Overview

In this assignment you are asked to program a BEM (Blade Element Momentum) model for one of two rotors:

- A wind turbine, in axial and yawed flow
- A propeller, in axial and yawed flow, in cruise (optional: and energy harvesting)

NOTE: choose one of the two rotor cases for the mandatory assignment, If you wish, you can do both rotors.

The BEM code should incorporate the Glauert correction for heavily loaded rotors for the wind turbine case, and the Prandtl tip and root corrections. Assume a constant airfoil along the span and use the provided polars of the:

- DU airfoil for the wind turbine
- ARA-D 8% airfoil for the propeller

Discuss the different inaccuracies introduced into the solution by using a single airfoil polar only.

Wind-turbine

Baseline design of the wind turbine rotor

Rotor Specs	
Radius	50 m
# of blades	3
Blade starts at	0.2 r/R (before that circular root section without influence)
Twist	14*(1-r/R) (for r/R>0.2)
Blade pitch	-2 degrees
Chord distribution function	(3*(1-r/R)+1) m (for r/R>0.2)
Airfoil	DU 95-W-180 (polar in attachment at end of description)
Rotor yaw angle	0, 15 and 30 degrees
Operational Specs	
U0	10 m/s
TSR (lambda)	6, 8, 10
Rotor yaw angle	0, 15 and 30 degrees

1-Calculate the performance for the different tip speed ratios for the axial flow case.

2-Calculate the performance for the different yawed flow cases at tip speed ratio 8 (eight).

3-Optional: For a given Ct=0.75, change the pitch or the chord distribution or the twist distribution in order to maximise the Cp in axial flow at tip speed ratio 8 (eight). You can choose your own design approach. Compare with the expected result from actuator disk theory. Discuss the rationale for your design, including the twist and chord distributions.

Propeller

1-Assess the cruise performance of the propeller at $C_T = T / \rho n^2 D^4 = 0.12$ (*n* is the rotational speed in Hz). You may have to modify the collective blade pitch in order to reach this condition.

2-Calculate the performance for the different yawed flow cases at the same rotational speed and pitch setting used for question 1.

Optional: During landing, a propeller can be used to slow down the aircraft. If the propeller is driven by an electric engine, power can be harvested from the flow in this condition. For the given operational specs and basic rotor specs (radius, number of blades), change the collective blade pitch or the chord distribution or the twist distribution in order to maximize the power coefficient in this regime. You can choose your own design approach. Compare with the expected result from actuator-disk theory. Discuss the rationale for your design, including the twist and chord distributions, and compare with the results obtained with the baseline rotor specs, **comparing cruise operation and landing operation with energy harvesting and the impact of your design choices (assume the same operational specs)**.

Baseline design of the propeller rotor

Basic Rotor Specs	
Radius	0.70 m
# of blades	6
Blade Specs	
Blade starts at	0.25 r/R (before that hub)
Twist	-50*(r/R) + 35 deg (for r/R>0.25)
Collective blade pitch	46 degrees at r/R = 0.70
Chord distribution function (*c/R*)	0.18 – 0.06*(r/R) (for r/R>0.25)
Airfoil	ARA-D8% (polar in attachment at end of description)
Operational Specs	
U0	60 m/s
RPM	1200
ISA altitude	2000 m
Freestream incidence angle	0 degrees
Rotor yaw angle	0, 15 and 30 degrees

The local blade pitch (defined as in Figure 1) is equal to the sum of the local blade twist angle (blade characteristic) plus the collective blade pitch at the reference location (operational characteristic). In this case, the reference location is chosen at r/R=0.70. The blade twist at this point then needs to be zero by definition.

Figure 1: Definition of blade pitch for propeller case.

Tasks

For this assignment you need to submit the following:

- A short report, containing:
  a. SHORT introduction (1 page)
  b. A flowchart of your code (1 page)
  c. Main assumptions with an explanation of their impact
  d. Plots with explanation of results (alpha/inflow/a/a'/Ct/Cn/Cq vs r/R)
     a. Spanwise distribution of angle of attack and inflow angle
     b. Spanwise distribution of axial and azimuthal inductions
     c. Spanwise distribution of thrust and azimuthal loading
     d. Total thrust and torque
     e. For the cases of yawed HAWT, also plot the azimuthal variation (suggestion: polar contour plot)
  e. Plots with explanation of the influence of the tip correction
  f. Plots with explanation of influence of number of annuli, spacing method (constant, cosine) and convergence history for total thrust.
  g. (optional) Explanation of the design approach used for maximizing the Cp or efficiency
  h. (optional) Plots with explanation of the new designs
  i. Plot the distribution of stagnation enthalpy as a function of radius at four locations: infinity upwind, at the rotor (upwind side), at the rotor (downwind side), infinity downwind.
  j. Plot a representation of the system of circulation. Discuss the generation and release of vorticity in relation to the loading and circulation over the blade.
  k. Discuss the operational point of the airfoil in terms of lift and drag, and the relation between the distribution of lift coefficient and chord (chose one case, not necessary to do all cases)
  l. SHORT discussion/conclusion, including the similarities and differences between the two rotor configurations, flow field and operation
- Code in .zip or .rar file. Make sure the code is ready to run, so include all relevant files.

References

[1] Burton T., Jenkins N., Sharpe D., Bossanyi E., "Wind Energy Handbook", sections 3.5 and 3.6

[2] Veldhuis, L. L. M., Propeller Wing Aerodynamic Interference, PhD thesis, Delft University of Technology, 2005, Appendix A.

[3] Sub-module 2.2.3 Programming a BEM model