OpenFAST: Prescribing Loads at Tower Top

Version 0
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In the Confluence site, it is possible to find a new version of OpenFAST solver. This version (based on OpenFAST v2.3.0) is not publicly available yet, but it can be already used in OC6 phase II.

Note that in order to use this new OpenFAST solver it's necessary to use the new main input file. In Figure 1, the new inputs are highlighted in red:

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------- OpenFAST example INPUT FILE -------------------------------------------
OpenFAST model: OC6 phase II. SubDyn (monopile) + ElastoDyn (tower). Land-based case. IMPORTANT: New template to account for SoildDyn.
---------------------- SIMULATION CONTROL --------------------------------------
False         Echo            - Echo input data to <RootName>.ech (flag)
"FATAL"       AbortLevel      - Error level when simulation should abort (string) {"WARNING", "SEVERE", "FATAL"}
       300    TMax            - Total run time (s)
     0.001    DT              - Recommended module time step (s)
         2    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}
     99999    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}
         0    CompInflow      - Compute inflow wind velocities (switch) {0=still air; 1=InflowWind; 2=external from OpenFOAM}
         0    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}
         1    CompHydro       - Compute hydrodynamic loads (switch) {0=None; 1=HydroDyn}
         1    CompSub         - Compute sub-structural dynamics (switch) {0=None; 1=SubDyn; 2=External Platform MCKF}
         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}
         0    CompSoil        - Compute soil-structural dynamics (switch) {0=None; 1=with SubDyn mesh}
---------------------- INPUT FILES ---------------------------------------------
"OC6_phaseII_Definition\OC6_phaseII_ElastoDyn_LC11.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)
"unused"                                                                 InflowFile      - Name of file containing inflow wind input parameters (quoted string)
"unused"                                                                 AeroFile        - Name of file containing aerodynamic input parameters (quoted string)
"unused"                                                                 ServoFile       - Name of file containing control and electrical-drive input parameters (quoted string)
"OC6_phaseII_Definition\OC6_phaseII_Platform_HydroDyn_damping_LC11.dat"   HydroFile       - Name of file containing hydrodynamic input parameters (quoted string)
"OC6_phaseII_Definition\OC6_phaseII_Monopile_SubDyn.dat"                  SubFile         - Name of file containing sub-structural input parameters (quoted string)
"unused"                                                                 MooringFile     - Name of file containing mooring system input parameters (quoted string)
"unused"                                                                 IceFile         - Name of file containing ice input parameters (quoted string)
"unused"                                                                 SoilFile        - Name of the file containing the SoilDyn input parameters (quoted string)
---------------------- OUTPUT --------------------------------------------------
True          SumPrint        - Print summary data to "<RootName>.sum" (flag)
          5   SttsTime        - Amount of time between screen status messages (s)
      99999   ChkptTime       - Amount of time between creating checkpoint files for potential restart (s)
       0.05   DT_Out          - Time step for tabular output (s) (or "default")
          0   TStart          - Time to begin tabular output (s)
          1   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 channel.  Resulting field should be 10 characters. (quoted string)
---------------------- LINEARIZATION -------------------------------------------
False         Linearize       - Linearization analysis (flag)
          1   NLinTimes       - Number of times to linearize (-) [>=1] [unused if Linearize=False]
0             LinTimes        - List of times at which to linearize (s) [1 to NLinTimes] [unused if Linearize=False]
          2   LinInputs       - Inputs included in linearization (switch) {0=none; 1=standard; 2=all module inputs (debug)} [unused if Linearize=False]
          1   LinOutputs      - Outputs included in linearization (switch) {0=none; 1=from OutList(s); 2=all module outputs (debug)} [unused if Linearize=False]
False         LinOutJac       - Include full Jacobians in linearization output (for debug) (flag) [unused if Linearize=False; used only if LinInputs=LinOutputs=2]
True          LinOutMod       - Write module-level linearization output files in addition to output for full system? (flag) [unused if Linearize=False]
---------------------- VISUALIZATION -------------------------------------------
          0   WrVTK           - VTK visualization data output: (switch) {0=none; 1=initialization data only; 2=animation}
          1   VTK_type        - Type of VTK visualization data: (switch) {1=surfaces; 2=basic meshes (lines/points); 3=all meshes (debug)} [unused if WrVTK=0]
True          VTK_fields      - Write mesh fields to VTK data files? (flag) {true/false} [unused if WrVTK=0]
         15   VTK_fps         - Frame rate for VTK output (frames per second){will use closest integer multiple of DT} [used only if WrVTK=2]
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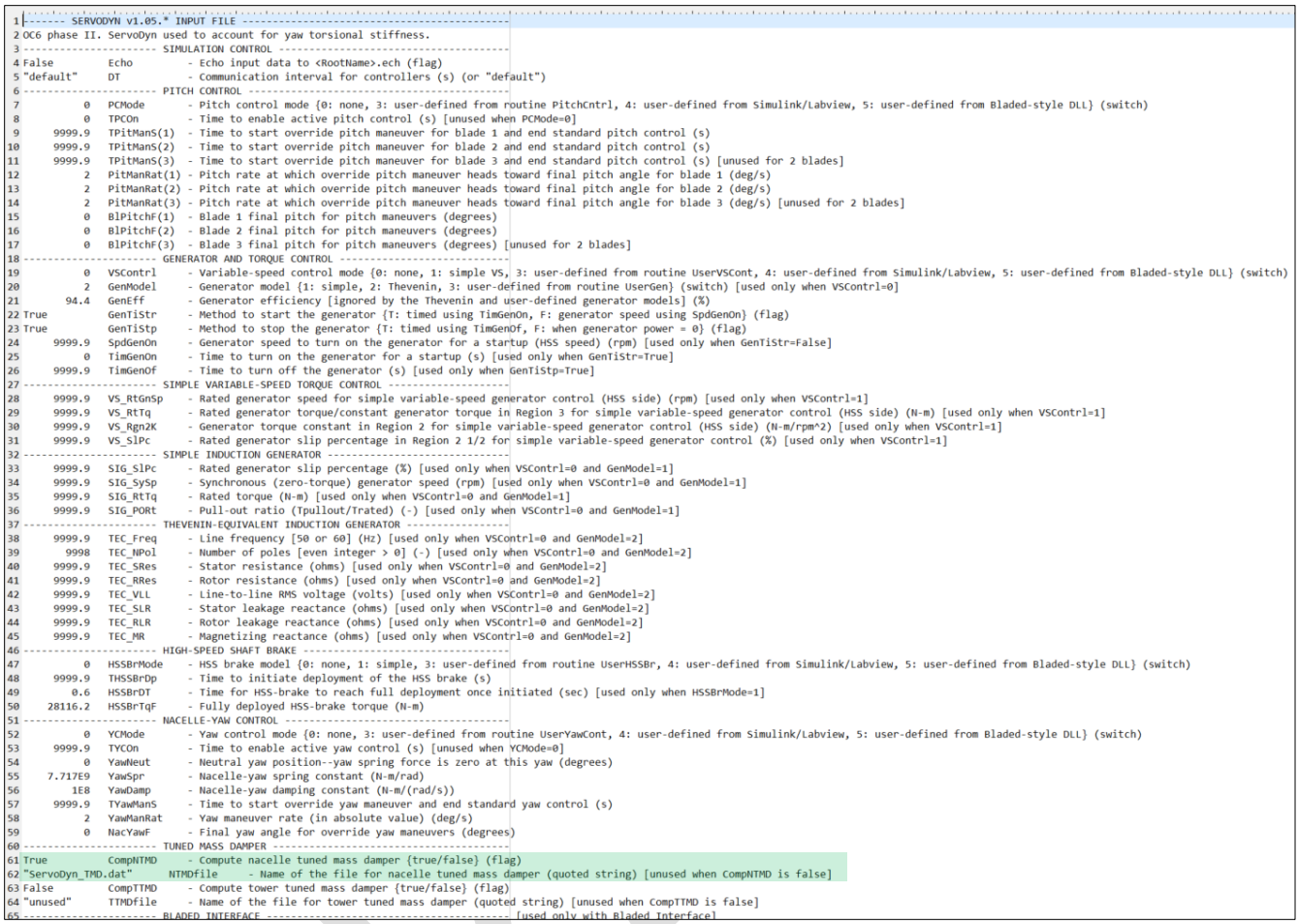
Figure 1. New OpenFAST main input file

To account for the input forces at tower top, it is necessary to enable the ServoDyn module (`CompServo = 1` in Figure 1, highlighted in green).

In the ServoDyn input file (see Figure 2), the nacelle tuned mass damper functionality (`CompNTMD = True`) will be used to input the tower top loads.



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------ SERVODYN v1.05.* INPUT FILE ------------------------------------------
OC6 phase II. ServoDyn used to account for yaw torsional stiffness.
---------------------- SIMULATION CONTROL --------------------------------------
False         Echo          - Echo input data to <RootName>.ech (flag)
"default"     DT            - Communication interval for controllers (s) (or "default")
---------------------- PITCH CONTROL -------------------------------------------
          0   PCMode        - Pitch control mode {0: none, 3: user-defined from routine PitchCntrl, 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 standard pitch control (s)
     9999.9   TPitManS(2)   - Time to start override pitch maneuver for blade 2 and end standard pitch control (s)
     9999.9   TPitManS(3)   - Time to start override pitch maneuver for blade 3 and end standard 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 ----------------------------
          0   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)
          2   GenModel      - Generator model {1: simple, 2: Thevenin, 3: user-defined from routine UserGen} (switch) [used only when VSContrl=0]
       94.4   GenEff        - Generator efficiency [ignored by the Thevenin and user-defined generator models] (%)
True          GenTiStr      - Method to start the generator {T: timed using TimGenOn, F: generator 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 variable-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 GenModel=2]
     9999.9   TEC_RRes      - Rotor resistance (ohms) [used only when VSContrl=0 and GenModel=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, 3: user-defined from routine 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 (degrees)
    7.717E9   YawSpr        - Nacelle-yaw spring constant (N-m/rad)
        1E8   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 ---------------------------------------
True          CompNTMD      - Compute nacelle tuned mass damper {true/false} (flag)
"ServoDyn_TMD.dat"     NTMDfile      - Name of the file for nacelle tuned mass damper (quoted string) [unused when CompNTMD is false]
False         CompTTMD      - Compute tower tuned mass damper {true/false} (flag)
"unused"      TTMDfile      - Name of the file for tower tuned mass damper (quoted string) [unused when CompTTMD is false]
---------------------- BLADED INTERFACE ----------------------------------------- [used only with Bladed Interface]
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Figure 2. ServoDyn input file to account for tower top loads

In the *ServoDyn_TMD.dat* file defined in ServoDyn (see Figure 2), it is necessary to indicate the location in the space of the tuned mass damper. It's important to realize that ServoDyn assumes the nacelle location as the tower top location rather than the nacelle center of mass location. Therefore, the user can leave the location as 0, 0, 0 (see Figure 3). Finally, it is necessary to provide the path to a text file where the actual tower top loads are defined.

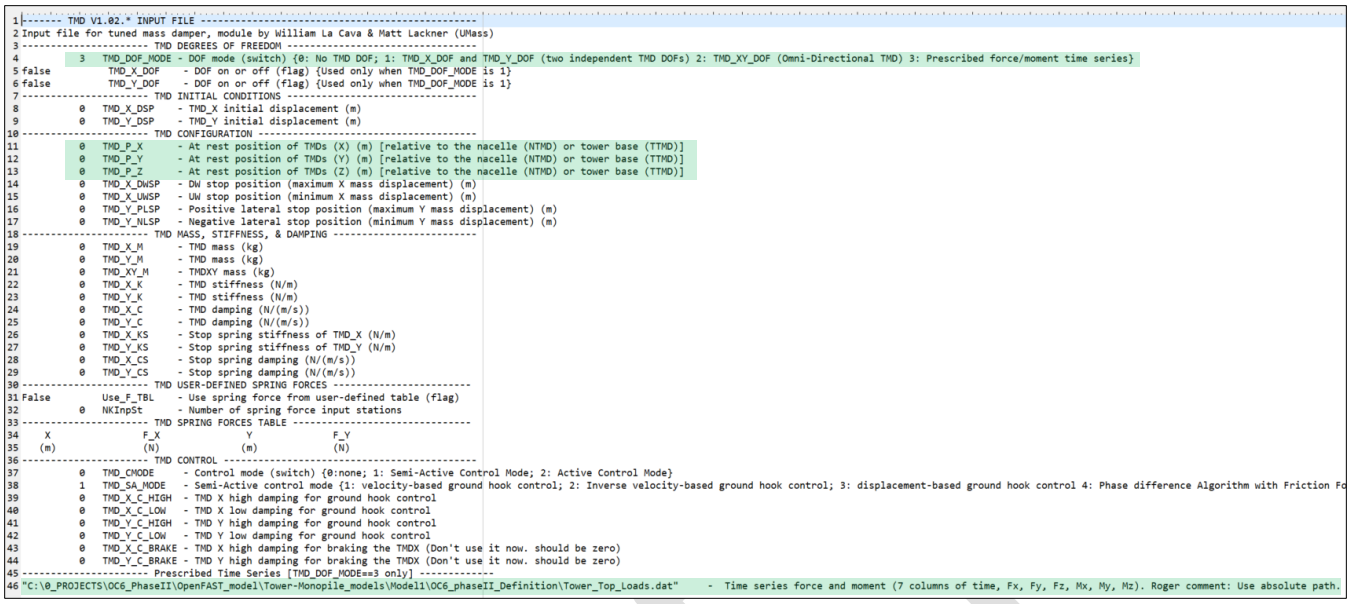

Figure 3. TMD input file to account for tower top loads

I personally use an absolute path instead of a relative path to prescribe the text file that contains the time series (see the bottom green rectangle in Figure 3). **The user must change this path accordingly**.

Figure 4 showns an example of text file (e.g. *Tower_Top_Loads.dat*) that contains the loads to be applied at tower top.

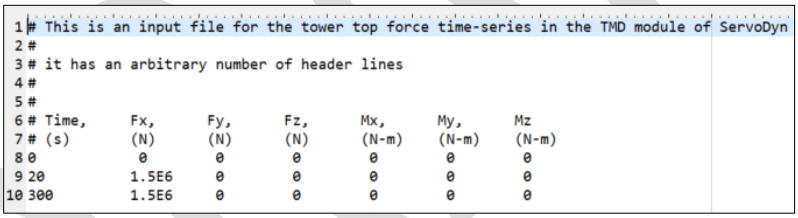

Figure 4. Example of text file with the prescribed loads to be applied at tower top

The loads are interpolated linearly between the points defined by the user.

Note that with this new capability, the user is now able to prescribe load time series at tower top. This also alows the user to prescribe free-decay tests in the six directions at tower top.