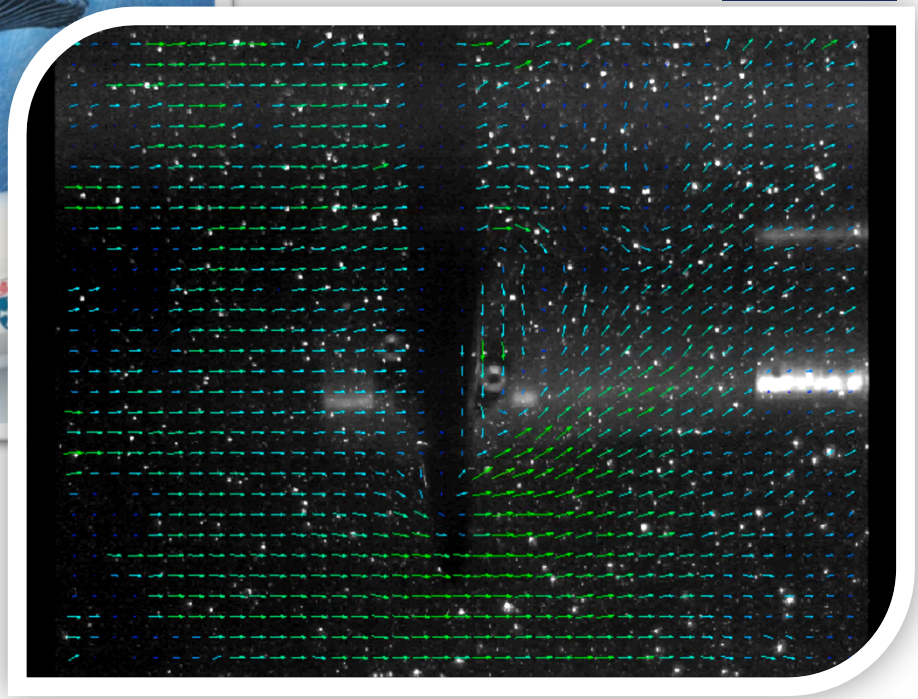


Biomimetic improvement of hydrodynamic performance for tidal turbines

Reporter: Weichao Shi

Position: Research assistant and PhD candidate

Supervisors: Prof. Mehmet Atlar & Dr. Rosemary Norman

Presentation layout

- Introduction
- Aims and objectives
- Study for a representative hydrofoil
- Study for tidal turbine models
- Conclusions

Newcastle University

University of Strathclyde Glasgow

Introduction-Understandings of the Unusual behaviour

"Humpback Whale"

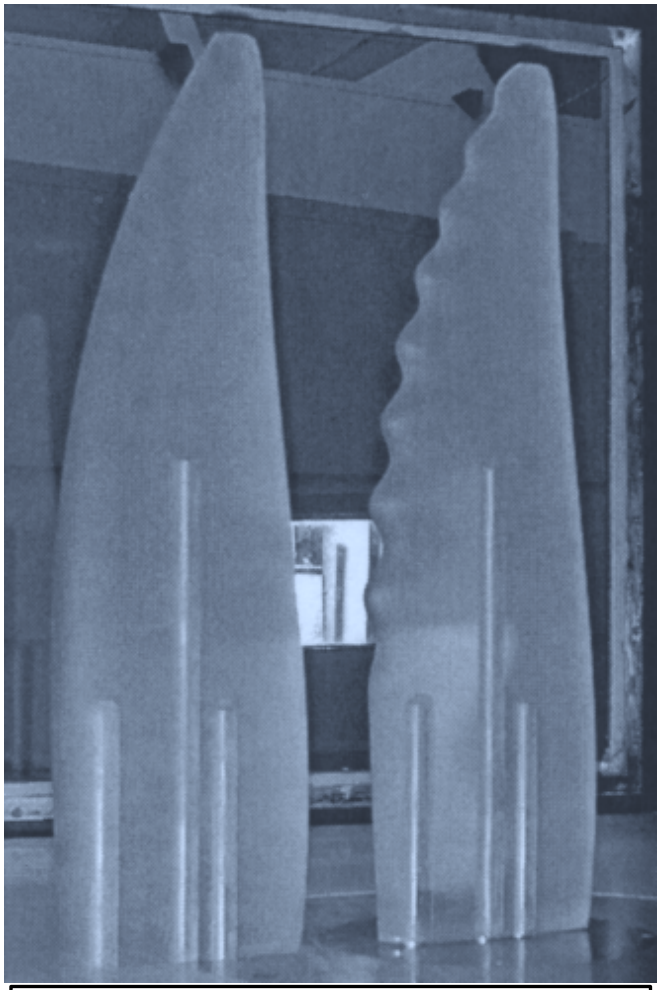
- Giant marine mammal, 12~16m long
- Distinctive body shape, with unusually long fins

Bubble net hunting:

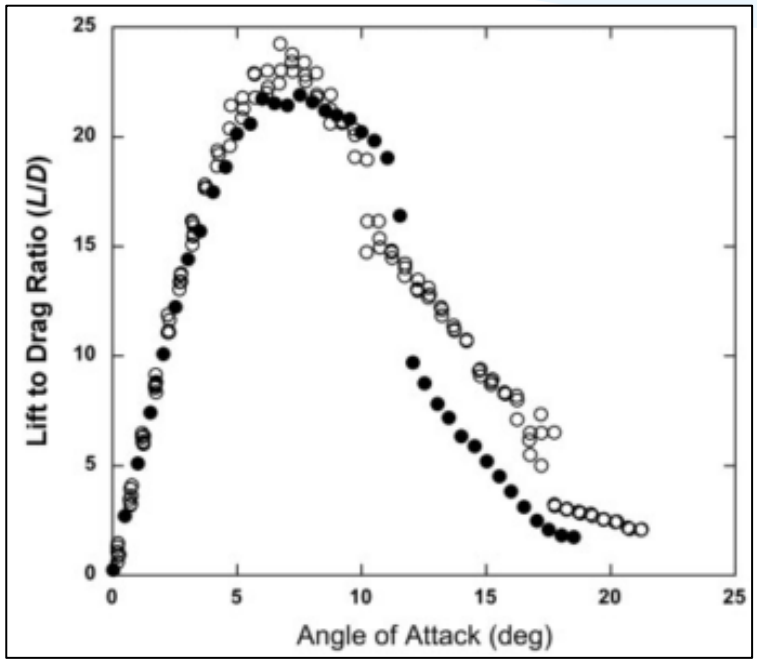
1. Swim circularly to drive ton of fish into a small circular zone
2. Produce bubbles as a bubble net to prevent the fish from escaping
3. All together open mouths to swallow tones of fish

Unusually long fins with leading-edge tubercles?

Introduction-Understandings of the Unusual behaviour



Replica of humpback whale fins

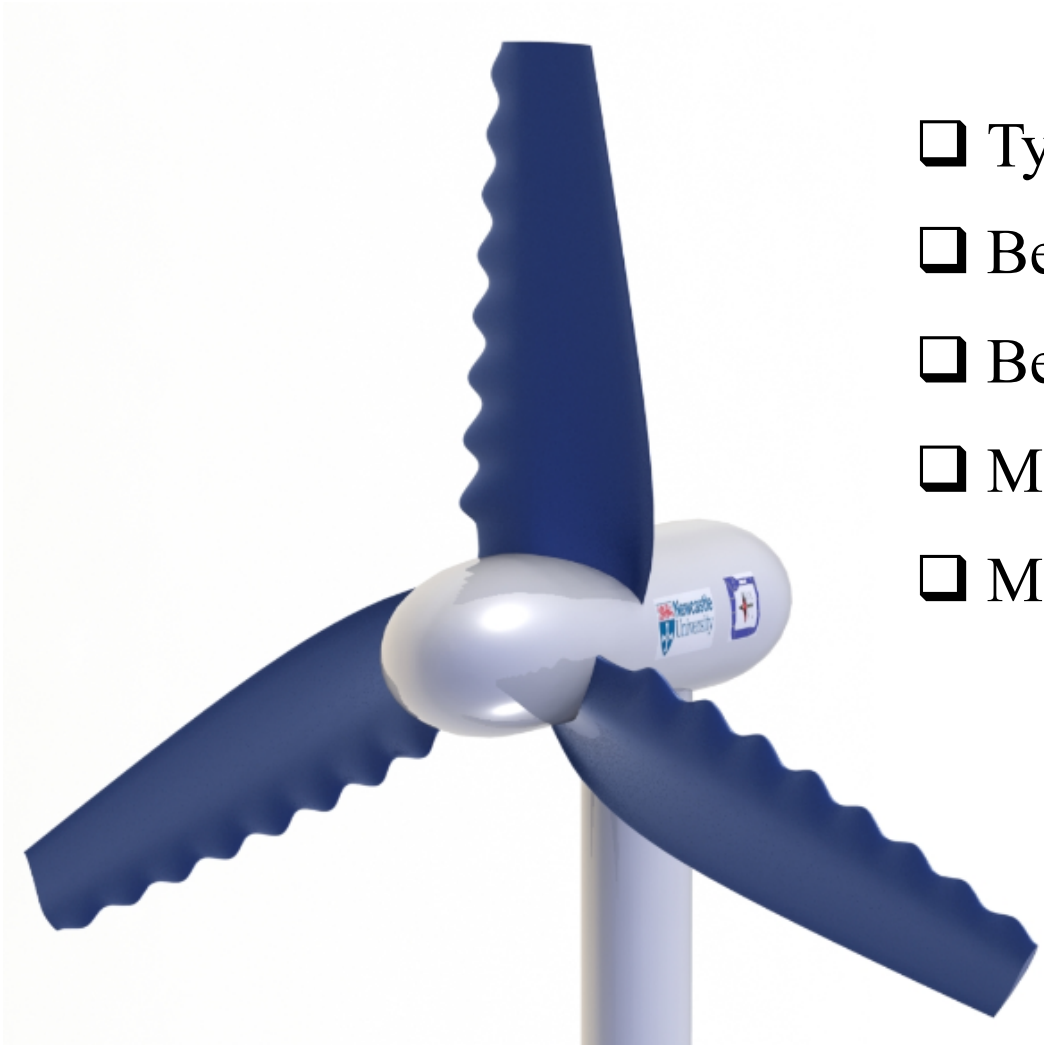


- Open circle: the foil with leading-edge tubercles
- Closed circle: the smooth foil

- Test in wind tunnel by Miklosovic et. al.
  - Increase lift
  - Decrease drag
  - Delay the stall angle

Introduction-Applications of Tubercles

Introduction-Applications of Tubercles



- Typical 3D foil application
- Better efficiency
- Better starting performance
- More economical
- More robust

Aims and Objectives

- **Aims**
  - To explore the **feasibility** of applying biomimetics via leading-edge tubercles to enhance the performance of tidal turbines.

- **Objectives**
  - **Stage I _ Hydrofoil study:** Apply tubercle technology to **hydrofoil** to achieve basic understandings for the tubercles

  - **Stage II _ Tidal Turbine study:** Redesign, optimise and test **turbines** with tubercles

Experiment for a representative hydrofoil

Hydrofoil Based on a Tidal Turbine Blade

- a same chord length distribution
- a constant pitch angle

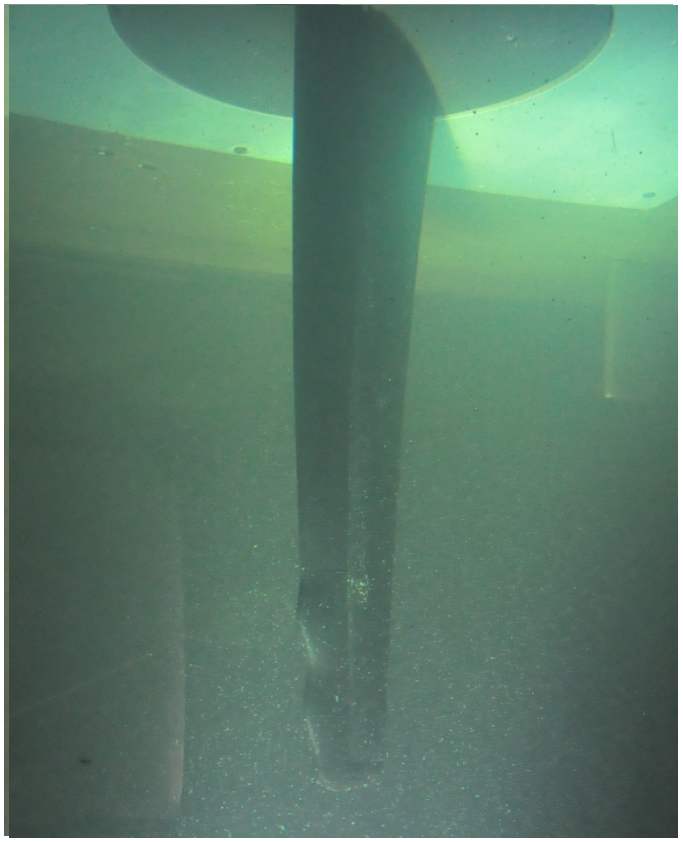
3D printed leading-edge sections

- 4 wavy leading-edge sections
- 4 smooth leading-edge sections

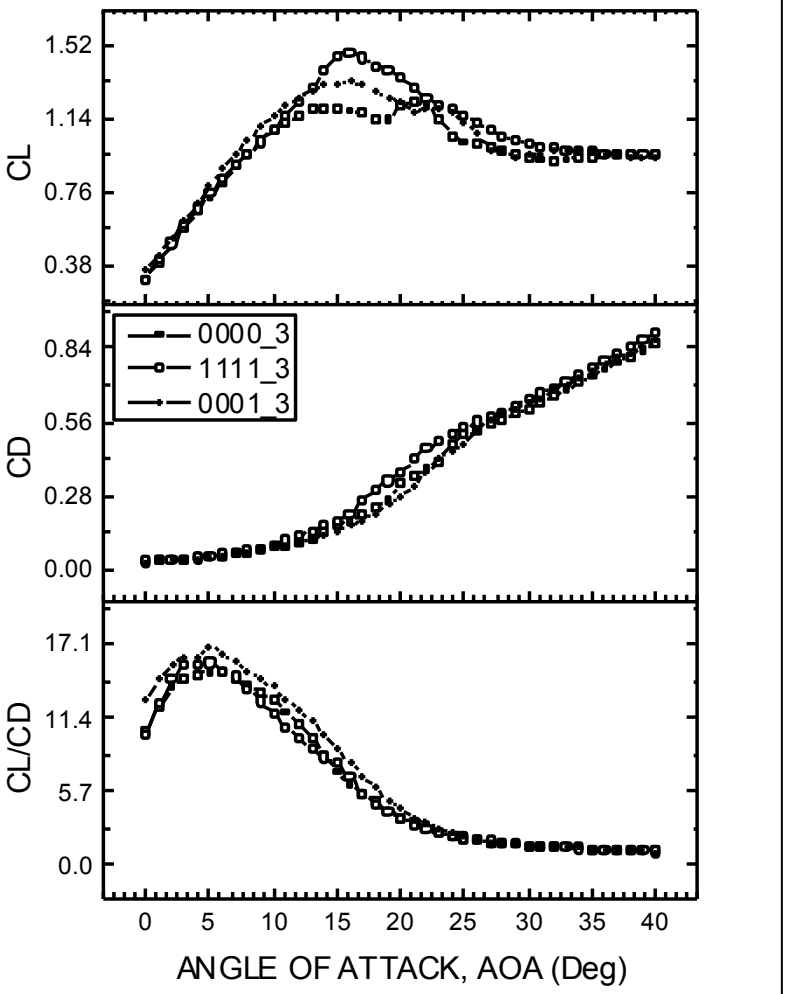
Support base part

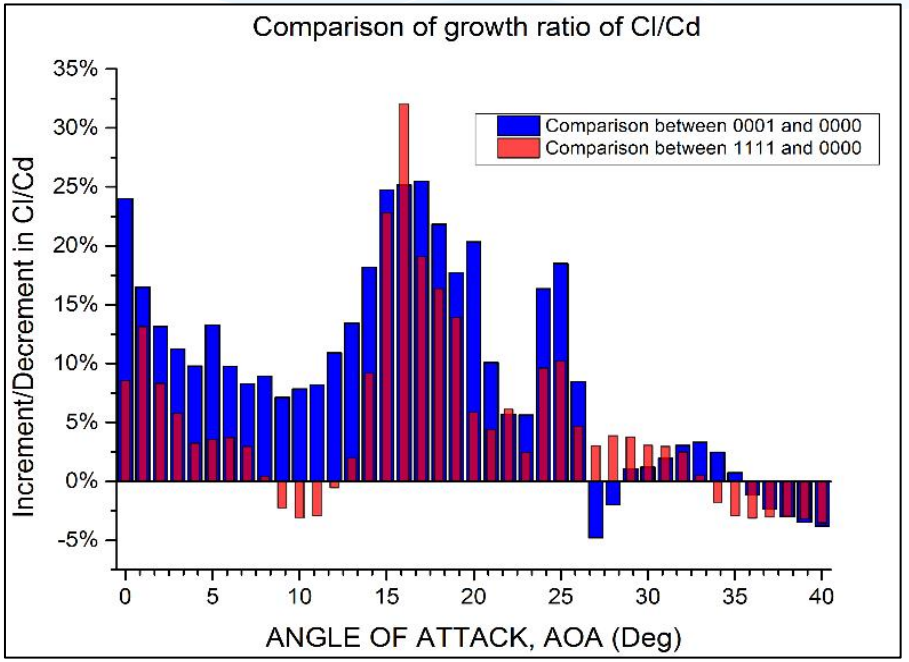
- CNC machined
- Carbon fibre reinforced plastic

Experiment for a representative hydrofoil

Configurations	Labels	Figures
All with smooth leading-edge modules	0000	
All with sinusoidal leading-edge modules	1111	
One smooth leading-edge module at the root and the other three sinusoidal modules	0111	
Two smooth leading-edge modules at the root and the other two sinusoidal modules	0011	
Three smooth leading-edge modules at the root and the other one sinusoidal module	0001	

Experiment for a representative hydrofoil





- The performance of the hydrofoil can be dramatically enhanced by the tubercles
- The lift coefficients were increased greatly
- The drag coefficients were maintained or lowered
- Foil with the shortest tubercle application length (1/4 of the span) at tip region overall displayed the best performance.

Newcastle University

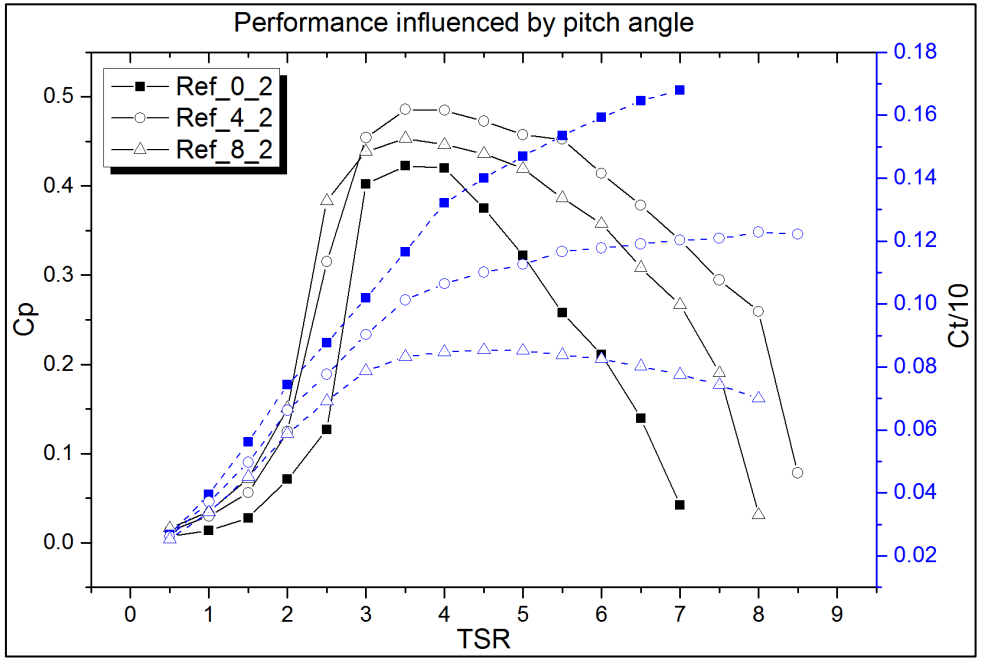
University of Strathclyde Glasgow

Experiment for tidal turbine models

- Three pitch adjustable model tidal turbines are currently under experimental test.
- Hydrodynamic Performance test: power coefficients and drag coefficients can be achieved to evaluate the efficiency of the turbine models.

V	TSR	RPM	Pitch angle	Tunnel pressure	Cav	Re
(m/s)			(°)	(mmhg)	(0.7r)	(0.7r)
2	0.5 ~ 8	47 ~ 763	0	850	48.534 ~ 1.684	0.76E+05 ~ 2.24E+05
2	0.5 ~ 8	47 ~ 763	+4	850	48.534 ~ 1.684	0.76E+05 ~ 2.24E+05
2	0.5 ~ 8	47 ~ 763	+8	850	48.534 ~ 1.684	0.76E+05 ~ 2.24E+05
3	0.5 ~ 8	71 ~ 1145	0	850	21.571 ~ 0.748	1.15E+05 ~ 3.36E+05
3	0.5 ~ 8	71 ~ 1145	+4	850	21.571 ~ 0.748	1.15E+05 ~ 3.36E+05
3	0.5 ~ 8	71 ~ 1145	+8	850	21.571 ~ 0.748	1.15E+05 ~ 3.36E+05
4	0.5 ~ 8	95 ~ 1527	0	850	12.134 ~ 0.421	1.53E+05 ~ 4.48E+05
4	0.5 ~ 8	95 ~ 1527	+4	850	12.134 ~ 0.421	1.53E+05 ~ 4.48E+05
4	0.5 ~ 8	95 ~ 1527	+8	850	12.134 ~ 0.421	1.53E+05 ~ 4.48E+05

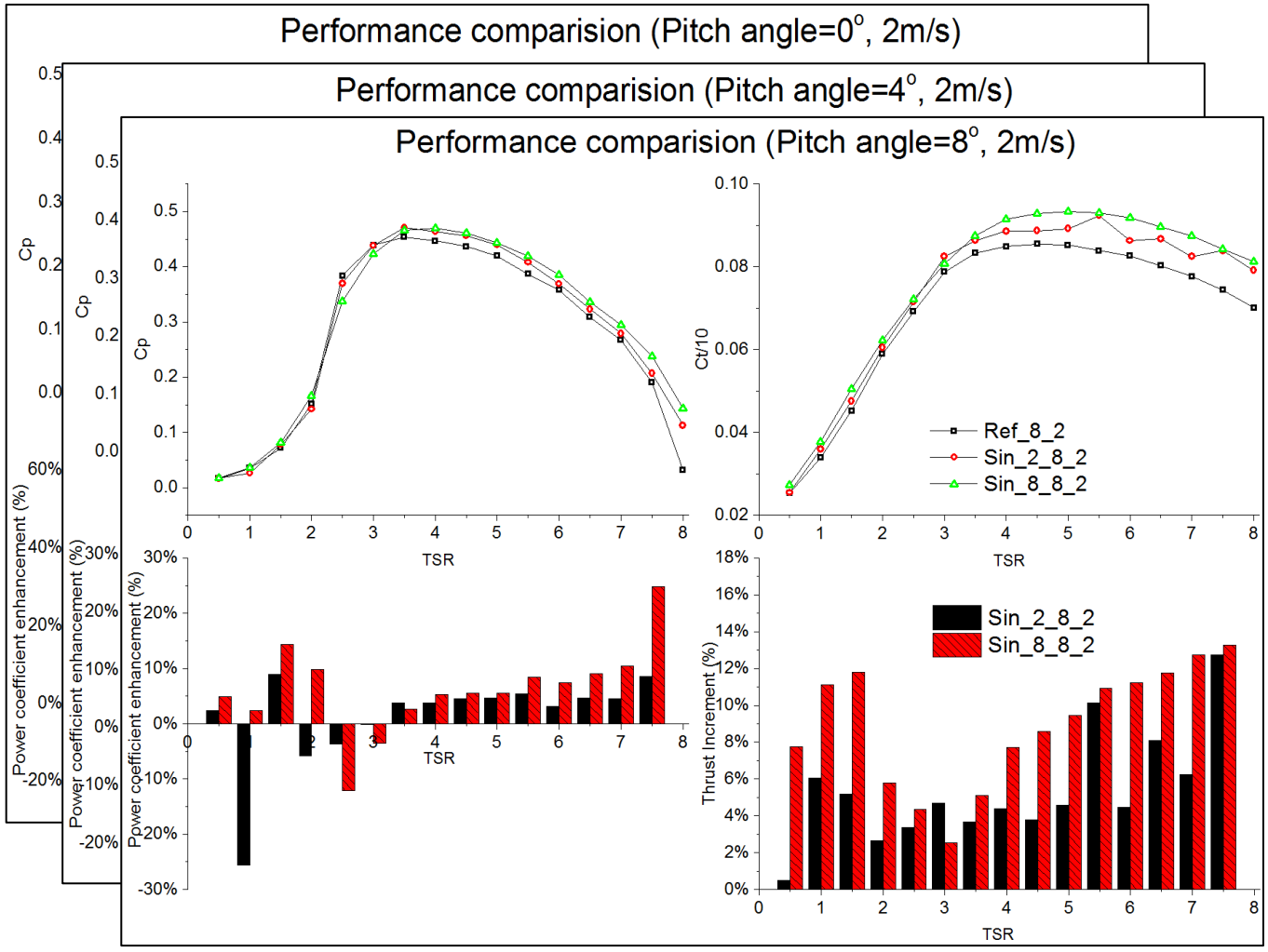
Effect of blade pitch angle



- Three different pitch angles was tested:
  - 0 degree;
  - +4 degree;
  - +8 degree
- Tests under 2m/s
- Reference turbine

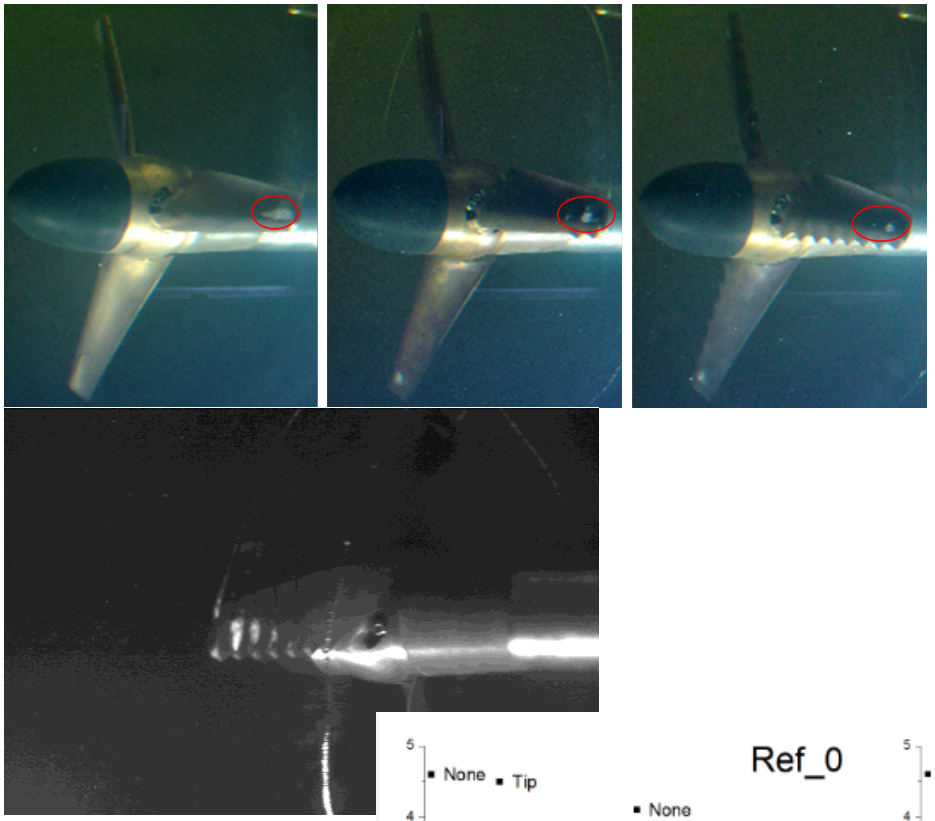
- Based on the test results the reference turbine had the best efficiency over the widest TSR when the blade pitch angle was set to +4°.
- When the blade pitch angle was set to 0° the force on the blade contributed more in the thrust.
- For the case +8° the increased pitch angle resulted in a reduced angle of attack and hence lower thrust force on the turbine but also lower power.

Effect of different leading-edge tubercle profiles

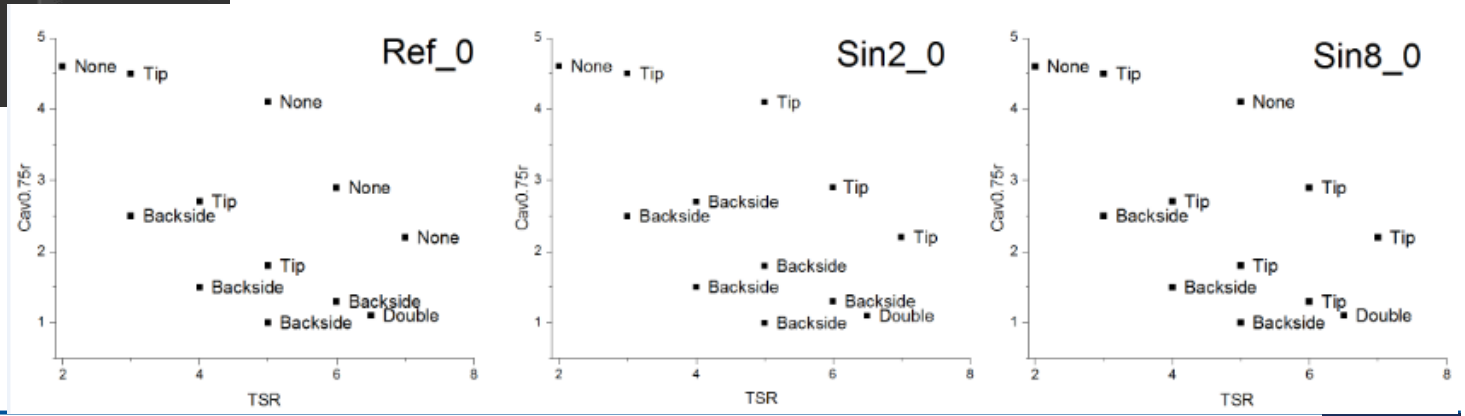


- Leading-edge tubercles can greatly enhance the performance on the lower range of TSRs, while the blade is operating under stall conditions.
- For the lower pitch angles, the improvement caused by the leading-edge tubercles is higher than the one for the higher pitch angle.
- The application of the leading edge tubercle concept does not compromise the maximum power coefficient

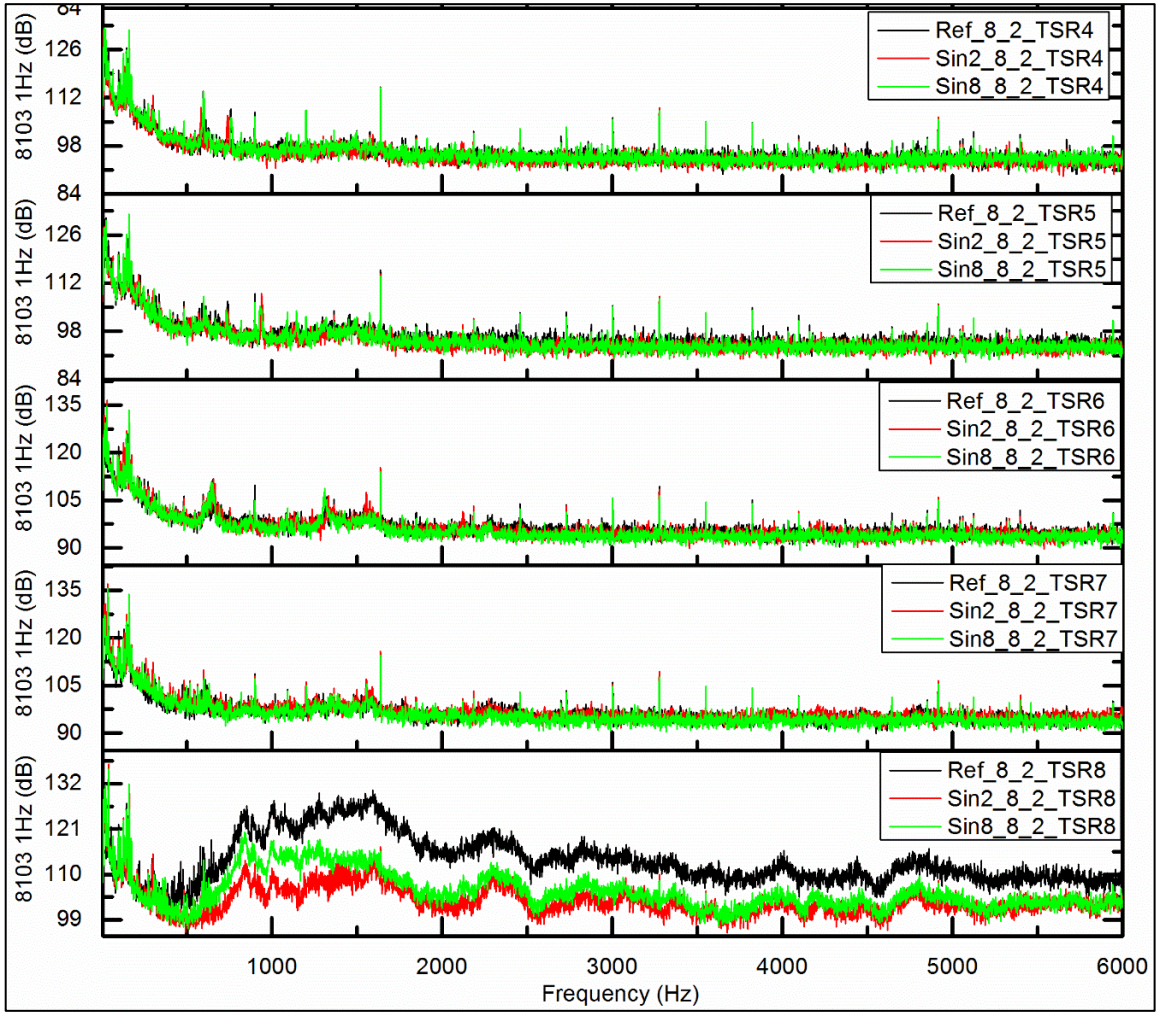
Cavitation observation and Noise measurement



- Effect on cavitation:
  - Limit the cavitation in the crest region
  - Trigger cavitation inception earlier



Cavitation observation and Noise measurement



- Noise level can be lowered down because of the constrained cavitation development during cloud cavitation
- During the normal conditions, the performance is similar to the reference turbine

Conclusions

Hydrofoil study

- Optimisation study for the design of tubercles
- Experimental study on a tidal turbine blade based hydrofoil
- The performance of the hydrofoil can be dramatically enhanced by the tubercles

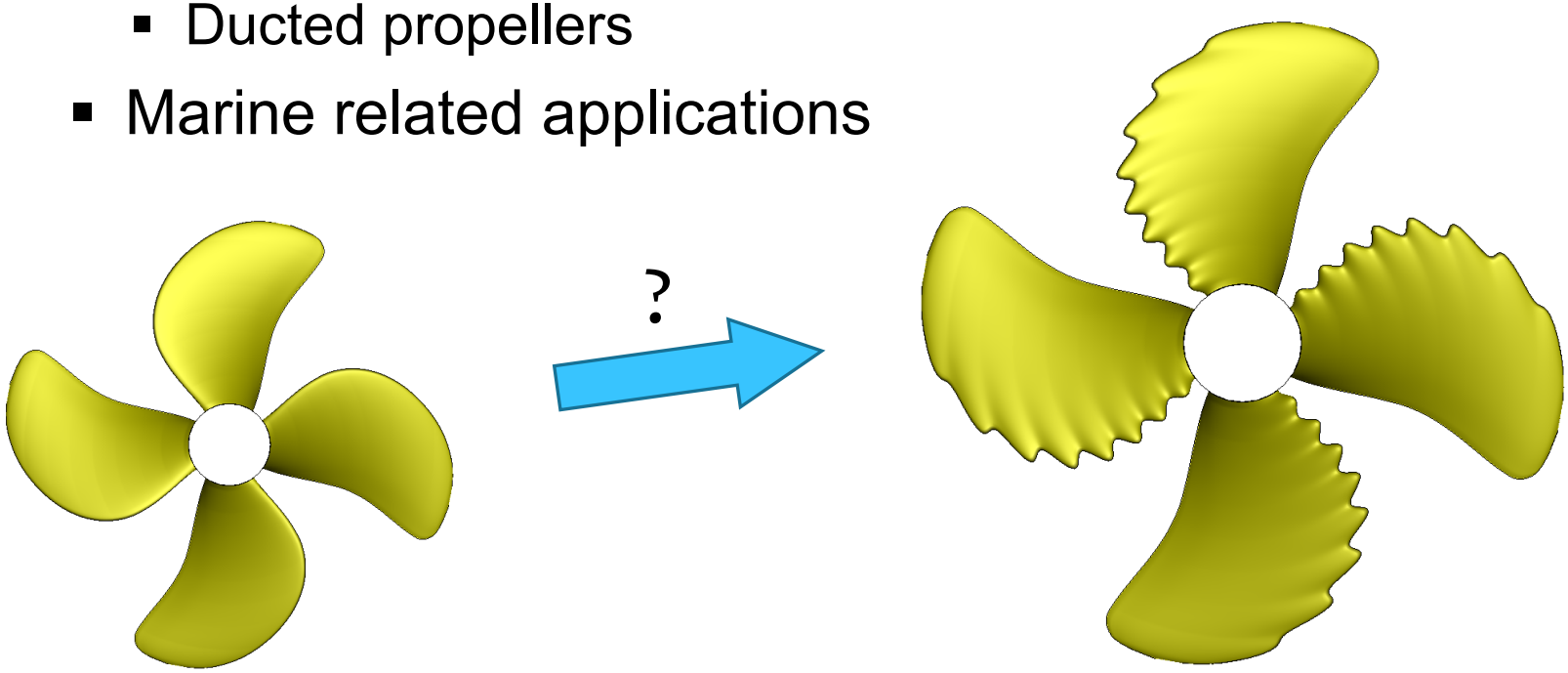
Leading-edge tubercles are very effective!

Tidal turbine study

- The models with the leading-edge tubercles had a better performance in the lower tip speed ratios (TSRs) where the turbine blades were working under the stall conditions.
- The biomimetic concept did not compromise the maximum power coefficient value of the turbine but shifted the distribution of the coefficient over TSR

Future Scope

- Potential application on marine propellers:
  - High speed propellers
  - CPPs
  - Tip loaded propellers
  - Ducted propellers
- Marine related applications



Thank you!
Q&A