Report #1: (Due: Sun 29-sep-2024 23:00) Aero-Elastic rotor design for Class IIIB

Assignment format

By Sunday night 29 September, **one** person from your group submits a PDF of your report. The report excluding appendices with descriptions must be no more than 12 pages. The format is up to you, but please list the names of who worked on the report. The assignment is divided into 4 parts. Each part has a recommended date for completion.

Before the class on Week 5, about half of the groups will be randomly selected to present their reports orally to the class. The presentation should last about 7 minutes, and you can scroll through your report – no need for a separate PowerPoint. After the presentation, there will be 8 minutes for questions.

Report objectives

Your report should accomplish the following objectives:

- Plot the geometry of a blade using simplified methods and show how different design parameters impact the design
- Present the aero-elastic scaling of the rotor
- Apply the step-by-step aerodynamic rotor design method presented in the class
- Present your aerodynamic re-design of the rigid DTU 10MW RWT rotor optimized for the Class IIIB of the IEC 61400-1 (Ed. 3) by plotting the geometry and parameters used in the design process
- This presentation will include plots of the geometry for the re-designed DTU 10 MW blade, plots of parameters required for the design and plots for the aerodynamic performance of the new design

Tips

- Don't describe what the plots look like! Instead, explain why the trends match your expectations, what are the ramifications, how it matches theory, etc. Demonstrate your theoretical understanding.
- Please make a sanity check of the plotted data. Do your results match each other and make sense? E.g., CP and CT values should correspond to the shown power and thrust curves. If plots or values are unexpected, please explain which plots and values are unexpected and try to explain why these unexpected values appear.

Required figures and tables

See lists in different parts below.

Step-by-step guide

Part 1: Simplified aerodynamic design (finalise before Wednesday 18 September)

As an introduction to the aerodynamic rotor design, you should design a blade in a simplified way:

- This is the exercise to work on in class Week 2:
    - Implement simplified equations for chord and twist (equation (A) and (B) in the slide show from the lecture)

- Vary the parameters α_{design}, *TSR* and *B* and plot chord and twist as function of radius
    - Let α_{design}=5 deg, *TSR=8 and B=3* as reference values.
    - Vary α_{design} from 3.0 to 7.0, *TSR* from 6 to 10 and *B* from 2 to 5
    - You can assume that $C_{l,design}$ and α_{design} is related by $c_{l,design}=(2*\pi)^2/360*\alpha_{design}+0.452$
- Answer the following questions:
    - What is assumed about the axial induction for equation (A) and (B)?
    - What happens to the chord and twist when increasing/decreasing $c_{l,design}$?
    - What happens to the chord and twist when increasing/decreasing *TSR*?
    - What happens to the chord and twist when increasing/decreasing *B*?
    - Are there differences in the inflow angle for the inner and outer part of the rotor?
    - If so: What is the difference? And please explain this using the velocity triangle
    - Are there differences in the angle of attack for the inner and outer part of the rotor?
    - If so: Explain why there is a difference

Required figures in Part 1

This is a list of figures that are required to pass. Other plots/tables that support your analysis are of course welcome.

1. **Figure:** Plot of chord as a function of radius with variation of $C_{l,design}$, TSR and B
2. **Figure:** Plot of twist as a function of radius with variation of $C_{l,design}$, TSR and B
3. **Figure:** A plot/sketch of the variation of inflow angle from root to tip of the blade

Changes to make_htc_files.py/myteampack

- None

Part 2: Design process and final result (finalise before Wednesday 25 September)

In this part you should describe the background for the re-design of the DTU 10 MW blade for Class IIIB. All of the design and evaluation in Part 2 is done with the Python code; you will not use HAWC2S here.

You should follow the step-by-step method as described in the lecture and you should have special focus on the following:

- For Step 2: Explain the determination of rotor radius (***not* blade length!**) for your new rotor and an argumentation of why this radius is chosen.
- For Step 4:
    - Find the absolute blade-thickness and the center-line for the DTU 10 MW and upscale them for your design (blade pre-bend and sweep should keep the same absolute values after upscaling).
    - Describe other issues influencing the design such as tip speed, maximum chord, number of blades etc. (the maximum tip speed should be chosen so that it is obtained below rated wind speed)
- For Step 6:
    - Argue for your choices of design angle of attack (*AoA*), design c_l and design *lift-drag* ratio for each airfoil
    - Plot and argue for your choice of design function. There are 3 design functions given in the python method `get_design_functions` from the `aero_design_functions.py`.
- For Step 7: Find the design with tip-speed-ratio that maximizes power (CP), as calculated with Python.
- For Step 8:

  - Present your final chord, twist, and relative thickness distributions and compare these curves to the original DTU 10MW rotor.
  - Explain the most important parameters for impacting chord and twist and compare with the values for the DTU 10 MW

Required figures in Part 2

This is a list of figures that are required to pass. Other plots/tables that support your analysis are of course welcome.

- **Figure:** Plot of your chosen absolute thickness distribution (versus blade length or rotor radius). You should plot the original thickness distribution of the DTU 10MW rotor for comparison.
- **Figures:** Side-by-side plots of lift-versus-drag (left) and lift-versus-AoA (right) for each airfoil used. You must indicate the design point that you have selected for each airfoil on the plots. *Skip* the data for the 60% airfoil. *Note:* For the 48% airfoil - base your selections on the local maximum lift that you observe at AoA=6°.
- **Figures:** Plots of the values for your selected design lift coefficient, design lift-drag ratio and design AoA versus the relative thickness for all selected airfoils and the spline that you selected that fits your choices best of 3 possible splines to describe this relationship. Even though airfoils only exist from t/c=24%: Please plot from 0(zero)% to 100% anyway.
- **Figure:** Plot of CP (calculated with Python) versus tip-speed-ratio and indicate your chosen design tip-speed-ratio and CP
- **Figures:** Plots of the final chord, twist, and relative thickness distributions of your rotor design. You should plot the original distributions of the DTU 10MW rotor for comparison in each of these plots. **Please be aware that the sign of the twist in the design code is opposite to HAWC2S.**

Changes to make_htc_files.py/myteampack

  - None

Part 3: Design evaluation with HAWC2S for a stiff rotor (finalise before Wednesday 25 September)

In this part you should present the design evaluation of the DTU 10 MW blade for Class IIIB **carried out with HAWC2S for a stiff rotor**.

Your prebend for the new rotor should be the same as for the original DTU 10MW Reference Wind Turbine, however stretched in the radial direction. Thus, the offset in the tip will in absolute numbers be the same for the existing and new blades.

- Set up the `our_design/` folder in `hawc_files/` by creating the `_master/` and `data/` folders and copying over the (a) DTU 10 MW master htc file, (b) the DTU 10 MW st files and (c) `dtu_10mw_rigid.opt`. Rename the master htc file to something that makes sense for your team, e.g., `groupX_redesign.htc`.
- Modify your HAWC files such that your blade has your designed chord, twist, and thickness.
  - **Do not** change the number of nodes in c2_def!
- Copy `make_htc_files.py` into the HAWC model directory for your design and update script variables as needed. Run the script and make sure it generates the 1-wsp and multi-TSR htc files for your turbine.
- Copy the 1-wsp opt file for the DTU 10 MW into your `data/` folder and update it so it corresponds to the design pitch/TSR for your turbine. Manually update the 1-wsp htc file to generate induction files and run

HAWC2S. Using the generated induction files, make plots comparing the HAWC2S lift coefficient with the design lift coefficient. Repeat for lift-drag ratio and AoA. Analyse the results.

- Copy the multi-TSR opt file for the DTU 10 MW into your `data/` folder and update it so it corresponds to the design pitch and desired range of TSRs for your turbine. Remember your changed rotor radius! Run HAWC2S on the multi-TSR cases to generate pwr files. Plot the rotor Cp and Ct versus TSR calculated with HAWC2S. Analyse the results with respect to Part 2.
- Modify `make_hawc2s()` in `myteampack.MyHTC` such that it:
  - Takes as keyword arguments `minpitch` and `opt_lambda`. These represent the minimum pitch and the optimum TSR, respectively. The default values should correspond to the DTU 10 MW.
  - Updates the corresponding values in the `operational_data` block.
  - **Hint:** Use `genspeed` as an example!
- Use HAWC2S to calculate the optimal pitch curve for your rigid turbine and place it in `data/`.
  - Modify `make_htc_files.py` to generate a new htc file, appending `_compute_rigid_opt` to the filename. This htc file should be rigid, be linked to `dtu_10mw_rigid.opt`[1], have your design pitch as `minpitch`, have your design TSR as `opt_lambda`, and should only have one HAWC2S command: `compute_optimal_pitch_angle`.
  - Run HAWC2S on the `_compute_rigid_opt` htc file for your rigid blade. **NOTE** This computation takes several minutes. It will generate an opt file in the `res_hawc2s/` folder with the same name as the htc file.
  - Rename the generated opt file to <YOUR_DESIGN_NAME>_rigid.opt and move it to the `data/` folder.
- Evaluate the pitch, rotor speed, thrust, and power in your rigid opt file and check that they are the same as your chosen design conditions. You might experience that the actual operational conditions are not in complete agreement with the design conditions because the aerodynamic model is not exactly the same, but they should be in fairly good agreement.

Required figures in Part 3

This is a list of figures that are required to pass. Other plots/tables that support your analysis are of course welcome.

- **Figures:** Side-by-side plots of the HAWC2S lift coefficient and the design lift coefficient versus relative thickness (left plot) and versus radius (right plot) for design pitch and design TSR. The same should be done for the lift-drag ratio and AoA. Thus, curves plotted in section 2 are repeated in the plots for the relative thickness.
- **Figures:** Plots of the HAWC2S lift coefficient, lift-drag ratio, AoA, axial induction (*a*), local *CT* and local *CP* versus radius at design TSR.
- **Figures:** Side-by-side plots of the power and thrust coefficients calculated with HAWC2S at design pitch versus TSR
- **Figures:** Side-by-side plots of the rotor speed (left plot) and pitch angles (right plot) versus wind speed
- **Figures:** Side-by-side plots of the aerodynamic power (left plot) and its coefficient (right plot), and the thrust (left plot) and its coefficient (right plot) versus wind speed

Changes to make_htc_files.py/myteampack

- New htc file: compute steady state and save power for 1-wsp opt file (at design pitch/TSR) for your rigid turbine (manually modified to save induction)

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[1] This is used as a dummy file.

- New htc file: compute steady state and save power for multi-TSR opt file (at design pitch) for your rigid turbine
- Modify `make_hawc2s()` to allow updating design pitch and design TSR in operational data block.
- New htc file: compute optimal pitch angle for your rigid turbine, given design pitch and design TSR

Part 4: Design evaluation with HAWC2S for an elastic rotor (finalise Sunday 29 September 23:00)

In this part you should present the design evaluation of the DTU 10 MW blade for Class IIIB **carried out with HAWC2S for an elastic rotor**:

- Apply the structural scaling for your updated design and update the necessary HAWC files. Plot selected structural values and compare with the DTU 10 MW. Use the `structural_scaling_example.py` as a basis for the upscaling but using your values.
- Use HAWC2S to calculate the optimal pitch curve for your flexible turbine and place it in `data/`.
    - Modify `make_htc_files.py` to generate a new htc file, appending `_compute_flex_opt` to the filename. This htc file should be flexible, be linked to `dtu_10mw_rigid.opt`[2], have your design pitch as `minpitch`, have your design TSR as `opt_lambda`, and should only have one HAWC2S command: `compute_optimal_pitch_angle`.
    - Run HAWC2S on the `_compute_flex_opt` htc file for your rigid blade. **NOTE** This computation takes a long time, **maybe over an hour**!
    - Rename the generated opt file to `<YOUR_DESIGN_NAME>_flex.opt` and place it in the `data/` folder.
- Use the flexible opt file to evaluate the power, thrust, and pitch of the flexible blade and compare it both to the stiff configuration and to the DTU 10 MW. Verify that your design choices are reflected in the operational curves. Please explain possible difference in performance and evaluate whether your design is expected to achieve the LAC design challenge.

Required figures in Part 4

This is a list of figures that are required to pass. Other plots/tables that support your analysis are of course welcome.

- **Figures:** Plot the distributed mass and moment of inertia (x,y).
- **Figures:** Side-by-side plots of the (flexible) power and thrust coefficients versus wind speed and comparison to stiff rotor
- **Figures:** Side-by-side plots of the (flexible) power and thrust versus wind speed and comparison with the flexible DTU 10 MW

Changes to make_htc_files.py/myteampack

- New htc file: compute optimal pitch angle for your flexible turbine, given design pitch and design TSR

Learning objectives

This assignment is designed to do the following:

- Get you familiar with the step-by-step aerodynamic rotor design method presented in the class.

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[2] This is used as a dummy file.

- Start you thinking about how the aerodynamic loads will affect the overall performance of the wind turbine re-design for IEC Class III-B
- Review your understanding of
    - The parameters controlling the aerodynamic rotor design
    - The parameters controlling the aero-elastic scaling of the rotor
    - How the overall loads determine the aerodynamic redesign of the DTU 10MW RWT rotor

References

[1] Bak C. Aerodynamic design of wind turbine rotors. In Brøndsted P, Nijssen R, Goutianos S, Advances in Wind Turbine Blade Design and Materials, Elsevier 2023, https://doi.org/10.1016/B978-0-08-103007-3.00001-X