Tidal Turbine Blade Design – Outreach Activity

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Project Description

Horizontal axis tidal-stream turbines are becoming increasingly prevalent since the 21st century, given their high energy predictability and low bio-environmental impact especially around the UK. However, tidal turbines experience oceanic gusts. Dynamic fluctuations in flow velocity translate to fluctuating flow angles, which causes changes in the loads on the blades, generator and the pylon.

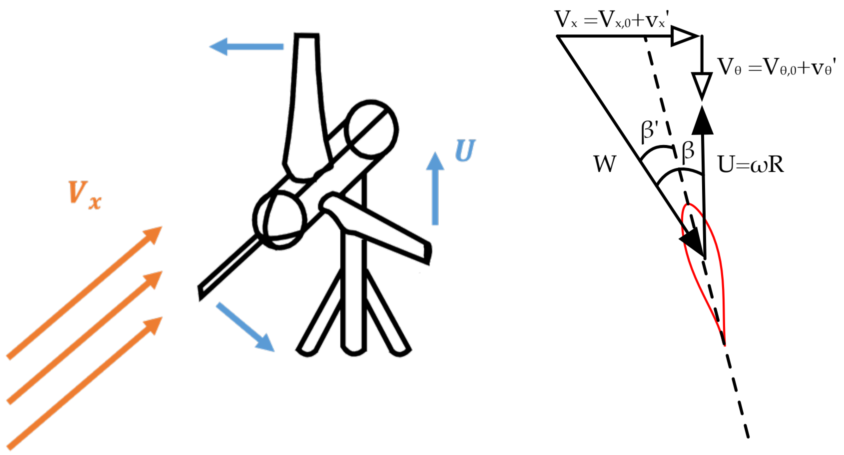


Figure 1: Velocity triangles showing effect of varying incoming streamwise velocity.

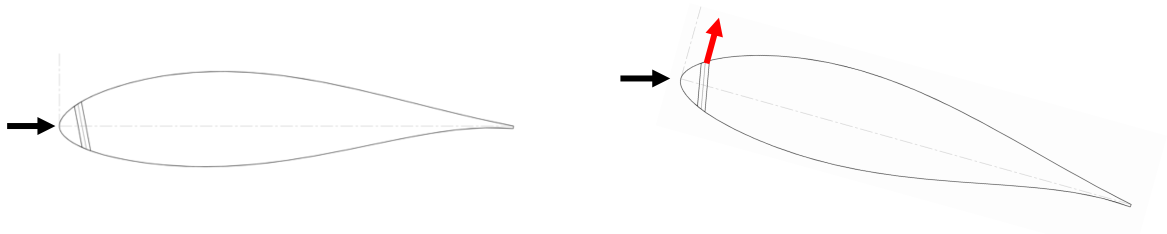
Essentially, the proposed solution implements flow passages around the leading edge of the turbine blade, connecting the suction and pressure surfaces. To verify that this would work, computational methods and experiments were used against a 2D blade section. Further, a parametric study was used to compare and determine the effects of varying each geometric parameter of the design, including the location of the opening, size, and span-wise separation of the passages. Results show that this method is able to provide effective passive flow control to alleviate blade loadings.

Introducing the Activity

For the ease of understanding for the audience, primary load parameters shall be introduced first, explaining the definition of lift and drag forces for a typical aerofoil. Using a printed blade section, geometric locations such as leading edge and trailing edge are introduced. Presenter would then ask the audience to identify the suction and pressure surface of the printed blade, and then provide the reasoning.

Explaining the Objective

If the blade gets more lift, there would be a subsequent increase in torque and thrust. As a result, the tidal turbine spins faster and experiences more backwards bending. To attempt to moderate the additional loading at higher stream-wise velocity, we need to reduce lift response at above-design incidences. Here the actual lift curve shall be optionally shown to the audience, with concepts of stall briefly mentioned.



$P_{SS} \approx P_{PS}$ (No Flow) $P_{SS} < P_{PS}$ (Fluidic Trip Active)

Figure 2: Design of blade passage and effect blade incidences within design range.

The task is to allow some flow to inject into the area around the leading edge of the suction surface. This is a key region whose geometric curvature allows for high lift generation of the blade (this provides hint to participant in subsequent activity). By altering the flow on the suction surface, we effectively reduce lift generation when angle of attack is above a certain threshold, thus achieving previously stated goal.

Lower Order Simulation

Understanding the pressure distribution around the blade is key to get to know how the theory works. For this reason, we ask the participants to deduce the likely low and high(est) pressure points on the blade surface at design incidence. The printed blade showing pressure tapping locations is provided for good visualisation. This introduces the concept of stagnation point on the blade (stagnation pressure).

To encourage participation, a sample test blade may be given to the person correctly identifying the likely position of stagnation point <u>and</u> the point of lowest pressure when <u>blade is positioned at the positive design incidence</u>. A hint may be optionally provided, suggesting the points should be around the front half of the blade.

Connecting the highest to lowest pressure point would thus provide the maximum pressure difference at design incidence, and therefore allows for more mass flow. But this is not necessarily the best solution, since we also need to consider secondary effects, as well as potential benefits if we adjust the geometric parameters of passage.

Higher Order Simulation

This provides a fuller picture of the flow physics. Show participants theory behind the finite volume approach with picture. The computational simulation is effectively defined by how the physics on how the fluid pressure and velocity in the individual cells would change/propagate in time and space. The denser the cells, the higher the resolution we can get. To this end, if we want to more accurately capture the region of complex flow features around and behind the blade, we would need more cells. But having more elements is not necessarily nice, because it would take lots of time. Therefore, we only want denser cells for the regions we want to look more closely at.

Experimental Validation

Experiments are used to validate against simulations. Doing all parametric studies in experiments takes a lot of time. We use simulations to skip ahead results we know.

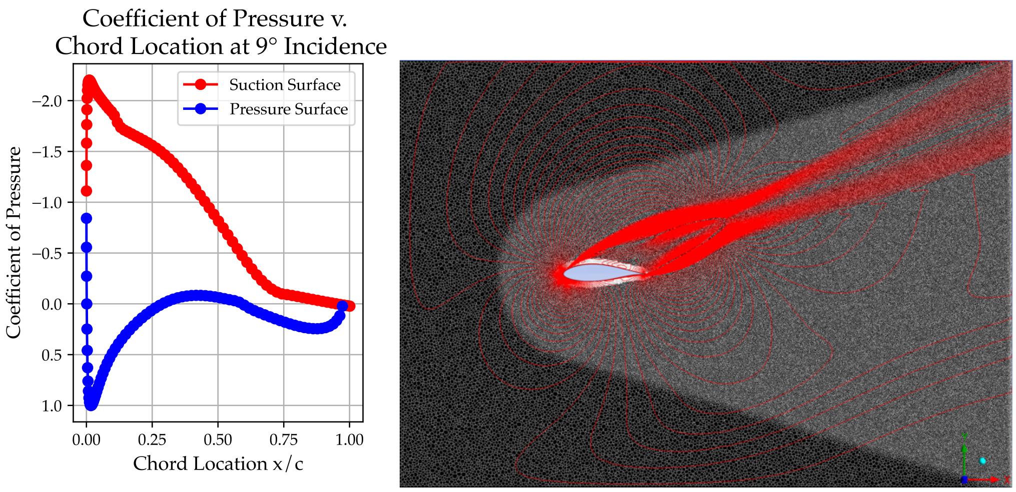


Figure 3: Results from low and high order simulations (left: Xfoil; right: Fluent).

In the actual experiment based in the Whittle Lab in west Cambridge, we used load cells to measure the blade forces and surface tappings around blade for pressure. It is also useful to compare downstream pressure using a traverse. These provided an opportunity to accurately examine the various parameters we are interested in, and our specially designed setup can allow for rapid blade changes for different designs.

In the Dyson Day demonstration, we are more interested in providing a more useful visualisation for the participants. For this reason, a smoke machine is used alongside the Dyson Centre wind tunnel to display the flow around the blades to the audience.

Running the Experiment

The Dyson Centre wind tunnel has a requirement of maximum 10% cross-sectional blockage. Therefore, simplified new blades were printed and assembled for the demonstration on the day. The original blade with hypos attached was left at the Whittle Lab for next student on the project (but can be made available for display).

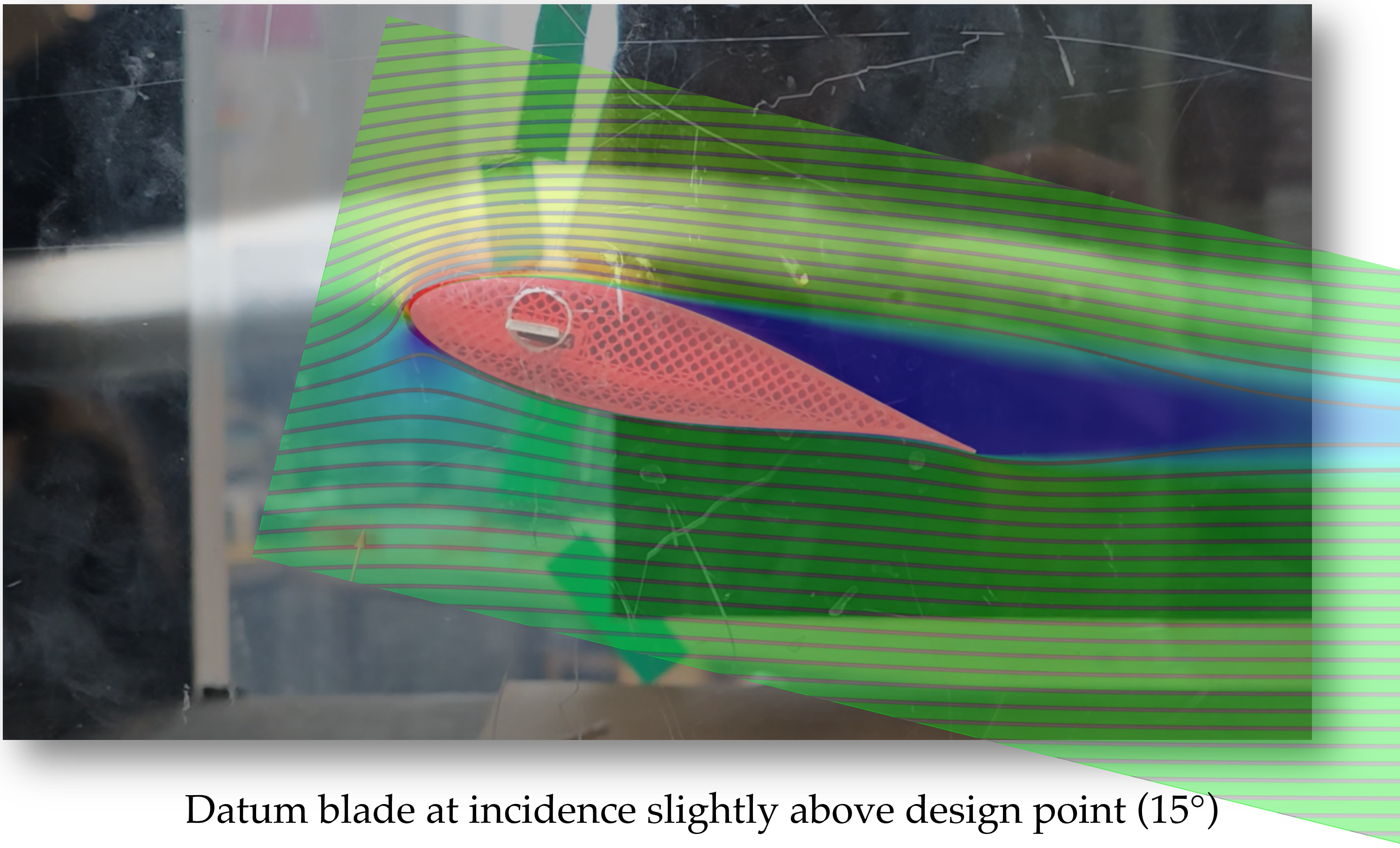
Adaptations have to be made since the tunnel now has a different maximum flow velocity, and the size limitation meant that the passage size and separation would need to be scaled down. Preliminary tests before the demo day indicate reasonably good consistency with the results obtained from the lab without much modification. Due to time constraint, only two tests would be shown with the datum and best case.

A small problem with the setup was that we do not have two tunnels running side-by-side simultaneously. This means it would not be easy for the participant to tell the difference unless they have a photographic memory. To fix this, I additionally took and printed pictures from previous tests before the day. By showing these results when the experiment is run, participants can more easily tell the difference.

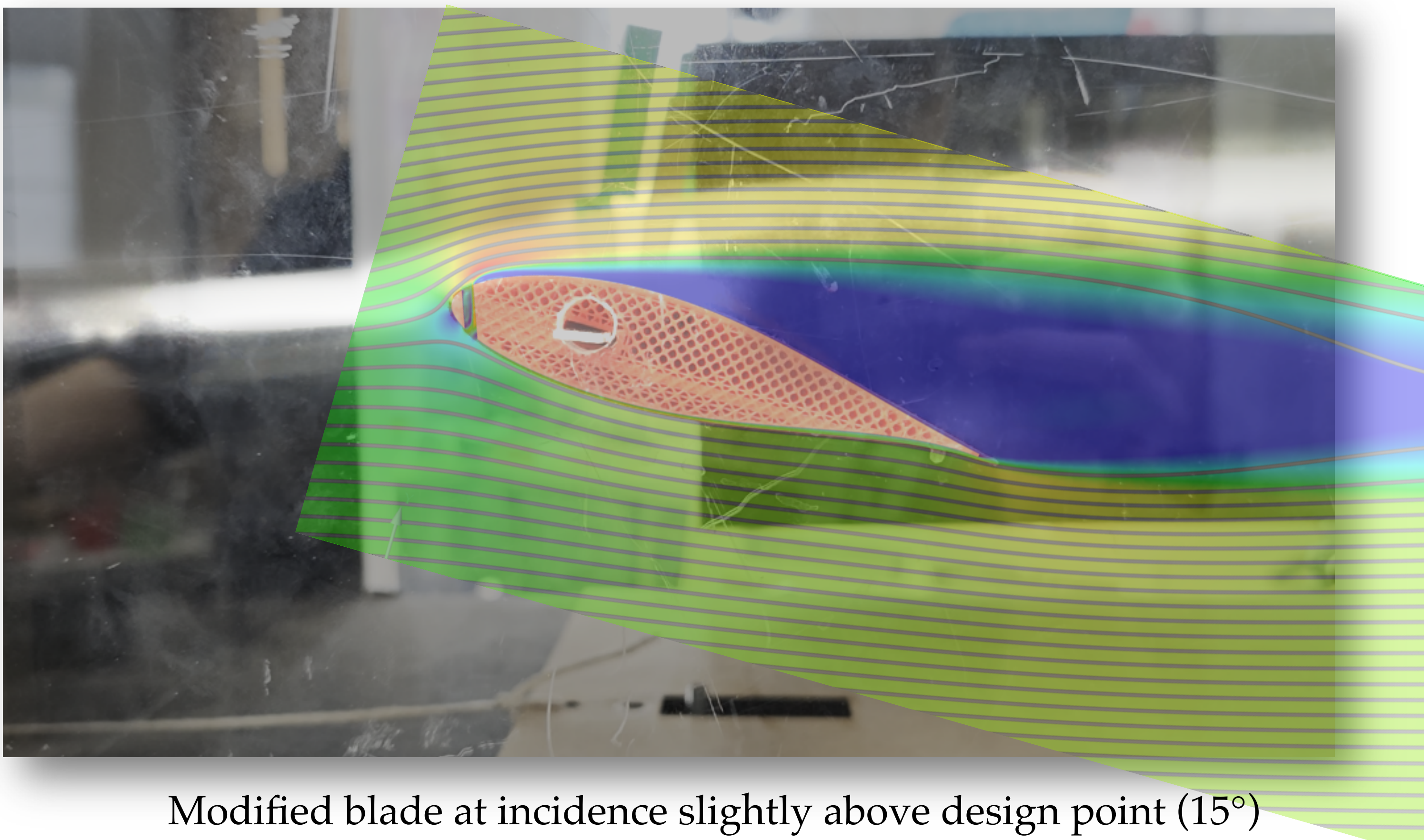
Smoke alarms are equipped in the department. To avoid accidentally trigger alarms during the day, smoke cannot be released when the tunnel is not in operation. Safety assessments were completed prior to the commencement of any tests. The tunnel is unlikely to pose any noise issues provided participants do not stay close to inlet grill. A copy of the distributed handout provided on the day is attached to this document.

Sample of Dyson Day Experiment with CFD Overlay

Results Produced by Stephen



Datum blade at incidence slightly above design point (15°)



Modified blade at incidence slightly above design point (15°)

* CFD performed under slightly different conditions, consistent with the original project rather than the later experiments in the Dyson Centre wind tunnel. Results are largely transferrable.