Lab of
Applied
MultiPhase
Thermal
Engineering

DALHOUSIE
UNIVERSITY

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Review of Dalhousie University's Past and Current Projects on Numerical Modelling of Tidal Turbines and Load Characterization

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Introduction

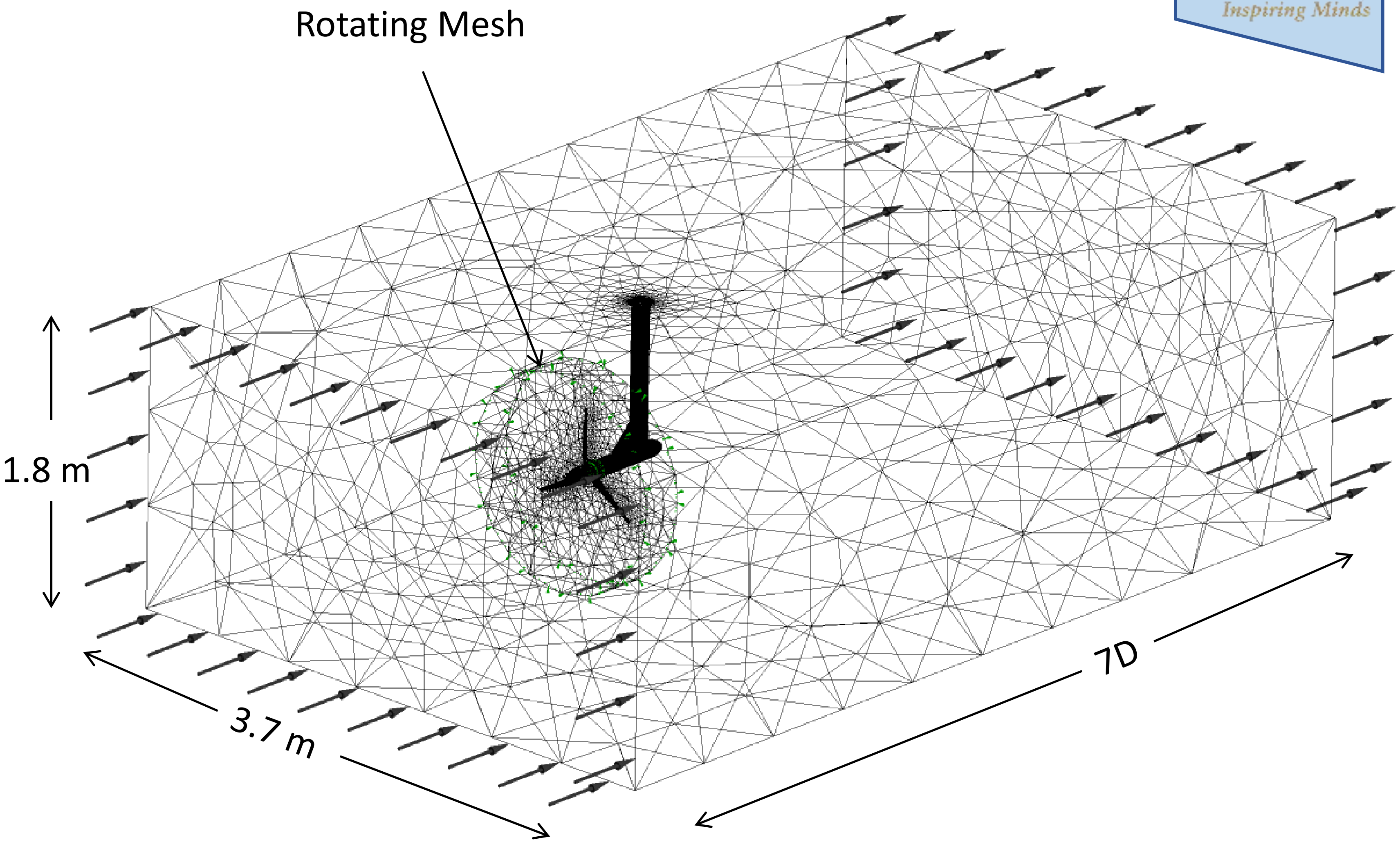
- Dalhousie University, with its proximity to the Bay of Fundy, the largest tidal reservoir in the world, aims to develop expertise in the field of Tidal Power engineering.
- One of the long term goal of Dalhousie Engineering CFD research is to develop expertise in "Fundy" high flow environment:
  - Turbulent modeling – turbines, other devices;
  - Wake study;
  - Turbine arrays.

Work Done – Osbourne (2014)

- ANSYS CFX
- Steady state, SST
- Rotating mesh
- 2D upstream, 5D downstream

Boundary Conditions

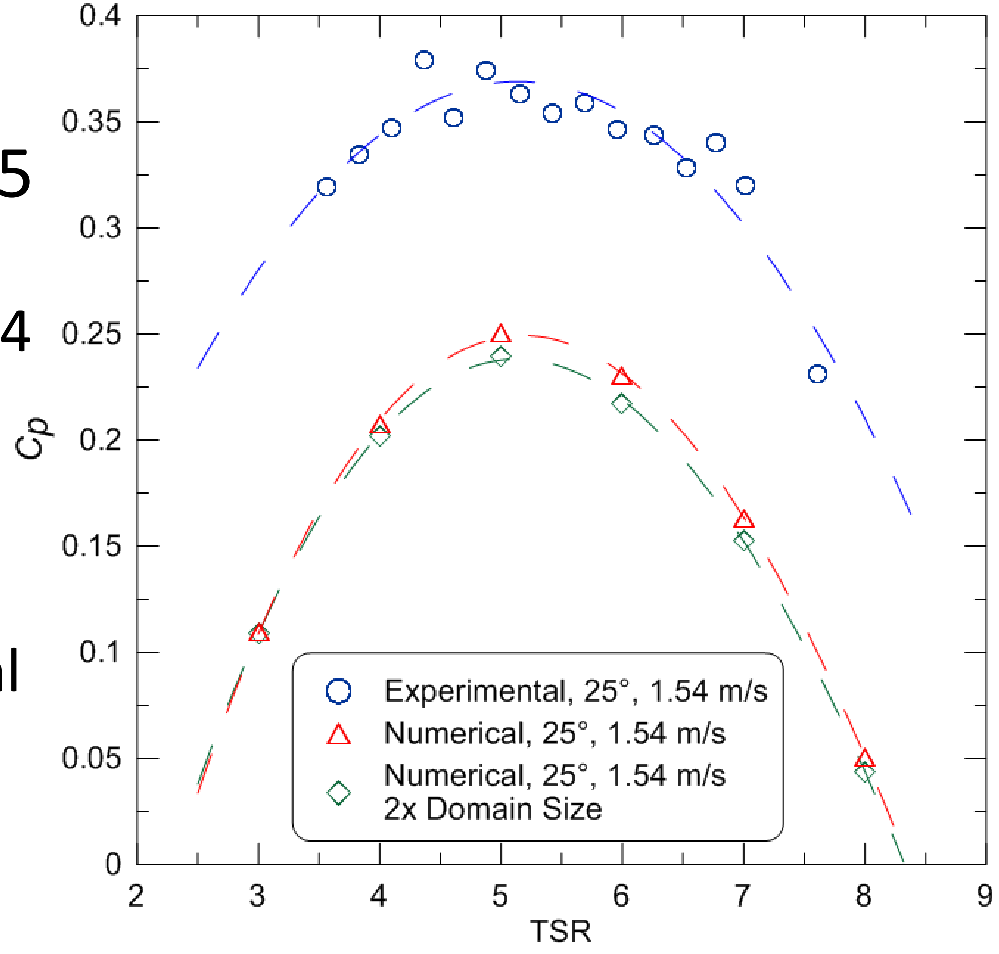
Boundary	Condition
Inlet	Normal Speed (1.54 m/s)
Outlet	$P_{rel} = 0$ Pa
Outer Walls	Free-Slip Condition
Turbine Walls	No-Slip Condition
Domain Interfaces (Steady State)	Frozen Rotor
Inlet Turbulence Intensity	5%



N. Osbourne, D. Groulx, I. Penesis (2014) Three Dimensional Simulation of a Horizontal Axis Tidal Turbine - Comparison with Experimental Results, 2^{nd} *Asian Wave and Tidal Energy Conference (AWTEC)*, 8 p.

Experimental Comparison

- General trend is observed but power coefficient is under-predicted. Peak of 0.25 at TSR = 5
  - Relative difference of 48% with average absolute difference of 0.14
- Increased domain size by factor of 2
  - Reduced power coefficient by additional 6% of original numerical result

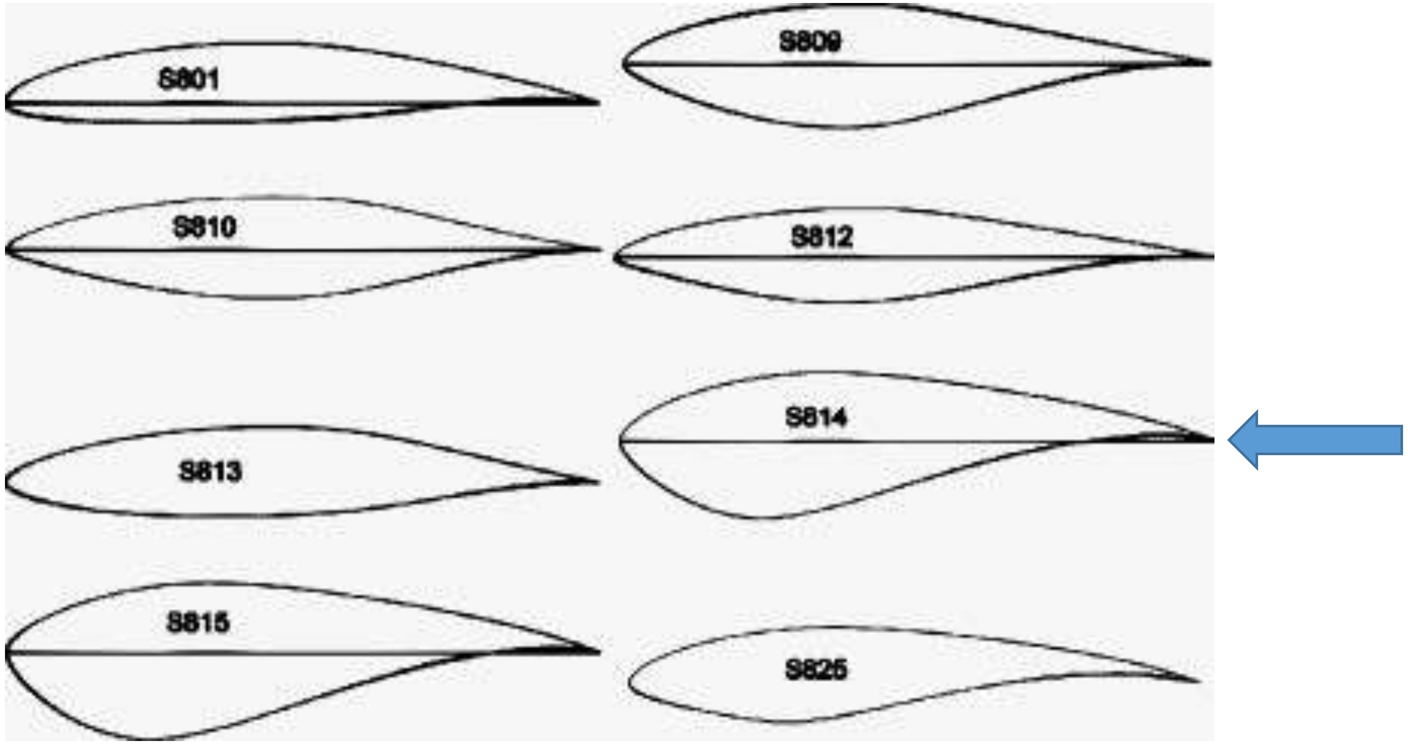


A. S. Bahaj *et al.* (2007) Power and thrust measurements of marine current turbines under various hydrodynamic flow conditions in a cavitation tunnel and a towing tank, *Renewable Energy*, 32, pp. 407-426.

Introduction

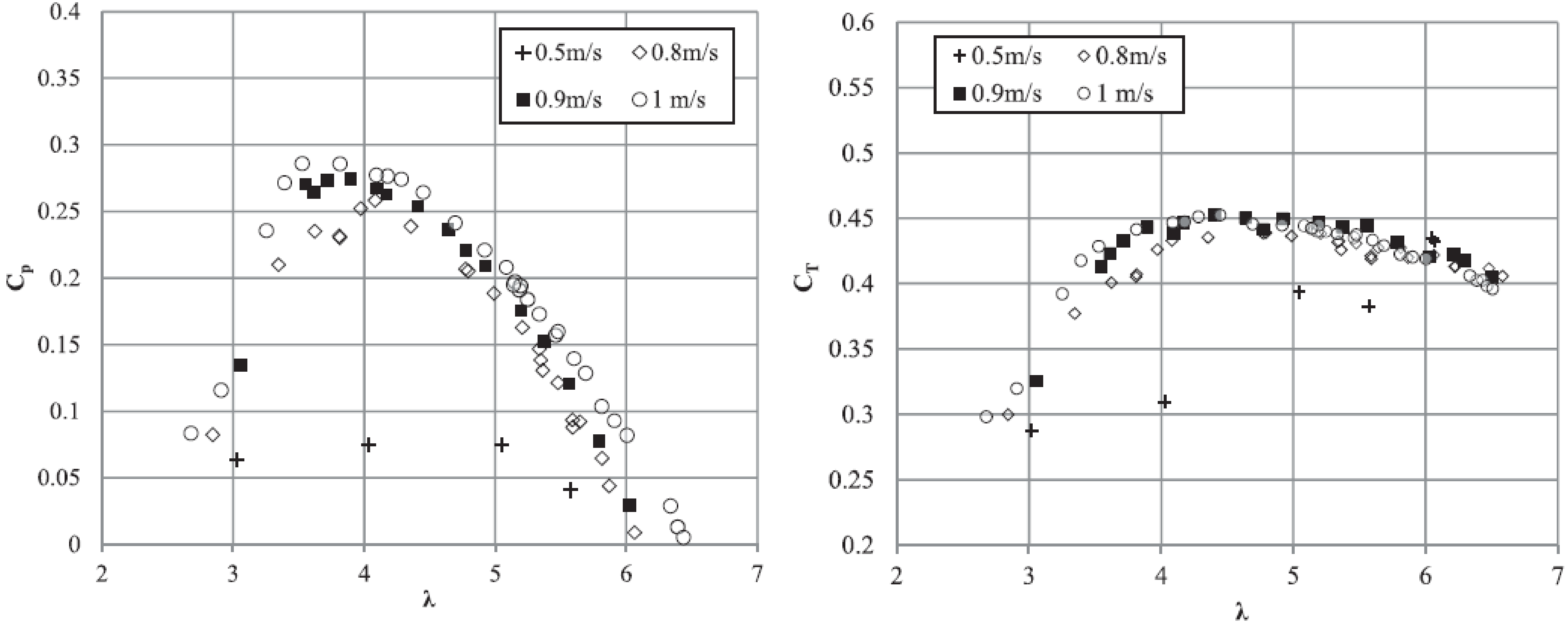
Researchers at Dalhousie and Strathclyde have been working on passively adaptive rotor blade for horizontal-axis tidal turbine using the bent-twist properties of composite materials.

The selected blade profile used for the study was the NREL S814



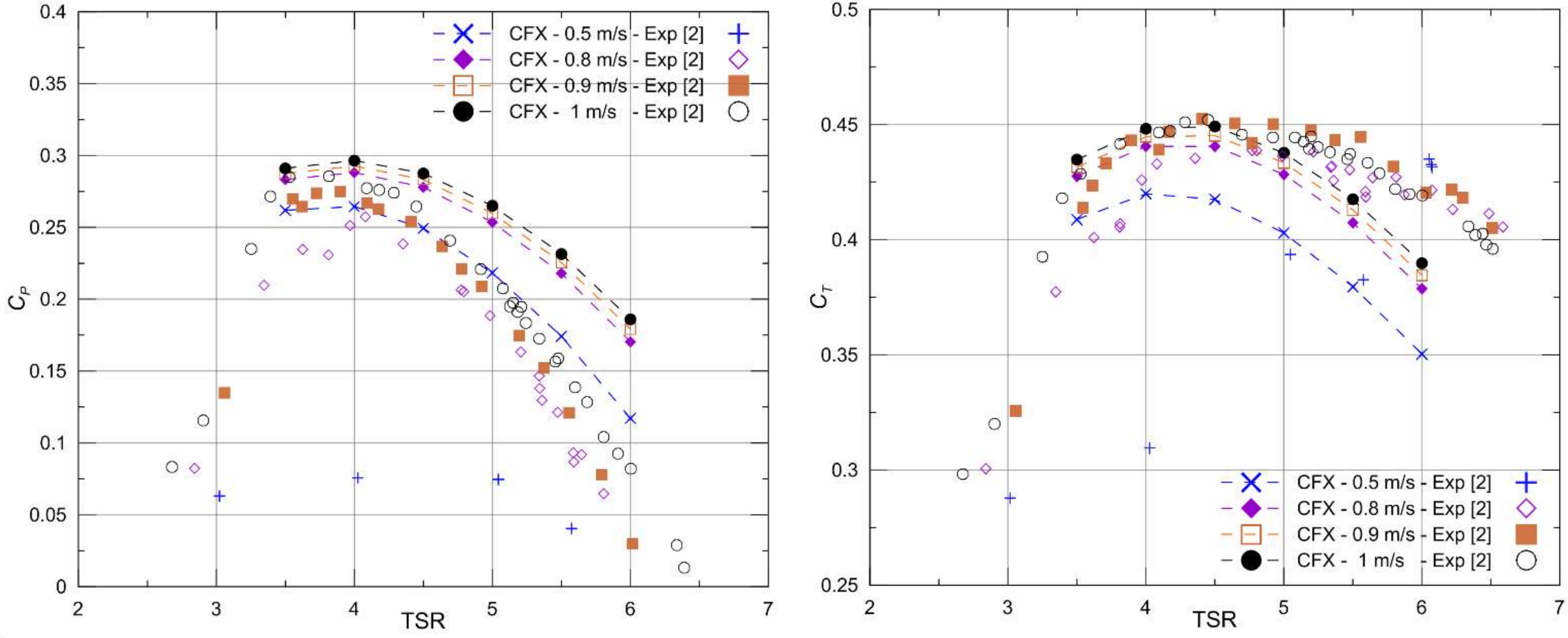
Introduction

As part of the project, a first series of tow tank tests, at 1/20th scale, was performed using rigid blades at Strathclyde's Kelvin Hydrodynamics Laboratory tow tank.



D.A. Doman, R.E. Murray, M.J. Pegg, K. Gracie, C.M. Johnstone, T. Nevalainen (2015) Tow-tank testing of a 1/20th scale horizontal axis tidal turbine with uncertainty analysis, *International Journal of Marine Energy*, 11, pp. 105-119

Comparison to Experimental



G. Currie, N. Osbourne, D. Groulx (2016) Numerical Modelling of a Three-Bladed NREL S814 Tidal Turbine, *3rd Asian Wave and Tidal Energy Conference (AWTEC)*, 10 p.

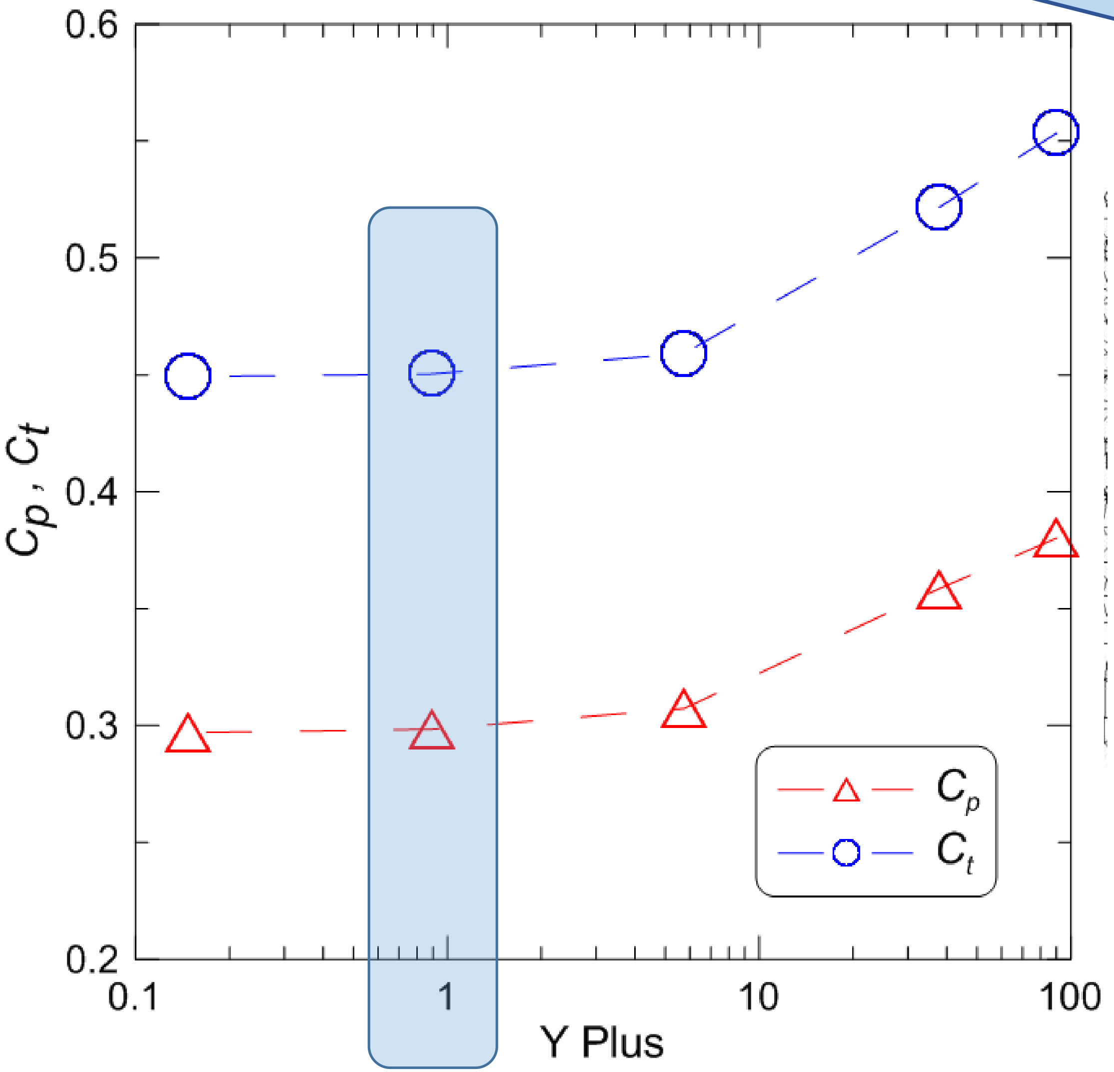
Wake **Mesh Convergence** Study

Inflation layers were used; y^+:

$$\boldsymbol{y^+ = \frac{\Delta y_p}{\upsilon}\sqrt{\frac{\tau_w}{\rho}}}$$

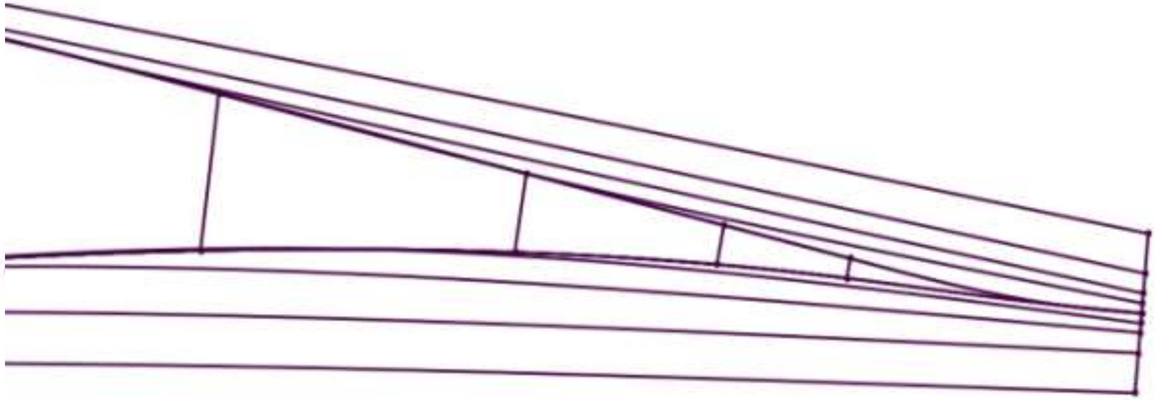
where Δy_p is the distance between the first and second grid points off the wall, υ is the fluid's kinematic viscosity, τ_w is the wall shear stress and ρ is fluid density.

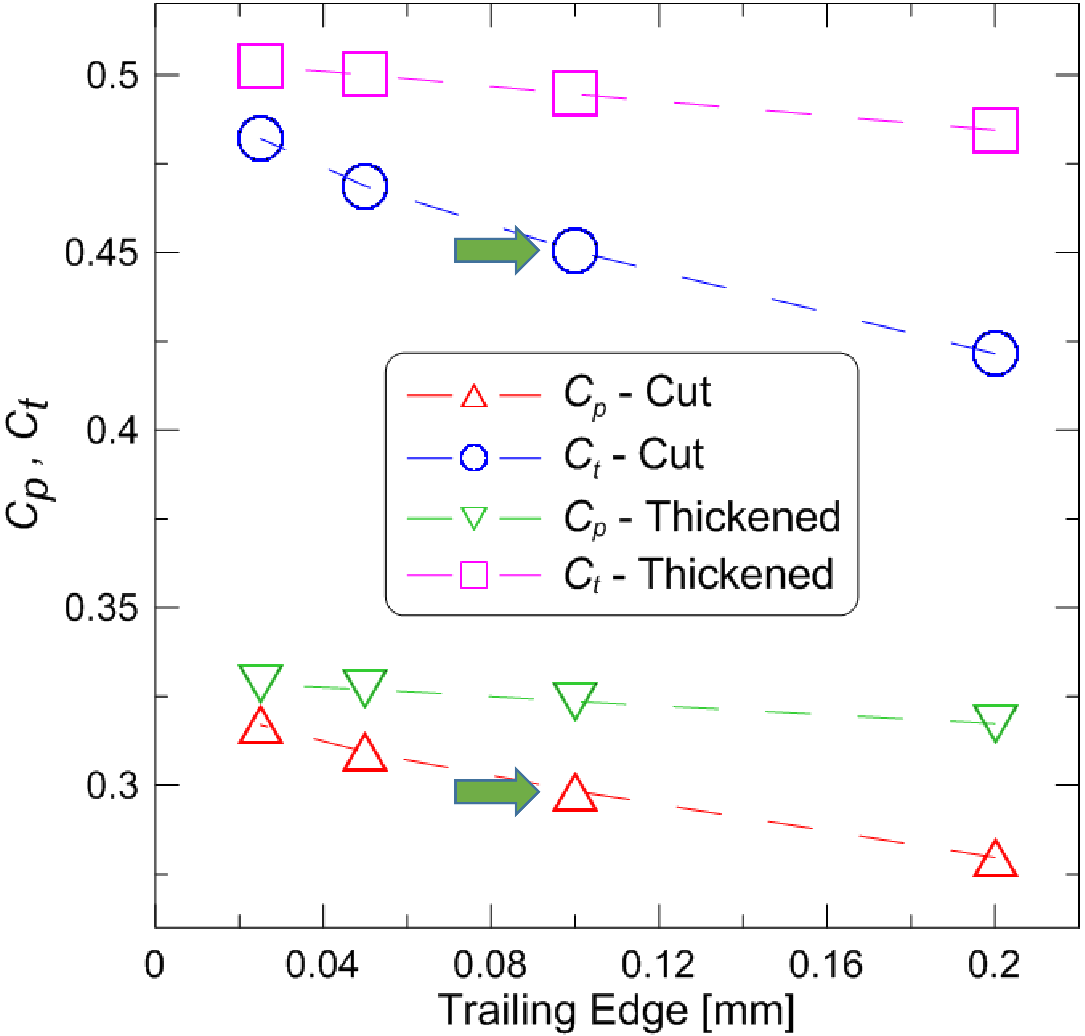
The baseline mesh contained a maximum global $y^+ < 11$ ensuring the first nodes are within the laminar sublayer and that the near wall flow is resolved instead of using wall functions.



Wake Mesh Convergence Study

Trailing edge effect





Wake Mesh Convergence Study

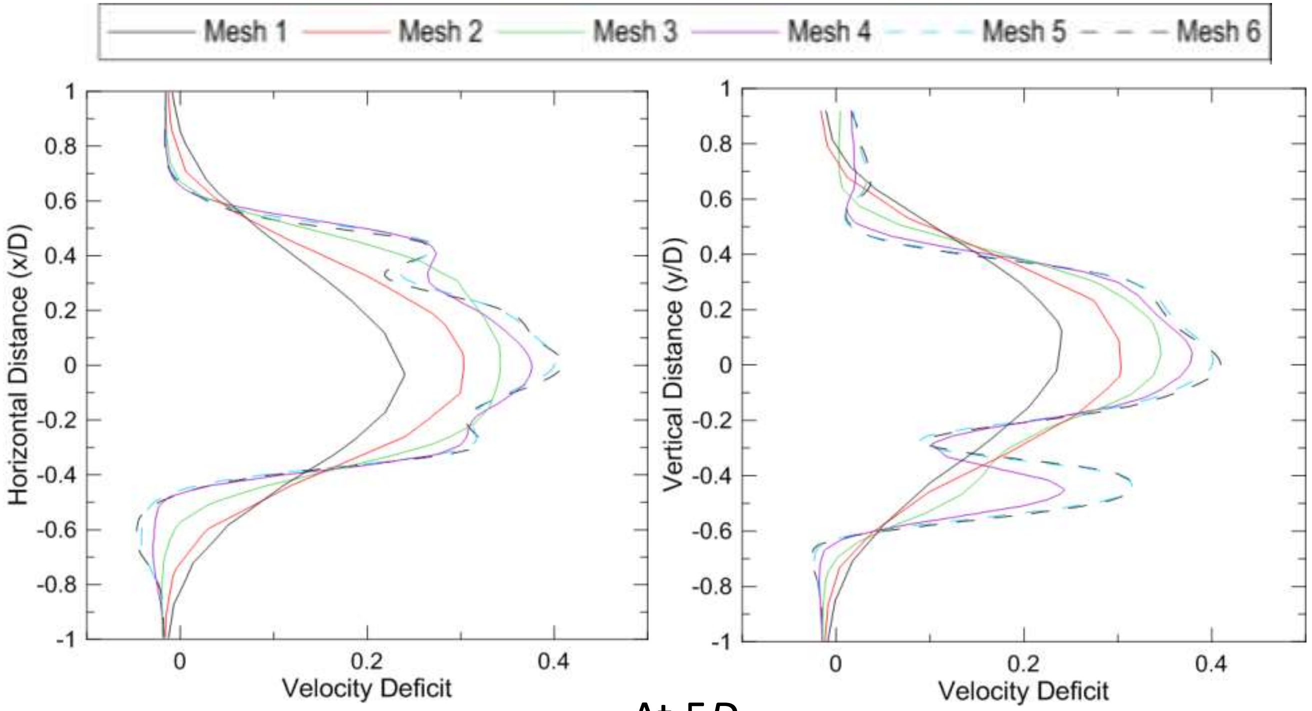
Now looking at the wake

$V_{deficit} = 1 - \frac{V_W}{\bar{V}}$ with V_W is the local wake velocity and $\bar{V}$ the inlet velocity (time-independent)

$TI = \frac{100}{\bar{V}}\sqrt{\frac{2}{3}k}$ with k is the turbulent kinetic energy

TABLE X Maximum Cell Size in Wake

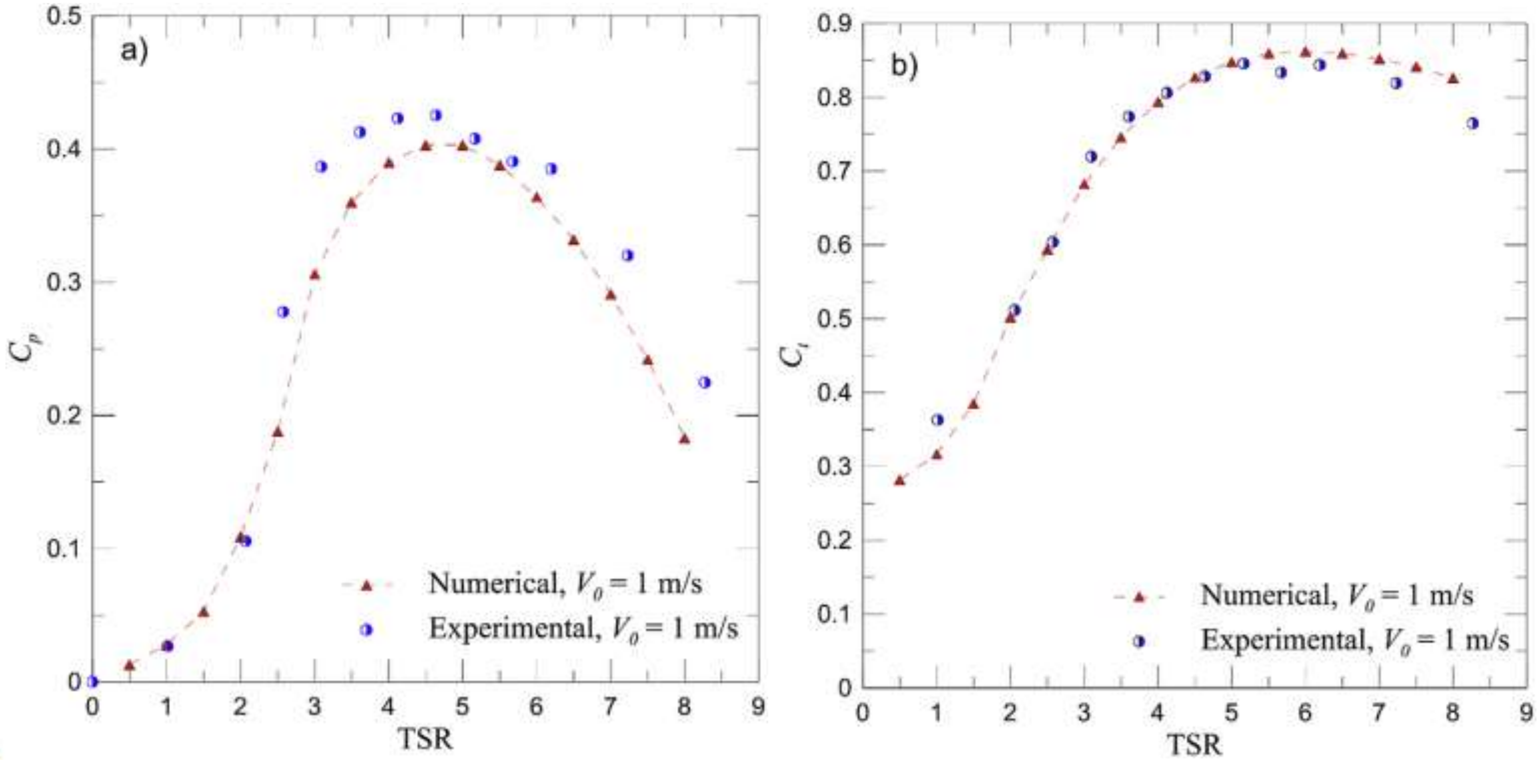
	Element Size [m]	# of Elements (millions)
Mesh 1	0.22	10.72
Mesh 2	0.11	10.72
Mesh 3	0.055	10.88
Mesh 4	0.0275	12.15
Mesh 5	0.017	16.64
Mesh 6	0.01375	21.69



At 5*D*

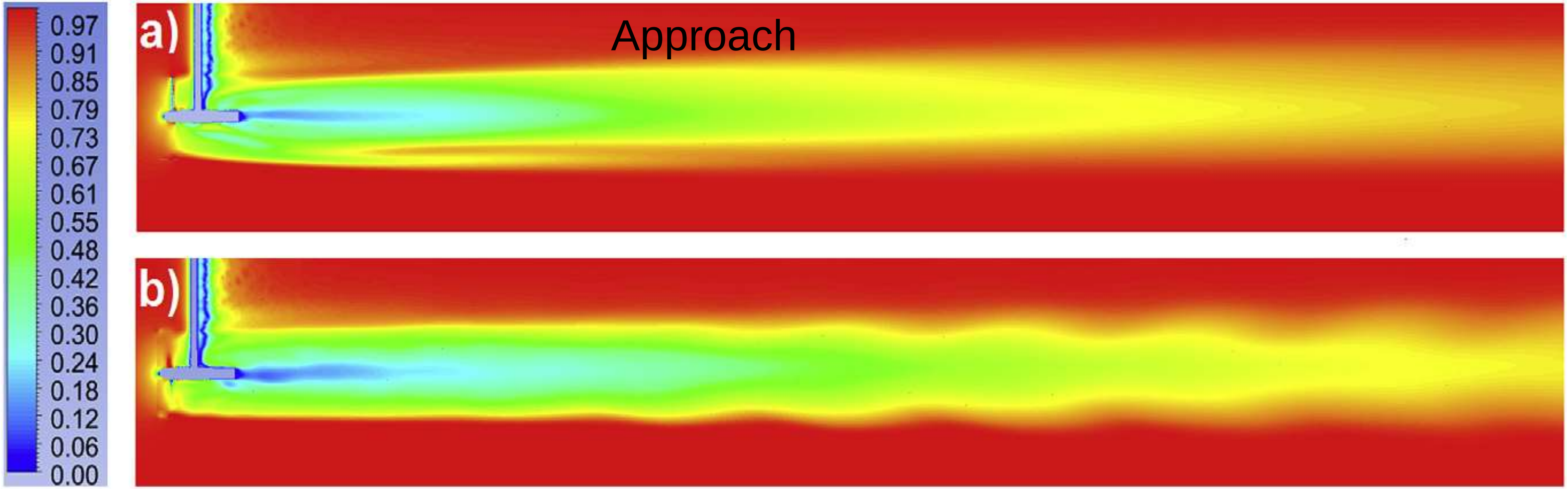
Third Geometry and Start of Transient Studies

The turbine used by IFREMER, with their accompanied studies where they took measurements in the wake was used to test the difference between the wake results obtained from steady-state or transient numerical studies.



P. Mycek, B. Gaurier, G. Germain, G. Pinon, E. Rivoalen (2014) Experimental study of the turbulence intensity effects on marine current turbines behaviour. Part I: One single turbine, *Renewable Energy*, 66, pp. 729-746

Normalized Velocity

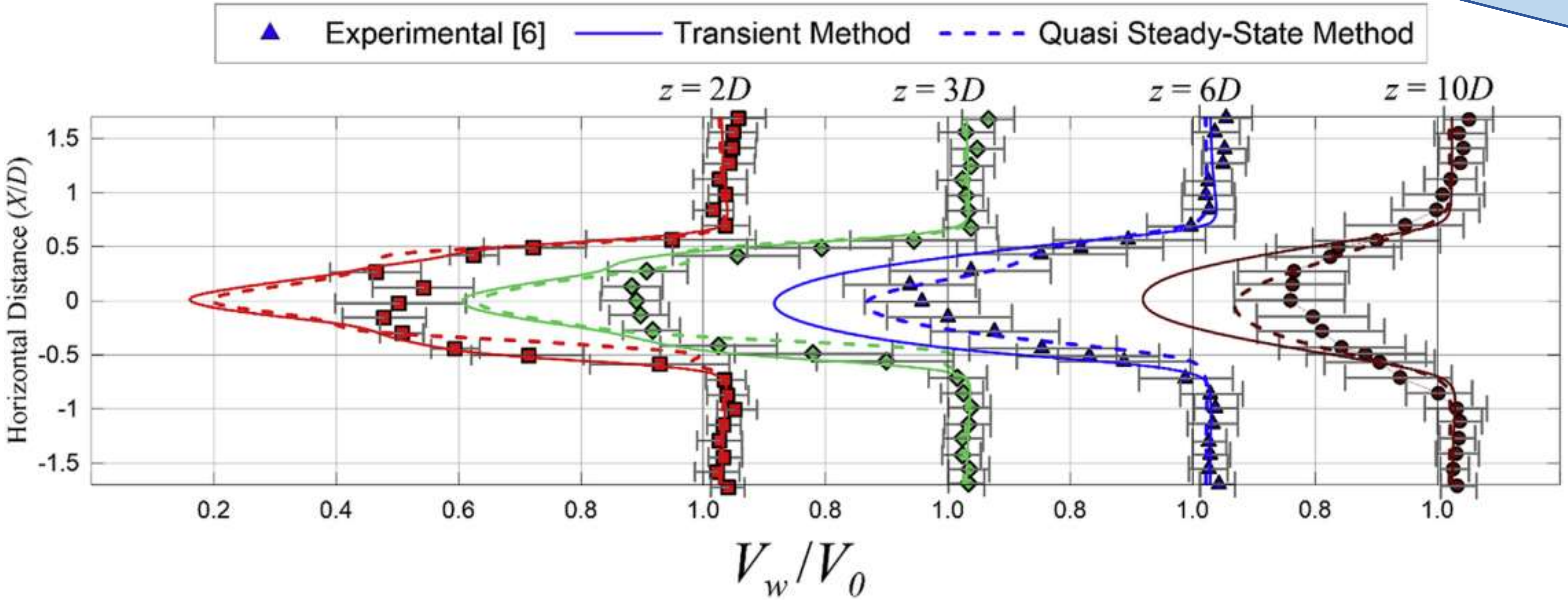


Frozen Rotor Approach

Transient Rotor Approach (snapshot at t=80 s)

T. Leroux, N. Osbourne, D. Groulx, (2019) Numerical study into horizontal tidal turbine wake velocity deficit: Quasi-steady state and transient approaches, *Ocean Engineering*, 181, pp. 240-251

Comparison to **Experimental Data**



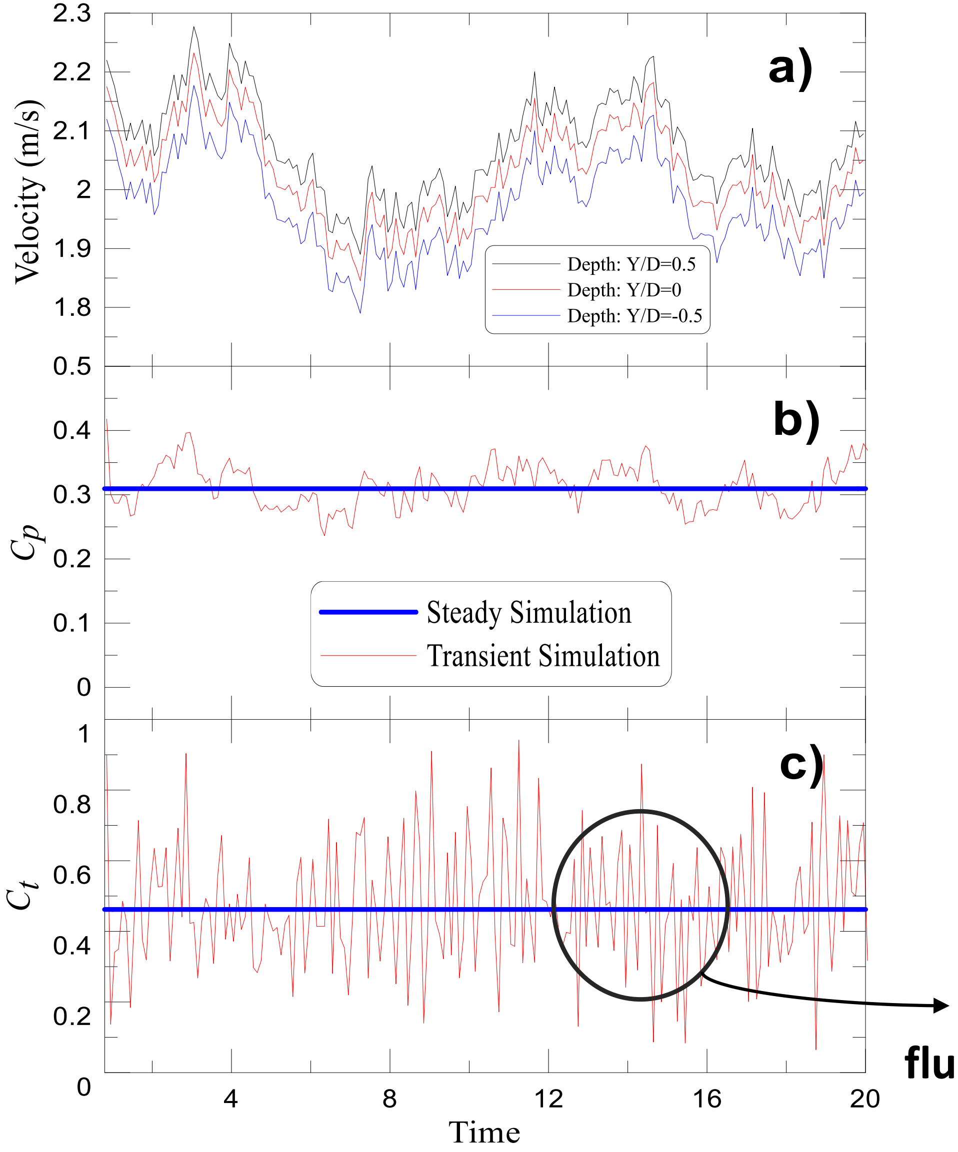
Normalized velocity comparison between IFREMER's experimental results (Mycek et al., 2014) and the quasi steady-state/transient-rotor simulations for distance behind the turbine of 2*D*, 3*D*, 6*D* and 10*D*. TSR=3.7, I_∞=3% and V_0=0.8 m/s.

Transient Simulation Results

Inlet Velocity as a function of time for 3 different depths

Power coefficient *Cp* as a function of time

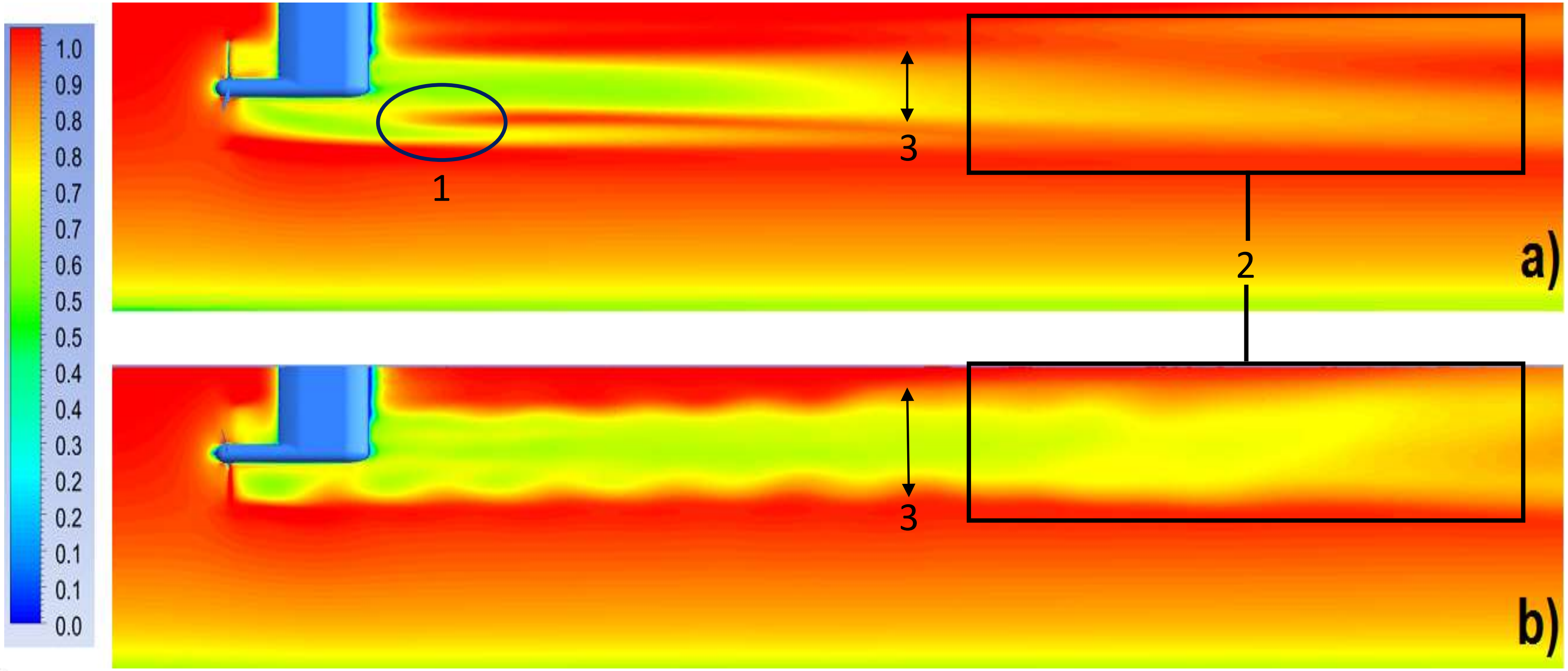
Thrust coefficient *Ct* as a function of time



High fluctuations

Wake Characteristics: Velocity Deficit

Normalized Velocity V/V_0 on mid-vertical plane:



Steady case:
Frozen-Rotor approach

Unsteady case:
Transient-Rotor approach

Numerical Domain

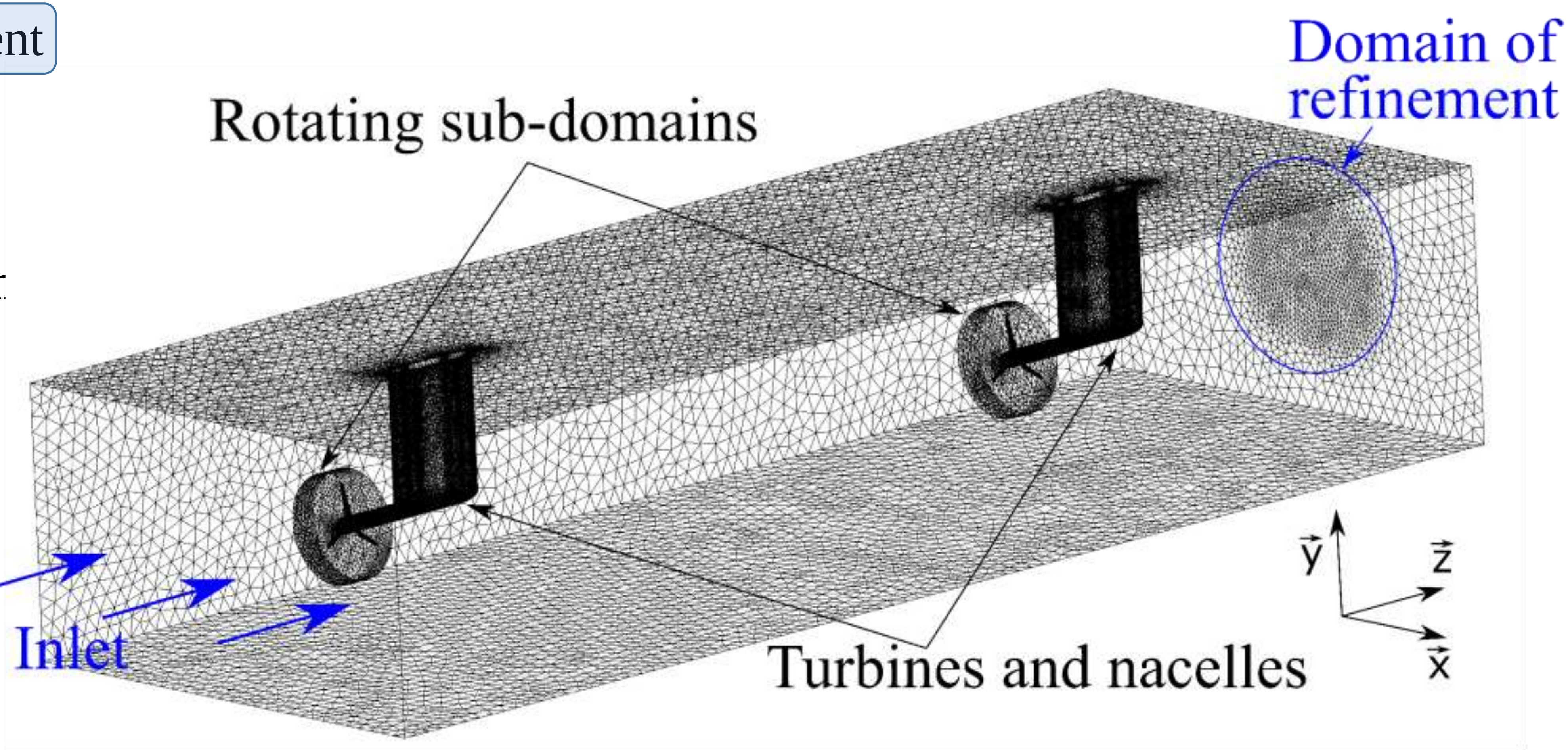
ANSYS CFX

Fully transient

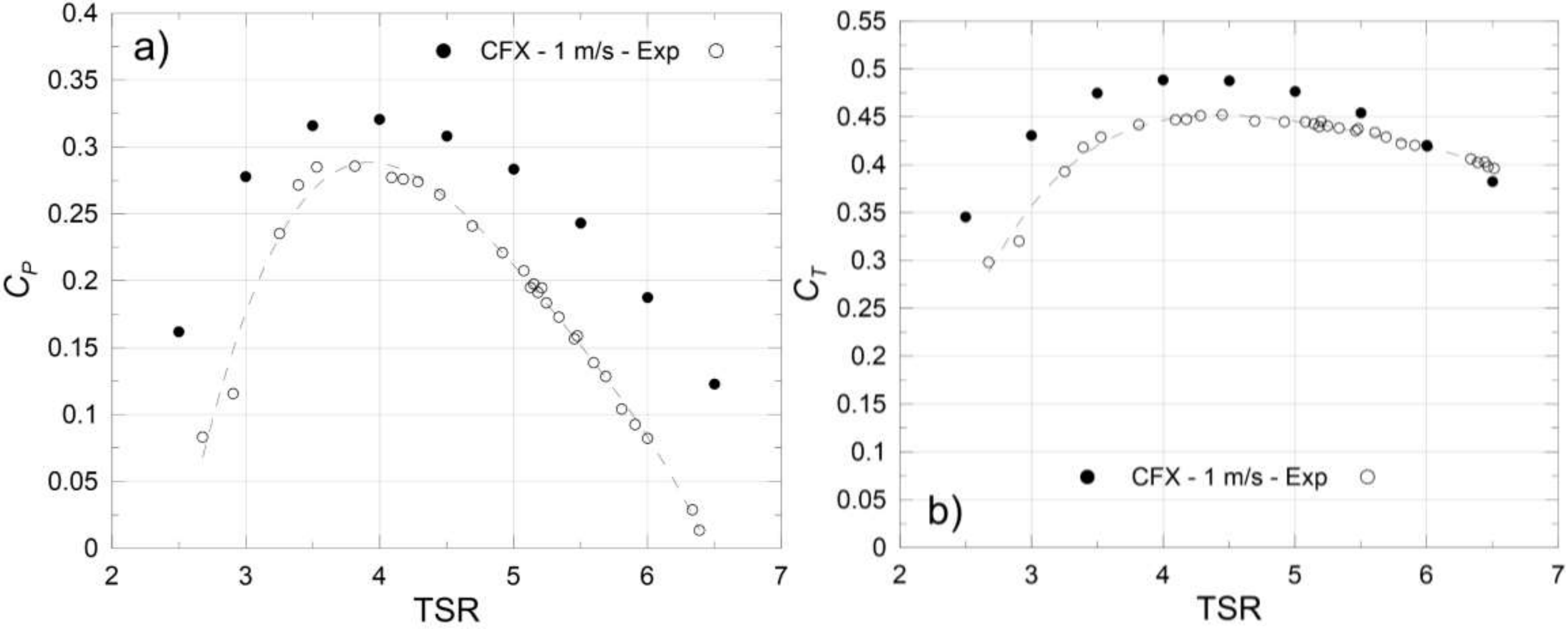
k - ω SST RANS turbulence m

5% Inlet Turbulence Intensity

1 m/s →

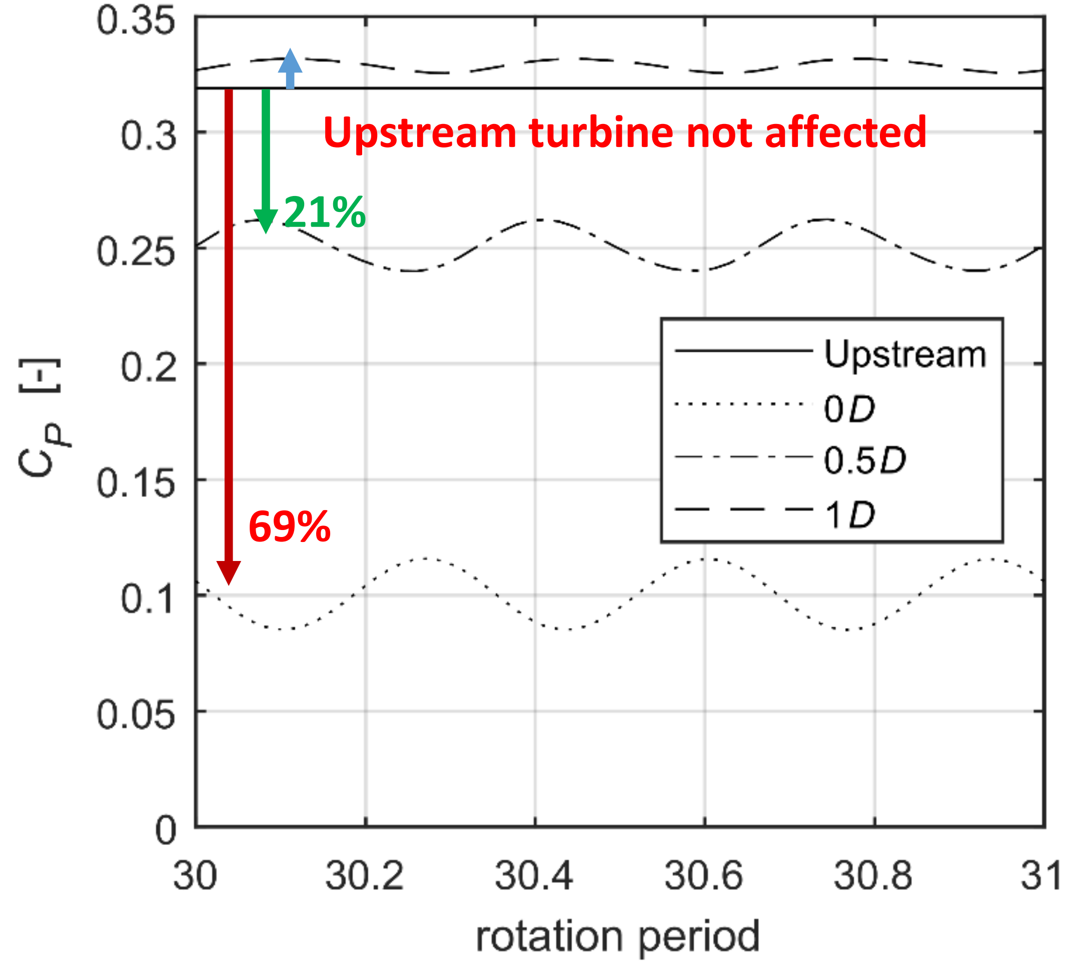


Comparison to Experimental



Downstream Turbine Performance

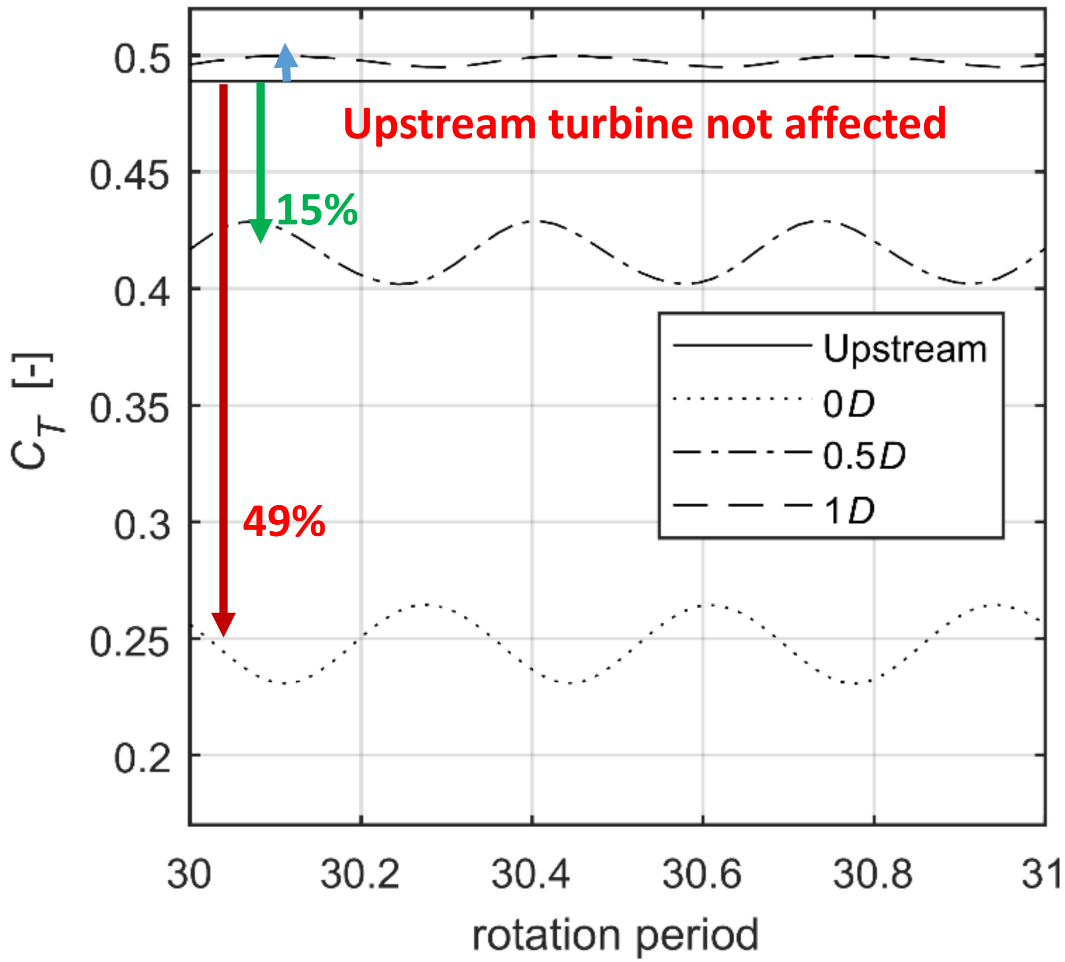
Results at TSR = 4, after a quasi-steady regime is attained



Upstream turbine not affected

21%

69%



Upstream turbine not affected

15%

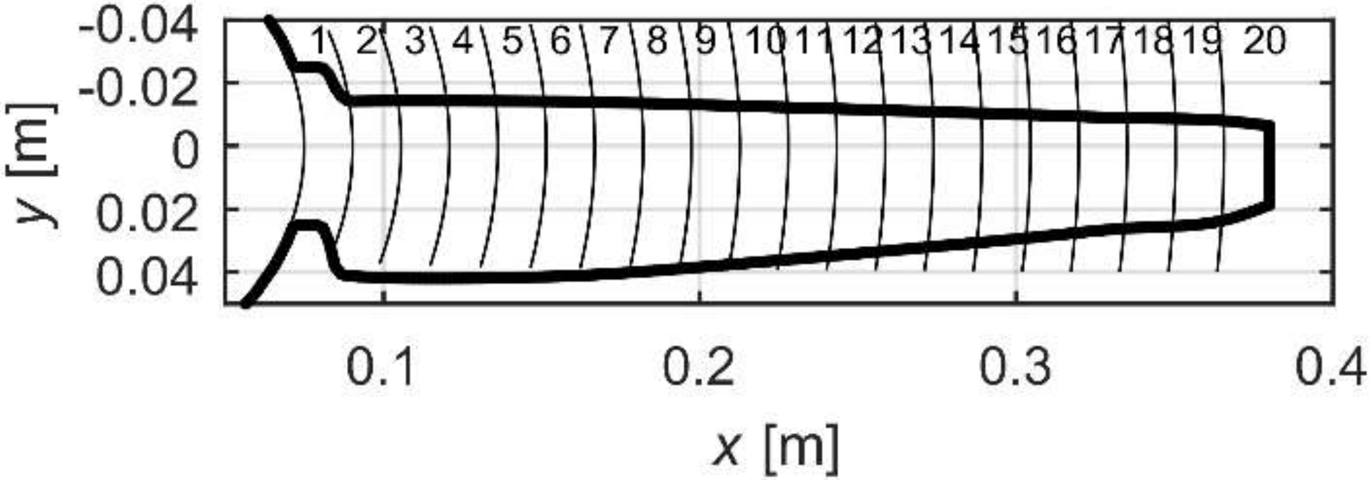
49%

Downstream Blade Loading

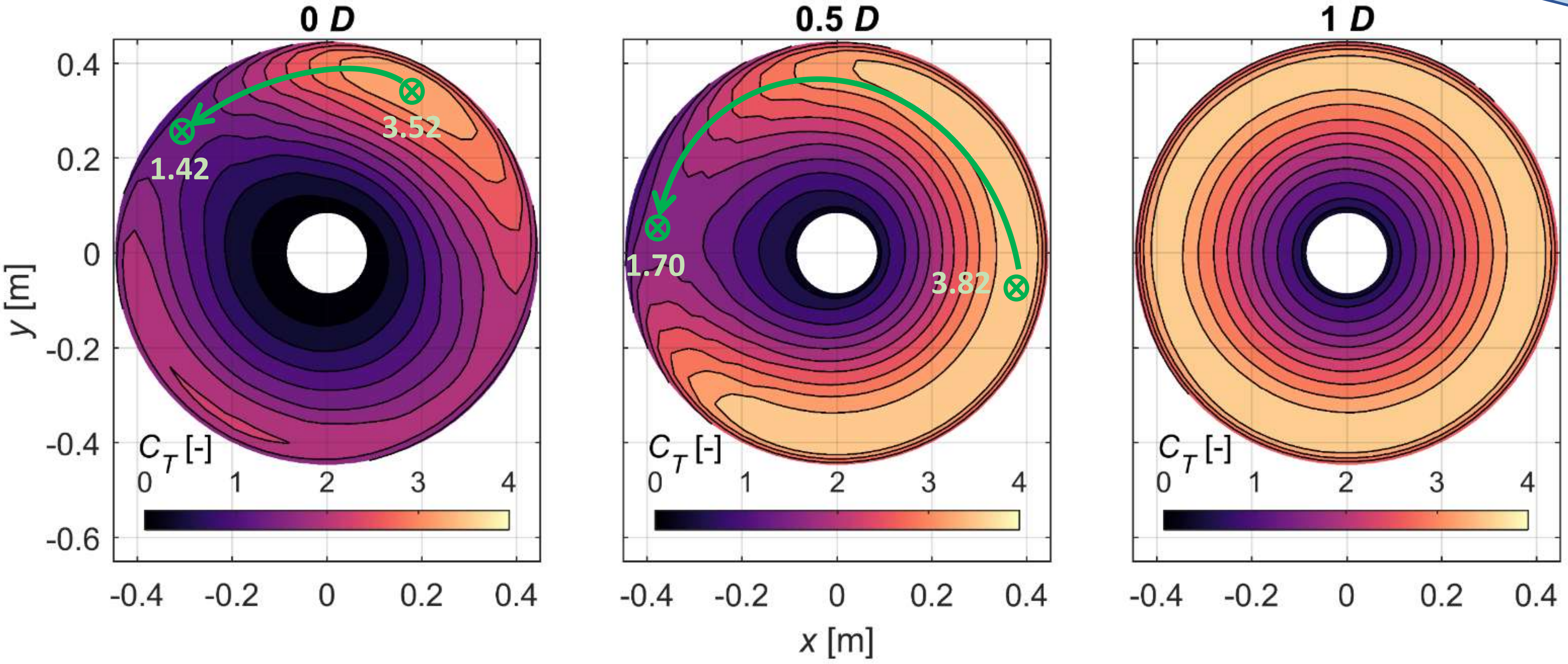
A blade loading map was created to evaluate the load evolution along the blade span with respect to the blade location. The results are presented using a local thrust coefficient:

$$C_{T_l} = \frac{T_l}{\frac{1}{2}\rho_w A_s U_0^2}$$

Evaluated for each blade over a finite number of sections (20).



Downstream Blade Loading



Values of $\overline{C_{T_l}}$ over the blade sections over their full rotation range for all three simulated configurations.

Downstream Blade Loading