F2A User's Guide

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Contents

1 Introduction and acknowledgements

This document is the user guide of F2A as a supplement material of the revised manuscript (*Development and Application of an Aero-Hydro-Servo-Elastic Coupling Framework for Analysis of Floating Offshore Wind Turbines*) submitted to *Renewable Energy Journal*.

F2A is an aero-hydro-servo-elastic tool developed based on AQWA by Yang Yang, a postdoctoral research associate in Liverpool John Moores University for performing fully coupled analysis of floating offshore wind turbines (FOWT). The aero-servo-elastic simulation capabilities are fully implemented within the user_force64.dll which is a built-in DLL of AQWA for external force calculation. For a coupled analysis of a floating offshore wind turbine subjected to wind, wave and current loadings, the aerodynamic loads acting on the rotor, the elastic responses of the blades and tower, and the servo-control are examined through the DLL, considering the influence from the platform motions. The platform position, velocity and acceleration at each degree of freedom are passed into the DLL to update the kinematics of the upper structures. Before being passed into DLL, these terms are transformed from the inertial coordinate system to the local coordinate system of the platform. Further details of the development of F2A are presented in the paper (*Development and Application of an Aero-Hydro-Servo-Elastic Coupling Framework for Analysis of Floating Offshore Wind Turbines, being re-reviewed*). Since the paper is still under review, only part of the source code is released to public. But a valid DLL is released for free use at the moment. The whole package of source code will be released to public once the paper is accepted for publication.

This work is mainly supported by the ARCWIND project funded by the European Regional Development Fund (ERDF), Interreg Atlantic Area (grant number: EAPA_344/2016). In addition, financial support from European Union’s Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement no. 730888 (RESET), Royal Society (grant number:

IEC\NSFC\170054), National Natural Science Foundation of China (grant numbers: 51676131, 51976131), Science and Technology Commission of Shanghai Municipality (grant number: 1906052200) is greatly appreciated. The aero-servo-elastic simulation capabilities of F2A are mainly based on an improved version of FASTv7. The author is very grateful for the open source tool provided by the National Renewable Energy Laboratory.

2 Basic use of F2A

2.1 Description of the input files for a simulation case

F2A is based on AQWA and FAST. The platform and mooring lines are modelled in AQWA, and the upper structures are defined in the required documents of FAST. In the repository of F2A, an example of the NREL 5 MW wind turbine is included, as presented in Fig. 1. "AQWAHydroData" folder contains the hydrodynamic data file with an extension of .hyd, which stores the frequency domain solutions of the spar platform obtained using AQWA, as shown in Fig. 2. "FASTConfig" folder contains the input files for FAST, including aerodynamic performance data of the airfoils, structural properties of the blade and tower, and wind data, as presented in Fig. 3. The other files in the folder of F2A are explained in Table 1.

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AQWAHydroData	Add files via upload	6 days ago
FAST_Config	Add files via upload	6 days ago
InputFileForFAST2AQWA.txt	Add files via upload	6 days ago
InputforreadAQWAResults_SingleFile.txt	Add files via upload	6 days ago
Spar_Turb_114.dat	Add files via upload	6 days ago
Spar_Turb_114.fst	Add files via upload	6 days ago
readAQWAResults_SingleFile.exe	Add files via upload	6 days ago
user_force64.dll	Add files via upload	6 days ago

Fig. 1: Input files of F2A for the NREL 5 MW Spar wind turbine

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SPARFREQ_NEW.HYD	Add files via upload	6 days ago

Fig. 2: Hydrodynamic data of the platform

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..		
AeroData	Add files via upload	6 days ago
ServoData	Add files via upload	6 days ago
WindData	Add files via upload	6 days ago
NRELOffshrBsline5MW_ADAMSSpecific.dat	Add files via upload	6 days ago
NRELOffshrBsline5MW_AeroDyn.ipt	Add files via upload	6 days ago
NRELOffshrBsline5MW_AeroDyn_14.ipt	Add files via upload	6 days ago
NRELOffshrBsline5MW_AeroDyn_16.ipt	Add files via upload	6 days ago
NRELOffshrBsline5MW_AeroDyn_Turb_11...	Add files via upload	6 days ago
NRELOffshrBsline5MW_Blade.dat	Add files via upload	6 days ago
NRELOffshrBsline5MW_Linear.dat	Add files via upload	6 days ago
NRELOffshrBsline5MW_Platform_OC3Hy...	Add files via upload	6 days ago
NRELOffshrBsline5MW_Spar_TMDControl...	Add files via upload	6 days ago
NRELOffshrBsline5MW_Tower_OC3Hywin...	Add files via upload	6 days ago

Fig. 3: Input files of FAST

Table 1: Input files of F2A

InputFileForFAST2AQWA.txt	Main input file of F2A, the filename cannot be changed
InputforreadAQWAResults_SingleFile.txt	Input file for reading the results from the .LIS file which is the output file of an analysis in AQWA
Spar_Turb_114.dat	The case file of AQWA for the spar platform. This file is generated using ANSYS-Workbench
Spar_Turb_114.fst	Input file of FAST v7.
readAQWAResults_SingleFile.exe	The executable file for reading the outputs of AQWA
user_force64.dll	The user-force DLL, core of F2A.

2.2 Running the simulation of the example

It is very simple to the example case of F2A. The processes include:

1) Replace the user force DLL

Copy the DLL file in the repository (user_force64.dll) to the bin folder of installation directory of AQWA. In my computer, the bin folder is "C:\Program Files\ANSYS Inc\v190\aqwa\bin\winx64". Replace the default user_force64.dll by the DLL given here.

2) Modify the input

Open the main input of F2A (InputFileForFAST2AQWA.txt), ensure the definition of Prifile is consistent with the filename of the .fst file. This is the main inputs of FAST, in which the aero-servo-elastic properties are defined. Please note that the filename of "InputFileForFAST2AQWA.txt" cannot be changed. But the variables defined in this file can be modified. For a coupled analysis, please also ensure "CouplingFlag" is set to TRUE.

"IndexTwrStr" represents the ID of the structure defined in AQWA connecting to the tower directly. In this example, only one structure is modelled in AQWA. Therefore, the integer variable is set to 1.

```
InputFileForFAST2AQWA.txt - 记事本
文件(F)  编辑(E)  格式(O)  查看(V)  帮助(H)
! Input file of the interface FAST2AQWA that is developed by Y.Yang (PDRA in LJMU) on 10-March-2020 for performing fully-coupled analysis of floating offshore wind turbines (FOWTs)
! The FAST2AQWA is implemented through the user_force DLL. FAST v7 is used to examine the aero-elastic effects of the wind turbine.
! This file is specified for NREL 5MW wind turbine supported by the OC3-Hywind platform (Do not remove anyline below)
--------------- FAST Configuration ------------------
"Spar_Turb_114.fst"     - Prifile        - Primary input file for FAST
True                    - CouplingFlag           - Flag of coupling interface. False: the platform motion and velocity imported to FAST WILL BE ZERO.
--------------- AQWA structure properties -----------
1                       - IndexTwrStr            - Index of the structure connecting to the tower directly.
True                    - OPtfmFrc               - Flag of whether output the platform forces
False                   - OPtfmMot               - Flag of whether output the platform motions (CoG w.s.t. O)
False                   - OPtfmRld               - Flag of whether output the relative displacement at the reference point((0,0,0)) due to the rotations
False                   - OPtfmAdm               - Flag of whether output the added mass due to the wind turbine
---------------- END OF THE INPUT ------------------
```

Fig. 4: Example of InputFileForFAST2AQWA.txt

3) Modify the simulation time step/ duration

The time step in solving the structural dynamics is allowed to be different with the time step of analysis to solving the platform motions, which are defined in the .fst file and the .dat file, respectively, as shown in Fig. 5. For the structural dynamics, it is suggested to use a time step no larger than 0.01 s. Here we used 0.005 s for this example. The time step defined in the AQWA input must be **double times** of the time step defined in the .fst file. The default time step in AQWA is 0.1 s. According to our sensitivity analysis of the time step, 0.1 s is small enough to avoid adverse effects due to non-convergence. Please note that AQWA has a very rigorous requirement on the format of the input file. Usually, each term occupies a length of 10 characters. Please keep this in mind when trying to make a modification. The time duration of the analysis using F2A depends on the definition in the .dat file only. The first value is the number of time steps, the second value is the time step. The third value is the start time of the simulation, it is suggested to use 0 for this term.

```
Spar_Turb_114.fst - 记事本
文件(F)  编辑(E)  格式(O)  查看(V)  帮助(H)
--------------------------------------------------------------------------------
------- FAST INPUT FILE --------------------------------------------------------
NREL 5.0 MW Baseline Wind Turbine for Use in Offshore Analysis.
Properties from Dutch Offshore Wind Energy Converter (DOWEC) 6MW Pre-Design (1
---------------------- SIMULATION CONTROL --------------------------------------
False         Echo         - Echo input data to "echo.out" (flag)
   1          ADAMSPrep    - ADAMS preprocessor mode {1: Run FAST, 2: use FAST as
   1          AnalMode     - Analysis mode {1: Run a time-marching simulation, 2:
   3          NumBl        - Number of blades (-)
 4000.0         TMax         - Total run time (s)
   0.005      DT           - Integration time step (s)
```

(a) Time step/length in the .fst file for the solution of structural dynamics

Spar_Turb_114.dat - 记事本

文件(F) 编辑(E) 格式(O) 查看(V) 帮助(H)

```
      COMP   15   40         1       250.       252.        0.
      ECAT                        77.7066 6.3617e-3 3.84243e8  2.9233e6      902.2
      ECAB                             0.
      ECAX                             0.         0.        0.
      ECAH                             1.                   1.      9.e-2     2.5e-2
      NCEL  100
      NLID    197009     097008
      DYNM
 END
*******************************************************************************
********************************** DECK 15 ************************************
*******************************************************************************
          STRT
      POS1                   0.         0.-89.915497        0.         0.         0.
 END
*******************************************************************************
********************************** DECK 16 ************************************
*******************************************************************************
          TINT
      TIME     40001      1.e-1         0.
 END
```

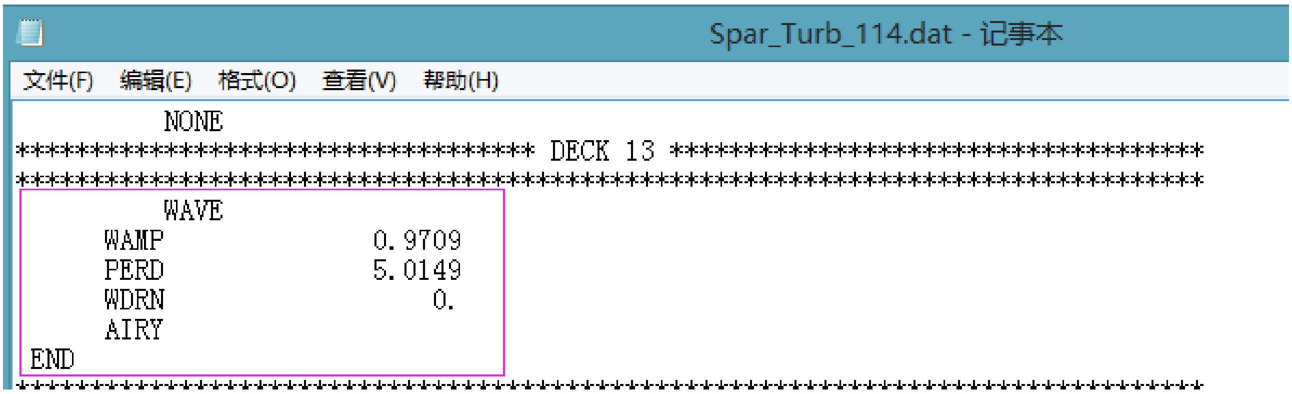
(b) Time step/length in the .dat file for the solution of platform motions

Fig. 5: Time step/length definition in the .fst file and .dat file

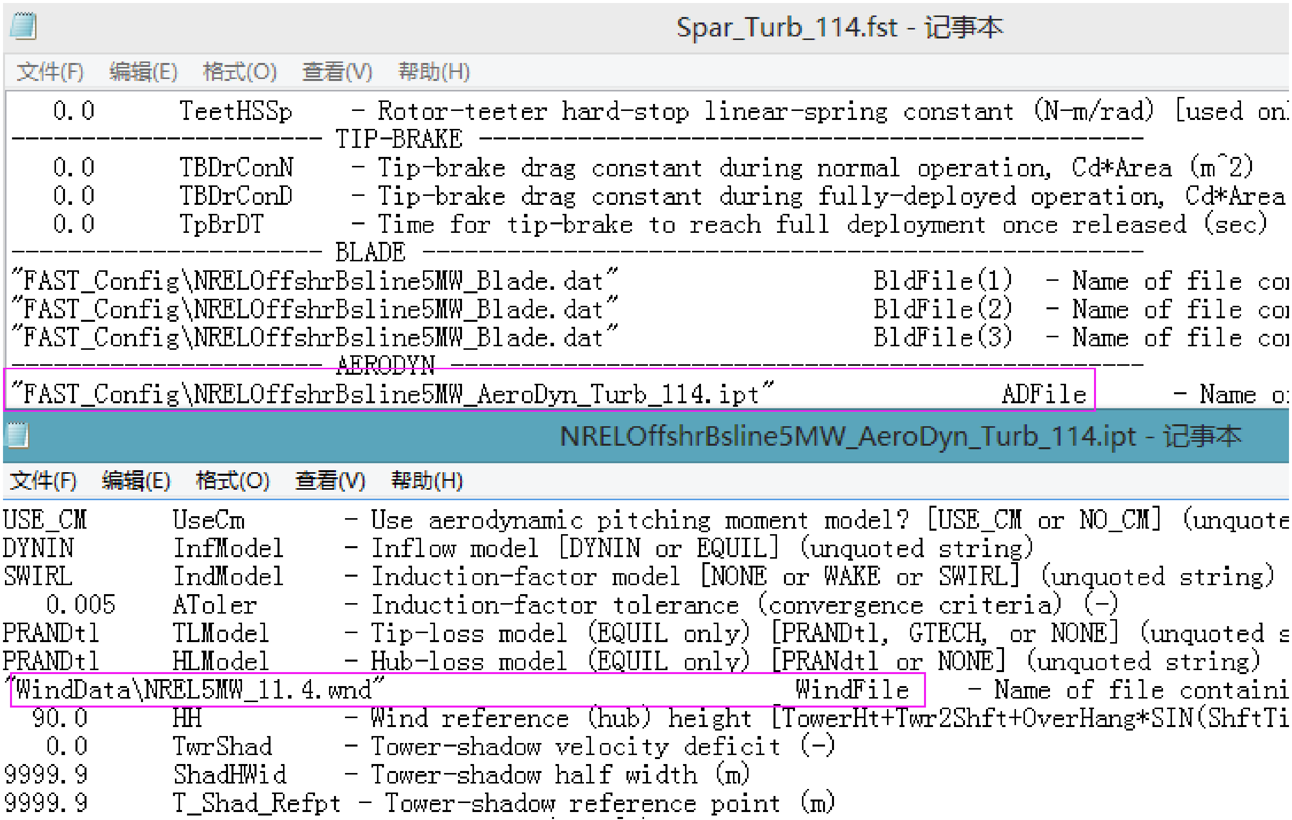
4) Modify the environmental condition

A regular wave and a turbulent wind are defined in the example. The wave properties are defined in DECK 13. The wave amplitude is 0.9709 m, corresponding to a wave height of 1.9718 m. The period of the regular wave is 5.0149 s and the wave direction is defined to 0 degree. If the user want to examine an irregular wave condition, please re-generate the main input using ANSYS-Workbench or make modifications according to the reference manual of AQWA based on this example file.

Wind condition is defined in the ADFile, where specified the directory of the wind data file. An input of TurbSim is also given in the wind data folder. The users can create the wind condition they want. The wind condition defined in the example is a turbulent wind based on the IEC Kaimal spectrum. The average wind speed at the hub height is 11.4 m/s.



(a) Wave condition



(b) Wind condition

Fig. 6: Environmental conditions

5) Other notice

The input fst file is for an improve version of FAST v7. Three modules are added into the original input of FASTv7. For the simulation using F2A, keep the current settings for the seismic loading module, and the soil-structure interaction module. The Structural Control module can be modified and applied into F2A. The DLL input is also modified to make it more flexible in use.

```
Spar_Turb_114.fst - 记事本
文件(F) 编辑(E) 格式(O) 查看(V) 帮助(H)
   0.0        TeetHSSp     - Rotor-teeter hard-stop linear-spring constant (N-m/rad) [used only for 2 blades and when '
---------------------- TIP-BRAKE -----------------------------------------------------
   0.0        TBDrConN     - Tip-brake drag constant during normal operation, Cd*Area (m^2)
   0.0        TBDrConD     - Tip-brake drag constant during fully-deployed operation, Cd*Area (m^2)
   0.0        TpBrDT       - Time for tip-brake to reach full deployment once released (sec)
---------------------- BLADE ---------------------------------------------------------
"FAST_Config\NRELOffshrBsline5MW_Blade.dat"                BldFile(1)  - Name of file containing properties for b
"FAST_Config\NRELOffshrBsline5MW_Blade.dat"                BldFile(2)  - Name of file containing properties for b
"FAST_Config\NRELOffshrBsline5MW_Blade.dat"                BldFile(3)  - Name of file containing properties for b
---------------------- AERODYN -------------------------------------------------------
"FAST_Config\NRELOffshrBsline5MW_AeroDyn_Turb_114.ipt"             ADFile      - Name of file containing AeroDyn
---------------------- NOISE ---------------------------------------------------------
"Dummy"       NoiseFile    - Name of file containing aerodynamic noise input parameters (quoted string) [used only whe
---------------------- ADAMS ---------------------------------------------------------
"FAST_Config\NRELOffshrBsline5MW_ADAMSSpecific.dat"        ADAMSFile   - Name of file containing ADAMS-specific i
---------------------- LINEARIZATION CONTROL -----------------------------------------
"FAST_Config\NRELOffshrBsline5MW_Linear.dat"               LinFile     - Name of file containing FAST linearizati
---------------------- Seismic loading ----------------------------------
False            SeismicLdMode               - The flag of seismic loads calculation. (Ture: with earthquake,Fal
"FAST_Config\DTU10MW_Monopile_Seismic_Kobe.dat"               SeismicFile      - Name of file containing seismic c
--------------------- Soil-Structure Interaction -----------------------------------
1                SSIMode                     - Model for SSI (0: none, 1: Coupled Springs (Wolf method), 2: Coup
150.0             ShrModuSoil                - The shear modulus of local soil (Unit:MPa) [Only used when SSIMod
1800.0            DenSoil                    - The denisty of local soil (Unit: kg/m^3) [Only used when SSIMode :
0.333            PoissRatio                  - The poisson ratio of local soil (Unit: -) [Only used when SSIMode
6.0              RadiusPtfm                  - The radius of platform (Unit: m) [Only used when SSIMode = 1]
"FAST_Config\SSIData\OC3PhraseII_SoilStiffness_CS.dat"  InFileGKCM          - Input file for specified stiffness a
"FAST_Config\SSIData\StiffnessDSModel_10MW30mWD.dat"    InFileDS            - Input file for DS model which define
"FAST_Config\SSIData\pyCurve_data.dat"                  InFileNonlinear     - Input file for nonlinear DS model us
--------------------- Structural Control -----------------------------------
False            StrcCtrlMode                - The flag of structural control. (Ture: activate the TMD control,F
"FAST_Config\DTU10MW_Monopile_TMDControl.dat"                StrcCtrlFile      - Name of the file containing TMD co
--------------------- Bladed style DLL ----------------------------------
"FAST_Config\ServoData\DISCON_x64_Spar.dll"      DLL_FileName            - DLL file name including the extension
"DISCON"                    DLL_ProcName            - Program name of the DLL control subroutine
"FAST_Config\ServoData\DISCON.IN"                 DLL_InFile              - Input file name of the DLL in whi
---------------------- OUTPUT --------------------------------------------------------
```

Fig. 7: Modified parts compared to the original version of FASTv7

6) Run the simulation

The simulation can be run in two different ways using F2A for the example. The first is the easier: lunch aqwa.exe and select the .dat input file in the window. The simulation is running as follows:

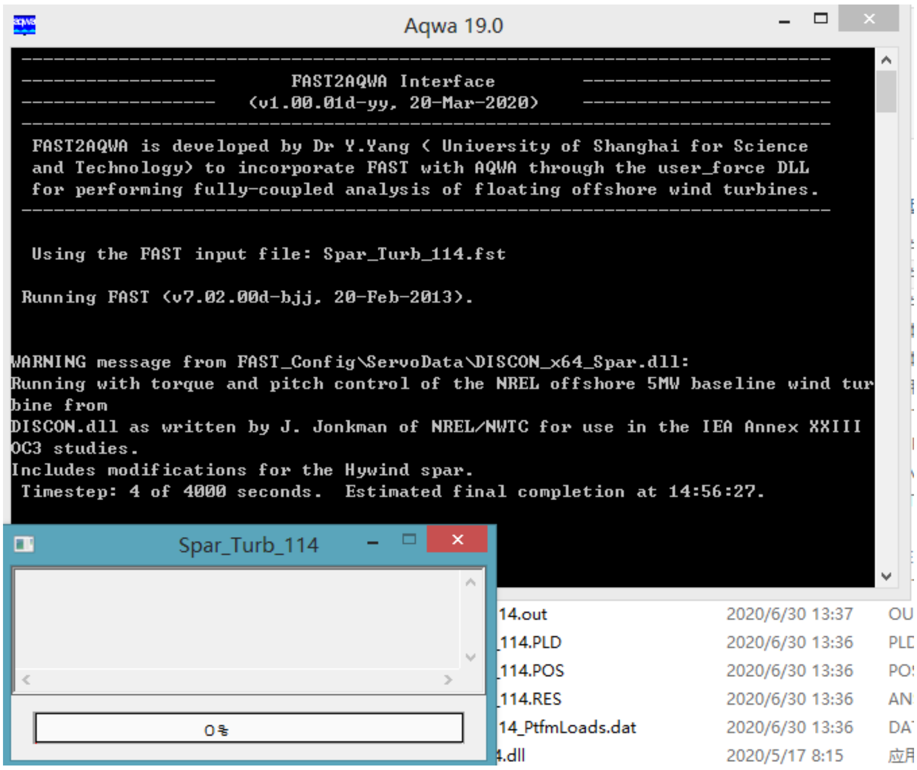


Fig. 8: Running the simulation in method 1

However, I prefer the second way to run the simulation, which is to run the simulation in the promote command window. (i) Open a promote command window <Win + R>, type CMD and enter. (ii)Go to the directory of the bin folder of AQWA; (iii) type aqwa.exe <space> directory of the input file.

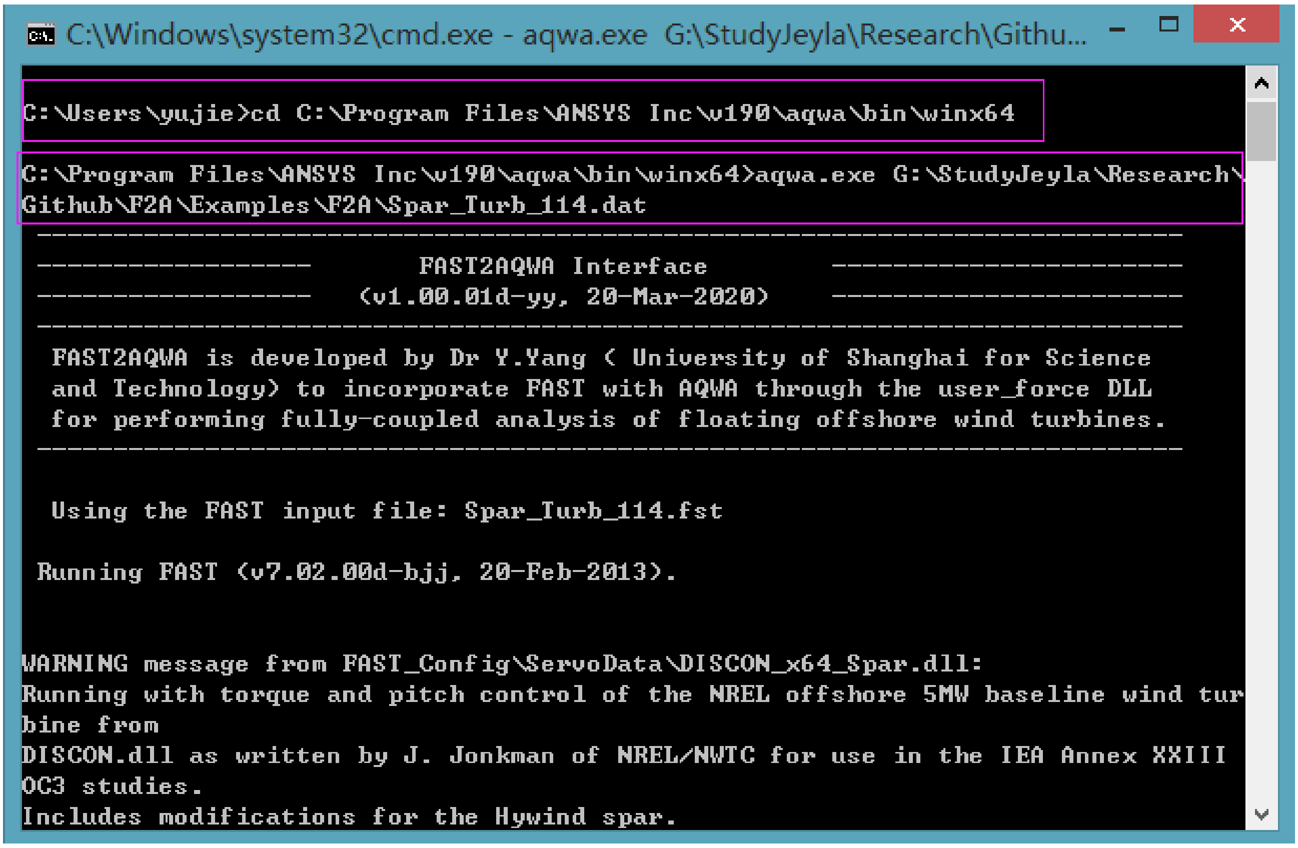
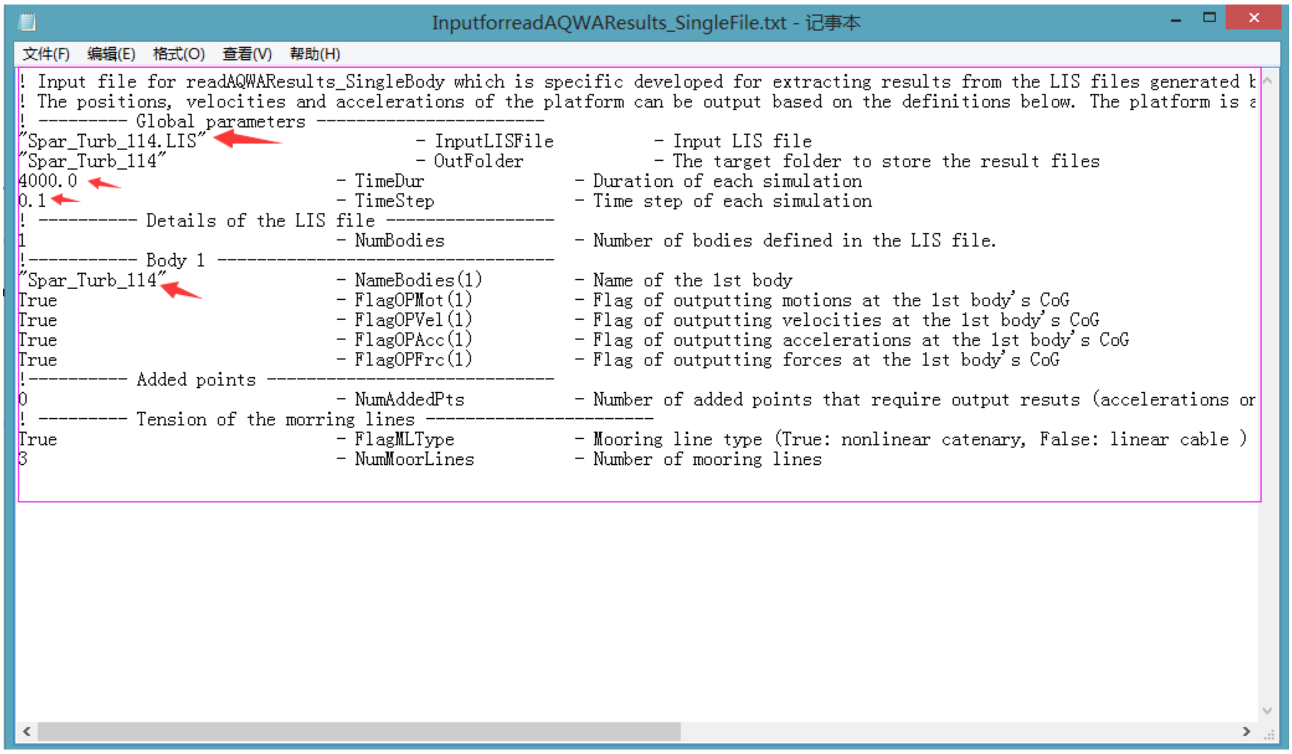


Fig. 9: Running the simulation in method 2

7) Extract the results

The results stored in the .LIS file can be extracted using the code (readAQWAResults_SingleFile.exe). The structure of the LIS file can be defined in the input file “InputforreadAQWAResults_SingleFile.txt” whose name is not allowed to be modified. The LIS file name, time duration and step must be defined appropriately. The platform position, velocity and acceleration results will be stored in the files with a base of the NameBodies(i).

The result extraction code is written in FORTRAN. The source code of this tool can be found in the source code repository.



```
InputforreadAQWAResults_SingleFile.txt - 记事本
文件(F) 编辑(E) 格式(O) 查看(V) 帮助(H)
! Input file for readAQWAResults_SingleBody which is specific developed for extracting results from the LIS files generated b
! The positions, velocities and accelerations of the platform can be output based on the definitions below. The platform is a
! --------- Global parameters -----------------------
"Spar_Turb_114.LIS"                    - InputLISFile          - Input LIS file
"Spar_Turb_114"                        - OutFolder             - The target folder to store the result files
4000.0                         - TimeDur               - Duration of each simulation
0.1                            - TimeStep              - Time step of each simulation
! ---------- Details of the LIS file ----------------
1                              - NumBodies             - Number of bodies defined in the LIS file.
!----------- Body 1 ---------------------------------
"Spar_Turb_114"                - NameBodies(1)         - Name of the 1st body
True                           - FlagOPMot(1)          - Flag of outputting motions at the 1st body's CoG
True                           - FlagOPVel(1)          - Flag of outputting velocities at the 1st body's CoG
True                           - FlagOPAcc(1)          - Flag of outputting accelerations at the 1st body's CoG
True                           - FlagOPFrc(1)          - Flag of outputting forces at the 1st body's CoG
!---------- Added points ----------------------------
0                              - NumAddedPts           - Number of added points that require output resuts (accelerations or
! --------- Tension of the morring lines -----------------------
True                           - FlagMLType            - Mooring line type (True: nonlinear catenary, False: linear cable )
3                              - NumMoorLines          - Number of mooring lines
```

Fig. 10: Example input of the result extraction code

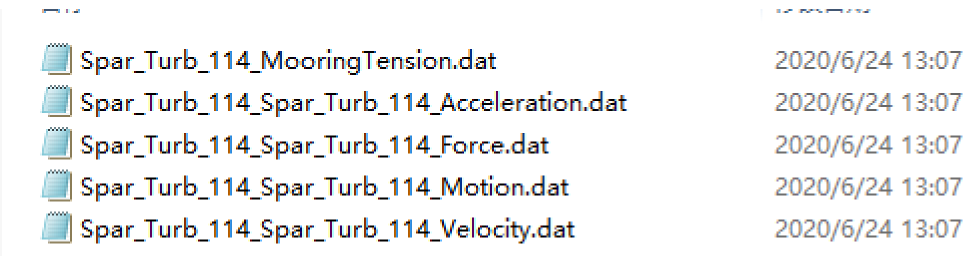


Fig. 11: Results of the example case

3 Advantages and limitations of F2A

F2A is the first tool based on AQWA for coupled analysis of floating offshore wind turbines. The advantages of F2A compared to FAST come from the superiority of AQWA in predicting hydrodynamic loads and mooring tensions. AQWA is capable of examining the interactions between multiple floaters. However, FAST only can consider one floater, or treating the multiple floaters as one unibody. For the modelling of multibody floating platform connected by flexible elements, F2A has the unique advantages. Moreover, F2A can be used to investigate the transient dynamic behavior of a floating wind turbine subjected to a sudden mooring breakage. The capability has not been implemented within FAST yet. F2A is better in examining the dynamics of the platform.

The current version of F2A is based on FASTv7. The BeamDyn and AeroDyn 15 modules, which are more advanced structural and aerodynamic modules for the blades, respectively, have not been integrated within AQWA. Therefore, compared to FAST, the aero-elastic responses of a larger wind turbine predicted by F2A may not be as accurate as the results using FAST with the activations of BeamDyn and AeroDyn 15.