Qualification of innovative floating substructures for 10MW wind turbines and water depths greater than 50m

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Disclaimer

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Definitions & Abbreviations

DLL	Dynamic Link Library
DOF	Degree of Freedom
DTU	Technical University of Denmark
F-A	fore-aft
FAST	Fatigue, Aerodynamics, Structures, and Turbulence
FEM	Finite Element Method
HAWC2	Horizontal Axis Wind Turbine simulation Code 2nd generation
IEC	International Electrotechnical Commission
NREL	National Renewable Energy Laboratory
S-S	side-side

Executive Summary

This report outlines the implementation of the DTU 10MW Reference Wind Turbine within the FAST numerical design tool for use within LIFES50+. The purpose of this implementation is to serve as a reference for floating substructure design and optimization activities carried out by partners within the project consortium. FAST v8.12.00a-bjj was selected as the version for developing the numerical model implementation. The whole wind turbine system structural model made use of the ElastoDyn module, which considers linearized response shape representations linked through a multi-body formulation. AeroDyn v14 was selected to carry out aerodynamic load calculations as it has unsteady aerodynamic capabilities. The DTU Wind Energy controller was included as a DLL, making use of the Bladed-style interface available in FAST. A systematic assessment of the FAST model implementation was carried out, starting with verifying isolated component natural frequencies as well as whole system natural frequencies. The steady state performance of the FAST model implementation was compared against HAWC2, with good overall agreement. Small discrepancies arise close to the rated wind speed due to model sensitivities. The steady state blade pitch angle was larger for the FAST model implementation at above-rated wind speeds due to the simpler blade structural model present relative to HAWC2. The absence of the blade torsional degree of freedom in FAST results in the whole blade required to be pitched to compensate for blade torsional deformations that occur in HAWC2. A wind ramp simulation was subsequently carried out to demonstrate that the FAST controller implementation performs adequately. Finally, a reduced set of stochastic simulations were run to characterize control and turbine response performance. Possible future developments regarding blade structural and aerodynamic modelling are discussed and accessibility to the public version of the DTU 10MW Reference Wind Turbine FAST model implementation is outlined.

Contents

1 Introduction

This report describes the implementation of the land-based DTU 10MW Reference Wind Turbine in the FAST aero-hydro-servo-elastic design tool developed by the National Renewable Energy Laboratory (NREL). The *onshore* aero-elastic model described here forms the basis for carrying out dynamic simulations of floating wind turbine concepts within LIFES50+. It is intended to serve as a reference for the simulations carried out by the LIFES50+ partners of the DTU 10 MW Reference Wind Turbine. Developments over the course of the project which are implemented into the model, and updates of the described FAST model will be shared within the consortium. Particularly this includes updates related to upcoming FAST versions as described in section 4, the floating offshore extension of the model for the planned two generic floater concepts (D4.2, D4.5) and an adaptation of the control system to accommodate the floating concepts (D1.4).

Following an overview of the differences between current versions of FAST and a brief description of the turbine, section 2 outlines the model development process. Section 3 then presents the assessment of the FAST model against the existing HAWC2 model, followed by section 4 that outlines future development activities in line with new releases of FAST. Finally section 5 directs the reader to the repository containing the publicly-available FAST model implementation.

1.1 FAST version overview

FAST is continually being updated to enhance the capabilities of the code to better simulate the dynamic response of wind turbines. In particular, NREL has recently implemented a new modularization framework within FAST to improve code usability and performance. In relation to LIFES50+, there are three versions of the code that were considered in this work. Table 1 lists these versions and their relevant modelling capabilities for the case of the land-based DTU 10MW Reference Wind Turbine. Note that additional modules in FAST for floating substructure and mooring system modelling are not included here.

Version	Release date	Code framework	Tower	Drivetrain	Blades	Controller
v7.02.00d-bjj	27.02.2013	Monolithic	Modal	Flexible DOF	Modal	DLL
v8.10.00a-bjj	31.03.2015	Modular	Modal	Flexible DOF	Modal	DLL
v8.12.00a-bjj	06.10.2015	Modular	Modal	Flexible DOF	Modal or FEM	DLL

Table 1 - Overview of FAST versions

1.2 Reference wind turbine description

The DTU 10MW Reference Wind Turbine, visualized in Figure 1, was originally developed through cooperation between DTU Wind Energy and Vestas with the Light Rotor project. The development of this rotor is described in detail in Bak et al. (Bak, 2013). The three-bladed, upwind wind turbine has been designed considering an IEC class 1A wind climate (IEC, 2009) and has a rated power of 10MW. Table 2 provides an overall description of the parameters defining the wind turbine (Bak, 2013).

2 Model development process and chosen FAST modules

Based on the design described by Bak et al. (Bak, 2013) and the HAWC2 aero-servo-elastic model available at http://dtu-10mw-rwt.vindenergi.dtu.dk/, a model of the Reference Wind Turbine was constructed in FAST version 8.12. FAST v8.12 is composed of a number of different modules, c.f. (Jonkman, 2015a), and allows for different levels of modelling detail. Initially v8.12 was used considering the FEM blade module, BeamDyn (Wang, 2015), to capture the dynamic response of the large flexible blades of the wind turbine. However, due to computational and development issues, the blade model was reverted back to the modal-based ElastoDyn module. AeroDyn v14 was selected as the aerodynamic module due to unsteady aerodynamic capabilities that are not yet available in AeroDyn v15. Table 3 shows the version of each module used for the current version of the DTU 10MW Reference Wind Turbine FAST model.

Rotor Orientation	Clockwise rotation – upwind
Control	Variable speed Collective pitch
Cut in wind speed [m/s]	4
Cut out wind speed [m/s]	25
Rated wind speed [m/s]	11.4
Rated power [MW]	10.0
Number of blades	3
Rotor diameter [m]	178.3
Hub diameter [m]	5.6
Hub height [m]	119.0
Drivetrain	Medium speed, multiple-stage gearbox
Minimum rotor speed [rpm]	6.0
Maximum rotor speed [rpm]	9.6
Gearbox ratio	50
Hub overhang [m]	7.1
Shaft tilt angle [deg]	5.0
Rotor precone angle [deg]	-2.5
Blade prebend [m]	3.332
Rotor mass [kg]	227,962
Nacelle mass [kg]	446,036
Tower mass [kg]	628,442

Table 2 - Overall parameters of the DTU 10MW Reference Wind Turbine

Figure 1 - The DTU 10MW Reference Wind Turbine

Implementation version	FAST release	AeroDyn	ElastoDyn	ServoDyn	InflowWind
v1.00	v8.12.00a-bjj	v14.04.00a-bjj	v1.03.00a-bjj	v1.03.01a-bjj	v3.011.00a-adp
		Steady/Unsteady aerodynamics	Modal	DLL	Steady + turbulent

Table 3 - Turbine and FAST module versions

2.1 Structural model implementation

The structural model representing the tower and blades of the system is based on a linearized response shape representation linked through a multi-body formulation. In ElastoDyn this is achieved by estimating sixth-order polynomials to a subset of the eigen-modes of the blades and tower. In the case of the tower, the first two fore-aft and first two side-side eigen-modes are considered. In the case of each blade, the first edgewise and first two flapwise eigen-modes are considered. The eigen-modes were calculated using BModes (Bir, 2007), see relevant input files in section 8.7, and the same structural damping determined by (Bak, 2013) was prescribed for each eigen-mode. The sixth-order polynomial coefficients required by FAST for representing the mode shapes were estimated through a least-squares approach with the MATLAB Curve Fitting Toolbox (Mathworks, 2015). The drivetrain is modelled with one flexible degree of freedom between the hub and generator with an equivalent linear torsional spring and linear torsional damper, c.f. (Jonkman, 2005). The same drivetrain stiffness and damping values as prescribed by (Bak, 2013) were applied in the FAST model.

2.2 Aerodynamic model implementation

The aerodynamic loading on the turbine is calculated using modified blade element momentum theory in AeroDyn, as detailed by (Moriarty, 2005). The airfoil data used by FAST is the same as that used in the HAWC2 model. As can be seen in the AeroDyn input file in section 8.2 unsteady aerodynamics are enabled (Beddoes-Leishman dynamic stall model). However, the influence of the tower on local airflow calculations is not enabled. This is because in AeroDyn v14, the tower potential flow model used to calculate this influence does not move with the tower but is fixed in the initial position. This is of relevance to floating wind turbine simulations, where this limitation can cause nonphysical local flow calculations. At present a moving tower potential flow model is not implemented with unsteady aerodynamics, and hence it was decided to select AeroDyn v14 which contains unsteady aerodynamics.

2.3 Controller model implementation

The DTU Wind Energy controller as described by (Hansen, 2013), was implemented as a DLL to interact with the FAST model. The controller enables both partial and full load operation, with switching mechanisms that streamline the transition between the two modes of operation. Based on proportional-integral control with additional filters, the controller uses the collective blade pitch angle and electromagnetic generator torque to control the wind turbine. The DLL implementation was compiled as a 32-bit application, and hence the 32-bit version of FAST v8.12 must currently be used with the DTU 10MW Reference Wind Turbine model. The controller was modified slightly for this implementation relative to the HAWC2 version. A wrapper was used around the original FORTRAN code to make use of the Bladed-style interface available in FAST. A filter was also included on the rotational speed in order to avoid instabilities in the FAST model within the full load region when employing a constant-power control strategy. However no tuning modifications were carried out and the present implementation is considered as the same controller as that in HAWC2.

2.4 HAWC2 and FAST differences

The HAWC2 design tool that was used to design the DTU 10MW Reference Wind Turbine contains different engineering models to simulate a wind turbine compared to FAST. Both tools have implemented blade element momentum theory and subsequent modifications in different ways such that they cannot be classified to have identical aerodynamic load models. Further to this, the structural models representing the wind turbine system are fundamentally different between the two tools. HAWC2 makes use of a multi-body formulation based largely on a finite element implementation of Timoshenko beam theory, whilst FAST makes uses of a response shape formulation. The latter linearizes the response of the individual turbine elements (e.g. blades and tower), excluding a subset of degrees of freedom that may be important for the large, flexible blades that compose the DTU 10MW Reference Wind Turbine rotor. Table 4 presents the number of degrees of freedom used to represent the blade and tower in HAWC2 and FAST. With this in mind, the following section assesses the FAST model implementation against the HAWC2 model, identifying differences between predictions from the two tools.

	HAWC2 model	FAST model
Blade, single	156	3
Tower	66	4

Table 4 - Number of blade and tower degrees of freedom considered in the HAWC2 and FAST models

2.5 Possible future updates of the FAST submodels

2.5.1 Structural model

NREL are currently developing FAST with the option of using an alternative structural module BeamDyn mentioned previously that could better capture the aeroelastic behaviour of the large flexible blades of the DTU 10MW Reference Wind Turbine. This module was investigated for use in the turbine model implemented here, but reduced computational efficiency and numerical instabilities have restricted the structural submodel to make use solely of ElastoDyn, described above. The main advantage of using BeamDyn would be to capture the bend-twist and other blade couplings that can have a significant impact on loads. However the current computational efficiency of the model has restricted its practical use in the design and optimization of floating substructures. Hence once computational and numerical issues are resolved it may be possible to substitute the ElastoDyn blade submodels with BeamDyn submodels.

2.5.2 Aerodynamic model

An updated AeroDyn module, version 15 (Jonkman, 2015b), is available that resolves the issue regarding the tower potential model mentioned previously. However the current release of AeroDyn v15 does not include unsteady aerodynamics, and this was seen as a critical priority for the wind turbine model. Hence AeroDyn v14 was selected. Once AeroDyn v15 includes unsteady aerodynamics and the BeamDyn structural submodel is considered, it may be possible to migrate to this version of AeroDyn.

3 Model assessment

3.1 System identification

The first step taken in assessing the model implementation was to check the predicted natural frequencies. First, the isolated modes of the blade identified by the FAST preprocessor tool BModes were checked against HAWC2 predictions. Table 5 presents the isolated natural frequencies for the first three eigen-modes that are considered in the FAST structural model, with an acceptable comparison between HAWC2 and BModes.

The same comparison is not possible for the isolated tower. This is because of the method through which eigen-modes are determined in BModes and in HAWC2. For the case of the tower, in BModes it is necessary to include the tower top mass to adequately derive the eigen-mode shapes and frequencies that are then considered in FAST. However, in HAWC2 the tower is considered to be cantilevered at one end and free at the other end and that is without the rotor-nacelle assembly installed. This would then result in different mode shapes and frequencies between the two models. Hence, a comparison of the isolated tower frequencies is not presented here.

Mode description	HAWC2 (Hz)	BModes/FAST (Hz)	Difference (%)
1st flap mode	0.610	0.620	1.64
1st edge mode	0.930	0.920	1.08
2nd flap mode	1.740	1.780	2.30

Table 5 - Natural frequencies for the isolated blade predicted by BModes and HAWC2

FAST v8.12 at present does not have a linearization capability to identify eigen values and modes of the whole wind turbine system. Hence, to verify the natural frequencies of the FAST model against those of the HAWC2 model, free decay simulations were carried out. Two simulations were considered:

1. An out-of-plane blade tip deflection of five metres was applied as an initial condition
2. A tower top displacement of five metres in the fore-aft direction was applied as an initial condition.

In both cases no aerodynamic loads were applied and the rotor was parked. A simulation duration of 300 seconds was considered and spectral plots of blade tip displacement and tower top displacement were derived. Figure 2 presents the spectral responses for the first case, and Figure 3 presents the spectral responses for the second case. Note that here the out-of-plane blade tip deflection is in the windward direction and is of the blade oriented vertically upwards, c.f. Figure 1. The tower top displacement is in the fore-aft direction.

The two decay tests allow a check of three global modes, namely the first tower fore-aft/side-side mode; the first collective blade flap mode; and the first asymmetric blade edge mode. The obtained frequencies are listed in Table 6 and shows an acceptable comparison to the HAWC2 results. The largest deviation of 4.28 percent for the first asymmetric blade edge mode is likely a consequence of the linearization in FAST. Note that more natural frequencies can be checked by additional decay tests with specialized initial conditions.

Mode description	HAWC2 (Hz)	FAST (Hz)	Difference (%)
1st tower fore-aft and side-side mode	0.251	0.247	1.59
1st collective blade flap mode	0.630	0.636	0.95
1st asymmetric blade edge mode	0.935	0.975	4.28

Table 6 - Identified natural frequencies

Whilst it would be ideal to identify a larger set of natural frequencies, it is not directly possible without linearization of the whole model (not yet available in FAST v8.12).

3.2 Steady-state system performance

The global steady-state performance of the FAST model implementation was evaluated across the operating wind speed range. Figure 4 presents the FAST model performance compared to results derived from HAWC2. These data may also be found tabulated in Appendix B.

The steady state performance can be summarized as follows:

In the range 4 – 10 m/s the FAST controller implementation matches the HAWC2 controller implementation in controlling rotational speed and blade pitch to yield optimum power production. For wind speeds below 7 m/s, the rotational speed reaches its lower limit of 6 RPM and the blades are pitched to yield optimum power at the actual tip speed ratio. A good match with the HAWC2 results is seen for the rotational speed, blade-pitch, tower top fore-aft shear force and power. The small discrepancies observed are ascribed to the difference in the modelling of blade-flexibility between HAWC2 and FAST, where the modal blade model is limited by the linear assumption of small deflections.

In the range 10 – 12 m/s there is a transition from partial to full load operation. Here, the model is particularly sensitive and discrepancies in rotor speed between HAWC2 and the FAST implementation are seen.

In wind speeds greater than 12 m/s, the turbine operates in the full load regime. Here the controller adjusts the generator torque to obtain the maximum rotor speed of 9.6 RPM and the blade pitch to obtain the target electrical power of 10 MW. Both values are reached with good accuracy by the FAST model. A larger blade pitch, however, is required by the FAST implementation. This is mainly due to the lack of blade torsional deformations that become more significant at above-rated wind speeds. The tower top fore-aft shear forces are in good agreement, with small differences attributed to the different aerodynamic and blade structural models used in the two tools. The electrical power output is also in good agreement, with small discrepancies around the rated wind speed due to the aforementioned reason.

In conclusion, the global performance of the FAST model shows an overall good match. The main differences occur at the transition to rated wind speed and within the rated wind speed regime and are explained by the differences between the HAWC2 and FAST aerodynamic and structural models.

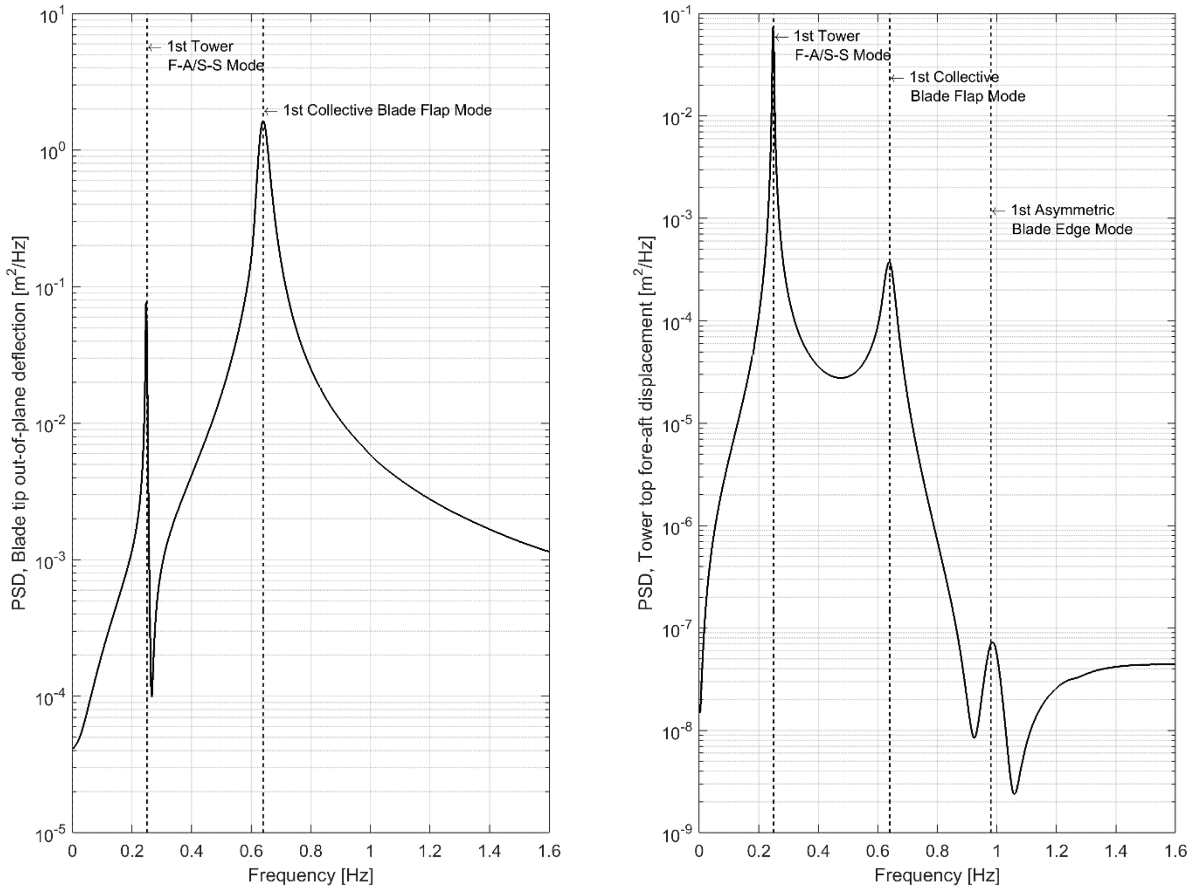

Figure 2 - Power spectral density plots for first free decay simulation. Left, blade tip out-of-plane deflection; right, tower top fore-aft displacement

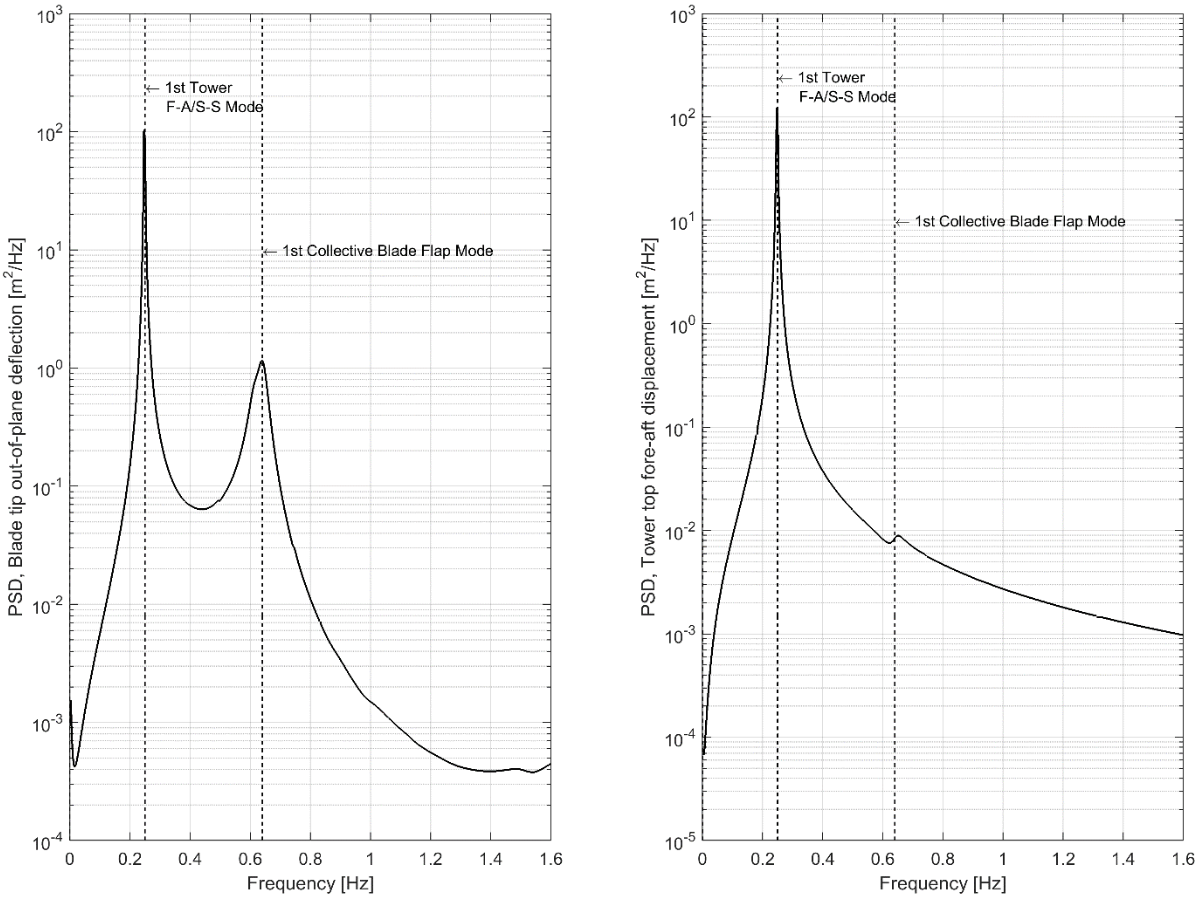

Figure 3 - Power spectral density plots for second free decay simulation. Left, blade tip out-of-plane deflection; right, tower top fore-aft displacement

3.3 Transient and stochastic system performance

A wind ramp scenario was next considered to assess the general performance of the wind turbine controller implementation. Starting at the cut-in wind speed (4m/s) positive step changes of 0.5m/s were successively applied every 50 seconds until the cut-out wind speed was reached. The global turbine response is presented in Figure 5. As can be seen the controller performs as required, achieving the steady-state power and fore-aft tower top shear force sufficiently without significant delay. For the rotational speed, an off-set of the rotational speed relative to the steady-state results are seen throughout the partial load regime. A clear explanation of this will be pursued in the update process of the model. It is noted, however, that the good match for power and tower top shear force is more important for the dynamic load calculations than the correct rotational speed.

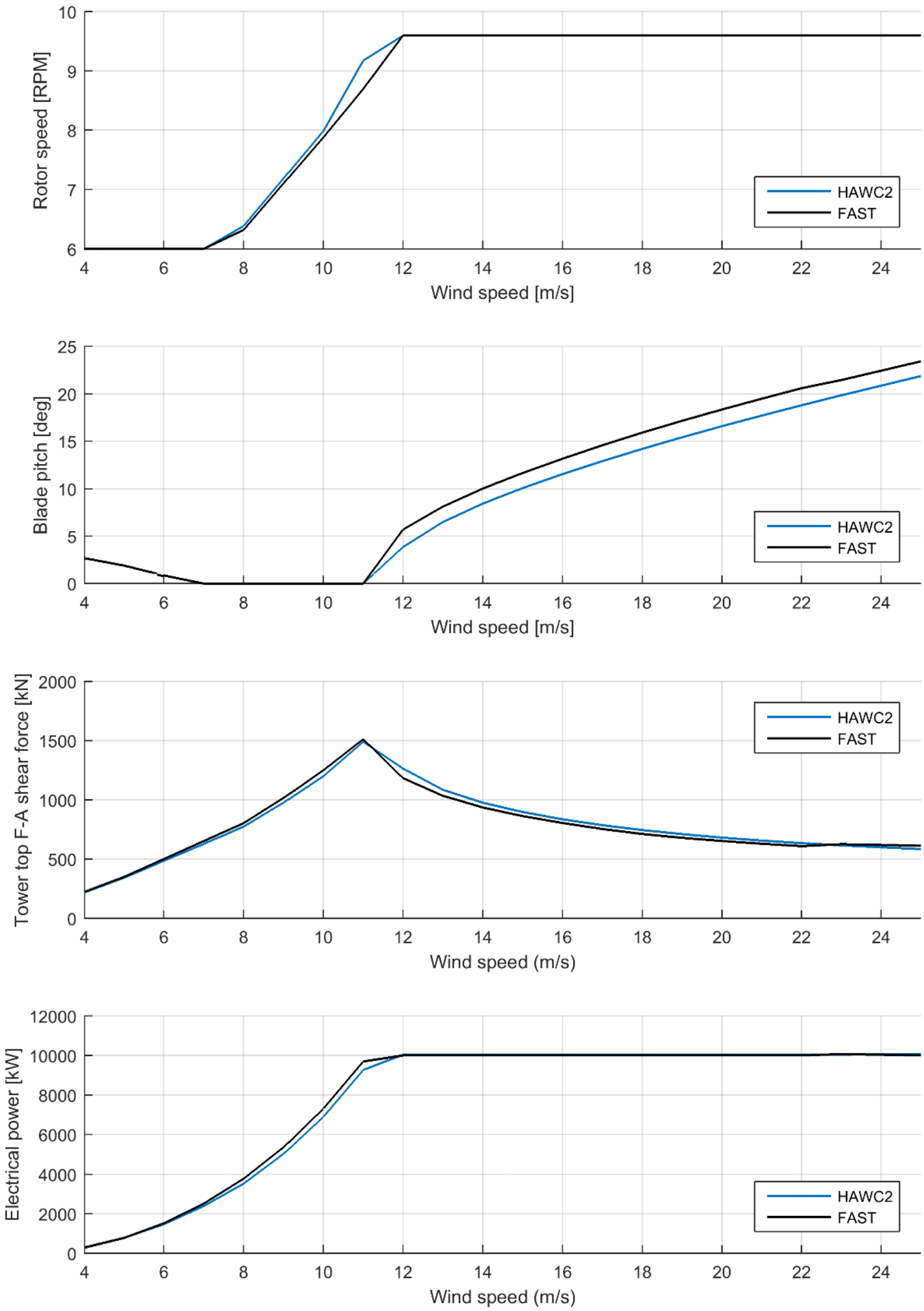

Figure 4 - Steady state performance of the FAST model implementation

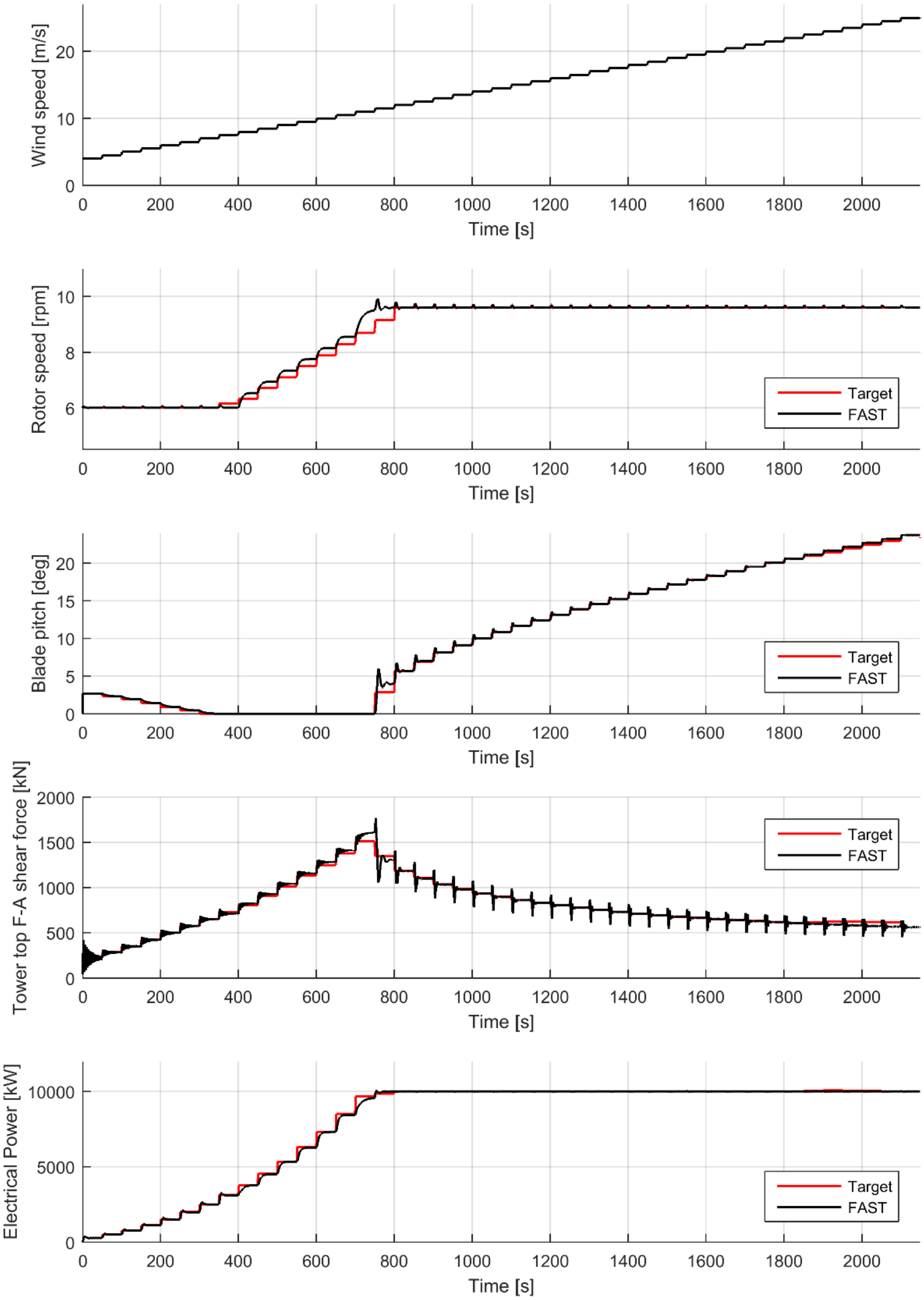

Figure 5 - Wind ramp simulation results for the FAST model. The target curves are based on steady-state FAST results.

Stochastic wind simulations were also carried out for three mean wind speeds: below-rated (7m/s), rated (11.4m/s) and above-rated (15m/s). The stochastic wind conditions were based on IEC Class A, using the Kaimal turbulence model. Refer to the TurbSim input file in section 8.6 for further details. Figure 6 presents sample results of the simulation for rated conditions, with rated power being maintained in the fluctuating wind. Table 8 in section 9.2 contains statistical data for the three stochastic simulations. These results can be used to benchmark local application of the FAST model.

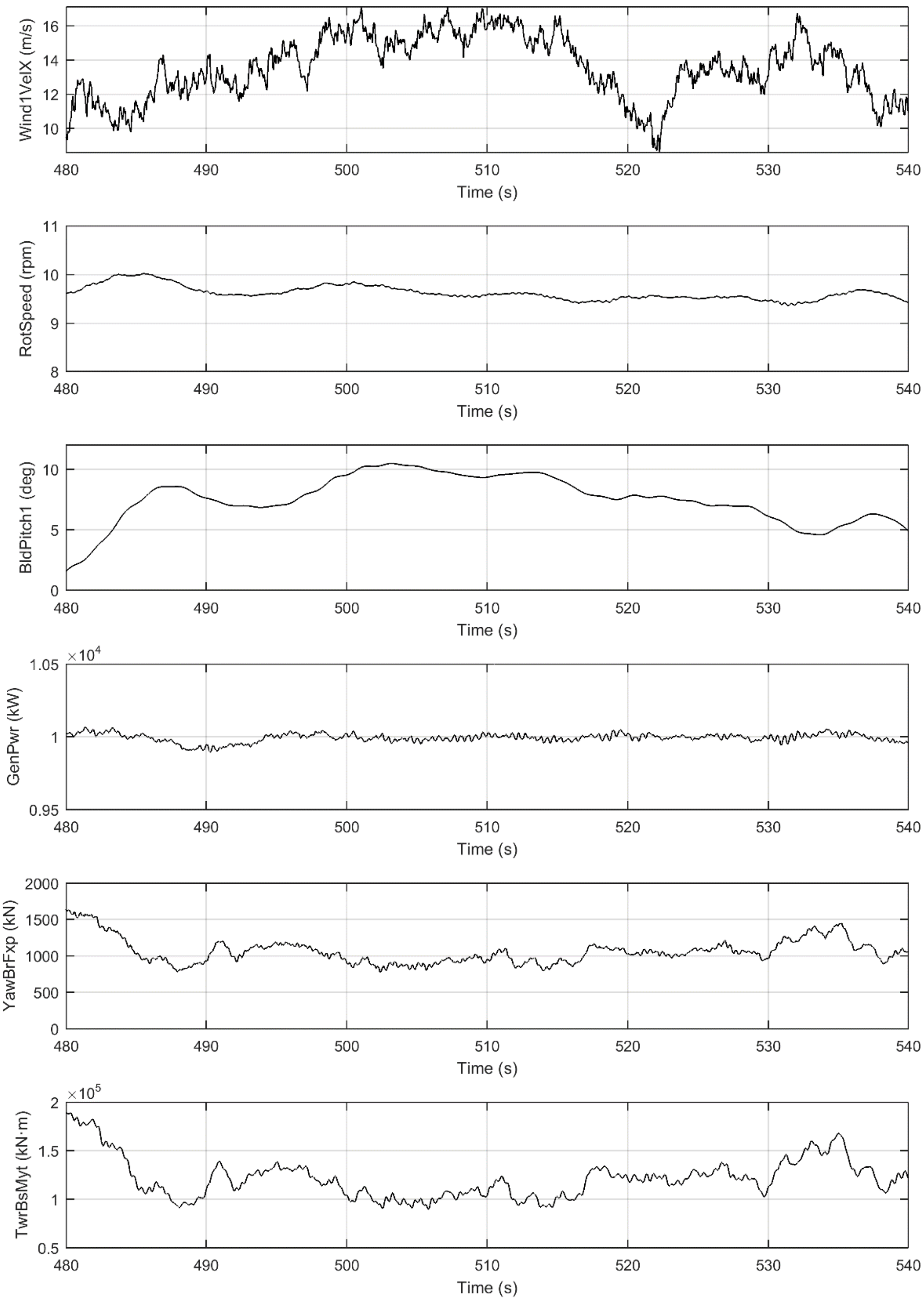

Figure 6 - Sample stochastic time series for FAST stochastic simulation at rated conditions

4 Future developments

Further development of the DTU 10MW Reference Wind Turbine FAST model will focus on integrating the improvements being made to BeamDyn and AeroDyn in future releases of FAST, as discussed in section 2.5. The computational speed is vital for practical use of the FAST model within design and optimization of floating substructures. The trade-off between blade model accuracy and computational efficiency will therefore be a central aspect in the decisions for future model updates.

5 Model accessibility & referencing

The FAST model is freely available to the public at http://dtu-10mw-rwt.vindenergi.dtu.dk/. In the event of publication of work resulting from the use of this model, appropriate referencing to Bak et al. (Bak, 2013) and this report should be made.

The associated repository contains two directories: ReferenceModal, a reference 'modal-based' model; and TestRuns, a set of test runs. The associated 'ReadMe' text file provides an overview of updated listings within the repository.

6 Conclusions

This report presented the development and assessment of a FAST model implementation of the DTU 10MW Reference Wind Turbine. FAST v8.12.00a-bjj was considered to carry out simulations, with the major point of interest being that the whole turbine structure is still modelled with a modal representation to maintain sufficient computational efficiency and stability, despite a more advanced blade structural model being available. The steady-state performance of the FAST model has been compared to the HAWC2 implementation and an overall good match has been found. Due to the inherent aerodynamic and structural modelling differences between the tool used to design the turbine, a perfect match cannot be expected. The tower top F-A shear force shows only smaller deviations to the HAWC2 results. For wind speeds below rated, a slight over-prediction occur, followed by a slight under-prediction up to about 23 m/s, where over-prediction occurs again until cut-out. The controller implementation was shown to perform satisfactorily to a wind ramp scenario. The FAST model presented in this report is available to the public at the repository listed above and at the LIFES50+ internal website. Finally, the FAST model implementation will continue to be developed during the LIFES50+ project, incorporating a generic floater, tuned controller settings and relevant new capabilities in future releases of FAST.

7 References

(Bak, 2013) C. Bak, F. Zahle, R. Bitsche, T. Kim, A. Yde, L.C. Henriksen, A. Natarajan, M.H. Hansen. *Description of the DTU 10 MW Reference Wind Turbine*, DTU Wind Energy Report-I-0092, Roskilde, Denmark.

(Bir, 2007) G.S. Bir. *User's Guide to BModes*. National Renewable Energy Laboratory, Golden, Colorado.

(Hansen, 2013) M.H. Hansen, L.C. Henriksen. *Basic DTU Wind Energy controller*, DTU Wind Energy Report-E-0018, Roskilde, Denmark.

(IEC, 2009) International Electrotechnical Commission. *Wind turbines – part 3: design requirements for offshore wind turbines*, IEC 61400-3:2009.

(Jonkman, 2005) J.M. Jonkman, M.L. Buhl. *FAST User's Guide*. NREL/EL-500-38230, National Renewable Energy Laboratory, Golden, Colorado.

(Jonkman, 2015a) B.J. Jonkman, J.M. Jonkman. *Guide to changes in FAST v8: v8.12.00a-bjj*. National Renewable Energy Laboratory, Golden, Colorado, available at: https://nwtc.nrel.gov/FAST8.

(Moriarty, 2005) P.J. Moriarty, A.C. Hansen. *AeroDyn Theory Manual*. NREL/TP-500-36881, National Renewable Energy Laboratory, Golden, Colorado, USA.

(Jonkman, 2015b) J.M. Jonkman, G.J. Hayman, B.J. Jonkman, R.R. Damiani. *AeroDyn v15 User's Guide and Theory Manual*. Draft report, National Renewable Energy Laboratory, Golden, Colorado, accessed 03/11/2015, available at: https://nwtc.nrel.gov/AeroDyn.

(Mathworks, 2015) Mathworks. *MATLAB Curve Fitting Toolbox: User's Guide*. Natick, MA, USA.

(Wang, 2015) Q. Wang, J.M. Jonkman, M. Sprague, B.J. Jonkman. *BeamDyn User's Guide*. Draft report, National Renewable Energy Laboratory, Golden, Colorado, accessed 03/11/2015, available at: https://nwtc.nrel.gov/BeamDyn.

8 Appendix A: FAST model input files

8.1 Primary input file

```
------- FAST v8.12.* INPUT FILE ------------------------------------------------
FAST model of the DTU 10MW Reference Wind Turbine, onshore version 1.00
---------------------- SIMULATION CONTROL --------------------------------------
False         Echo            - Echo input data to <RootName>.ech (flag)
"FATAL"       AbortLevel      - Error level when simulation should abort (string) {"WARNING",
"SEVERE", "FATAL"}
       630   TMax            - Total run time (s)
     0.0125   DT              - Recommended module time step (s)
          1   InterpOrder     - Interpolation order for input/output time history (-)
{1=linear, 2=quadratic}
          0   NumCrctn        - Number of correction iterations (-) {0=explicit calculation,
i.e., no corrections}
     999999   DT_UJac         - Time between calls to get Jacobians (s)
      1E+06   UJacSclFact     - Scaling factor used in Jacobians (-)
---------------------- FEATURE SWITCHES AND FLAGS ------------------------------
          1   CompElast       - Compute structural dynamics (switch) {1=ElastoDyn; 2=ElastoDyn
+ BeamDyn for blades}
                 1   CompInflow      - Compute inflow wind velocities (switch) {0=still air;
1=InflowWind; 2=external from OpenFOAM}
          1   CompAero        - Compute aerodynamic loads (switch) {0=None; 1=AeroDyn v14;
2=AeroDyn v15}
          1   CompServo       - Compute control and electrical-drive dynamics (switch)
{0=None; 1=ServoDyn}
          0   CompHydro       - Compute hydrodynamic loads (switch) {0=None; 1=HydroDyn}
          0   CompSub         - Compute sub-structural dynamics (switch) {0=None; 1=SubDyn}
          0   CompMooring     - Compute mooring system (switch) {0=None; 1=MAP++;
2=FEAMooring; 3=MoorDyn; 4=OrcaFlex}
          0   CompIce         - Compute ice loads (switch) {0=None; 1=IceFloe; 2=IceDyn}
---------------------- INPUT FILES ---------------------------------------------
"10MWRWT\DTU_10MW_RWT_ElastoDyn.dat"       EDFile          - Name of file containing ElastoDyn
input parameters (quoted string)
"unused"      BDBldFile(1)    - Name of file containing BeamDyn input parameters for blade 1
(quoted string)
"unused"      BDBldFile(2)    - Name of file containing BeamDyn input parameters for blade 2
(quoted string)
"unused"      BDBldFile(3)    - Name of file containing BeamDyn input parameters for blade 3
(quoted string)
"10MWRWT\DTU_10MW_InflowWind.dat"    InflowFile      - Name of file containing inflow wind
input parameters (quoted string)
"10MWRWT\DTU_10MW_RWT_AeroDyn.dat"      AeroFile        - Name of file containing aerodynamic
input parameters (quoted string)
"10MWRWT\DTU_10MW_ServoDyn.dat"    ServoFile       - Name of file containing control and elec-
trical-drive input parameters (quoted string)
```

```
"unused"    HydroFile       - Name of file containing hydrodynamic input parameters (quoted string)
"unused"      SubFile         - Name of file containing sub-structural input parameters (quot-ed string)
"unused"    MooringFile     - Name of file containing mooring system input parameters (quoted string)
"unused"      IceFile         - Name of file containing ice input parameters (quoted string)
---------------------- OUTPUT --------------------------------------------------
True          SumPrint        - Print summary data to "<RootName>.sum" (flag)
              2       SttsTime        - Amount of time between screen status messages (s)
      99999   ChkptTime       - Amount of time between creating checkpoint files for potential restart (s)
       0.0125   DT_Out          - Time step for tabular output (s)
          0   TStart          - Time to begin tabular output (s)
          2   OutFileFmt      - Format for tabular (time-marching) output file (switch) {1: text file [<RootName>.out], 2: binary file [<RootName>.outb], 3: both}
True          TabDelim        - Use tab delimiters in text tabular output file? (flag) {uses spaces if false}
"ES10.3E2"    OutFmt          - Format used for text tabular output, excluding the time chan-nel.  Resulting field should be 10 characters. (quoted string)
```

8.2 AeroDyn v14 input file

```
--------- AeroDyn v14.04.* INPUT FILE -----------------------------------------------------------------------
DTU 10.0 MW onshore baseline aerodynamic input properties, v1.00;Compatible with AeroDyn v14
BEDDOES                          StallMod       - Dynamic stall included [BEDDOES or STEADY] (unquoted string)
USE_CM                           UseCm          - Use aerodynamic pitching moment model? [USE_CM or NO_CM] (unquoted string)
EQUIL                            InfModel       - Inflow model [DYNIN or EQUIL] (unquoted string)
SWIRL                            IndModel       - Induction-factor model [NONE or WAKE or SWIRL] (unquoted string)
   0.005                         AToler         - Induction-factor tolerance (convergence cri-teria) (-)
PRANDtl                          TLModel        - Tip-loss model (EQUIL only) [PRANDtl, GTECH, or NONE] (unquoted string)
PRANDtl                          HLModel        - Hub-loss model (EQUIL only) [PRANdtl or NONE] (unquoted string)
"NEWTOWER"    TwrShad         - INSTEAD OF:   0.0      TwrShad     - Tower-shadow velocity def-icit (-)
False          TwrPotent      - Calculate tower potential flow (flag)  INSTEAD OF  9999.9 ShadHWid    - Tower-shadow half width (m)
False         TwrShadow       - Calculate tower shadow (flag)          INSTEAD OF  9999.9 T_Shad_Refpt- Tower-shadow reference point (m)
"unused"   TwrFile         - Tower drag file name (quoted string)
False                             CalcTwrAero    - Calculate aerodynamic drag of the tower at the ElastoDyn nodes.  TwrPotent must be true.
   1.225                         AirDens        - Air density (kg/m^3)
   1.464E-5                      KinVisc        - Kinematic air viscosity [CURRENTLY IGNORED] (m^2/sec)
   default                       DTAero         - Time interval for aerodynamic calculations (sec) !bjj: was 0.02479
   6        NumFoil      - Number of airfoil files (-)
"AeroData\Cylinder.dat"                         FoilNm      - Names of the airfoil files[NumFoil lines] (quoted strings)
"AeroData\FFA_W3_600.dat"
"AeroData\FFA_W3_480.dat"
"AeroData\FFA_W3_360.dat"
"AeroData\FFA_W3_301.dat"
"AeroData\FFA_W3_241.dat"
37         BldNodes     - Number of blade nodes used for analysis (-)
RNodes       AeroTwst        DRNodes  Chord       NFoil  PrnElm
4.800000 14.491060  4.0000 5.380000 1 NOPRINT
7.512000 14.424209  1.4240 5.422947 1 NOPRINT
9.119000 14.260414  1.7900 5.503171 1 NOPRINT
10.275000 14.043888 0.5220 5.577011 2 NOPRINT
11.658000 13.581343 2.2440 5.678866 2 NOPRINT
13.258000 12.908756 0.9560 5.802144 2 NOPRINT
15.068000 11.908994 2.6640 5.937015 2 NOPRINT
17.075000 10.680366 1.3500 6.063689 3 NOPRINT
19.267000 9.479599  3.0340 6.157123 3 NOPRINT
21.633000 8.385097  1.6980 6.201273 4 NOPRINT
24.156000 7.606940  3.3480 6.191868 4 NOPRINT
26.823000 6.957972  1.9860 6.128953 4 NOPRINT
29.617000 6.369216  3.6020 6.013883 5 NOPRINT
```

```
32.521000 5.809149  2.2060 5.854190 5 NOPRINT
35.519000 5.254826  3.7900 5.657992 5 NOPRINT
38.591000 4.691180  2.3540 5.434810 5 NOPRINT
41.720000 4.087893  3.9040 5.190131 6 NOPRINT
44.886000 3.445390  2.4280 4.929373 6 NOPRINT
48.072000 2.790276  3.9440 4.658367 6 NOPRINT
51.257000 2.125135  2.4260 4.383529 6 NOPRINT
54.423000 1.481714  3.9060 4.110851 6 NOPRINT
57.550000 0.868340  2.3480 3.844928 6 NOPRINT
60.620000 0.294717  3.7920 3.588651 6 NOPRINT
63.615000 -0.221191 2.1980 3.344616 6 NOPRINT
66.516000 -0.704843 3.6040 3.115337 6 NOPRINT
69.306000 -1.120529 1.9760 2.902838 6 NOPRINT
71.968000 -1.517145 3.3480 2.707497 6 NOPRINT
74.487000 -1.876009 1.6900 2.529161 6 NOPRINT
76.847000 -2.210462 3.0300 2.364962 6 NOPRINT
79.034000 -2.520387 1.3440 2.200110 6 NOPRINT
81.034000 -2.797971 2.6560 2.018238 6 NOPRINT
82.837000 -3.032812 0.9500 1.811887 6 NOPRINT
84.431000 -3.220965 2.2380 1.536297 6 NOPRINT
85.806000 -3.369622 0.5120 1.138400 6 NOPRINT
86.955000 -3.427960 1.7860 1.138400 6 NOPRINT
87.870000 -3.427960 0.0440 1.138400 6 NOPRINT
88.546000 -3.427960 1.3080 1.138400 6 NOPRINT
```

8.3 ElastoDyn input file

```
------- ELASTODYN V1.01.* INPUT FILE ----------------------------------------------
FAST model of the DTU 10MW Reference Wind Turbine, onshore version 1.00
---------------------- SIMULATION CONTROL --------------------------------------
False          Echo        - Echo input data to "<RootName>.ech" (flag)
          3    Method      - Integration method: {1: RK4, 2: AB4, or 3: ABM4} (-)
      0.0025   DT          - Integration time step (s)
---------------------- ENVIRONMENTAL CONDITION ---------------------------------
    9.80665    Gravity     - Gravitational acceleration (m/s^2)
---------------------- DEGREES OF FREEDOM --------------------------------------
True           FlapDOF1    - First flapwise blade mode DOF (flag)
True           FlapDOF2    - Second flapwise blade mode DOF (flag)
True           EdgeDOF     - First edgewise blade mode DOF (flag)
False          TeetDOF     - Rotor-teeter DOF (flag) [unused for 3 blades]
True          DrTrDOF     - Drivetrain rotational-flexibility DOF (flag)
True           GenDOF      - Generator DOF (flag)
False           YawDOF      - Yaw DOF (flag)
True           TwFADOF1    - First fore-aft tower bending-mode DOF (flag)
True           TwFADOF2    - Second fore-aft tower bending-mode DOF (flag)
True           TwSSDOF1    - First side-to-side tower bending-mode DOF (flag)
True           TwSSDOF2    - Second side-to-side tower bending-mode DOF (flag)
False          PtfmSgDOF   - Platform horizontal surge translation DOF (flag)
False          PtfmSwDOF   - Platform horizontal sway translation DOF (flag)
False          PtfmHvDOF   - Platform vertical heave translation DOF (flag)
False          PtfmRDOF    - Platform roll tilt rotation DOF (flag)
False          PtfmPDOF    - Platform pitch tilt rotation DOF (flag)
False          PtfmYDOF    - Platform yaw rotation DOF (flag)
---------------------- INITIAL CONDITIONS --------------------------------------
          0    OoPDefl     - Initial out-of-plane blade-tip displacement (meters)
          0    IPDefl      - Initial in-plane blade-tip deflection (meters)
          0    BlPitch(1)  - Blade 1 initial pitch (degrees)
          0    BlPitch(2)  - Blade 2 initial pitch (degrees)
          0    BlPitch(3)  - Blade 3 initial pitch (degrees) [unused for 2 blades]
          0    TeetDefl    - Initial or fixed teeter angle (degrees) [unused for 3 blades]
        9.6    Azimuth     - Initial azimuth angle for blade 1 (degrees)
          0    RotSpeed    - Initial or fixed rotor speed (rpm)
          0    NacYaw      - Initial or fixed nacelle-yaw angle (degrees)
          0    TTDspFA     - Initial fore-aft tower-top displacement (meters)
          0    TTDspSS     - Initial side-to-side tower-top displacement (meters)
          0    PtfmSurge   - Initial or fixed horizontal surge translational displacement of
platform (meters)
          0    PtfmSway    - Initial or fixed horizontal sway translational displacement of
platform (meters)
          0    PtfmHeave   - Initial or fixed vertical heave translational displacement of
platform (meters)
          0    PtfmRoll    - Initial or fixed roll tilt rotational displacement of platform
(degrees)
          0    PtfmPitch   - Initial or fixed pitch tilt rotational displacement of platform
(degrees)
          0    PtfmYaw     - Initial or fixed yaw rotational displacement of platform (degrees)
```

```
---------------------- TURBINE CONFIGURATION -----------------------------------
          3   NumBl       - Number of blades (-)
        89.2  TipRad      - The distance from the rotor apex to the blade tip (meters)
        2.8   HubRad      - The distance from the rotor apex to the blade root (meters)
        -2.5  PreCone(1)  - Blade 1 cone angle (degrees)
        -2.5  PreCone(2)  - Blade 2 cone angle (degrees)
        -2.5  PreCone(3)  - Blade 3 cone angle (degrees) [unused for 2 blades]
        0.0   HubCM       - Distance from rotor apex to hub mass [positive downwind] (meters)
        0.0   UndSling    - Undersling length [distance from teeter pin to the rotor apex]
(meters) [unused for 3 blades]
          0   Delta3      - Delta-3 angle for teetering rotors (degrees) [unused for 3 blades]
          0   AzimB1Up    - Azimuth value to use for I/O when blade 1 points up (degrees)
        -7.1  OverHang    - Distance from yaw axis to rotor apex [3 blades] or teeter pin [2
blades] (meters)
        3.55  ShftGagL    - Distance from rotor apex [3 blades] or teeter pin [2 blades] to
shaft strain gages [positive for upwind rotors] (meters)
        -5.0  ShftTilt    - Rotor shaft tilt angle (degrees)
       2.687  NacCMxn     - Downwind distance from the tower-top to the nacelle CM (meters)
          0   NacCMyn     - Lateral  distance from the tower-top to the nacelle CM (meters)
        2.45  NacCMzn     - Vertical distance from the tower-top to the nacelle CM (meters)
    -3.09528  NcIMUxn     - Downwind distance from the tower-top to the nacelle IMU (meters)
          0   NcIMUyn     - Lateral  distance from the tower-top to the nacelle IMU (meters)
     2.23336  NcIMUzn     - Vertical distance from the tower-top to the nacelle IMU (meters)
        2.75  Twr2Shft    - Vertical distance from the tower-top to the rotor shaft (meters)
      115.63 TowerHt      - Height of tower above ground level [onshore] or MSL [offshore]
(meters)
          0   TowerBsHt   - Height of tower base above ground level [onshore] or MSL [off-
shore] (meters)
          0   PtfmCMxt    - Downwind distance from the ground level [onshore] or MSL [off-
shore] to the platform CM (meters)
          0   PtfmCMyt    - Lateral distance from the ground level [onshore] or MSL [offshore]
to the platform CM (meters)
          0   PtfmCMzt    - Vertical distance from the ground level [onshore] or MSL [off-
shore] to the platform CM (meters)
          0   PtfmRefzt   - Vertical distance from the ground level [onshore] or MSL [off-
shore] to the platform reference point (meters)
---------------------- MASS AND INERTIA ----------------------------------------
                 0    TipMass(1)  - Tip-brake mass, blade 1 (kg)
          0   TipMass(2)  - Tip-brake mass, blade 2 (kg)
          0   TipMass(3)  - Tip-brake mass, blade 3 (kg) [unused for 2 blades]
   105.520E3  HubMass     - Hub mass (kg)
  325.6709E3  HubIner     - Hub inertia about rotor axis [3 blades] or teeter axis [2 blades]
(kg m^2)
      1500.5  GenIner     - Generator inertia about HSS (kg m^2)
 446.03625E3  NacMass     - Nacelle mass (kg)
7326.34645E3  NacYIner    - Nacelle inertia about yaw axis (kg m^2)
          0   YawBrMass   - Yaw bearing mass (kg)
          0   PtfmMass    - Platform mass (kg)
          0   PtfmRIner   - Platform inertia for roll tilt rotation about the platform CM (kg
m^2)
          0   PtfmPIner   - Platform inertia for pitch tilt rotation about the platform CM (kg
m^2)
          0   PtfmYIner   - Platfrom inertia for yaw rotation about the platform CM (kg m^2)
---------------------- BLADE ---------------------------------------------------
        51    BldNodes    - Number of blade nodes (per blade) used for analysis (-)
"DTU_10MW_ElastoDyn_Blades.dat"    BldFile(1)  - Name of file containing properties for blade
1 (quoted string)
"DTU_10MW_ElastoDyn_Blades.dat"    BldFile(2)  - Name of file containing properties for blade
2 (quoted string)
"DTU_10MW_ElastoDyn_Blades.dat"    BldFile(3)  - Name of file containing properties for blade
3 (quoted string) [unused for 2 blades]
---------------------- ROTOR-TEETER --------------------------------------------
          0   TeetMod     - Rotor-teeter spring/damper model {0: none, 1: standard, 2: user-
defined from routine UserTeet} (switch) [unused for 3 blades]
          0   TeetDmpP    - Rotor-teeter damper position (degrees) [used only for 2 blades and
when TeetMod=1]
          0      TeetDmp     - Rotor-teeter damping constant (N-m/(rad/s)) [used only for 2
blades and when TeetMod=1]
          0   TeetCDmp    - Rotor-teeter rate-independent Coulomb-damping moment (N-m) [used
only for 2 blades and when TeetMod=1]
          0   TeetSStP    - Rotor-teeter soft-stop position (degrees) [used only for 2 blades
and when TeetMod=1]
          0   TeetHStP    - Rotor-teeter hard-stop position (degrees) [used only for 2 blades
and when TeetMod=1]
          0   TeetSSSp    - Rotor-teeter soft-stop linear-spring constant (N-m/rad) [used only
for 2 blades and when TeetMod=1]
```

```
          0    TeetHSSp    - Rotor-teeter hard-stop linear-spring constant (N-m/rad) [used only
for 2 blades and when TeetMod=1]
---------------------- DRIVETRAIN ------------------------------------------------
        100    GBoxEff     - Gearbox efficiency (%)
       50.0    GBRatio     - Gearbox ratio (-)
 2.317025E9    DTTorSpr    - Drivetrain torsional spring (N-m/rad)
    9240560    DTTorDmp    - Drivetrain torsional damper (N-m/(rad/s))
---------------------- FURLING ---------------------------------------------------
False          Furling     - Read in additional model properties for furling turbine (flag)
[must currently be FALSE)
"unused"       FurlFile    - Name of file containing furling properties (quoted string) [unused
when Furling=False]
---------------------- TOWER -----------------------------------------------------
         20    TwrNodes    - Number of tower nodes used for analysis (-)
"DTU_10MW_ElastoDyn_Tower.dat"    TwrFile     - Name of file containing tower properties
(quoted string)
---------------------- OUTPUT ----------------------------------------------------
True           SumPrint    - Print summary data to "<RootName>.sum" (flag)
          1    OutFile     - Switch to determine where output will be placed: {1: in module
output file only; 2: in glue code output file only; 3: both} (currently unused)
True           TabDelim    - Use tab delimiters in text tabular output file? (flag) (currently
unused)
"ES10.3E2"     OutFmt      - Format used for text tabular output (except time).  Resulting
field should be 10 characters. (quoted string)  [not checked for validity!] (currently unused)
        0.0    TStart      - Time to begin tabular output (s) (currently unused)
          1    DecFact     - Decimation factor for tabular output {1: output every time step}
(-) (currently unused)
          0    NTwGages    - Number of tower nodes that have strain gages for output [0 to 9]
(-)
          0    TwrGagNd    - List of tower nodes that have strain gages [1 to TwrNodes] (-)
[unused if NTwGages=0]
          0    NBlGages    - Number of blade nodes that have strain gages for output [0 to 9]
(-)
               BldGagNd    - List of blade nodes that have strain gages [1 to BldNodes] (-)
[unused if NBlGages=0]
               OutList     - The next line(s) contains a list of output parameters.  See Out-
ListParameters.xlsx for a listing of available output channels, (-)
END of input file (the word "END" must appear in the first 3 columns of this last OutList
line)
---------------------------------------------------------------------------------------
```

8.4 ServoDyn input file

```
------- SERVODYN V1.02.* INPUT FILE ----------------------------------------------
ServoDyn input file for the DTU 10MW Reference Wind Turbine, onshore version 1.00
---------------------- SIMULATION CONTROL ----------------------------------------
False          Echo         - Echo input data to <RootName>.ech (flag)
"default"      DT           - Communication interval for controllers (s)
---------------------- PITCH CONTROL ---------------------------------------------
          5    PCMode       - Pitch control mode {0: none, 3: user-defined from routine Pitch-
Cntrl, 4: user-defined from Simulink/Labview, 5: user-defined from Bladed-style DLL} (switch)
          0    TPCOn        - Time to enable active pitch control (s) [unused when PCMode=0]
     9999.9    TPitManS(1)  - Time to start override pitch maneuver for blade 1 and end stand-
ard pitch control (s)
     9999.9    TPitManS(2)  - Time to start override pitch maneuver for blade 2 and end stand-
ard pitch control (s)
     9999.9    TPitManS(3)  - Time to start override pitch maneuver for blade 3 and end stand-
ard pitch control (s) [unused for 2 blades]
          2    PitManRat(1) - Pitch rate at which override pitch maneuver heads toward final
pitch angle for blade 1 (deg/s)
          2    PitManRat(2) - Pitch rate at which override pitch maneuver heads toward final
pitch angle for blade 2 (deg/s)
          2    PitManRat(3) - Pitch rate at which override pitch maneuver heads toward final
pitch angle for blade 3 (deg/s) [unused for 2 blades]
          0    BlPitchF(1)  - Blade 1 final pitch for pitch maneuvers (degrees)
          0    BlPitchF(2)  - Blade 2 final pitch for pitch maneuvers (degrees)
          0    BlPitchF(3)  - Blade 3 final pitch for pitch maneuvers (degrees) [unused for 2
blades]
---------------------- GENERATOR AND TORQUE CONTROL ------------------------------
          5    VSContrl     - Variable-speed control mode {0: none, 1: simple VS, 3: user-
defined from routine UserVSCont, 4: user-defined from Simulink/Labview, 5: user-defined from
Bladed-style DLL} (switch)
          1    GenModel     - Generator model {1: simple, 2: Thevenin, 3: user-defined from
routine UserGen} (switch) [used only when VSContrl=0]
      100.0    GenEff       - Generator efficiency [ignored by the Thevenin and user-defined
generator models] (%)
```

```
True          GenTiStr     - Method to start the generator {T: timed using TimGenOn, F: gener-
ator speed using SpdGenOn} (flag)
True          GenTiStp     - Method to stop the generator {T: timed using TimGenOf, F: when
generator power = 0} (flag)
     9999.9   SpdGenOn     - Generator speed to turn on the generator for a startup (HSS
speed) (rpm) [used only when GenTiStr=False]
          0   TimGenOn     - Time to turn on the generator for a startup (s) [used only when
GenTiStr=True]
     9999.9   TimGenOf     - Time to turn off the generator (s) [used only when GenTiStp=True]
---------------------- SIMPLE VARIABLE-SPEED TORQUE CONTROL --------------------
     9999.9   VS_RtGnSp    - Rated generator speed for simple variable-speed generator control
(HSS side) (rpm) [used only when VSContrl=1]
     9999.9   VS_RtTq      - Rated generator torque/constant generator torque in Region 3 for
simple variable-speed generator control (HSS side) (N-m) [used only when VSContrl=1]
     9999.9   VS_Rgn2K     - Generator torque constant in Region 2 for simple variable-speed
generator control (HSS side) (N-m/rpm^2) [used only when VSContrl=1]
     9999.9   VS_SlPc      - Rated generator slip percentage in Region 2 1/2 for simple varia-
ble-speed generator control (%) [used only when VSContrl=1]
---------------------- SIMPLE INDUCTION GENERATOR ------------------------------
     9999.9   SIG_SlPc     - Rated generator slip percentage (%) [used only when VSContrl=0
and GenModel=1]
     9999.9   SIG_SySp     - Synchronous (zero-torque) generator speed (rpm) [used only when
VSContrl=0 and GenModel=1]
     9999.9   SIG_RtTq     - Rated torque (N-m) [used only when VSContrl=0 and GenModel=1]
     9999.9   SIG_PORt     - Pull-out ratio (Tpullout/Trated) (-) [used only when VSContrl=0
and GenModel=1]
---------------------- THEVENIN-EQUIVALENT INDUCTION GENERATOR -----------------
     9999.9   TEC_Freq     - Line frequency [50 or 60] (Hz) [used only when VSContrl=0 and
GenModel=2]
       9998   TEC_NPol     - Number of poles [even integer > 0] (-) [used only when VSContrl=0
and GenModel=2]
     9999.9   TEC_SRes     - Stator resistance (ohms) [used only when VSContrl=0 and GenMod-
el=2]
     9999.9   TEC_RRes     - Rotor resistance (ohms) [used only when VSContrl=0 and GenMod-
el=2]
     9999.9   TEC_VLL      - Line-to-line RMS voltage (volts) [used only when VSContrl=0 and
GenModel=2]
     9999.9   TEC_SLR      - Stator leakage reactance (ohms) [used only when VSContrl=0 and
GenModel=2]
     9999.9   TEC_RLR      - Rotor leakage reactance (ohms) [used only when VSContrl=0 and
GenModel=2]
     9999.9   TEC_MR       - Magnetizing reactance (ohms) [used only when VSContrl=0 and
GenModel=2]
---------------------- HIGH-SPEED SHAFT BRAKE ----------------------------------
          0   HSSBrMode    - HSS brake model {0: none, 1: simple, 3: user-defined from routine
UserHSSBr, 4: user-defined from Simulink/Labview, 5: user-defined from Bladed-style DLL}
(switch)
     9999.9   THSSBrDp     - Time to initiate deployment of the HSS brake (s)
        0.6   HSSBrDT      - Time for HSS-brake to reach full deployment once initiated (sec)
[used only when HSSBrMode=1]
    28116.2   HSSBrTqF     - Fully deployed HSS-brake torque (N-m)
---------------------- NACELLE-YAW CONTROL -------------------------------------
          0   YCMode       - Yaw control mode {0: none, 1: simple, 3: user-defined from rou-
tine UserYawCont, 4: user-defined from Simulink/Labview, 5: user-defined from Bladed-style
DLL} (switch)
     9999.9   TYCOn        - Time to enable active yaw control (s) [unused when YCMode=0]
          0   YawNeut      - Neutral yaw position--yaw spring force is zero at this yaw (de-
grees)
9.02832E+09   YawSpr       - Nacelle-yaw spring constant (N-m/rad)
  1.916E+07   YawDamp      - Nacelle-yaw damping constant (N-m/(rad/s))
     9999.9   TYawManS     - Time to start override yaw maneuver and end standard yaw control
(s)
          2   YawManRat    - Yaw maneuver rate (in absolute value) (deg/s)
          0   NacYawF      - Final yaw angle for override yaw maneuvers (degrees)
---------------------- TUNED MASS DAMPER ---------------------------------------
False         CompNTMD     - Compute nacelle tuned mass damper {true/false} (flag)
"NRELOffshrBsline5MW_ServoDyn_TMD.dat"    NTMDfile     - Name of the file for nacelle tuned
mass damper (quoted string) [unused when CompNTMD is false]
---------------------- BLADED INTERFACE ----------------------------------------
".\ServoData\dtu_we_controller_bladed.dll"    DLL_FileName - Name/location of the dynamic li-
brary {.dll [Windows] or .so [Linux]} in the Bladed-DLL format (-) [used only with Bladed In-
terface]
"DISCON.IN"    DLL_InFile   - Name of input file sent to the DLL [used only with Bladed Inter-
face] (-)
"default"     DLL_DT       - Communication interval for dynamic library [used only with Bladed
Interface] (s) (or "default")
```

```
false         DLL_Ramp     - Whether a linear ramp should be used between DLL_DT time steps
[introduces time shift when true] (flag)
9999.9        BPCutoff     - Cuttoff frequency for low-pass filter on blade pitch from DLL
(Hz)
          0   NacYaw_North - Reference yaw angle of the nacelle when the upwind end points due
North (deg) [used only with Bladed Interface]
          0   Ptch_Cntrl   - Record 28: Use individual pitch control {0: collective pitch; 1:
individual pitch control} (switch) [used only with Bladed Interface]
          0   Ptch_SetPnt  - Record  5: Below-rated pitch angle set-point (deg) [used only
with Bladed Interface]
          0   Ptch_Min     - Record  6: Minimum pitch angle (deg) [used only with Bladed In-
terface]
          0   Ptch_Max     - Record  7: Maximum pitch angle (deg) [used only with Bladed In-
terface]
          0   PtchRate_Min - Record  8: Minimum pitch rate (most negative value allowed)
(deg/s) [used only with Bladed Interface]
          0   PtchRate_Max - Record  9: Maximum pitch rate  (deg/s) [used only with Bladed
Interface]
          0   Gain_OM      - Record 16: Optimal mode gain (Nm/(rad/s)^2) [used only with Blad-
ed Interface]
          0   GenSpd_MinOM - Record 17: Minimum generator speed (rpm) [used only with Bladed
Interface]
          0   GenSpd_MaxOM - Record 18: Optimal mode maximum speed (rpm) [used only with Blad-
ed Interface]
          0   GenSpd_Dem   - Record 19: Demanded generator speed above rated (rpm) [used only
with Bladed Interface]
          0   GenTrq_Dem   - Record 22: Demanded generator torque above rated (Nm) [used only
with Bladed Interface]
          0   GenPwr_Dem   - Record 13: Demanded power (W) [used only with Bladed Interface]
---------------------- BLADED INTERFACE TORQUE-SPEED LOOK-UP TABLE -------------
          0   DLL_NumTrq   - Record 26: No. of points in torque-speed look-up table {0 = none
and use the optimal mode parameters; nonzero = ignore the optimal mode PARAMETERs by setting
Record 16 to 0.0} (-) [used only with Bladed Interface]
 GenSpd_TLU   GenTrq_TLU
 (rpm)          (Nm)
---------------------- OUTPUT --------------------------------------------------
True          SumPrint     - Print summary data to <RootName>.sum (flag) (currently unused)
          1   OutFile      - Switch to determine where output will be placed: {1: in module
output file only; 2: in glue code output file only; 3: both} (currently unused)
True          TabDelim     - Use tab delimiters in text tabular output file? (flag) (currently
unused)
"ES10.3E2"    OutFmt       - Format used for text tabular output (except time).  Resulting
field should be 10 characters. (quoted string) (currently unused)
          0   TStart       - Time to begin tabular output (s) (currently unused)
              OutList      - The next line(s) contains a list of output parameters.  See Out-
ListParameters.xlsx for a listing of available output channels, (-)
"GenPwr"                  - Electrical generator power and torque
"GenTq"                   - Electrical generator power and torque
"NTMD_XQ, NTMD_XQD"
"NTMD_YQ, NTMD_YQD"
END of input file (the word "END" must appear in the first 3 columns of this last OutList
line)
---------------------------------------------------------------------------------------
```

8.5 Sample InflowWind input file

```
------- InflowWind v3.01.* INPUT FILE ---------------------------------------------------
-----------------
Steady uniform wind inflow for DTU 10MW RWT offshore baseline turbine
-----------------------------------------------------------------------------------------
-----------------
False         Echo           - Echo input data to <RootName>.ech (flag)
          1   WindType       - switch for wind file type (1=steady; 2=uniform; 3=binary
TurbSim FF; 4=binary Bladed-style FF; 5=HAWC format; 6=User defined)
          0   PropogationDir - Direction of wind propogation (meteoroligical rotation from
aligned with X (positive rotates towards -Y) -- degrees)
          1   NWindVel       - Number of points to output the wind velocity (0 to 9)
          0   WindVxiList    - List of coordinates in the inertial X direction (m)
          0   WindVyiList    - List of coordinates in the inertial Y direction (m)
         90   WindVziList    - List of coordinates in the inertial Z direction (m)
================== Parameters for Steady Wind Conditions [used only for WindType = 1]
=========================
       11.4   HWindSpeed     - Horizontal windspeed
        119   RefHt          - Reference height for horizontal wind speed
          0   PLexp          - Power law exponent
================== Parameters for Uniform wind file   [used only for WindType = 2]
============================
```

```
"unused"    Filename        - Filename of time series data for uniform wind field.
         90   RefHt           - Reference height for horizontal wind speed
     125.88   RefLength       - Reference length for linear horizontal and vertical sheer
================== Parameters for Binary TurbSim Full-Field files   [used only for WindType =
3] ==============
"Wind/08ms.wnd"    Filename        - Name of the Full field wind file to use (.bts)
================== Parameters for Binary Bladed-style Full-Field files   [used only for
WindType = 4] =========
"unused"      FilenameRoot    - Rootname of the full-field wind file to use (.wnd, .sum)
False         TowerFile       - Have tower file (.twr) [flag]
================== Parameters for HAWC-format binary files  [Only used with WindType = 5]
=====================
"wasp\Output\basic_5u.bin"    FileName_u      - name of the file containing the u-component
fluctuating wind
"wasp\Output\basic_5v.bin"    FileName_v      - name of the file containing the v-component
fluctuating wind
"wasp\Output\basic_5w.bin"    FileName_w      - name of the file containing the w-component
fluctuating wind
         64   nx              - number of grids in the x direction (in the 3 files above)
         32   ny              - number of grids in the y direction (in the 3 files above)
         32   nz              - number of grids in the z direction (in the 3 files above)
         16   dx              - distance (in meters) between points in the x direction
          3   dy              - distance (in meters) between points in the y direction
          3   dz              - distance (in meters) between points in the z direction
         90   RefHt           - reference height; the height (in meters) of the vertical center
of the grid
  -------------   Scaling parameters for turbulence   ---------------------------------------
-----------------
          1   ScaleMethod     - Turbulence scaling method   [0 = none, 1 = direct scaling, 2 =
calculate scaling factor based on a desired standard deviation]
          1   SFx             - Turbulence scaling factor for the x direction (-)   [ScaleMeth-
od=1]
          1   SFy             - Turbulence scaling factor for the y direction (-)   [ScaleMeth-
od=1]
          1   SFz             - Turbulence scaling factor for the z direction (-)   [ScaleMeth-
od=1]
         12   SigmaFx         - Turbulence standard deviation to calculate scaling from in x
direction (m/s)    [ScaleMethod=2]
          8   SigmaFy         - Turbulence standard deviation to calculate scaling from in y
direction (m/s)    [ScaleMethod=2]
          2   SigmaFz         - Turbulence standard deviation to calculate scaling from in z
direction (m/s)    [ScaleMethod=2]
  -------------   Mean wind profile parameters (added to HAWC-format files)   ----------------
-----------------
          5   URef            - Mean u-component wind speed at the reference height [m/s]
          2   WindProfile     - Wind profile type (0=constant;1=logarithmic,2=power law)
          0   PLExp           - Power law exponent [-] (used only when WindProfile=2)
       0.03   Z0              - Surface roughness length [m] (used only when WindProfile=1)
====================== OUTPUT
==================================================================================
False         SumPrint      - Print summary data to <RootName>.IfW.sum (flag)
              OutList       - The next line(s) contains a list of output parameters.  See Out-
ListParameters.xlsx for a listing of available output channels, (-)
"Wind1VelX"               X-direction wind velocity at point WindList(1)
"Wind1VelY"               Y-direction wind velocity at point WindList(1)
"Wind1VelZ"               Z-direction wind velocity at point WindList(1)
END of input file (the word "END" must appear in the first 3 columns of this last OutList
line)
-------------------------------------------------------------------------------------
```

8.6 Sample TurbSim input file

```
TurbSim Input File. Valid for TurbSim v1.06.00, 21-Sep-2012

---------Runtime Options-----------------------------------
276943            RandSeed1       - First random seed  (-2147483648 to 2147483647)
RANLUX            RandSeed2       - Second random seed (-2147483648 to 2147483647) for in-
trinsic pRNG, or an alternative pRNG: "RanLux" or "RNSNLW"
False             WrBHHTP         - Output hub-height turbulence parameters in binary form?
(Generates RootName.bin)
False             WrFHHTP         - Output hub-height turbulence parameters in formatted
form?  (Generates RootName.dat)
False             WrADHH          - Output hub-height time-series data in AeroDyn form?
(Generates RootName.hh)
True              WrADFF          - Output full-field time-series data in TurbSim/AeroDyn
form? (Generates Rootname.bts)
```

```
False                  WrBLFF          - Output full-field time-series data in BLADED/AeroDyn
form?  (Generates RootName.wnd)
False                  WrADTWR         - Output tower time-series data? (Generates RootName.twr)
False                  WrFMTFF         - Output full-field time-series data in formatted (reada-
ble) form?  (Generates RootName.u, RootName.v, RootName.w)
False                   WrACT           - Output coherent turbulence time steps in AeroDyn form?
(Generates RootName.cts)
True                   Clockwise       - Clockwise rotation looking downwind? (used only for
full-field binary files - not necessary for AeroDyn)
 0                     ScaleIEC        - Scale IEC turbulence models to exact target standard
deviation? [0=no additional scaling; 1=use hub scale uniformly; 2=use individual scales]

--------Turbine/Model Specifications-----------------------
67                     NumGrid_Z       - Vertical grid-point matrix dimension
67                     NumGrid_Y       - Horizontal grid-point matrix dimension
0.05                   TimeStep        - Time step [seconds]
700                    AnalysisTime    - Length of analysis time series [seconds] (program will
add time if necessary: AnalysisTime = MAX(AnalysisTime, UsableTime+GridWidth/MeanHHWS) )
630                    UsableTime      - Usable length of output time series [seconds] (program
will add GridWidth/MeanHHWS seconds)
119.00                 HubHt           - Hub height [m] (should be > 0.5*GridHeight)
200.00                 GridHeight      - Grid height [m]
200.00                 GridWidth       - Grid width [m] (should be >=
2*(RotorRadius+ShaftLength))
0                      VFlowAng        - Vertical mean flow (uptilt) angle [degrees]
0                      HFlowAng        - Horizontal mean flow (skew) angle [degrees]

--------Meteorological Boundary Conditions-------------------
"IECKAI"               TurbModel        - Turbulence model ("IECKAI"=Kaimal, "IECVKM"=von Karman,
"GP_LLJ", "NWTCUP", "SMOOTH", "WF_UPW", "WF_07D", "WF_14D", "TIDAL", or "NONE")
"1-ED3"                IECstandard      - Number of IEC 61400-x standard (x=1,2, or 3 with option-
al 61400-1 edition number (i.e. "1-Ed2") )
"A"                    IECturbc         - IEC turbulence characteristic ("A", "B", "C" or the tur-
bulence intensity in percent) ("KHTEST" option with NWTCUP model, not used for other models)
"NTM"                  IEC_WindType     - IEC turbulence type ("NTM"=normal, "xETM"=extreme turbu-
lence, "xEWM1"=extreme 1-year wind, "xEWM50"=extreme 50-year wind, where x=wind turbine class
1, 2, or 3)
default                ETMc             - IEC Extreme Turbulence Model "c" parameter [m/s]
IEC             WindProfileType - Wind profile type ("JET";"LOG"=logarithmic;"PL"=power
law;"H2L"=Log law for TIDAL spectral model;"IEC"=PL on rotor disk, LOG elsewhere; or "de-
fault")
119.00                 RefHt            - Height of the reference wind speed [m]
11.4                   URef             - Mean (total) wind speed at the reference height [m/s]
(or "default" for JET wind profile)
default                ZJetMax          - Jet height [m] (used only for JET wind profile, valid
70-490 m)
0.14                    PLExp            - Power law exponent [-] (or "default")
default                Z0               - Surface roughness length [m] (or "default")

--------Non-IEC Meteorological Boundary Conditions------------
default                Latitude        - Site latitude [degrees] (or "default")
0.05                   RICH_NO         - Gradient Richardson number
default                UStar           - Friction or shear velocity [m/s] (or "default")
default                ZI              - Mixing layer depth [m] (or "default")
default                PC_UW           - Hub mean u'w' Reynolds stress (or "default")
default                PC_UV           - Hub mean u'v' Reynolds stress (or "default")
default                PC_VW           - Hub mean v'w' Reynolds stress (or "default")
default                IncDec1         - u-component coherence parameters (e.g. "10.0  0.3e-3" in
quotes) (or "default")
default                IncDec2         - v-component coherence parameters (e.g. "10.0  0.3e-3" in
quotes) (or "default")
default                IncDec3         - w-component coherence parameters (e.g. "10.0  0.3e-3" in
quotes) (or "default")
default                CohExp          - Coherence exponent (or "default")

--------Coherent Turbulence Scaling Parameters-------------------
"M:\coh_events\eventdata"  CTEventPath     - Name of the path where event data files are lo-
cated
"Random"               CTEventFile     - Type of event files ("LES", "DNS", or "RANDOM")
true                   Randomize       - Randomize the disturbance scale and locations?
(true/false)
 1.0                   DistScl         - Disturbance scale (ratio of wave height to rotor disk).
(Ignored when Randomize = true.)
 0.5                   CTLy            - Fractional location of tower centerline from right
(looking downwind) to left side of the dataset. (Ignored when Randomize = true.)
 0.5                   CTLz            - Fractional location of hub height from the bottom of the
dataset. (Ignored when Randomize = true.)
```

```
30.0              CTStartTime     - Minimum start time for coherent structures in Root-
Name.cts [seconds]

==================================================
NOTE: Do not add or remove any lines in this file!
==================================================
```

8.7 BModes input files

8.7.1 Tower input files

```
======================   BModes v1.03 Main Input File  ==================
Modes of a 115.63m tower with tip mass (output is space-delimited)

--------- General parameters -----------------------------------------------------------------
----
False      Echo        Echo input file contents to *.echo file if true.
2          beam_type   1: blade, 2: tower (-)
0.         romg:       rotor speed (rpm), automatically set to zero for tower modal analysis
1.0        romg_mult:  rotor speed muliplicative factor (-)
115.63     radius:     rotor tip radius measured along coned blade axis OR tower height (m)
0.         hub_rad:    hub radius measured along coned blade axis OR tower rigid-base height
(m)
0.         precone:    built-in precone angle (deg), automatically set to zero for a tower
0.         bl_thp:     blade pitch setting (deg), automatically set to zero for a tower
1          hub_conn:   hub-to-blade connection [1: cantilevered; other options not yet availa-
ble]
10         modepr:     number of modes to be printed (-)
f          TabDelim     (true: tab-delimited output tables; false: space-delimited tables)
f          mid_node_tw  (true: output twist at mid-node of elements; false: no mid-node out-
puts)

--------- Blade-tip or tower-top mass properties --------------------------------------------
676723     tip_mass    blade-tip or tower-top mass (see users' manual) (kg) !MB: calculated
from HAWC2 body output 5.11.15
-0.62      cm_loc      tip-mass c.m. offset from the tower axis measured along the tower-tip x
reference axis (m)
1209543.   ixx_tip     blade lag or tower s-s mass moment of inertia about the tip-section x
reference axis (kg-m^2)
1277740.   iyy_tip     blade flap or tower f-a mass moment of inertia about the tip-section y
reference axis (kg-m^2)
411854.5   izz_tip     torsion mass moment of inertia about the tip-section z reference axis
(kg-m^2)
0.         ixy_tip     cross product of inertia about x and y reference axes(kg-m^2)
-739106.   izx_tip     cross product of inertia about z and x reference axes(kg-m^2)
0.         iyz_tip     cross product of inertia about y and z reference axes(kg-m^2)

--------- Distributed-property identifiers ---------------------------------------------------
-----
1          id_mat:     material_type [1: isotropic; non-isotropic composites option not yet
available]
'DTU10MW_BModeBaseline_Tower_st.dat' sec_props_file   name of beam section properties file (-)

Property scaling factors..............................
1.0        sec_mass_mult:   mass density multiplier (-)
1.0        flp_iner_mult:   blade flap or tower f-a inertia multiplier (-)
1.0        lag_iner_mult:   blade lag or tower s-s inertia multiplier (-)
1.0        flp_stff_mult:   blade flap or tower f-a bending stiffness multiplier (-)
1.0        edge_stff_mult:  blade lag or tower s-s bending stiffness multiplier (-)
1.0        tor_stff_mult:   torsion stiffness multiplier (-)
1.0        axial_stff_mult: axial stiffness multiplier (-)
1.0        cg_offst_mult:   cg offset multiplier (-)
1.0        sc_offst_mult:   shear center multiplier (-)
1.0        tc_offst_mult:   tension center multiplier (-)

--------- Finite element discretization --------------------------------------------------
29         nselt:     no of blade or tower elements (-)
Distance of element boundary nodes from blade or flexible-tower root (normalized wrt blade or
tower length), el_loc()
0.000   0.0345  0.0690  0.1034  0.1379  0.1724  0.2069  0.2414  0.2759  0.3103  0.3448  0.3793
        0.4138  0.4483  0.4828  0.5172  0.5517  0.5862  0.6207  0.6552  0.6897  0.7241  0.7586
        0.7931  0.8276  0.8621  0.8966  0.9310  0.9655  1.0000

--------- Properties of tension wires suporting the tower --------------------------------
0          n_attachments: no of wire-attachment locations on tower, maxm allowable is 2; 0: no
tension-wire support (-)
```

```
3 3        n_wires:       no of wires attached at each location (must be 3 or higher) (-)
6 9        node_attach:   node numbers of attacments location (node number must be more than 1
and less than nselt+2) (-)
0.e0 0.e0 wire_stfness:  wire sifnness in each set (see users' manual) (N/m)
0. 0.      th_wire:       angle of tension wires wrt the tower axis at each attachment point
(deg)
```

8.7.2 Blade input files

```
======================   BModes v1.03 Main Input File   ==================
Sample non-uniform blade (output is space-delimited)

--------- General parameters ------------------------------------------------------------
----
False      Echo         Echo input file contents to *.echo file if true.
1          beam_type    1: blade, 2: tower (-)
0.0        romg:        rotor speed, automatically set to zero for tower modal analysis (rpm)
1.0        romg_mult:   rotor speed muliplicative factor (-)
89.15     radius:      rotor tip radius measured along coned blade axis OR tower height (m)
2.8        hub_rad:     hub radius measured along coned blade axis OR tower rigid-base height
(m)
-2.5        precone:     built-in precone angle, automatically set to zero for a tower (deg)
0.         bl_thp:      blade pitch setting, automatically set to zero for a tower (deg)
1          hub_conn:    hub-to-blade connection [1: cantilevered; other options not yet availa-
ble] (-)
10         modepr:      number of modes to be printed (-)
f          TabDelim     (true: tab-delimited output tables; false: space-delimited tables)
t          mid_node_tw  (true: output twist at mid-node of elements; false: no mid-node out-
puts)

--------- Blade-tip or tower-top mass properties ------------------------------------------
0.         tip_mass     blade-tip or tower-top mass (kg)
0.         cm_loc       tip-mass c.m. offset from the blade axis measured along the tip section
y reference axis (m)
0.         ixx_tip      blade lag mass moment of inertia about the tip-section x reference axis
(kg-m^2)
0.         iyy_tip      blade flap mass moment of inertia about the tip-section y reference axis
(kg-m^2)
0.         izz_tip      torsion mass moment of inertia about the tip-section z reference axis
(kg-m^2)
0.         ixy_tip      cross product of inertia about x and y reference axes(kg-m^2)
0.         izx_tip      cross product of inertia about z and x reference axes(kg-m^2)
0.         iyz_tip      cross product of inertia about y and z reference axes(kg-m^2)

--------- Distributed-property identifiers -----------------------------------------------
-----
1          id_mat:      material_type [1: isotropic; non-isotropic composites option not yet
available]
'DTU10MW_BModeBaseline_Blade_st.dat' sec_props_file   name of beam section properties file (-)

Property scaling factors.............................
1.0        sec_mass_mult:   mass density multiplier (-)
1.0        flp_iner_mult:   blade flap or tower f-a inertia multiplier (-)
1.0        lag_iner_mult:   blade lag or tower s-s inertia multiplier (-)
1.0        flp_stff_mult:   blade flap or tower f-a bending stiffness multiplier (-)
1.0        edge_stff_mult:  blade lag or tower s-s bending stiffness multiplier (-)
1.0        tor_stff_mult:   torsion stiffness multiplier (-)
1.0        axial_stff_mult: axial stiffness multiplier (-)
1.0        cg_offst_mult:   cg offset multiplier (-)
1.0        sc_offst_mult:   shear center multiplier (-)
1.0        tc_offst_mult:   tension center multiplier (-)

--------- Finite element discretization --------------------------------------------------
29         nselt:     no of blade or tower elements (-)
Distance of element boundary nodes from blade or flexible-tower root (normalized wrt blade or
tower length), el_loc()
0.000   0.0345  0.0690  0.1034  0.1379  0.1724  0.2069  0.2414  0.2759  0.3103  0.3448  0.3793
        0.4138  0.4483  0.4828  0.5172  0.5517  0.5862  0.6207  0.6552  0.6897  0.7241  0.7586
        0.7931  0.8276  0.8621  0.8966  0.9310  0.9655  1.0000

--------- Properties of tension wires suporting the tower --------------------------------
0          n_attachments: no of wire-attachment locations on tower, maxm allowable is 2; 0: no
tension-wire support (-)
3 3        n_wires:       no of wires attached at each location (must be 3 or higher) (-)
6 9        node_attach:   node numbers of attacments location (node number must be more than 1
and less than nselt+2) (-)
```

```
0.e0 0.e0 wire_stfness:  wire spring constant in each set (see users' manual) (N/m)
0. 0.     th_wire:       angle of tension wires wrt the tower axis at each attachment point
(deg)
```

9 Appendix B: Tabulated data

9.1 Steady state performance data

Wind Speed	Rotational Speed	Blade Pitch	Tower top F-A shear force	Electrical Power
[m/s]	[RPM]	[deg]	[kN]	[kW]
4	5.999823	2.680706	222.1997	279.5153
5	5.999823	1.896353	349.4111	773.2868
6	5.99982	0.862641	500.0706	1513.725
7	5.999826	0.000119	651.5948	2509.611
8	6.315921	8.88E-05	802.0436	3765.155
9	7.09967	8.8E-05	1014.227	5347.875
10	7.88004	0.000192	1249.202	7312.266
11	8.695861	0.00025	1511.007	9694.805
12	9.597031	5.691753	1182.251	10000
13	9.597033	8.108231	1033.31	9999.999
14	9.597032	10.00277	935.0078	9999.995
15	9.597034	11.65345	861.7119	10000
16	9.597037	13.15337	803.7923	10000
17	9.597039	14.56892	753.1849	10000
18	9.597039	15.89906	711.1684	10000
19	9.597039	17.14434	678.6325	9999.998
20	9.597039	18.32942	652.258	10000
21	9.59704	19.4766	628.5636	9999.999
22	9.597037	20.5836	608.2663	10000
23	9.596703	21.44531	625.1782	10000
24	9.596703	22.4466	618.7737	10000
25	9.597006	23.41406	612.3692	10000

Table 7 - Steady state performance data obtained for the present FAST model implementation

9.2 Stochastic performance data

	Below rated			Rated			Above-rated		
	Mean	Max.	Std.	Mean	Max.	Std.	Mean	Max.	Std.
Wind speed, x-dir. [m/s]	7.138944	12.00205	1.351943	11.14626	17.94943	2.217723	15.08077	24.56727	2.436389
RPM [-]	6.127671	7.013211	0.24782	8.979648	10.23838	0.768457	9.60026	10.07971	0.152199
Power [kW]	2679.093	4633.463	788.0388	8937.013	10093.55	1470.308	10000.19	10102.84	26.83527
Thrust [kN]	657.5264	1141.771	157.0603	1276.38	1824.363	251.139	868.0195	1636.117	180.7147
Tower base moment, y-axis [kNm]	72506.49	128532.8	19398.03	145722.2	212261.8	29428.45	99373.27	182715.4	21882.12

Table 8 - Statistical data for the three stochastic simulations