Advances on Hydrodynamic Design of Horizontal-Axis Hydrokinetic Turbines

Prof. Jerson R. P. Vaz

FEM-PPGEM-PRODERNA/ITEC/UFPA

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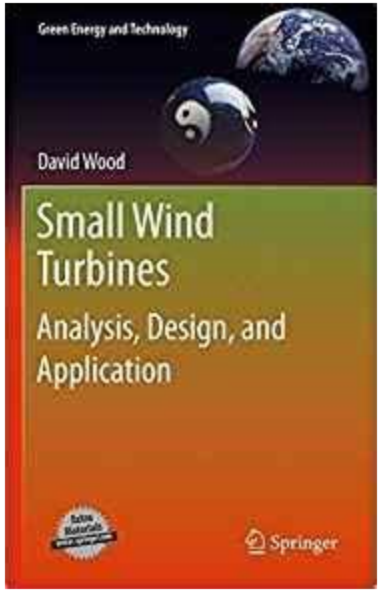


Eric Limacher
(Princenton University)

Jerson Vaz
(UFPA)

David Wood
(University of Calgary)

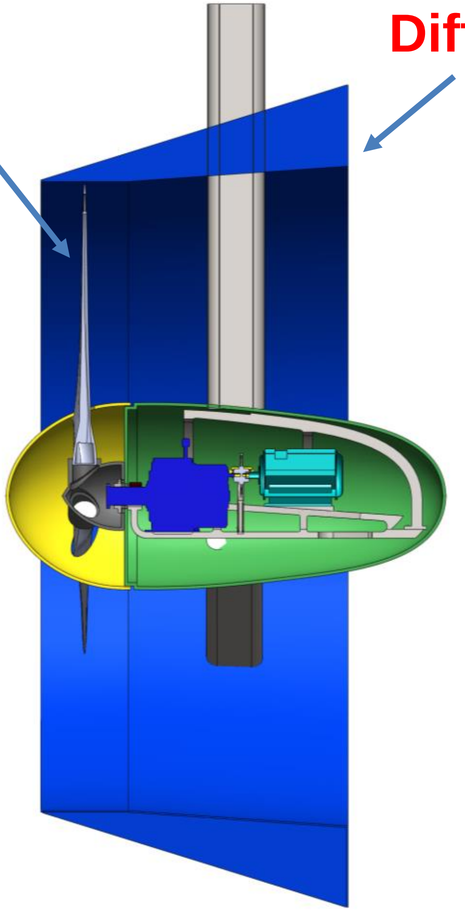
Hydrokinetic Turbine Applications

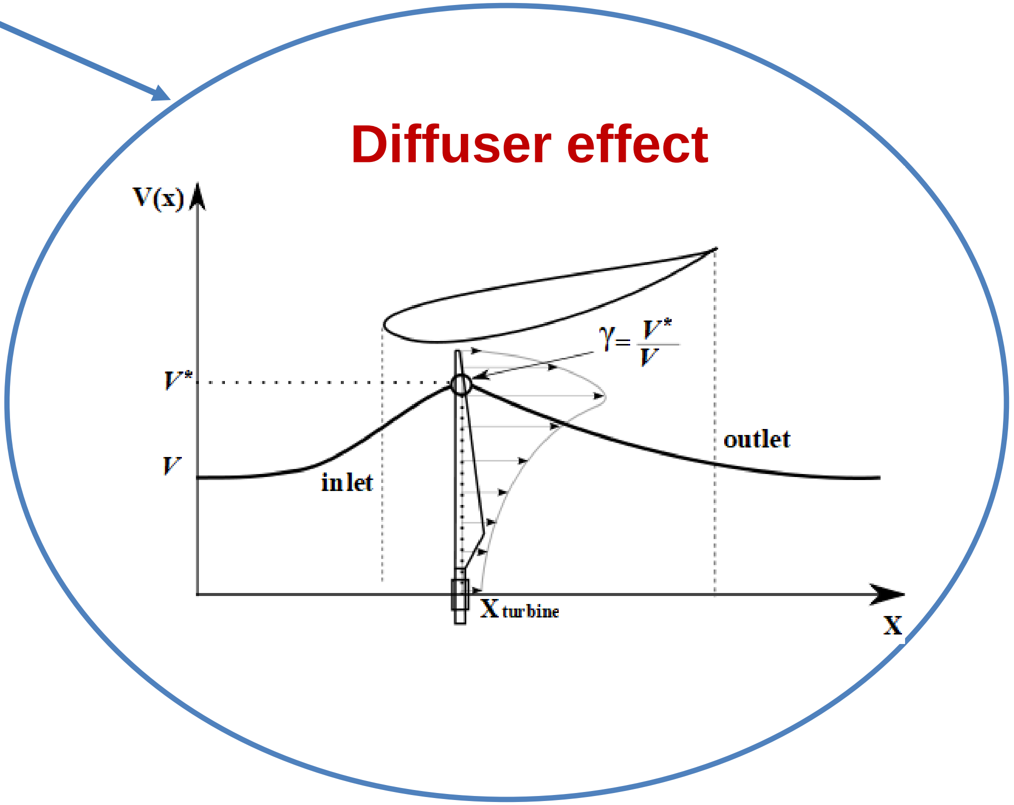
https://www.motherearthnews.com/renewable-energy/other-renewables/micro-hydro-momentum-zwfz1210zrob

Rotor

Hub

Diffuser





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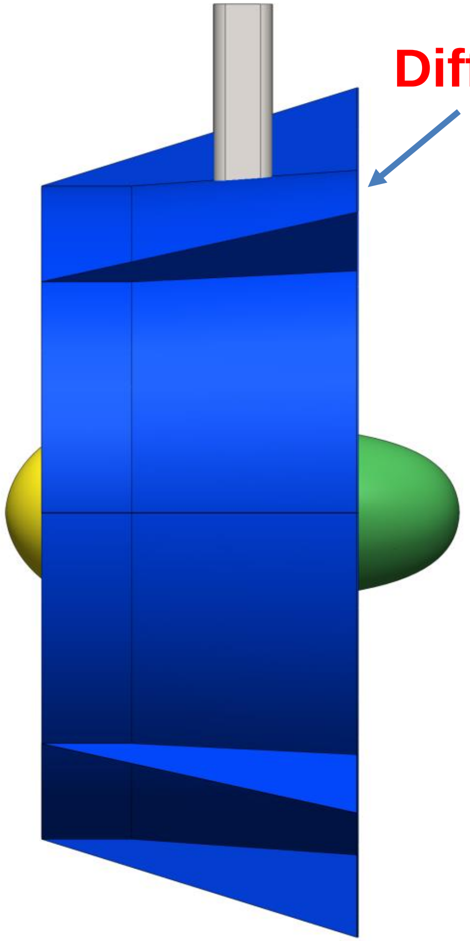
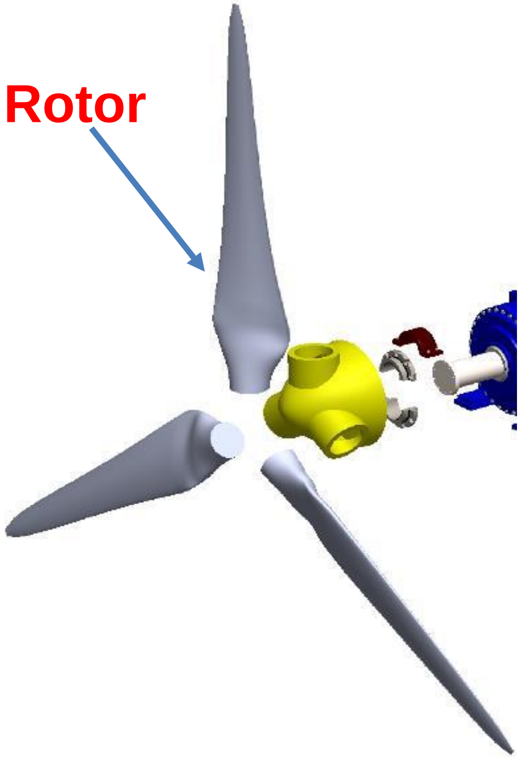
Hydrodynamic design of:

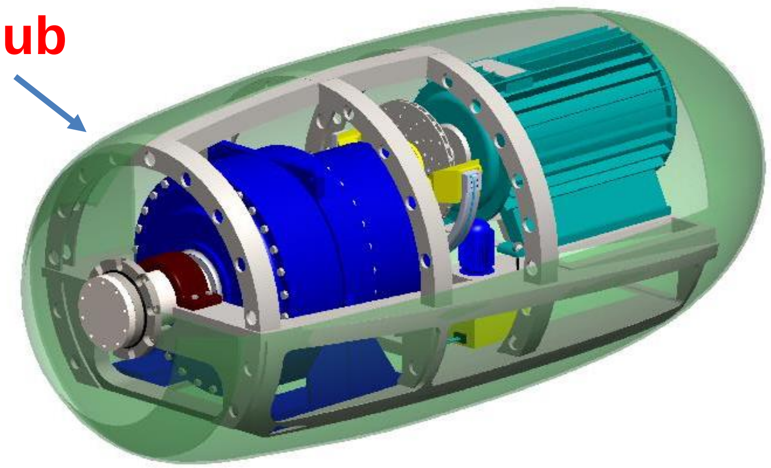
Diffuser



Rotor



Hub



Diffuser design

Eric, Pedro Oliveira, Pedro Elias

Total thrust vs. sectional lift.

Thrust force

$$T_d = -2\pi \oint_S y n_x p dl$$

Radial coordinate of each point on the contour, *S*.

Pressure

Outward facing unit normal component in the *x* direction.

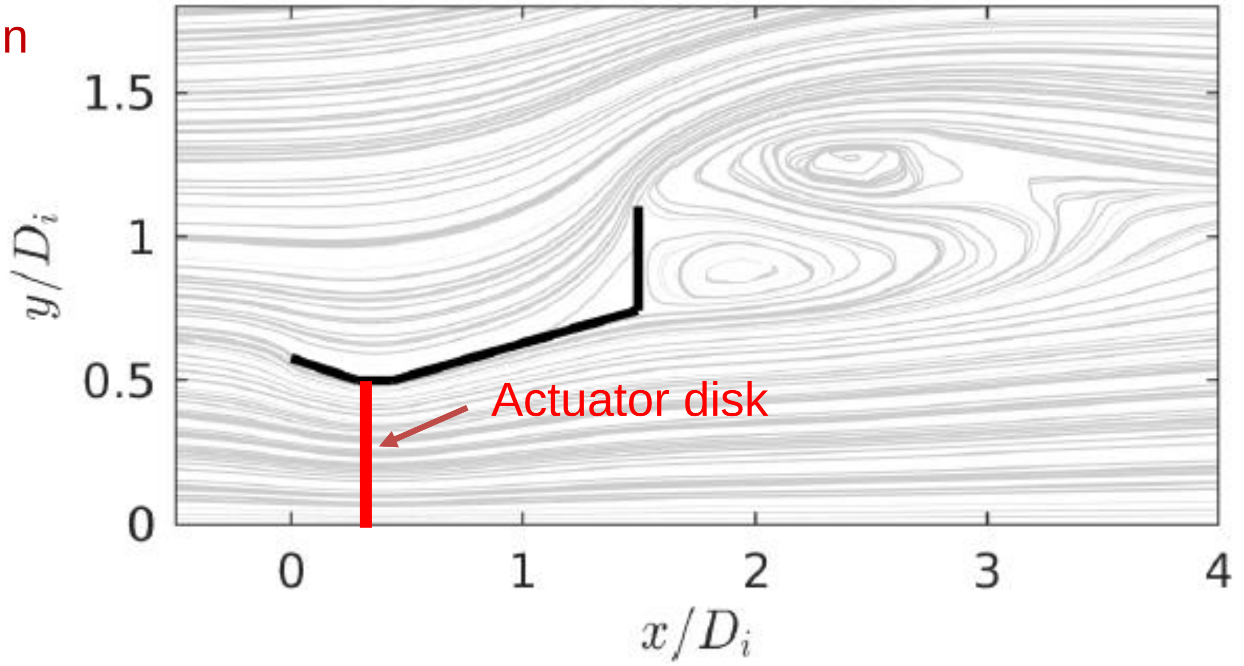
Lift force

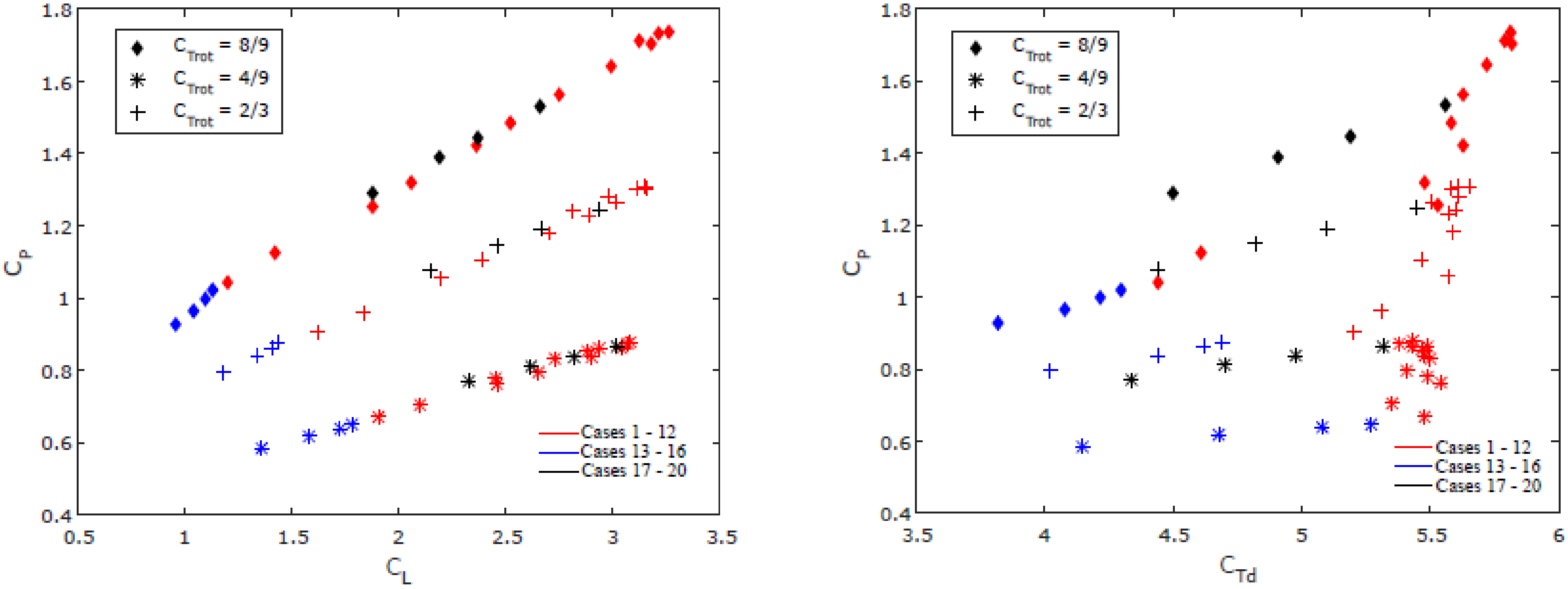
$$L_d = -\oint_S y n_y p dl$$

Radial coordinate of each point on the contour, *S*.

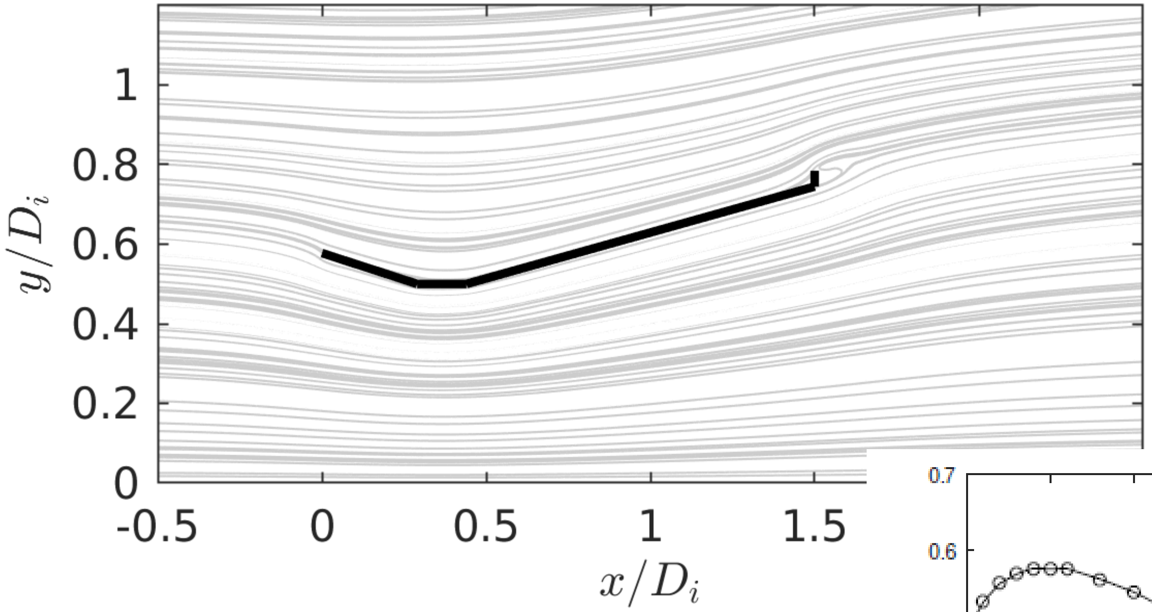
Pressure

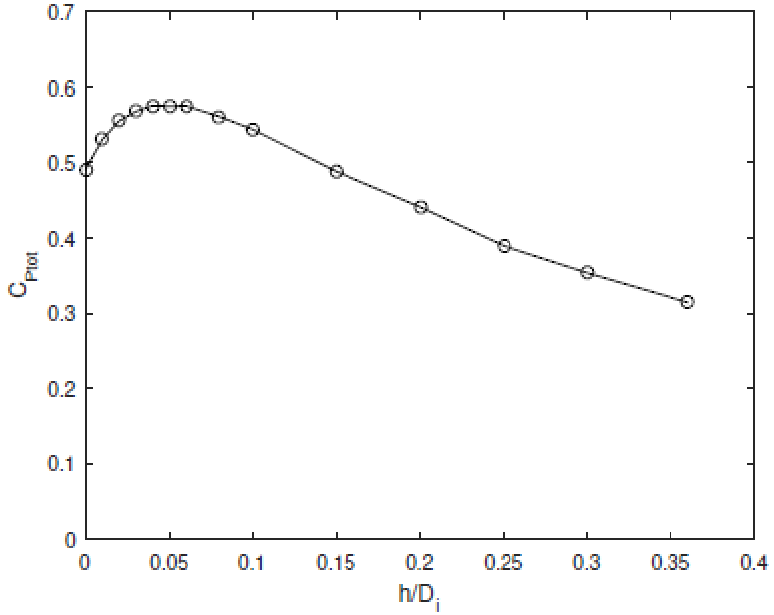
Outward facing unit normal component in the *y* direction.

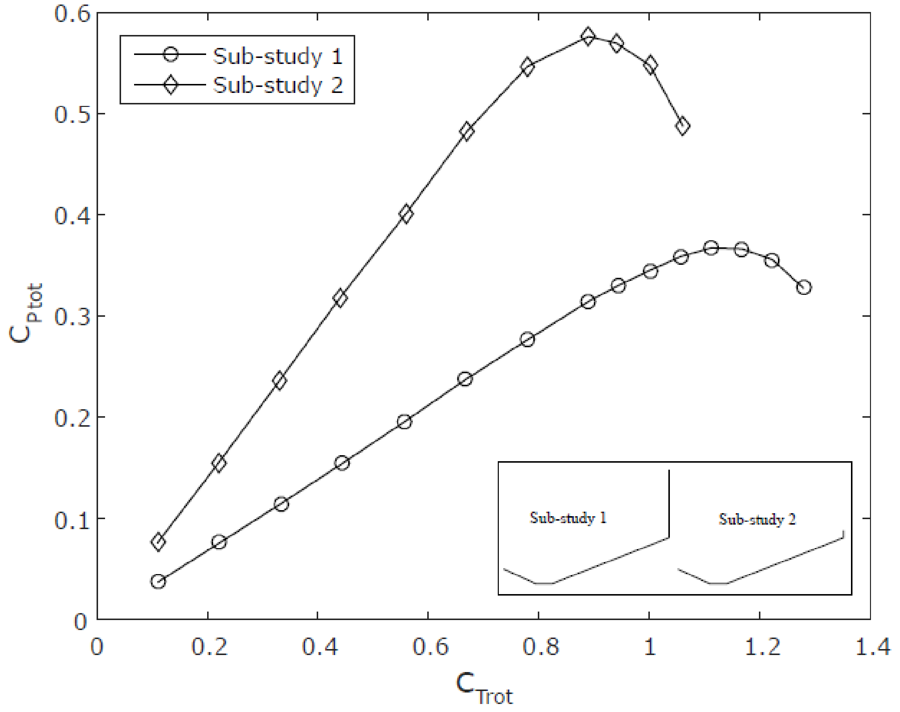



C_{Trot} = 8/9
C_{Trot} = 4/9
C_{Trot} = 2/3
Cases 1 - 12
Cases 13 - 16
Cases 17 - 20
C_P
C_L
C_{Td}
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6

(a) (b)


y/D_i
x/D_i
-0.5
0
0.5
1
1.5
0
0.2
0.4
0.6
0.8
1


C_Ptot
h/D_i
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.1
0.2
0.3
0.4
0.5
0.6
0.7


Sub-study 1
Sub-study 2
C_Ptot
C_Trot
0
0.2
0.4
0.6
0.8
1
1.2
1.4
0.1
0.2
0.3
0.4
0.5
0.6

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Large exit flanges in diffuser-augmented turbines lead to sub-optimal performance

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The Journal of the International Association for Wind Engineering

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> CiteScore: 3.86 ⓘ Impact Factor: 3.010 ⓘ

Rotor design

Rio Vaz et al (2018)

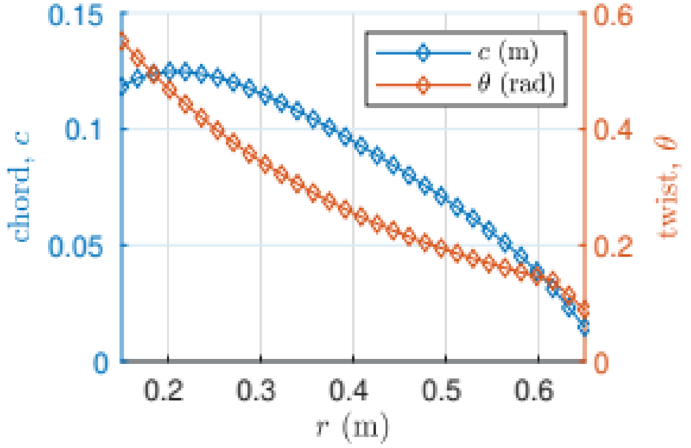
$$16a_{opt}^3 - 24a_{opt}^2 + \left[9 - 3\left(\frac{x}{\gamma}\right)^2\right]a_{opt} + \left(\frac{x}{\gamma}\right)^2 - 1 = 0.$$

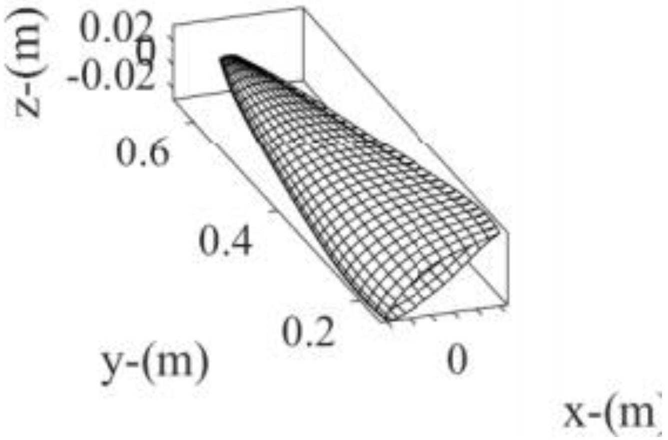
Vaz & Wood (2018)

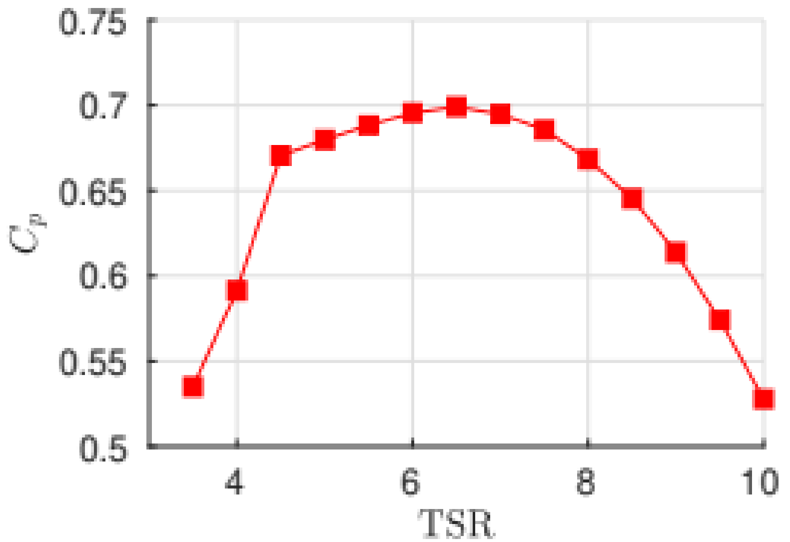
$$6\varepsilon_{1opt}^3\left[\beta^2(1-\eta_d)+\eta_d\right] - C_{Td}\Delta + 4\varepsilon_{1opt}(1 + C_{Td} + \Delta) - 2\varepsilon_{1opt}^2(5+3\Delta) = 0$$

where

$$\Delta = \sqrt{1 + C_{Td} + \varepsilon_{1opt}\left\{-2 + \varepsilon_{1opt}\left[\beta^2(1-\eta_d)+\eta_d\right]\right\}}$$







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Energy for Sustainable Development 45 (2018) 142–149

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Energy for Sustainable Development

An approach for the optimization of diffuser-augmented hydrokinetic blades free of cavitation

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ABSTRACT

Due to the Venturi effect caused by a diffuser, which speed-up the velocity through the rotor, shrouded turbines are able to exceed the Betz-Joukowsky limit if the power coefficient is based on the rotor diameter. However, on hydrokinetic turbines this increased velocity may also promote cavitation on the blade. As this subject is still not clear on the current literature, this work presents a novel approach for optimizing hydrokinetic turbines free of cavitation under diffuser effect. The model uses the minimum pressure coefficient as the criterion to keep the pressure near blade tip above water vapor pressure. It includes an extension of Vaz & Wood's optimization in order to take into account the influence of the diffuser speed-up ratio regarding cavitation effect. A changing on the thrust coefficient is assumed to optimize chord and twist angle distributions along the blade. As a result, the proposed model shows that cavitation is indeed sensitive to the diffuser speed-up ratio, demonstrating that such a phenomenon needs to be considered in the design of diffuser-augmented hydrokinetic turbines. Also, the optimization method corrects the chord without relevant changing in the turbine power coefficient, where the increased power output is about 42% higher than the bare turbine for a water velocity of 2.5 m/s. In this case, the model is assessed through comparisons using a 3-bladed hydrokinetic turbine with 10 m diameter, in which the diffuser speed-up ratio is varied. Furthermore, an evaluation is made with models available in the literature, suggesting good performance concerning the cavitation analysis on shrouded rotor design with the proposed optimization procedure.

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Effect of the diffuser efficiency on wind turbine performance

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ABSTRACT

A diffuser surrounding a rotor is able to increase the power coefficient of a wind turbine above the Betz-Joukowsky limit (16/27), and so has attracted great attention for many years. This work presents a novel analysis of the performance of diffuser-augmented wind turbines (DAWTs) taking into account the influence of the diffuser efficiency and thrust, in which a new formulation for the far-wake velocity is proposed. The mathematical model extends Blade Element Theory to include the diffuser efficiency in the axial velocity formulation, which in turn, modifies the thrust and power. Additionally, a correction for high rotor thrust is presented, where a quadratic equation is used to incorporate the losses within the diffuser that are associated with the efficiency being less than 100%. An algorithm to assess DAWT performance was developed and implemented. The new model was validated by comparison with experimental data match and shows good agreement when a diffuser efficiency of 80% is assumed. The impact of the diffuser is assessed by the augmentation factor, the ratio of turbine efficiency to the Betz-Joukowsky limit. It is shown, for example, that the augmentation factor exceeds unity only for efficiency greater than 74% when the diffuser thrust is 0.2 of the total thrust and ratio of the rotor area to diffuser exit area is 0.54.

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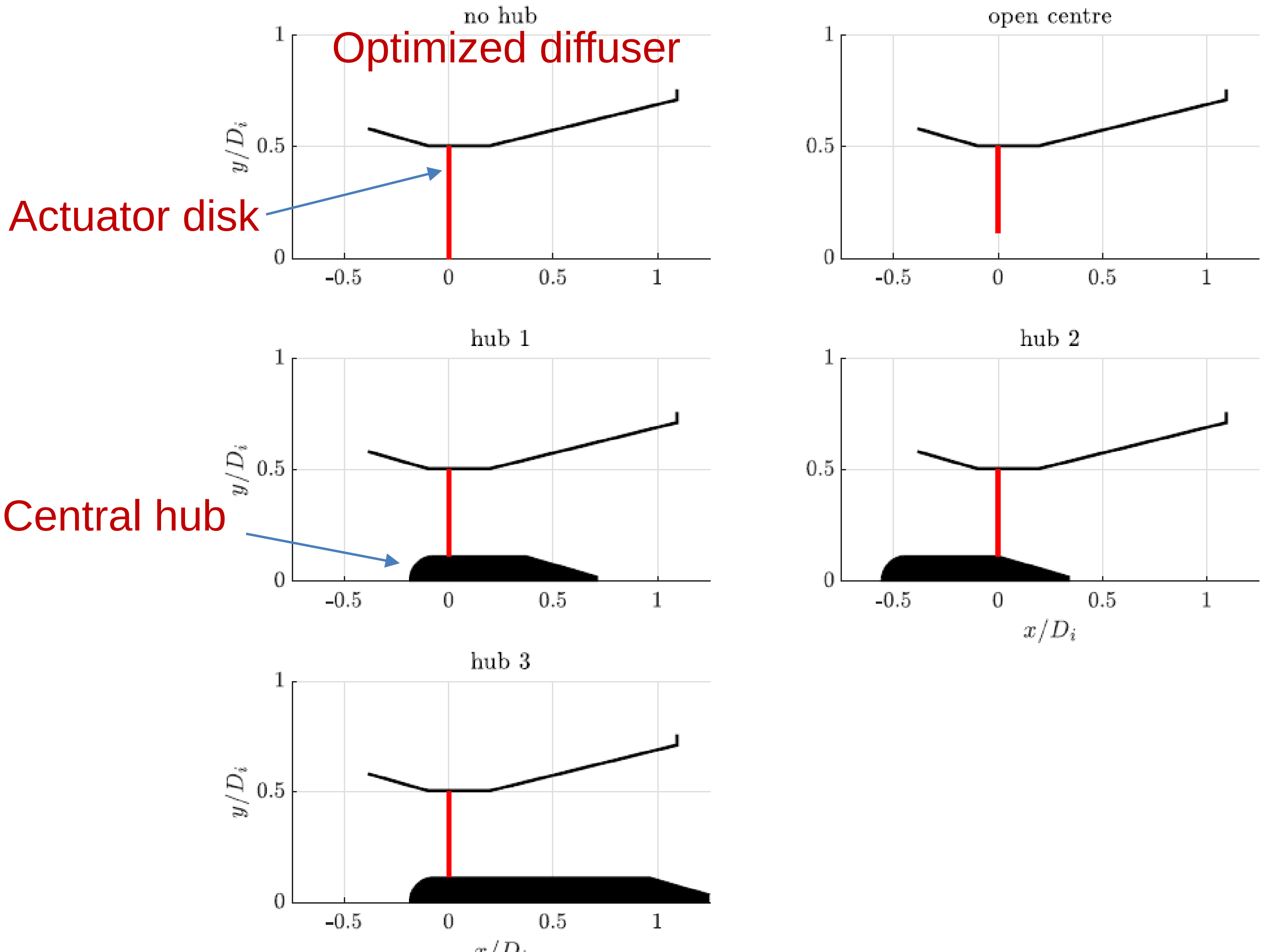
Central hub design

Collaboration with Princeton University

Dr. Eric J. Limacher

Collaboration with ITAJUBA

Profs. Ramiro and Thiago Rezek



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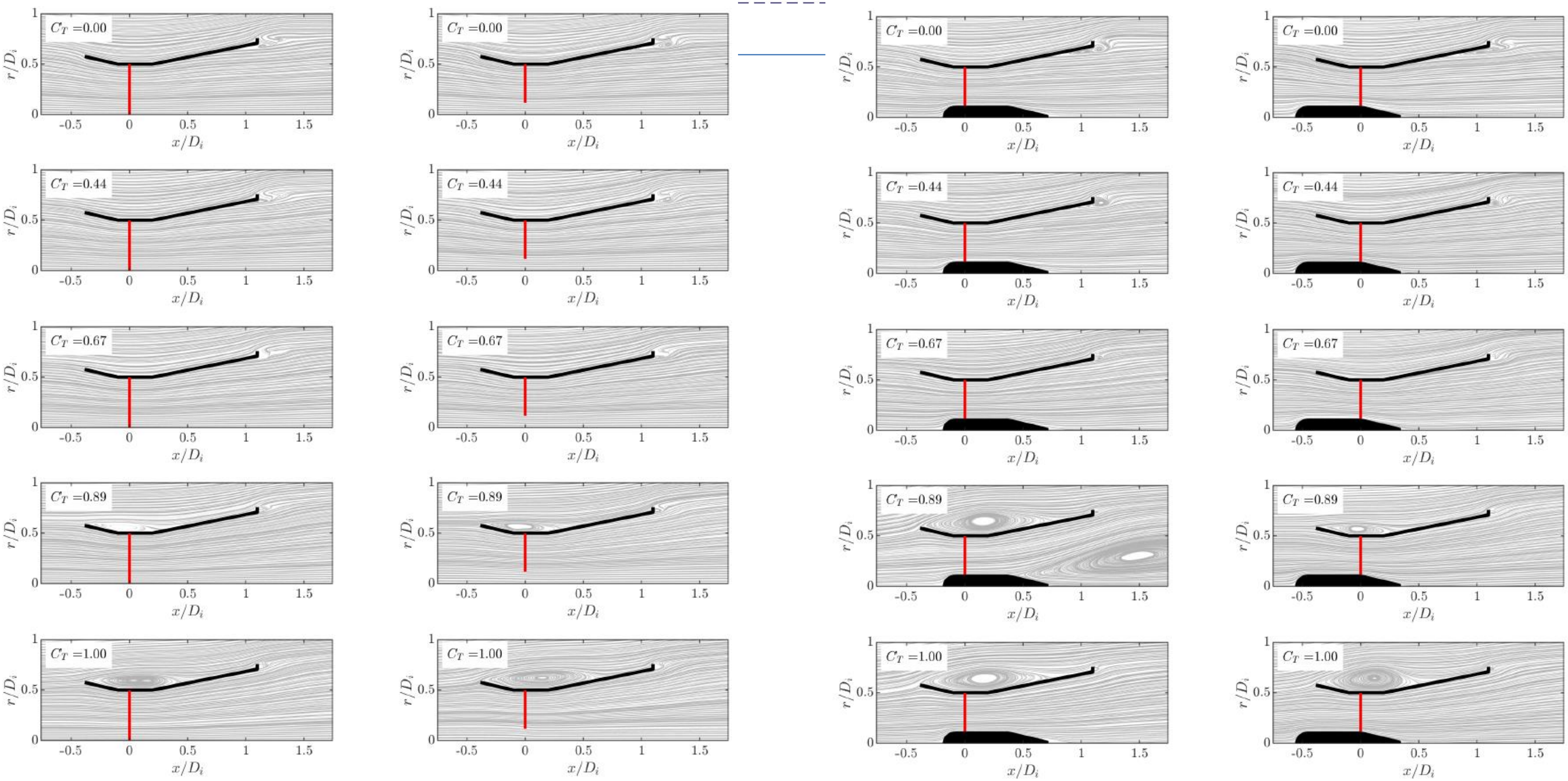

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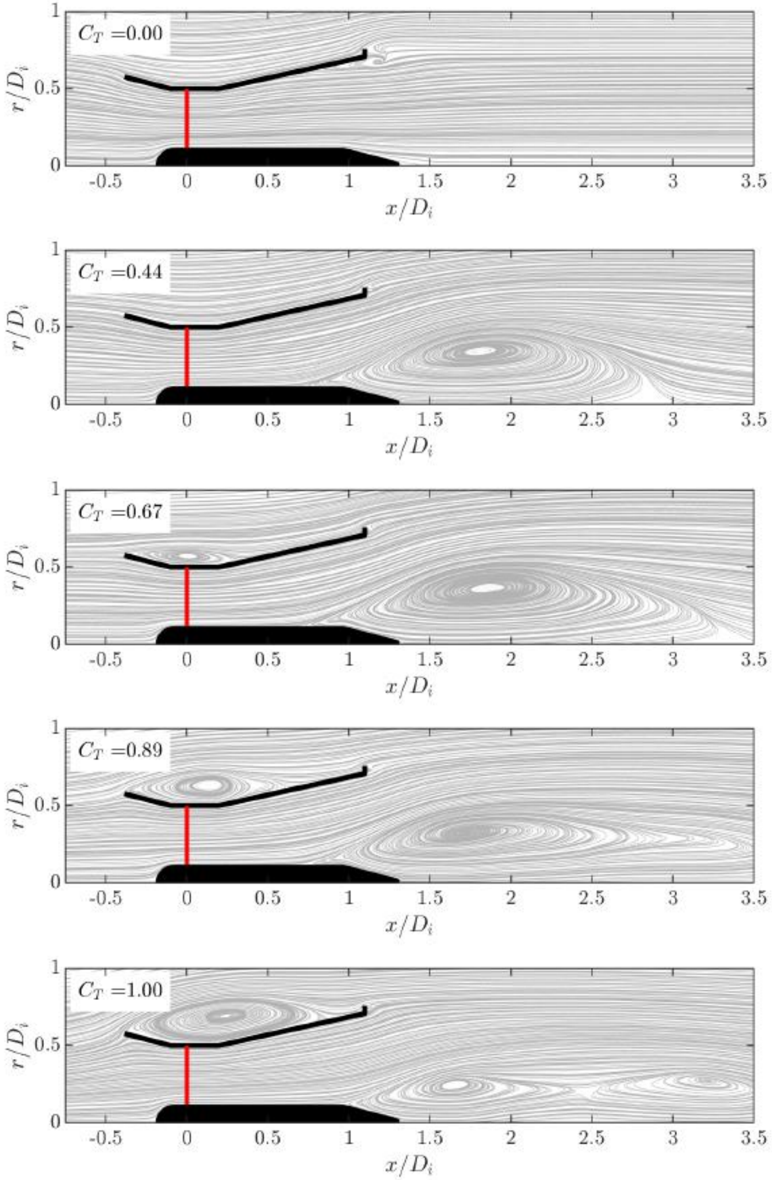

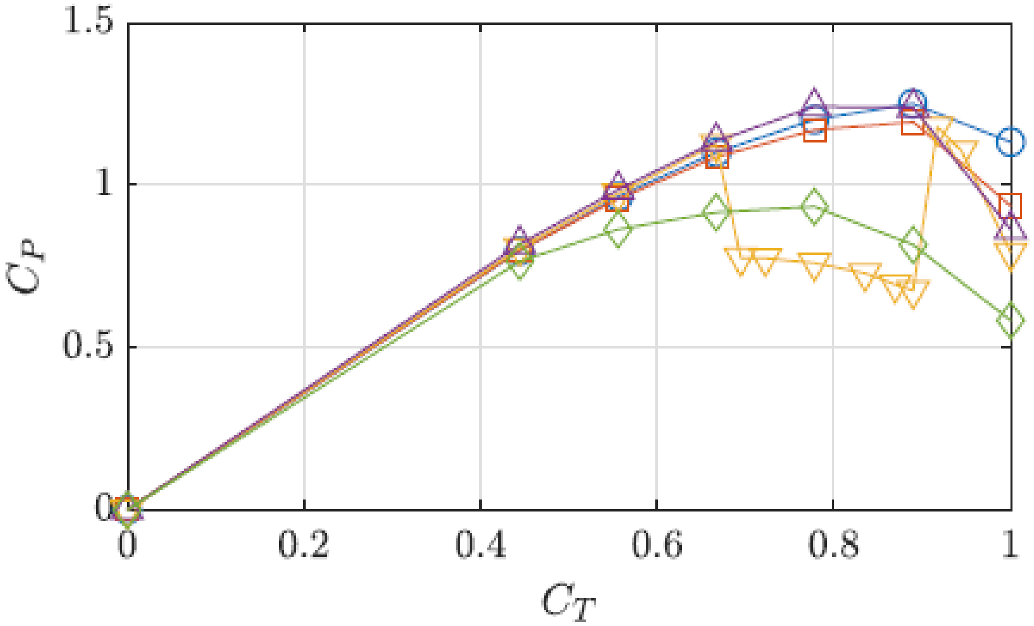

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The effect of a central hub on shrouded turbine performance

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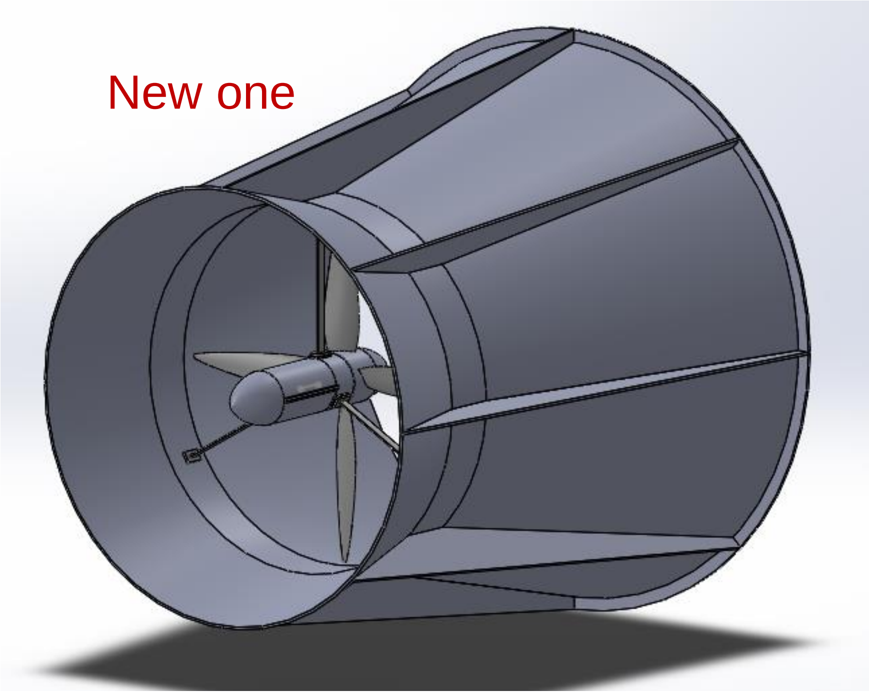
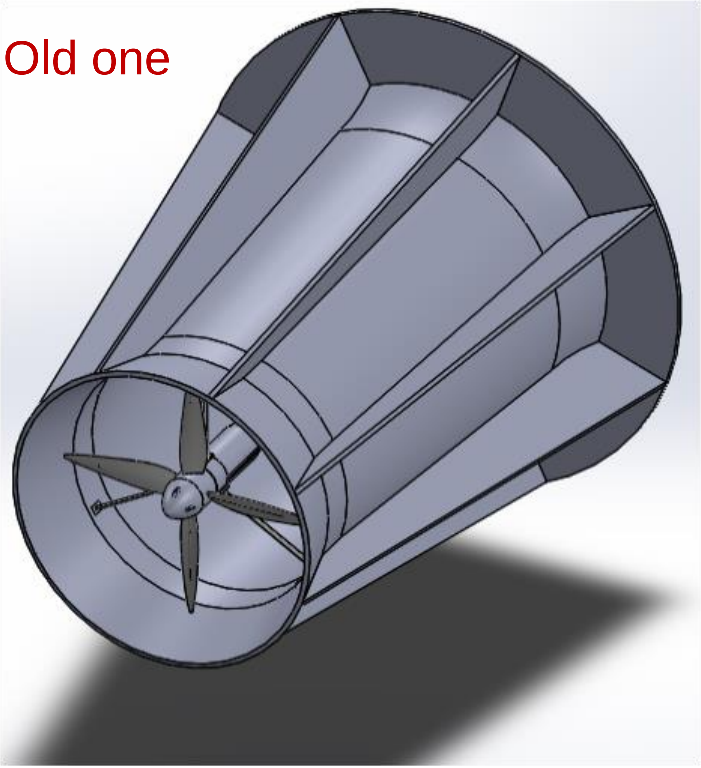
Current fluvial turbine design

- Rated velocity: 1 m/s

Total length: 2.0m
Outer diameter: 1.9m
Rotor diameter: 1.3m



Total length: 2.4m
Outer diameter: 2.7m
Rotor diameter: 1.3m



Thank you!