Axial flow turbines for ocean current and wave power systems.

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Introduction

- Renewable energy turbines:
  - Solar chimney
  - Wind turbines
  - Ocean current turbines
  - Shrouded ocean current turbines
  - SWEC turbine

Figures in this presentation were sourced from:

Undergraduate final year projects of:

Josh Reinecke, Richard Stanford,

Thomas Lewis, Pieka Grobelaar

MScEng theses of:

Warrick Pierce

Josh Reinecke,

Paul Ackerman

PhD thesis of:

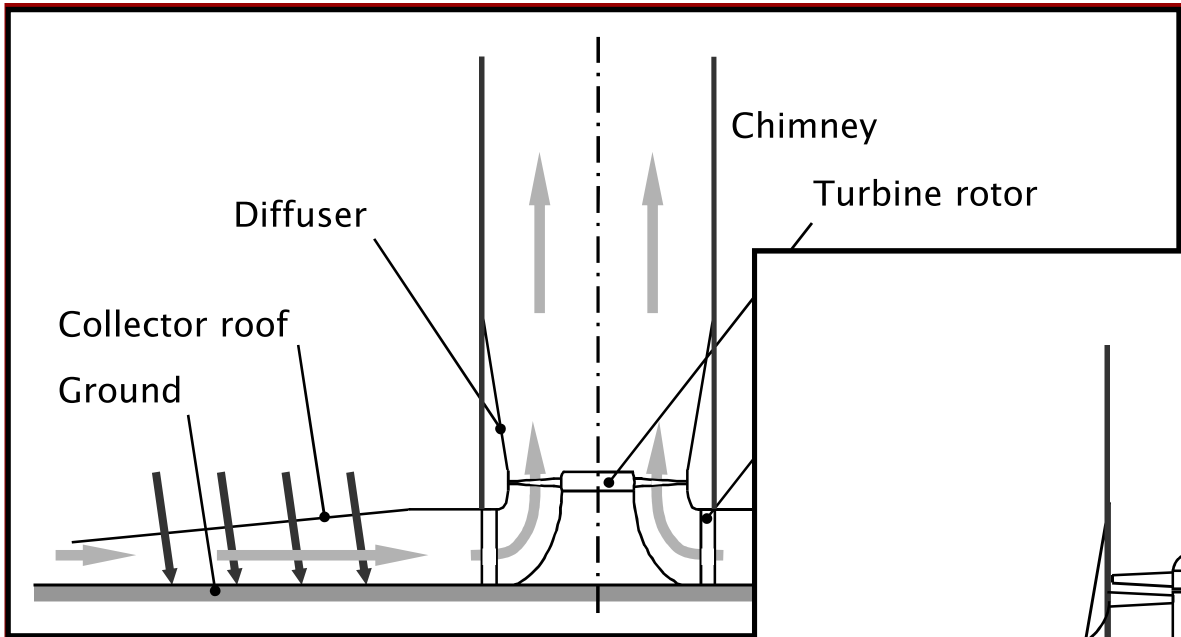
Tom Fluri

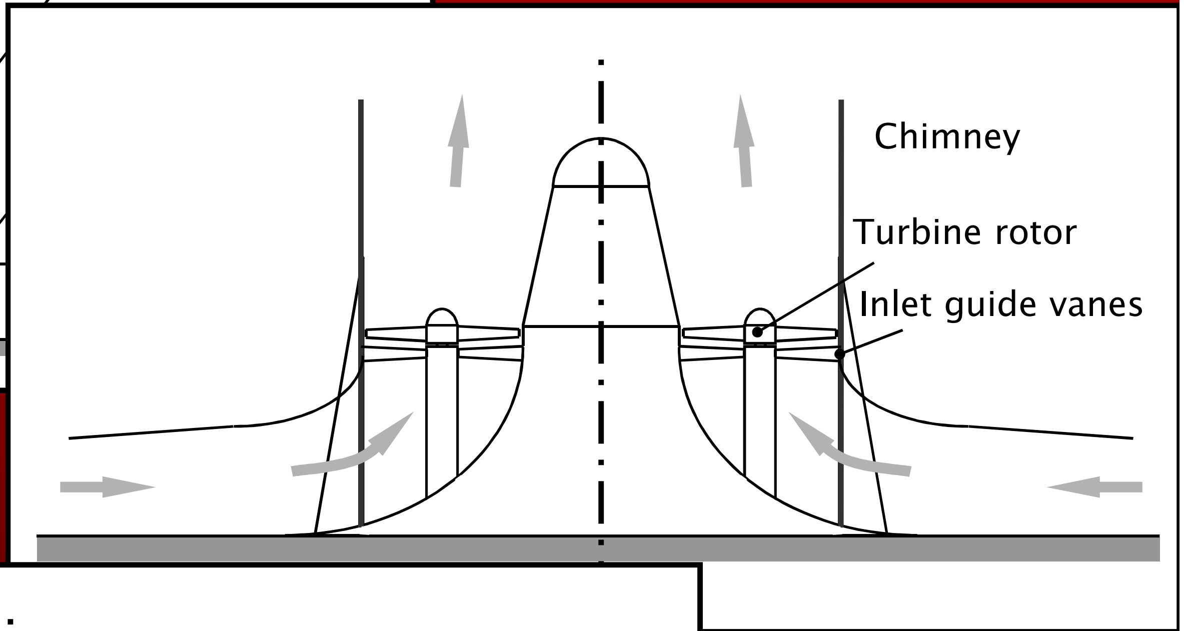
Co-supervisors:

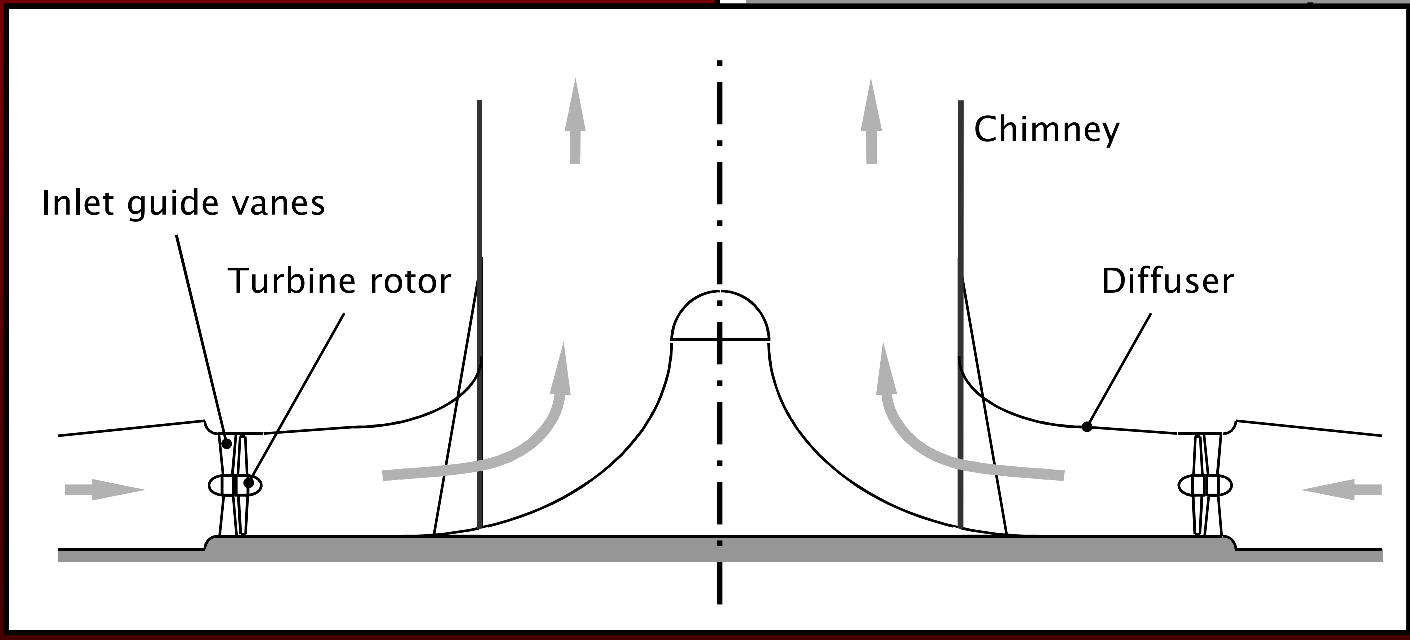
Prof. Wikus van Niekerk, Prof. Gerhard Venter,

Mr. Johan van der Spuy, MS. Nicola Cencelli.

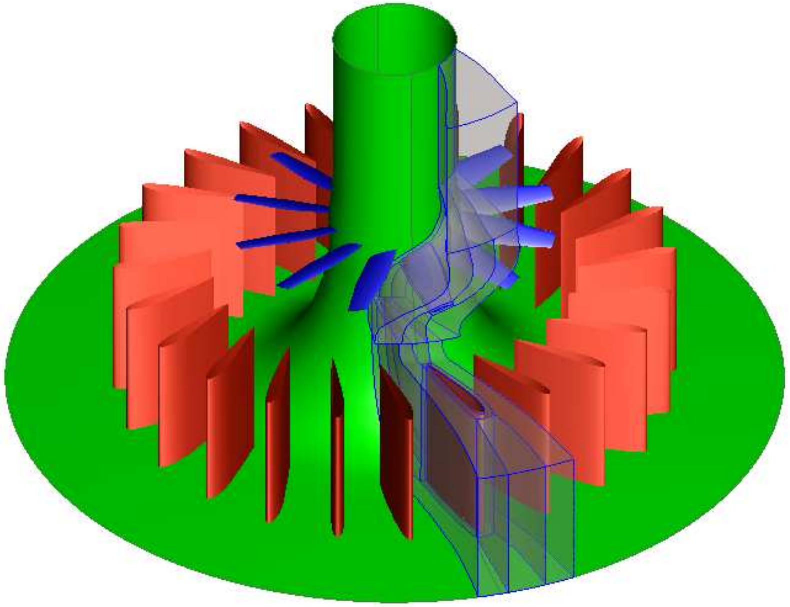
Solar chimney configurations



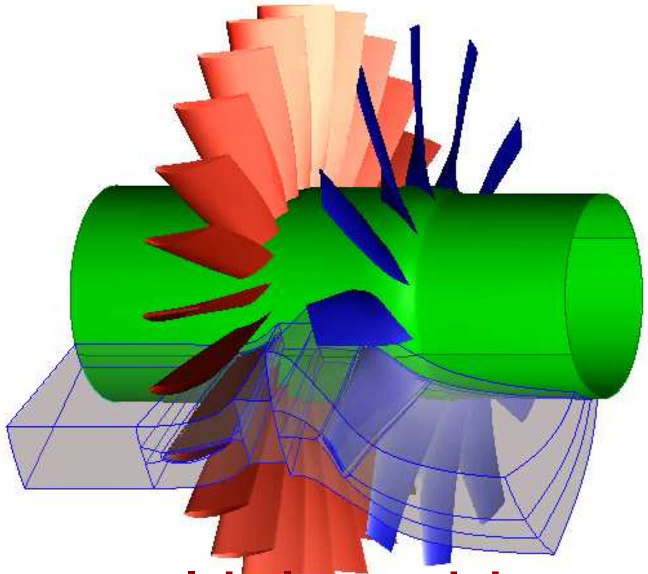




Solar chimney turbine models used in CFD analyses

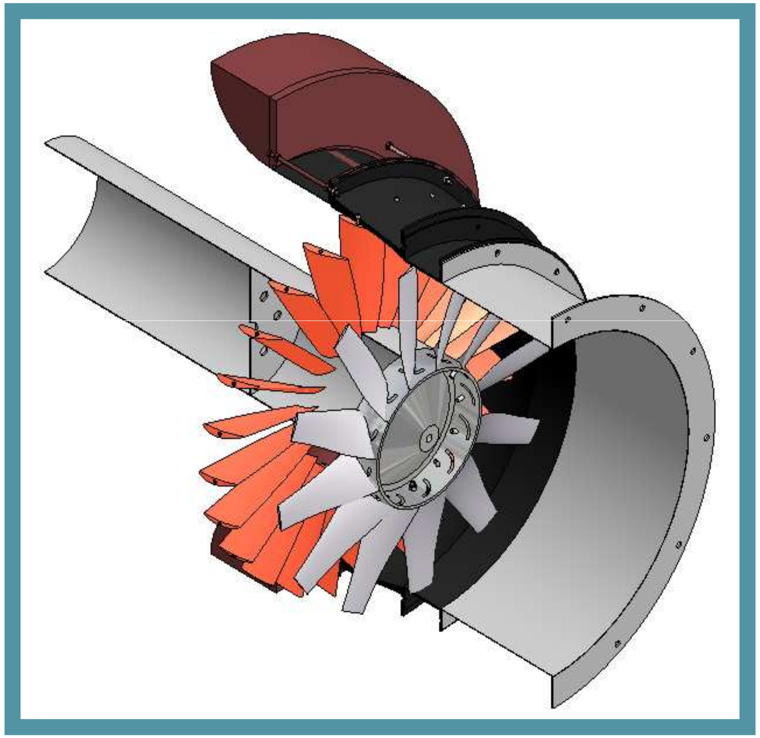


Single turbine model



Multiple turbine model

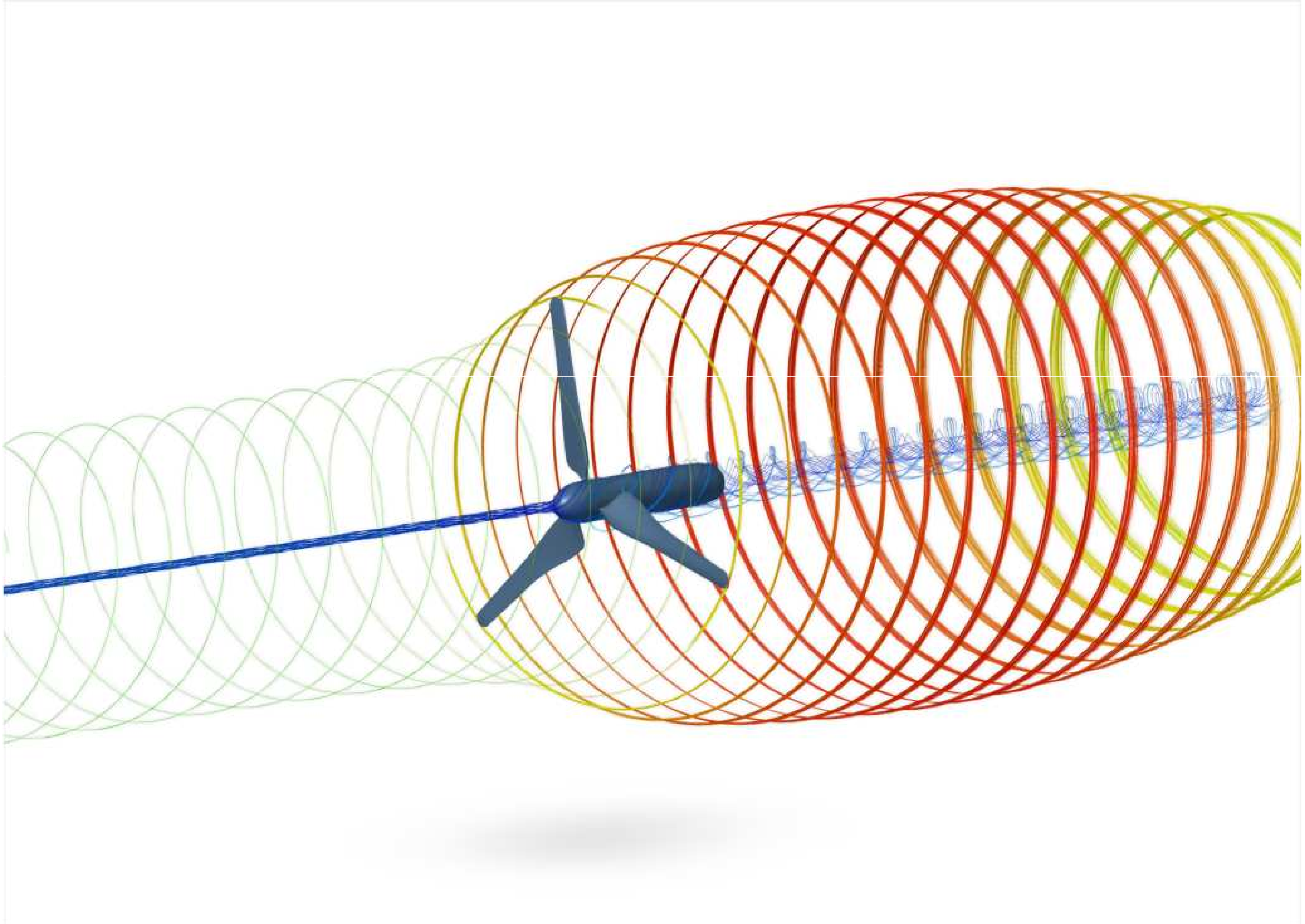
Solar chimney turbine models



CAD model

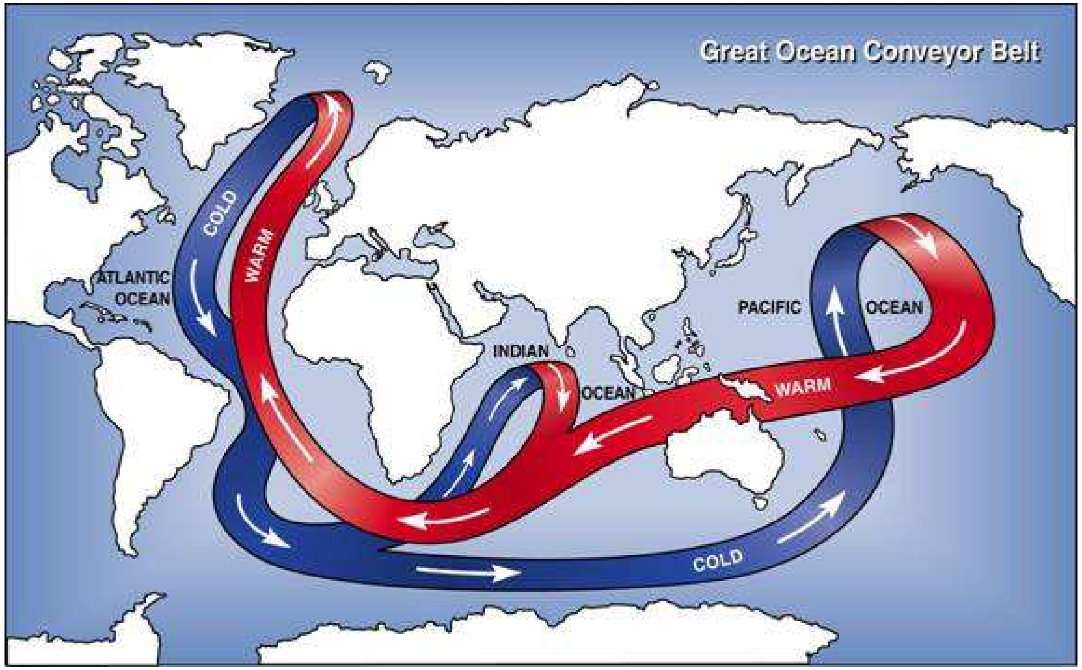
Laboratory model

CFD model of low speed wind turbine



Background to Ocean Current Turbines (OCTs)

- Renewable energy systems
- In principle similar to wind turbines
  - Kinetic energy from ocean currents
  - Density of water
    - 800x greater than air
  - Predictable
  - EU - 50 TWh/year
  - UK 25% of current energy need

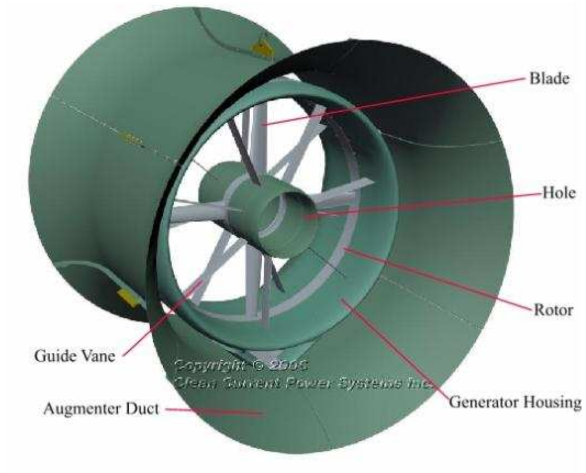


- OCT's generate 4x the power of a wind turbine of same size.

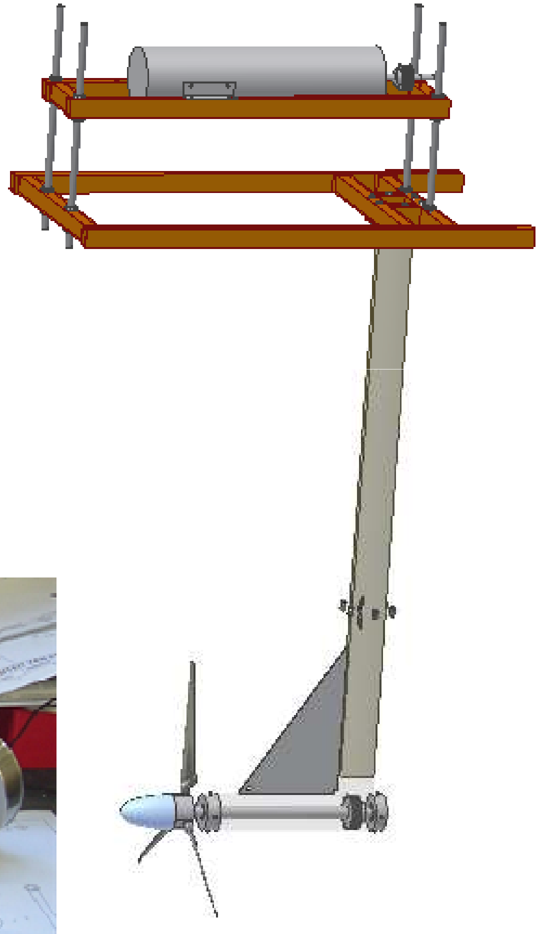
Background to OCTs

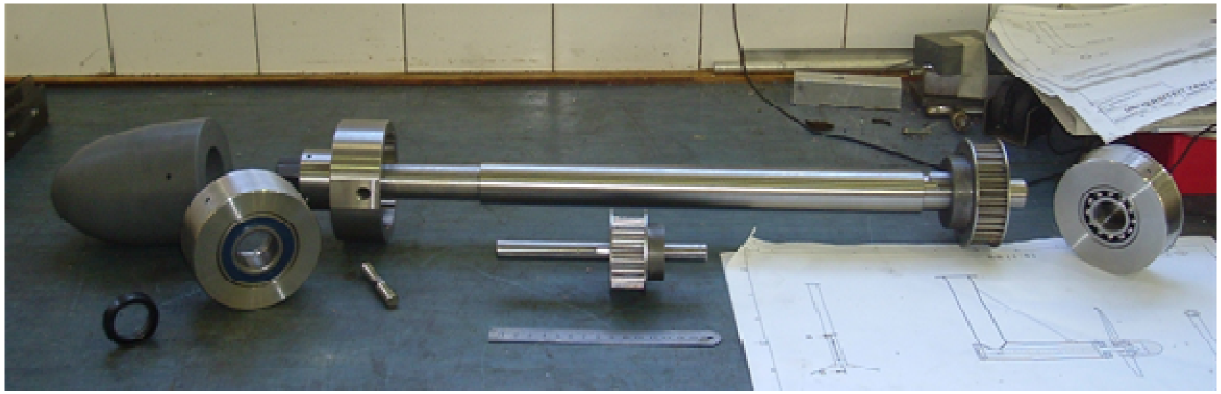
- Current prototypes
  - A few already in operation
  - Marine Current Turbines Ltd.
  - SeaGen
  - UEK, Clean current etc.

SeaGen turbine farm
(1.2 MW/unit)



Stellenbosch model turbine

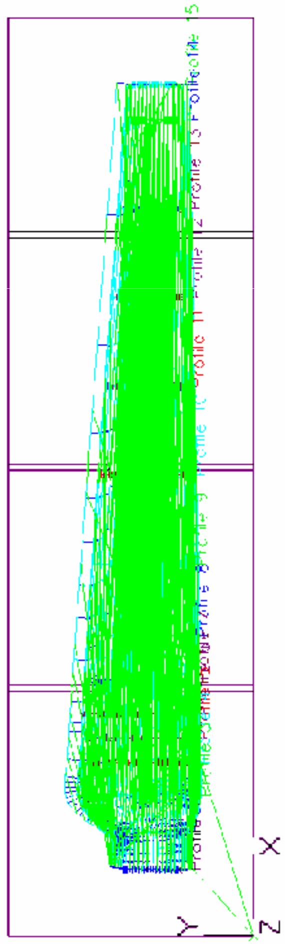




Initial studies

- Reinecke , 2007
  - Main objective
    - Build a model test ocean current turbine.
    - Benchmark design against Bahaj's rotor design

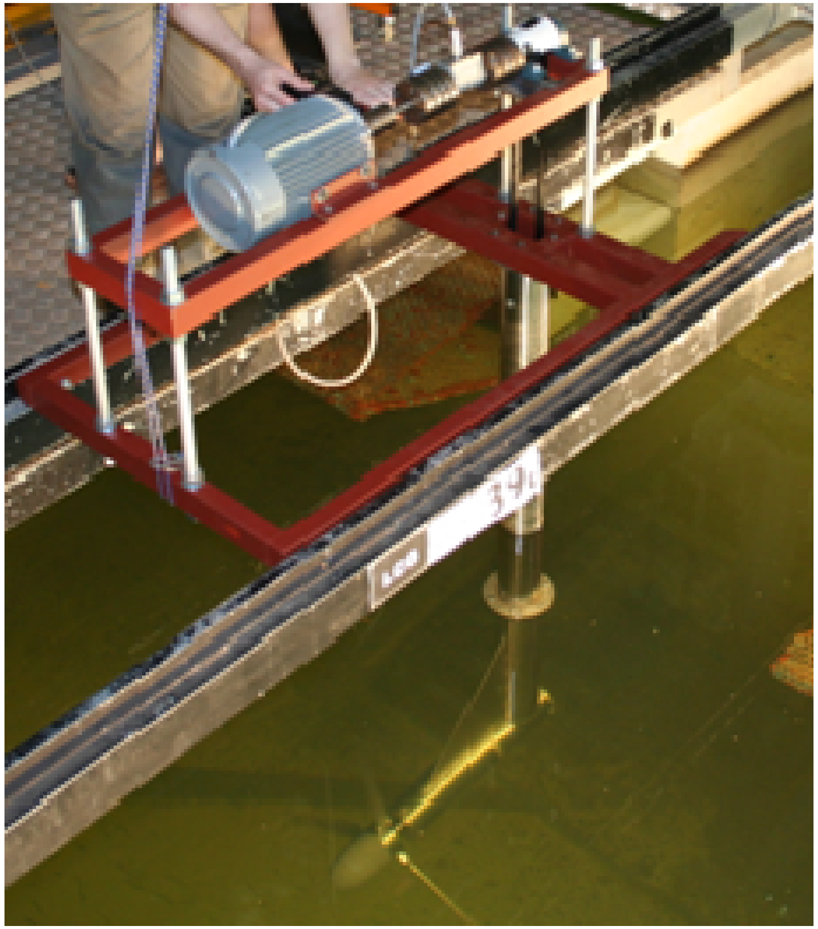
- Blade Design
  - Xfoil used to generate shape points
  - NCBlade™ used to generate CNC code (G-code)
  - Blade manufactured



Previous Studies (continued)

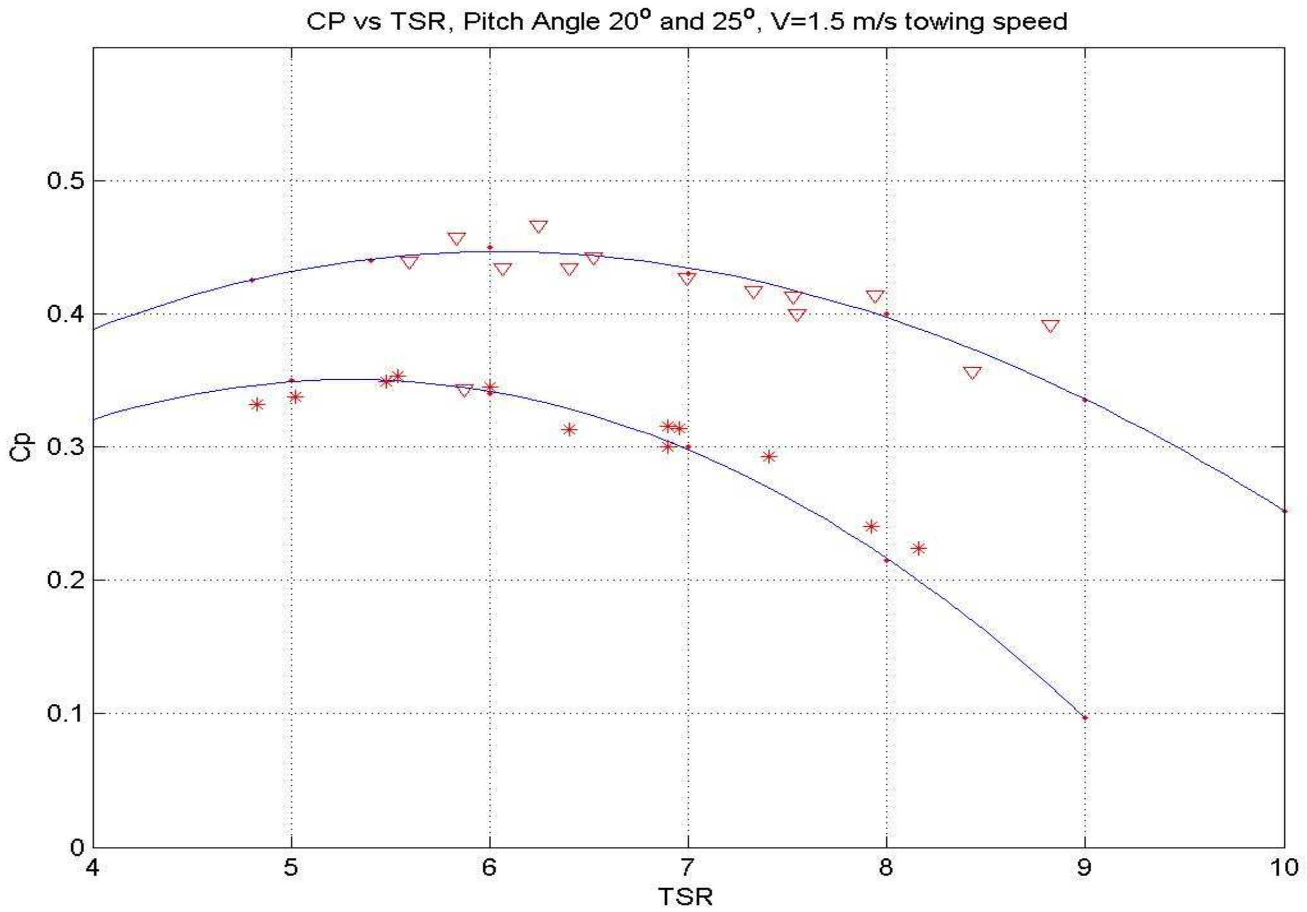
- Rest of hardware designed and manufactured

- Tests conducted at SU towing tank facility.



Previous Studies (continued)

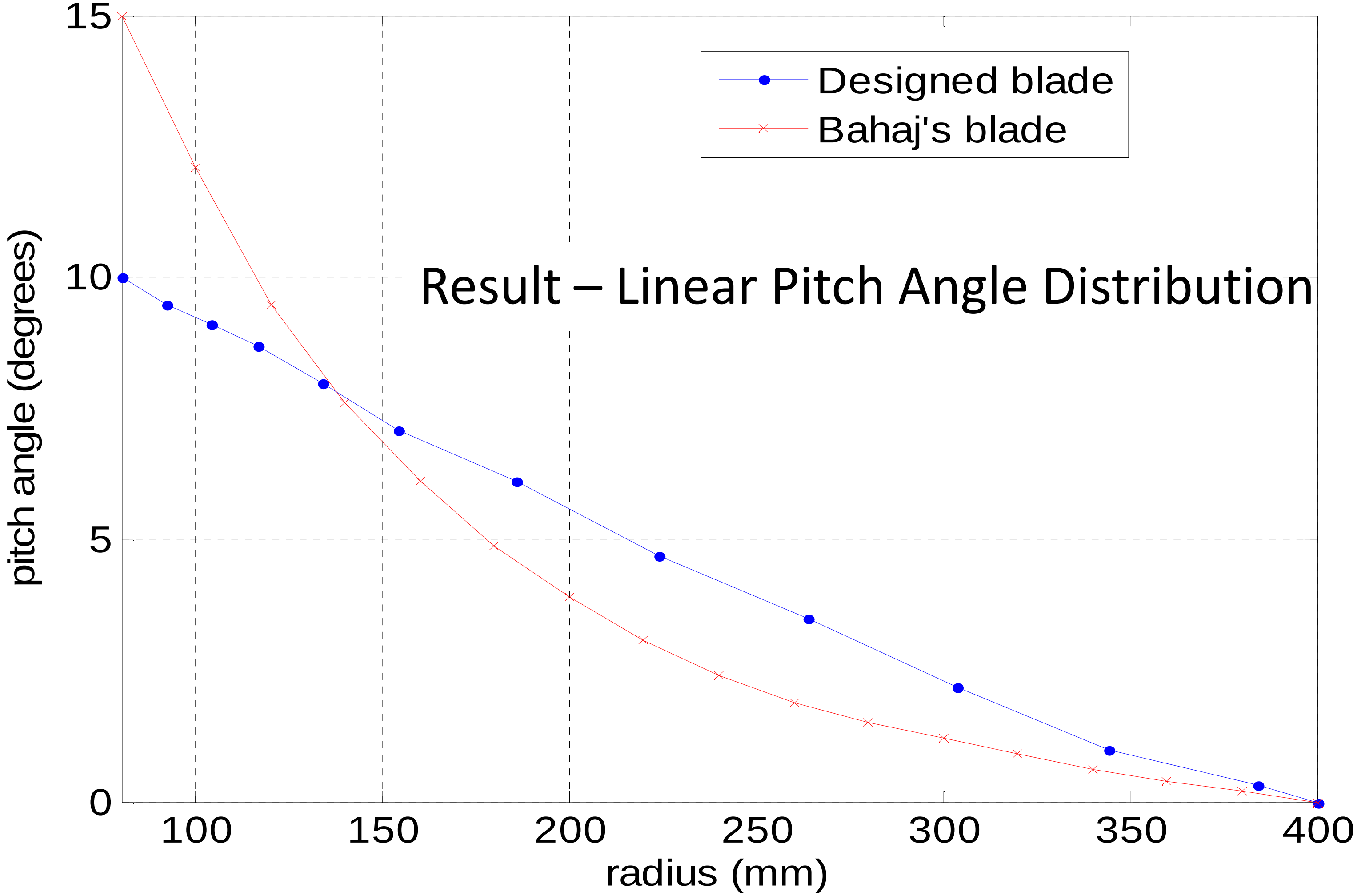
- Results



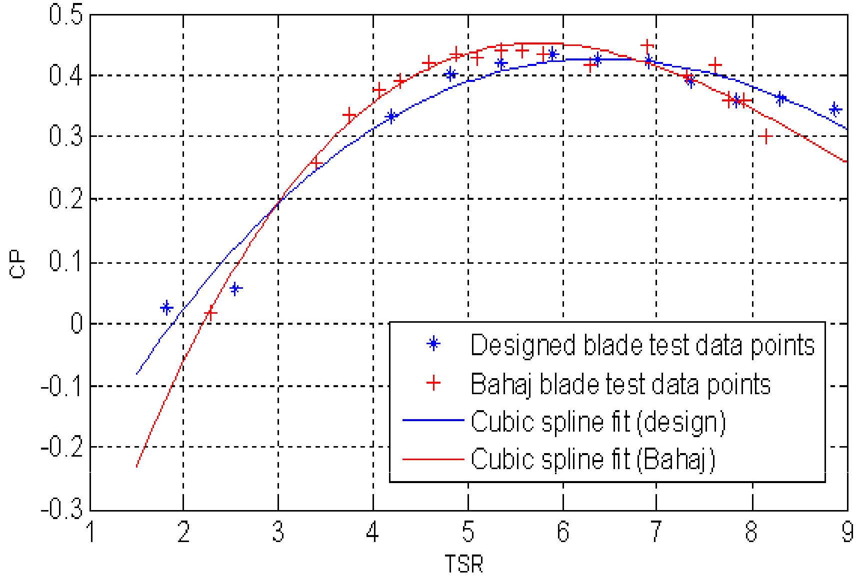
- Good Correlation with Bahaj

Stanford’s pitch angle distribution

Original distribution: $\theta = atan(\frac{1}{4}\pi x) + \theta_A$



Comparative performance of Stanford and Bahaj rotors

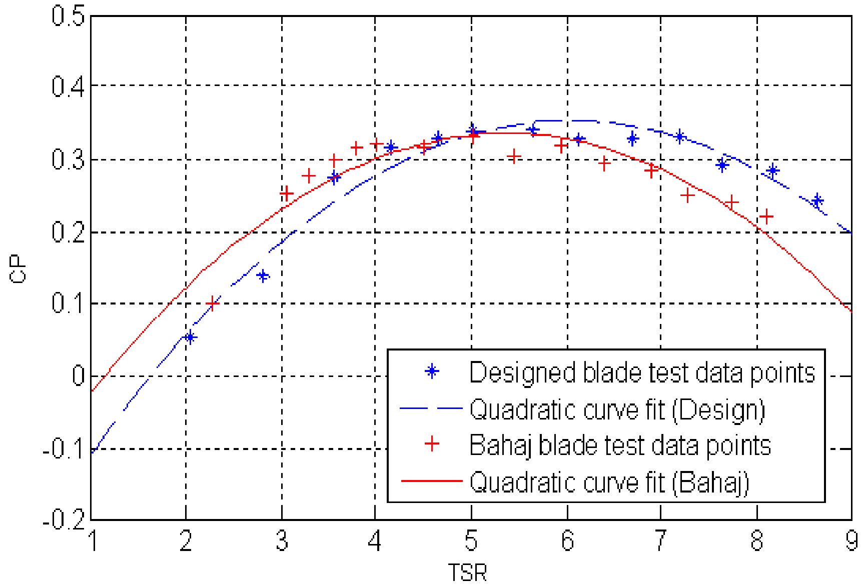


Design Blade Pitch

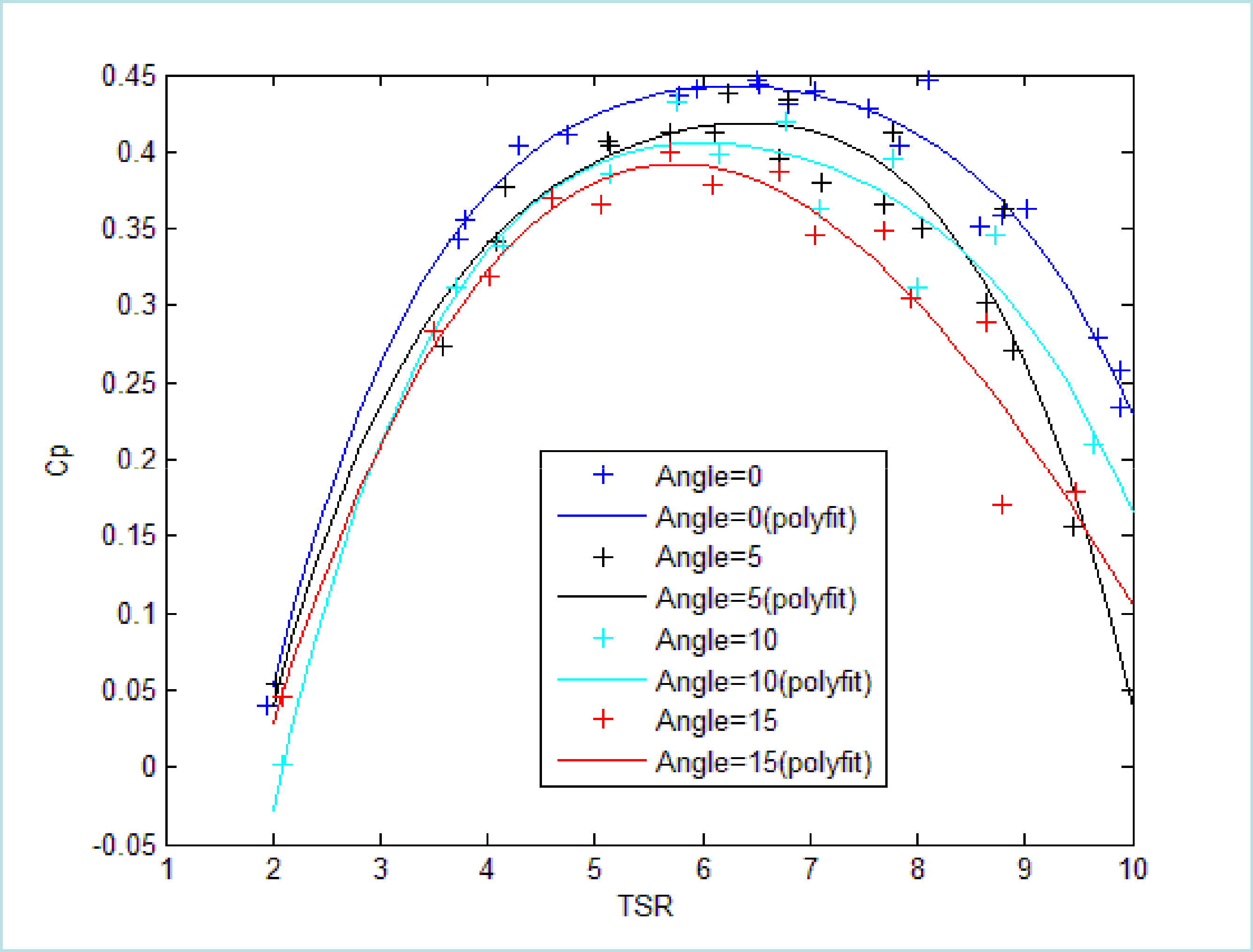
- Designed blade shows flatter distribution
- Better performance for TSR > 7

5˚ Blade Pitch Offset

- Designed blade shows better performance for TSR > 5
- Designed blade not badly affected by blade pitch

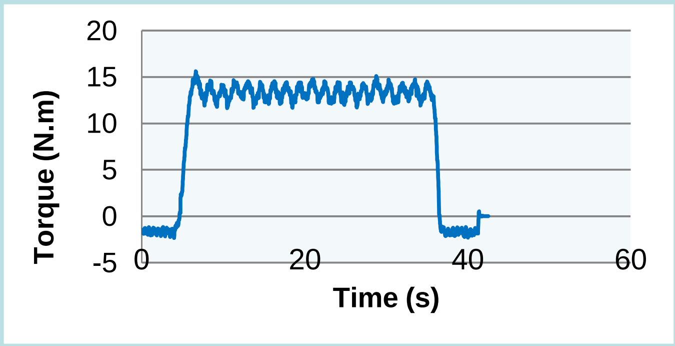


Effect of turbine yaw

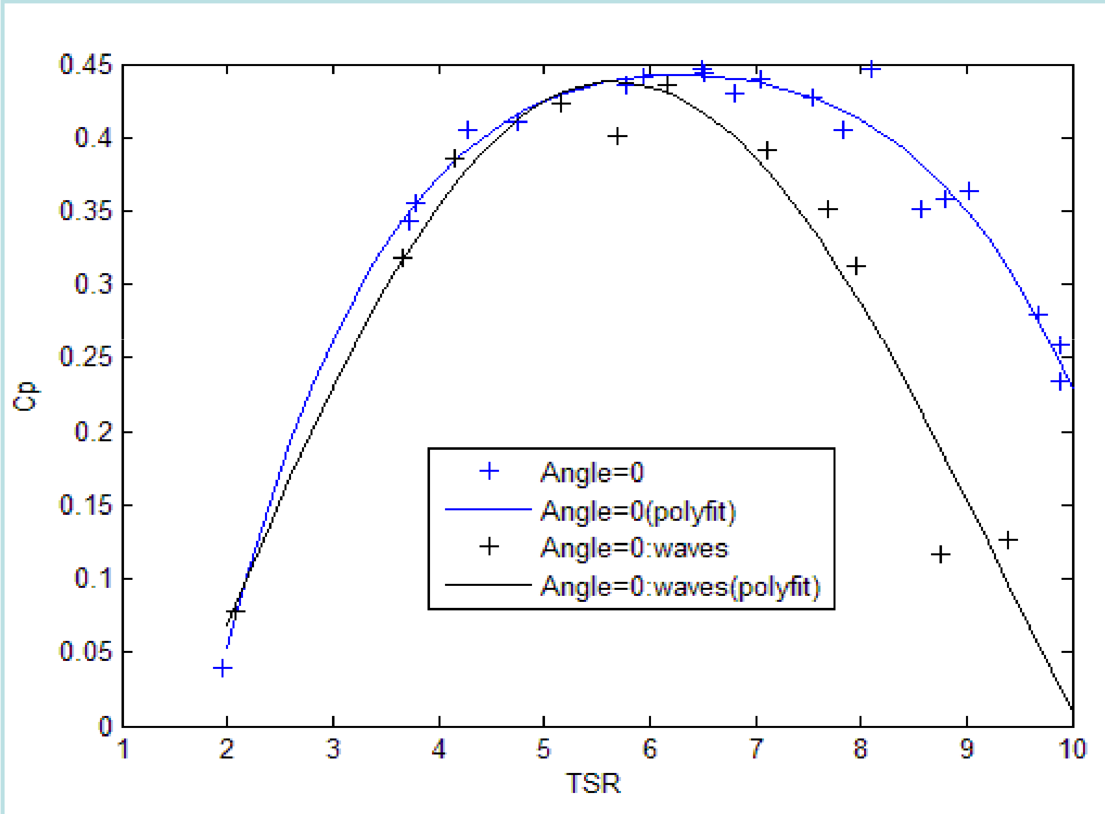


Performance coefficient vs tip speed ratio

Effect of waves



	TSR	Maximum Coefficient of Performance
No Waves	6.5	0.446
Waves	5.5	0.439

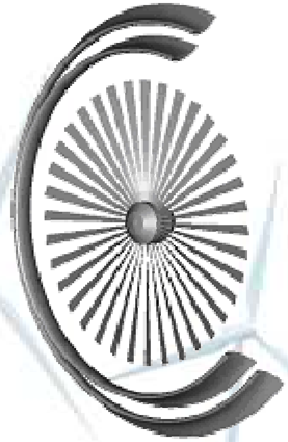


Performance coefficient vs tip speed ratio

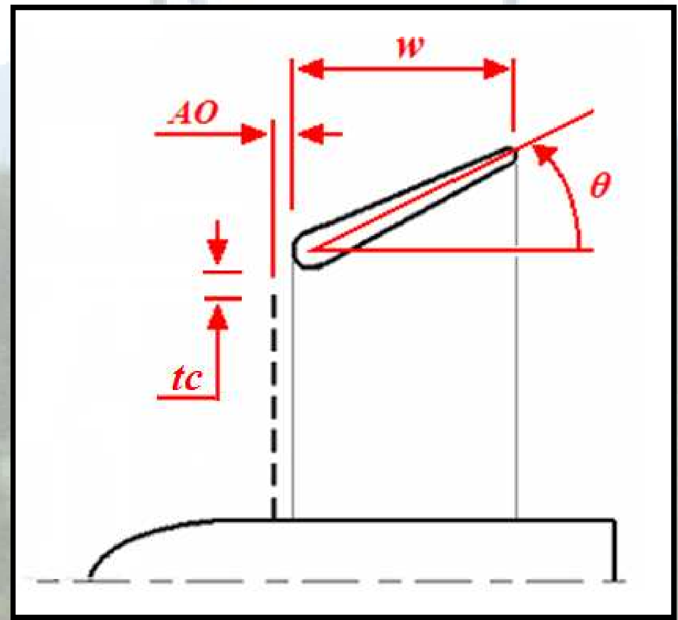
Flow augmentation devices

Shroud

"Partially static turbine"



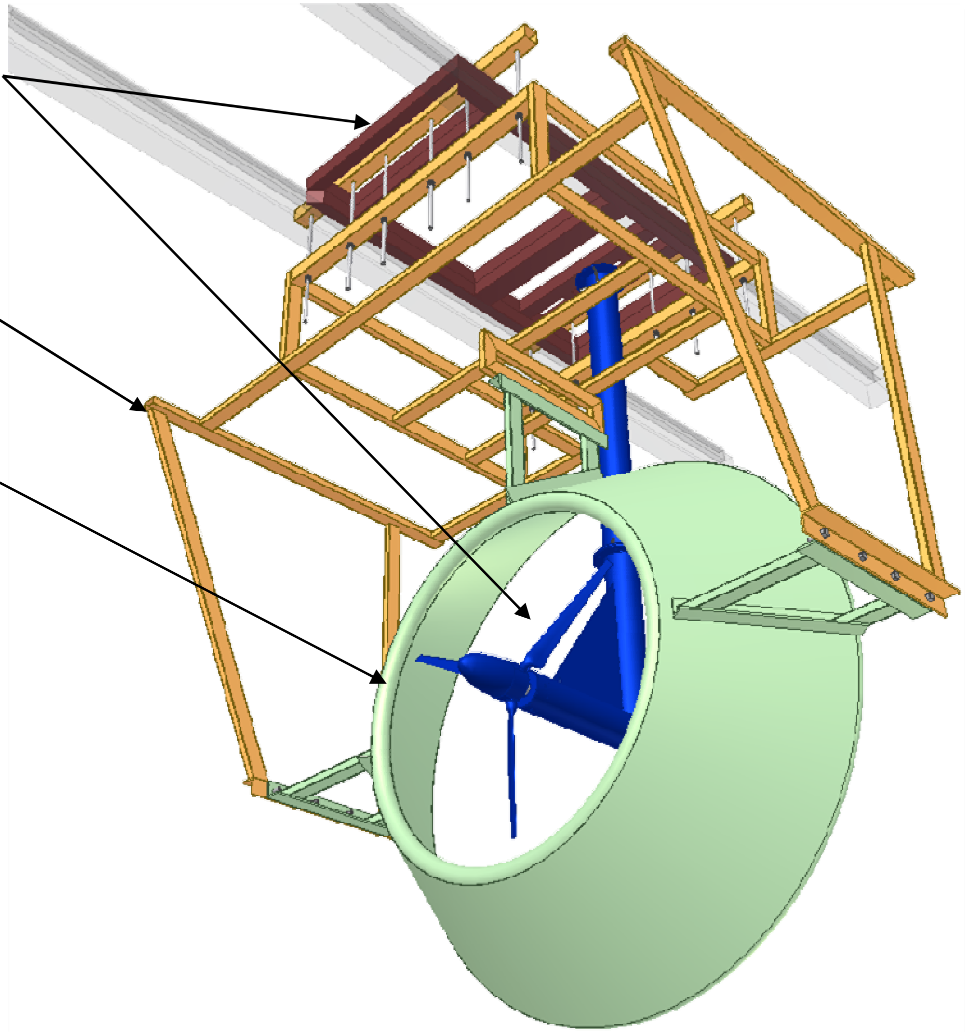
Diffuser



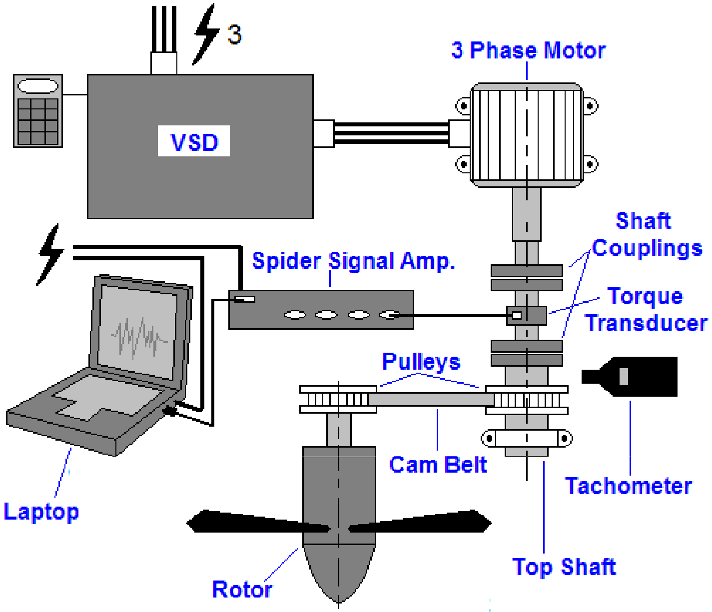
Shroud-diffuser combination

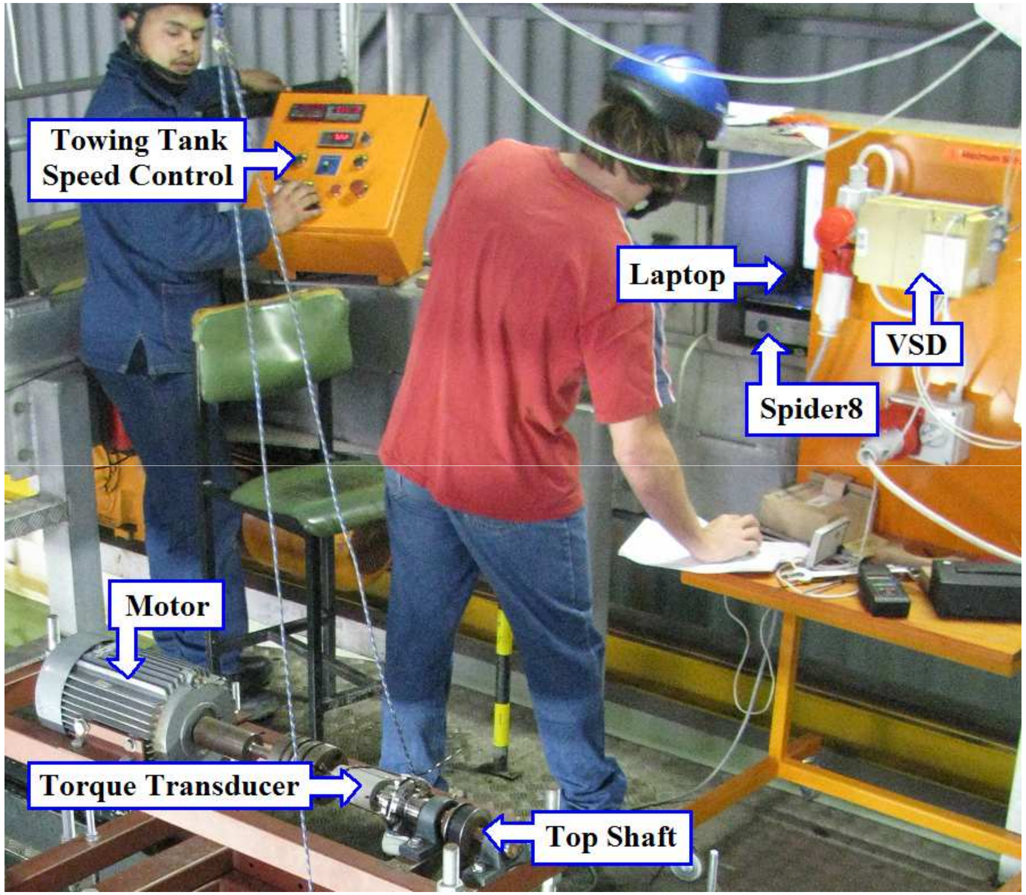
First shrouded turbine

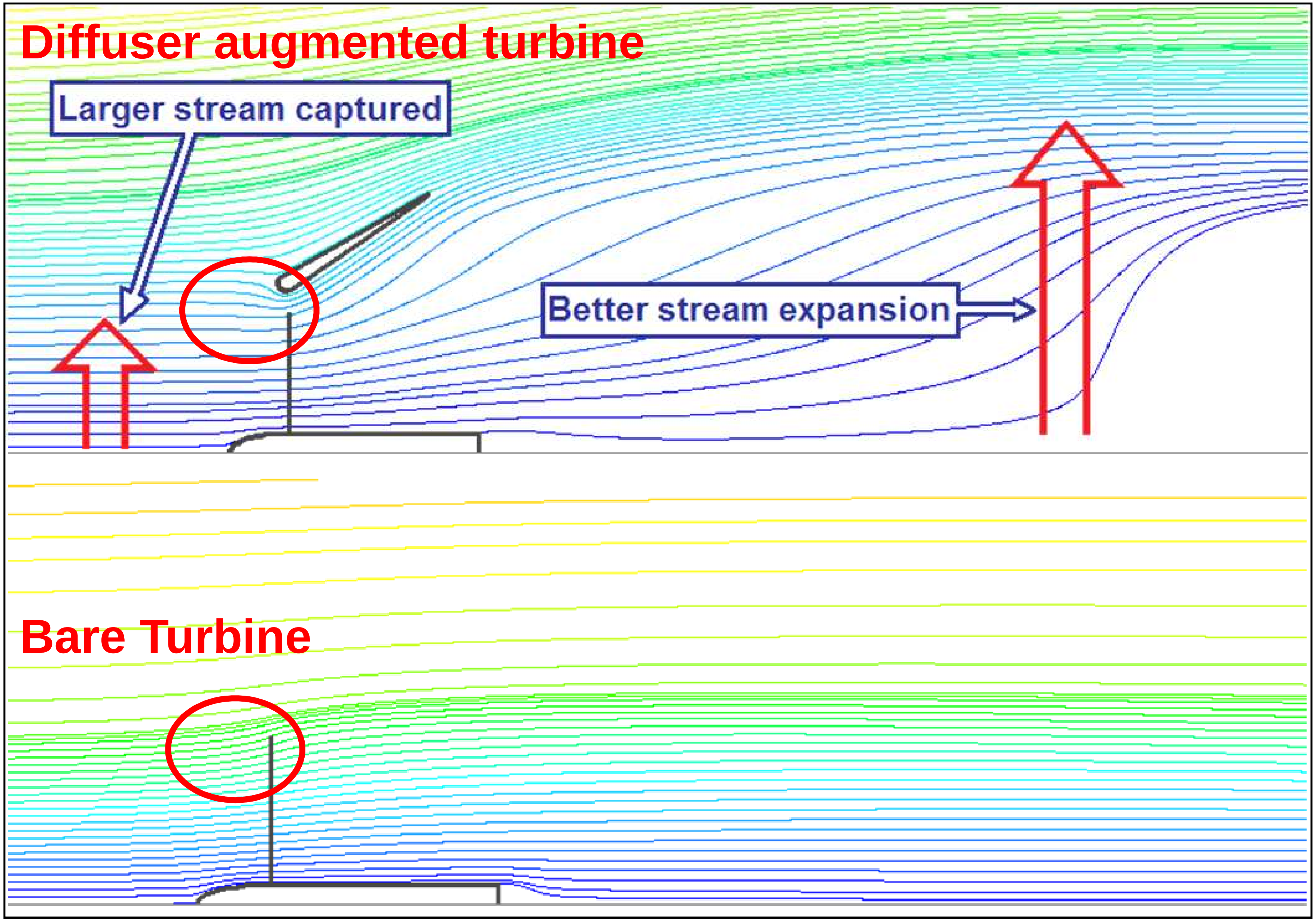
1. Pre-existing equipment
2. Attachment rig
3. Diffuser



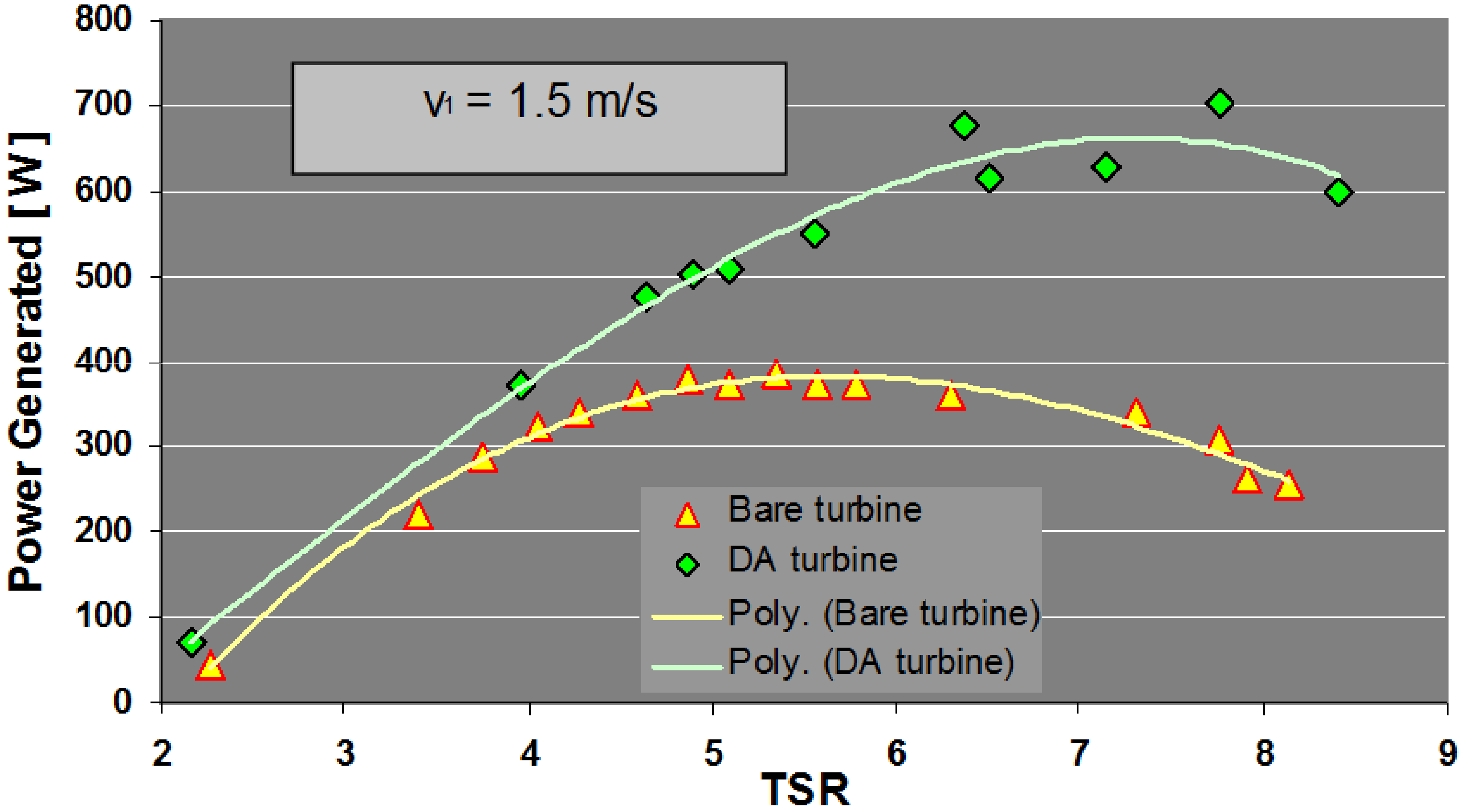
Experimental Setup



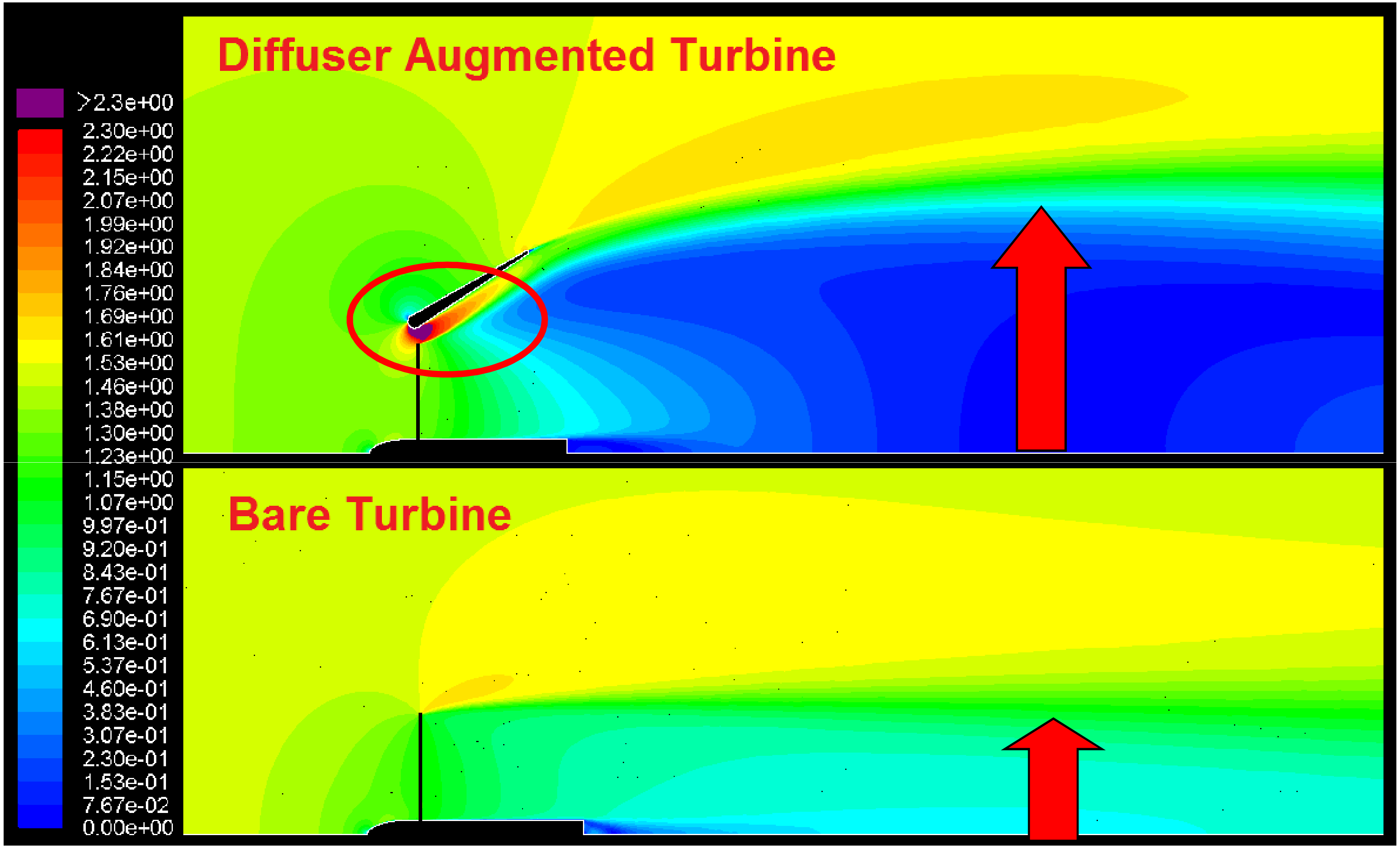



Diffuser augmented turbine
Larger stream captured
Better stream expansion
Bare Turbine

Previous studies

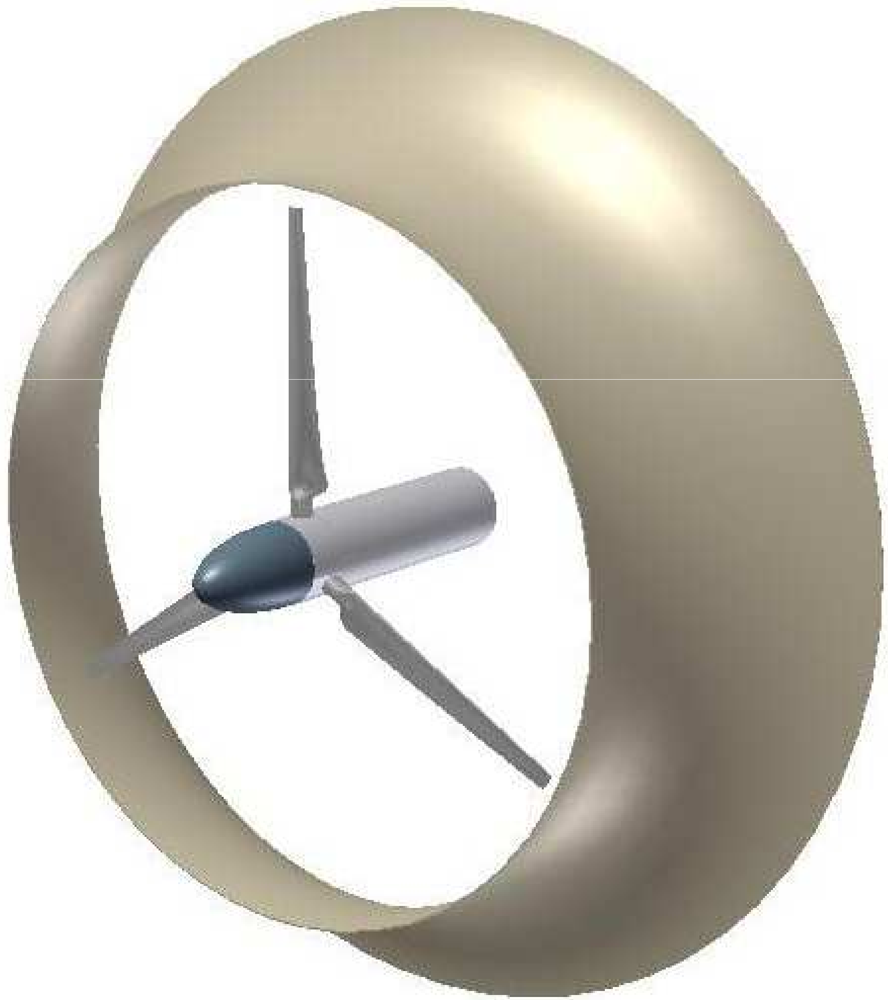


- Power increase between 44% and 87%!



Velocity contours

Advanced shrouded turbines



Objectives

- Increase power output by factor 2+
- Use split curved plate diffuser and/or airfoil type diffuser
- Compare two diffuser designs
- Manufacture chosen concept using composites
- Compare experimental data with CFD data

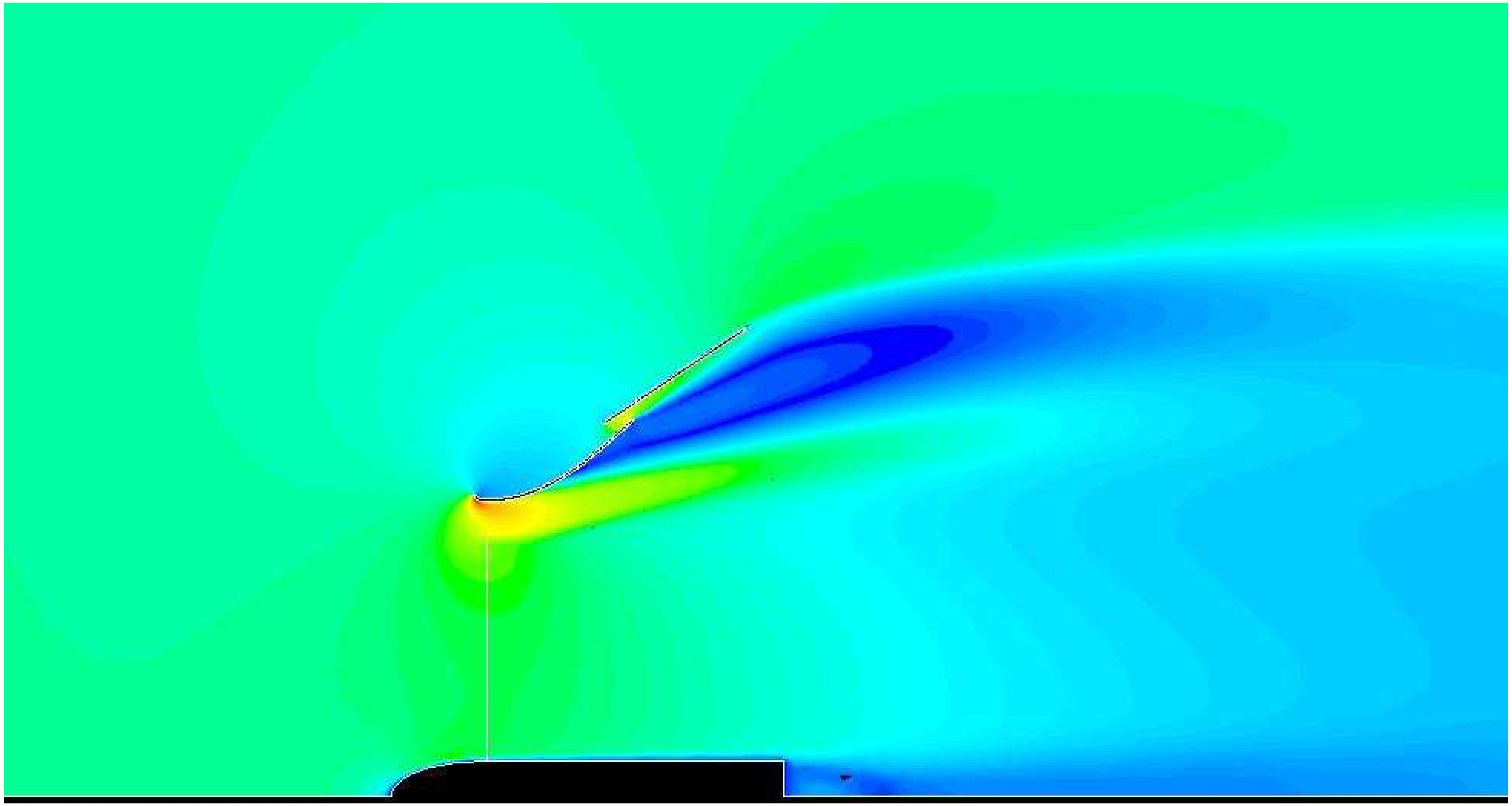
Results so far

- Literature study completed
  - Boundary layer bleed slots found to reduce flow separation
  - Preliminary studies using diffuser shows increase of 20%-85%
  - Diffuser momentum theory in infancy. Theoretical understanding limited
  - Application of optimization to diffuser problems no significant increase over DOE
  - Economically more feasible for OCT’s
  - Prototype complexities, installation and maintenance

Results so far (cont.)

- Pre CFD studies
  - Fluent™ code and solver types investigated.
  - Simulations vs. 1-D Momentum theory for
    - Rotor with hub case
      - Turbulence Model
      - Laminar Solution
    - Rotor no hub case
      - Turbulence model
      - Laminar Solution
    - Turbulence models
      - Various investigated, Spalart-Almaras, K-e standard, K-e Realizable.
      - K-e Realizable superior in turbulence prediction

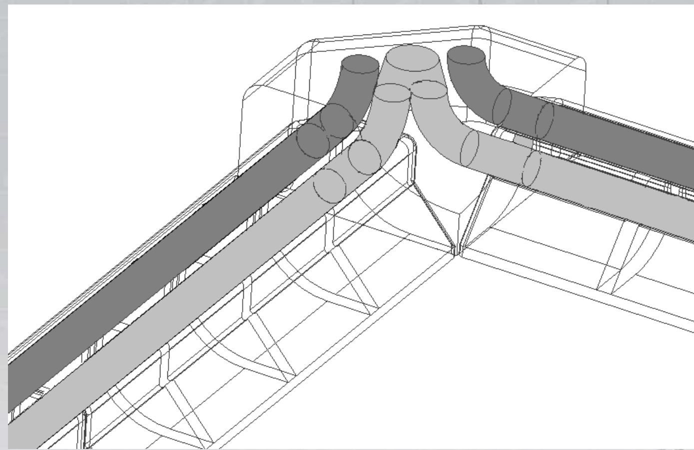
CFD velocity contours of split shroud



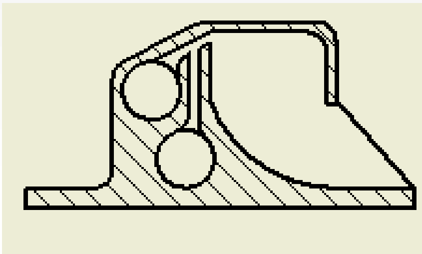
Conclusions of this section

- Shrouds can be used to to increase power developed
- More studies are necessary to determine if shrouds are economically competitive with increasing the turbine rotor diameter
- Turbine shroud optimisation is proceeding
- For more detail and the very latest developments ask Josh Reinecke

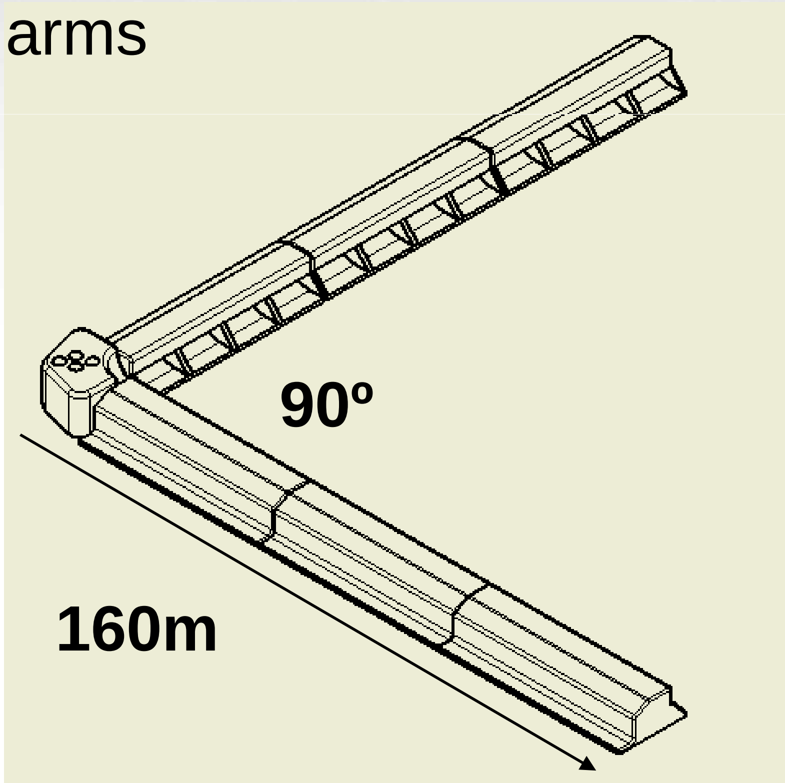
Stellenbosch Wave Energy Converter (SWEC)



Physical Layout : Collector arms



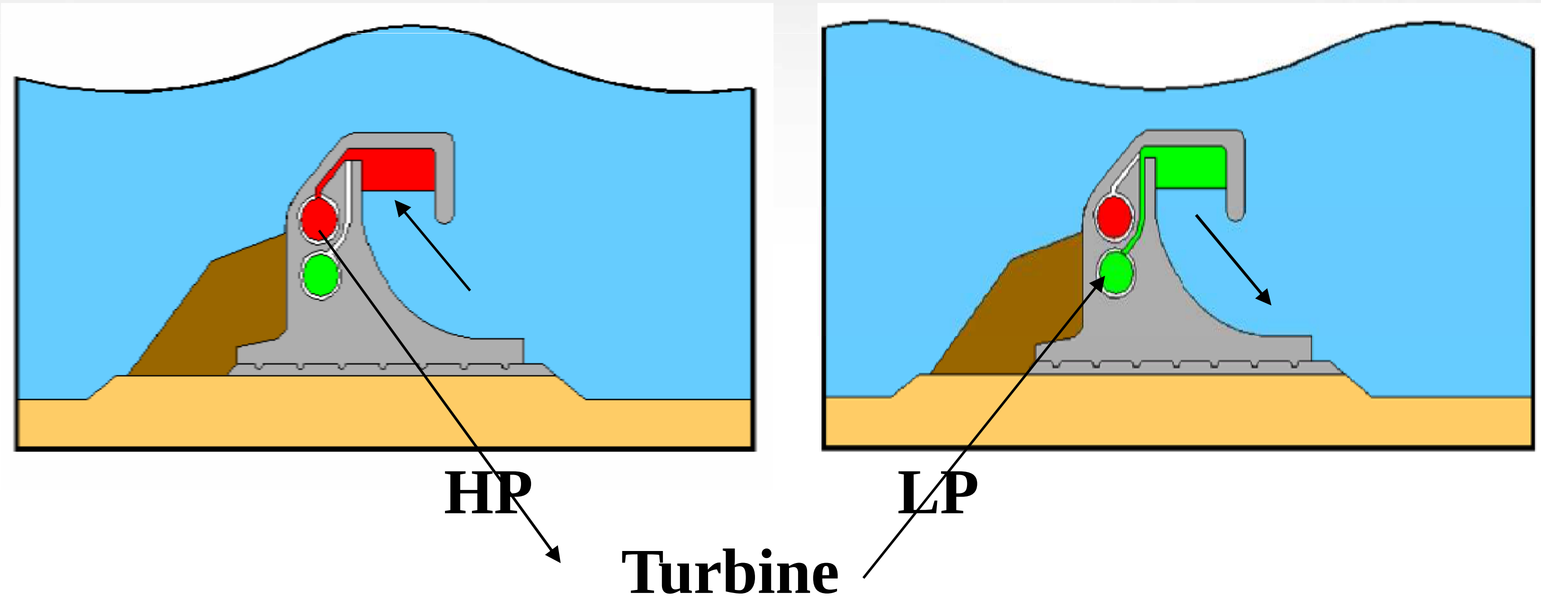
12m x 6m x 3.5m



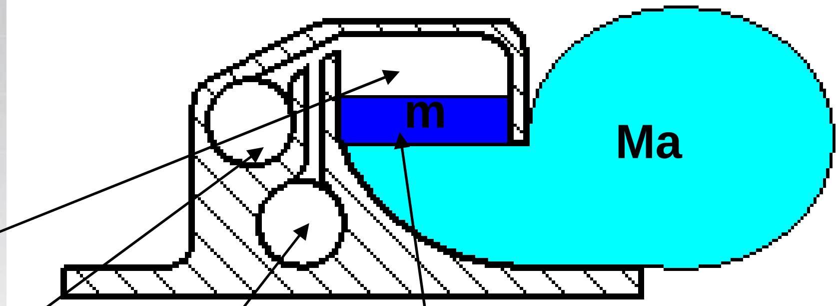
Introduction

SWEC Energy extraction principal

Subsurface pressure/velocity fluctuations



SWEC system modelling



- State Equations
- OWC chambers (air)

$$\Rightarrow \dot{P}_1 = \frac{P_1}{(H_1 - x)A_1}\left[\dot{x}A_1 - \frac{\dot{m}_o}{\rho_1}\right]$$

- High and low pressure manifolds

$$\Rightarrow \dot{P}_2 = P_2\left[\frac{(\dot{m}_o - \dot{m}_{Ti})}{\rho_2 \forall_2}\right] \qquad \Rightarrow \dot{P}_3 = P_3\left[\frac{(\dot{m}_o + \dot{m}_{To})}{\rho_3 \forall_3}\right]$$

- OWC chambers (water)

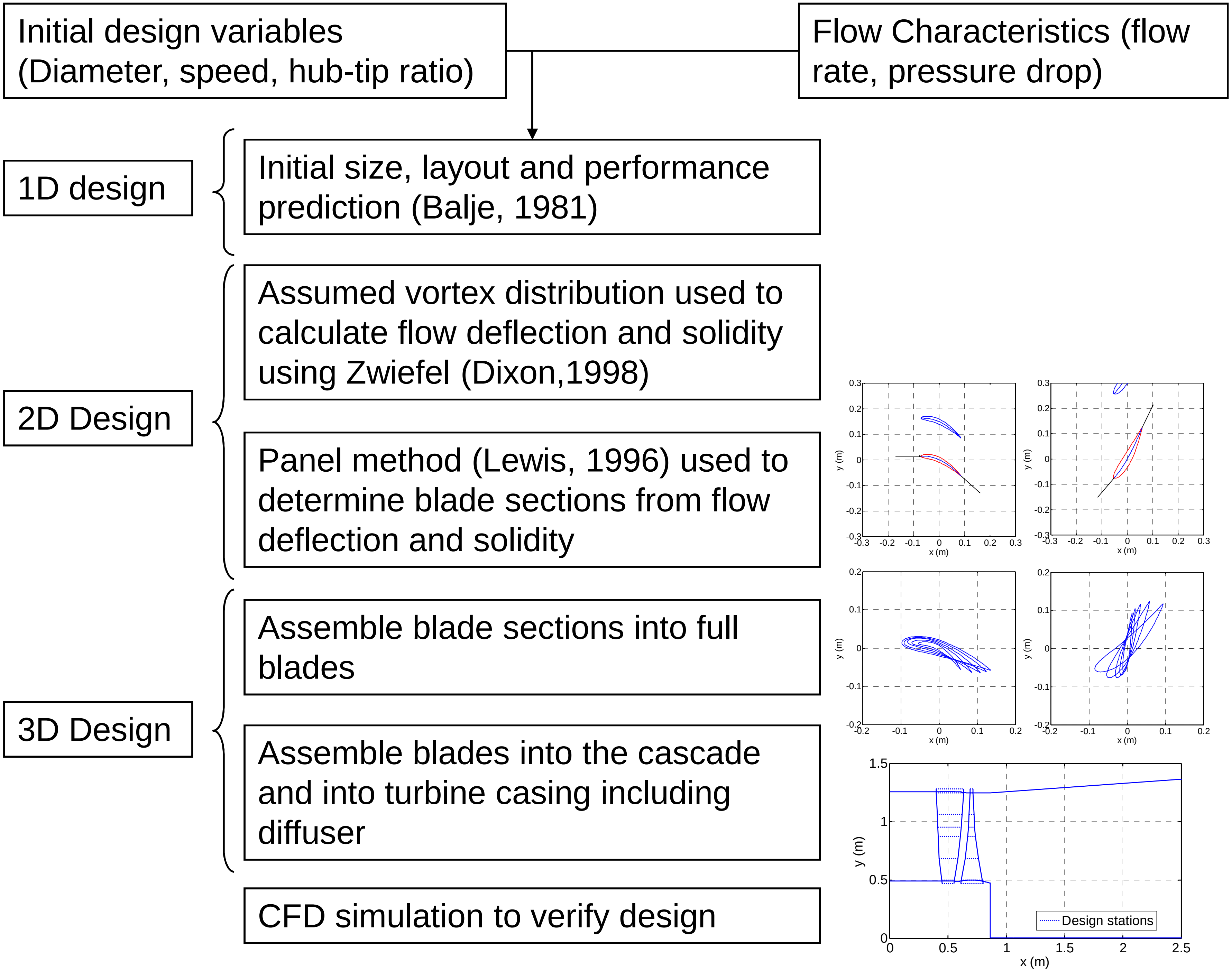
$$\therefore \ddot{x} = \frac{1}{\rho_W (H_W + x) + \frac{M_a}{A_1}}\left[P_W - P_1 - \rho_W g (H_W + x) - \frac{1}{A_1}\left(\frac{4\mu_W (L_1 + B_1)}{A_1} + N\right)\dot{x}\right]$$

- Turbine

$$\dot{m}_t = \frac{P_{Ti}}{\sqrt{T_{Ti}}} k_T \left[1 - \left(\frac{P_{To}}{P_{Ti}}\right)^2\right]^{1/2}$$

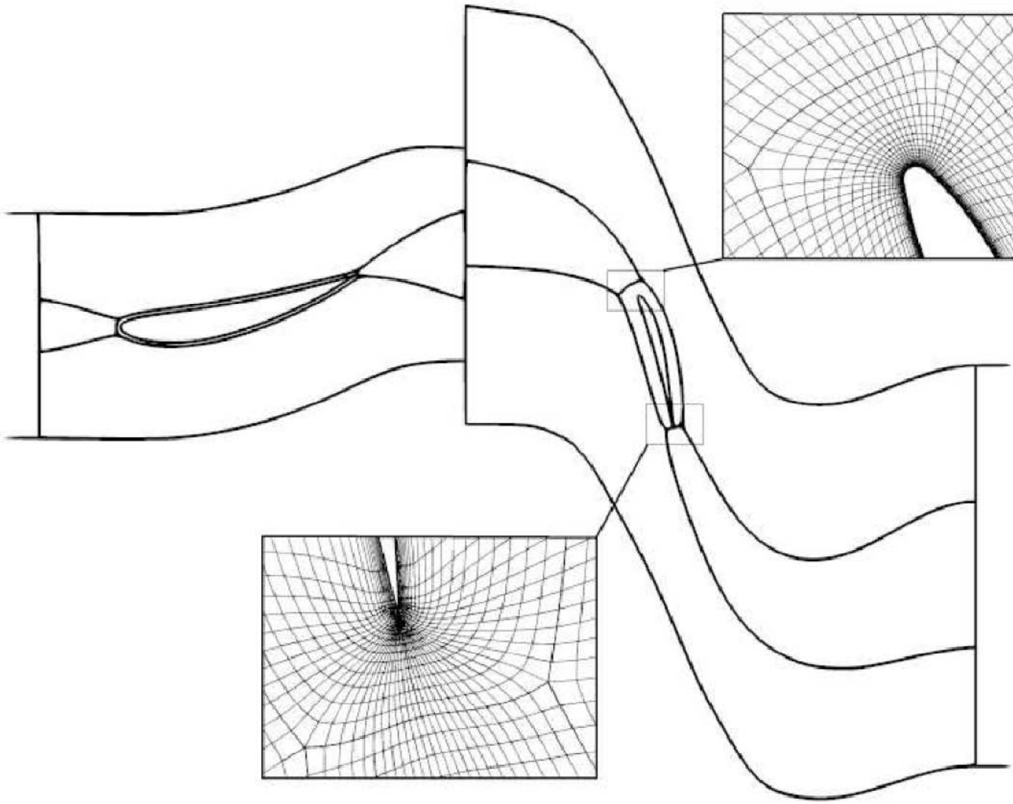
SWEC turbine design procedure

- Next slide
- Also ask Paul Ackerman

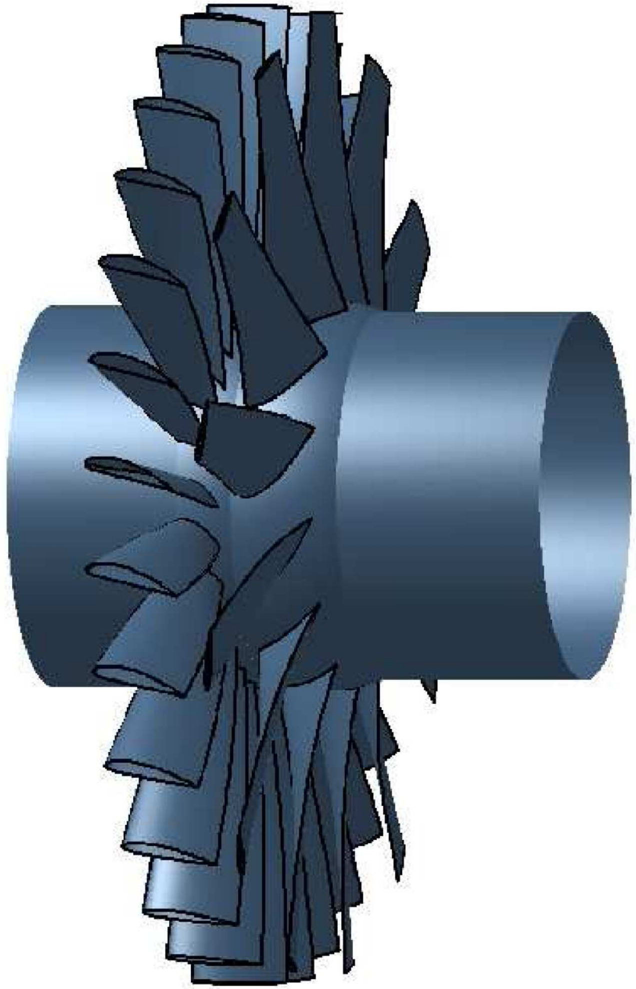


Initial design variables (Diameter, speed, hub-tip ratio)
Flow Characteristics (flow rate, pressure drop)
1D design
Initial size, layout and performance prediction (Balje, 1981)
2D Design
Assumed vortex distribution used to calculate flow deflection and solidity using Zwiefel (Dixon,1998)
Panel method (Lewis, 1996) used to determine blade sections from flow deflection and solidity
3D Design
Assemble blade sections into full blades
Assemble blades into the cascade and into turbine casing including diffuser
CFD simulation to verify design
x (m)
y (m)
Design stations

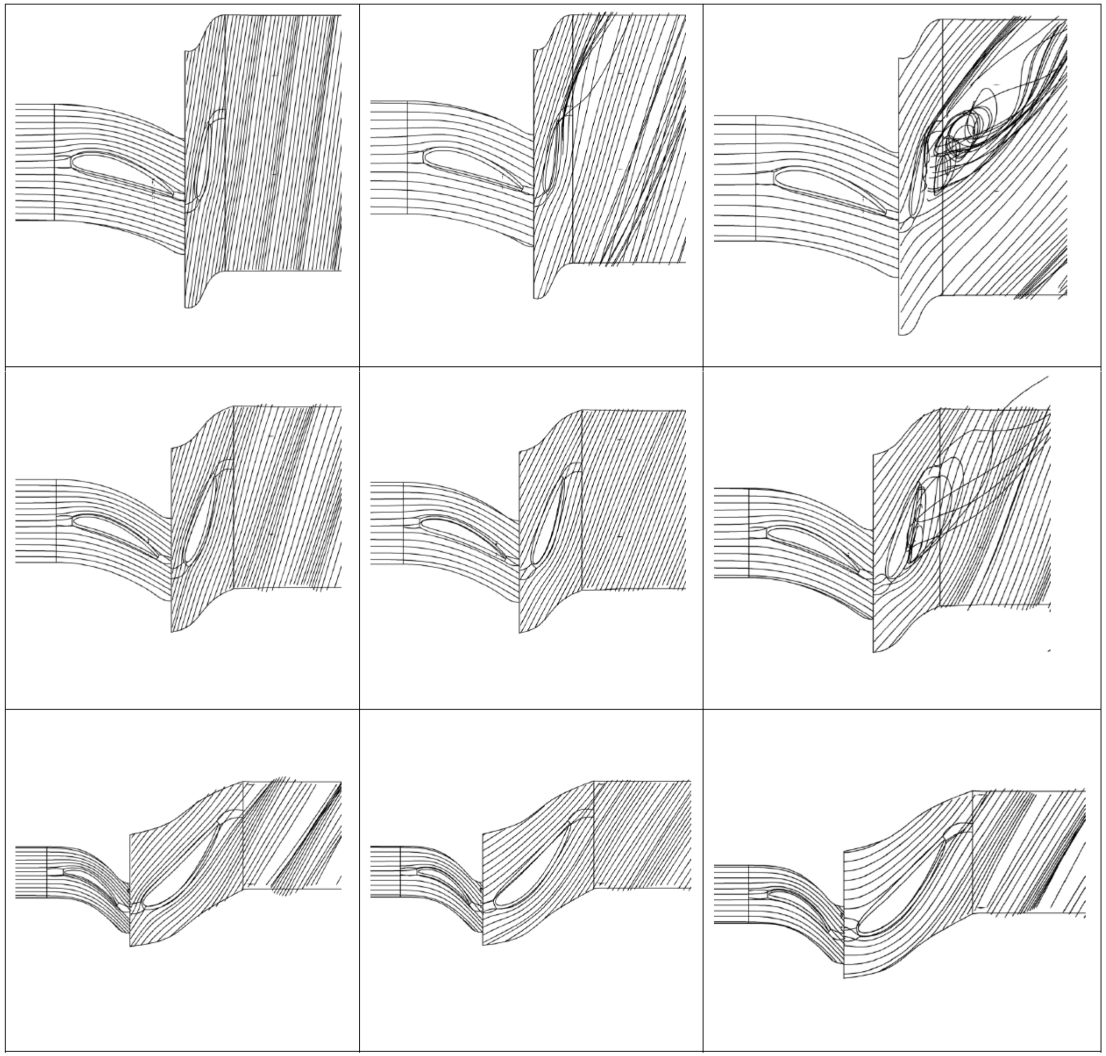
CFD meshing



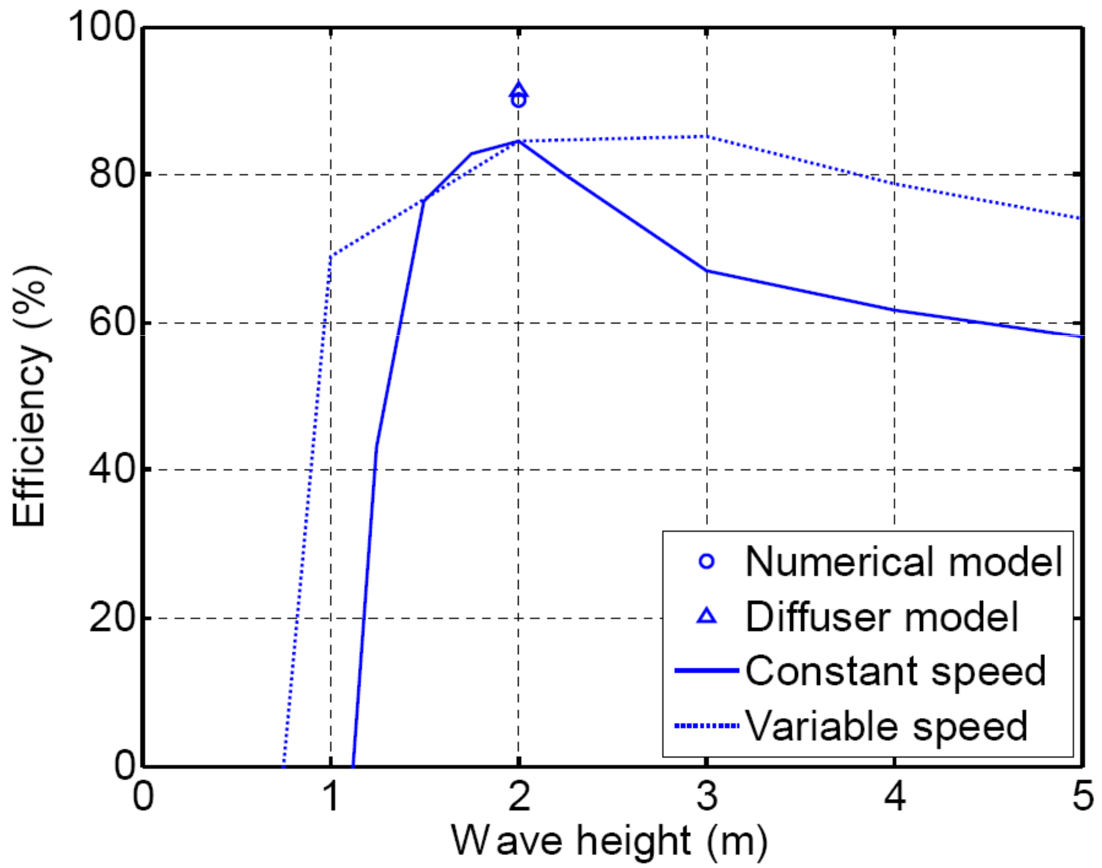
Layout of SWEC turbine



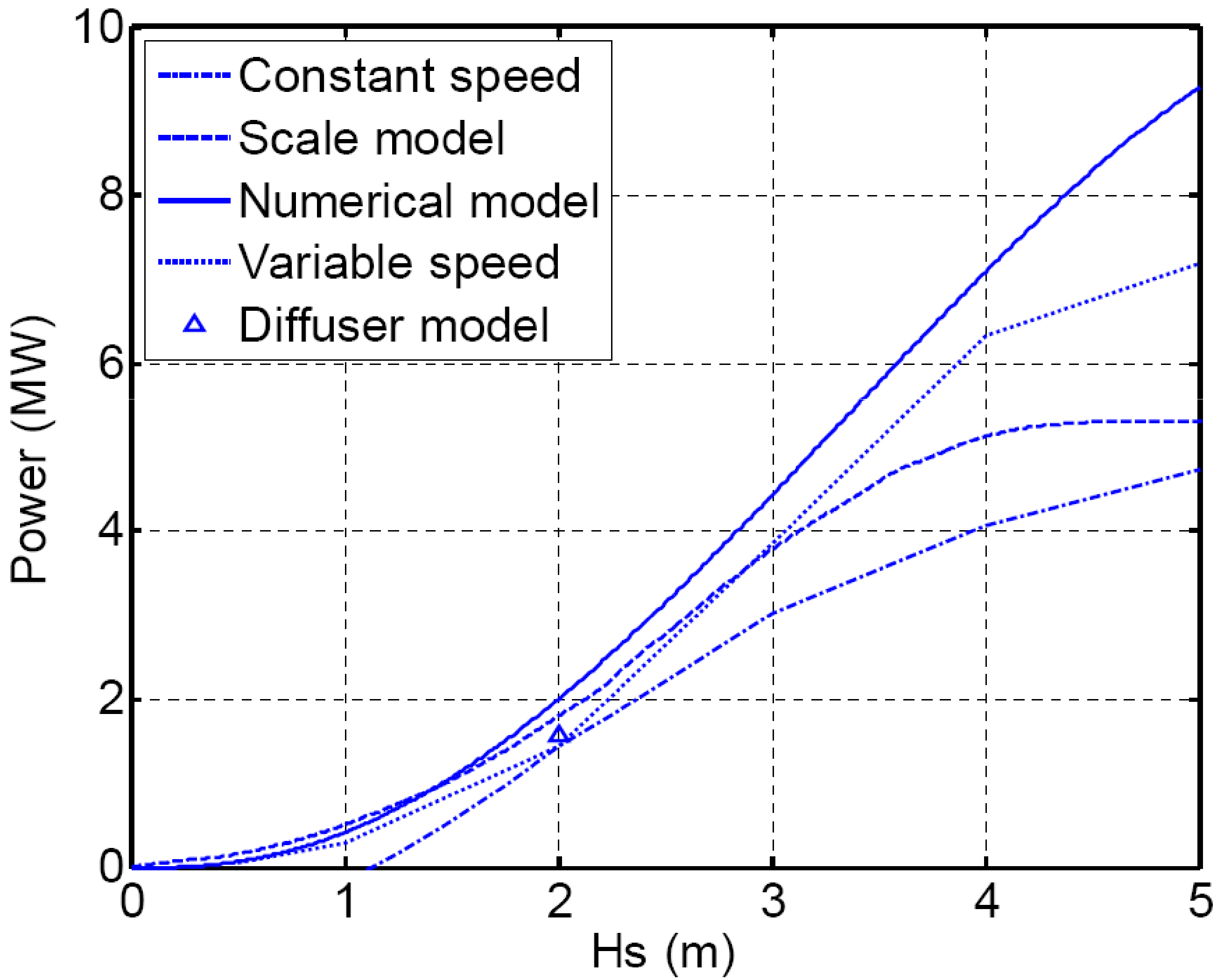
Turbine blade hub, mid and tip performance at high, medium and design flows



SWEC turbine performance



Power as dependent on wave height



Conclusion of this section

This work has shown that:

- The one-dimensional dynamic system model agrees well with the previous model studies
- A highly efficient turbine can be developed
- The generator should preferably be of the variable-speed type

Conclusion of the talk

- Work done at Stellenbosch over the last few years on ocean current and wave system turbines has been presented.
- Students have designed, built and analysed various open and shrouded turbines.