COLLEGE OF ENGINEERING
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Array Optimization of Marine Hydrokinetic (MHK) Turbines Using the Blade Element Momentum Theory

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Goals

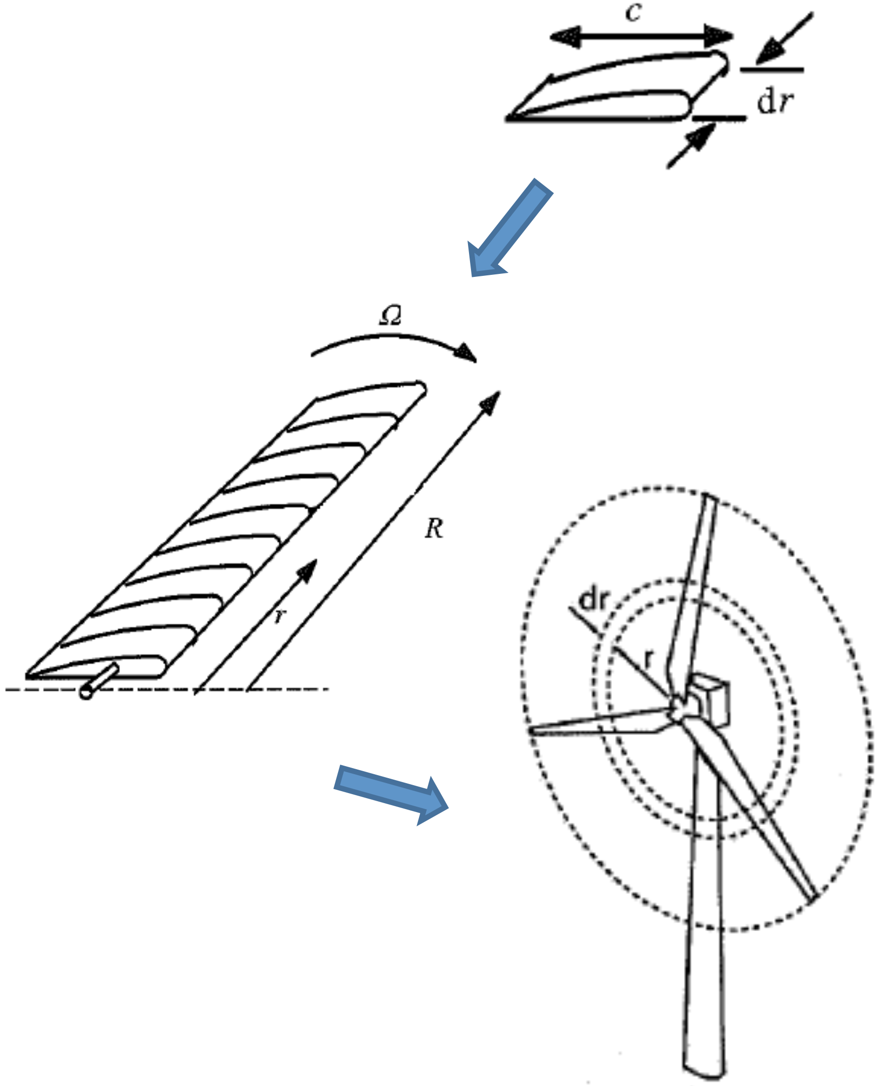
- Develop a general numerical methodology for array optimization of horizontal axis MHK turbines.

- Address and investigate the key variables in Marine Hydrokinetic (MHK) turbine array optimization (i.e. different operating conditions and spacing between devices)

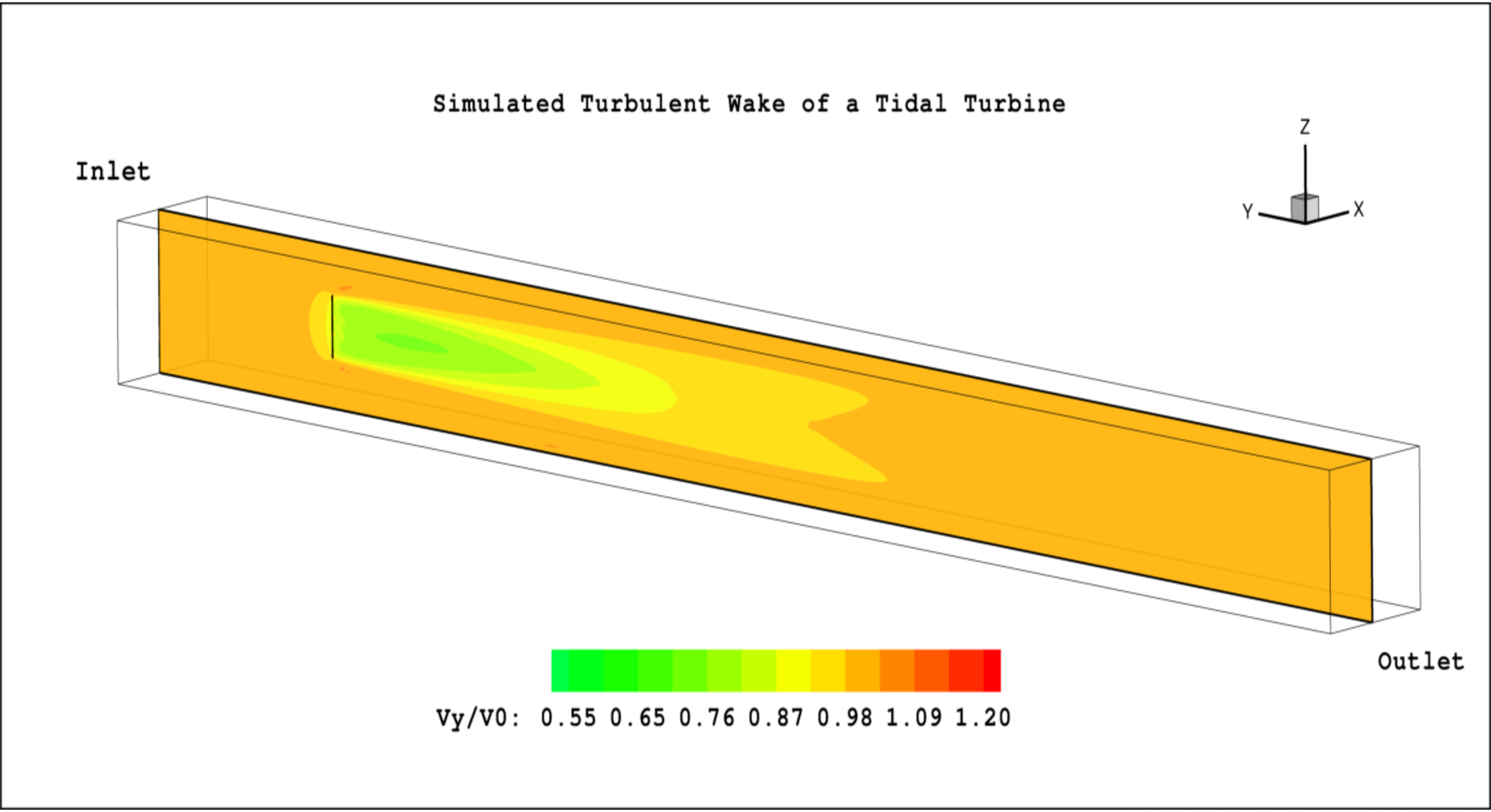
- Maximize energy extraction from a very concentrated resource in estuaries and rivers.

Numerical Methodology

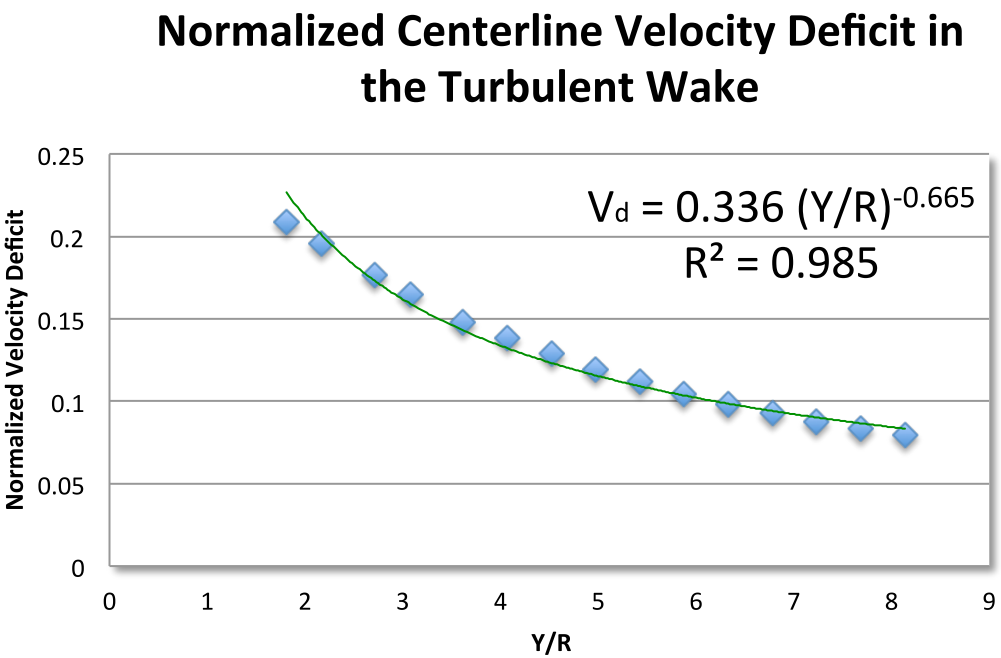
- This model is an implementation of Blade Element Momentum Theory (BEM) in ANSYS FLUENT.
- Lift and Drag forces are calculated for each blade element based on their lift and drag coefficients as input for the model.
- Calculated forces are averaged over a cycle of rotation.
- Effect of rotating blades is simulated on the fluid through a body force.



Computational Domain for a Single Turbine



V_y = 2 [m/s] , Tip Speed Ratio (T.S.R) = 4.9



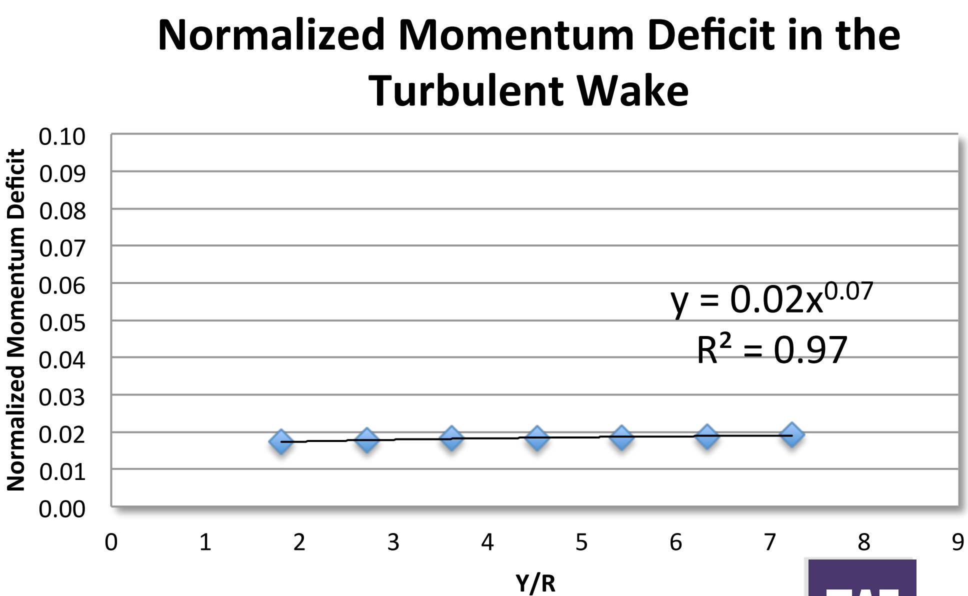
$$V_d = \frac{\left|V_0 - V_y\right|}{V_0}$$

$$\left(\frac{Y}{R}\right)^{-\frac{2}{3}}$$

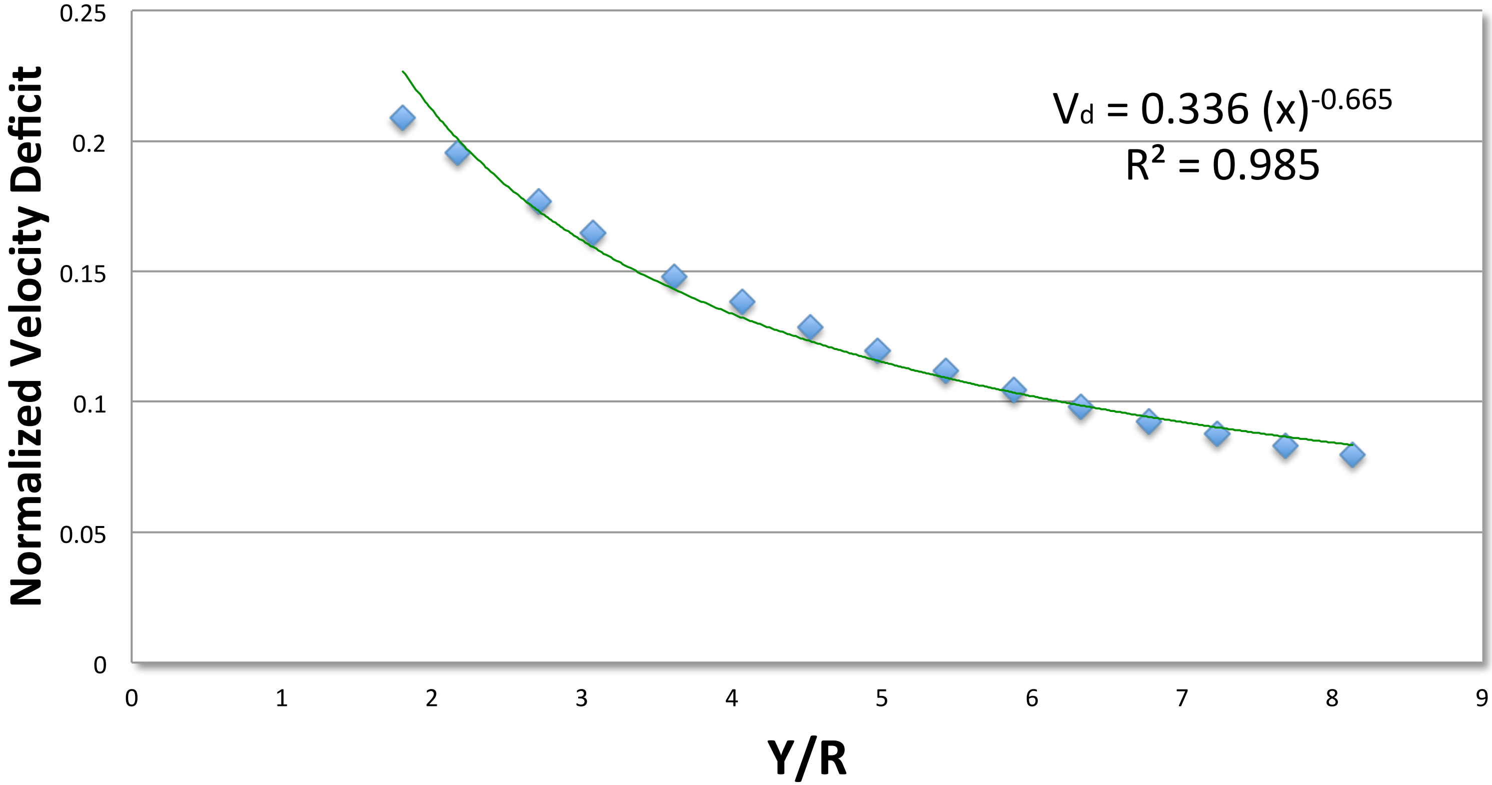
$$\dot{M}_y = \int_0^{3R} 2\pi r \rho V_y^{\,2} dr$$

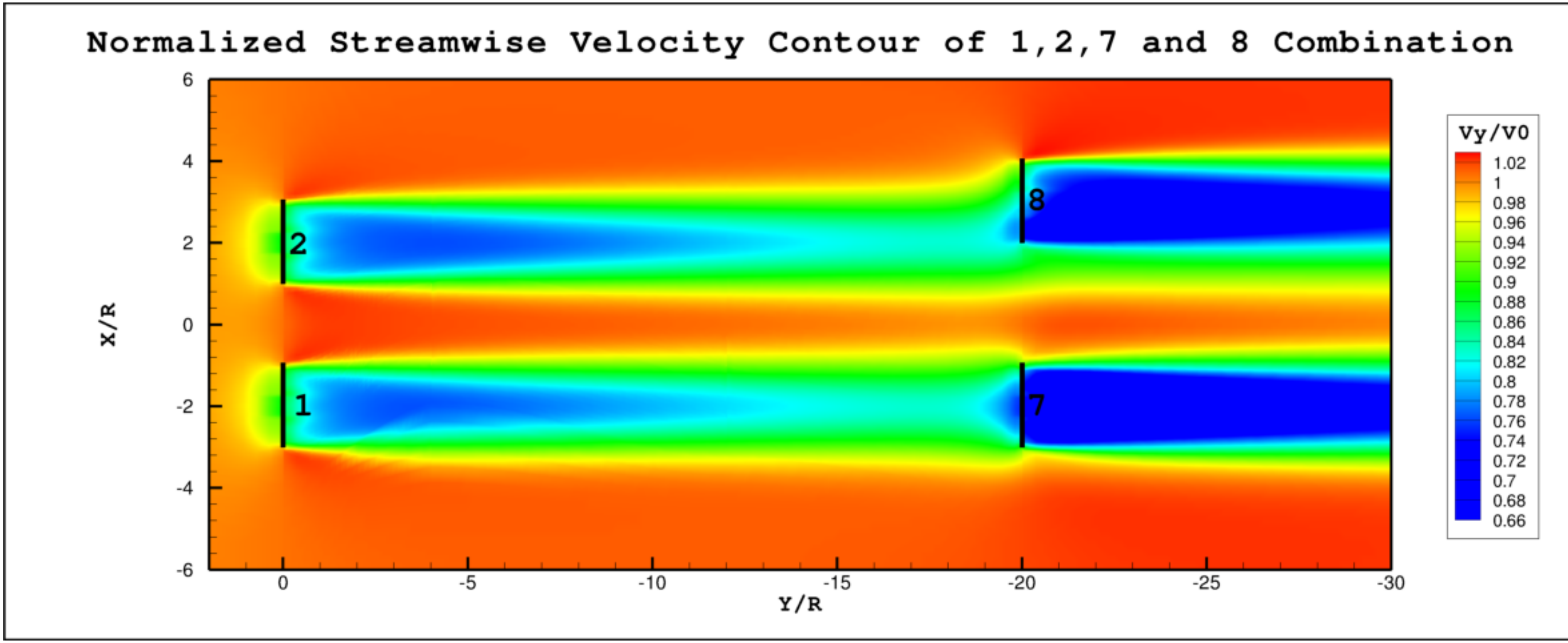
$$\dot{M}_d = \frac{\left|\dot{M}_\infty - \dot{M}_y\right|}{\dot{M}_\infty}$$

Constant



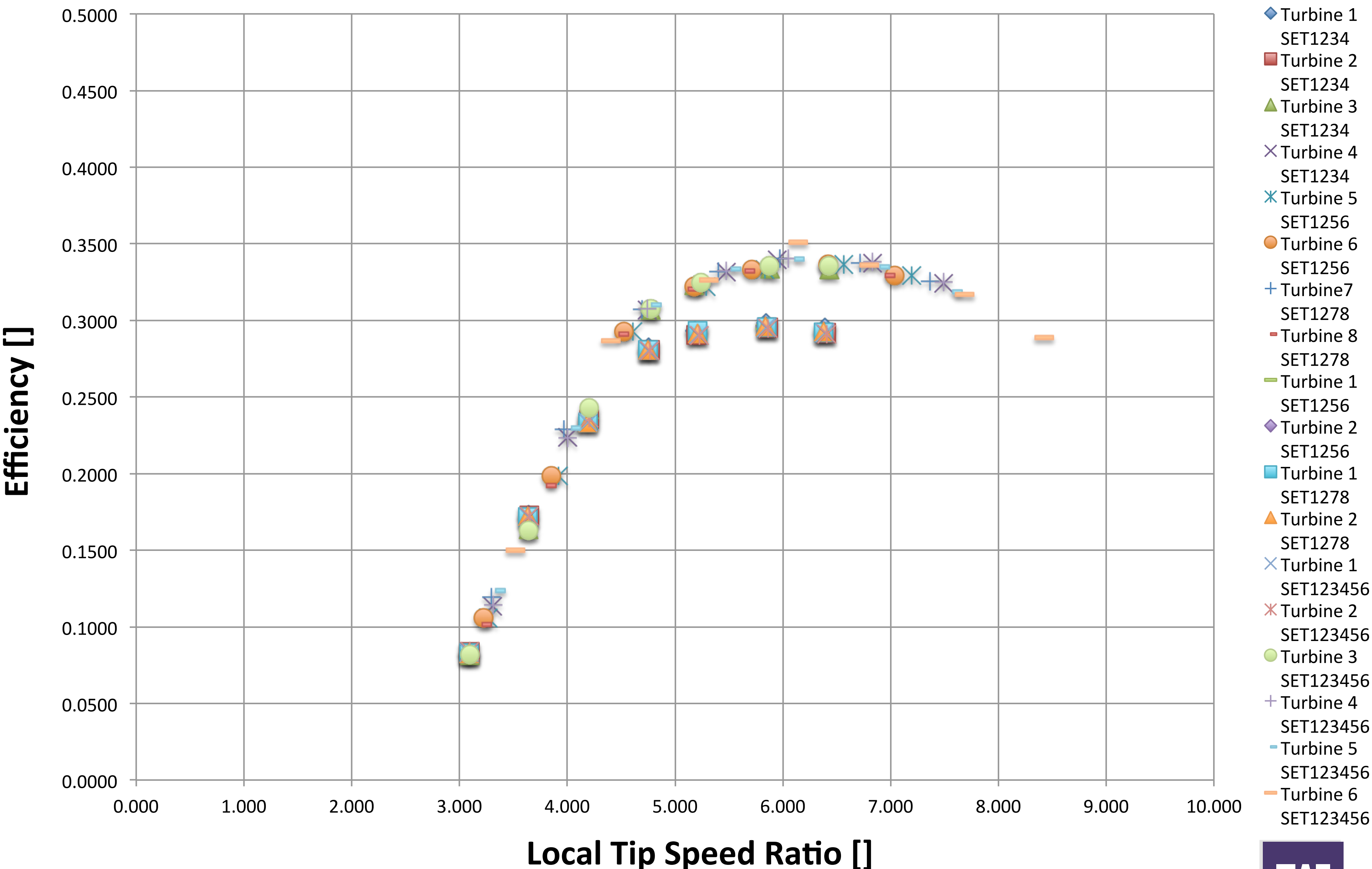
Normalized Centerline Velocity Deficit in the HAHT Turbulent Wake Modeled via the VBM.



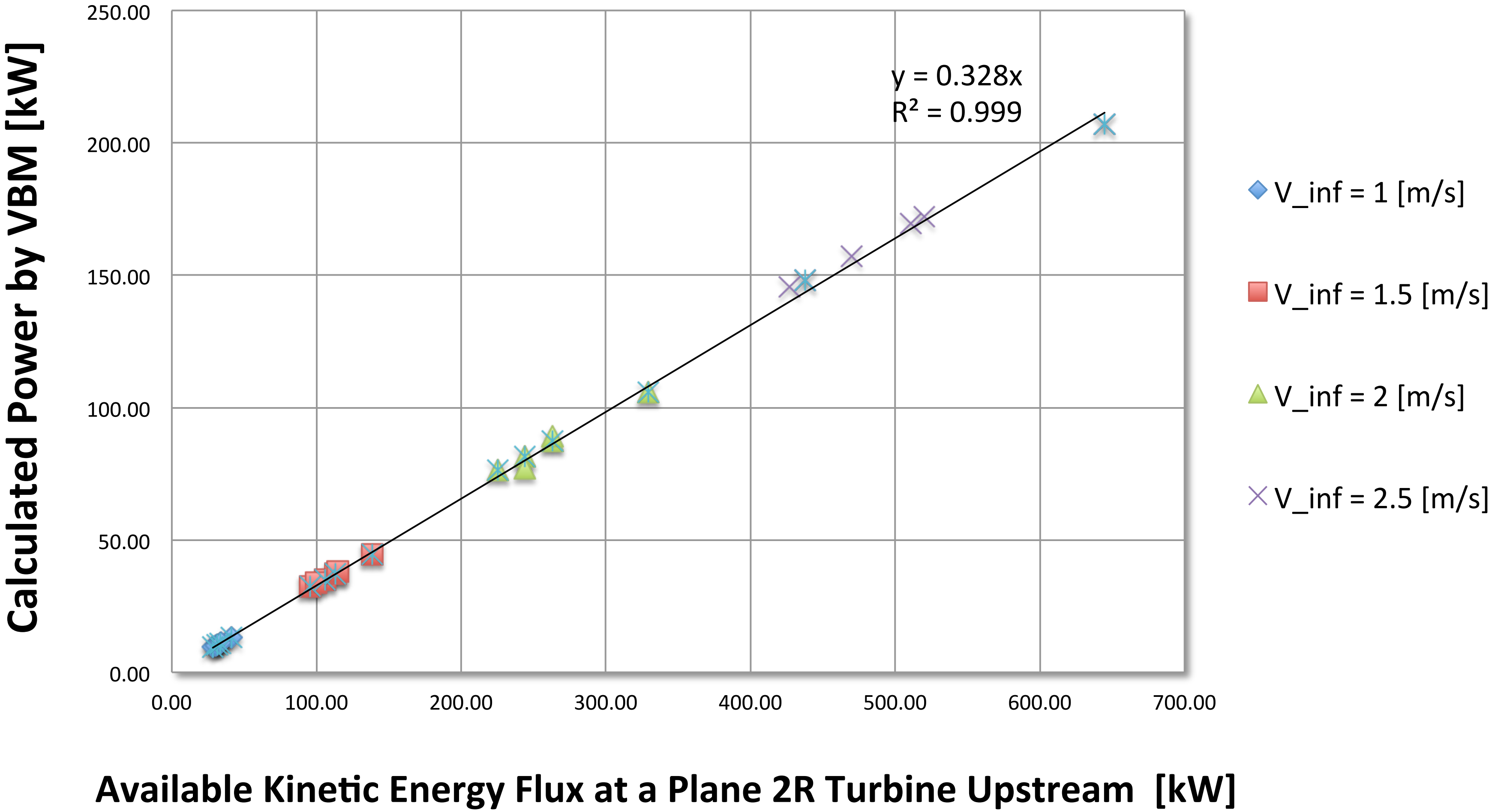


	Thrust [kN]	Torque [Nm]	Max. AOA [°]	Min. AOA [°]	Calculated Power by VBM [kW]	Available Kinetic Energy Flux on Turbine Plane [kW]	Efficiency []
Turbine 1	75.739	54.042	10.246	6.561	96.207	327.848	0.294
Turbine 2	75.451	53.640	10.231	6.522	95.493	327.488	0.292
Turbine 7	67.443	43.297	8.150	5.838	77.080	226.572	0.340
Turbine 8	72.631	50.022	10.203	5.175	89.052	268.899	0.331

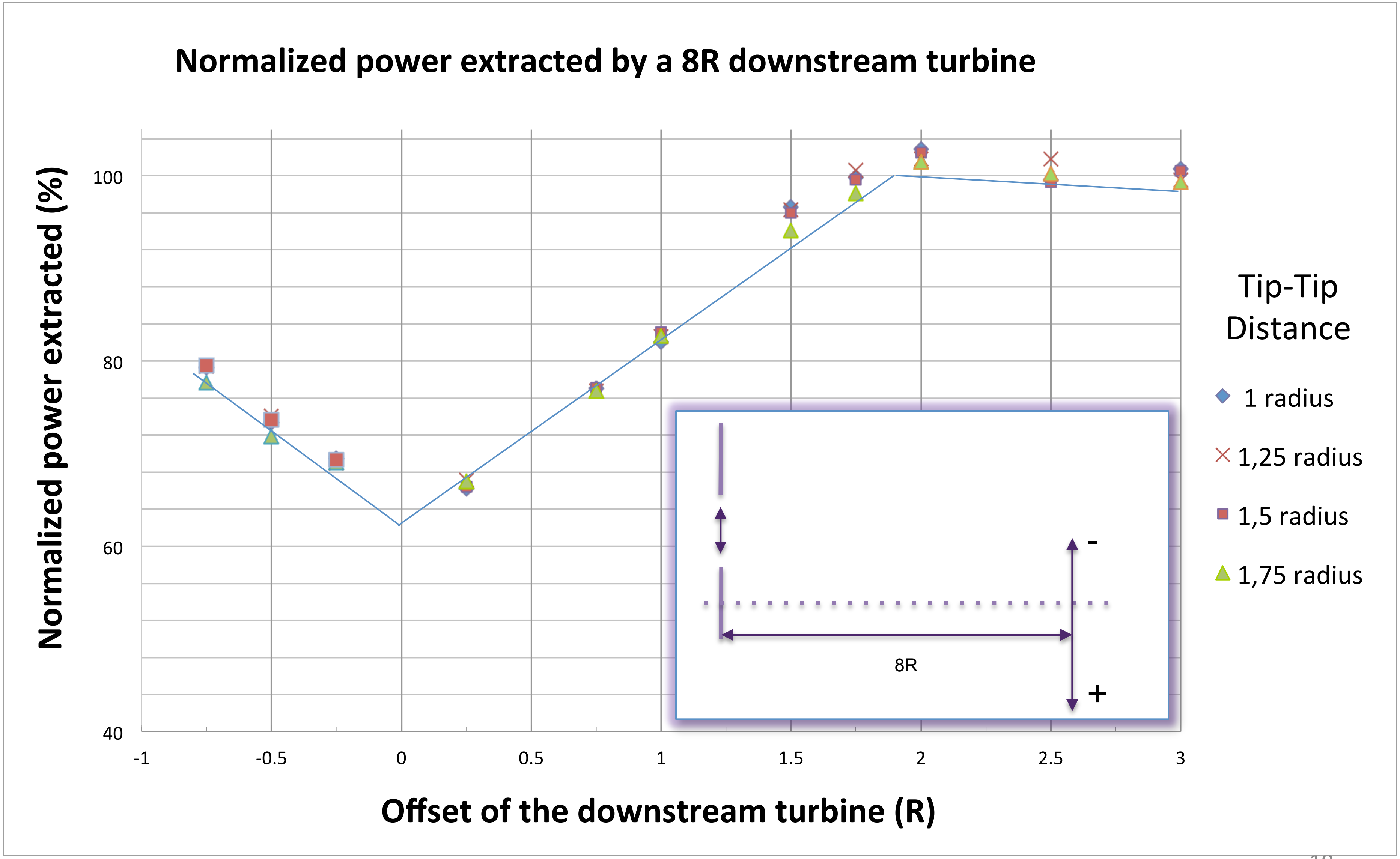
Turbine Efficiency vs. Local Tip Speed Ratio

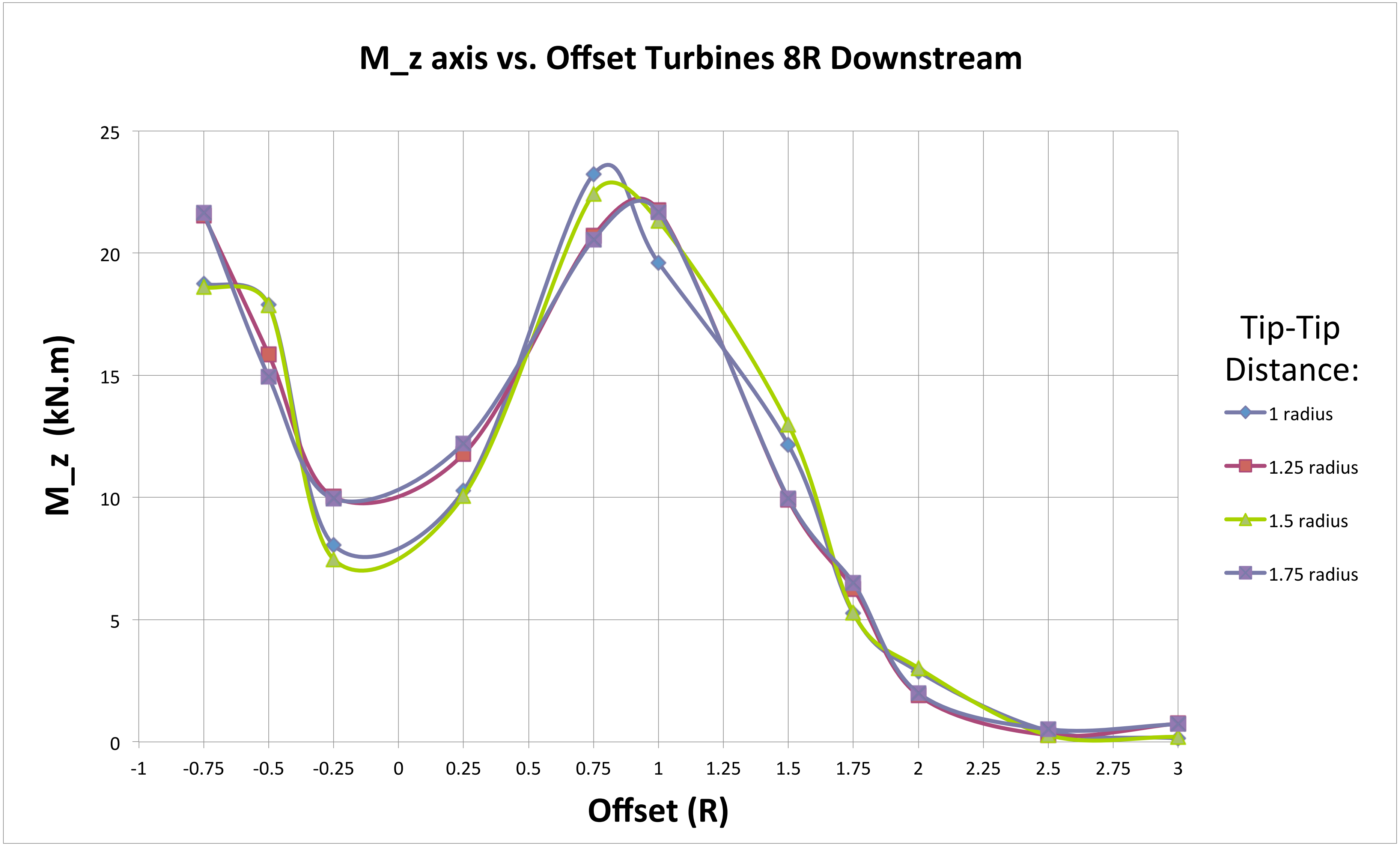


Efficiency of Downstream Turbines at constant Tip Speed Ratio (T.S.R=4.9)



Effect of Lateral Offset




M_z axis vs. Offset Turbines 8R Downstream
M_z (kN.m)
25
20
15
10
5
0
-1
-0.75
-0.5
-0.25
0
0.25
0.5
0.75
1
1.25
1.5
1.75
2
2.25
2.5
2.75
3
Offset (R)
Tip-Tip Distance:
1 radius
1.25 radius
1.5 radius
1.75 radius

Conclusions

- A general numerical methodology was developed to study the key parameters in array optimization of MHK turbine.
- Computed a constant efficiency for turbines operating in arrays above a certain TSR (linear behavior), as well as the efficiency decay consistent with separated flow at low TSR (non-linear regime).
- Tip-Tip distance has very small effect on efficiency of neighbor and downstream turbines.
- Offset distance plays an important role in an array of turbine. A lateral offset of 1.75-2 radii provides optimum spacing and minimum loading stress on the device.

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