Wind Energy Notes

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[1-4]

Contents

1 Wind Energy (CEJ01)

1.1 Characteristics of the Wind

- The random variable of interest is wind speed (u) as this is the main determinant in power output.

1.2 Turbulence

- **Turbulence can be thought of as random wind speed fluctuations imposed on mean wind speed.**
- Fluctuations occur in the direction of the wind (longitudinal), perpendicular to the wind and vertical.
- The mean wind speed may be constant over relatively longer time periods.

The winds variability is characterized by a few statistical properties.

- Turbulence Intensity
- Power spectral density function
- Wind speed probability density functions
- Autocorrelation

1.3 Weibull Distribution

- Wind speed variations is well characterized by the Weibull distribution.
- Density vs distribution function?
  - Density function provides a relative likelihood for the random variable to take on the supplied value.
  - I think here, the distribution function is saying, the relative probability that the random variable will be less than or equal the supplied parameter.

1.4 Rayleigh Distribution

- A special case of the Weibull distribution.
- Has a higher k value (a shape parameter for Weibull distribution).
- A lower k value indicates greater deviation around the mean wind speed.

1.5 Correlation and Covariance

- The deviation of random variables from their expected values.
- Covariance is the measure of joint variability of two random variables.

1.6 Autocorrelation

probably need to go over this again

- Provide information on what wind speed is likely to be.
- Similarity of a random variable between observations.
- Used to find repeating patterns.

1.7 Power Spectral Density Function

- The wind speed is treated as a 'signal' through time. With time on the x axis and wind speed on the y.
- To determine how speed is changing through time it's assumed that this 'signal' wave is a composite of lots of waves that cause variation to the mean wave.
- A spectrum, using Fourier analysis, is used to determine power across frequencies.
- The integral across all frequencies is equal to the total variance.
- The power spectral density function gives the energy distribution of the wind over different frequencies.
- When this function is unknown, known general functions can be used.

1.8 Height variation on wind speed

- This variation is know as the *vertical profile of the wind* or *wind shear*.
- Important to determine for lifetime of rotor and productivity of turbine.
- Falls under two models, Power law and the log law (from fluid mechanics).
- Subject to uncertainty.

1.9 Power Available

- $P = \frac{1}{2}\rho A v^3$.
- Wind speed doubling will generate 8 times the power.
- This equation tells us that wind turbines will keep getting bigger.

Wind speed (m/s)	Power/Area (W/m²)
0	0
5	80
10	610
15	2,070
20	4,900
25	9,560
30	16,550

- C_p is the ratio between the actual power obtained and the maximum available power.
- The *Betz limit* is the theoretical maximum at 59.3%.

1.10 Power Curve

- The speed at which the blades will start to rotate is called the *cut in* speed.
- The power output rises with wind speed until it hits a rated power output which is the limit of the electrical generator.
- Cut out power involves breaking the system to reduce power.

1.11 Betz Limit

- The simplest model of turbine is actuator disk model.
- The turbine modelled as a circular disc through which air flows with velocity $\vec{v_t}$ with a pressure drop from P_1 to P_2.
- I'm not going to go through derivation yet. Just going to try get some exposure to it first.
- One interesting thing, power is $1/2 \cdot mv^2$ because $\cdot m$ here is the mass flow rate.
- Using mass flow equations to derive what power is for the simple actuator model.
- Efficiency can vary with the ratio of upstream (before the turbine) and downstream (after the turbine) velocity.
- Can think of it as extracting energy from a specified volume of air moving like an object towards the turbine.

- Turbines do not achieve the Betz limit for several reasons: rotation of wake behind rotor, finite number of blades (tip losses), non-zero aerodynamic drag.
- The ratio between the speed of the blade tip v_{tip} and the wind speed v_0 is called the tip speed ratio.
- To capture max power tip speed ratio to Cp curve should be kept at a maximum.

2 Aerodynamics of Wind Turbines

- More generally, I think this a term represents the dampening factor that the turbine has on the air flow through it.
- The mass flow rate of the air is constant. When the rotor disk causes this flow velocity to slow it's area after the rotor must increase.
- There's a decrease in Kinetic Energy, a reduction in speed of the mass flow of the air. This causes an increase in pressure as the lost of KE is transferred to energy in the volume of air.
- There is a drop in this pressure as it passes through the rotor disk(?).
- Interesting question: Why not have drag based turbines? So, the rotors would be parallel to the wind?

2.1 Actuator Disk Model

- What happens to the kinetic energy that the turbine extracts. It may be put to useful work but some of it will be returned to the airflow and dissipated as heat.
- It's assumed that the actuator disc (which is just a circular area?) induces a velocity variation on the free stream velocity.
- The force on the wind turbine is due to the **change in momentum** of the mass flow.

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2.2 $F = \dot{m}v$

- Skipping derivation of force exerted on the air.
- $F = 2\rho A_d U_{infty}^2 a(1-a)$
- Ultimately, the force on the actuator disk is due to the **pressure drop** across it.
- Power is then the rate of work done (FU_d)

2.3 Rotor Disc Theory

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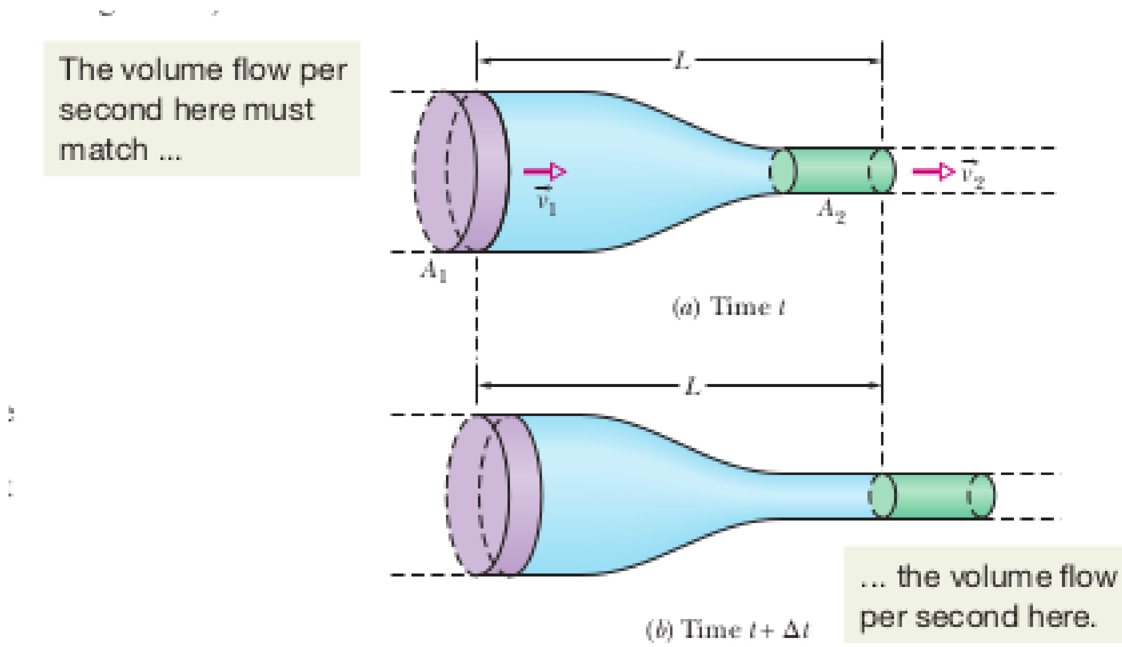

Figure 1: '—-'

2.4 Due to the rotation of the blades, incoming air gains angular momentum, a rotational component.

- An *airfoil* is a streamlined shape that is capable of generating significantly more lift than drag.
- Lift increases linearly with angle of attack α.
- Drag is more dependent on Reynolds number.

Bernoulli's Principle and Continuity

Chapter 14 of Halliday

Continuity

- A *streamline* is a path followed by an individual fluid particle.
- A *tube of flow* is a bundle of streamlines.
- The more spacing between streamlines, the lower the pressure, the less acceleration imparted by particles on one another.
- Thinking of a garden hose, the velocity of exiting fluid can be increased by reducing the area.
- If we consider the fluid incompressible then taking a volume that enters on the left side of the tube and equating it with one leaving the right side of the tube.

- Volume flows must match at all points in a tube, or all cross sections.
- The Volume flow rate: $\Delta V/\Delta t = Av$ which is a constant.
- If fluid is uniform mass flow rate: $\Delta V/\Delta t\rho = \rho Av$

Bernoulli's Principle

- When the fluid does not change elevation.
- The kinetic energy per unit volume (kinetic energy density).
- If a fluid element increases speed along a horizontal streamline, the pressure of the overall fluid must somehow decrease.
- Is this due to the transfer of kinetic energy to this streamline?