Steady State Comparisons HAWC2 v12.5 vs HAWCStab2 v2.14: Integrated and distributed aerodynamic performance

Verelst, David Robert; Hansen, Morten Hartvig; Pirrung, Georg

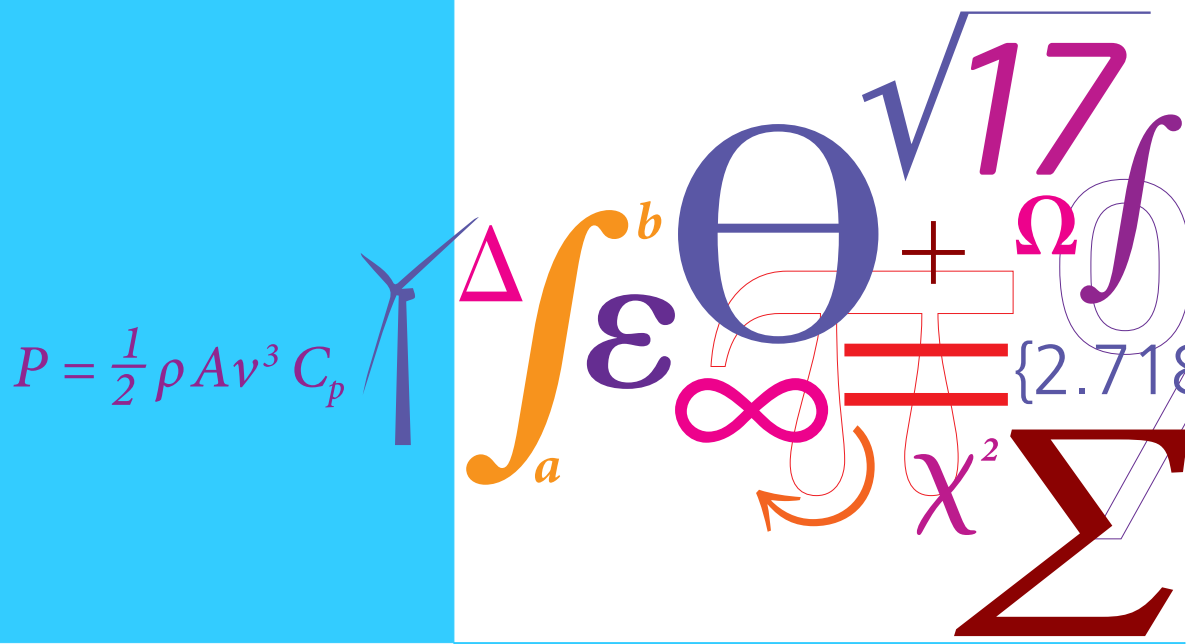
Publication date:
2018

Document Version
Publisher's PDF, also known as Version of record

Steady State Comparisons HAWC2 v12.5 vs HAWCStab2 v2.14

Integrated and distributed aerodynamic performance

DTU Wind Energy E-report



David R.S. Verelst
Morten H. Hansen
Georg Pirrung

Report number: DTU Wind Energy E-0172
ISBN: 978-87-93549-40-1

Compiled on Monday 13th August, 2018 at 12:46

DTU Wind Energy
Department of Wind Energy

Contents

1 Introduction

This reports presents comparison of the steady state HAWC2 [1] [2] [3] simulation results and the HAWCStab2 computations of the DTU10MW reference turbine [5] [6]. It serves as a simple validation for the HAWCStab2 [7] [8] [9] steady state computations. Due to HAWCStab2 the following simplifications are made:

- no gravity
- shaft tilt angle is set to zero since HAWCStab2 assumes the inflow is perpendicular to the rotor plane
- aligned inflow conditions (no turbulence, shear, veer or yaw)
- tower and shaft flexibility are not considered to assure the shaft remains perfectly aligned with the wind inflow vector (horizontal)
- the dynamic stall model is disabled

Further, the HAWC2 model needs to contain as many bodies as there are structural nodes for both structural models to behave in the same way.

There are three test cases considered in the comparison:

- Case 1: no blade flexibility, and the aerodynamic modelling reduced to strip theory: no induction and no tip correction, labelled as "no induction" or "without induction"
- Case 2: no blade flexibility in conjunction with BEM induction model and Prandtl tip correction (labelled as "induction+tip")
- Case 3: flexible blades in conjunction with "induction+tip"

Both HAWC2 and HAWCStab2 have the ability to use different aerodynamic models. For the "induction+tip" model, the rotor induced velocities are calculated with Blade Element Momentum theory, and the presence of the tip vortex is accounted for by the Prandtl tip loss model. Although available in both codes, dynamic stall is not included within the scope of this comparison.

By considering these three model variations, potential differences in the results can be more easily related to the different models used in both codes.

This investigation has been carried out with HAWC2 version 12.5 and HAWCStab2 version 2.14. A previous iteration of this report compared HAWC2 version 12.2 with HAWCStab2 2.12 [4]. Section 3 briefly discusses how the results presented here are an improvement over the previous comparison [4].

2 DTU10MW: Comparing Steady State Results

The DTU 10MW reference wind turbine is used for this investigation, and the HAWC2 and HAWCStab2 models for this turbine are available from [6].

This comparison considers the following integrated rotor performance parameters, as function of wind speed:

- Mechanical rotor power
- Rotor thrust

The following distributed blade performance parameters are considered:

- The z-coordinate of the blade section (in blade coordinates) on the x-axis
- Lift and drag coefficients (Cl and Cd respectively)
- Angle of attack (AoA)
- Relative velocity as seen from the blade section (vrel)
- Distributed lateral and axial forces (F_x and F_y respectively) in rotor polar coordinates
- Axial and tangential induced velocities (ax_ind_vel and tan_ind_vel)

2.1 Case 1: Stiff Blades and "no Induction"

This is the most basic and simple comparison possible: an entirely stiff structure, steady and uniform inflow conditions, and basic strip theory for the aerodynamics (no induction, not tip correction, no dynamic stall). From the power curve given in Figure 1 it can be noted that in the absence of deflections, and without the proper aerodynamic model, the nominal power is significantly over estimated.

From Figure 1 is noted that the difference between HAWC2 and HAWCStab2 is very small:

- maximum difference on power output is 80 kW (roughly 0.46% at $\approx$ 17.5 MW)
- maximum difference on thrust is 0.6 kN (roughly 0.08% at 800 kN)

These differences are considered very small and are argued to be caused by the small differences in numerical integration schemes used for integrating the rotor forces.

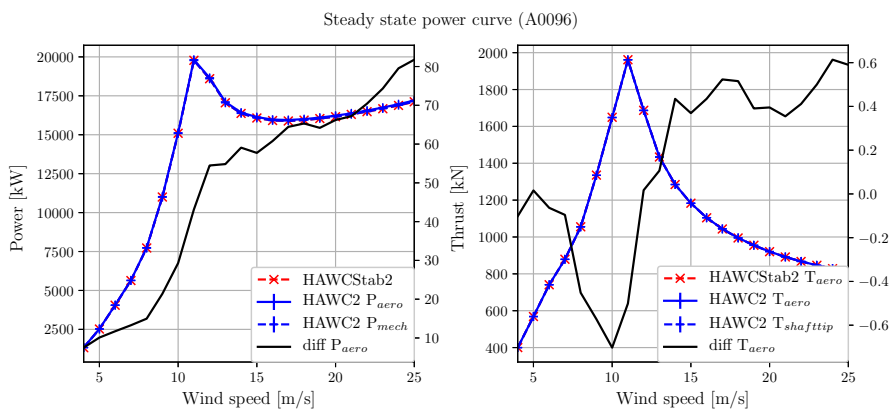


Figure 1: Power and thrust curves. The absolute difference between HAWC2 and HAWCStab2 is labelled as *diff*, and its axis is on the right side of the plot.

Figures 2 to 5 consider the blade distributed aerodynamic parameters. For the fully stiff case with simple aerodynamics the distributed forces compare very well between HAWC2 and HAWCStab2. The minor differences that occur are mainly located within the inner part of the blade. Notice that the induced velocities are zero since the induction model is switched off.

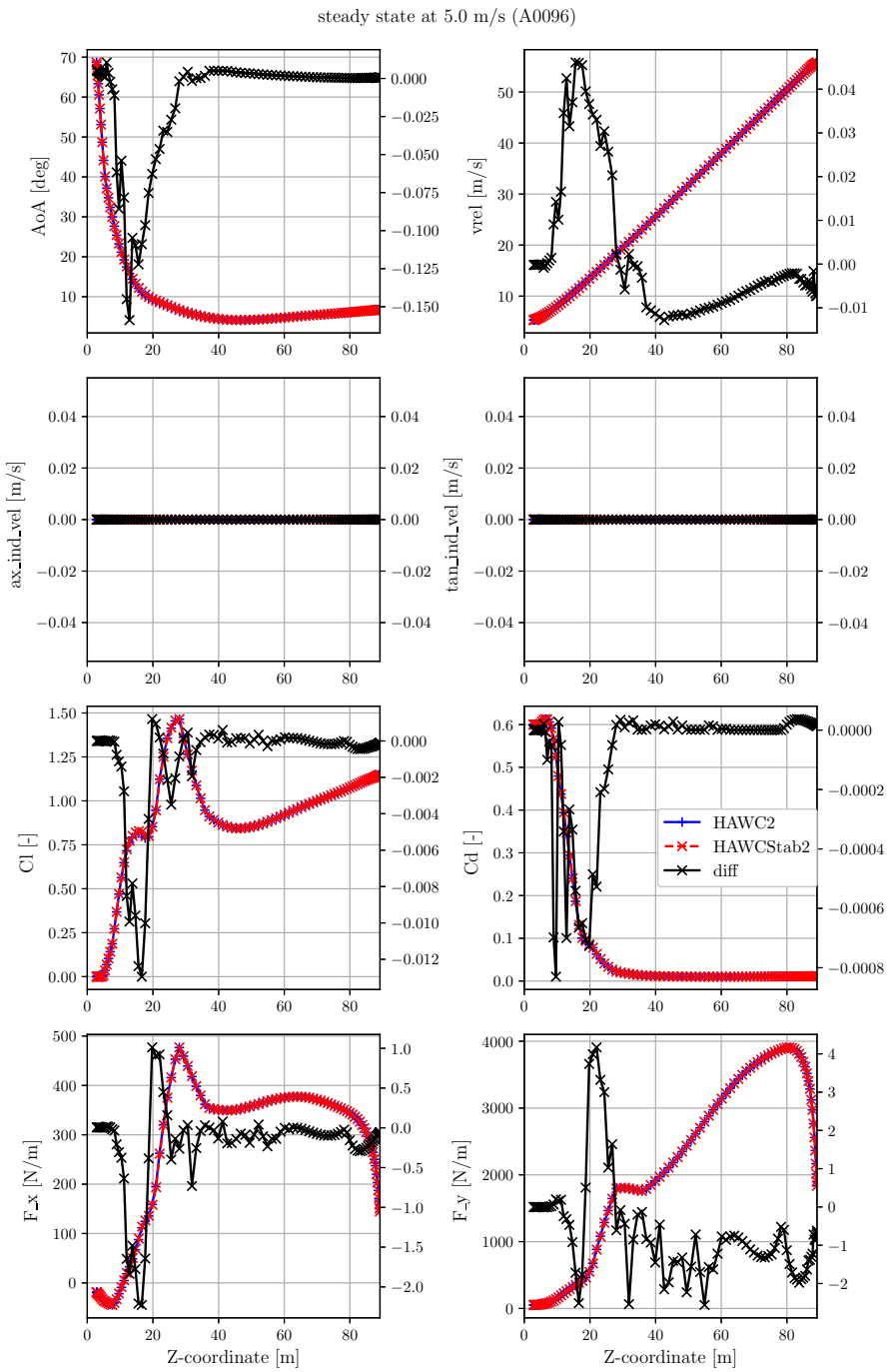


Figure 2: Blade load distribution at 5 m/s. The absolute difference between HAWC2 and HAWCStab2 is labelled as *diff*, and its axis is on the right side of the plot.

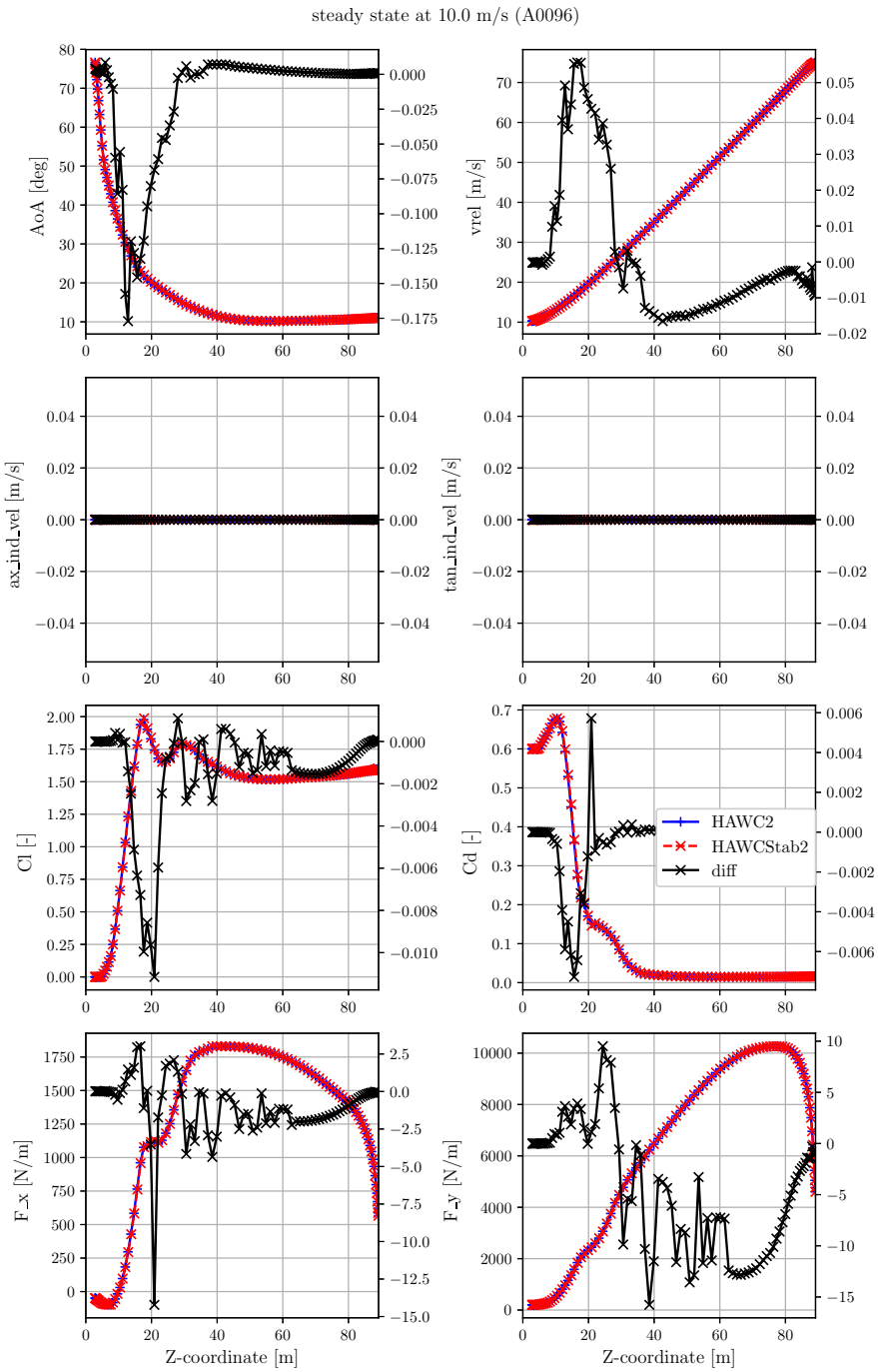


Figure 3: Blade load distribution at 10 m/s

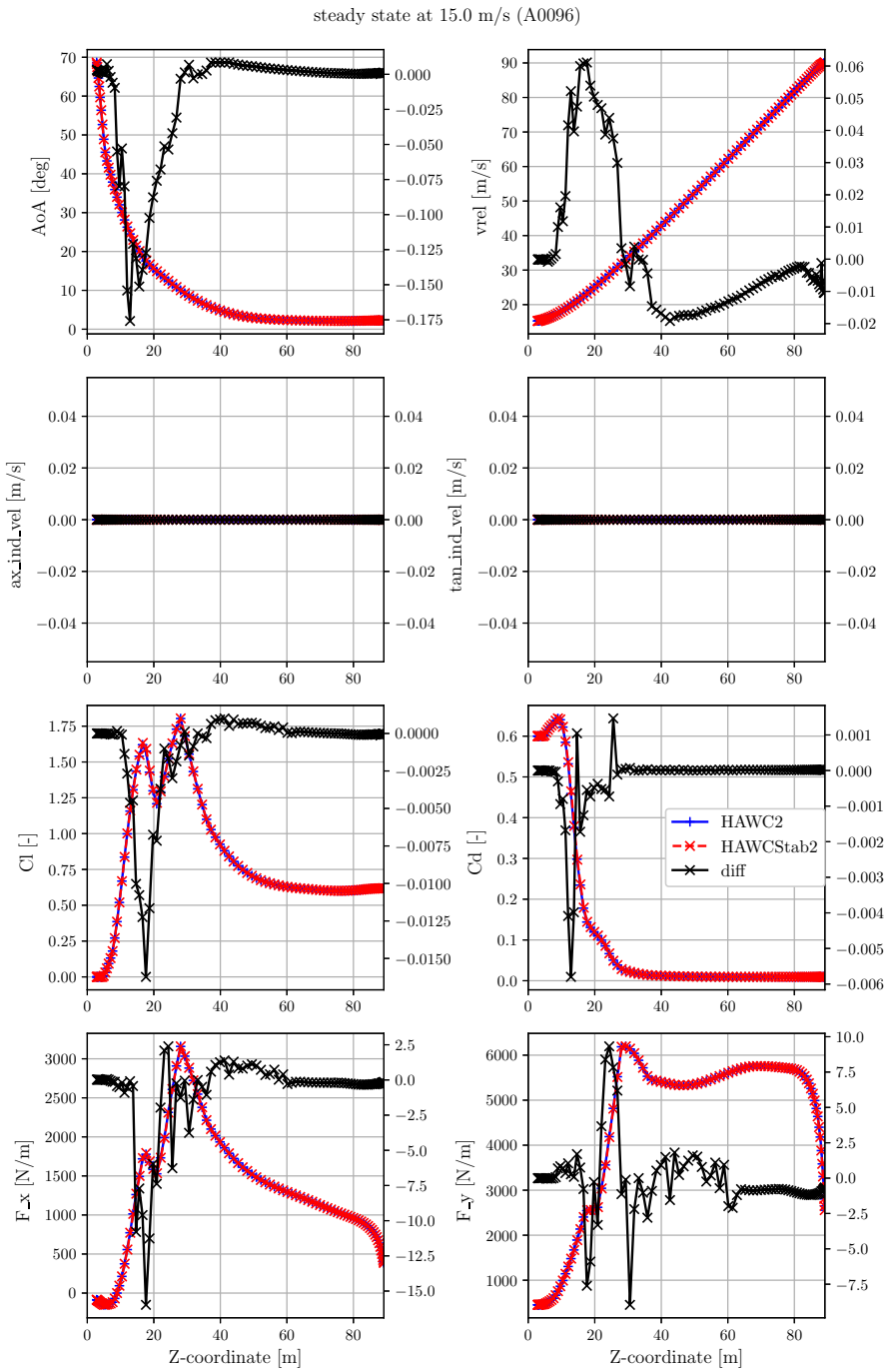


Figure 4: Blade load distribution at 15 m/s

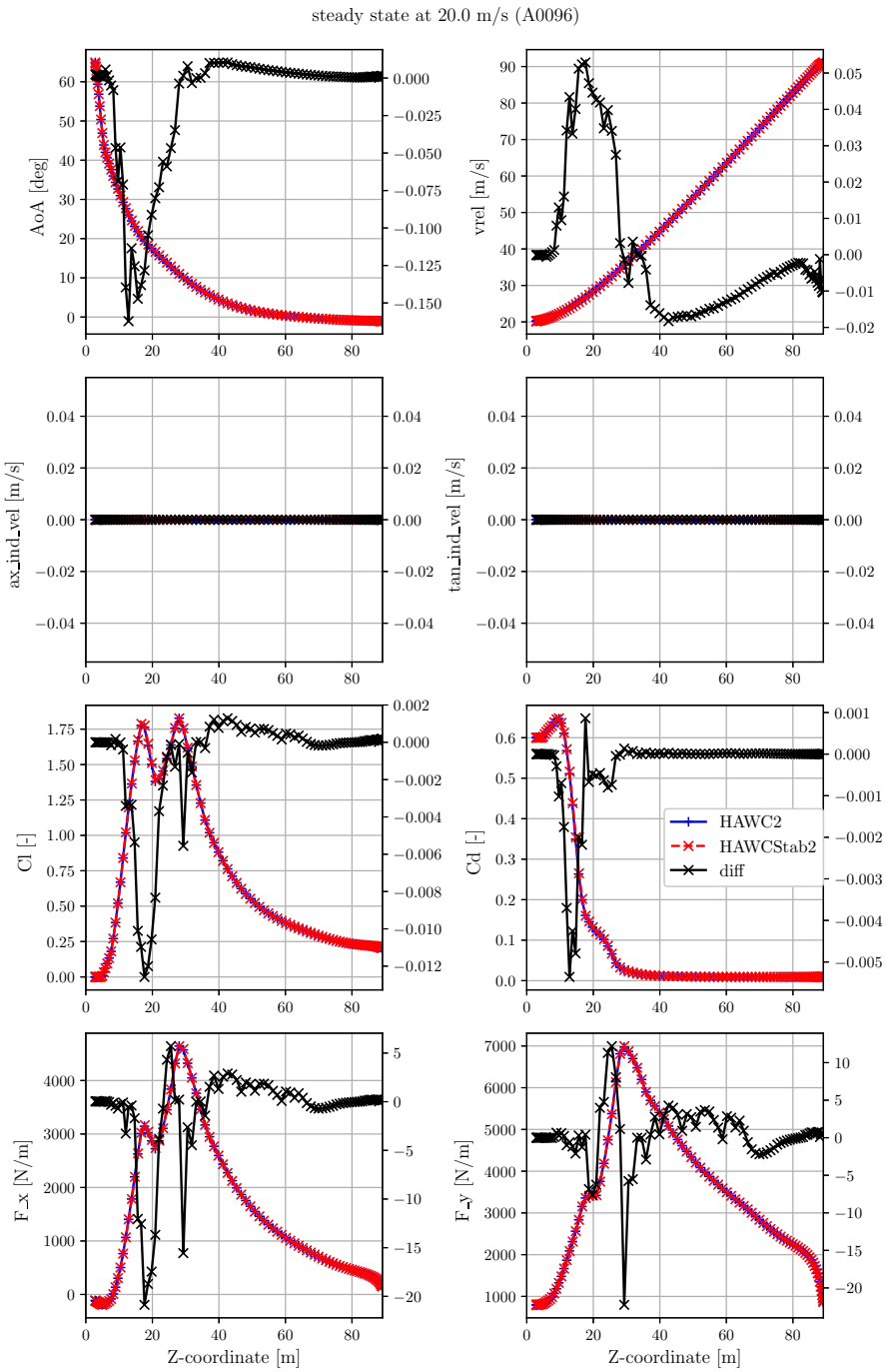


Figure 5: Blade load distribution at 20 m/s

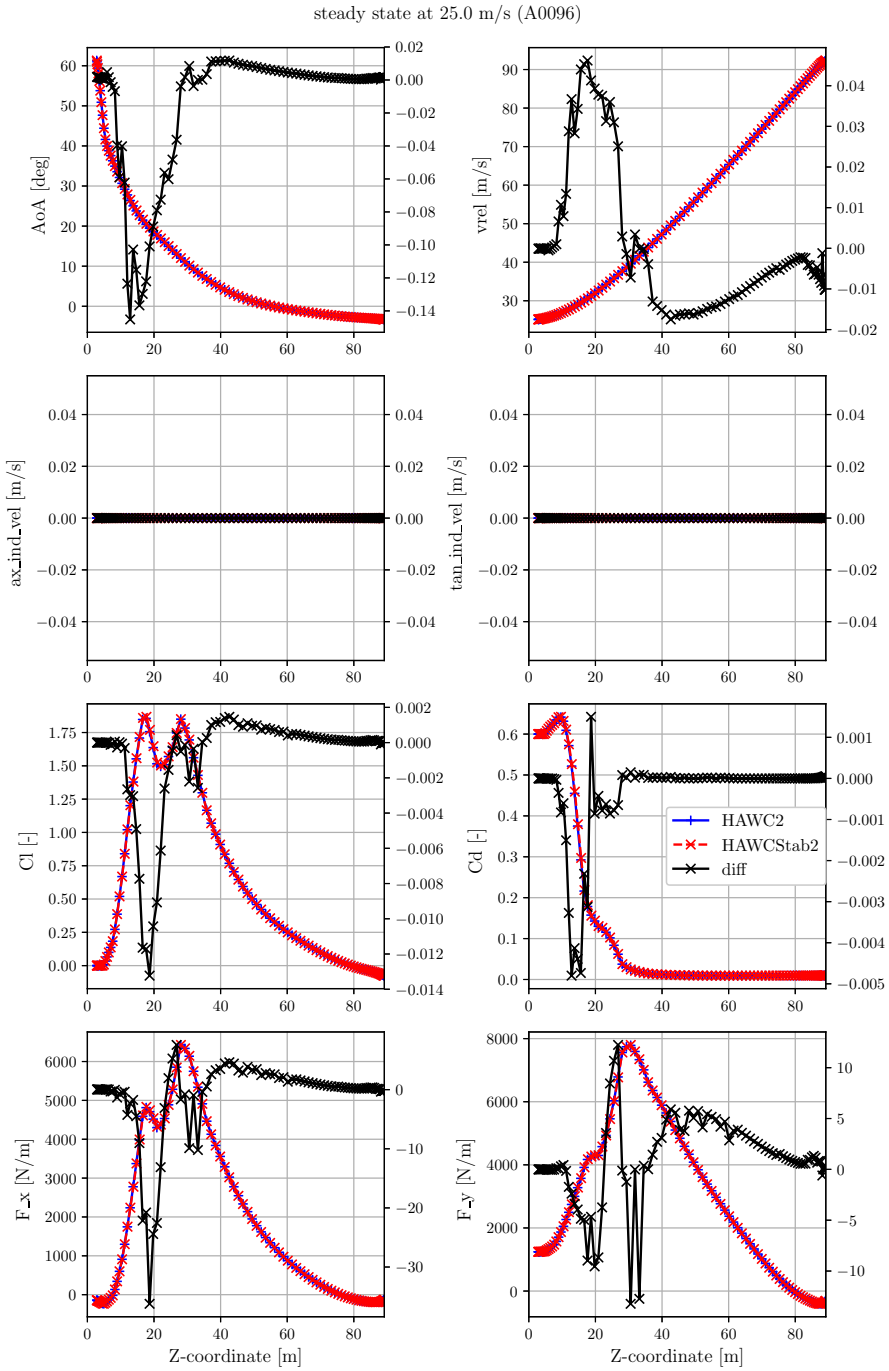


Figure 6: Blade load distribution at 25 m/s

2.2 Case 2: Stiff Blades and "Induction+Tip"

When using a more realistic aerodynamic model, but still stiff blades, the good agreement between HAWC2 and HAWCStab2 still holds. The integrated forces are shown in Figure 7 in the form of the power and thrust curves as function of wind speed. The error between HAWC2 and HAWCStab2 remains well below 1%.

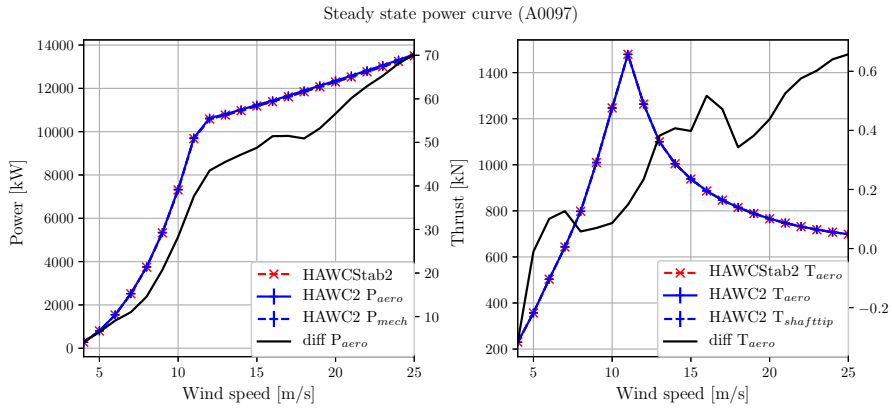


Figure 7: Power and thrust curves. The absolute difference between HAWC2 and HAWCStab2 is labelled as *diff*, and its axis is on the right side of the plot.

The distributed aerodynamic parameters (Figures 8 to 12) show a very good agreement between both codes. However, following minor differences are observed:

- The same minor differences are occurring at the inner part of the blade compared to case 1.
- At the tip a small discrepancy exists due to presence of the tip loss model. A more detailed assessment as of why the tip loss model causes this difference is referred to future work.

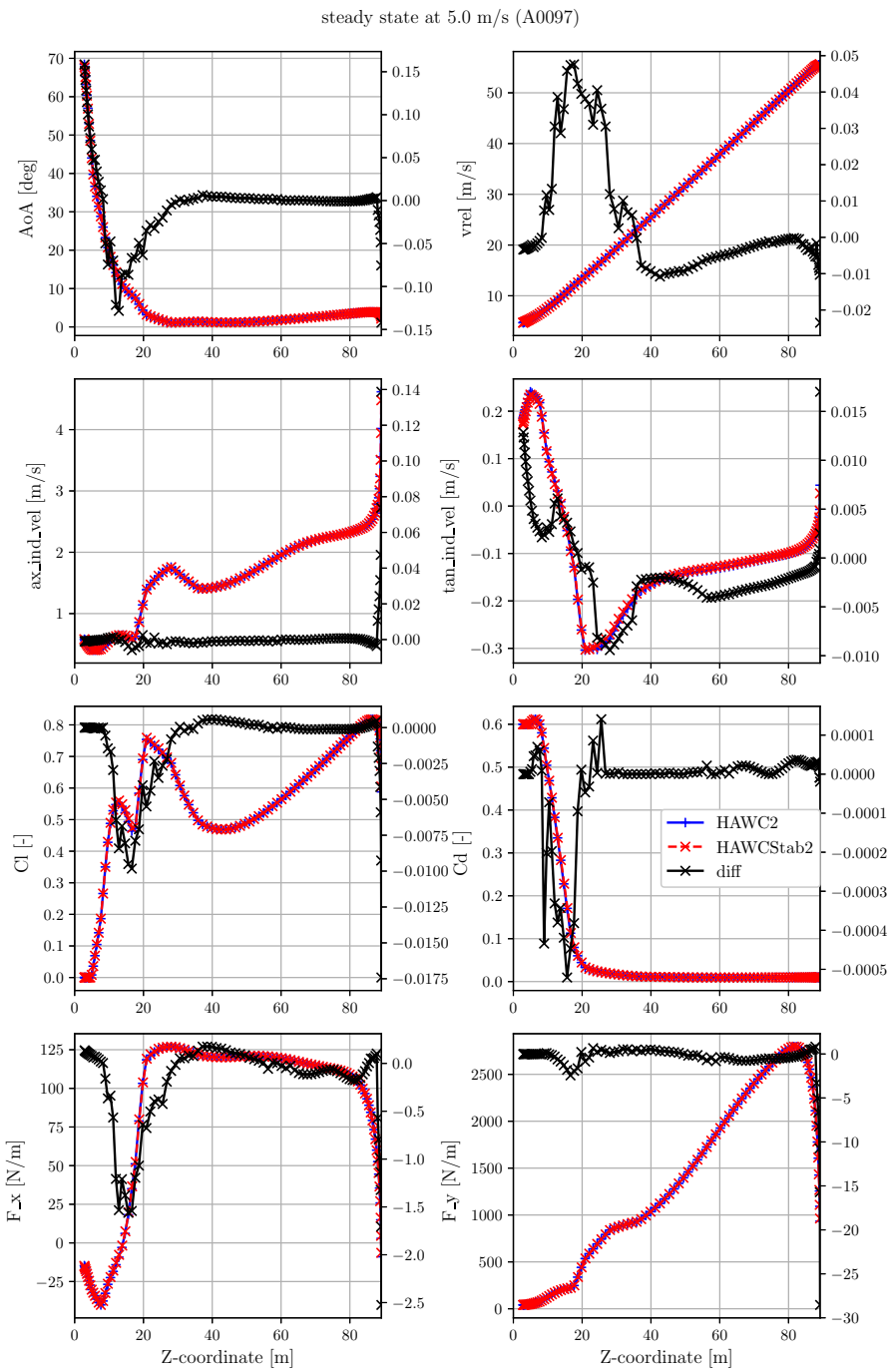


Figure 8: Blade load distribution at 5 m/s

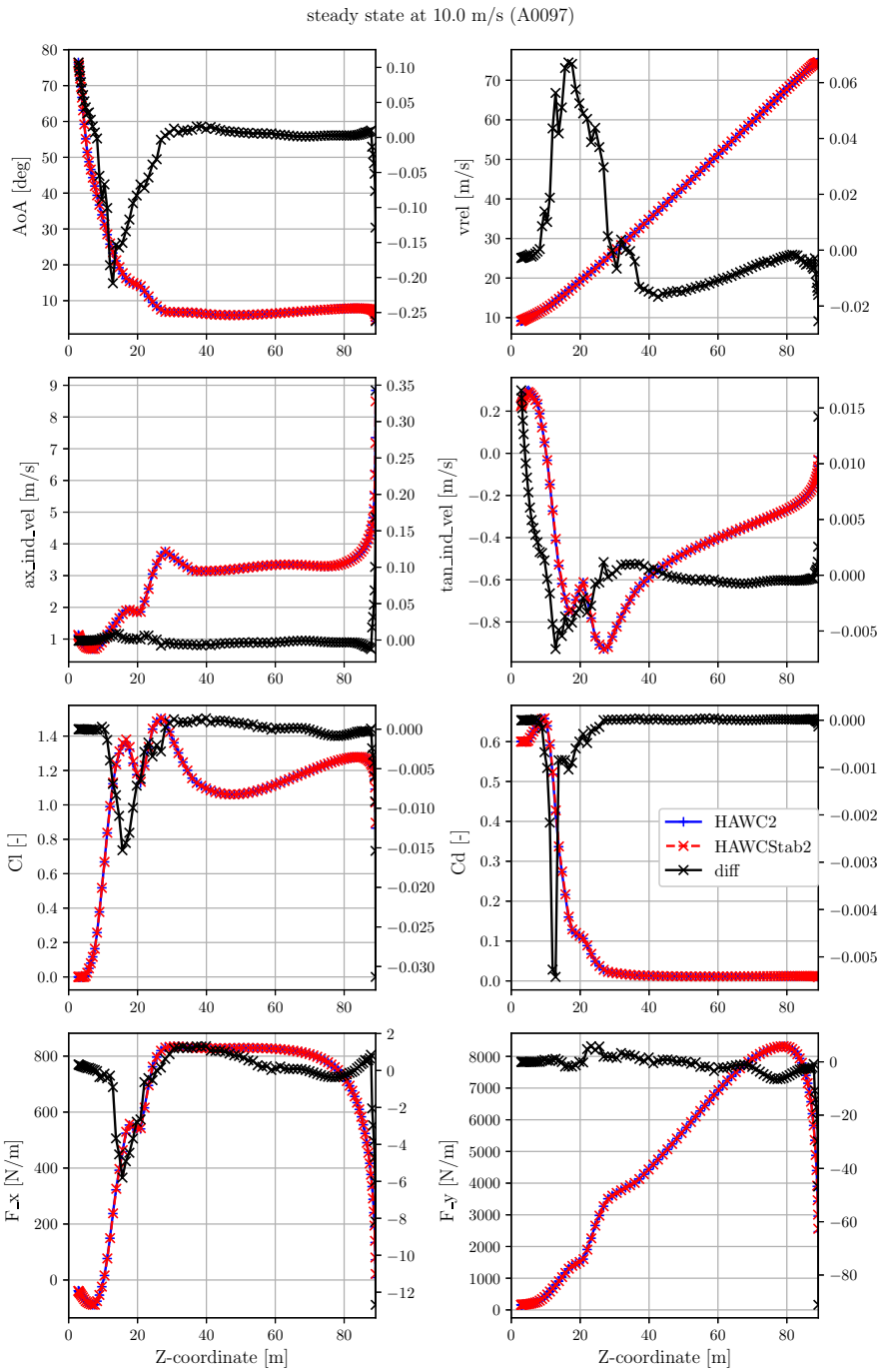


Figure 9: Blade load distribution at 10 m/s

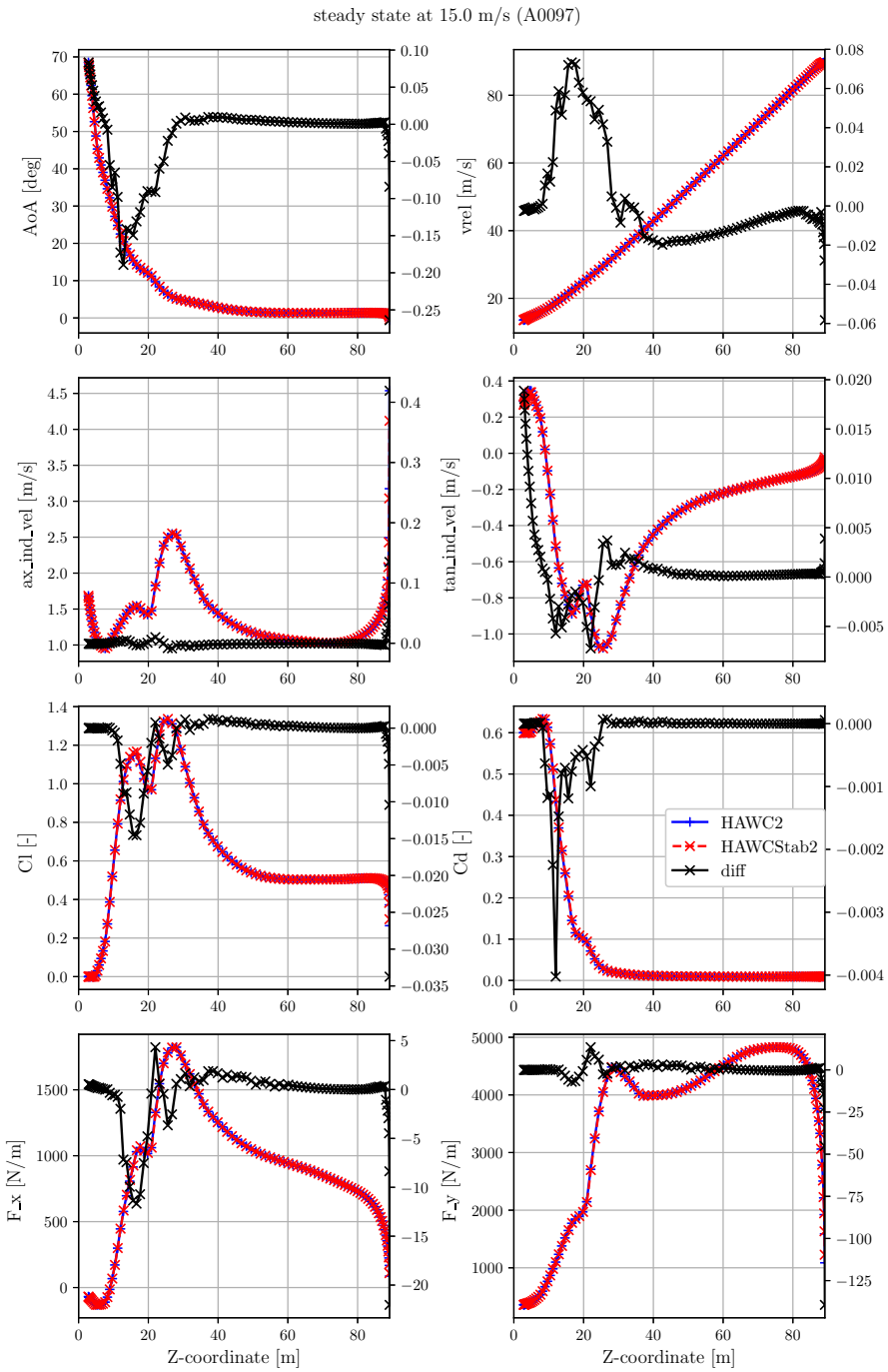


Figure 10: Blade load distribution at 15 m/s

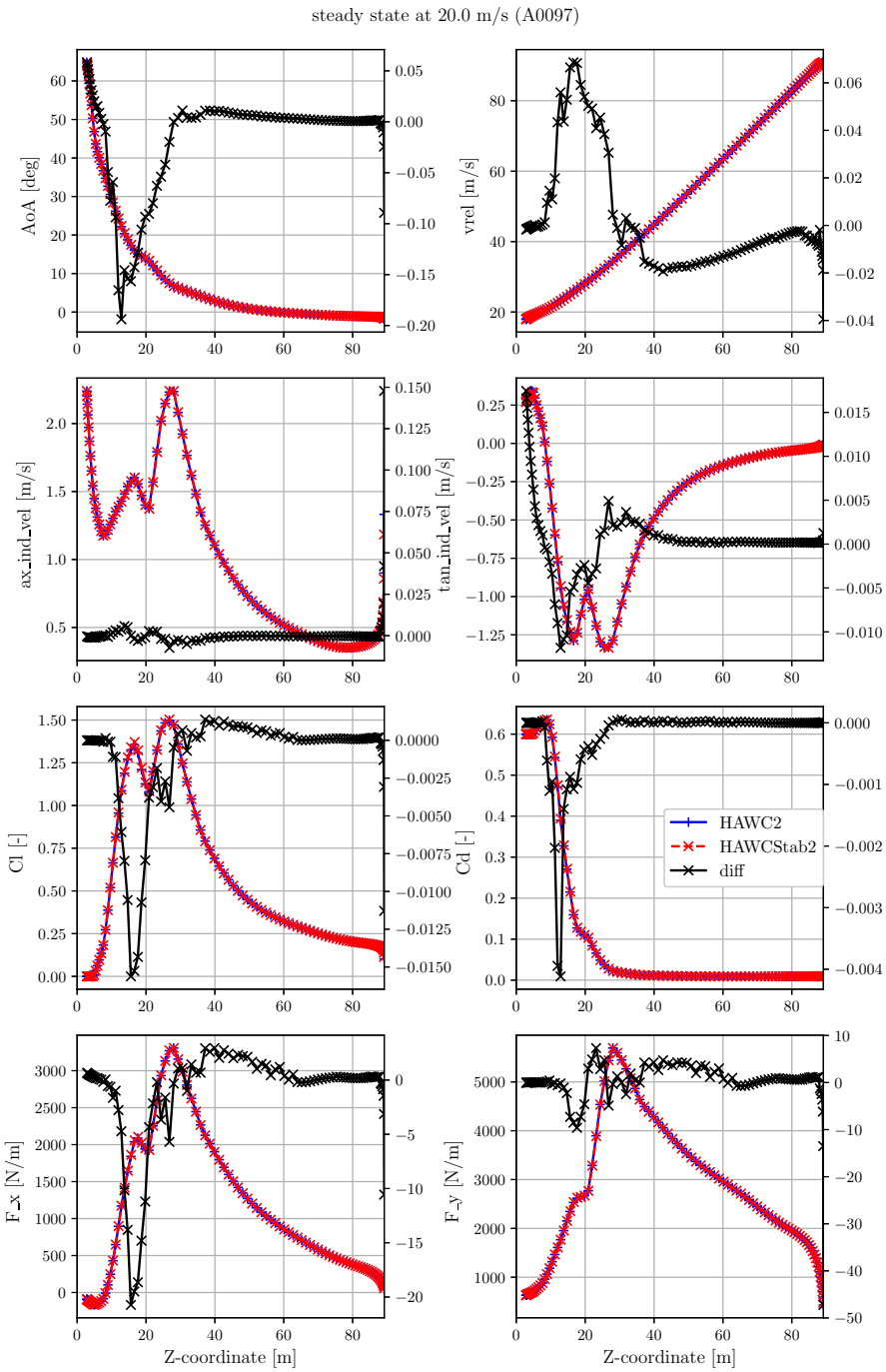


Figure 11: Blade load distribution at 20 m/s

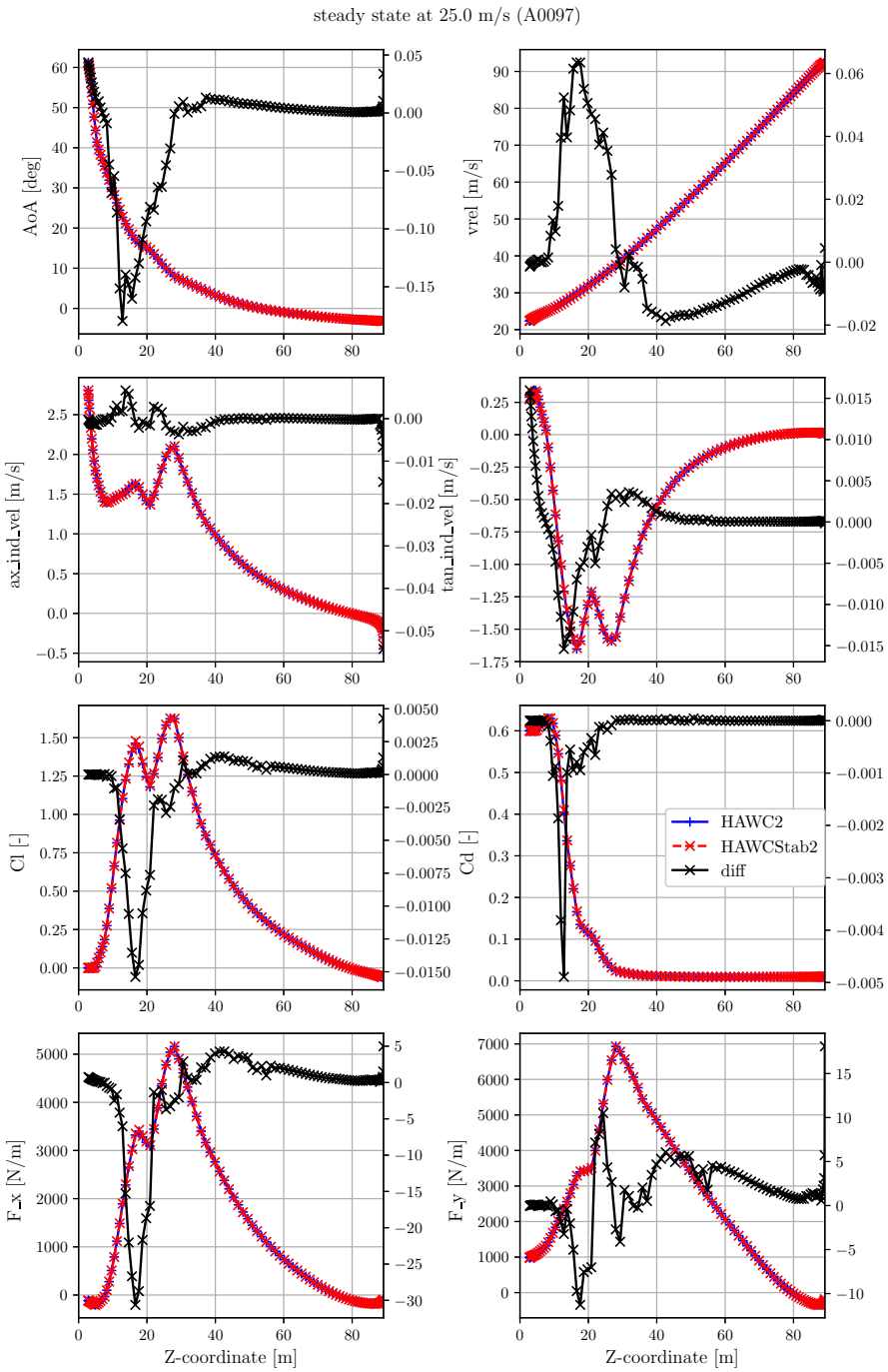


Figure 12: Blade load distribution at 25 m/s

2.3 Case 3: Flexible Blades and "Induction+Tip"

When considering both the "BEM+tip aerodynamic" model and blade flexibility the same consistent and good agreement between both HAWC2 and HAWCStab2 is found. This for both integrated rotor forces (see Figure 13 and distributed aerodynamic parameters (Figures 14 to 17). However, note that the integrated rotor forces of HAWCStab2 for case 3 are now closer to HAWC2 when compared to cases 1 and 2: around rated wind speed the flexible case (figure 13) has only a rated power difference of approximately 10 kW, while for the stiff case this was around 40 kW (figure 7).

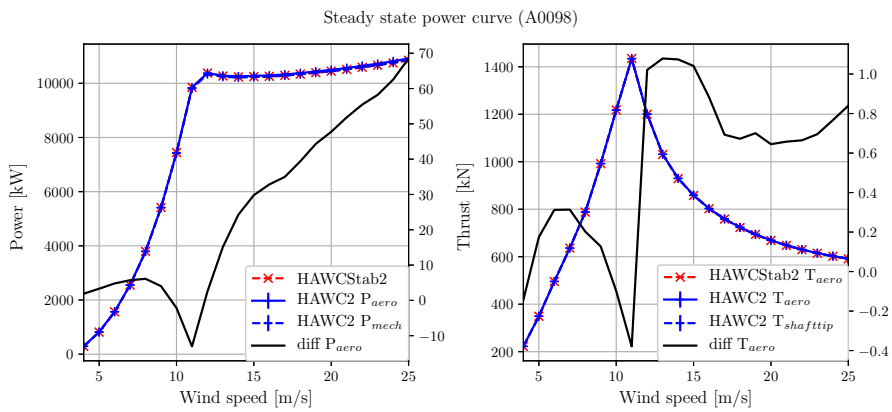


Figure 13: Power and thrust curves. The absolute difference between HAWC2 and HAWCStab2 is labelled as *diff*, and its axis is on the right side of the plot.

The load distributions show similar trends compared to the stiff rotor (case 2, Figures 8 to 12). Without considering the detailed comparison of the blade deflection curves in this report (see section 5), it seems that differences caused by the aerodynamics are minor, and they do not affect significantly the blade deformation.

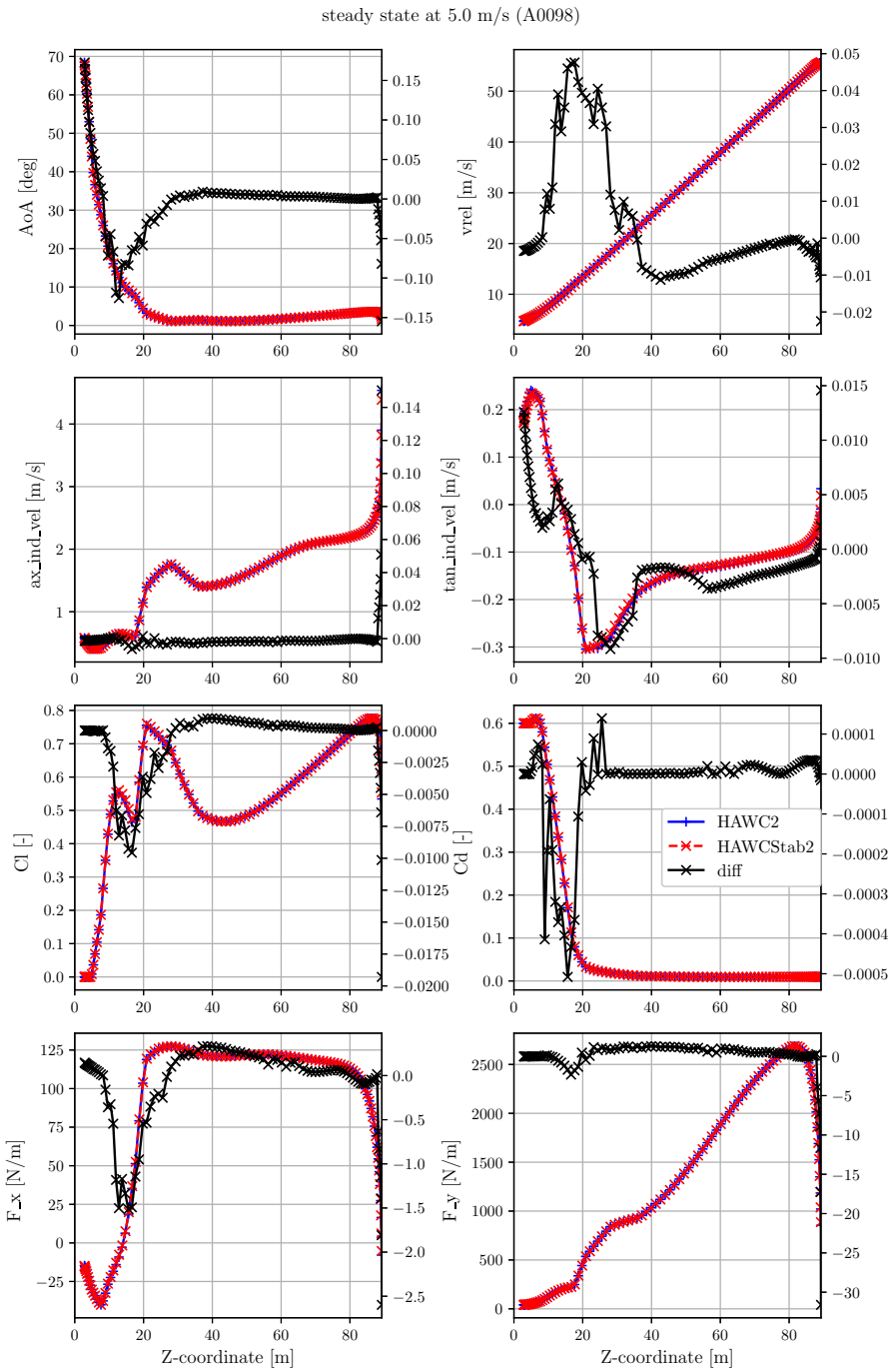


Figure 14: Blade load distribution at 5 m/s

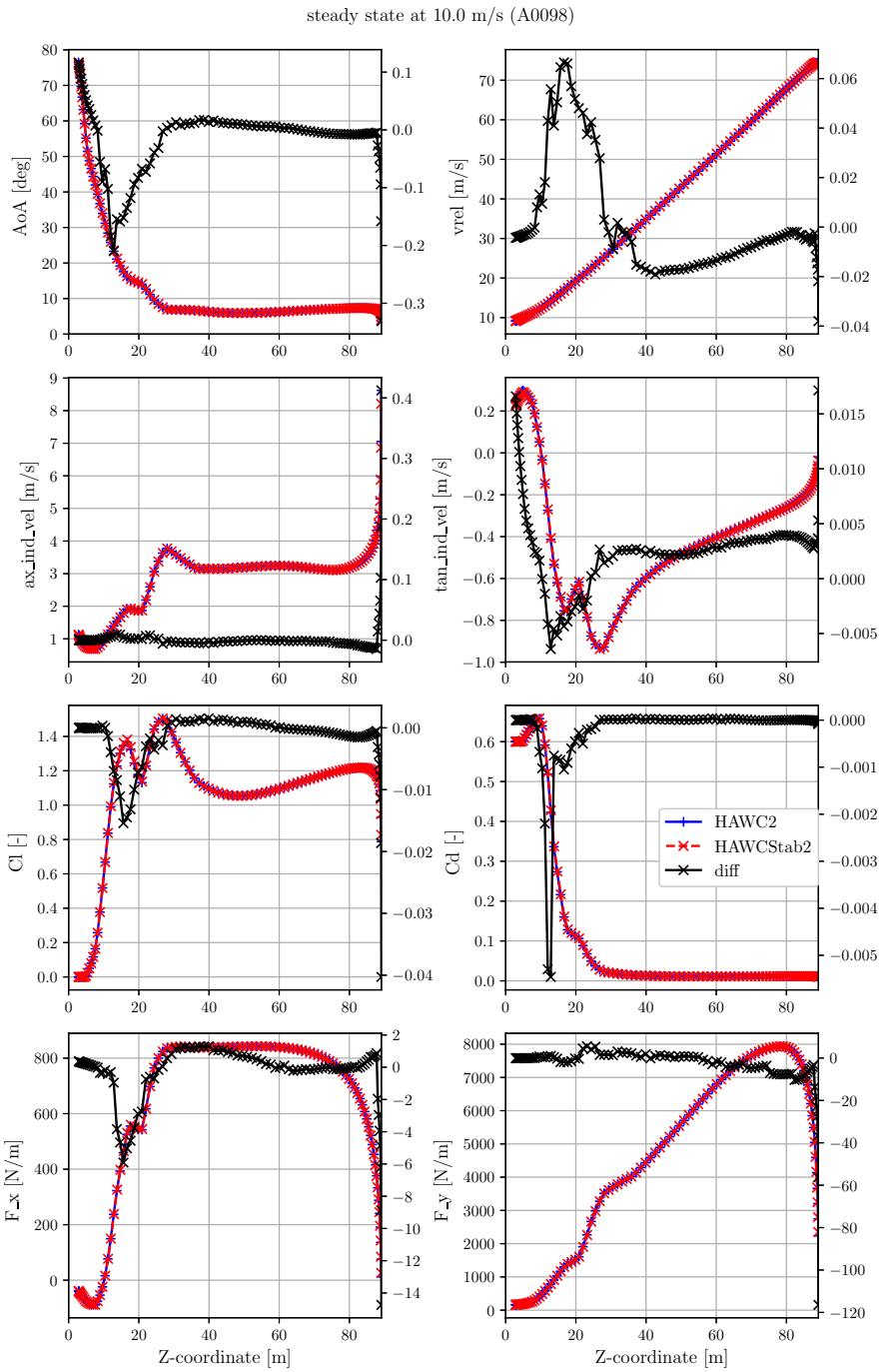


Figure 15: Blade load distribution at 10 m/s

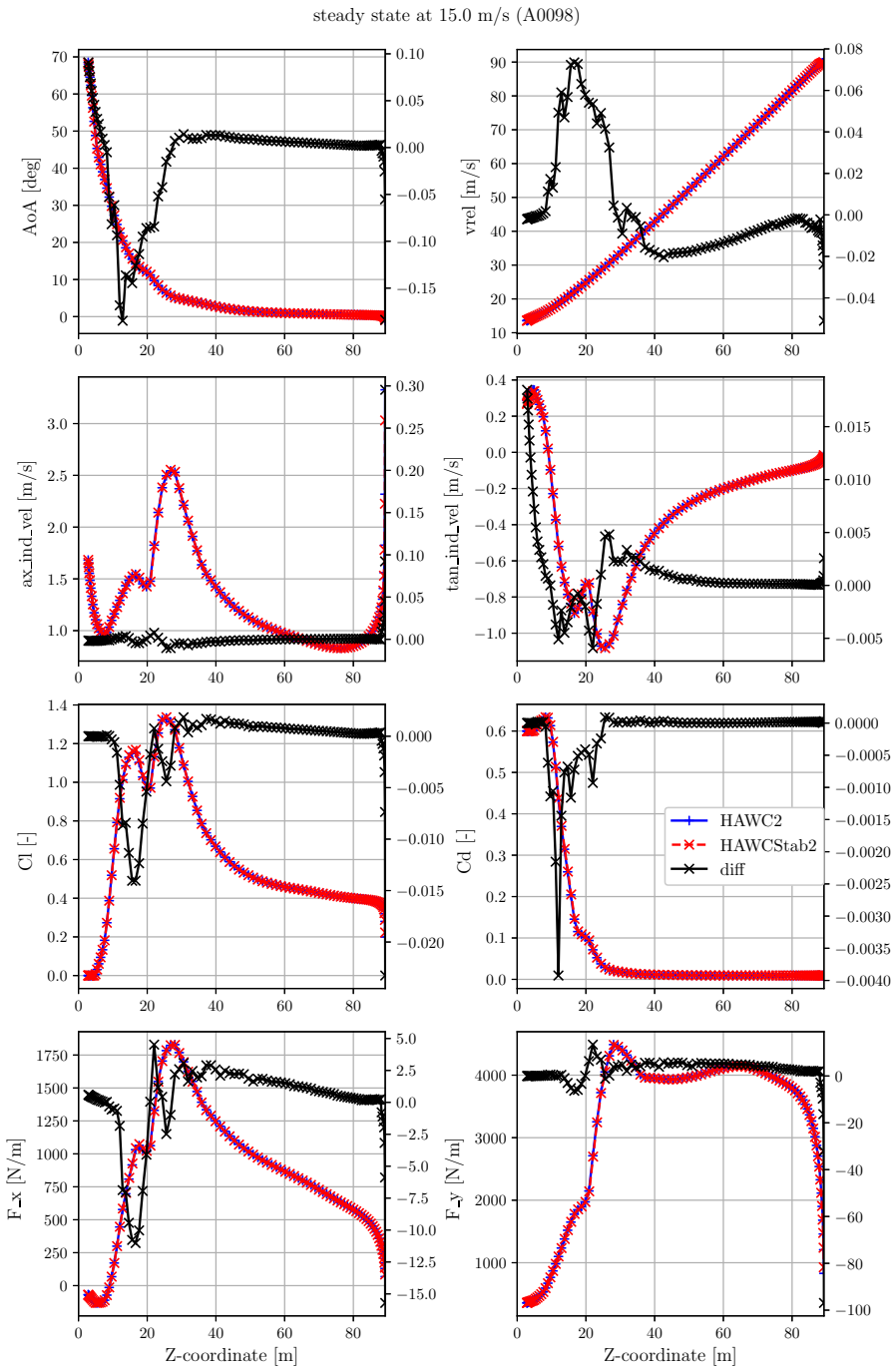


Figure 16: Blade load distribution at 15 m/s

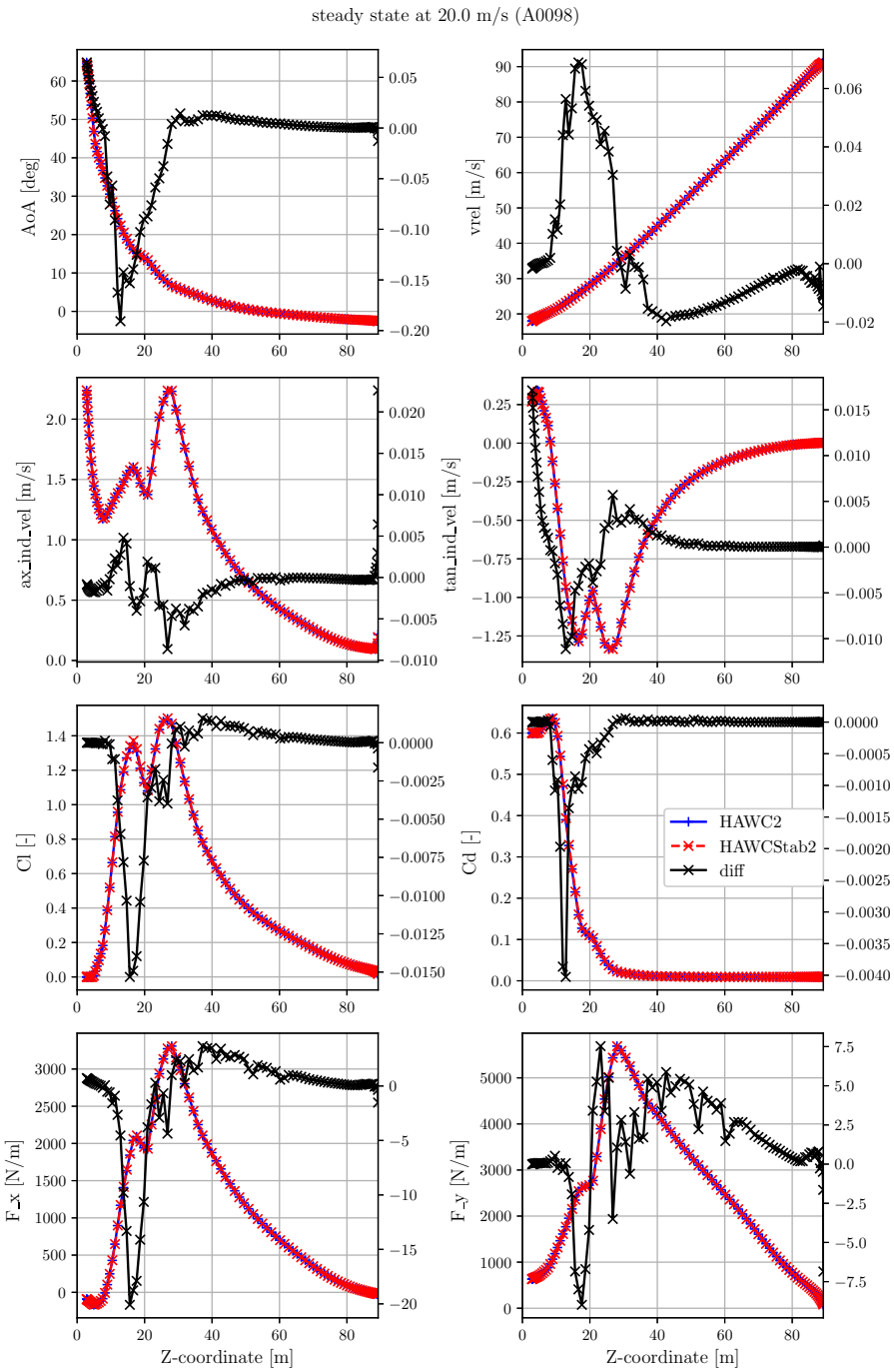


Figure 17: Blade load distribution at 20 m/s

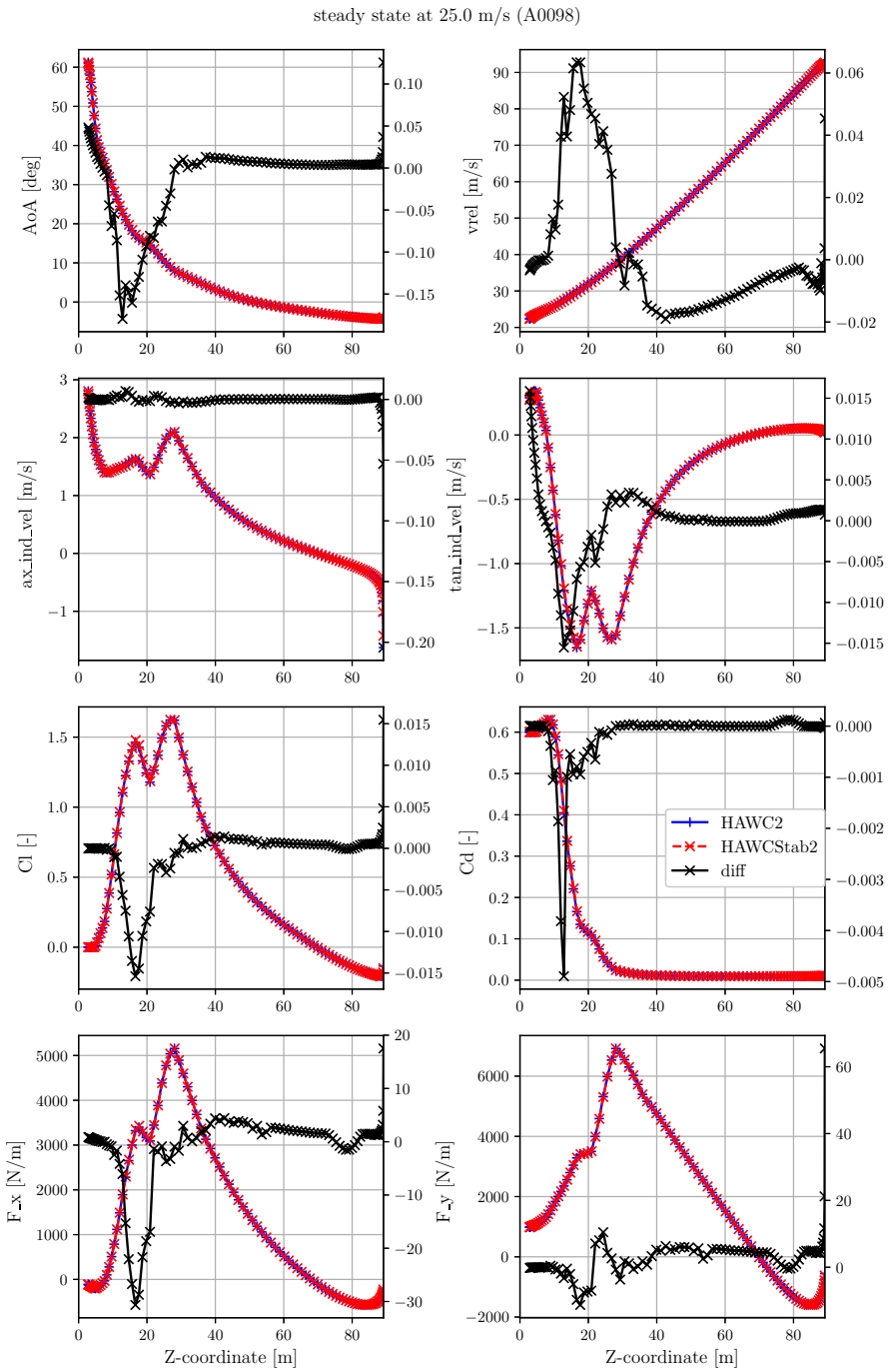


Figure 18: Blade load distribution at 25 m/s

3 Improvements Since Previous Comparison

The previous published steady state comparison between HAWC2 and HAWCStab2 considered versions 12.2 and 2.12 respectively [4]. The results shown here are in general an improvement compared to the previous releaseses. The absolute error for the distributed loading for example has decreased with factor of roughly two. A detailed one to one comparison between successive releases of HAWCStab2 is not considered within the scope of this report, but the reader is encouraged to compare the figures between this and the previous comparison [4] side-by-side.

Note that both HAWC2 and HAWCStab2 have now an updated relationship between c_t and the axial induction a_x (see [4] section 2.4) that has a smooth transition when going towards negative thrust. At high wind speeds there is no longer a larger error for the outboard sections of the blade.

There remains a small difference at the inboard blade sections. In [4] it was expected that recent changes to HAWC2 would have solved this issue. However, these changes did not hold the expected improvements with respect to the comparison to HAWCStab2. Resolving this issue therefore is again referred to future work.

HAWC2 had some minor modifications in how the aerodynamic integrated forces are calculated when going from version 12.2 to 12.5. These changes explain some of the minor differences, considering the absolute errors on the integrated rotor performance characteristics, that can be observed in this report compared to the previous iteration.

4 Conclusions

This report discussed the differences of the aerodynamic performance and loading of the DTU10MW reference turbine using steady state results between HAWC2 and HAWCStab2. There is a consistently good agreement between HAWC2 and HAWCStab2 for both the rotor integrated forces as well as for the distributed blade performance parameters. The small differences that have been noted can be summarized as follows:

- Integrated rotor performance parameters (rotor power and thrust) differences are below 1%.
- Distributed blade parameters show a small difference at the inboard sections, but the exact source of this discrepancy remains unclear.
- The Prandtl tip correction model introduces a small discrepancy at the tip. This issue is referred to future work.

Finally, it is concluded that the steady state performance computations of HAWCStab2 v2.14 are very close to the steady state simulation results of HAWC2 v12.5. Minor differences, who do not show to affect the steady state performance of the DTU10MW in a significant manner, are to be addressed in future version comparisons.

5 Future Work

Future comparisons should consider the following additional parameters:

- Rotor blade deflections (flap, edge and torsion)
- Tip correction model
- Aerodynamic torsion moment
- Structural eigenfrequencies at standstill
- Transfer functions, for example between rotor speed and blade loads

References

[1] Larsen, T. J. Hansen, A. M., *How 2 HAWC2, the user's manual.* version 3-1, 2007 URL http://orbit.dtu.dk/en/publications/how-2-hawc2-the-users-manual(18aac953-55e6-4130-9b54-a6830618c5ca).html

[2] Latest HAWC2 user manual download page. URL http://www.hawc2.dk/Download/HAWC2-Manual

[3] HAWC2 website. URL http://www.hawc2.dk/

[4] Verelst et. al. *Steady state comparisons HAWC2 v12.2 vs HAWCStab2 v2.12* URL http://orbit.dtu.dk/en/publications/steady-state-comparisons-hawc2-v122-vs-hawcstab2-v212(45074c27-fb34-4530-b387-54f9acdd8f0b).html

[5] Bak et. al. *The DTU 10-MW Reference Wind Turbine.* presented at the Danish Wind Power Research 2013, Fredericia, Denmark, 2013. URL http://orbit.dtu.dk/en/publications/the-dtu-10mw-reference-wind-turbine(bc5f61cd-4c51-442f-89eb-02df89ab0aa4).html

[6] The DTU 10MW Reference Wind Turbine Project Site. URL http://dtu-10mw-rwt.vindenergi.dtu.dk/

[7] Hansen, M. H., *Aeroelastic stability analysis of wind turbines using an eigenvalue approach.* Wind Energy, 7: 133–143, 2014. doi: 10.1002/we.116.

[8] Hansen, M. H., *Aeroelastic Properties of Backward Swept Blades.* In 49th AIAA Aerospace Sciences Meeting Including the New Horizons Forum and Aerospace Exposition, 2011. Orlando, FL. doi: 10.2514/6.2011-260.

[9] HAWCStab2 webite. URL http://www.hawcstab2.vindenergi.dtu.dk/

[10] Madsen, H. A. *A CFD Analysis of the Actuator Disc Flow Compared with Momentum Theory Results.* Proceedings of the 10th Symposium on Aerodynamics of Wind Turbines, pp. 109–124, IEA Joint Action, Edinburgh, 1996. URL https://www.researchgate.net/publication/281319996

DTU Wind Energy
Department of Wind Energy
Technical University of Denmark

RisøCampus Building 118
Frederiksborgvej 399
DK-4000 Roskilde
www.vindenergi.dtu.dk