Loughborough University

WIND POWER
22WSD534

Semester 1 2022 In-Person Exam paper

This examination is to take place in-person at a central University venue under exam conditions. The standard length of time for this paper is **2 hours**.

You will not be able to leave the exam hall for the first 30 or final 15 minutes of your exam. Your invigilator will collect your exam paper when you have finished.

Help during the exam

Invigilators are not able to answer queries about the content of your exam paper. Instead, please make a note of your query in your answer script to be considered during the marking process.

If you feel unwell, please raise your hand so that an invigilator can assist you.

You may use a calculator for this exam. It must comply with the University's Calculator Policy for In-Person exams, in particular that it must not be able to transmit or receive information (e.g. mobile devices and smart watches are **not** allowed).

Loughborough University

WIND POWER

(22WSD534)

January 2023 | 2 Hours

Answer **ALL FOUR** questions.

Each question carries a total of 25 marks.

Any university-approved calculator is permitted.

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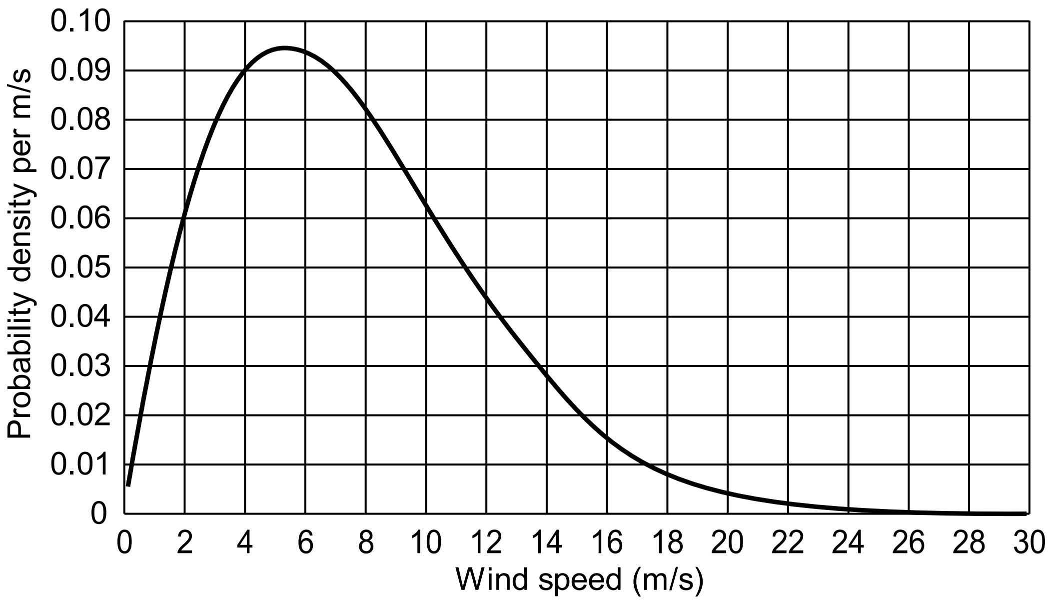
1. The figure below shows a Weibull distribution.



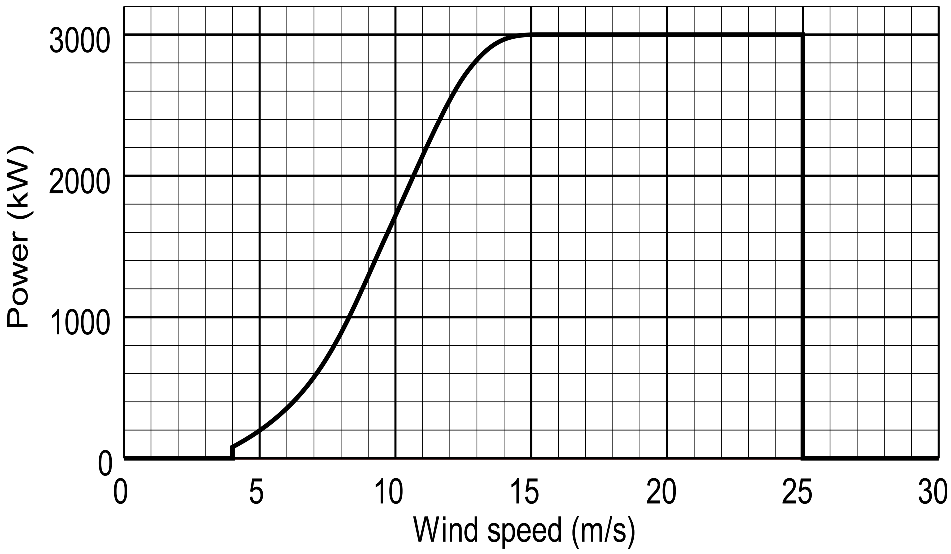
a) For how many hours per year is the wind between 6 m/s and 8 m/s? [3 marks]

b) The wind speeds of part a) are at 30 metres height. Convert the 6 m/s and 8 m/s to 80 metres height, using the log law

$$u(z) = u(z_\mathrm{r})\frac{\ln(z/z_0)}{\ln(z_r/z_0)}$$

with a surface roughness length of 0.5 metres. [3 marks]

c) Use the power curve below to estimate the annual energy electricity yield for the hours identified in part a). [4 marks]

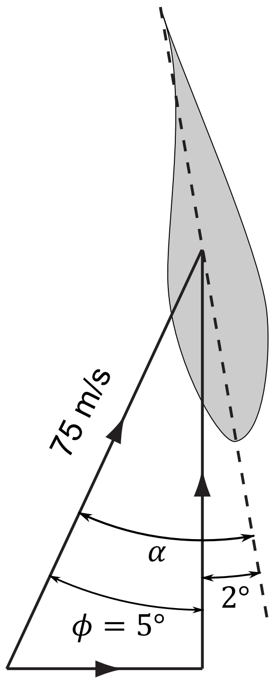


d) Combination of the whole of the Weibull distribution with the whole of the turbine power curve provides a first estimate of electricity yield.

List reasons that the electrical energy actually exported to the grid may differ. [15 marks]

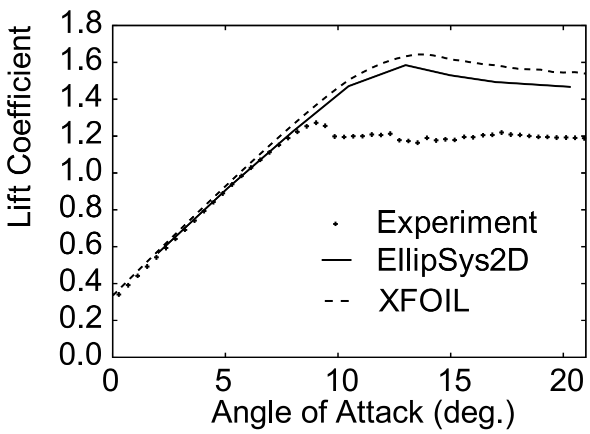
2.

a) A 15 MW turbine is operating at 7.4 rpm. The profile of a blade at 96 metres radius is shown below, along with graphs of its lift and drag coefficients.

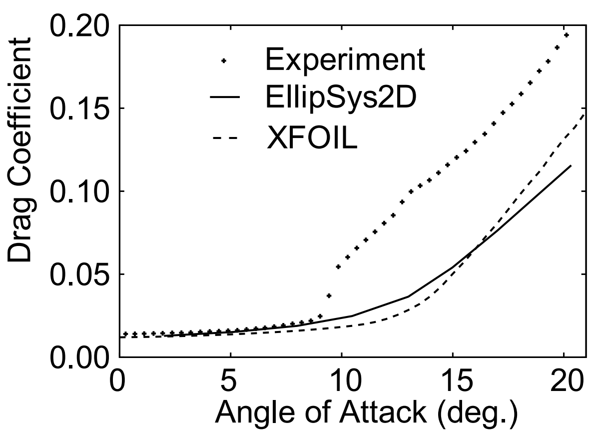


Chord = 2.76 metres

Angles are increased in the drawing, for clarity.



$$C_L = \frac{lift}{\frac{1}{2}\rho U^2 A} = \frac{lift\,/\,unit\ span}{\frac{1}{2}\rho U^2 c}$$



$$C_d = \frac{drag}{\frac{1}{2}\rho U^2 A} = \frac{drag\,/\,unit\ span}{\frac{1}{2}\rho U^2 c}$$

/continued

Air density may be taken as $\rho = 1.225\ \mathrm{kgm^{-3}}$

The thrust on an annular ring containing elements of N blades is

$$\delta T = (\delta L \cos\phi + \delta D \sin\phi) \times N$$

The torque on an annular ring containing elements of N blades is

$$\delta Q = (\delta L \sin\phi - \delta D \cos\phi) \times N \times r$$

i. State the angle of attack in degrees. [1 mark]

ii. Estimate the lift and drag coefficients from the graphs. [2 marks]

iii. Estimate the lift and drag forces on a blade element from 95 m to 97 m radius. [6 marks]

iv. Estimate the thrust, torque and power due to that ***one*** blade element. [8 marks]

b) The Betz limit is given by:

$$C_\mathrm{P} = \frac{\textit{power}}{\frac{1}{2}\rho U_\infty^3 A_\mathrm{D}} = \frac{2\rho A_\mathrm{D} U_\infty^3 a(1-a)^2}{\frac{1}{2}\rho U_\infty^3 A_\mathrm{D}} = 4a(1-a)^2$$

which has a maximum at $a = \frac{1}{3}$ giving $C_{\mathrm{P\,max}} = \frac{16}{27}$

Account for the other 11/27. [8 marks]

Hint: The 11/27 may be accounted for in more than one place.

Also: The mass flow rate remains constant all along the streamtube and so $\rho A_\infty U_\infty = \rho A_\mathrm{D} U_\mathrm{D} = \rho A_\mathrm{W} U_\mathrm{W}$

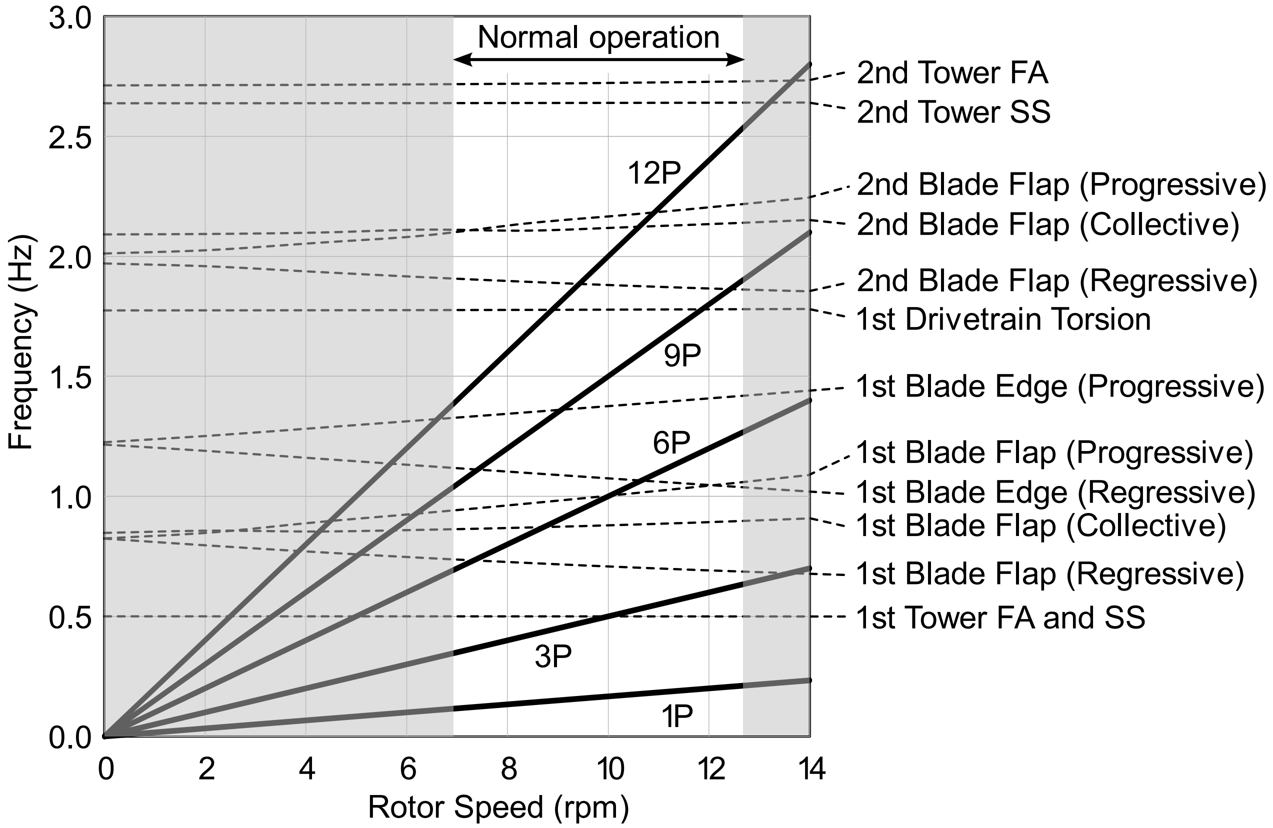
3.

a) Variable speed wind turbines require power-electronic converters, which are expensive.

i. Fully explain the ***main*** benefit provided by variable speed. [10 marks]

ii. Briefly explain a secondary benefit. [5 marks]

b) The Campbell diagram below suggests there may be a problem with the design of a large wind turbine.



i. Identify and fully explain the possible problem. [5 marks]

ii. Suggest how the problem might be mitigated, making reference to the concepts of "soft" and "soft-soft". [5 marks]

4.

a) Explain how ice can be a safety concern with wind turbines and how the risk can be managed. [8 marks]

b) Explain what is meant by shadow flicker, and describe how it can be managed during both the design and operational phases of a wind farm. [8 marks]

c) Explain why detailed and accurate knowledge of the seabed is critical to the financial success of an offshore wind farm development. [9 marks]

Murray Thomson
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