Assignment 3: Blade Optimisation

Introduction and Context

In Dr Sam Bull's lecture series, and accompanying notes, he has outlined the principles of Blade Element Momentum Theory (BEMT). In this assignment, you will be using this branch of physics to design 'optimal' wind turbine blade geometries. After you have modelled these blades and convinced yourself that you have an optimal set, they will be manufactured via additive manufacturing (3D printing). You will **not** have to manufacture your own blades, but you will have to supply the CAD files that will be used for printing. For your assessment, you will join Drs Bull and Flynn on a Zoom call where we will showcase your blades operating on the 'Big Rig' wind turbine. After the demonstration, you will deliver a 15 minute presentation and there will be a Q&A session to follow. Remember, this assignment (blade design, manufacture, demonstration and presentation) represents 40% of the mark for this course.

Part 1 of the Assignment: Build Your MATLAB Model

You will need to create at least one MATLAB script. This MATLAB script will take the following inputs as a minimum (use more if you wish):

i. the number of blades on your rotor,
ii. the tip-speed ratio that you are designing for,
iii. the distribution of chord lengths, from root to tip, which may be a linear transition or something more complex, if you prefer, and
iv. the distribution of the angle, γ, from root to tip, which may be a linear transition or something more complex, if you prefer.

There are several assumptions that we require you to make as part of this assignment. Please ensure that all these assumptions are upheld in your model.

i. **The rotor must rotate clockwise from the point of view of facing the wind turbine when you are stood between it and the fan.**
ii. The maximum number of blades is three
iii. The velocity of the free stream (wind from the fan) is 3 m/s
iv. The maximum rotor radius is 500 mm
v. The maximum chord length at any cross-section of the blade is 200 mm
vi. Your first aerofoil section must start no sooner than 120 mm from the axis of rotation. If it is any less, you will not be able to interface with the provided connector that attaches your blades to the rotor
vii. The kinematic viscosity of the air is set at 15.06×10^{-6}
viii. The density of air can be taken as 1.225 kg/m³
ix. It is perfectly acceptable to ignore drag in this assignment (hence, a CD of zero), but this can be added as an extension exercise if you have time. Please note that top marks can still be achieved without this addition.

Part 2 of the Assignment: Optimisation

Now that you have built your model, you have everything you need to begin your optimisation. The variables at your disposal are:

i. Tip-speed ratio
ii. Chord distribution along the blade
iii. γ-angle distribution along the blade
iv. The number of blades in your rotor
v. The radius of your rotor, up to a maximum of 500 mm
vi. You will be given data for CL and CD at different Reynolds numbers for the S822 aerofoil (some initial information here: http://airfoiltools.com/airfoil/details?airfoil=s822-nr). However, some may decide to choose a different aerofoil profile. In this case, you will need to build your own database for CL and CD at different Reynolds numbers. This can be time consuming and will require you to use a new piece of software, called XFoil. Dr Flynn can help you here. Please only consider this additional parameter if you think you have a couple of days of spare time!

From this, it should be clear that there is quite a lot of variables. You may wish to deploy some of the techniques from Assignment 1 to help you navigate this space more efficiently.

Some Early Warnings and an Indication of Extra Support

The following serve as some early warnings. Please consider these carefully and speak to the support staff at a time that suits you.

- Check that you have arranged your aerofoils in a configuration that will produce clockwise rotation. A member of support staff can help you here.
- If you choose a high tip-speed ratio, you are assuming that your rotor will be spinning at a higher RPM. This will mean that most of the blade is almost perpendicular to the free-stream (wind from the fan). In this case, the rotor will be very difficult to start and will almost certainly not start itself. To see if your rotor will self-start you will want to check that you can produce torque at very low RPM values. This will mean some of your blade, near the root, should be closer to, say, a 40-60 degree γ-angle.
- Joe will be showing you how to extract blade geometry from your MATLAB model and then import this into CAD to save you doing lots of tedious drawing
- Joe will show you how to create a look-up table for CL (and possibly CD) based on a given Reynolds number and the supplied database.
- Please use the Zoom one-to-one meetings to help you overcome some of the challenges you are facing.

Part 3 of the Assignment: Demonstration, Presentation and Q&A

You must prepare a presentation that describes your entire blade optimisation journey. This does not need to cover the material in Assignments 1 and 2 unless this is directly relevant. You will be asked questions to check your understanding of your model and related activities. You will also be expected to defend your claim of optimality. A small part of the mark scheme will be dedicated to the visual and verbal quality of your presentation.