Loughborough University

Wind Power

23WSP034

Semester 1 23/24 | In-Person Exam Paper

Please fill in:

Student ID Number:		Desk Number:	

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.

Use of a calculator is permitted - 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).

Answer **ALL FOUR** questions.

Each question carries a total of 25 marks.

Write your answers in the spaces provided below each question part.

Do all rough work in this book.

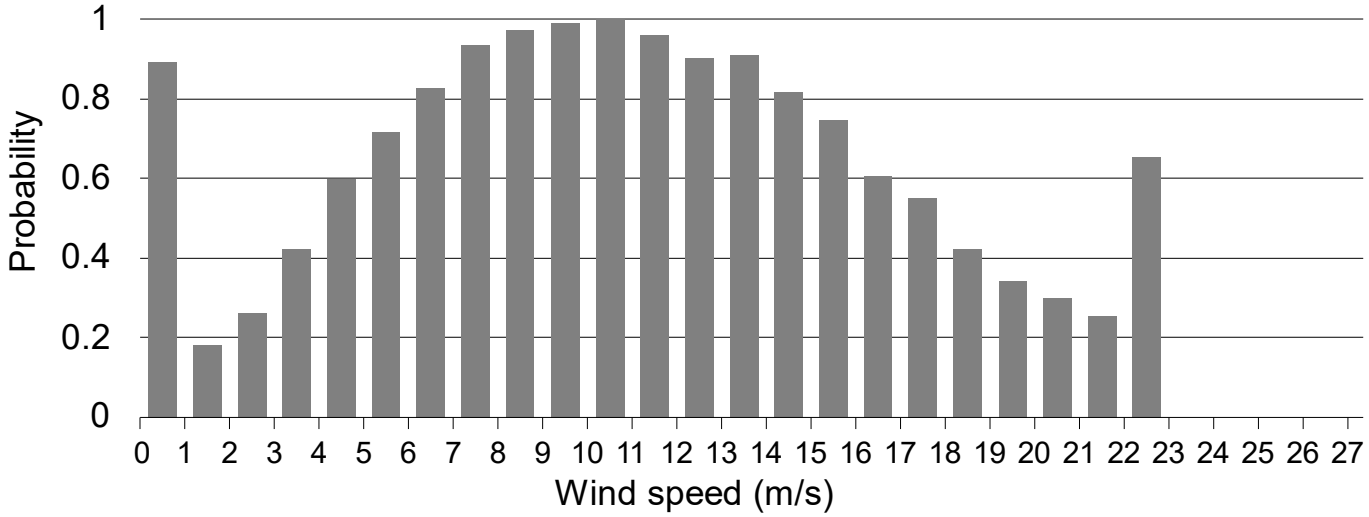
Additional space is provided at the back of this book if you need it.

1.

a) The distribution plot below is based on measured ten-minute average wind speeds.

It is intended to show the probability of the wind speed being within each bin.

The bins are: $0\ \mathrm{m/s} \leq U < 1\ \mathrm{m/s}$, $1\ \mathrm{m/s} \leq U < 2\ \mathrm{m/s}$, etc.



Identify **three** problems with the data or the way it has been plotted. For **each** problem, suggest a likely cause and say how you could workaround that problem so as to improve the plot, ready for an estimate of electricity yield based on this plot. (You have no access to the original data nor time to take more measurements.) [12 marks]

/continued

Continue your answer to question 1.a)

/continued

b) A floating lidar costs in the order of £1 million.

i. At what stage, in a project development timeline, would a floating lidar typically be used on-site? [4 marks]

ii. Describe the information a lidar can provide, and how this differs from that given by conventional technologies. [6 marks]

/continued

iii. A wind farm developer says a floating lidar can “pay for itself”.
Explain what they mean. [3 marks]

/continued

2.

a) The power coefficient for a wind turbine can be expressed as:

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

State in words the meanings of the numerator and the denominator in this equation. There are no marks for stating the meanings of the individual symbols. [4 marks]

b) State the theoretical maximum of C_{P} and explain why a turbine designer may not seek to reach this limit. [4 marks]

/continued

c) The diagram on the page 8 shows a section (element) of a wind turbine blade that is moving downwards, with the wind approaching from the left.

- Undisturbed upstream wind speed: 8 m/s
- Axial induction factor: 0.25
- Rotational speed: 9 rpm
- Radius of this section: 30 m
- Tangential flow induction factor: 0 (neglect)

Calculate the following **and indicate them on the diagram**. [7 marks]

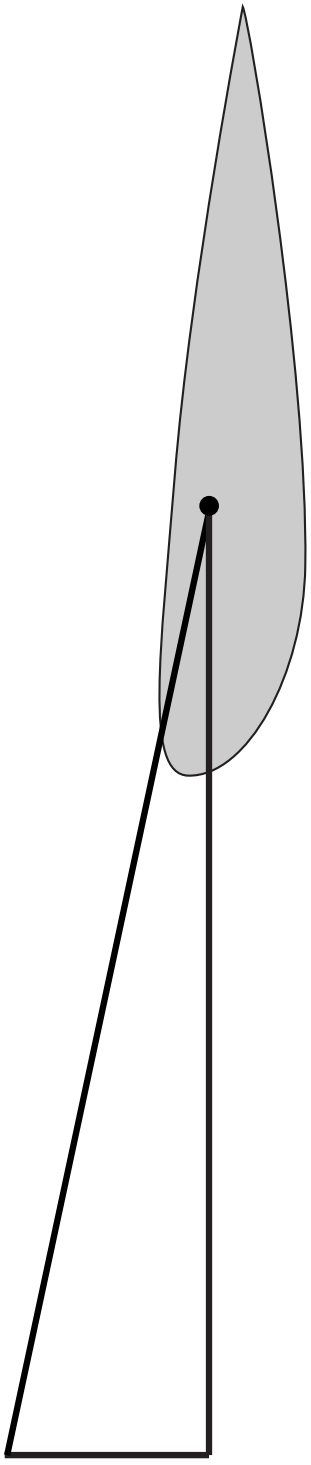
i. The axial wind speed through the disc U_{D}.

ii. The tangential velocity of this blade element.

iii. The resultant flow speed W with respect to the blade.

iv. The direction ϕ of this flow with respect to the plane of rotation, giving your answer in degrees.

/continued



/continued

d) With the same rotational speed of 9 rpm,
but now at a radius of 36 m,
the resultant flow speed W is 34.4 m/s
and the flow angle ϕ is 10°.

The chord of the blade is 1.3 m and is at 2° from the plane of rotation, as shown in the diagram on page 10.

The air density may be taken as 1.225 kgm^{-3}.

The characteristics of the aerofoil are:

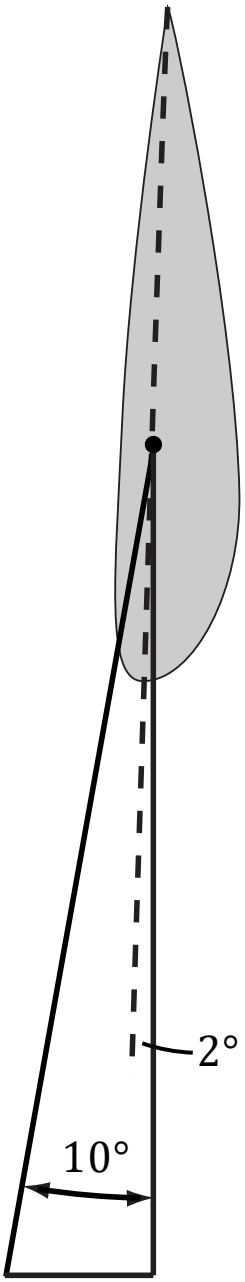
Angle of attack	C_{L}	C_{d}
0°	0.4	0.016
2°	0.6	0.017
4°	0.8	0.018
6°	1.0	0.019
8°	1.2	0.020
10°	1.4	0.022
12°	1.5	0.034
14°	1.5	0.048

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

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

Estimate the lift and drag forces per unit span and indicate them on the diagram on page 10. [5 marks]

/continued


2°
10°

e) Indicate the tangential force on the above diagram and calculate the torque per unit span. [3 marks]

f) Calculate the power per unit span, assuming the rotor has 3 blades. [2 marks]

/continued

3.

a) Considering a typical horizontal-axis wind turbine with a high-speed generator, list the bearings that need to withstand the thrust forces, stating where those bearings are located (or draw them if you prefer). [5 marks]

/continued

b) Explain how pre-cone and pre-bend can improve the recyclability of a wind turbine. [5 marks]

/continued

c) Explain the purpose of a Campbell diagram in wind turbine design and why meeting its requirements is more challenging for a variable-speed turbine than fixed-speed. [5 marks]

/continued

d) Explain how the fast control offered by power electronics can make up for the slow control offered by a pitch mechanism. [10 marks]

/continued

Continue your answer to question 3.d)

/continued

4.

a) Describe two different techniques that can be implemented within the controller of a wind turbine to reduce its environmental impact and so improve its acceptability to the planning permission authorities. [10 marks]

/continued

Continue your answer to question 4.a)

/continued

b) Explain the benefits and challenges presented by monopile foundations, compared to other types of support structures for offshore wind turbines. [8 marks]

/continued

c) The UK government has supported the development of offshore wind farms via its Contracts for Difference (CfD) Allocation Rounds.

Describe how a CfD works and its effect on investment risk. [7 marks]

End of questions

Murray Thomson
Tom Betts

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If you write any answers on this page, please indicate the question numbers clearly.

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