COMPARISON BETWEEN OPENFOAM CFD & BEM THEORY FOR VARIABLE SPEED - VARIABLE PITCH HAWT

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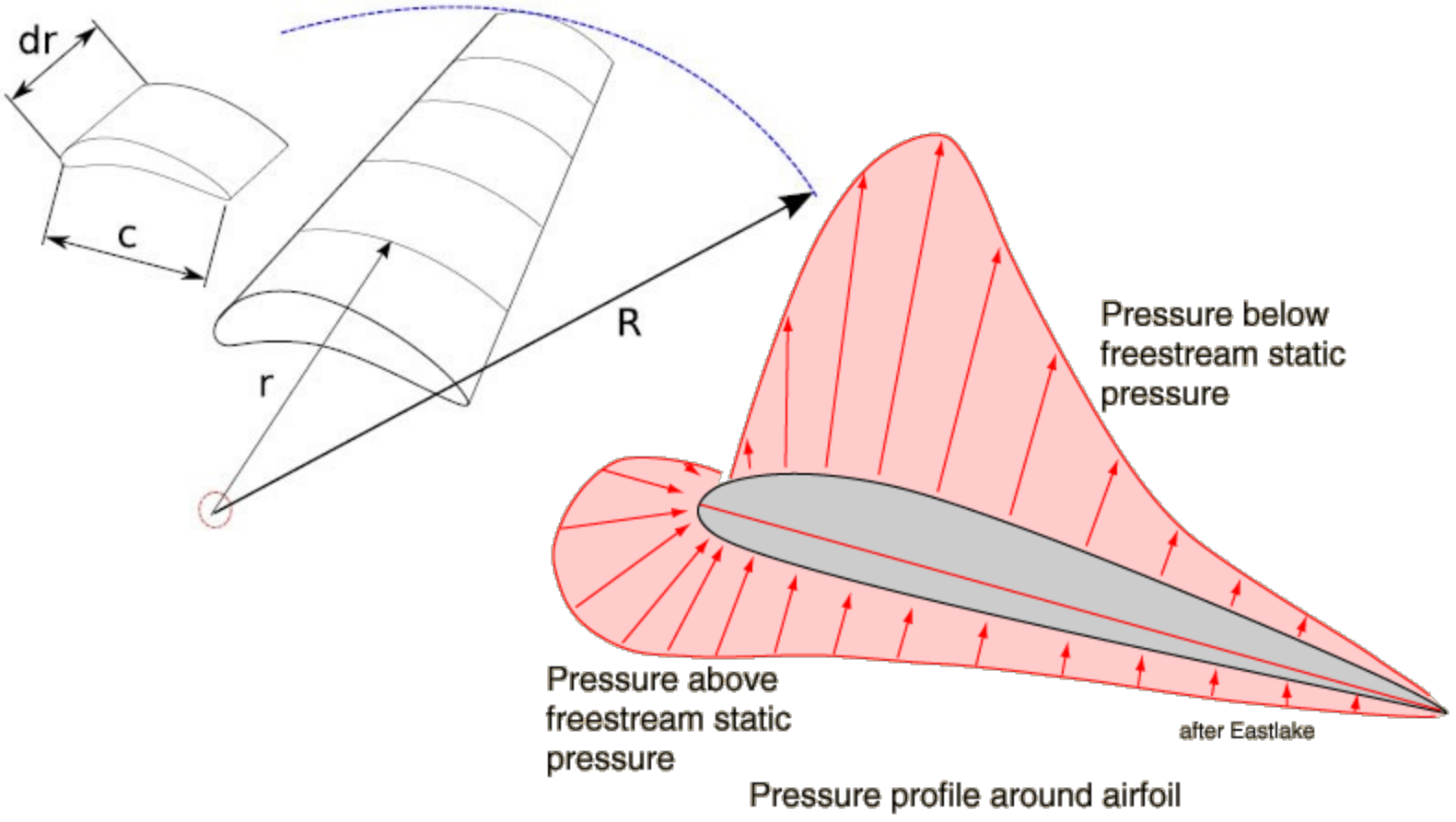
Outline

- Introduction
- Blade Element Momentum Theory (BEM)
  - 7m wind turbine blade design and performance
- Computational Fluid Dynamics (CFD) model
  - The idea of Multiple References of Frame (MRF)
  - Computational domain and boundary conditions used
- Results and Discussion
  - Comparison between BEM and CFD
    - Integrated Quantities (Output Power, Thrust Force and pitch angles
    - Results investigations based on Normal and Tangential loads distribution over the blade.

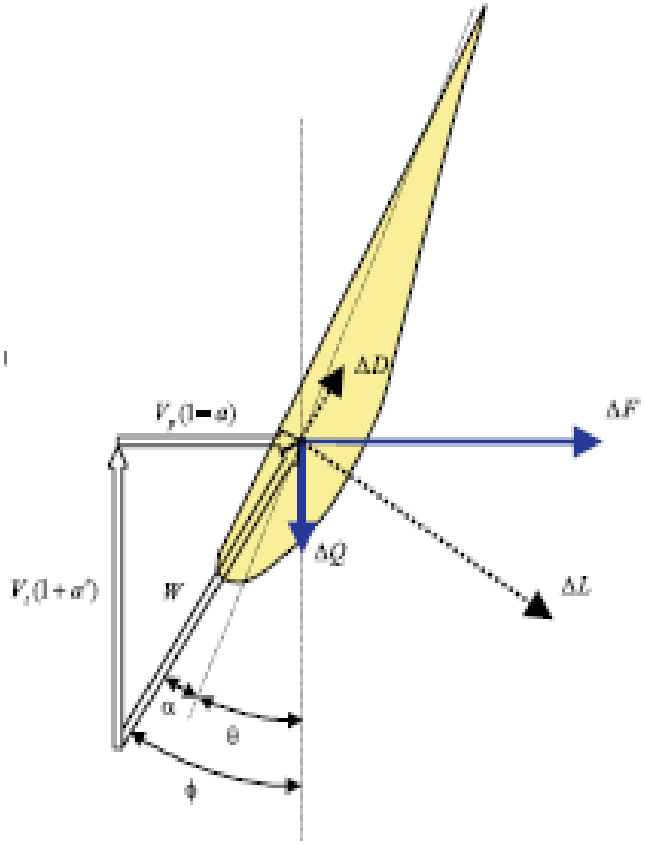

- What we did?
- Why?



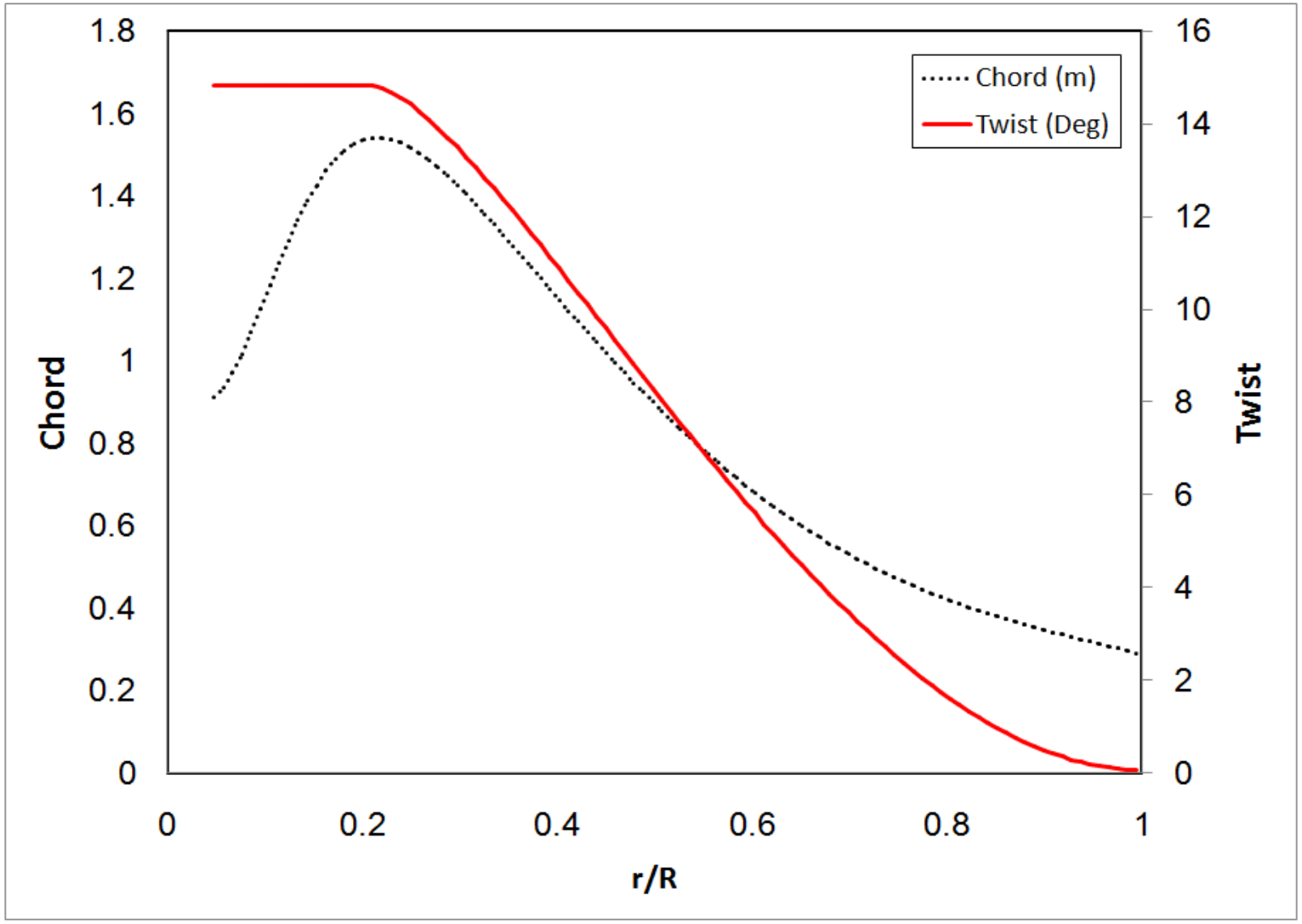
Blade Element Momentum Theory (BEM)

- Main Assumption
  - 2D strip theory
  - Aerodynamic interactions
  - Pressure difference over the blade elements

- 7m blade design and performance
  - Airfoil used (NACA 63-415)
  - Chord and Twist distribution of the blade

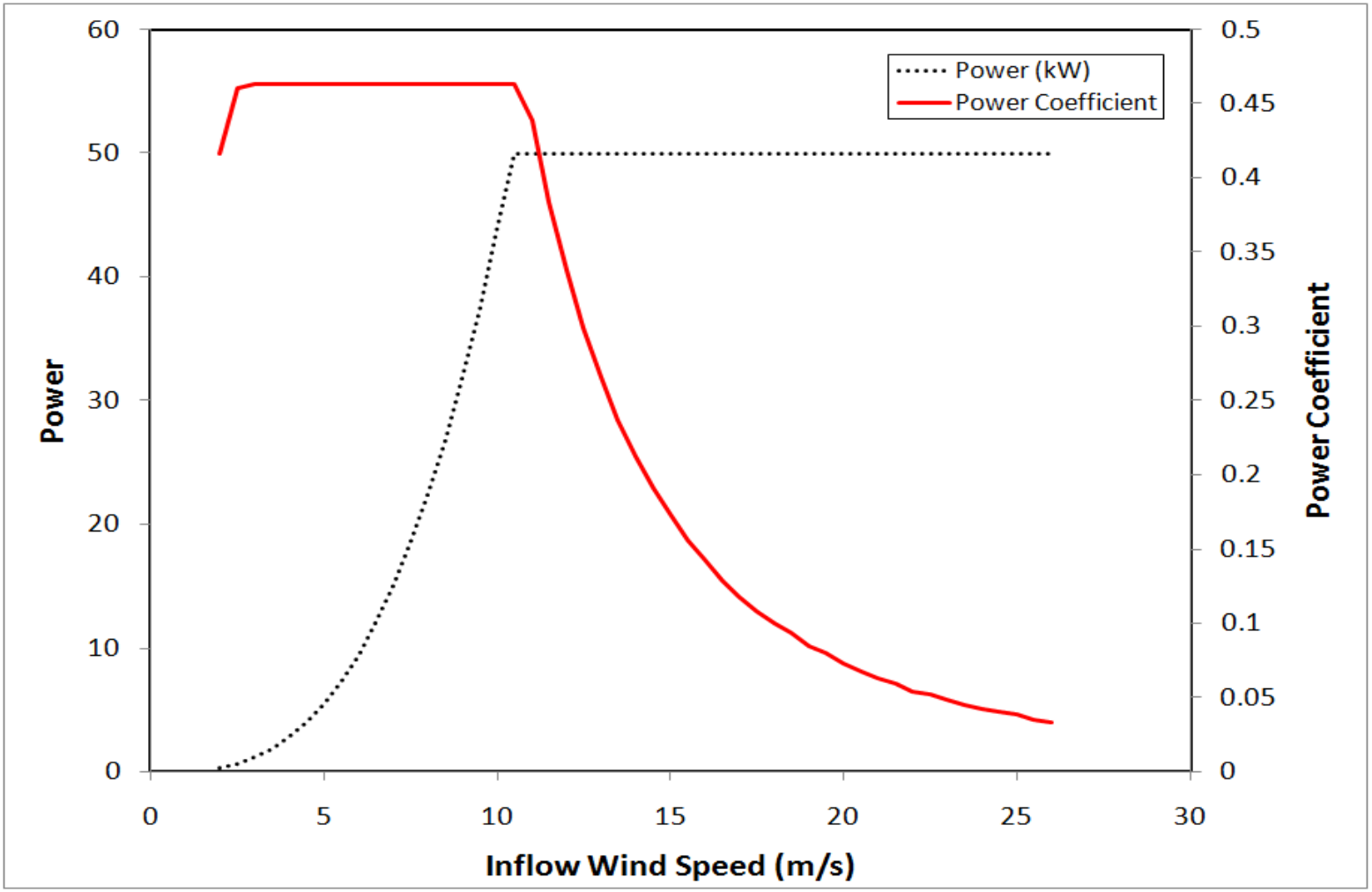


Blade Element Momentum Theory (BEM)



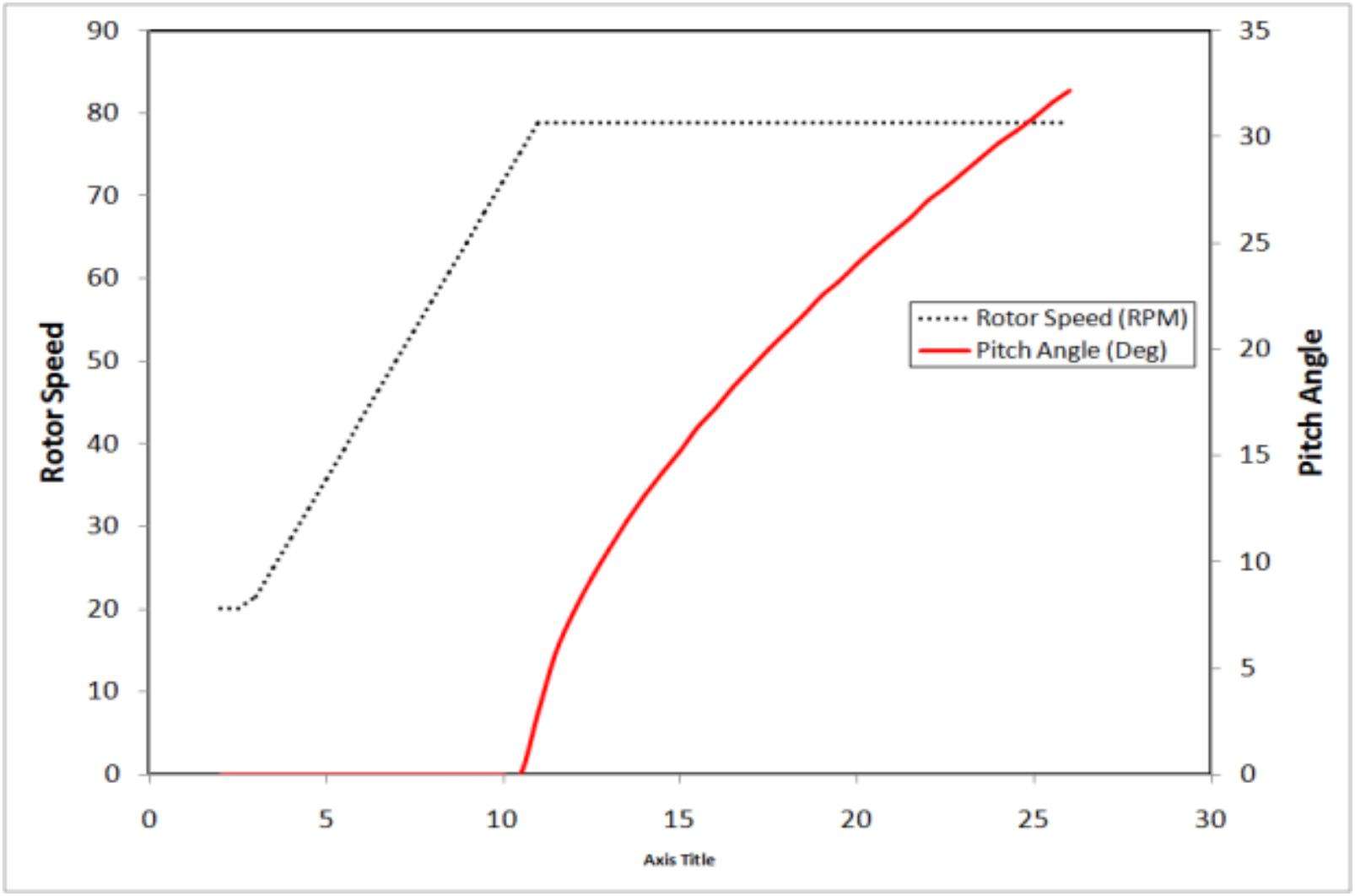
Blade Element Momentum Theory (BEM)

- Wind Turbine Performance



Blade Element Momentum Theory (BEM)

- Wind Turbine Performance

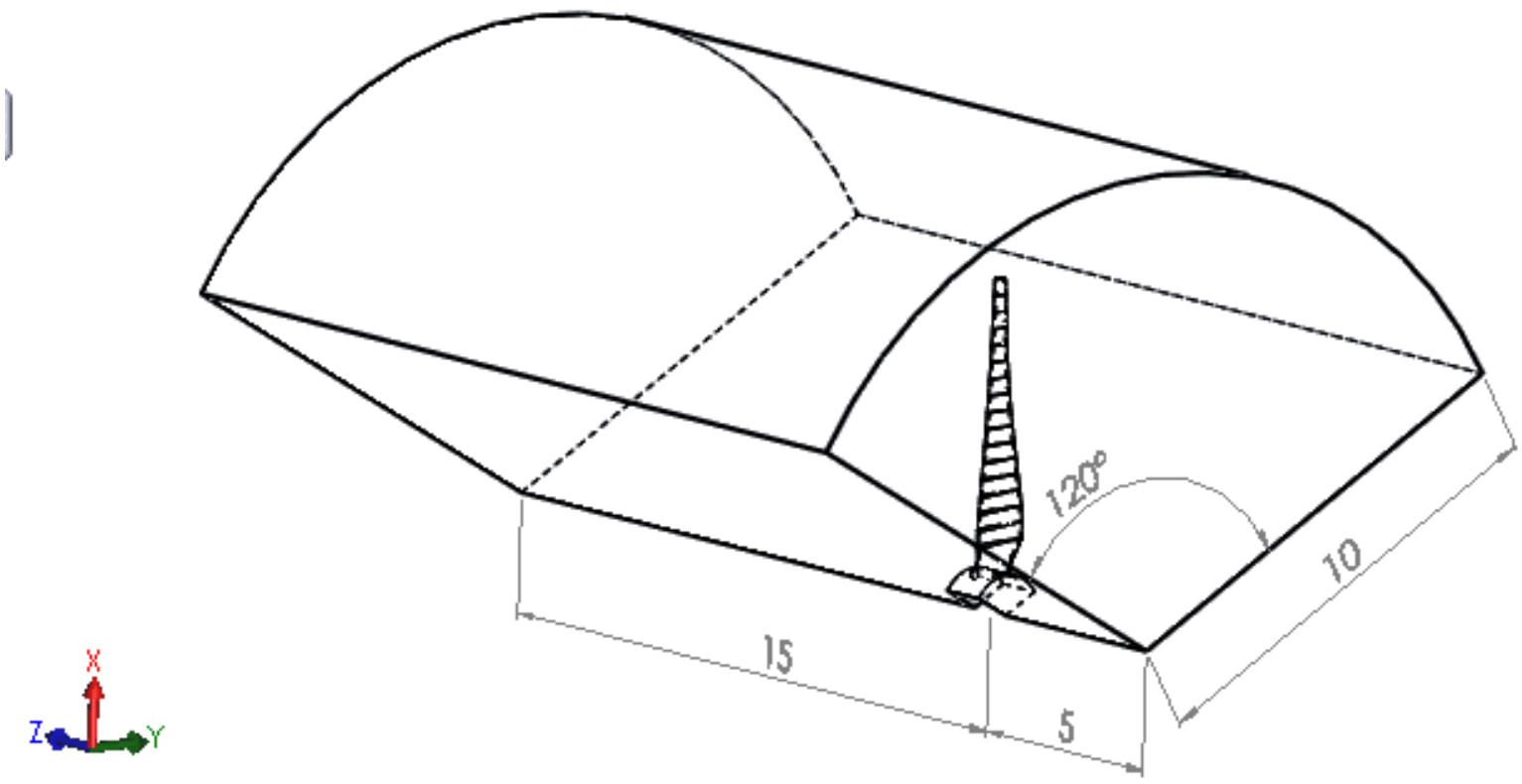


Computational Fluid Dynamics (CFD) model

- The modified Reynolds Averaged Navier-Stokes (RANS) equations for incompressible flow in a multiple reference frames are solved in this paper (MRFSimpleFoam solver in OpenFoam).
- For turbulence model we used The two-equation k-ε model.
- The MRFSimpleFoam solver applies the SIMPLE algorithm together with the GAMG multi-grid solver for the pressure calculations and Gauss Seidel technique as a smoother.

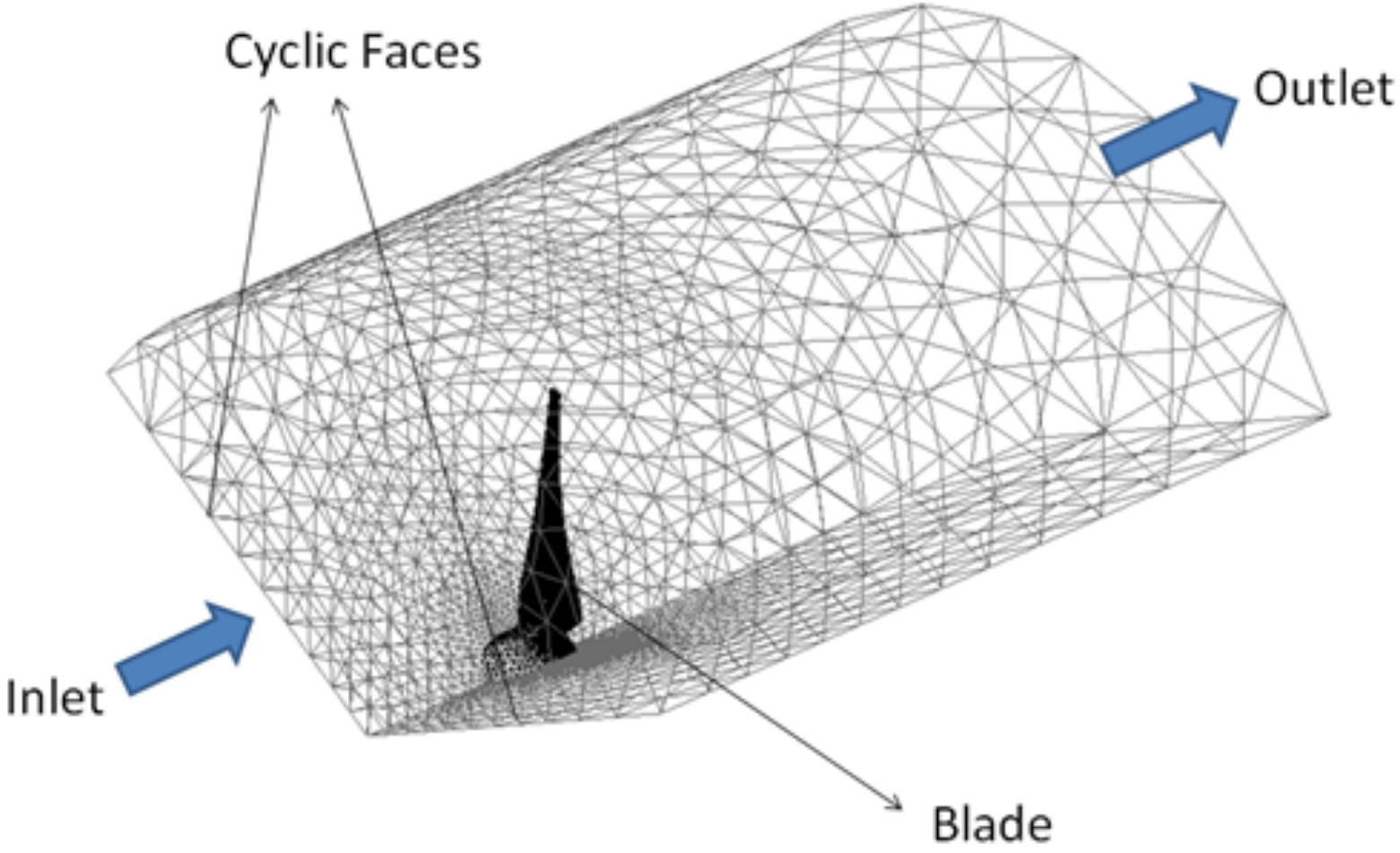
Computational Fluid Dynamics (CFD) model

- Computational domain and boundary conditions used (all the numbers relative to blade length)

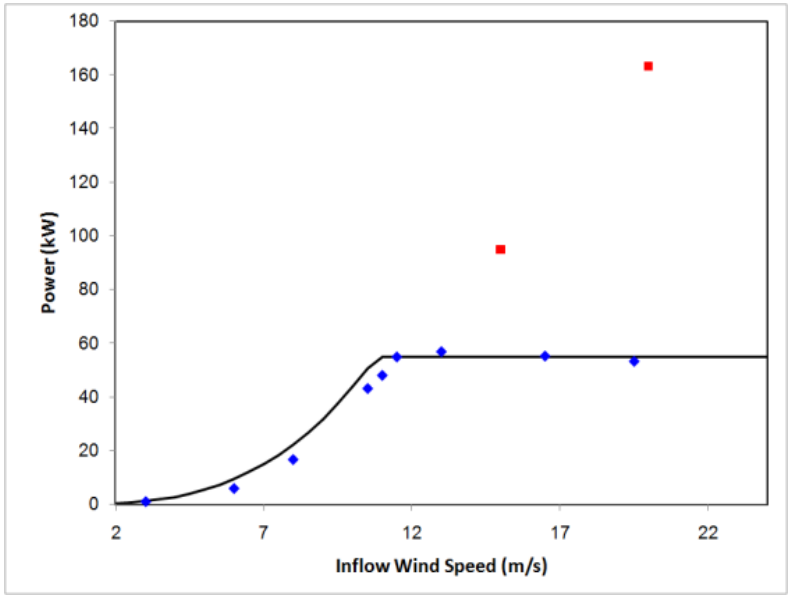


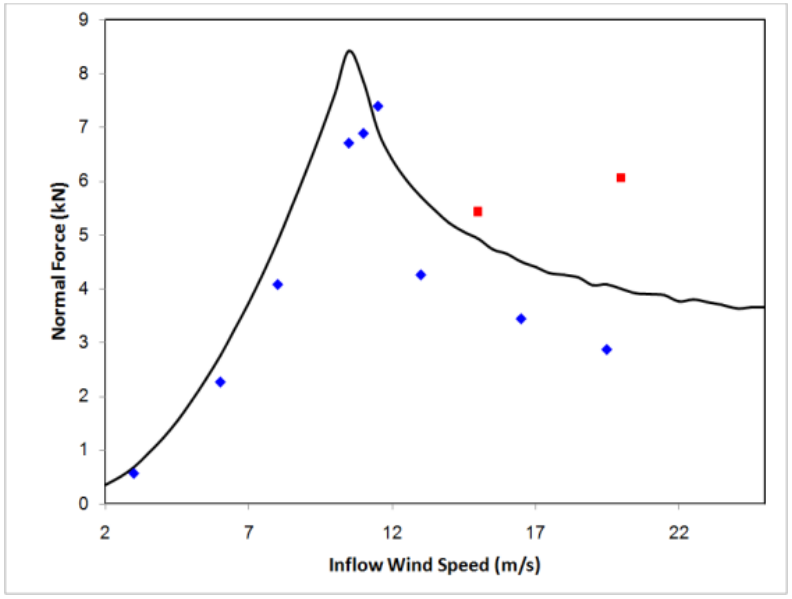
Computational Fluid Dynamics (CFD) model

- Computational domain and boundary conditions used

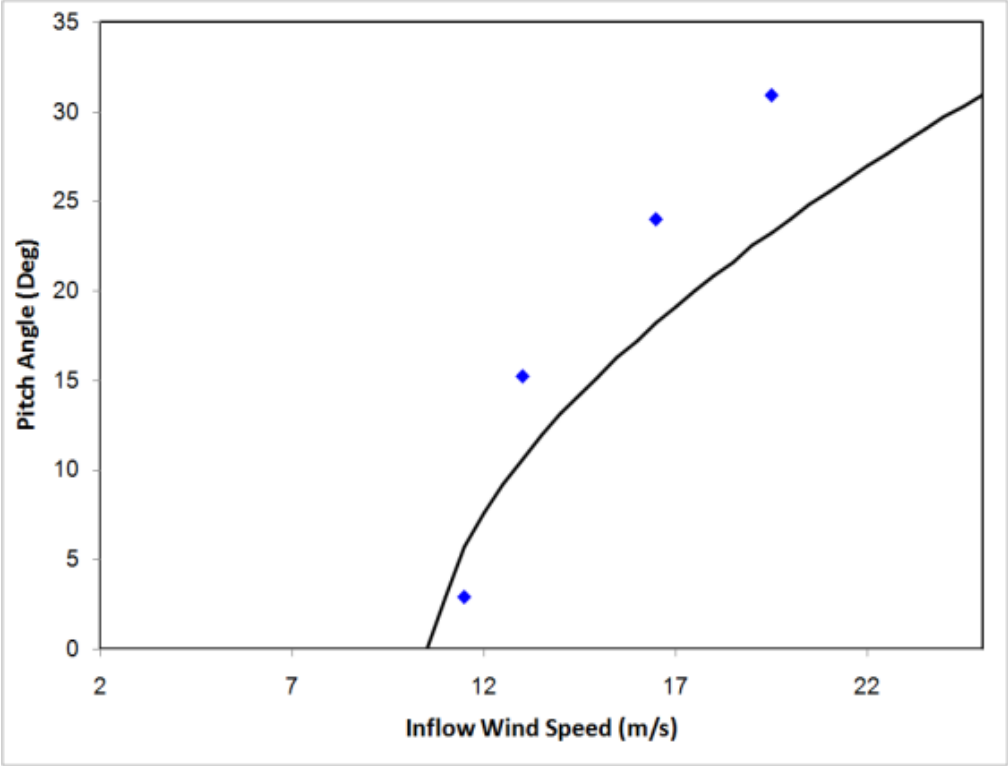


- Comparison between BEM and CFD





Results and Discussion



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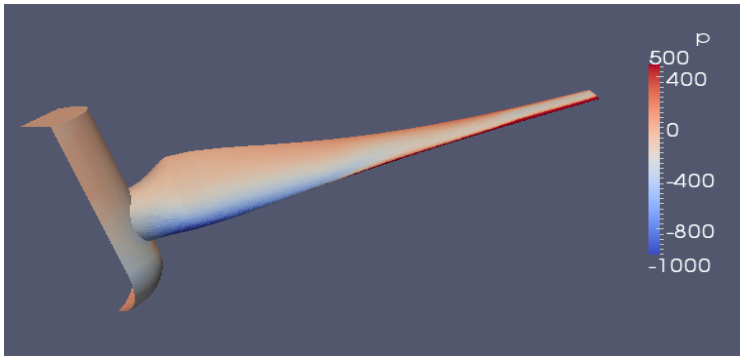

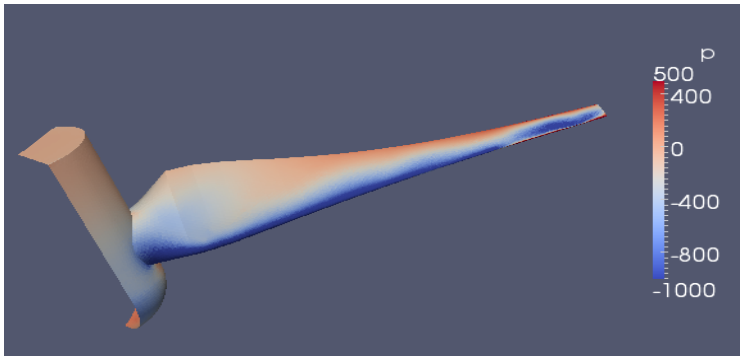

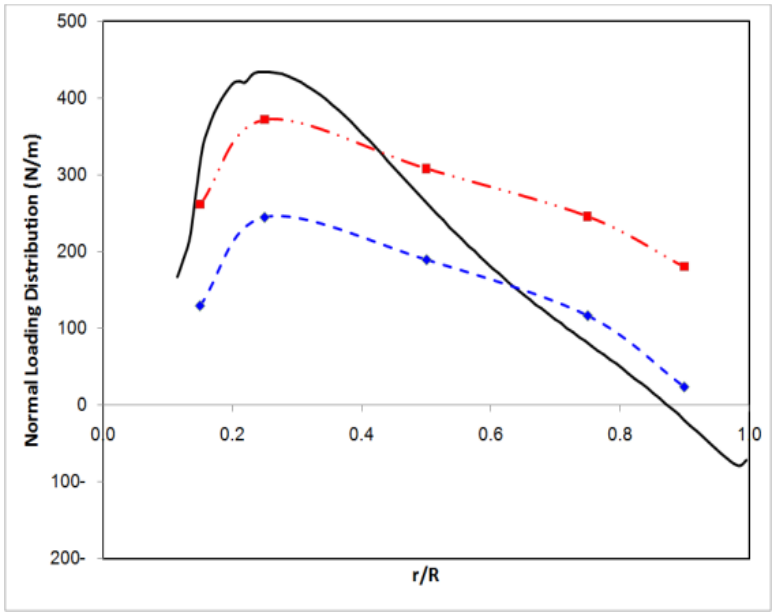

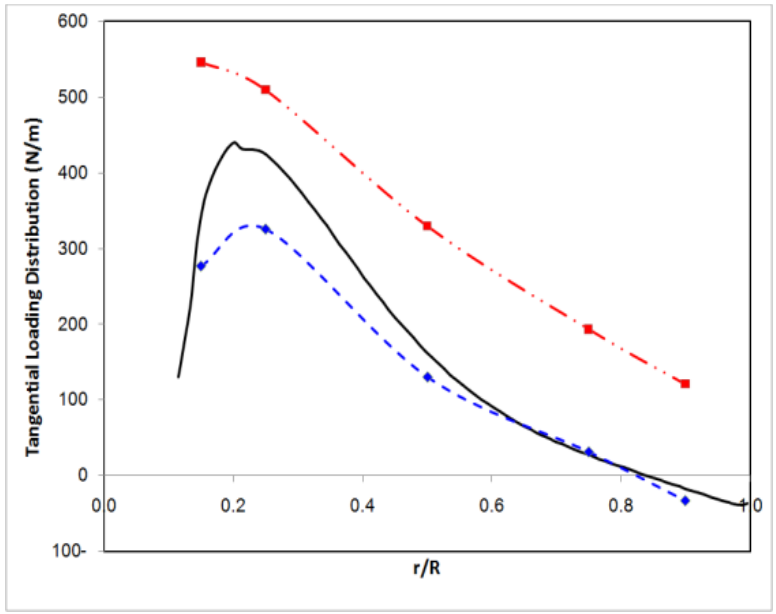

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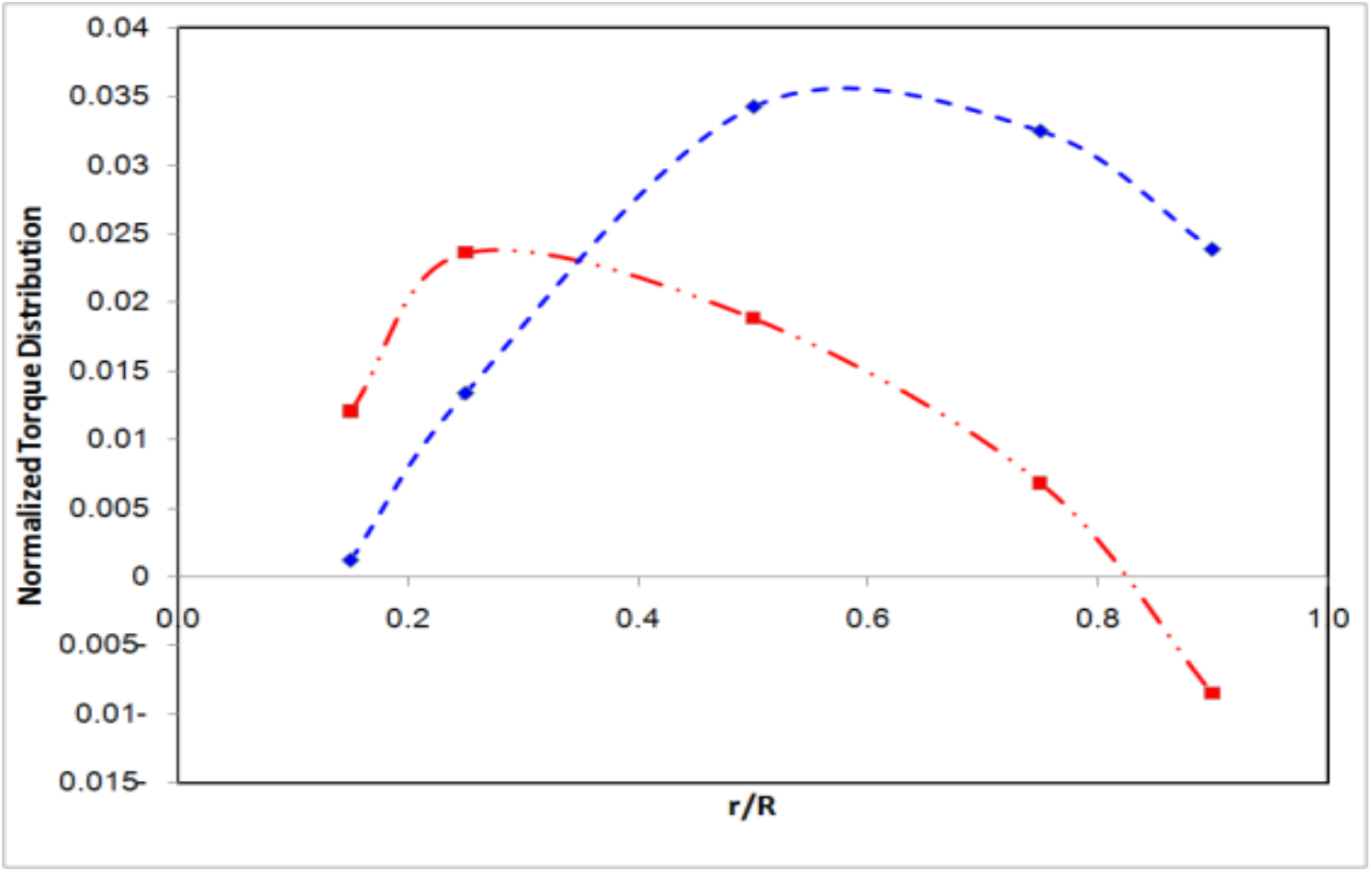

Conclusions

- Comparing the power curve generated from the BEM to the CFD concludes that the BEM can be used in the variable speed operating zone.
- This is attributed to the fact that the most of the power is produced by the outer sections of the wind turbine which are essentially in two-dimensional flow.
- In the variable pitch operating zone, the results show significant deviation between the BEM and CFD.

Conclusions

- In this mode of operation the power is mostly produced from the inner sections which suffer from three-dimensional flow effects and cannot be modeled by the BEM.
- The deviation of the pitch angle between the BEM and CFD can reach up to 10^{o}. This is a significant angle and must be taken into consideration when designing pitch control systems for wind turbine blades.
- An experiment is underway to further validate the results of the CFD model.