ANALYSIS OF THE DRIVETRAIN PERFORMANCE OF A LARGE HORIZONTAL–AXIS WIND TURBINE: AN AEROELASTIC APPROACH

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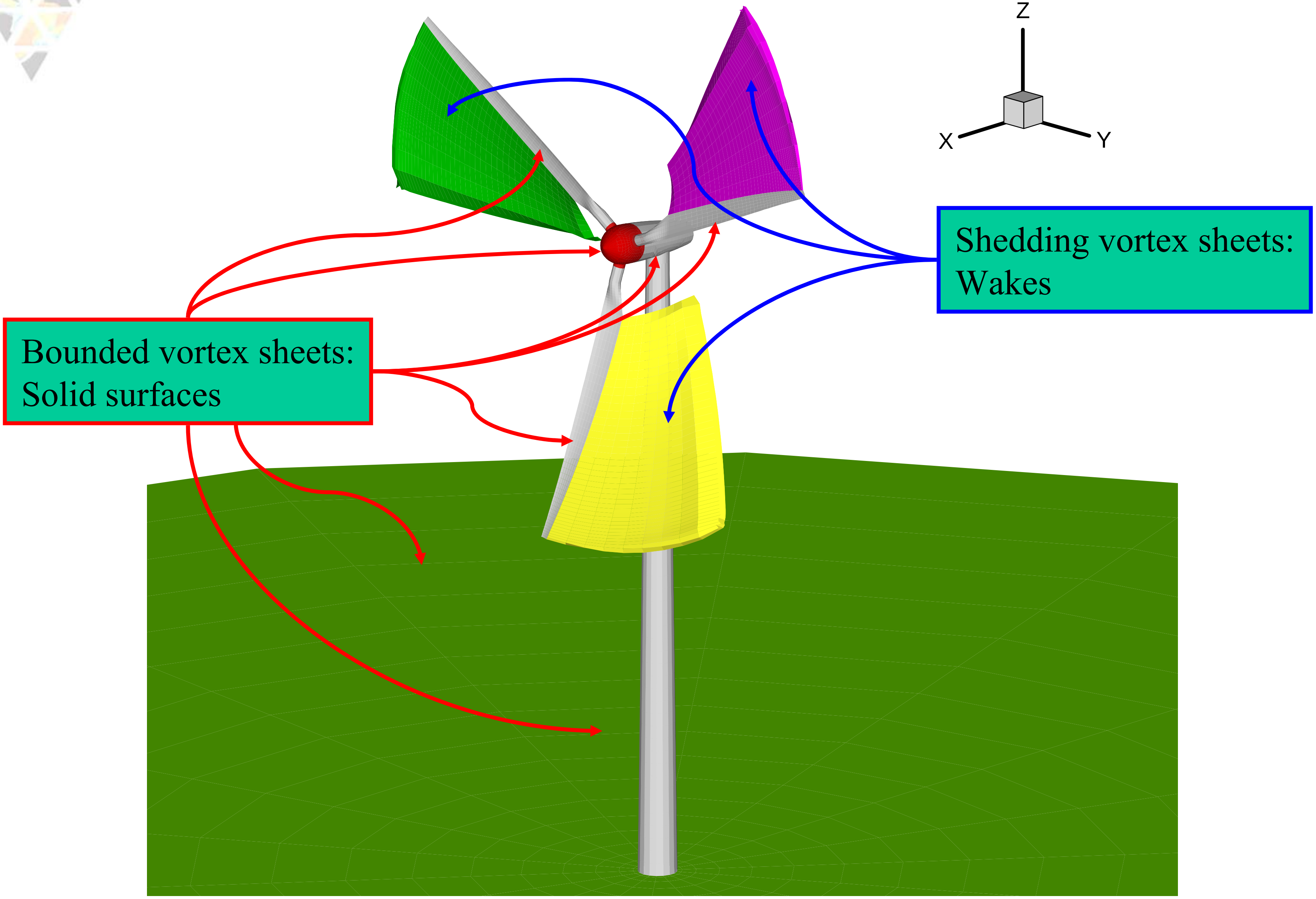
CONICET

Aerodynamic Model

Aerodynamic models used by wind turbine engineering:

- Momentum Theory.
- Blade Element Theory.
- Blade Element and Momentum Theory (**BEM**).
- Unsteady BEM.
- Vortex-Lattice Method (**VLM**).
- ***Non-Linear and Unsteady Vortex-Lattice Method* (NLUVLM).**
- Computational Fluid Dynamics (**CFD**).

NLUVLM

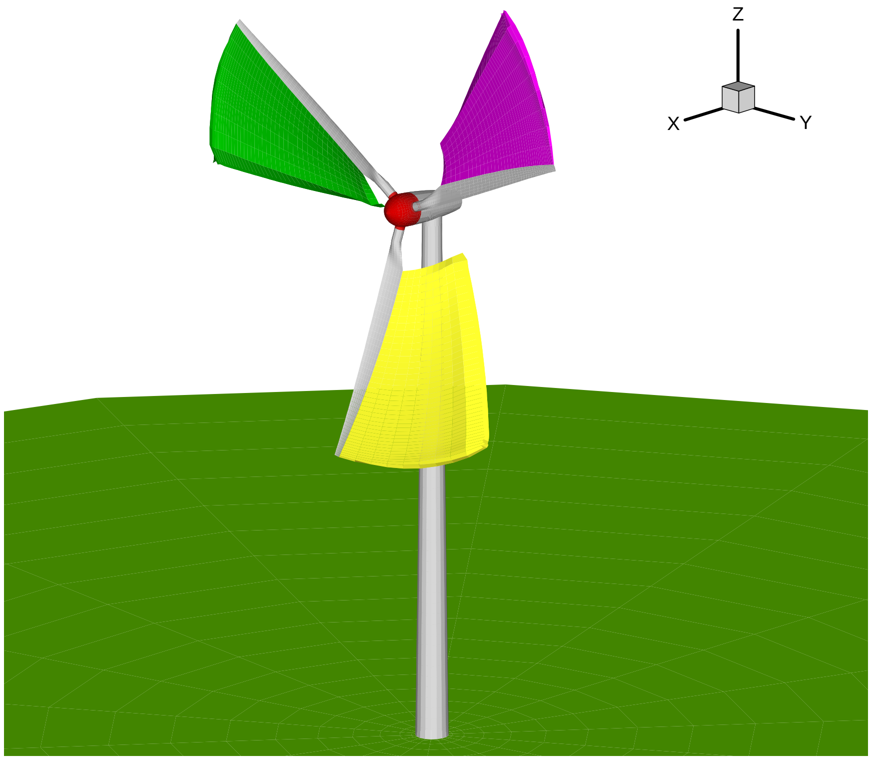

Z
X
Y
Shedding vortex sheets:
Wakes
Bounded vortex sheets:
Solid surfaces

NLUVLM (Condt.)

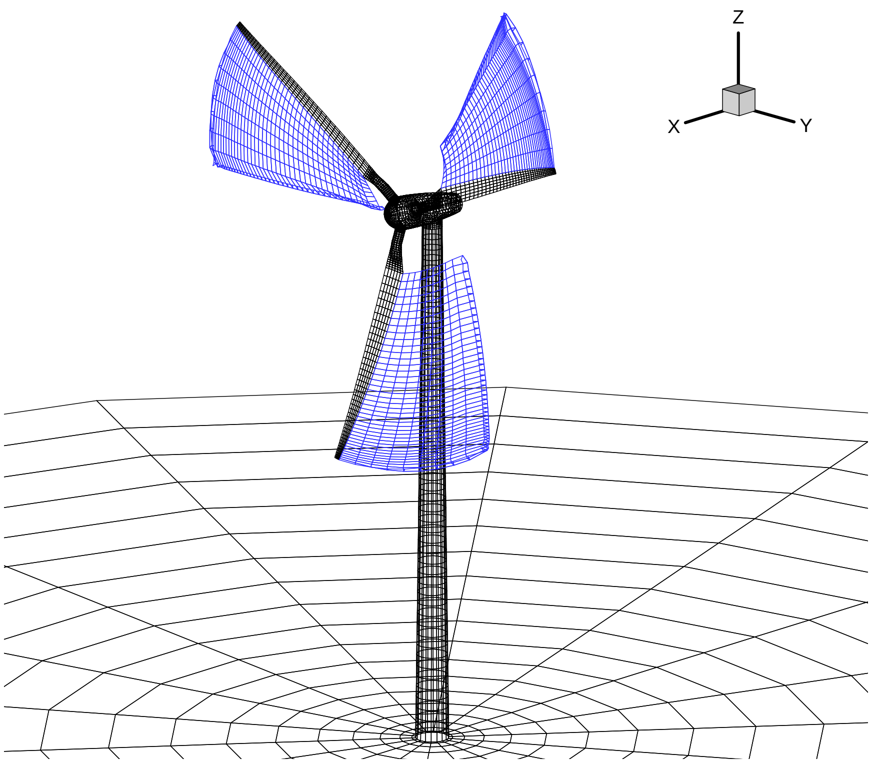
Order reduction:

- The vortex sheets are replaced using lattices formed by vortex segments.

Sheets Model



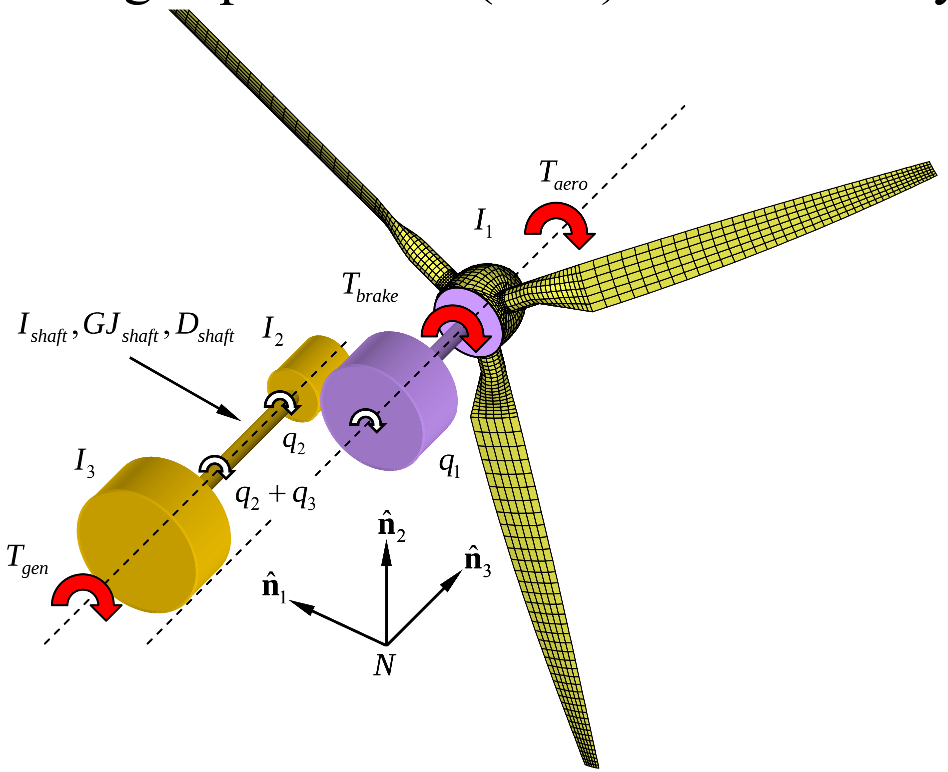
Lattices Model



Dynamic Model

Drivetrain dynamic model:

- Rotor, gears and low speed shaft (LSS): rigid bodies.
- High speed shaft (HSS): flexible body.



$$[\mathbf{M}]\{\ddot{\mathbf{q}}\} + [\dot{\mathbf{M}} + \mathbf{D}]\{\dot{\mathbf{q}}\} + [\mathbf{K}]\{\mathbf{q}\} = \{\mathbf{F}\}$$

$$\{\mathbf{q}\} = \{q_1 \quad q_3\}^T$$

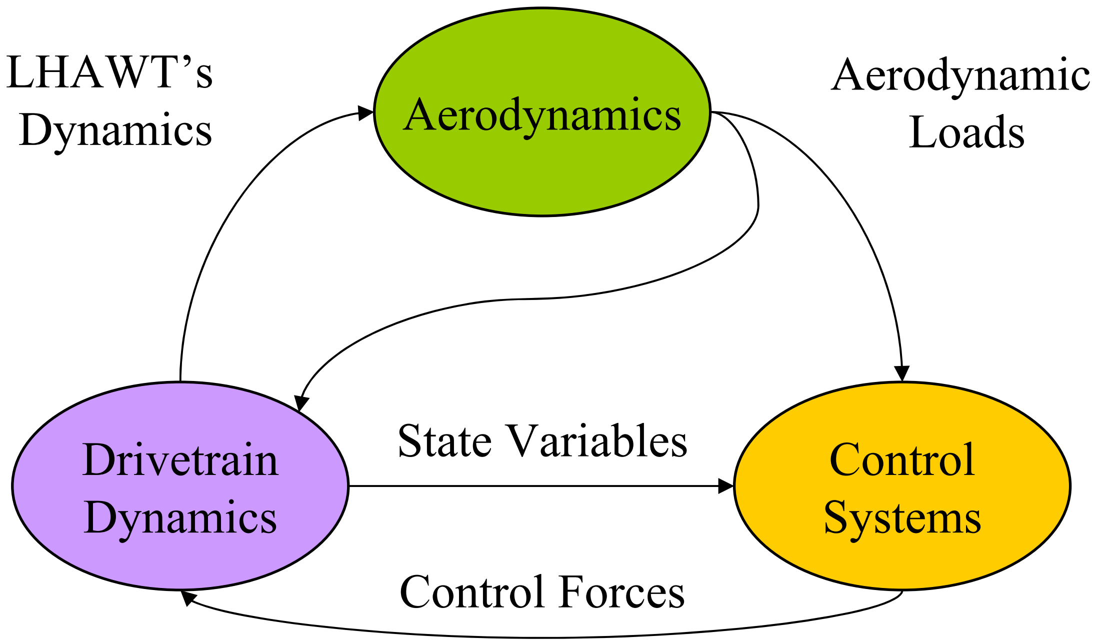
$$[\mathbf{M}] = \begin{bmatrix} I_1 + n_g^2\left(I_2 + I_3 + I_{shaft}L\right) & -n_g\left(I_3 + I_{shaft}L\right) \\ -n_g\left(I_3 + I_{shaft}L\right) & I_3 + I_{shaft}L \end{bmatrix}$$

$$[\dot{\mathbf{M}} + \mathbf{D}] = \begin{bmatrix} \dot{I}_1 & 0 \\ 0 & 0 \end{bmatrix} + \begin{bmatrix} 0 & 0 \\ 0 & D_{shaft} \end{bmatrix} = \begin{bmatrix} \dot{I}_1 & 0 \\ 0 & D_{shaft} \end{bmatrix}$$

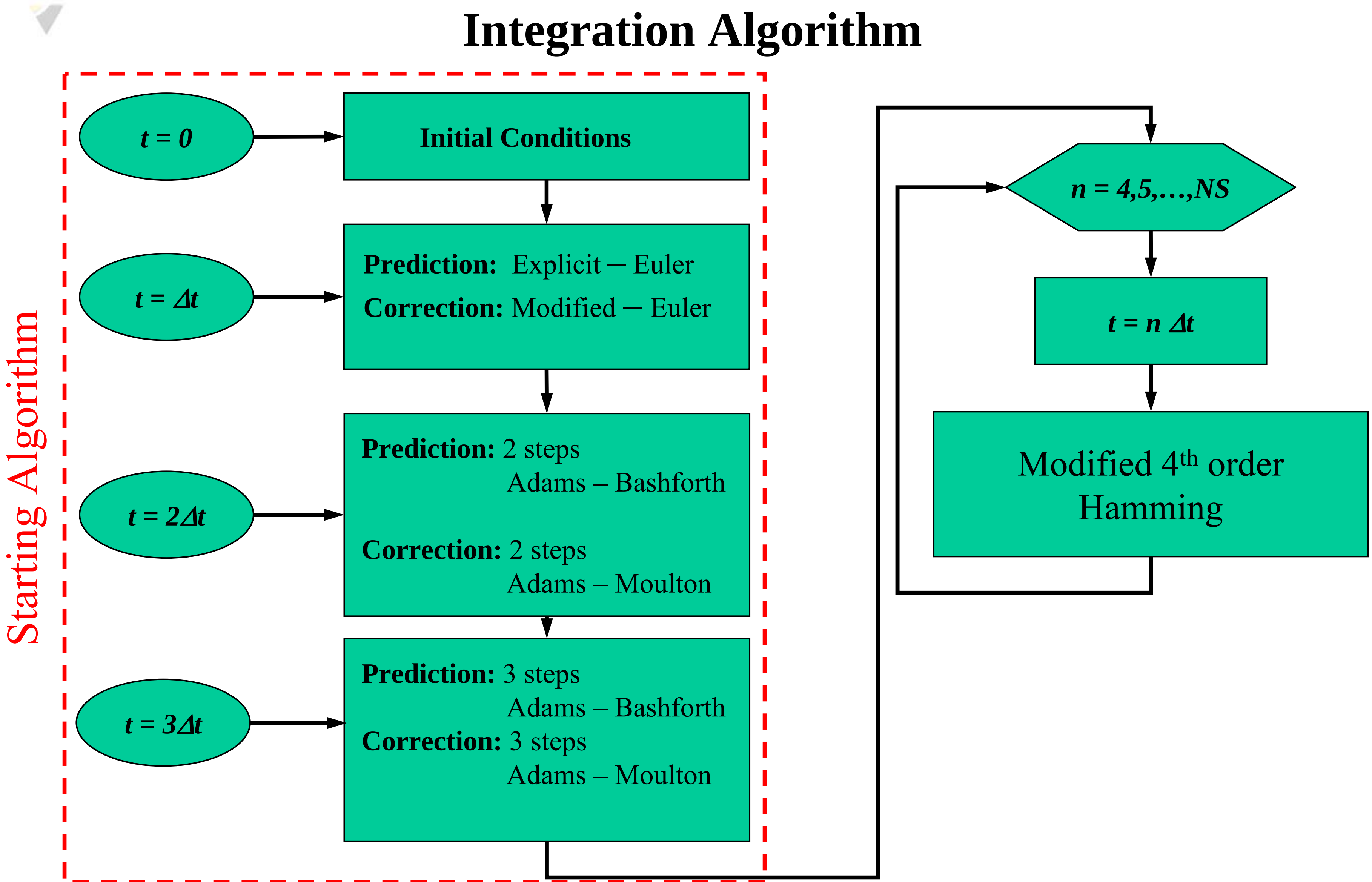
$$[\mathbf{K}] = \begin{bmatrix} 0 & 0 \\ 0 & \dfrac{GJ_{shaft}}{L} \end{bmatrix}$$

$$\{\mathbf{F}\} = \begin{Bmatrix} T_{aero} - n_g T_{gen} + T_{brake} \\ T_{gen} \end{Bmatrix}$$

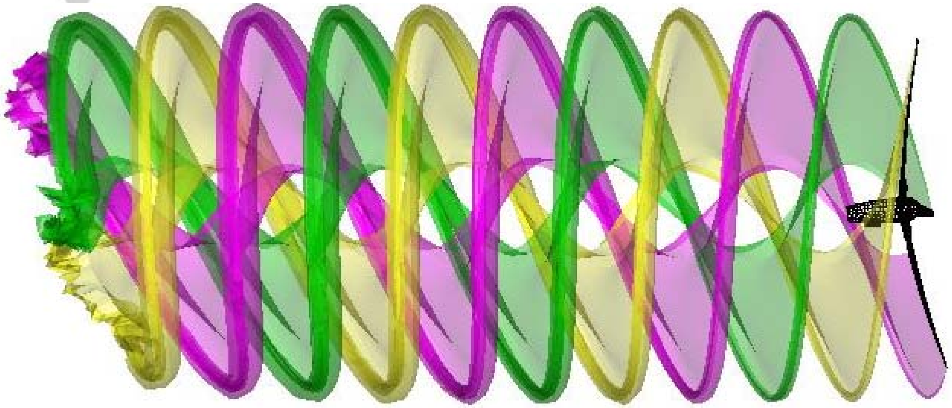
Combining the Models



Combining the Models

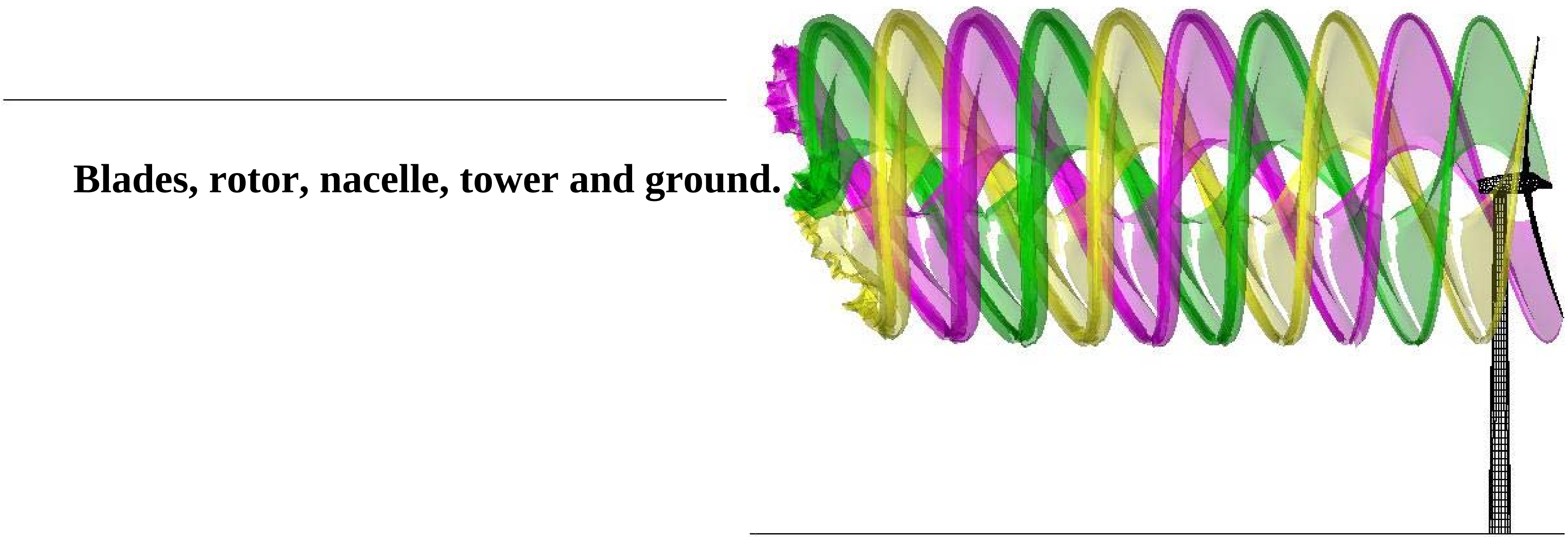


Aerodynamical Interactions

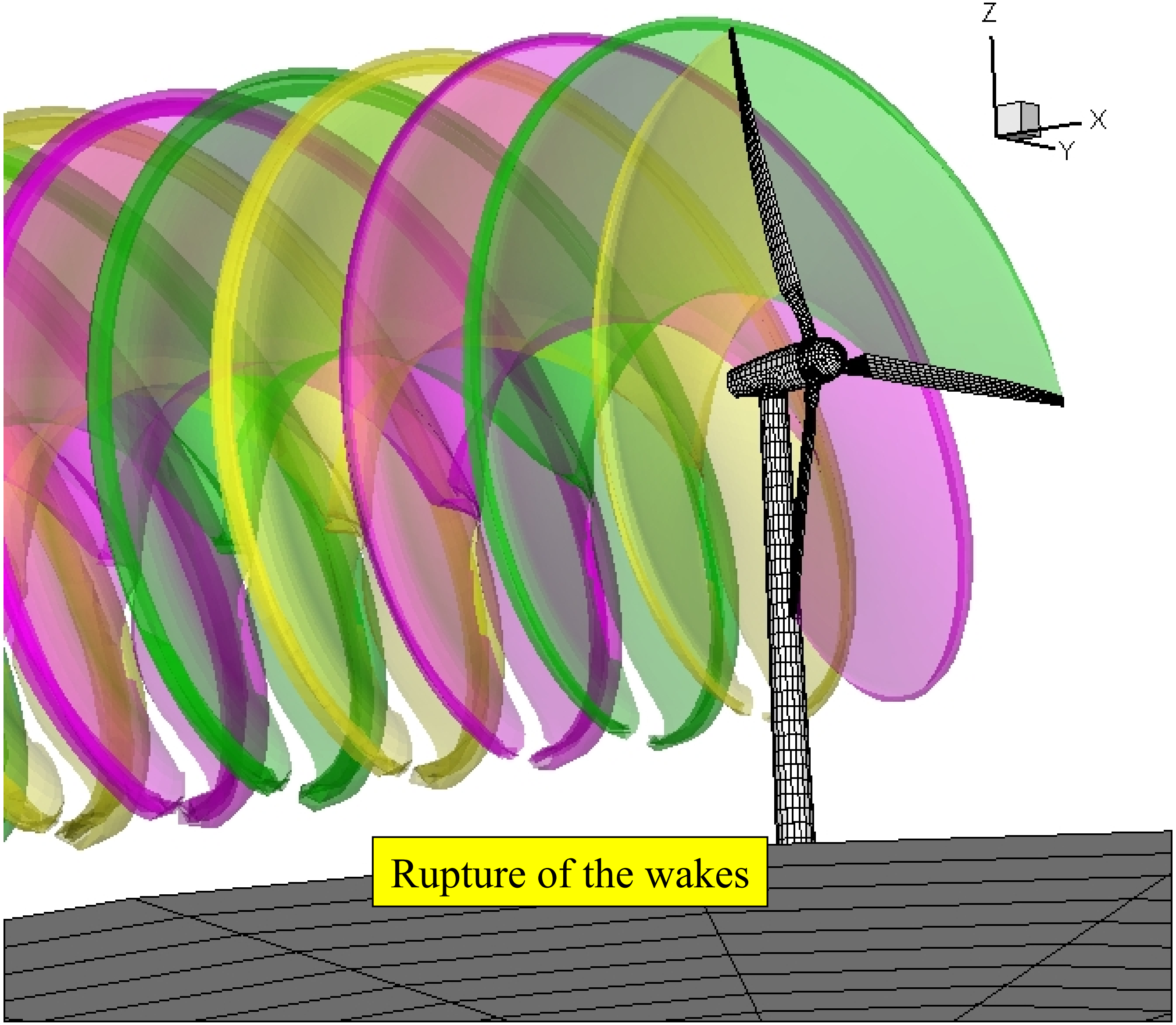


Blades, rotor, nacelle and ground.

Blades, rotor, nacelle, tower and ground.



Wakes Rupture

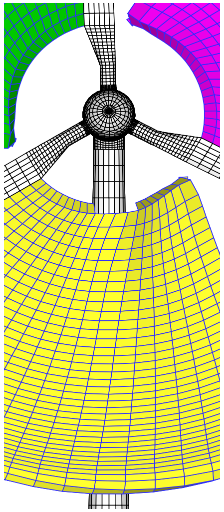


Model of Wake Rupture

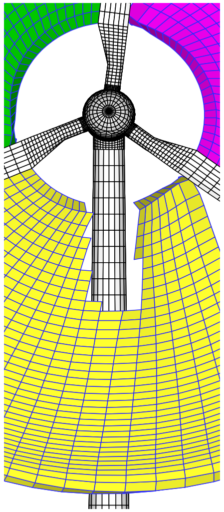
Main Considerations:

- The vorticity only can be created or destroyed at the solid surfaces.
- Outside of the boundary layers of solid surfaces the fluid is irrotational and incompressible, and the vorticity only can be transported.
- When the wakes crash the tower, these are broken because the wakes can not penetrate the solid surfaces.
- Only at the solid boundary the circulation readjustment of vortex segments can be performed.

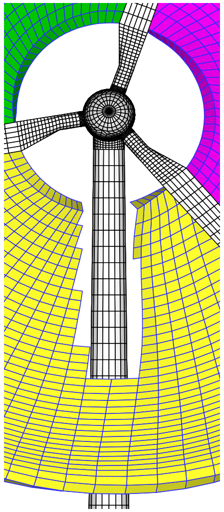
Model of Wake Rupture



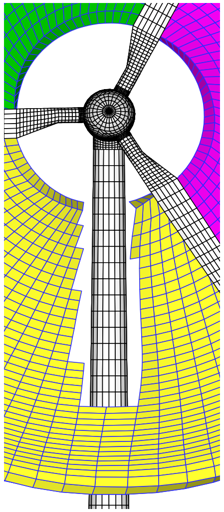
Step 3



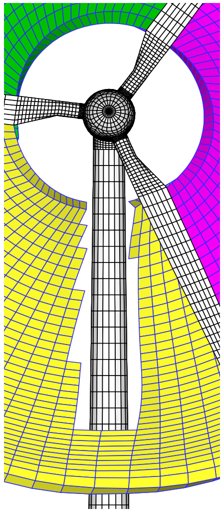
Step 5



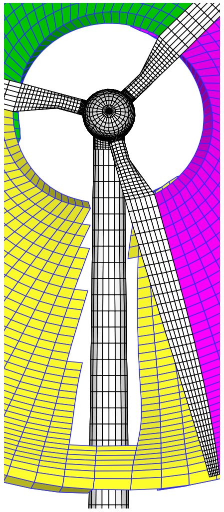
Step 7



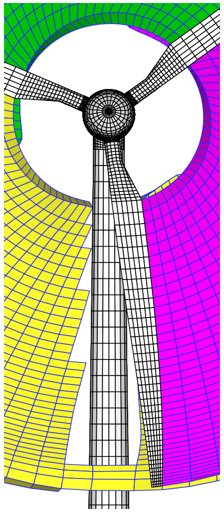
Step 9



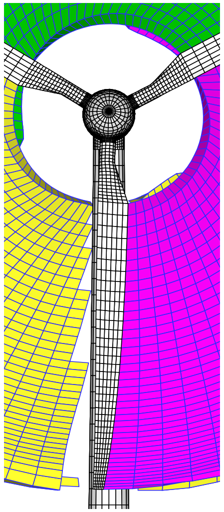
Step 11



Step 13



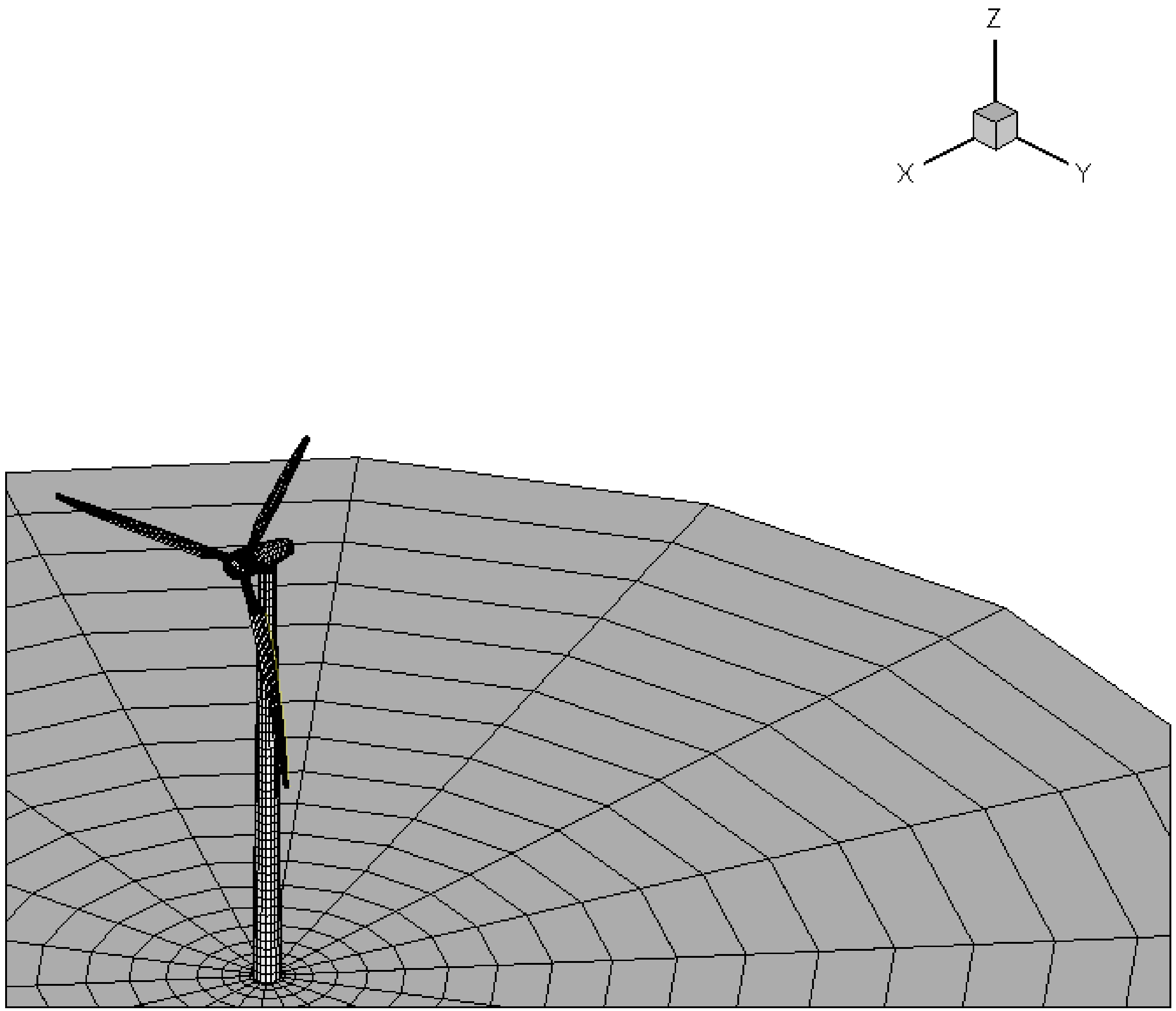
Step 15



Step 17

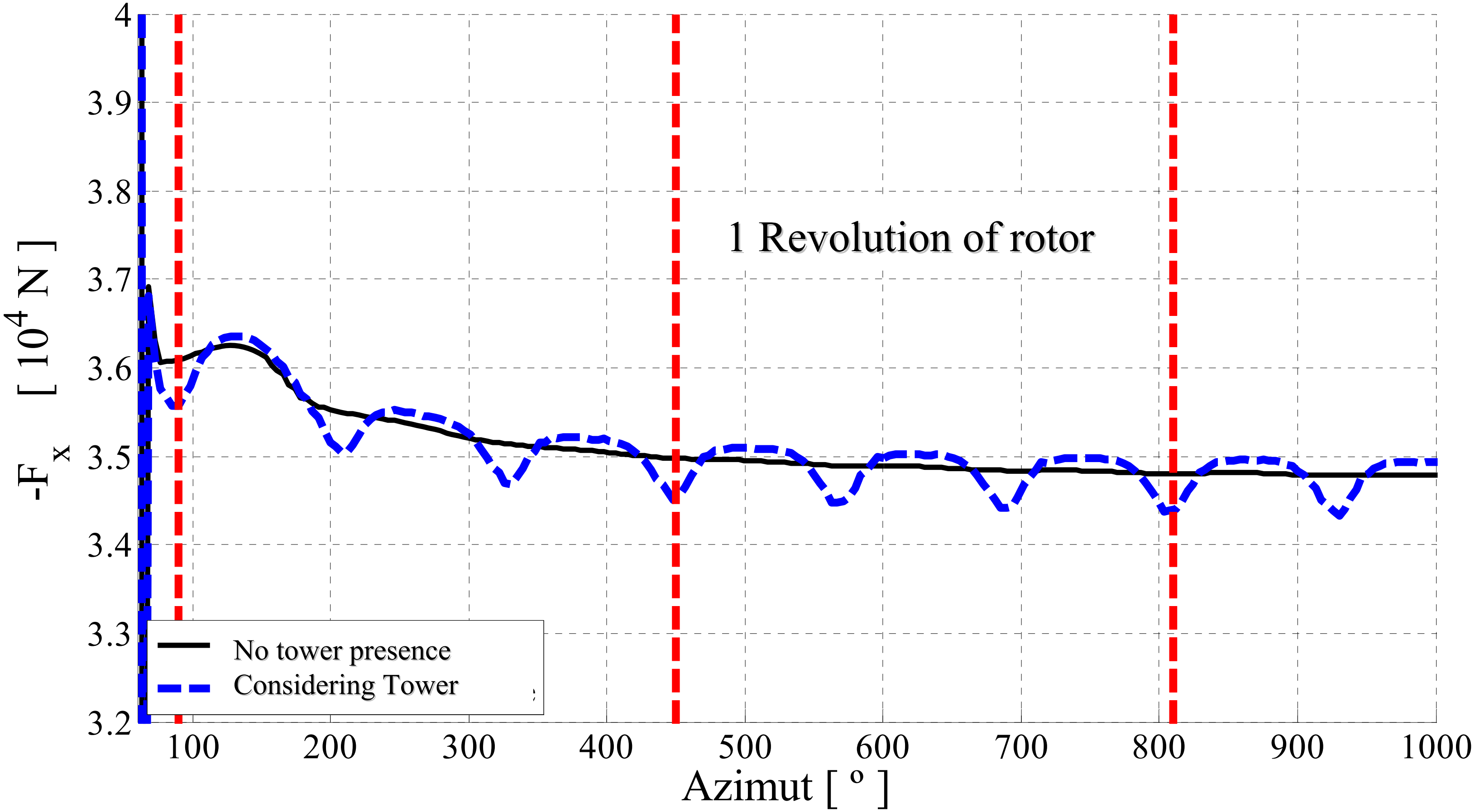
Model of Wake Rupture

Free stream direction -x, v_∞= 10 m/s, 15 RPM. Global View.

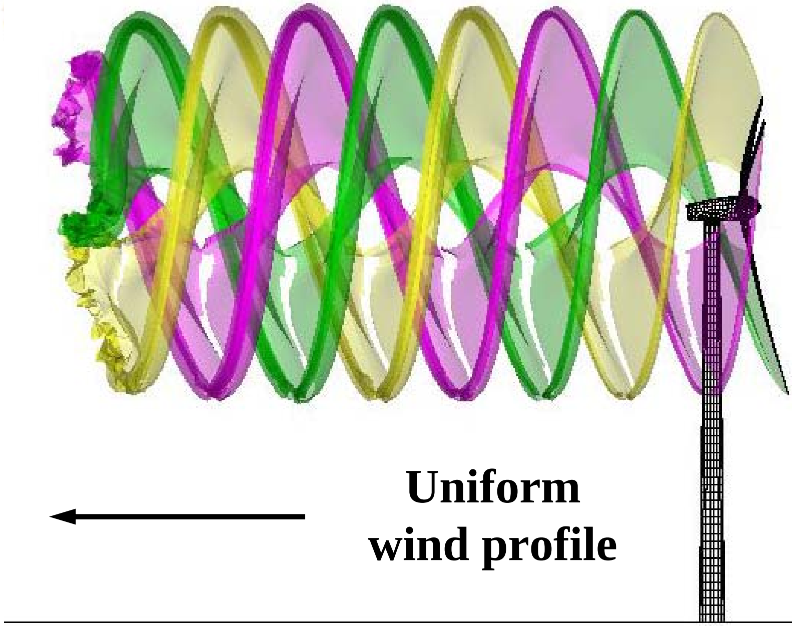


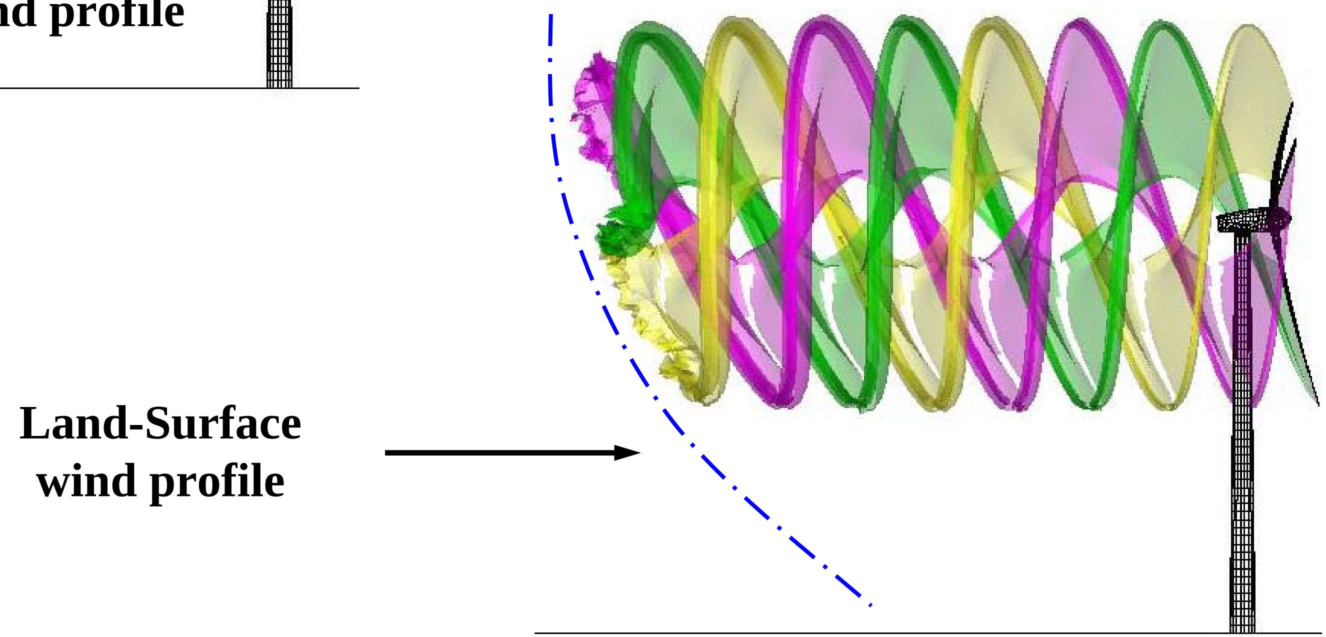
Model of Wake Rupture

Free stream direction -*x*, v_∞= 10 m/s, 15 RPM.
Axial Force



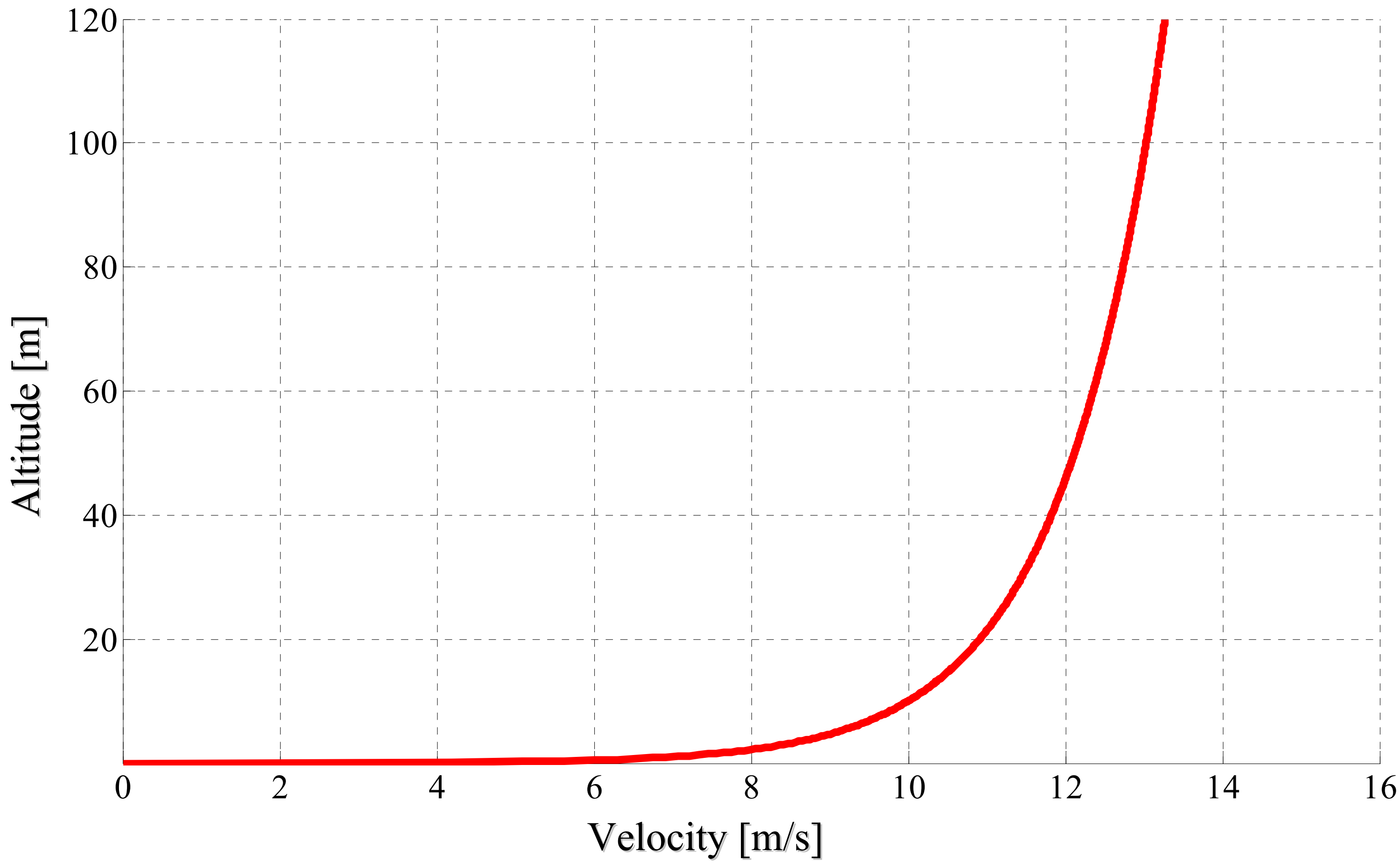
Land-Surface Boundary Layer





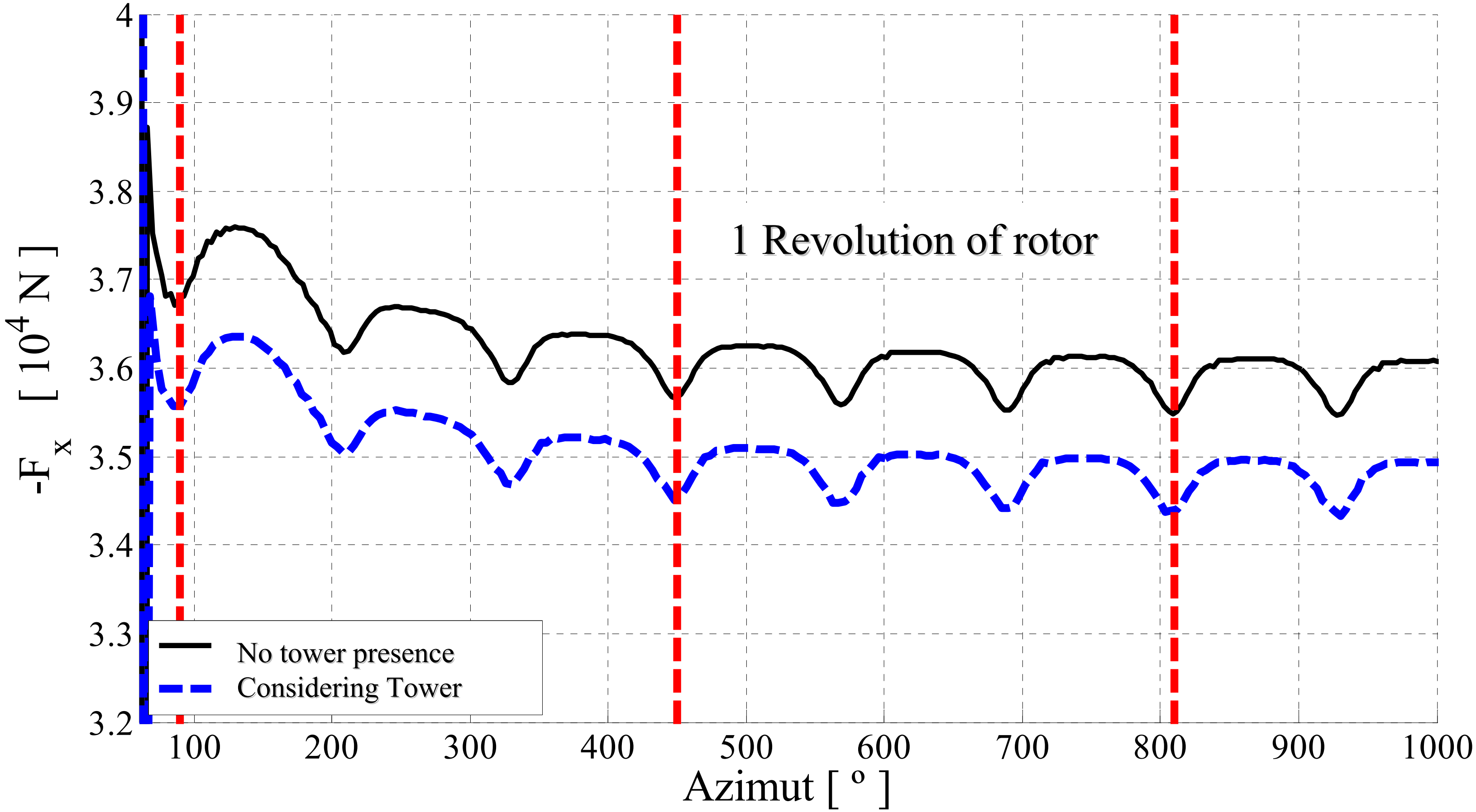
Land-Surface Boundary Layer

The wind profile as vertical distance function:



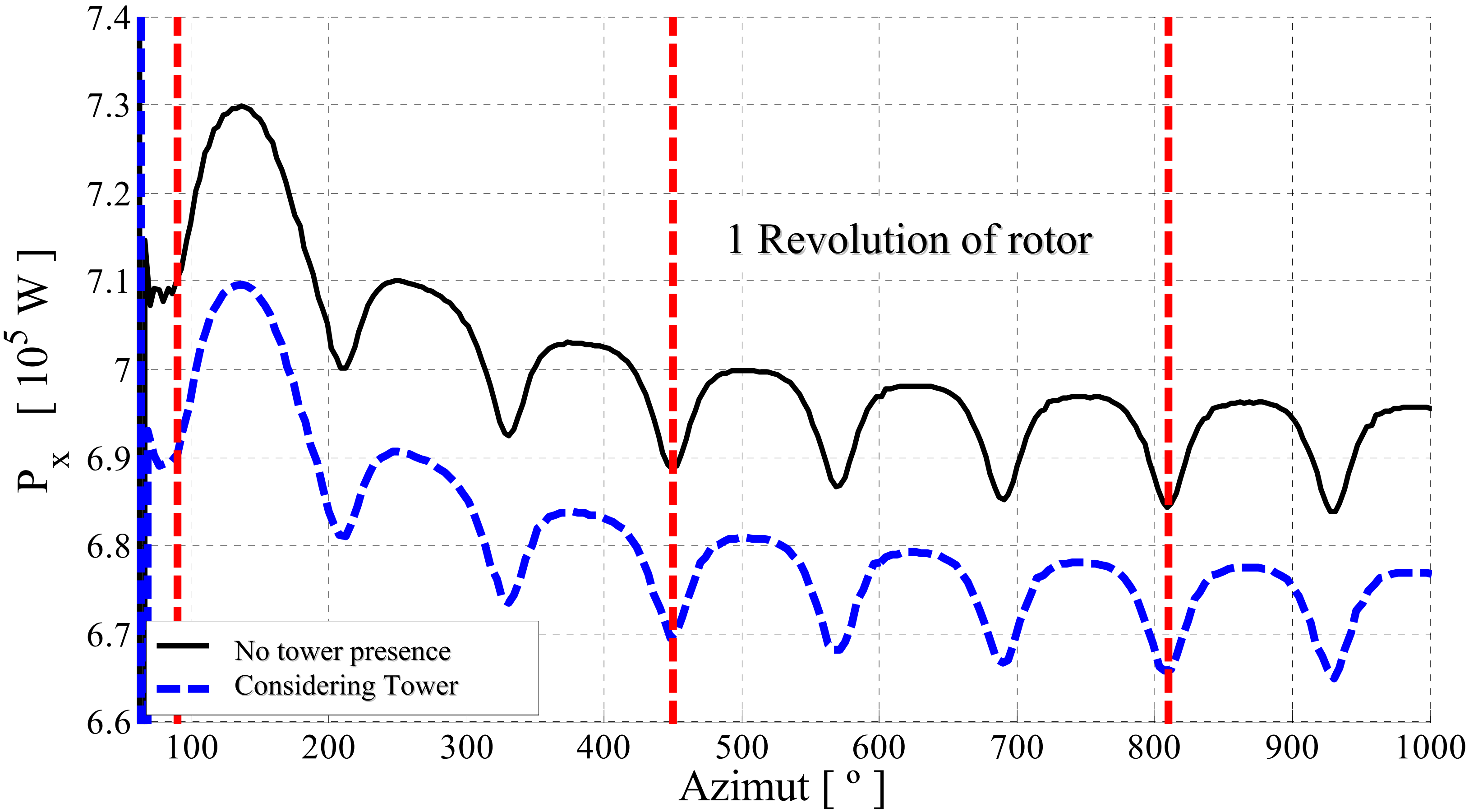
Land-Surface Boundary Layer

Free stream direction -x, v_∞= 10 m/s, 15 RPM.
Axial Force

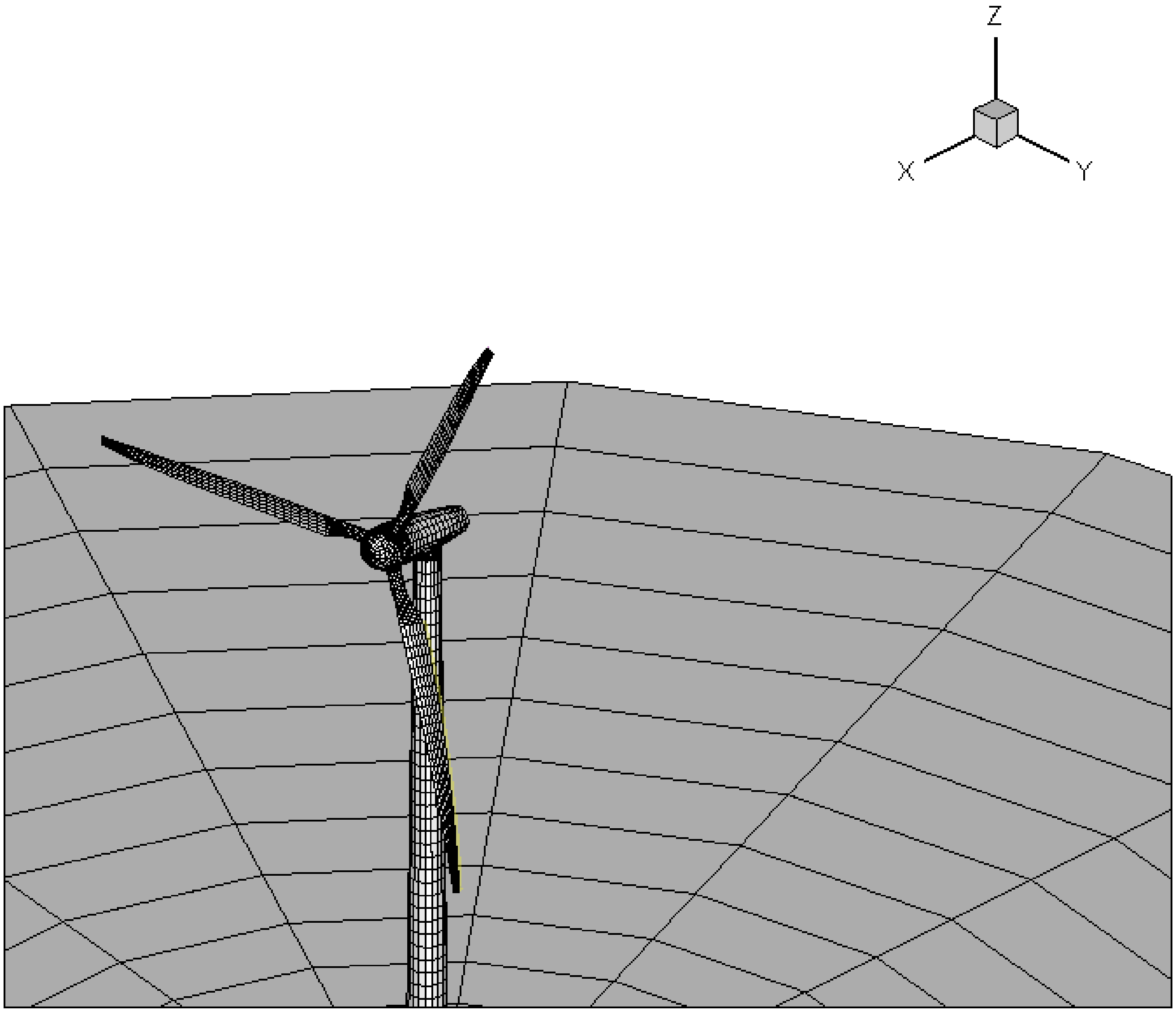


Land-Surface Boundary Layer

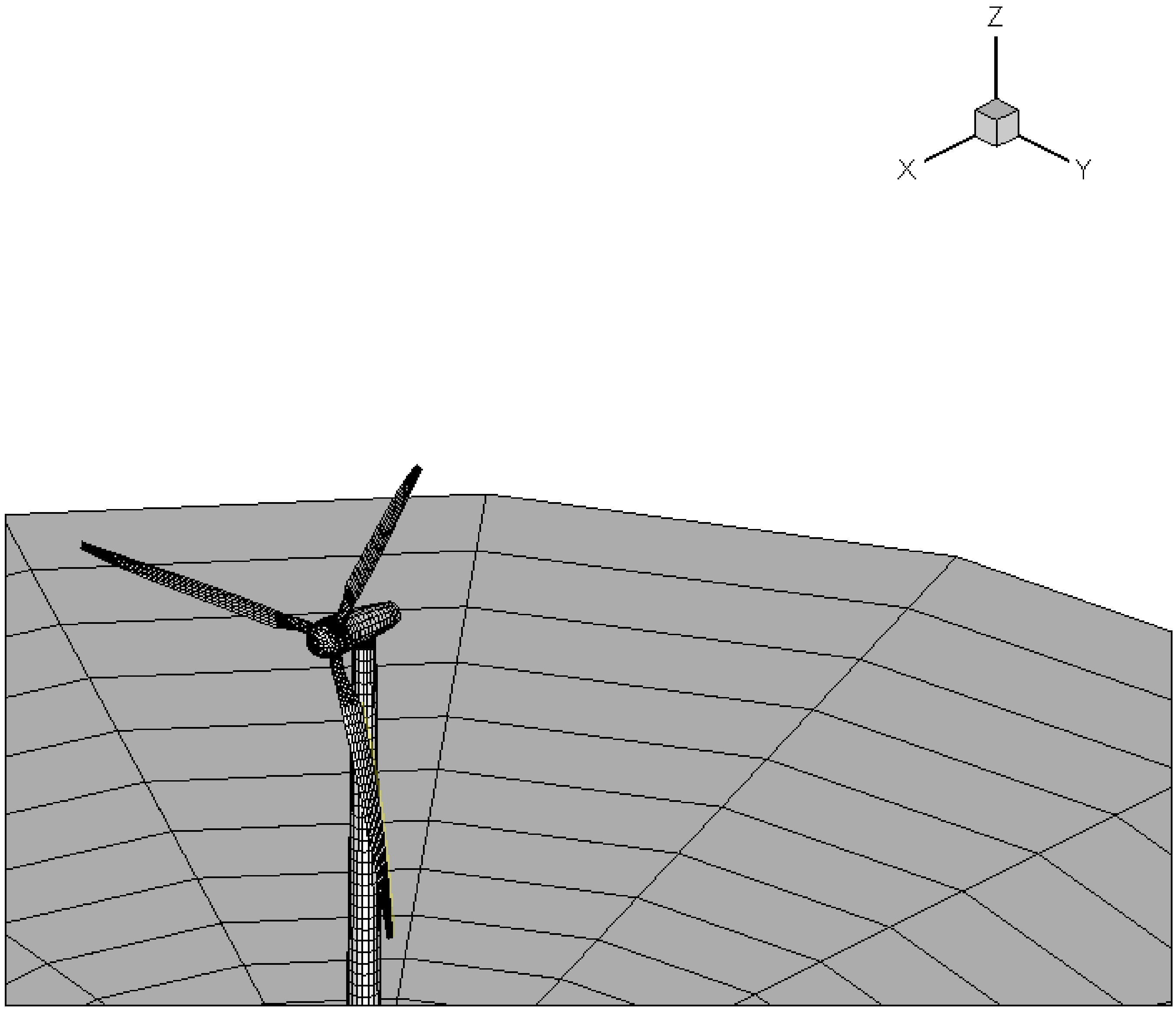
Free stream direction -*x*, v_∞= 10 m/s, 15 RPM.
Produced Power



Wake Rupture During Pitching of Blades



Wake Rupture During Yawing of Nacelle

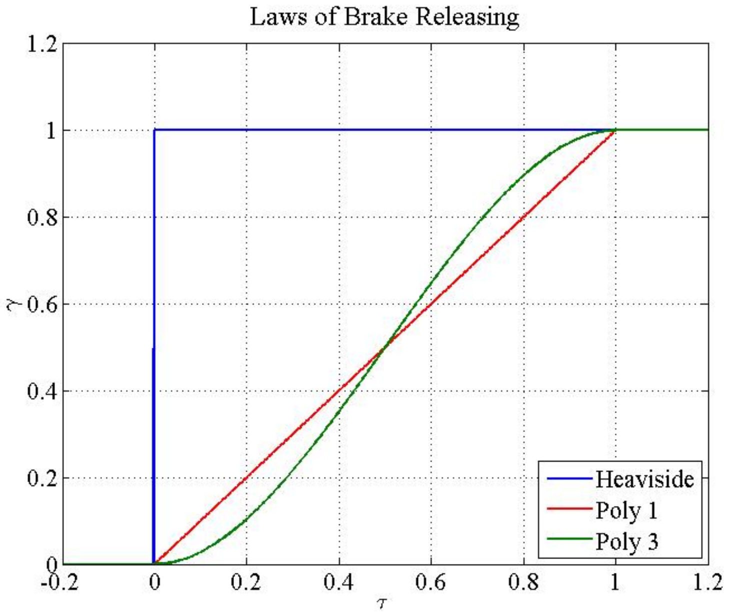


Laws of Brake Releasing

$\gamma(\tau)$	$\tau < 0$	$0 \le \tau \le 1$	$\tau > 1$
Heaviside	0	1	1
Poly 1	0	τ	1
Poly 3	0	$-2\tau^3 + 3\tau^2$	1

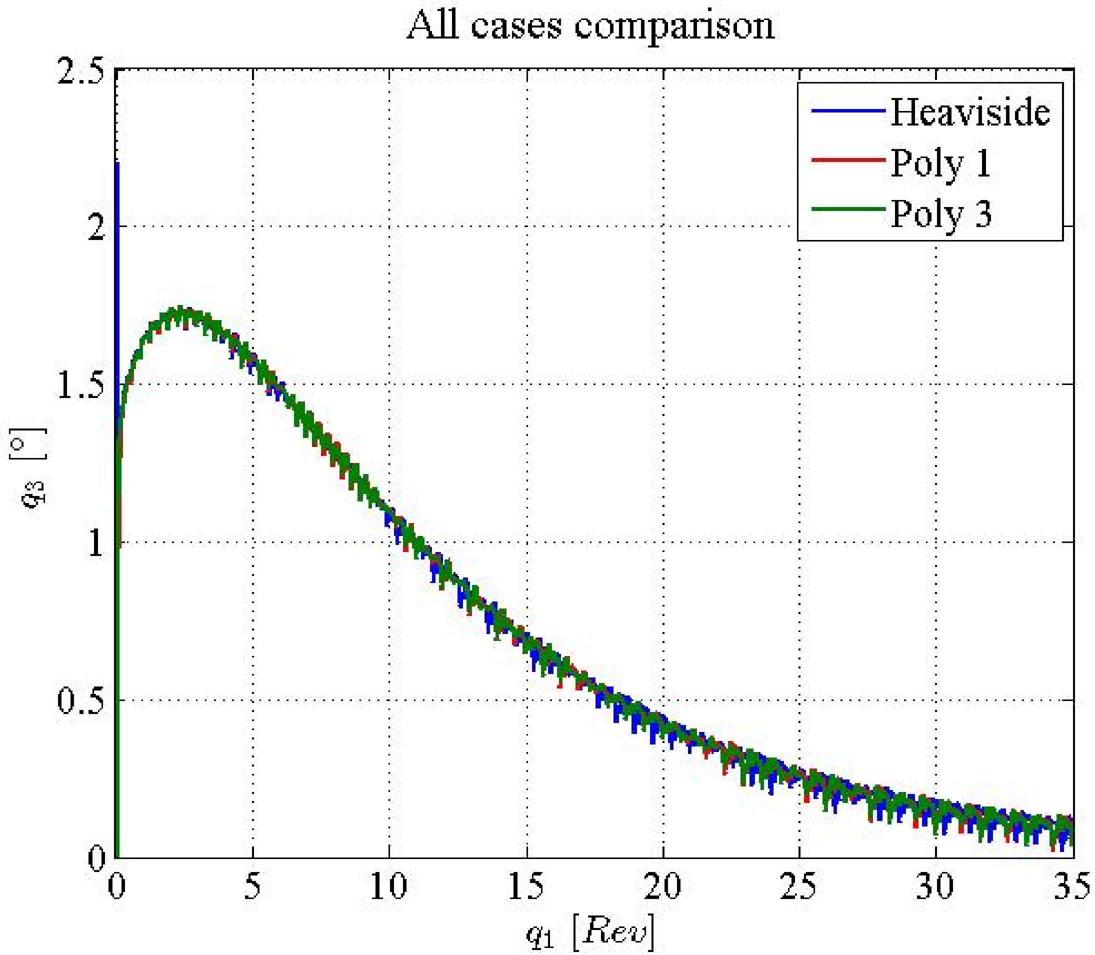
$$\tau = \left(t/t_{rel}\right)$$

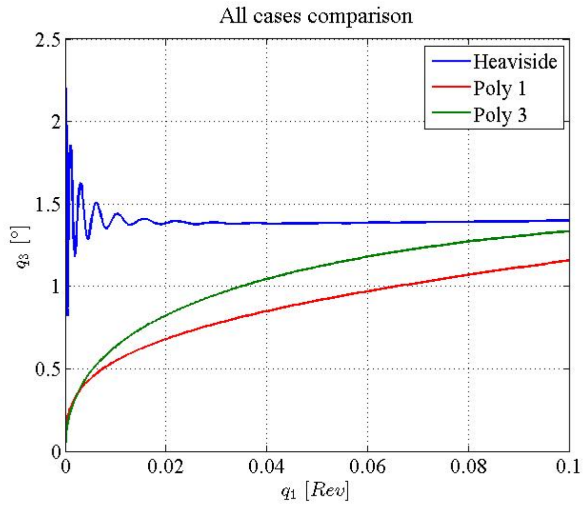
t_{rel} is the reference time at which the brake is completely released



Comparison of the Brake Releasing laws

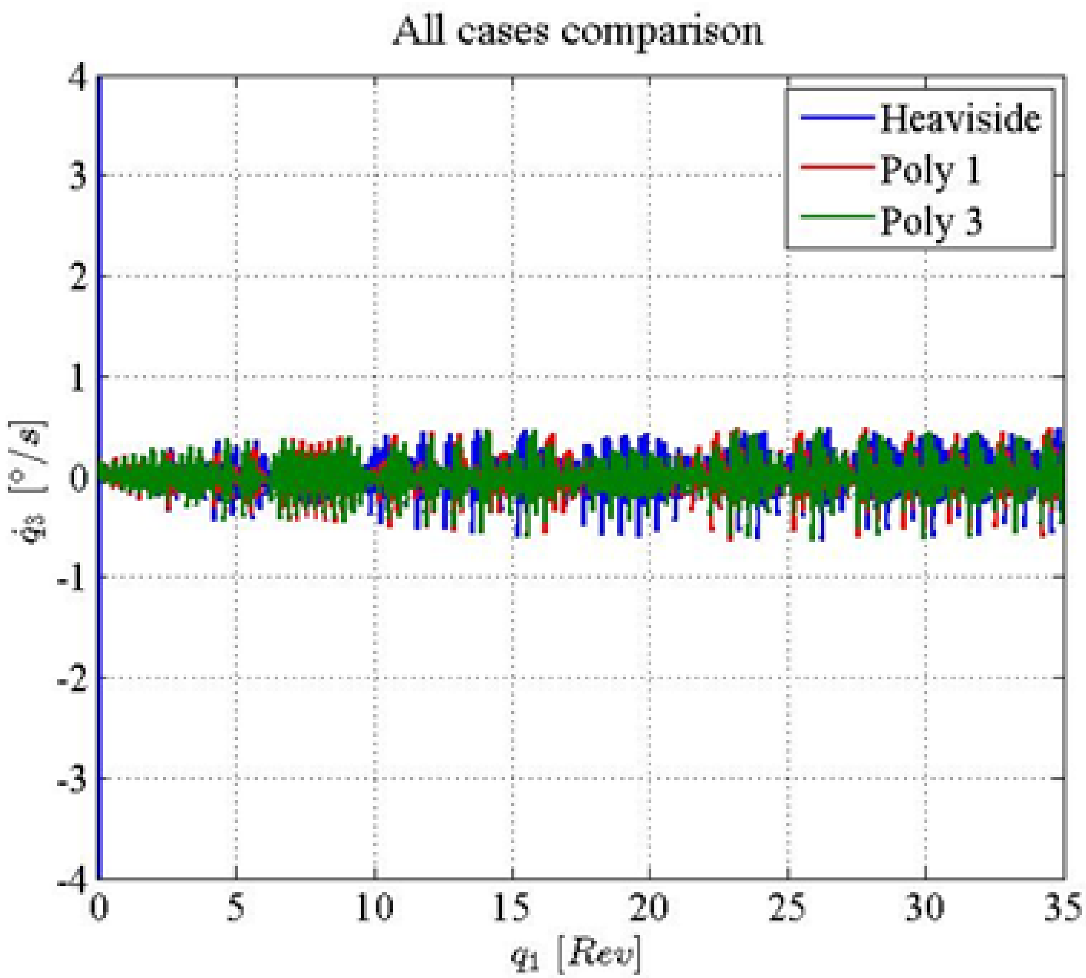
Response of High Speed Shaft-Torsional displacement

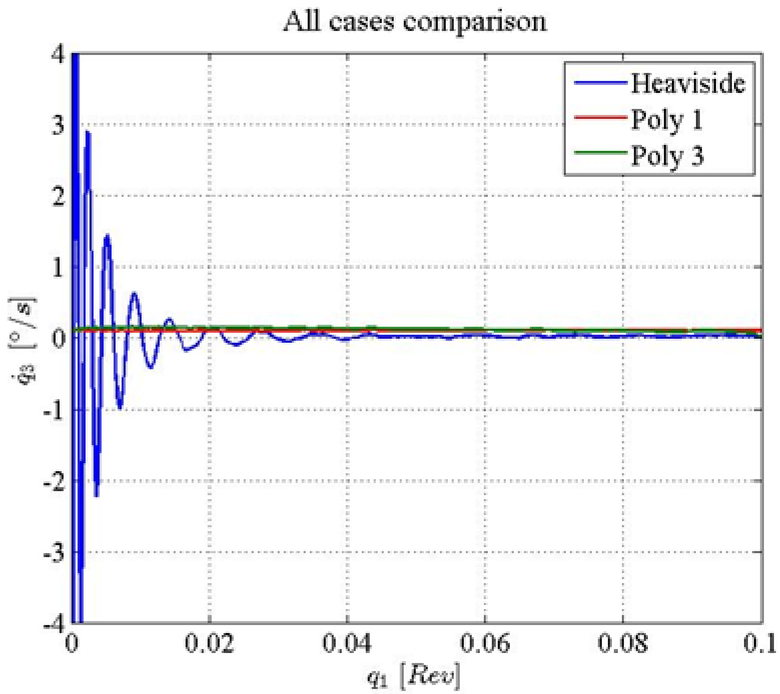




Comparison of the Brake Releasing laws

Response of High Speed Shaft-Torsional Speed





Concluding Remarks

- The effects produced by the tower presence have been captured in a satisfactory way.
- Tower presence does not change the performance mean value, this gives origin to alternating loads components, which can produce fatigue in the **LHAWT** components or non-desirable and unstable dynamics behaviors.
- **LSBL** reduces the **LHAWT** efficiency respect to the produced performances neglecting the terrestrial boundary layer.
- The drivetrain performance and the influence of the brake releasing laws in the start regime is studied in a satisfactory way.
- Proposed methodology is a good starting point to obtain a better understanding of the aeroelastic behavior of LHAWT's in order to overcome the bleak of creating test setups and test plans.


Thank
You