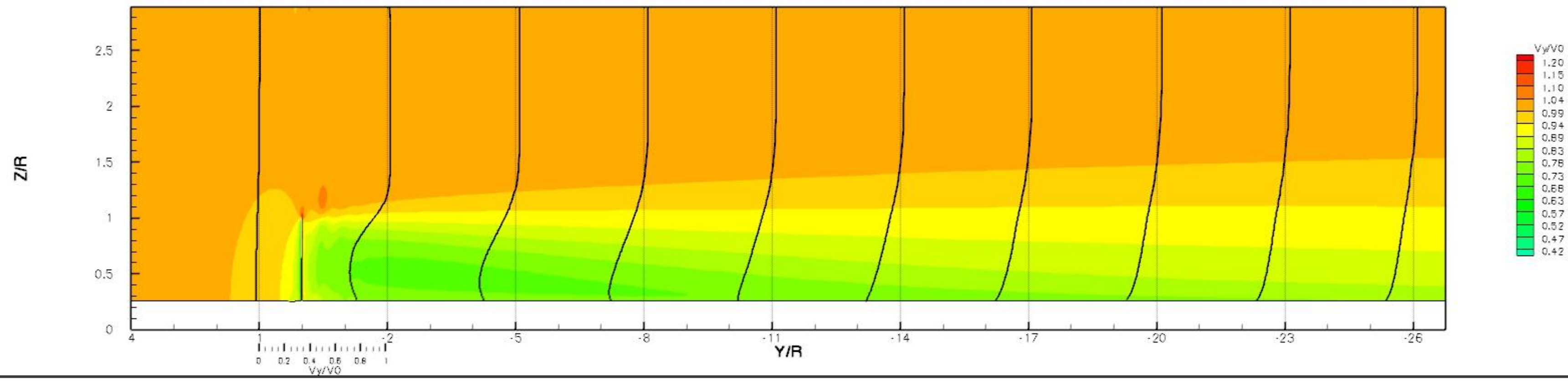


VBM 1% TI vs. VBM 10% TI

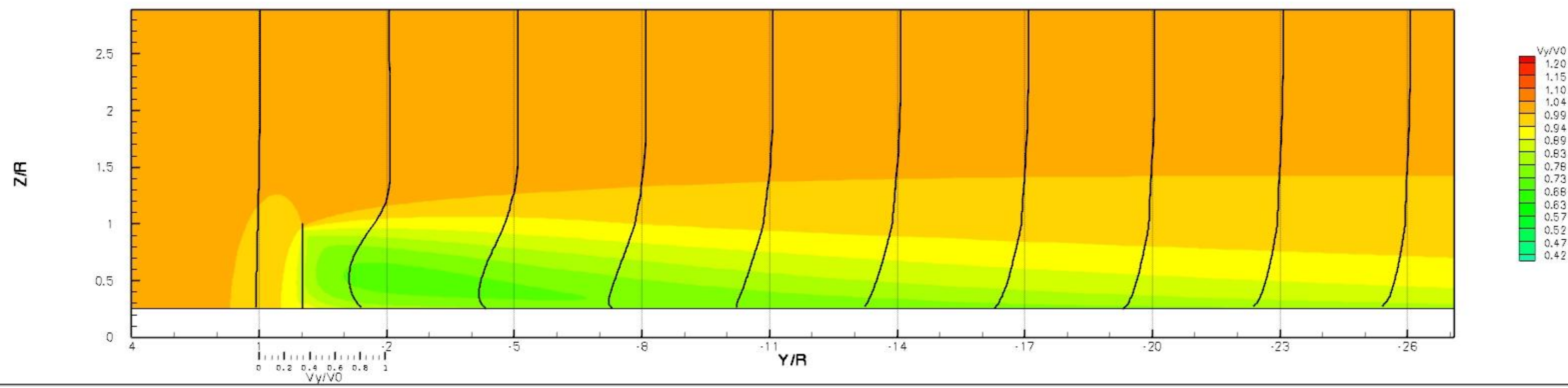
Turbulent intensity [%]	1.00	10.00	Difference [%]
Thrust [N]	1254.27	1258.00	0.30
Torque [N-m]	718.15	722.76	0.64
Power [Watt]	5414.75	5449.53	0.64
Min. Angle of Attack [deg]	5.12	5.21	1.76
Max. Angle of Attack [deg]	7.54	7.55	0.13

- Turbulent Intensity does not effect the amount of extracted power, but it has effect on length of the turbulent wake.

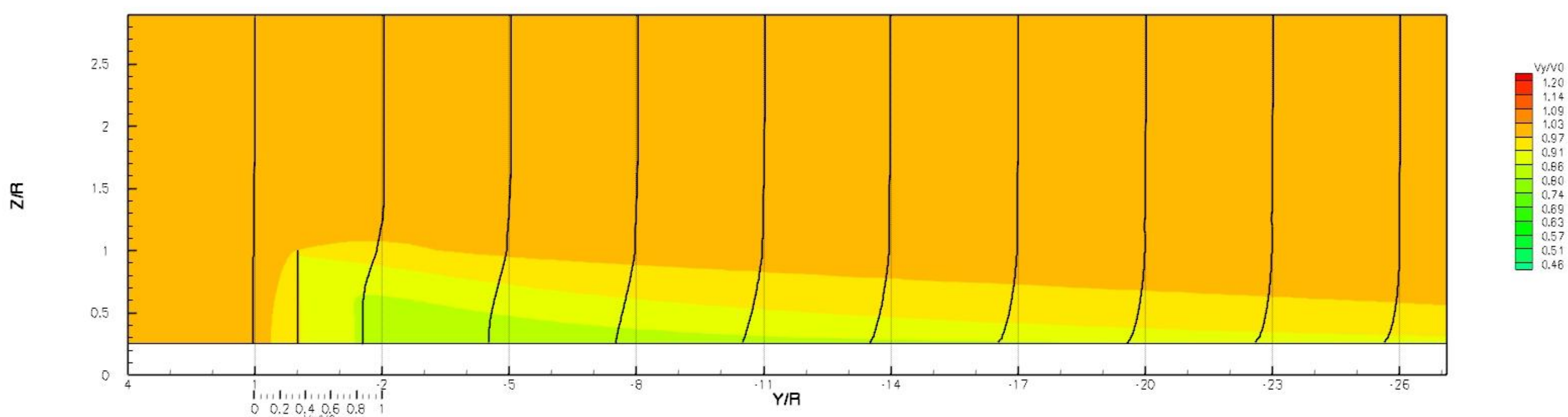
SRF / Velocity Contour / X-Cut / 10% Turbulent Velocity



VBM / Velocity Contour / X-Cut / 10% Turbulent Intensity



ADM / Velocity Contour / X-Cut / 10% Turbulent Intensity



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Summary

- SRF results has been validated with the NREL reports.
- VBM results has been validated with SRF both in the integral performance metrics (torque, power and thrust) and in detailed comparison of the far wake.
- VBM can be validated and used for study of the far wake with complex boundary conditions and of multiple turbines.
- ADM presents the opportunity of studying large turbine arrays with reasonable accuracy and computational cost.

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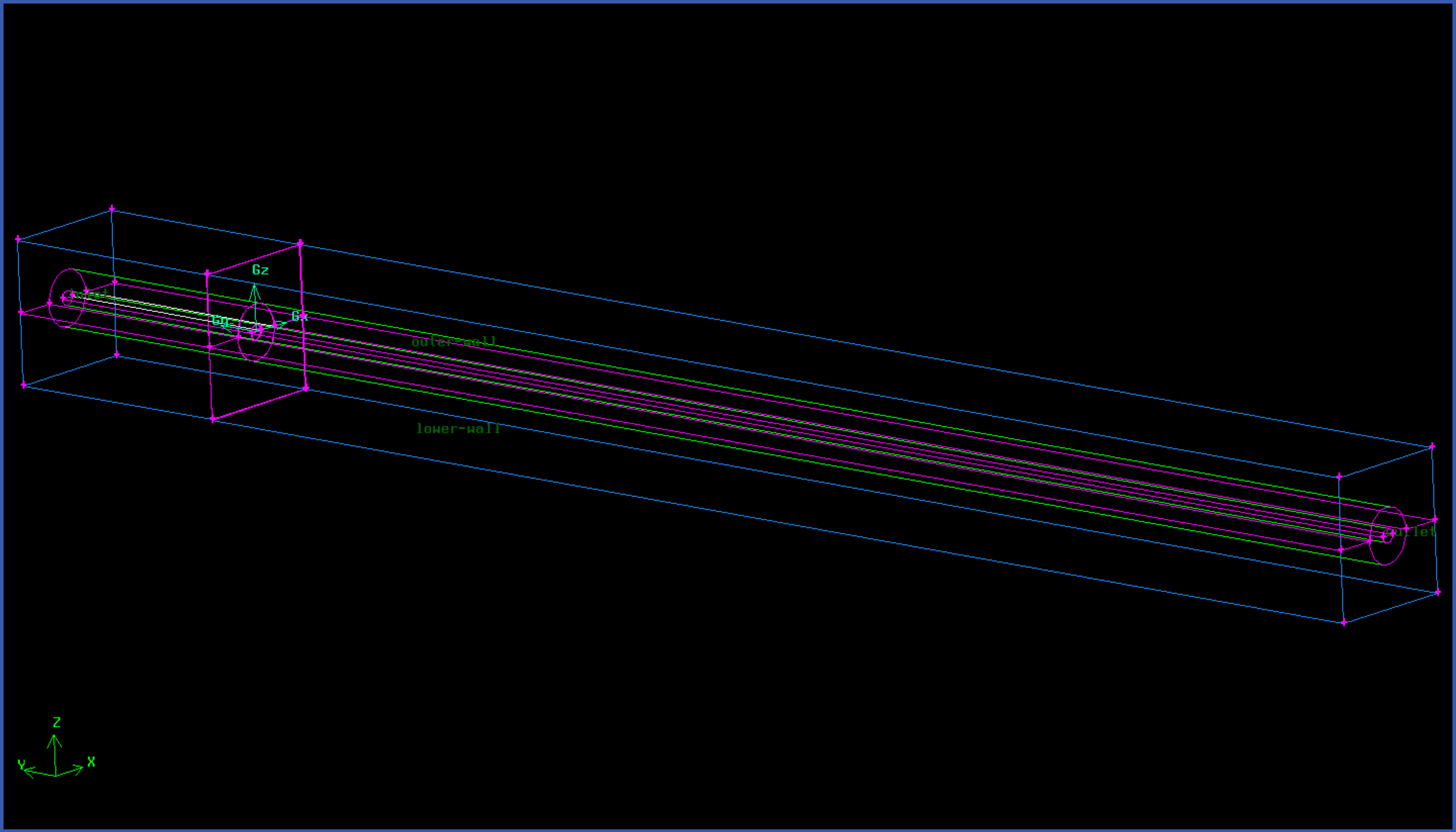
Future Work

- Modifying SRF mesh for change the working fluid from air to water.
- Optimizing the VBM mesh to minimize the computational timing.
- Modeling a farm of turbine with ADM and VBM.
- Study of the far wake in more details.
- Modeling hub of turbine in VBM.

Future Work

- Rectangular channel with shear velocity profile at the inlet.



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