

FAST.Farm: An Open-Source Tool for Physics-Based Engineering Modeling and Loads Analysis of Wind Turbines in Wind Farms

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UT Dallas (Davidson-Gundy Alumni Center) – Dallas, TX (USA)

Workshop Materials at:
<https://tinyurl.com/yc3r3sd6>

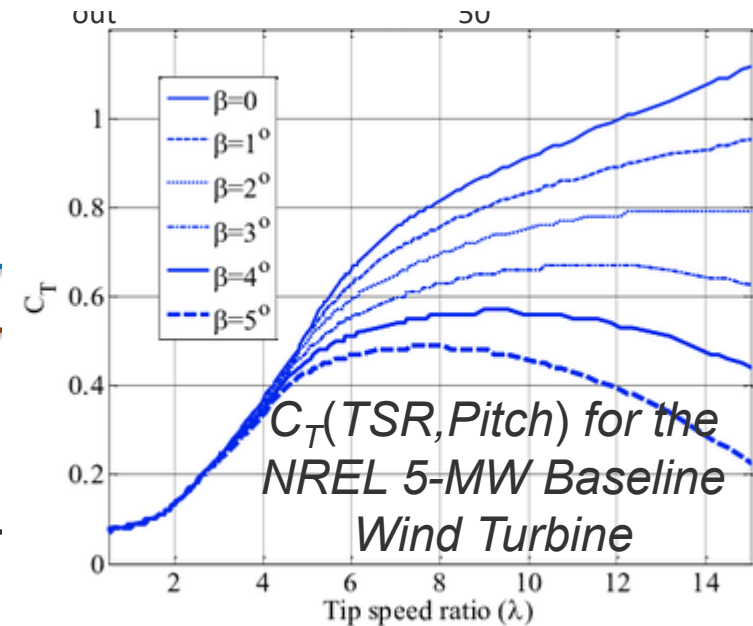
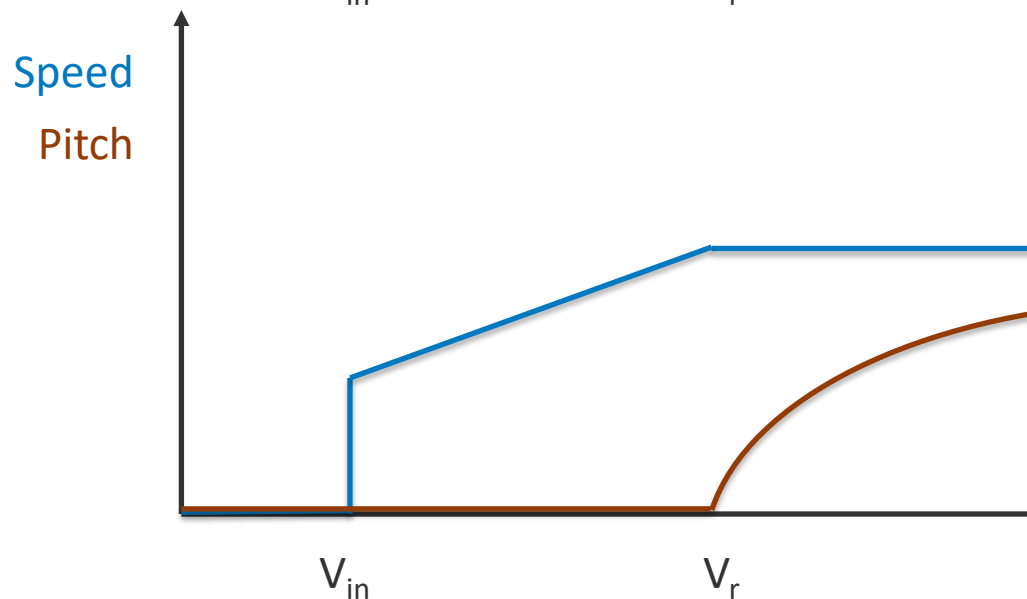
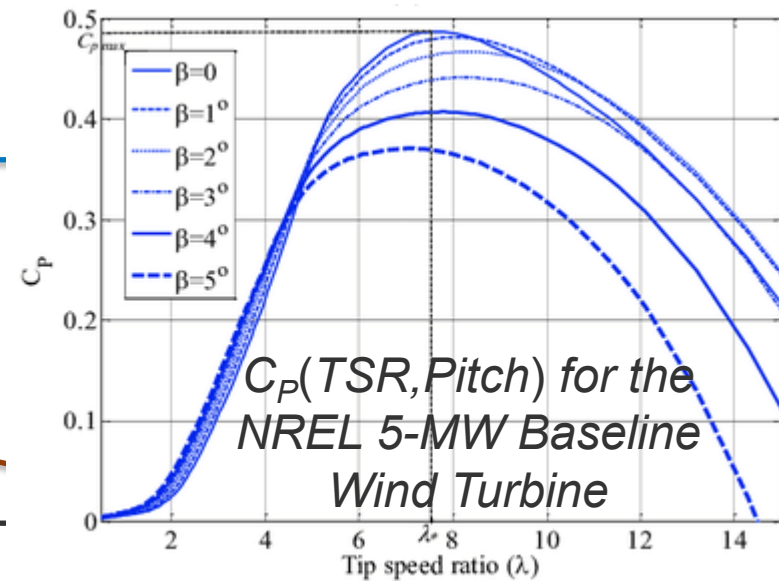
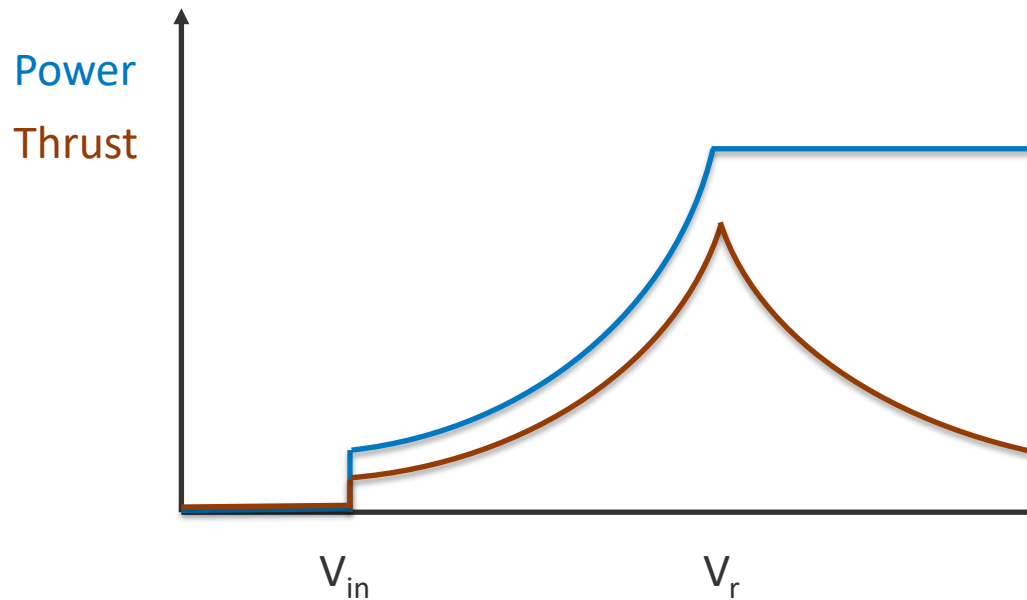
Agenda

- 1** Fundamental Concepts
- 2** Overview of OpenFAST and FAST.Farm
- 3** FAST.Farm Framework and Modules
- 4** Example 0
- 5** FAST.Farm Input File and Modeling Guidance
- 6** Examples 1-3
- 7** Recent FAST.Farm V&V and Applications
- 8** Outlook

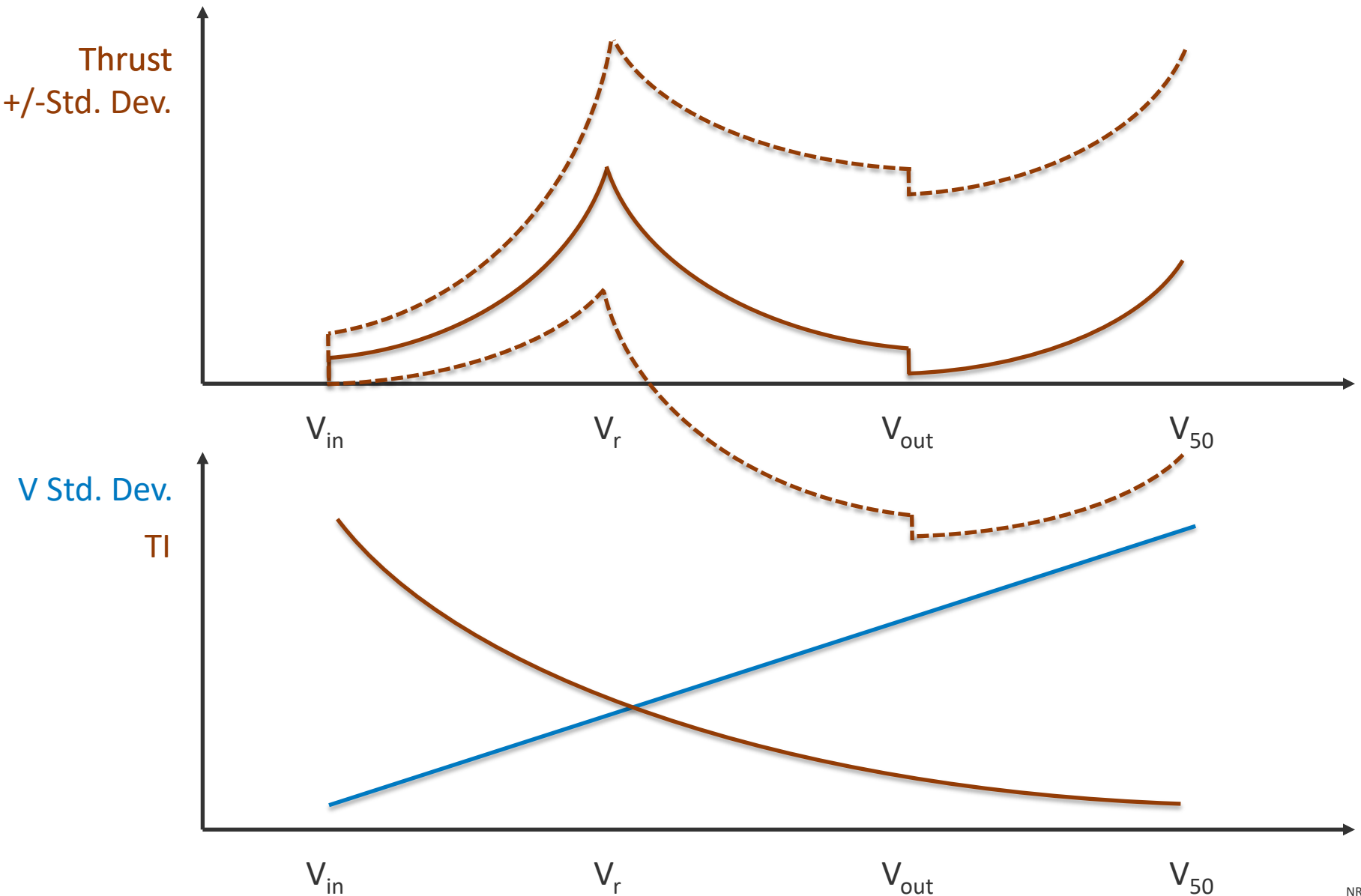
Break

Fundamental Concepts

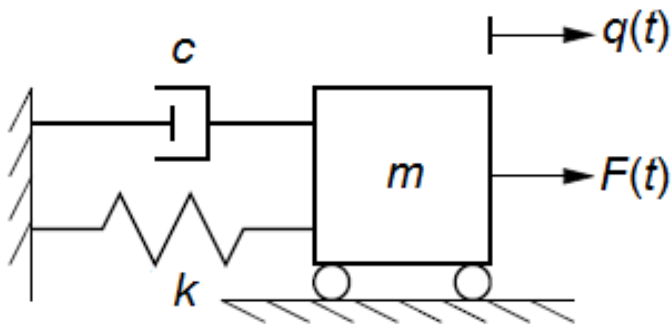
Mean and Standard Deviation of Wind, Power, Thrust



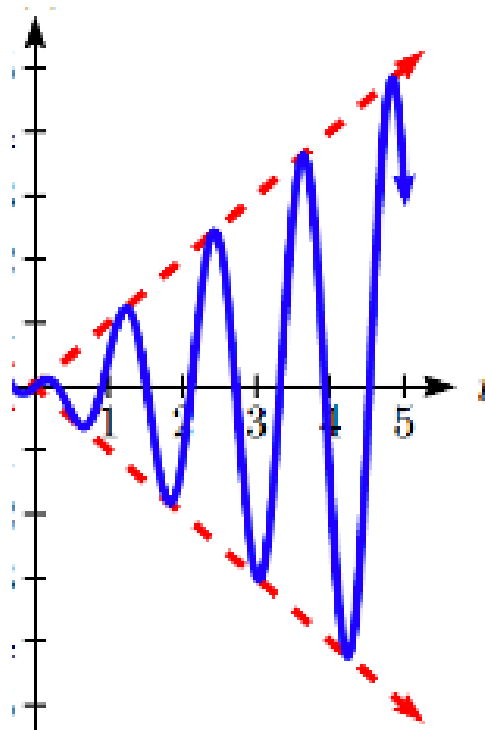
Mean and Standard Deviation of Wind, Power, Thrust



Mass-Spring-Damper: Resonance Versus Instability

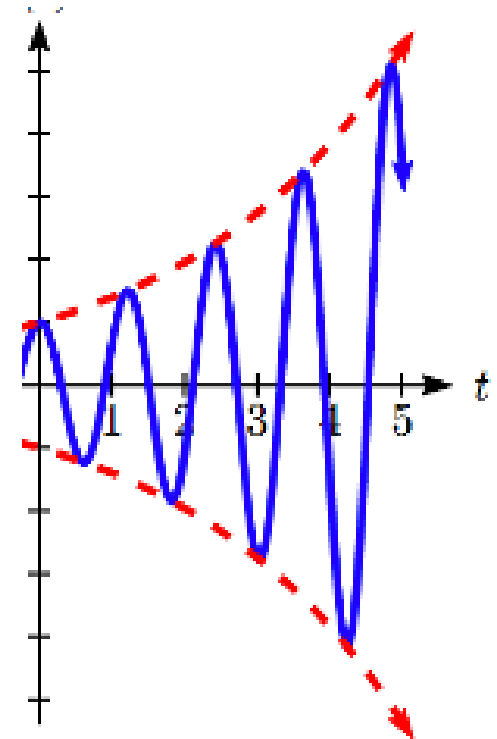


$$m\ddot{q} + c\dot{q} + kq = F$$



*Resonance
(with Small Damping)*

$$\omega_n = \sqrt{\frac{k}{m}}$$

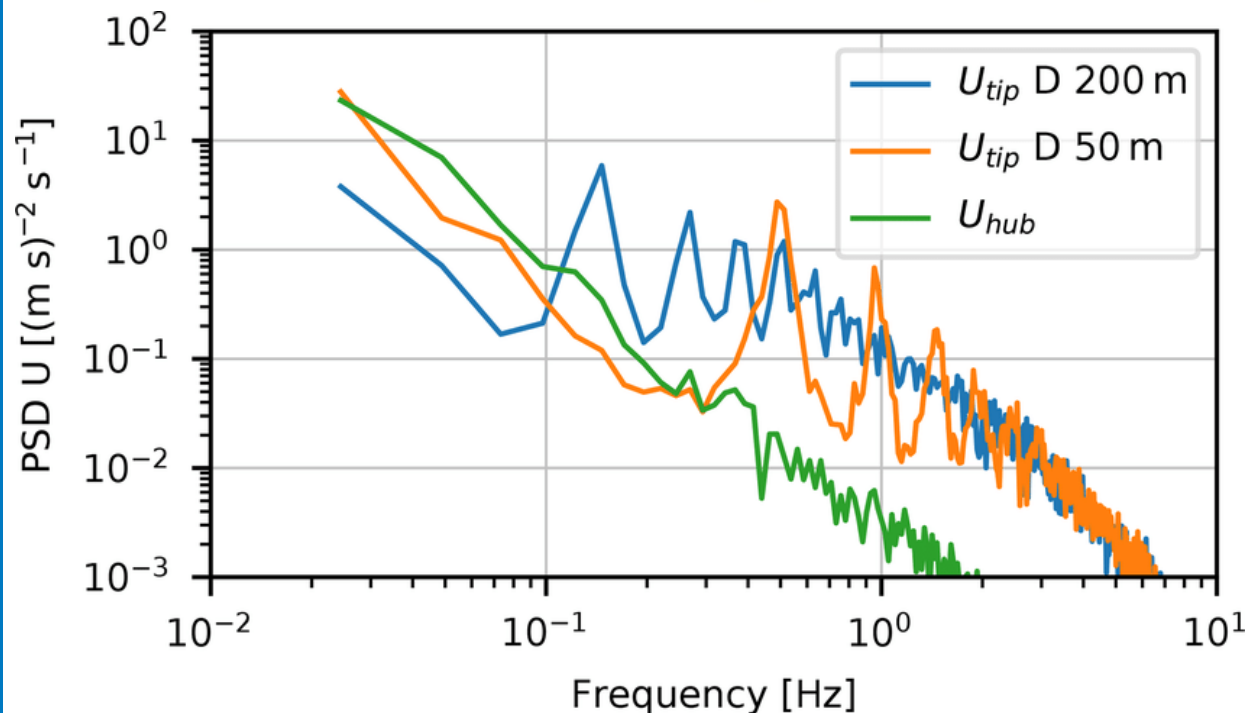
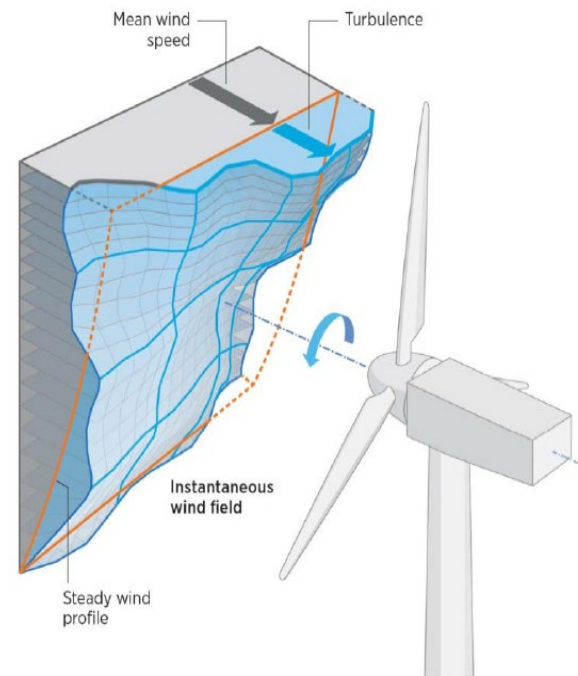


Instability

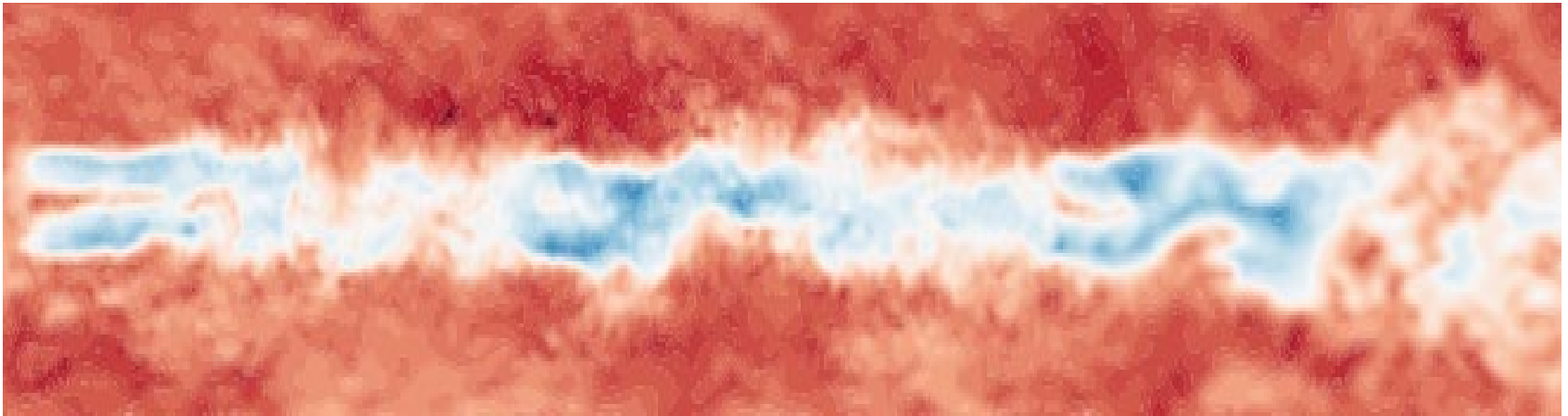
$$c < 0$$

Rotational Sampling of Turbulence

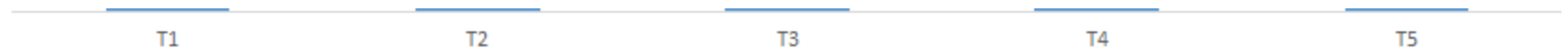
- Rotor rotation samples turbulent inflow
- Results in n -per-rev (nP) excitation of the 3-bladed wind turbine:
 - Blades (rotating frame): 0P, 1P, 2P, 3P, etc.
 - Drivetrain, nacelle, support structure (fixed frame): 0P, 3P, 6P, etc.
- Lower frequencies for larger turbines



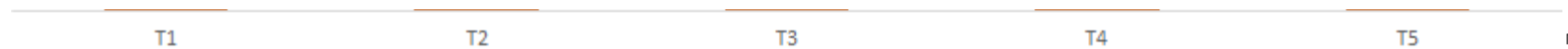
Power and Thrust for Flow Down a Row Below Rated



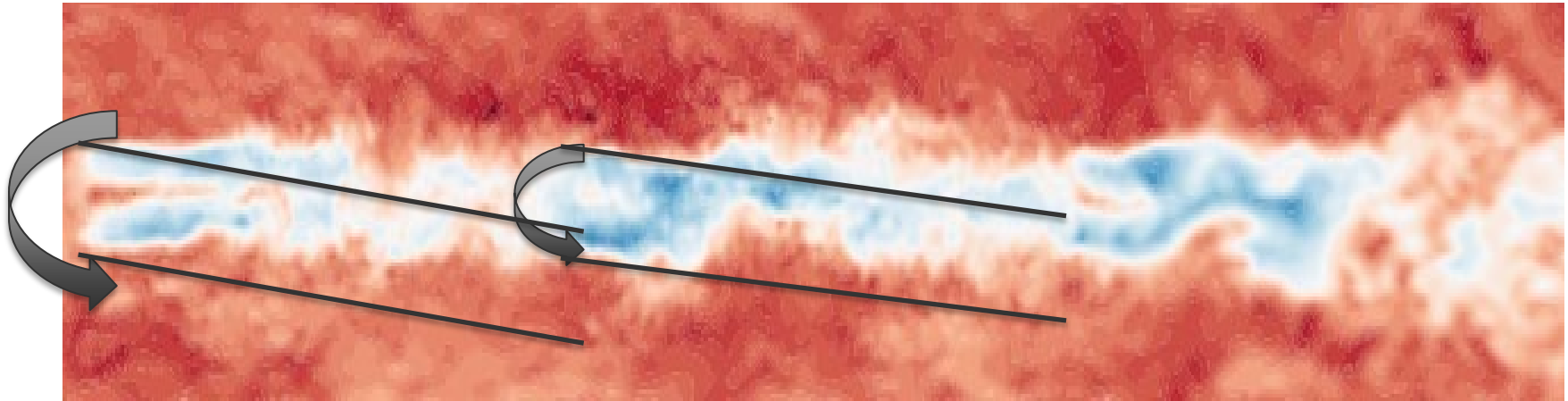
Mean Power and Range Without Wake Steering Below Rated



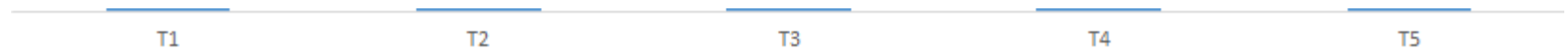
Mean Thrust and Range Without Wake Steering Below Rated



Power and Thrust for Flow Down a Row Below Rated with Wake Steering



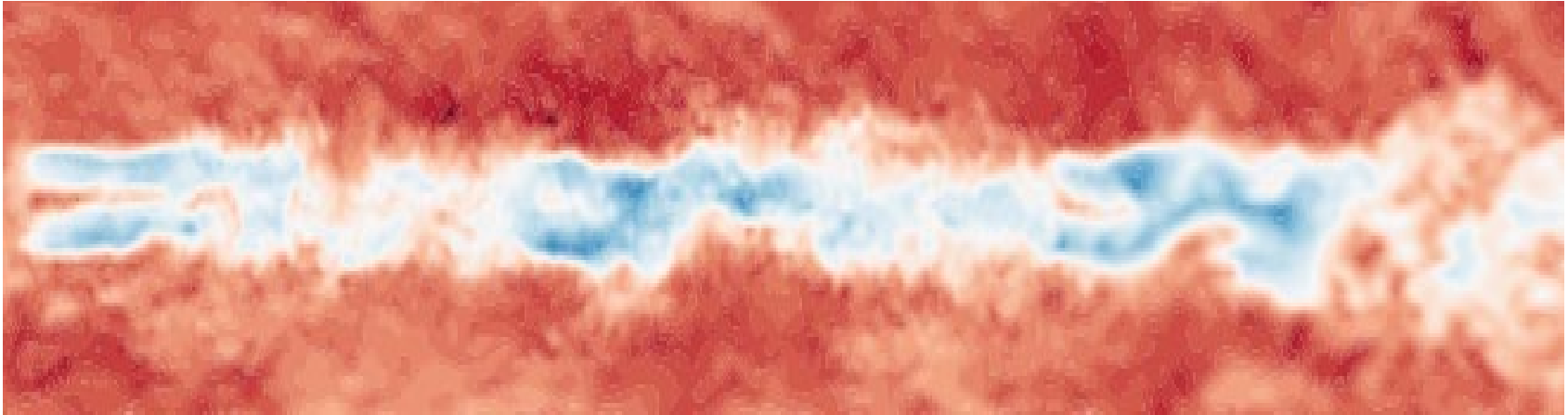
Mean Power and Range With Wake Steering Below Rated



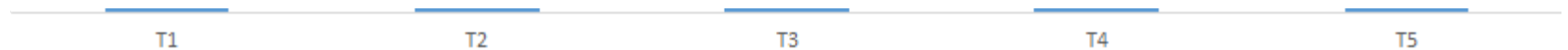
Mean Thrust and Range With Wake Steering Below Rated



Power and Thrust for Flow Down a Row Above Rated



Mean Power and Range Without Wake Steering Above Rated

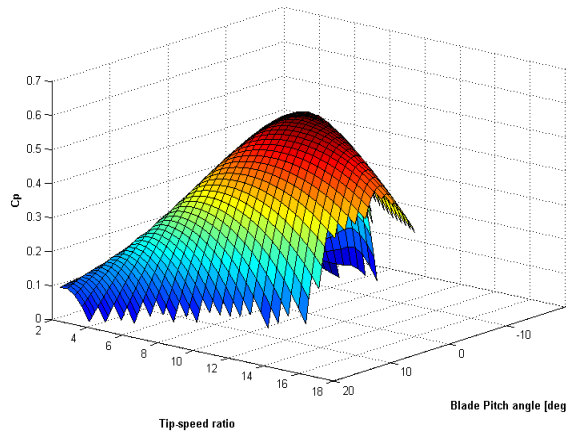


Mean Thrust and Range Without Wake Steering Above Rated



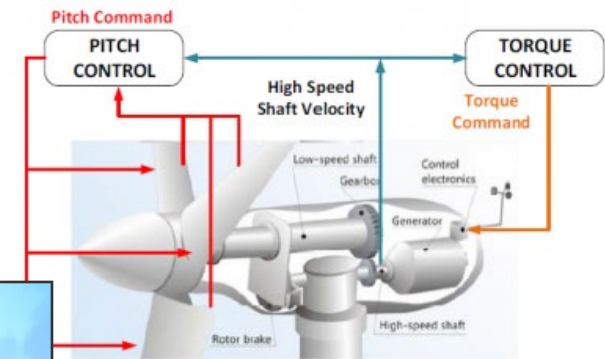
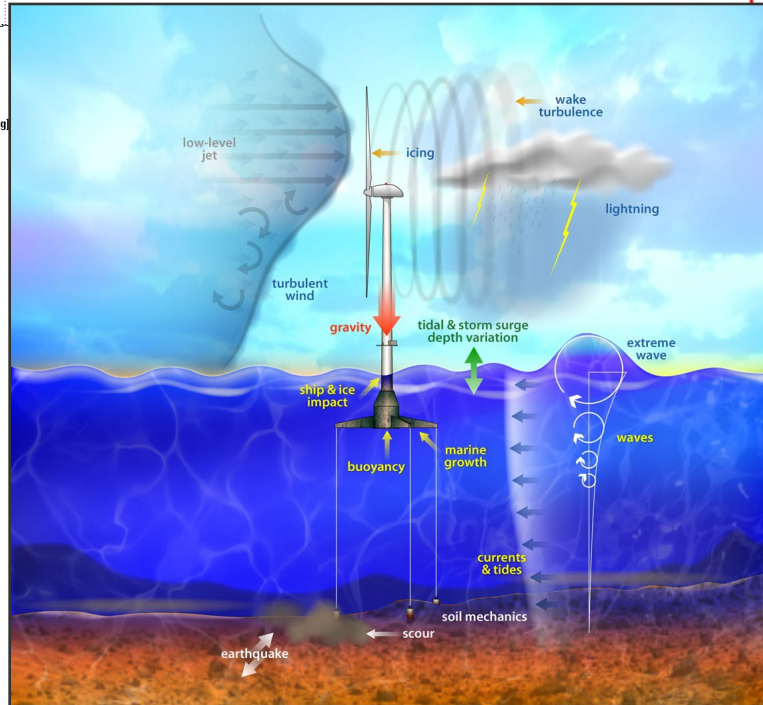
Overview of OpenFAST and FAST.Farm

Coupling Between Fluids, Structures, and Controls



Aerodynamics →

Structures →

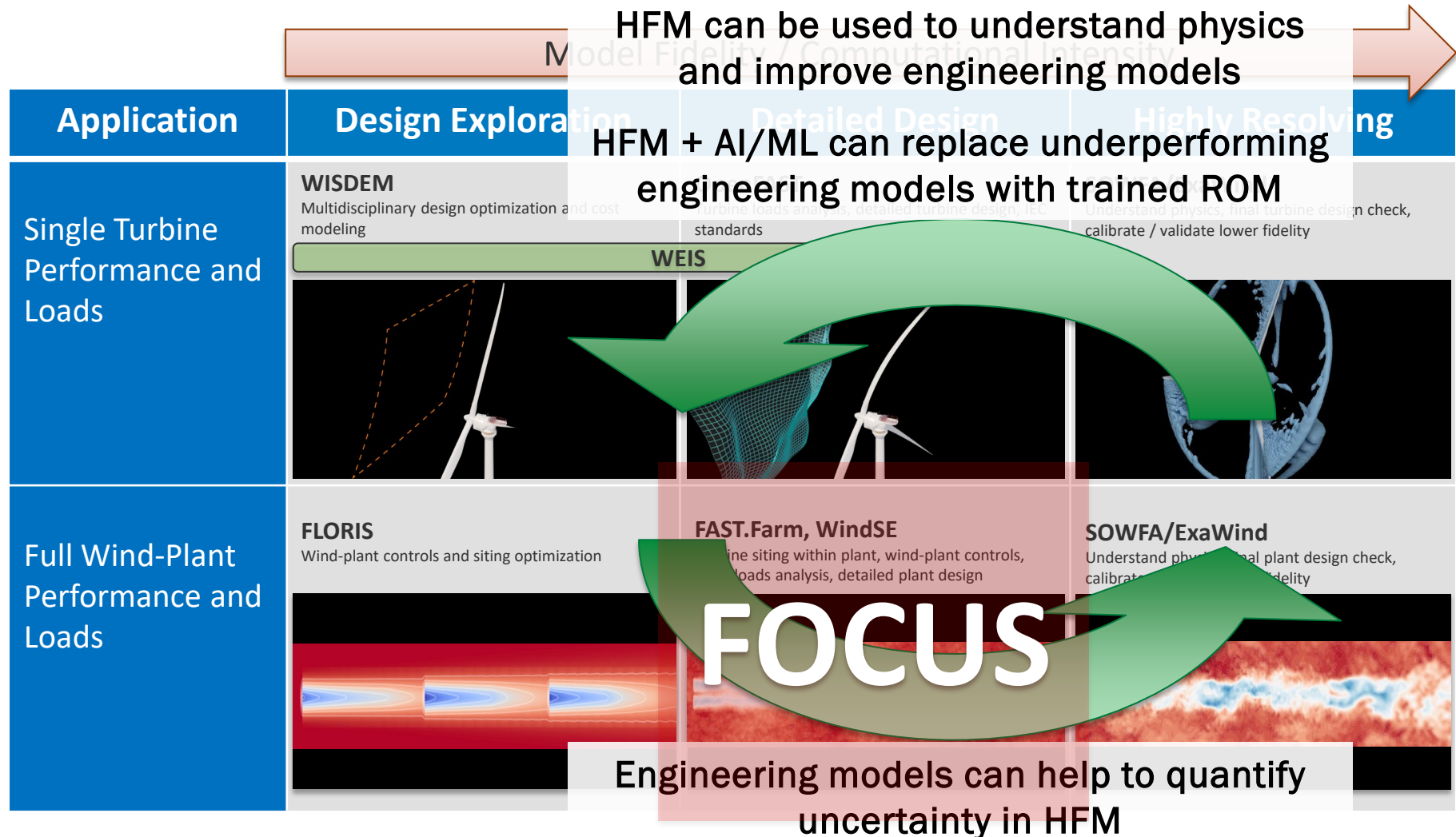


← *Controls*

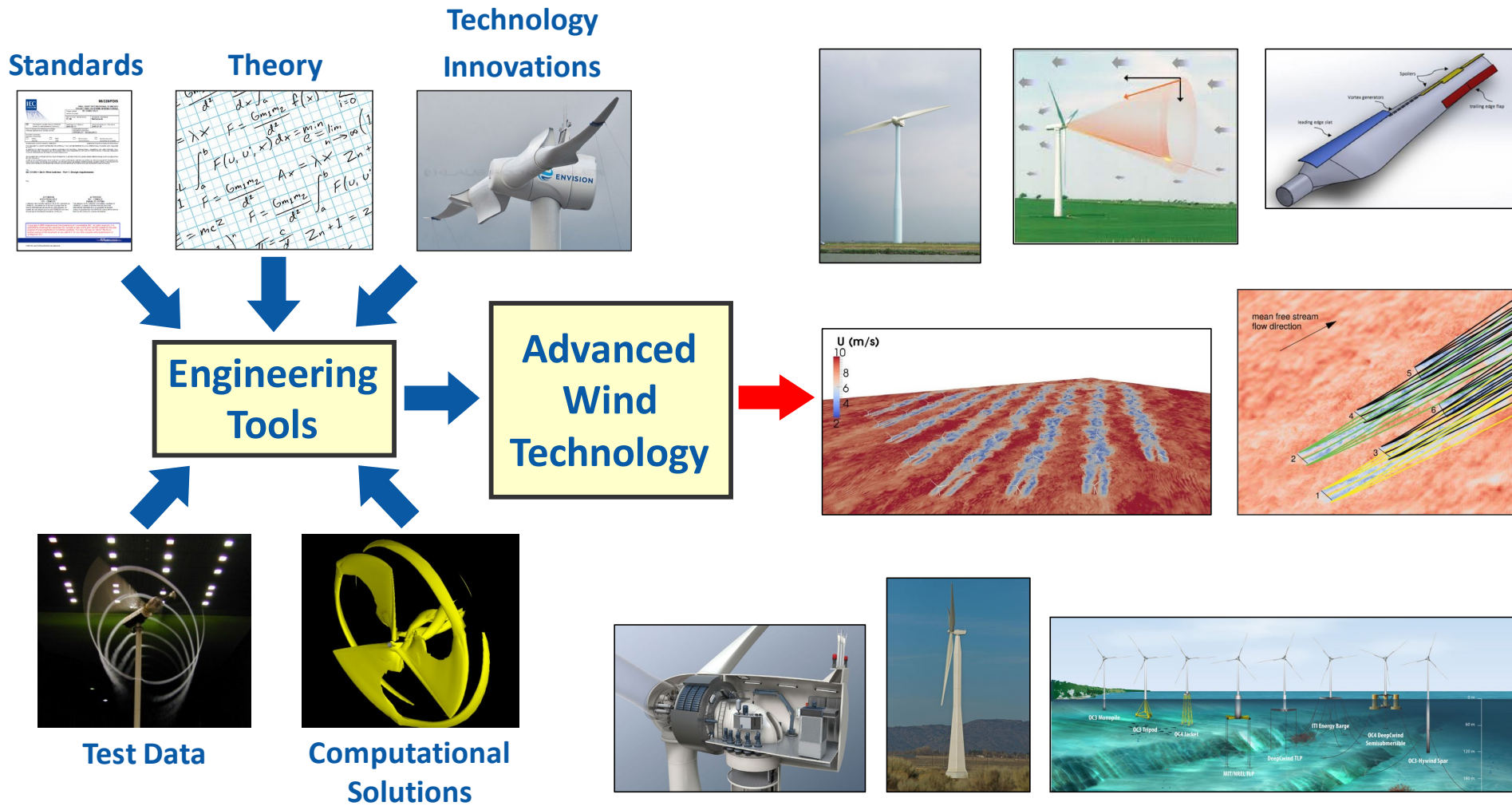
← *Hydrodynamics*



NREL/DOE Open-Source Modeling Tool Overview



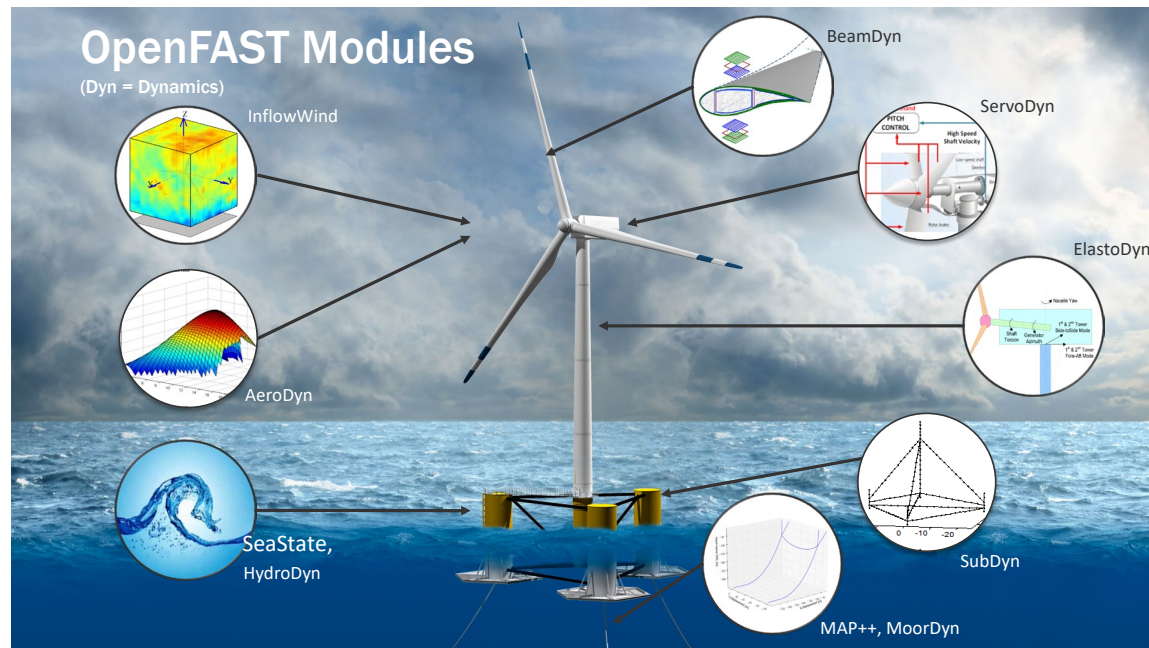
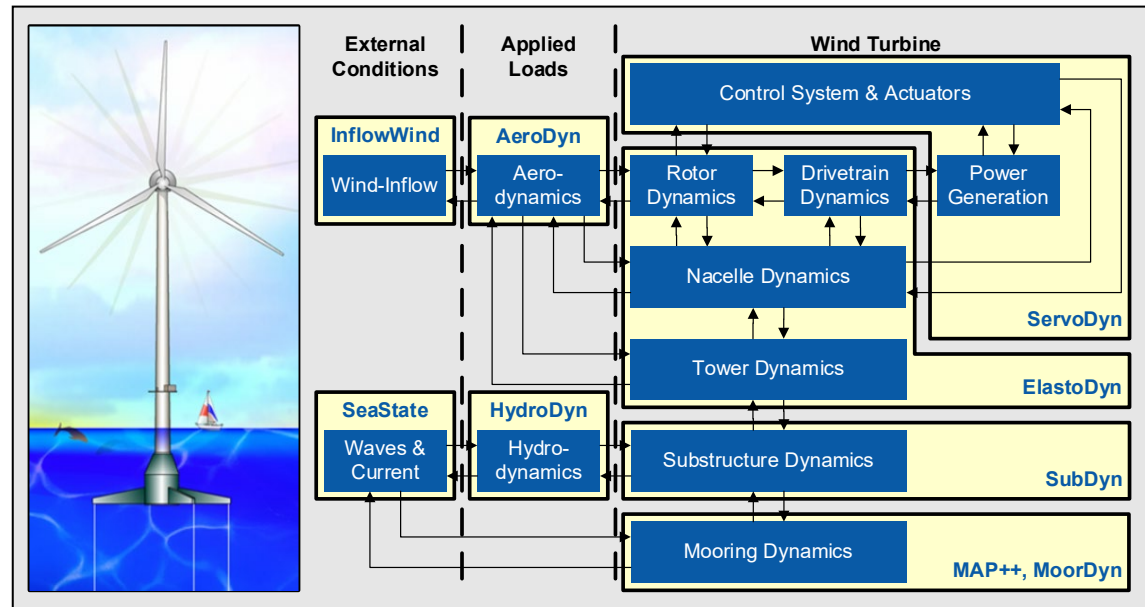
Engineering Tools Enable Technology Advancement



OpenFAST Overview

OpenFAST provides state-of-the-art coupled aero-hydro-servo-elastic simulation of individual land-based, fixed-bottom offshore, and floating offshore wind and MHK turbines with the ability to:

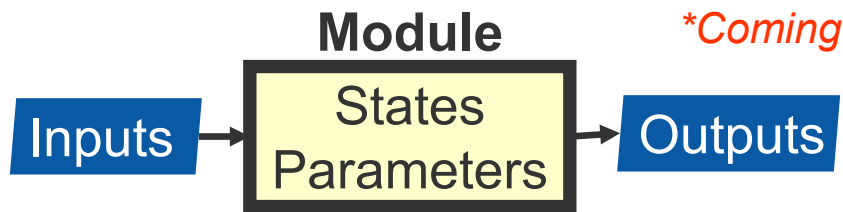
- Run large numbers of nonlinear time-domain simulations in real time to enable standards-based loads analysis for predicting wind system ultimate and fatigue loads
- Linearize the underlying nonlinear model about an operating point to understand the wind system response and enable modal analysis; controls design; and aero-elastic instability studies



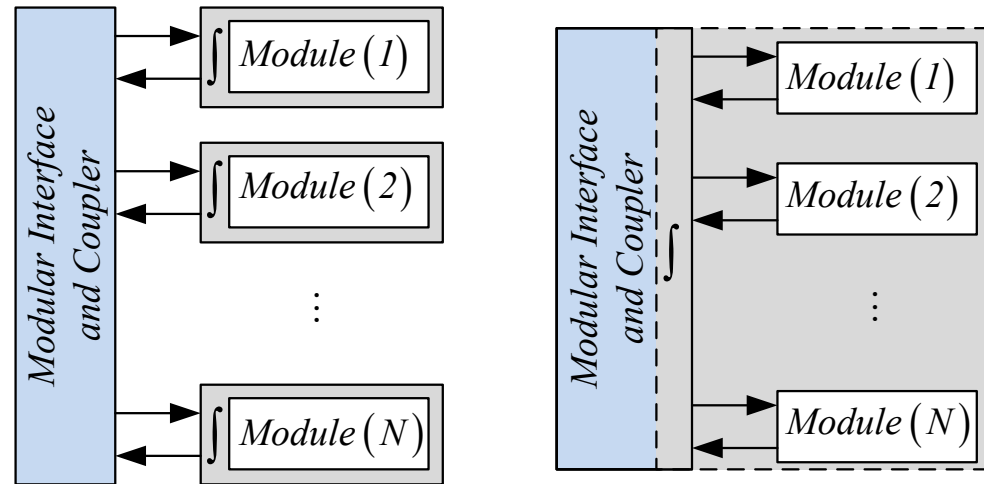
OpenFAST Modular Framework

- Module-independent inputs, outputs, states, and parameters
- States in continuous-time, discrete-time, constraint, and “other” form
- Loose and tight* coupling
- Independent time and spatial discretizations
- Time marching, operating-point determination, and linearization
- Data encapsulation and dynamic allocation
- Visualization capability
- Checkpoint/restart capability

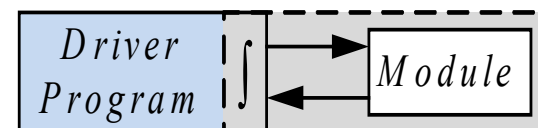
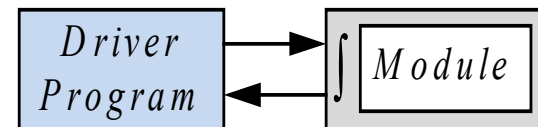
*Coming in v5



Modularization Concept



Loose- (Left) & Tight- (Right) Coupling

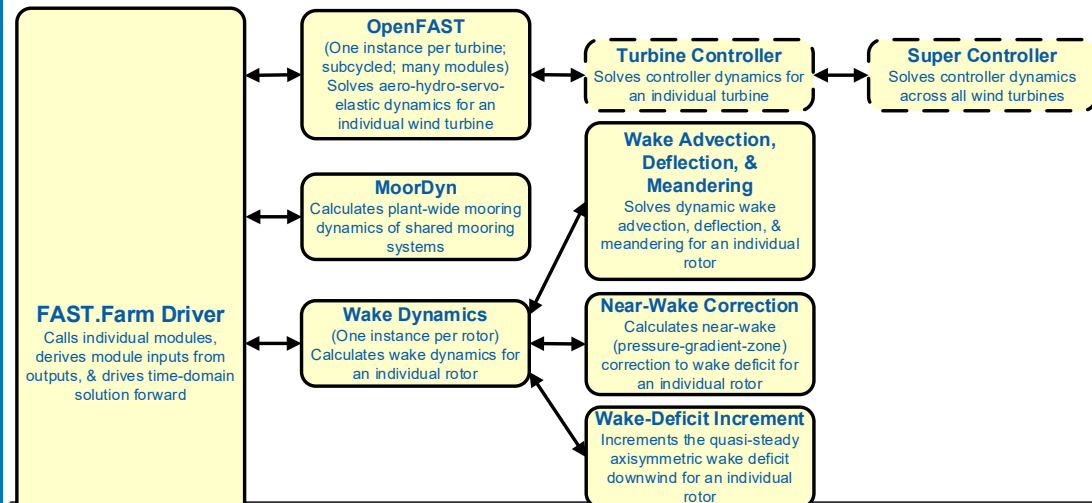


Uncoupled Solution of a Module Intended for Loose (Top) and Tight (Bottom) Coupling

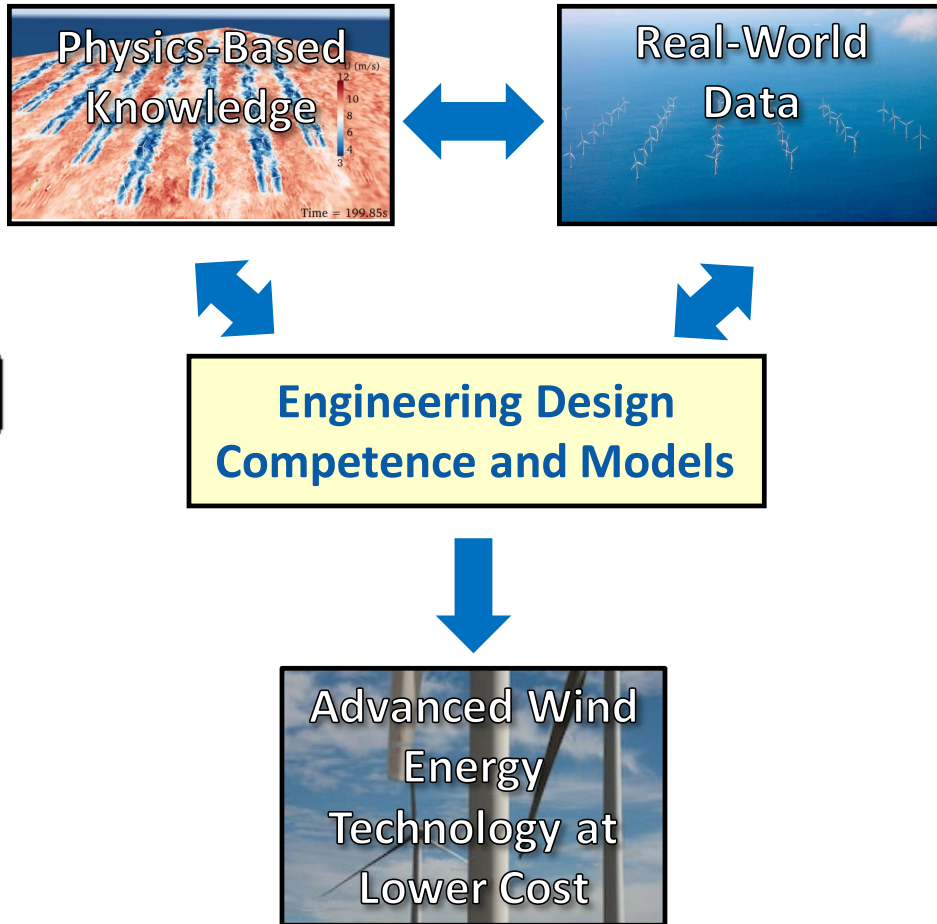
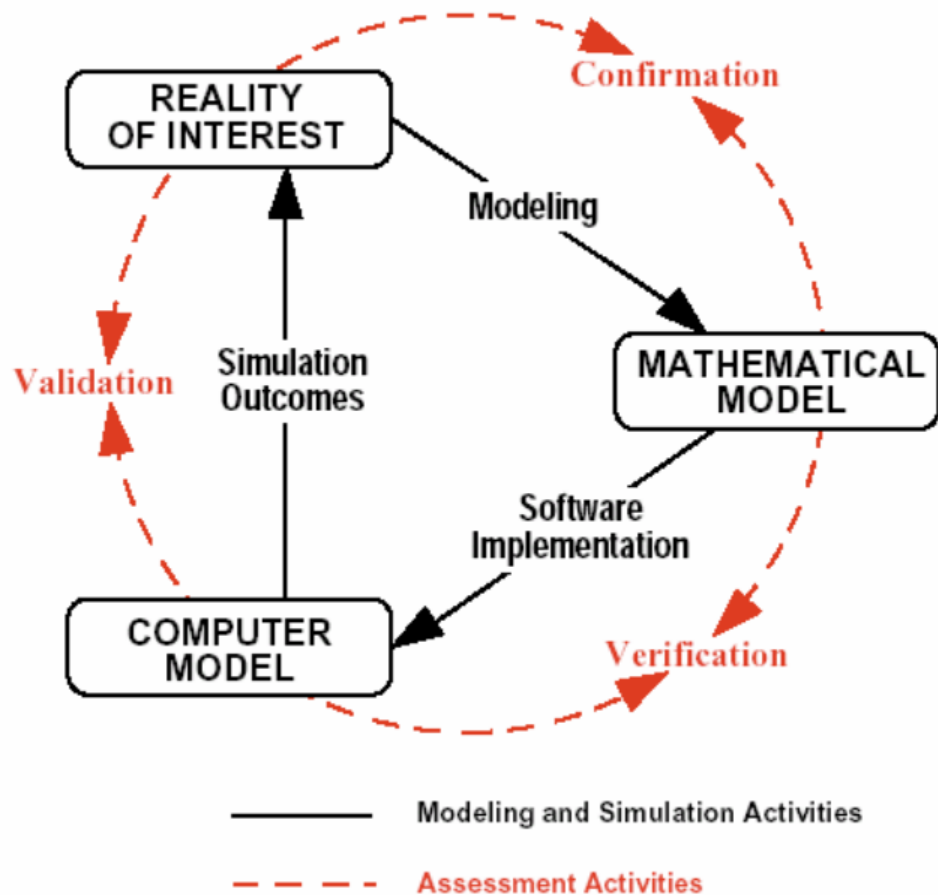
FAST.Farm Overview

FAST.Farm extends the capabilities of OpenFAST to provide physics-based engineering simulation of multi-turbine land-based, fixed-bottom offshore, and floating offshore wind farms with the ability to:

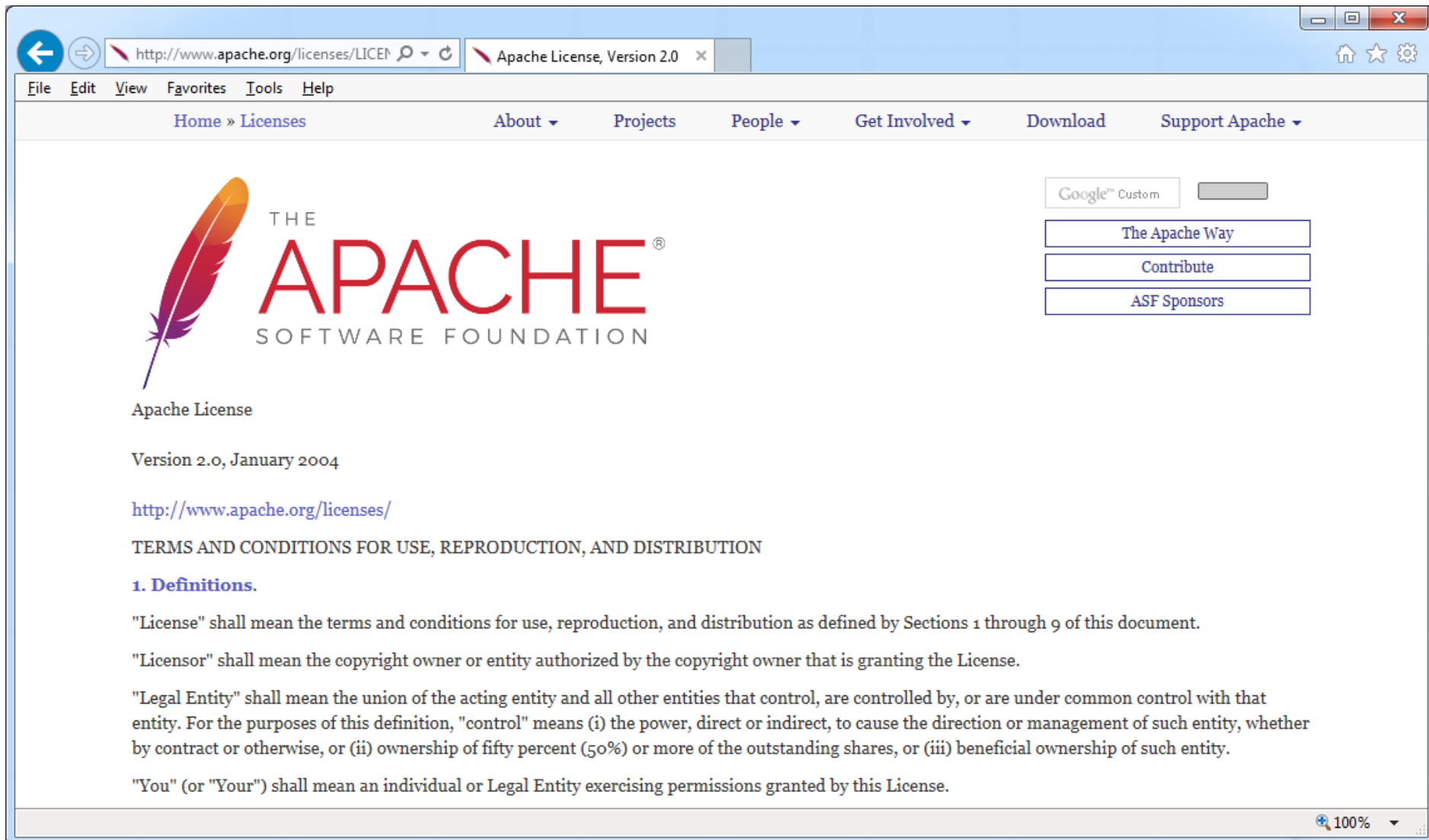
- Simulate each wind turbine in the farm with an OpenFAST model
- Capture relevant physics for prediction of wind farm power performance and structural loads, including wind farm-wide ambient wind, super controller, and wake advection, meandering, and merging
- Maintain computational efficiency through parallelization to enable loads analysis for predicting the ultimate and fatigue loads of each wind turbine in the farm



Model Verification and Validation Is Important to Understand Accuracy and Applicability



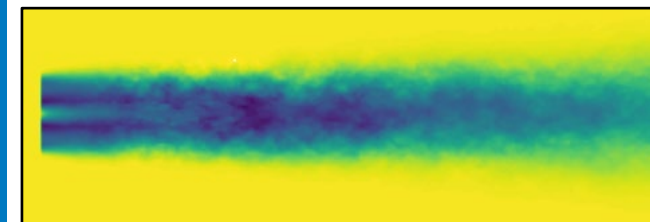
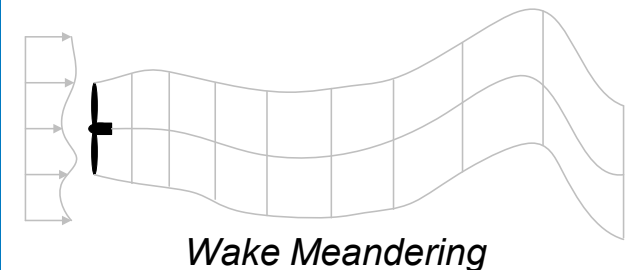
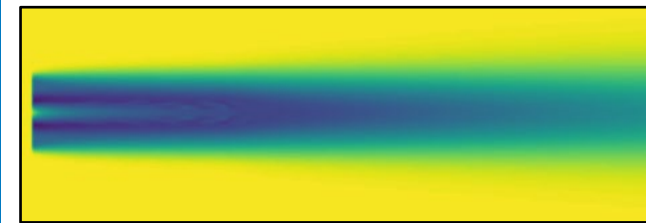
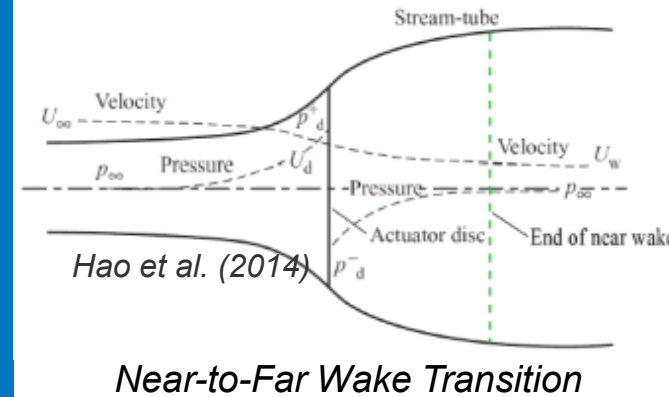
Officially Released Under Apache 2.0 Open-Source License



FAST.Farm Framework and Modules

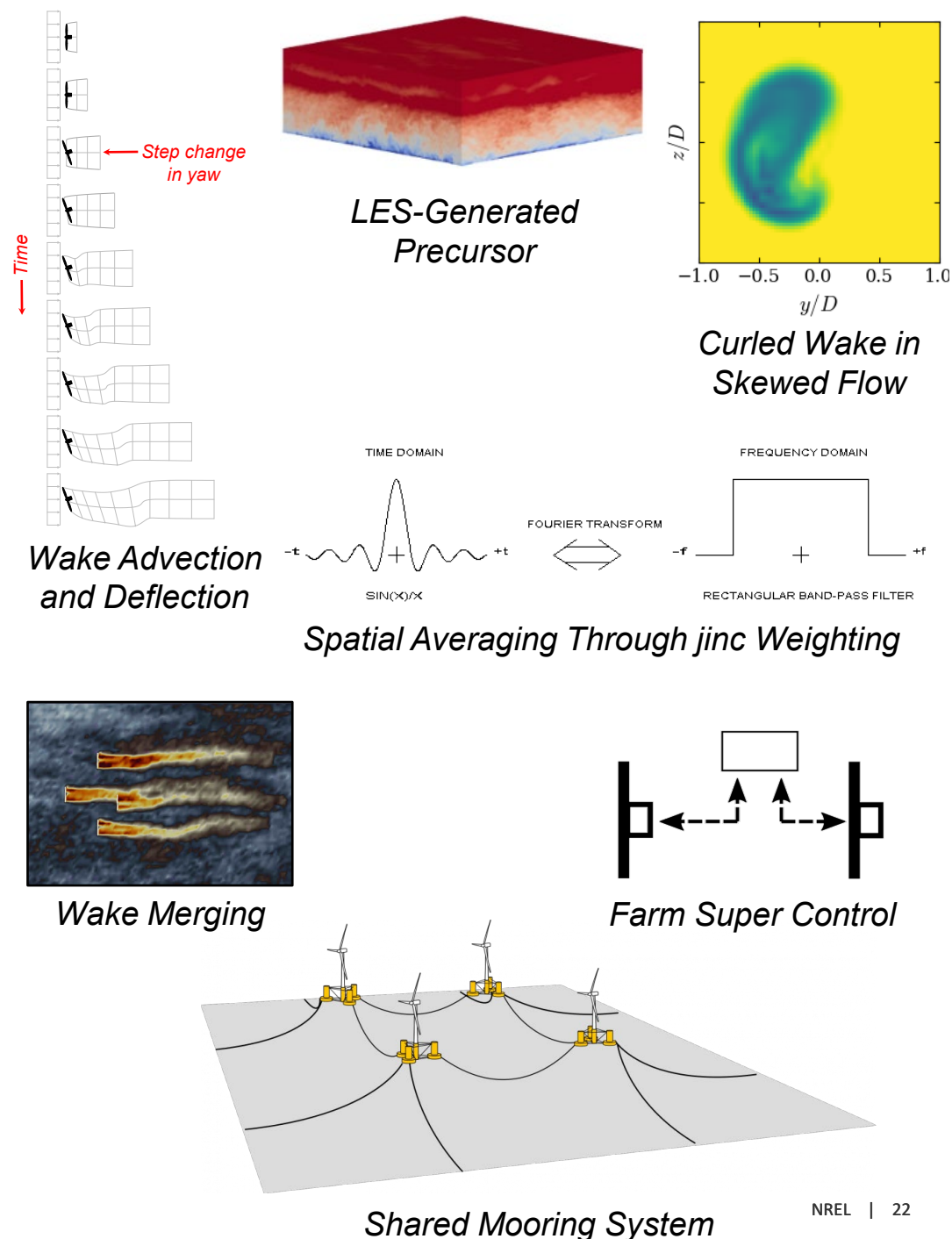
Dynamic Wake Meandering (DWM) Principles

- FAST.Farm relies on DWM principles, but avoids many limitations of past implementations
- Wake-deficit evolution:
 - Flow speed reduction behind rotor, recovering to freestream
 - Modeled in meandering frame of reference by solving continuity and momentum (Navier Stokes) equations under simplified conditions (steady state, near-wake correction, eddy-viscosity, axisymmetric (polar) or curled formulation)
- Wake meandering:
 - Large scale movement of wake deficit (deficit transferred to global frame of reference)
 - Modeled as passive tracer transported from large turbulent eddies
- Wake-added turbulence:
 - Additional turbulence generated from wake shear layer
 - Modeled by scaling isotropic turbulence by the wake deficit



FAST.Farm Innovations

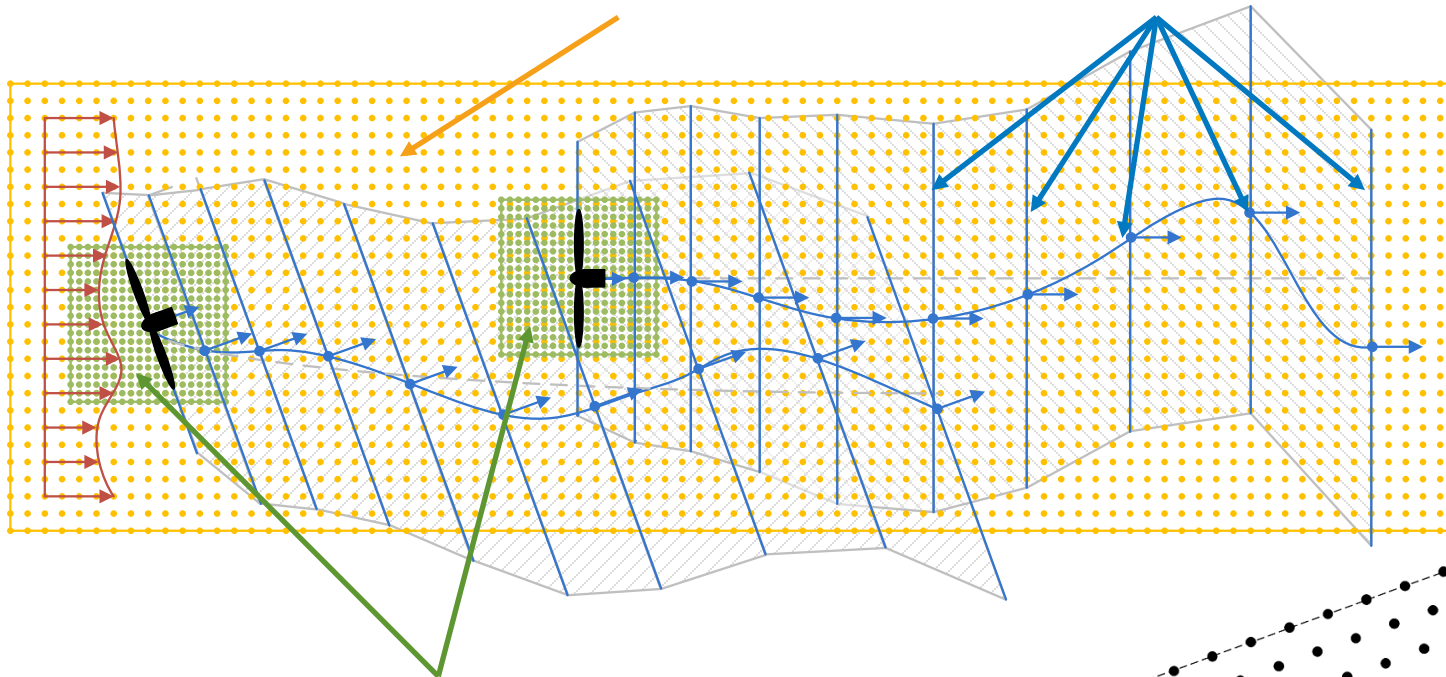
- Modular, following requirements of OpenFAST modularization framework
- Use of LES-generated or synthetic precursor for ambient wind
- Improvement of wake advection, deflection, and merging compared to past DWM-implementations
- Farm-wide wake-added turbulence
- Optional inclusion of wind-farm-wide super controller
- Optional inclusion of shared mooring systems
- Ability to solve entire wind farm in serial or parallel
- Calibration of wake-related model parameters against high-fidelity simulations



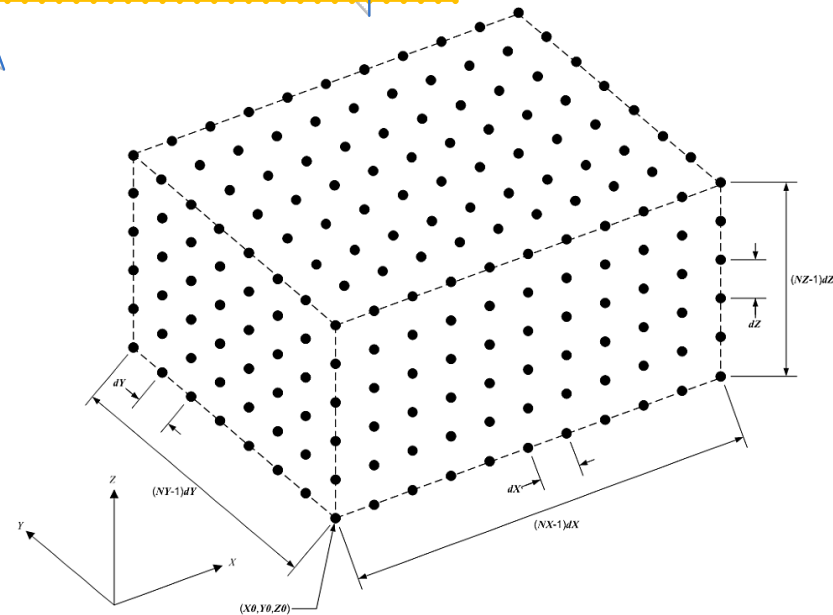
FAST.Farm Wake Planes and Domains

Low-Resolution Domain

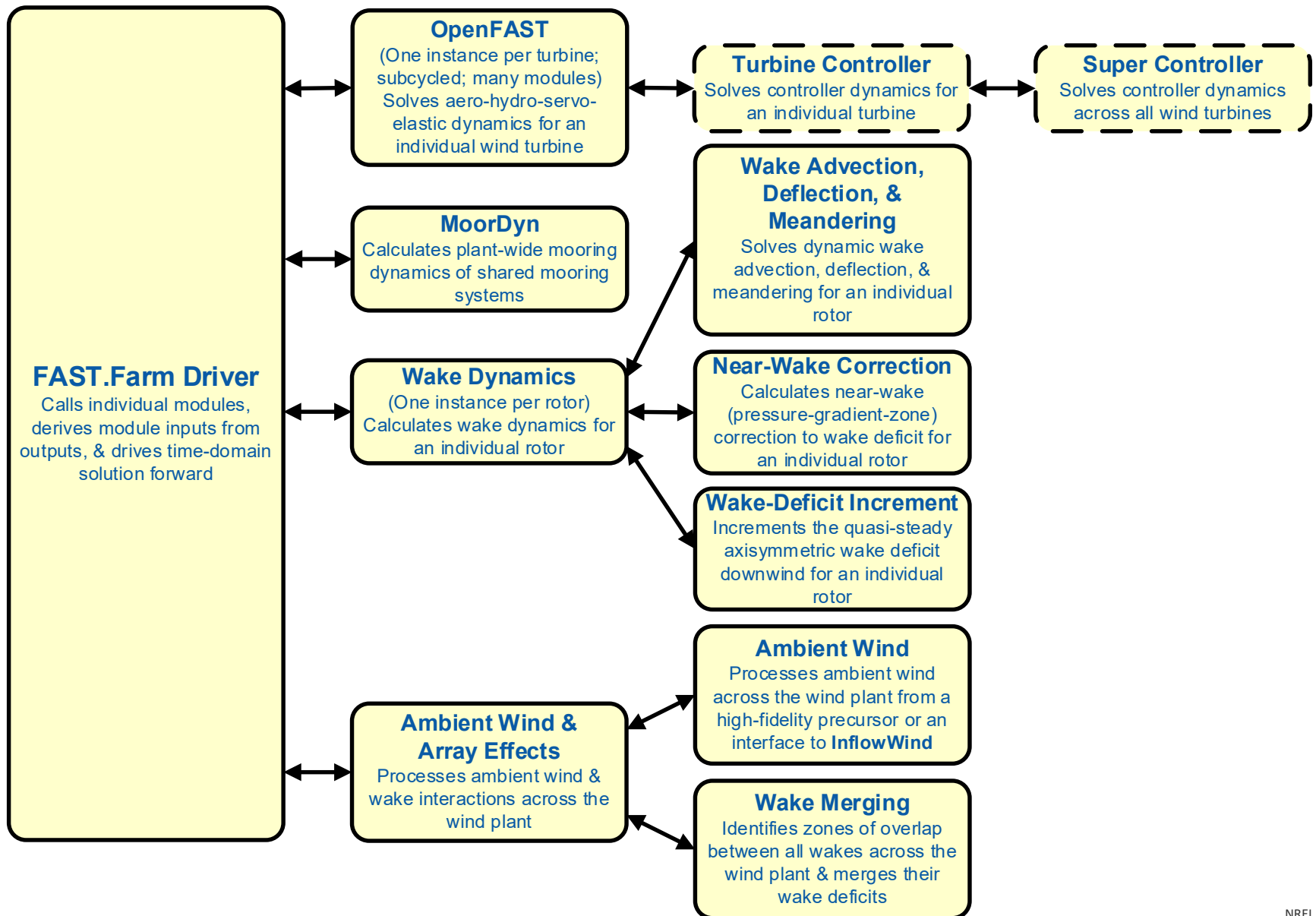
Wake Planes



High-Resolution Domains

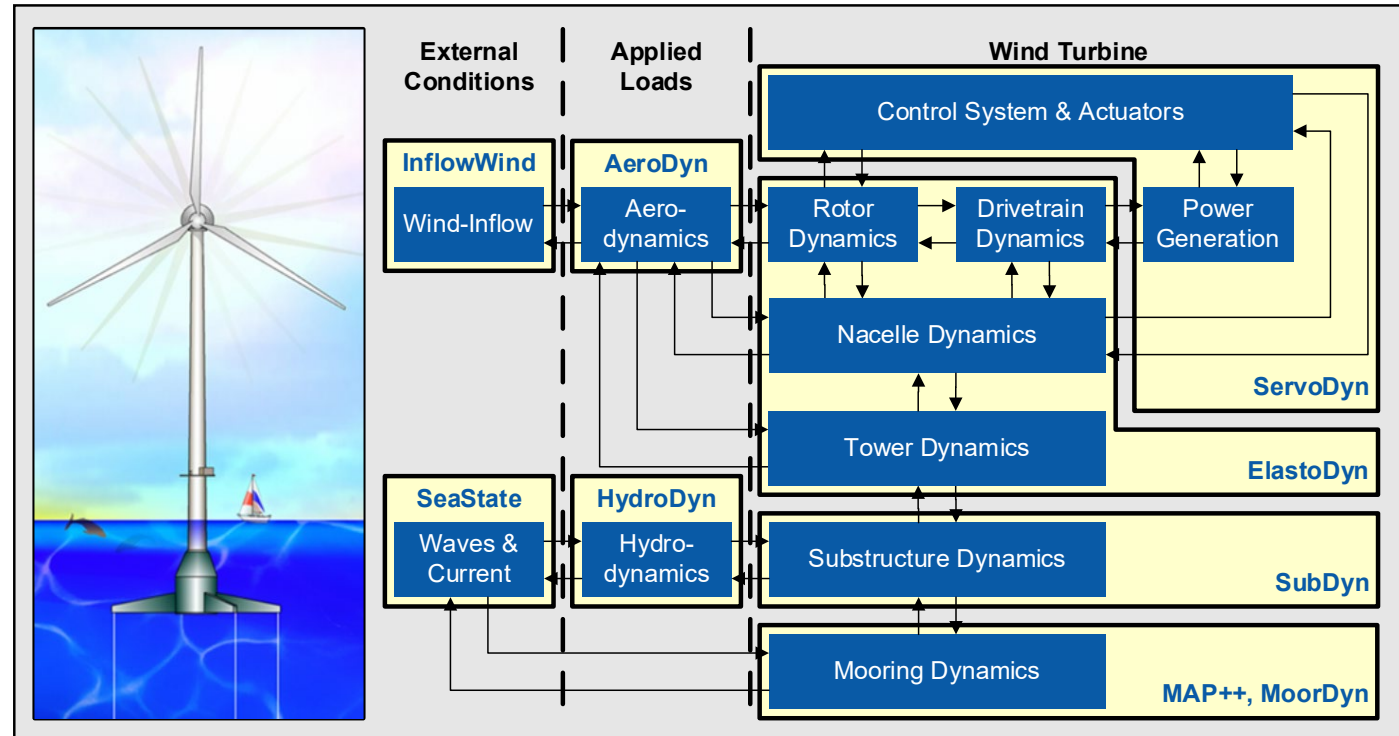
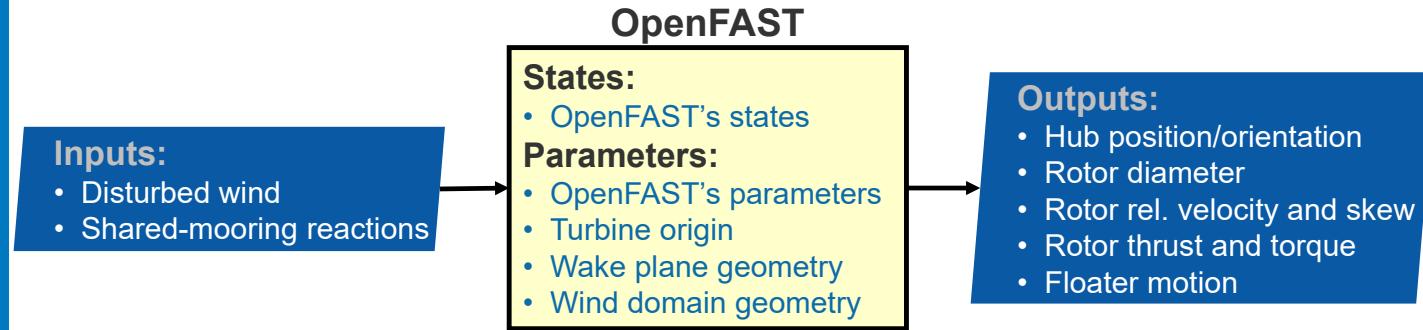


FAST.Farm Modules



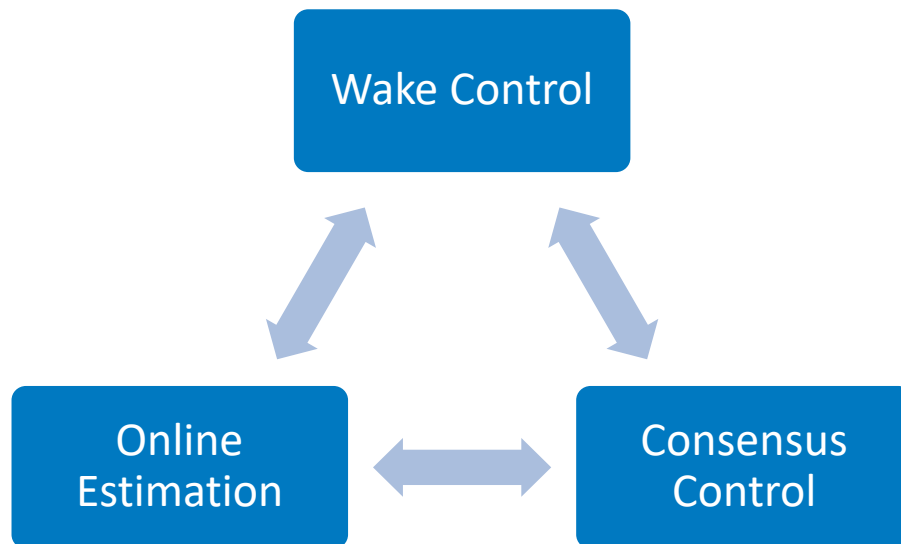
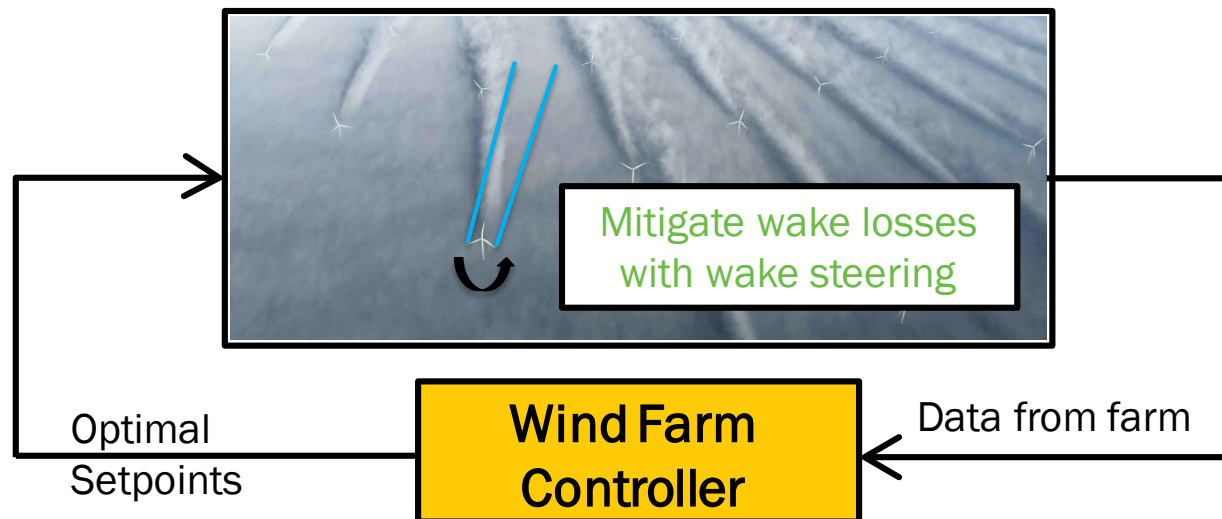
OpenFAST

- Wrapper for OpenFAST, which solves aero-hydro-servo-elastics for an individual wind turbine
- One instance per turbine:
 - Number of turbines and their global positions set at initialization
 - Each instance optionally solved in parallel with OpenMP
- Subcycled for smaller time steps



Super Controller

- Interface to ROSCO through ZeroMQ message passing:
 - Receives data from individual WT controllers
 - Sends commands to individual WT controllers
- Sample super controller (WHOC: Wind Hybrid Open Controller) coming soon supporting wake steering and consensus control
- Or user-defined implementation

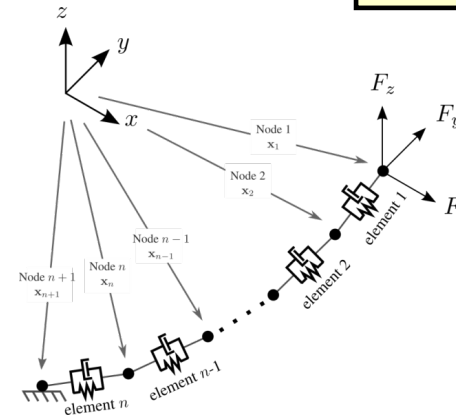
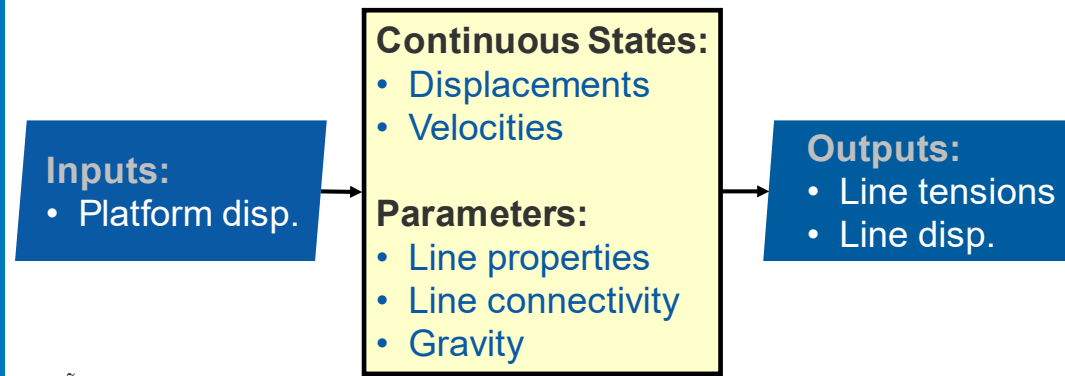


MoorDyn

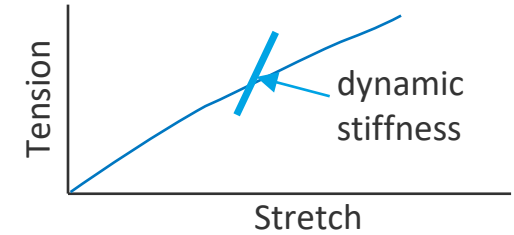
- Same as in OpenFAST, but for shared moorings at farm level
- Lumped-mass dynamics
- Multi-segmented array of taut or catenary lines
- Nonlinear geometric restoring
- Elastic stretching and damping:
 - Linear
 - Synthetics w/ viscoelastics
- Bending for dynamic power cable
- Nonlinear spring elements
- Hydrodynamic added mass and drag
- Apparent weight of lines
- User-specified wave kinematics
 - No coupling yet to SeaState*
- Clump weights and buoyancy cans
- Line failure
- Seabed bathymetry and friction

*Coming in v5

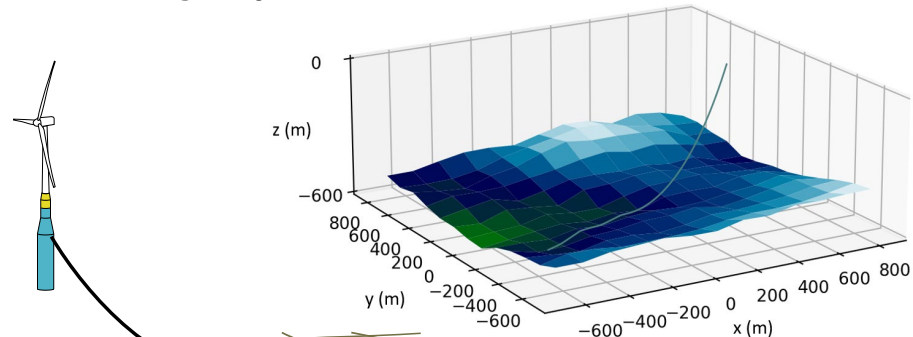
MoorDyn



*Lumped-Mass
Mooring Dynamics*



*Synthetic Rope
Viscoelastics*



Seabed Bathymetry and Friction

Wake Dynamics

- Wake dynamics for an individual rotor
 - One instance per rotor
 - Solved on wake planes in meandering frame of reference
- Many CFD-calibrated parameters (dependent on turbine operation and atmospheric condition)

Wake Dynamics

Inputs:

- Hub position/orientation
- Rotor diameter
- Rotor rel. velocity and skew
- Rotor ambient wind and TI
- Rotor thrust and torque
- Wake plane velocity

Discrete States:

- Filtered rotor inputs
- Wake plane pos./rot.
- Velocity deficit

Parameters:

- Wake plane geometry
- Wake parameters

Outputs:

- Wake plane pos./rot.
- Velocity deficit
- Wake diameter

Global frame

Initial plane

Wake plane i

Actuator disk

Wake centerline

y_g
 z_a
 x_g

V_w
 ψ_s
 χ_s

$\hat{y}_{p,i}$
 $\hat{z}_{p,i}$
 $\hat{x}_{p,i}$
 $V_{c,i}$
 p_i

Convection and dynamics between t and $t + dt$

$i = 0$
Wake deficit Δu

Meandering frame

$i = 0 \quad 1, \dots$

i

y
 z
 x

y_p
 z_p
 x_p

U

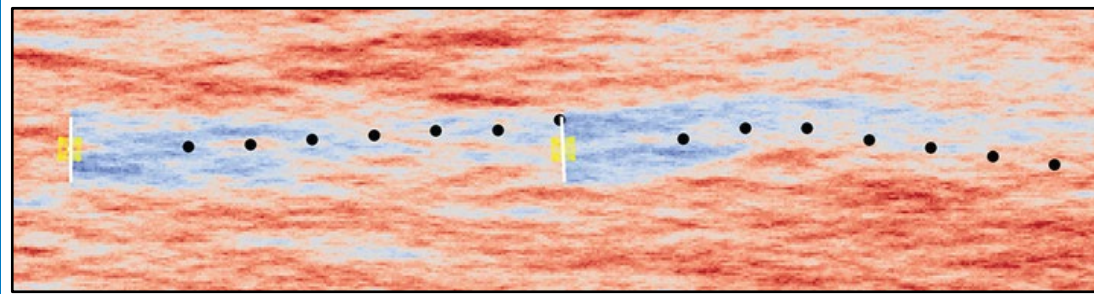
Wake Dynamics

Wake Advection, Deflection, and Meandering:

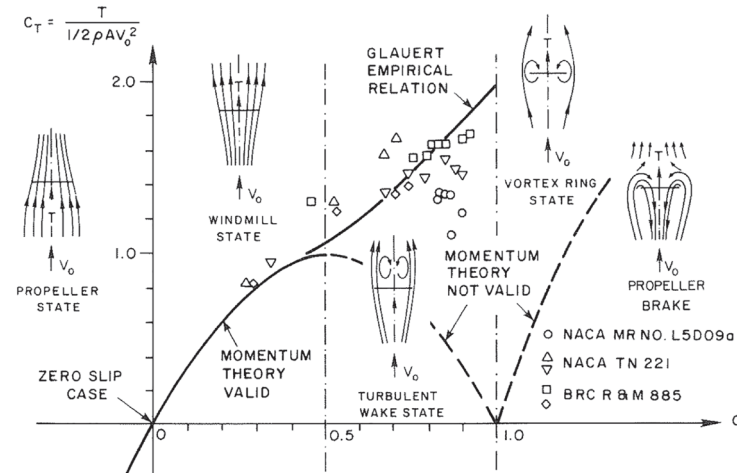
- Simple extensions to passive-tracer solution:
 - 3D passive tracer, including spatially averaged velocity of disturbed (not just ambient)
 - Wake planes released parallel to rotor plane (not wind)
 - Low-pass time-filter of inputs at rotor (not fixed)

Near-Wake Correction

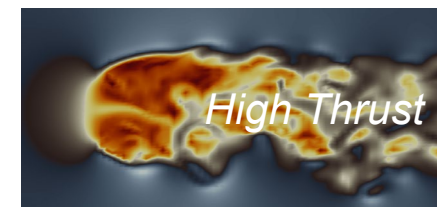
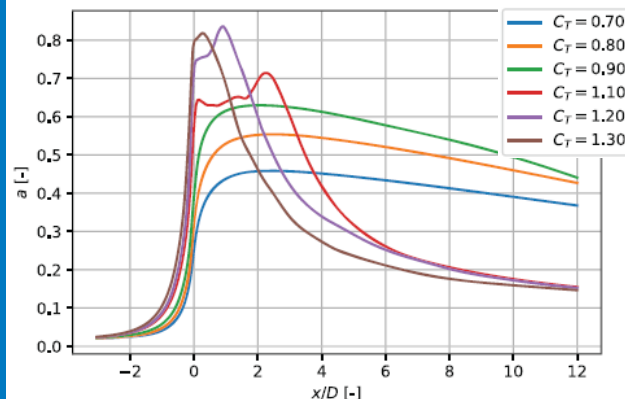
- Calculates near-wake (pressure-gradient zone) correction to wake deficit:
 - Low thrust ($C_T < 24/25$) – momentum theory
 - High thrust ($1.1 < C_T < 2$) – Gaussian fit to LES
 - Transition: Blending of these two



Wake Meandering



Thrust Coefficient versus Induction at the Rotor



LES Solutions for Induction Downstream of a Rotor

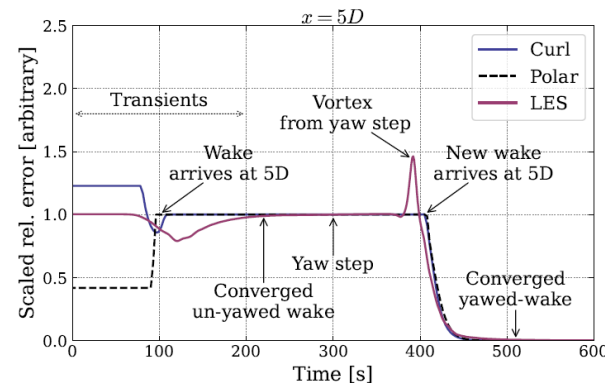
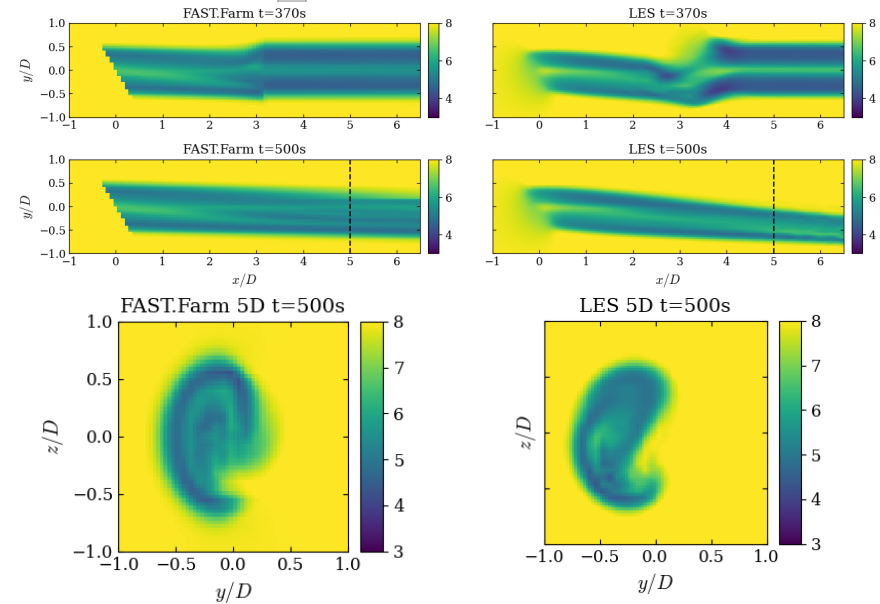
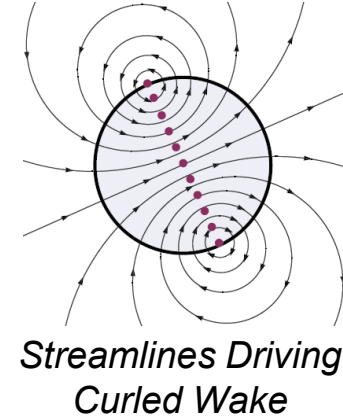
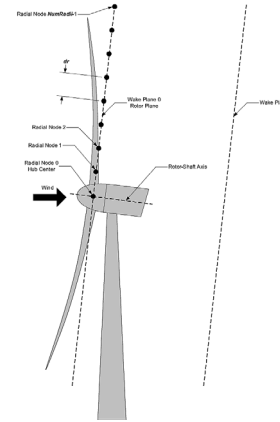
Wake Dynamics

Wake-Deficit Increment:

- Increments quasi-steady axisymmetric wake deficit downwind:
 - Polar – Solved via thin shear-layer approximation of momentum and continuity in axisymmetric coordinates via 2nd-order accurate Crank-Nicolson scheme
 - Curled – Solves momentum for axial induction resulting from trailing vortex-induced velocities in Cartesian coordinates via 1st-order Euler scheme
 - Pending improvements for continuity, high shear, and veer*
 - Turbulence closure through eddy-viscosity model, including influence of ambient turbulence and wake shear layer

*Coming in v5

Radial Finite-Difference Grid for Polar Wake



FAST.Farm and LES Flow Fields After 30° Yaw Step at 300 s

Ambient Wind & Array Effects

- Processes ambient flow:
 - For both the low- and high-resolution domains
 - LES precursor (e.g., from AMR-Wind) is 3D+time and may include atmospheric stability effects and terrain (recommended for moderate-to-large farms)
 - Synthetic (TurbSim or Mann) is 2D+time $\rightarrow$ 3D+time via Taylor's Frozen turbulence
 - Future work: hybrid inflow generation (low: precursor, high: synthetic)

Ambient Wind & Array Effects

Inputs:

- Wake plane pos./rot.
- Velocity deficit
- Wake diameter

States:

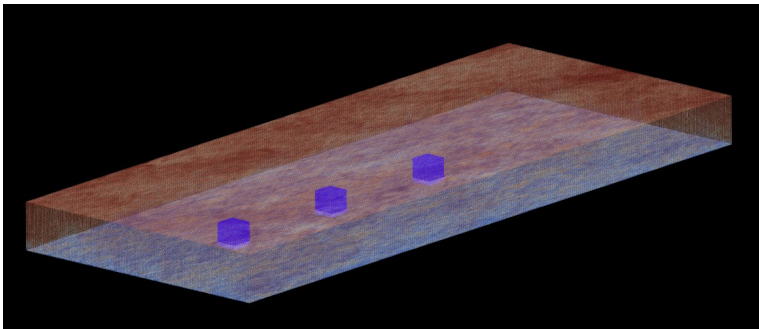
- None

Parameters:

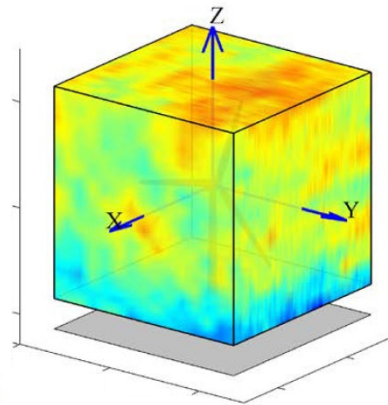
- Ambient wind
- Wake plane geometry
- Wind domain geometry
- Wake parameters

Outputs:

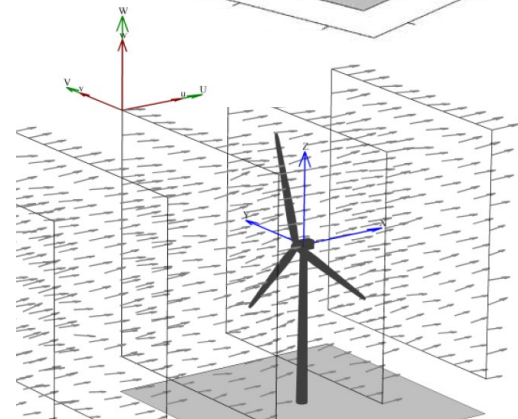
- Disturbed wind
- Rotor ambient wind and TI
- Wake plane velocity



LES-Generated Precursor



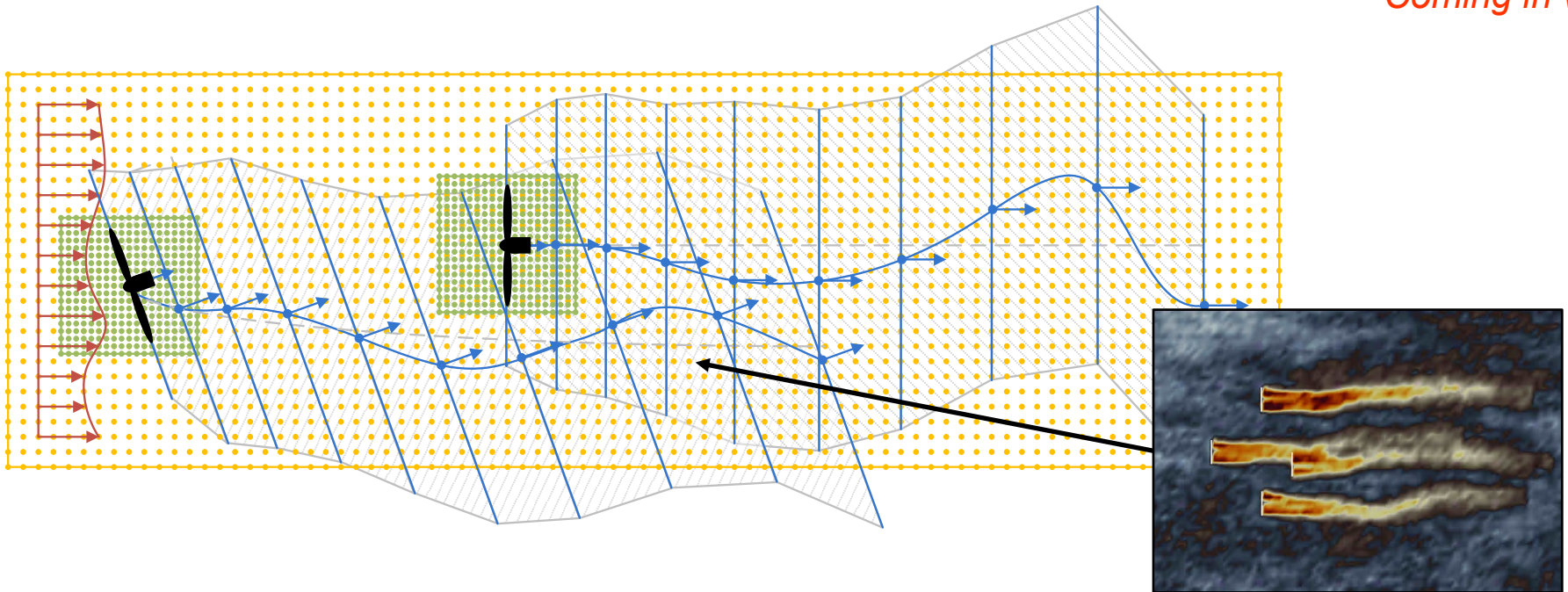
TurbSim-Generated Inflow with Taylor's Frozen Turbulence



Ambient Wind & Array Effects

- Identifies zones of overlap between wakes and merges wake deficits:
 - Local, not global, superposition
 - Root-sum-square method for axial wake deficits
 - Vector-sum superposition for transverse wake deficits
 - Calculations require looping through grid points, turbines, and wake planes
 - Support for regions of wake influence coming soon ($N_t^2 \rightarrow N_t \log(N_t)$ operation)*
 - Optionally parallelized with OpenMP

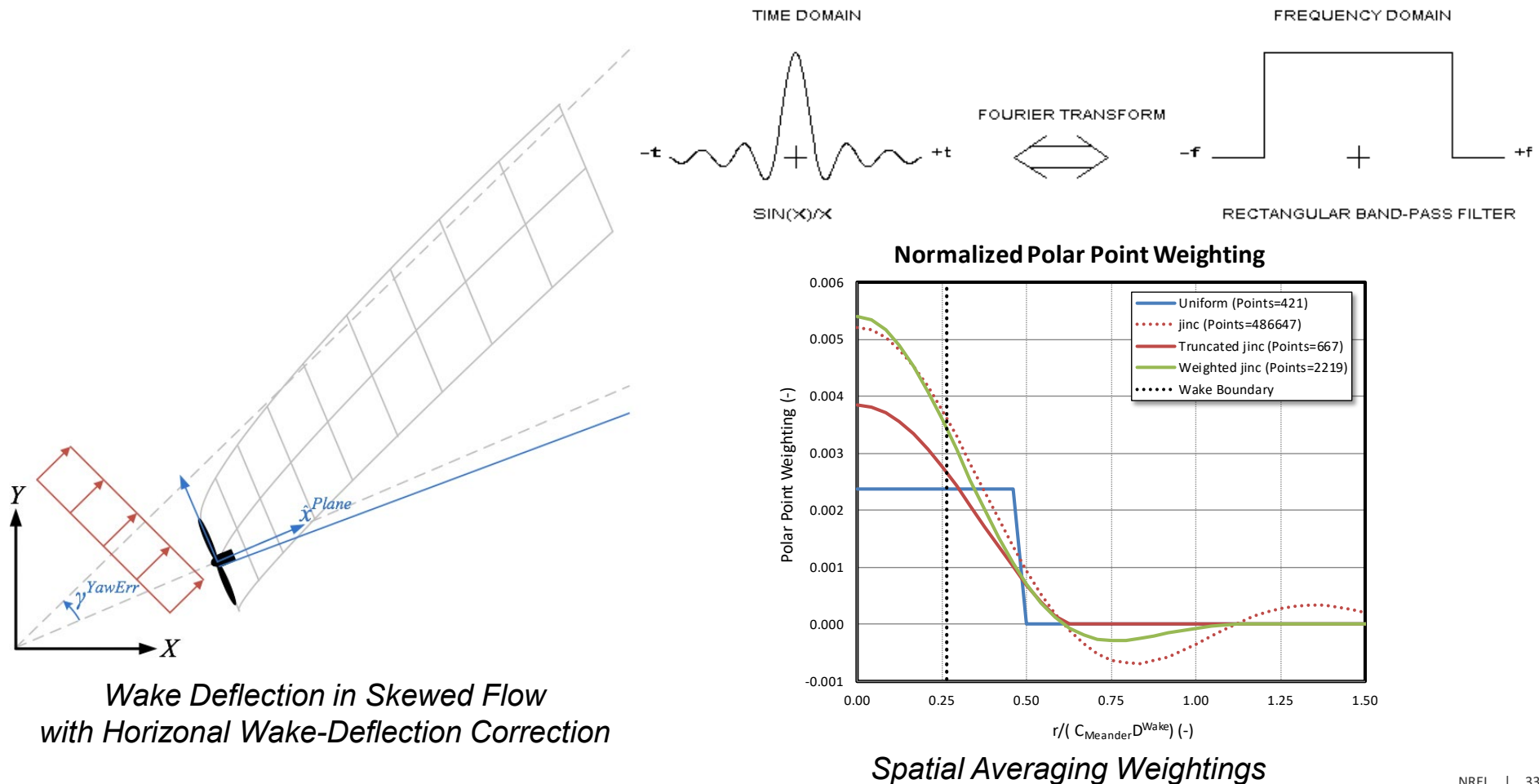
**Coming in v5*



Wake Merging

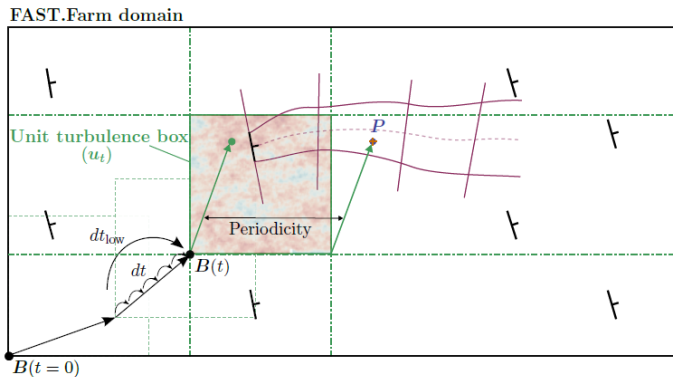
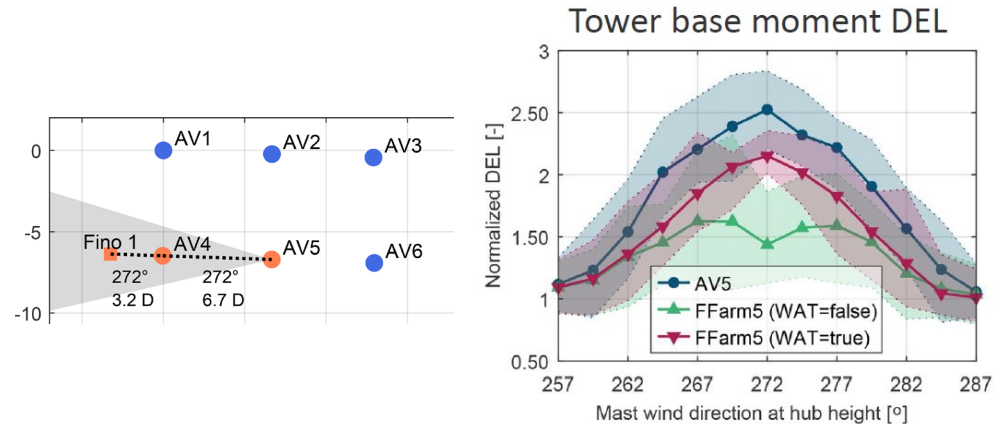
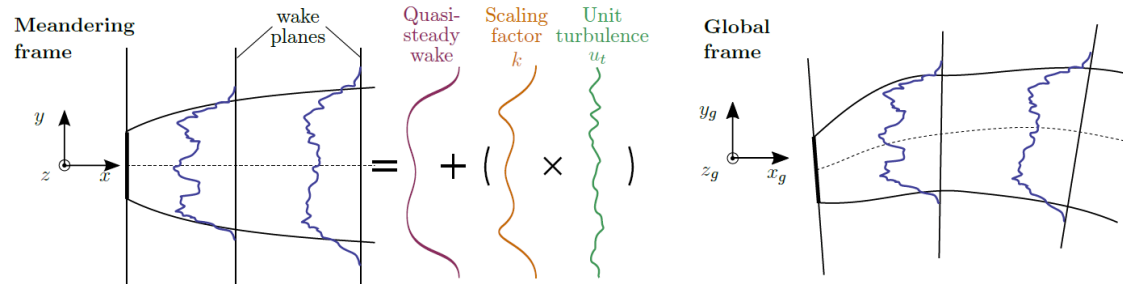
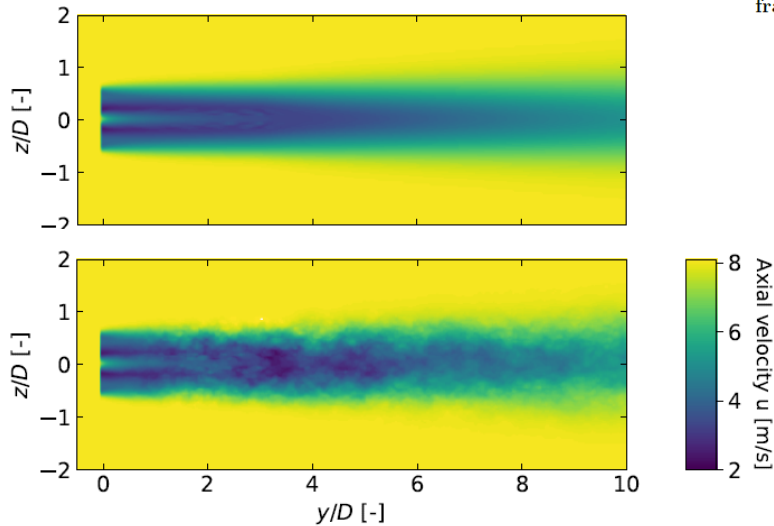
Ambient Wind & Array Effects

- Spatially averages disturbed flow across wake planes:
 - Use of disturbed wind supports wake deflection in skewed flow and wake advection speed up from near-to-far wake
 - Three optional weightings (uniform, truncated jinc, windowed jinc)

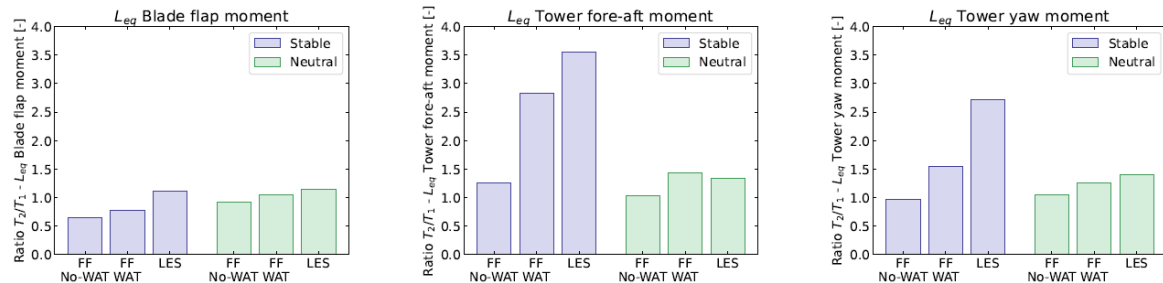


Ambient Wind & Array Effects

- Superimposes wake-added turbulence



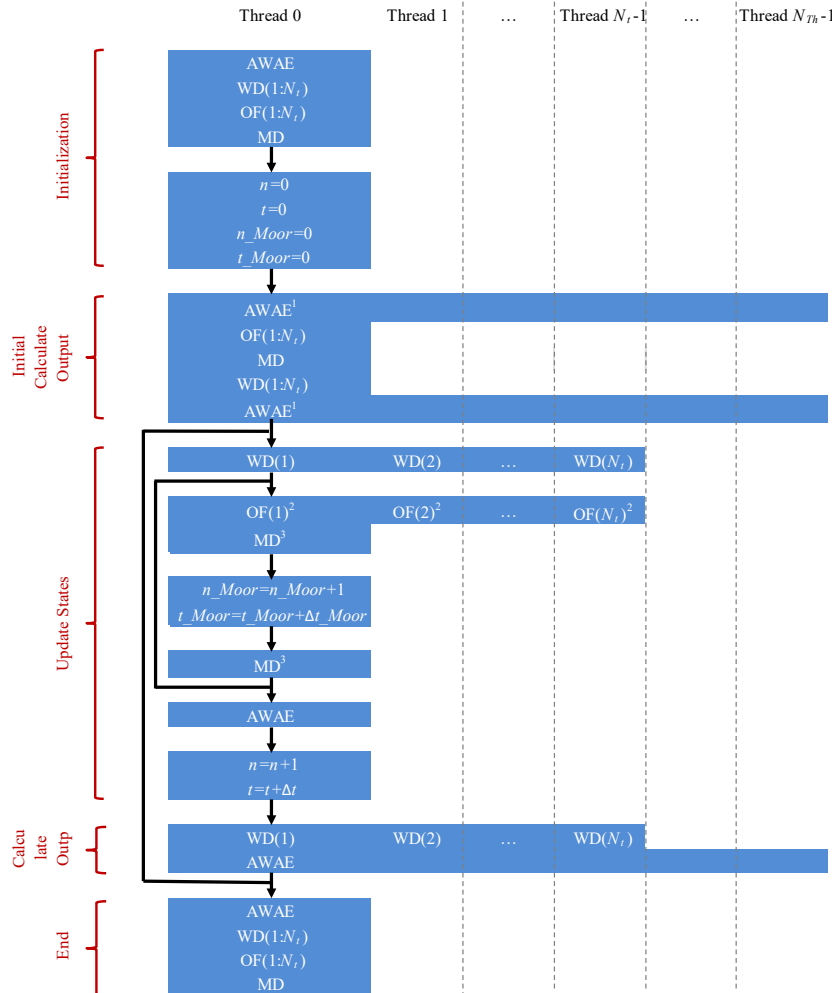
Validation Against Alpha Ventus Data



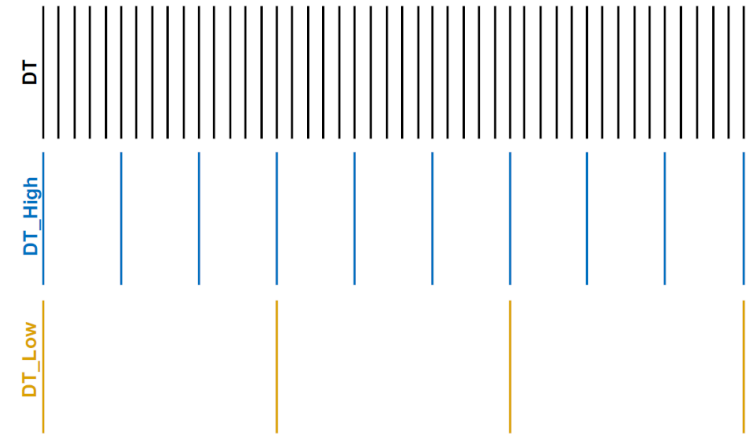
Validation Against LES

FAST.Farm Driver

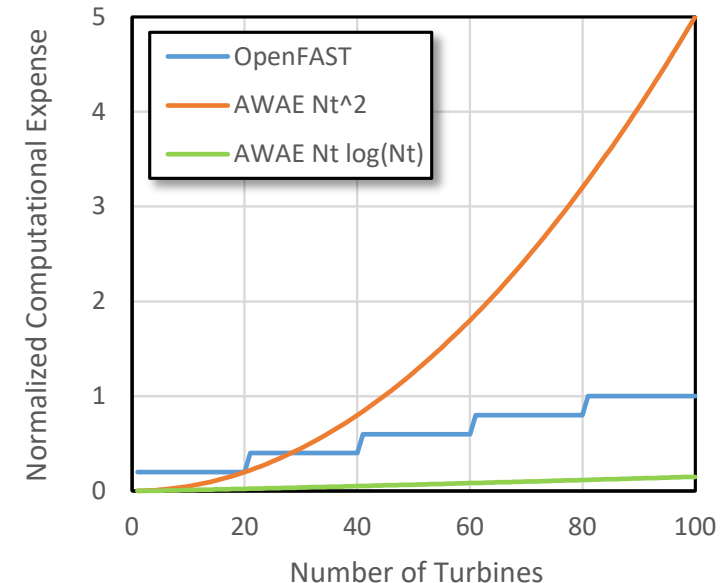
- Calls individual modules, derives module inputs from outputs, and drives time-domain solution forward



*Timesteps in
OpenFAST and
FAST.Farm*



*Normalized
Computational
Expense with
 $N_{Th} = 20$*

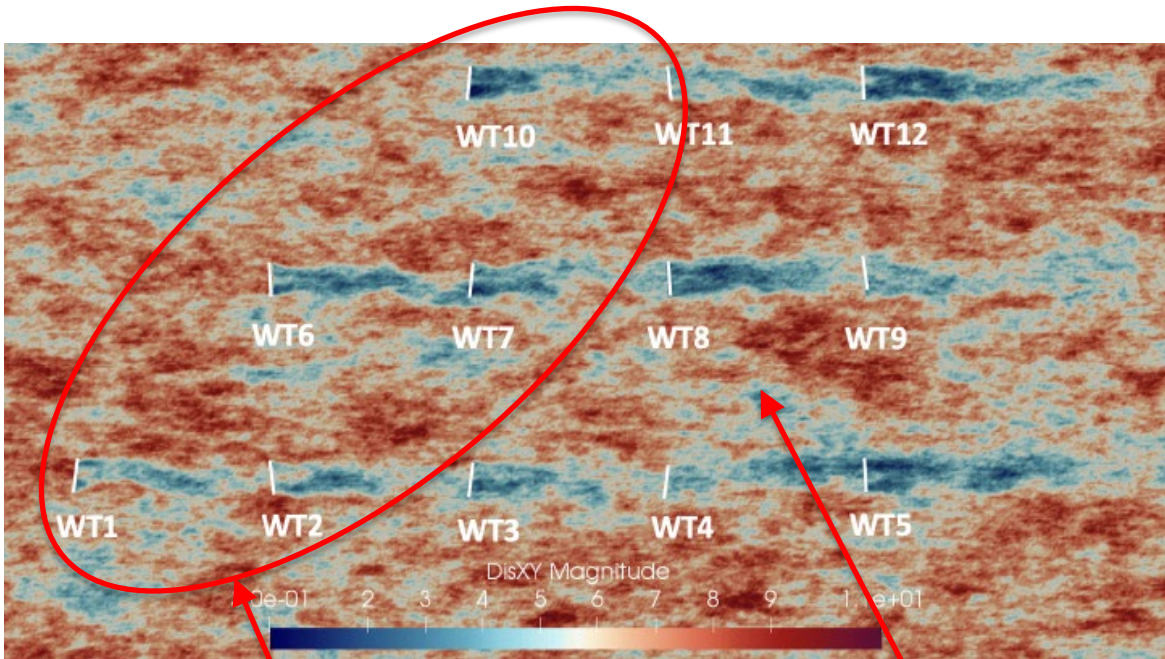


¹The output calculation of AWAE is called twice at initialization--first to return the high-resolution ambient wind before initializing OF and second to fully initialize the output

²In OF, state update and output calculations are combined into a single routine, which is subcycled relative to the FAST.Farm Δt

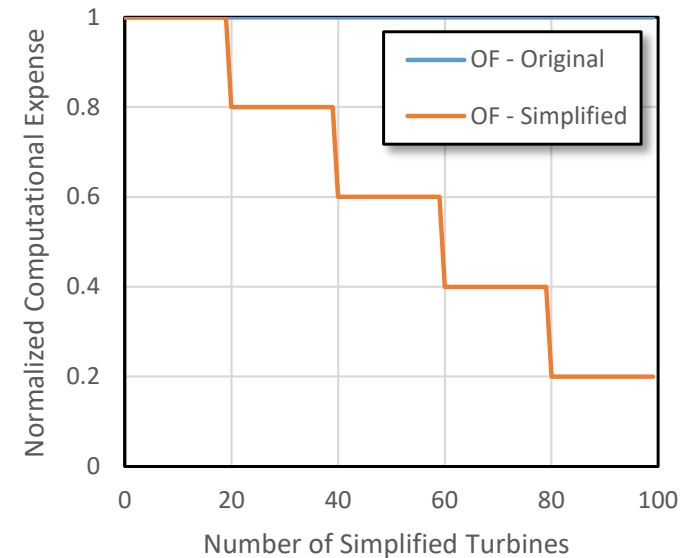
³For MD, the states are updated after OF is called, followed by the output calculation, all subcycled relative to the FAST.Farm Δt

Simplified Turbine Modeling



Simplified OpenFAST models with wakes and control

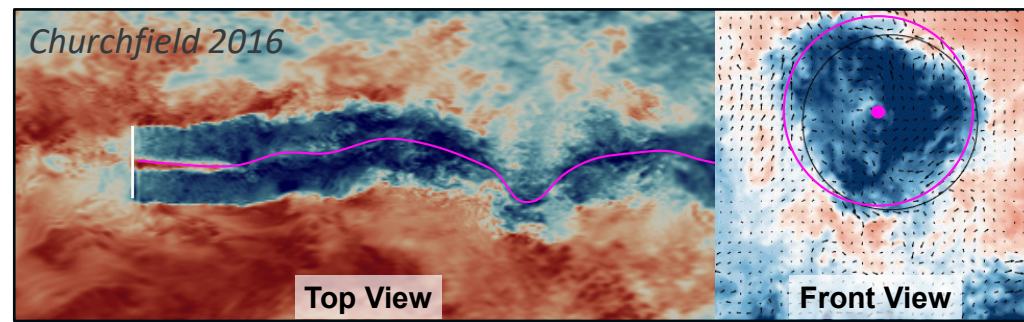
Full OpenFAST models with wakes, control, and structural loads



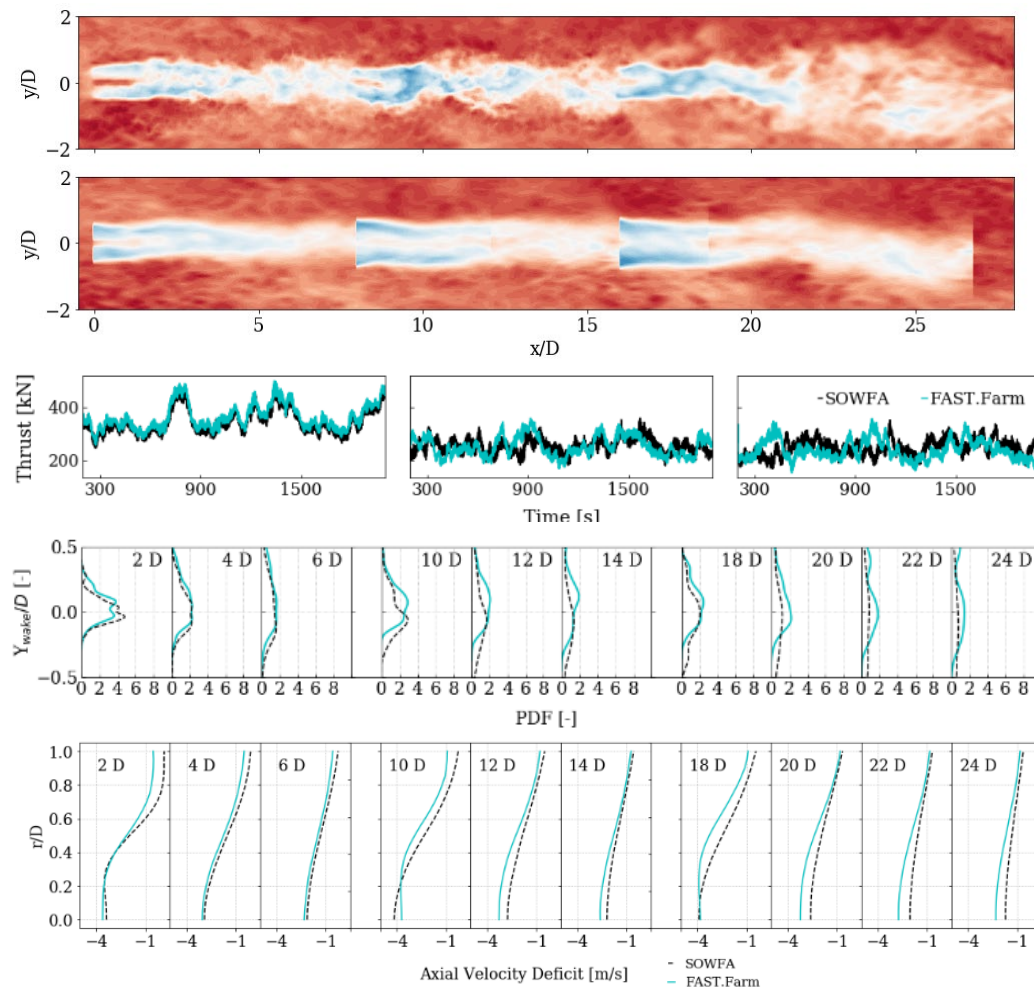
Normalized Computational Expense with 100 Turbines on 20 Threads

Calibration of Wake Parameters

- Many (≈ 20) parameters influence FAST.Farm wake dynamics
- Calibration against LES has been used to set default parameters
- Approach:
 - Identify calibration cases
 - Identify starting values and range of calibration parameters
 - Run LES and extract wake characteristics
 - Run FAST.Farm with varied parameters (sequenced grid search)
 - Identify parameters that minimize error between FAST.Farm and LES
- Past calibrations: original (NREL 5-MW), curled wake, IEA 15-MW, floating, wake-added turbulence



SOWFA-Derived Wake Deficit & Centerline



NREL 5-MW Baseline Results for $V=8$ m/s, $TI=10\%$ After Calibration

Example 0

FAST.Farm Input File and Modeling Guidance

FAST.Farm Input File

```
1  --- FAST.Farm FOR OpenFAST INPUT FILE ---
2  Sample FAST.Farm input file
3  --- SIMULATION CONTROL ---
4  False ..... Echo ..... Echo input data to <RootName>.ech? (flag)
5  FATAL ..... AbortLevel ..... Error level when simulation should abort (string) {"WARNING", "SEVERE", "FATAL"}
6  2000.0 ..... TMax ..... Total run time (s) [>=0.0]
7  1 ..... Mod_AmbWind ..... Ambient wind model (switch) {1: high-fidelity precursor in VTK format, 2: one InflowWind module, 3: multiple ins
8  2 ..... Mod_WaveField ..... Wave field handling (switch) {1: use individual HydroDyn inputs without adjustment, 2: adjust wave phases based
9  0 ..... Mod_SharedMooring ..... Shared mooring system model (switch) {0: None, 3=MoorDyn}
10 --- SHARED MOORING SYSTEM --- [used only for Mod_SharedMoor>0]
11 "" ..... SharedMoorFile ..... Name of file containing shared mooring system input parameters (quoted string) [used only when Mod_SharedMooring
12 0.04 ..... DT_Mooring ..... Time step for farm-level mooring coupling with each turbine (s) [used only when Mod_SharedMooring > 0]
13 False ..... WrMooringVis ..... Write shared mooring visualization, at the global FAST.Farm time step (-) [used only for Mod_SharedMooring = 3]
14 --- AMBIENT WIND: PRECURSOR IN VTK FORMAT --- [used only for Mod_AmbWind=1]
15 2.0 ..... DT_Low-VTK ..... Time step for low-resolution wind data input files; will be used as the global FAST.Farm time step (s) [>0.0]
16 0.333333 ..... DT_High-VTK ..... Time step for high-resolution wind data input files (s) [>0.0]
17 "Y:\Wind\Public\Projects\Projects\F\FAST.Farm\AmbWind\steady" ..... WindFilePath ..... Path name to VTK wind data files from precursor (string)
18 False ..... ChkWndFiles ..... Check all the ambient wind files for data consistency? (flag)
19 --- AMBIENT WIND: INFLOWWIND MODULE --- [used only for Mod_AmbWind=2 or 3]
20 2.0 ..... DT_Low ..... Time step for low-resolution wind data interpolation; will be used as the global FAST.Farm time step (s) [>0.0]
21 0.333333 ..... DT_High ..... Time step for high-resolution wind data interpolation (s) [>0.0]
22 300 ..... NX_Low ..... Number of low-resolution spatial nodes in X direction for wind data interpolation (-) [>=2]
23 300 ..... NY_Low ..... Number of low-resolution spatial nodes in Y direction for wind data interpolation (-) [>=2]
24 35 ..... NZ_Low ..... Number of low-resolution spatial nodes in Z direction for wind data interpolation (-) [>=2]
25 5.0 ..... X0_Low ..... Origin of low-resolution spatial nodes in X direction for wind data interpolation (m)
26 5.0 ..... Y0_Low ..... Origin of low-resolution spatial nodes in Y direction for wind data interpolation (m)
27 5.0 ..... Z0_Low ..... Origin of low-resolution spatial nodes in Z direction for wind data interpolation (m)
28 10.0 ..... dX_Low ..... Spacing of low-resolution spatial nodes in X direction for wind data interpolation (m) [>0.0]
29 10.0 ..... dY_Low ..... Spacing of low-resolution spatial nodes in Y direction for wind data interpolation (m) [>0.0]
30 10.0 ..... dZ_Low ..... Spacing of low-resolution spatial nodes in Z direction for wind data interpolation (m) [>0.0]
31 16 ..... NX_High ..... Number of high-resolution spatial nodes in X direction for wind data interpolation (-) [>=2]
32 16 ..... NY_High ..... Number of high-resolution spatial nodes in Y direction for wind data interpolation (-) [>=2]
33 17 ..... NZ_High ..... Number of high-resolution spatial nodes in Z direction for wind data interpolation (-) [>=2]
34 "InflowWind.dat" ..... InflowFile ..... Name of file containing InflowWind module input parameters (quoted string)
```

FAST.Farm Input File

```

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8  2 ..... Mod_WaveField ..... Wave field handling (switch) {1: use individual HydroDyn inputs without adjustment, 2: adjust wave phases based
9  0 ..... Mod_SharedMooring ..... Shared mooring system model (switch) {0: None, 3=MoorDyn}
10 --- SHARED MOORING SYSTEM --- [used only for Mod_SharedMoor>0]
11 "" ..... SharedMoorFile ..... Name of file containing shared mooring system input parameters (quoted string) [used only when Mod_SharedMooring
12 0.04 ..... DT_Mooring ..... Time step for farm-level mooring coupling with each turbine (s) [used only when Mod_SharedMooring > 0]
13 False ..... WrMooringVis ..... Write shared mooring visualization, at the global FAST.Farm time step (-) [used only for Mod_SharedMooring = 3]
14 --- AMBIENT WIND: PRECURSOR IN VTK FORMAT --- [used only for Mod_AmbWind=1]
15 2.0 ..... DT_Low-VTK ..... Time step for low-resolution wind data input files; will be used as the global FAST.Farm time step (s) [>0.0]
16 0.333333 ..... DT_High-VTK ..... Time step for high-resolution wind data input files (s) [>0.0]
17 "Y:\Wind\Public\Projects\Projects_F\FAST.Farm\AmbWind\steady" ..... WindFilePath ..... Path name to VTK wind data files from precursor (string)
18 False ..... ChkWndFiles ..... Check all the ambient wind files for data consistency? (flag)
19 --- AMBIENT WIND: INFLOWWIND MODULE --- [used only for Mod_AmbWind=2 or 3]
20 2.0 ..... DT_Low ..... Time step for low-resolution wind data interpolation; will be used as the global FAST.Farm time step (s) [>0.0]
21 0.333333 ..... DT_High ..... Time step for high-resolution wind data interpolation (s) [>0.0]
22 300 ..... NX_Low ..... Number of low-resolution spatial nodes in X direction for wind data interpolation (-) [>=2]
23 300 ..... NY_Low ..... Number of low-resolution spatial nodes in Y direction for wind data interpolation (-) [>=2]
24 35 ..... NZ_Low ..... Number of low-resolution spatial nodes in Z direction for wind data interpolation (-) [>=2]
25 5.0 ..... X0_Low ..... Origin of low-resolution spatial nodes in X direction for wind data interpolation (m)
26 5.0 ..... Y0_Low ..... Origin of low-resolution spatial nodes in Y direction for wind data interpolation (m)
27 5.0 ..... Z0_Low ..... Origin of low-resolution spatial nodes in Z direction for wind data interpolation (m)
28 10.0 ..... dX_Low ..... Spacing of low-resolution spatial nodes in X direction for wind data interpolation (m) [>0.0]
29 10.0 ..... dY_Low ..... Spacing of low-resolution spatial nodes in Y direction for wind data interpolation (m) [>0.0]
30 10.0 ..... dZ_Low ..... Spacing of low-resolution spatial nodes in Z direction for wind data interpolation (m) [>0.0]
31 16 ..... NX_High ..... Number of high-resolution spatial nodes in X direction for wind data interpolation (-) [>=2]
32 16 ..... NY_High ..... Number of high-resolution spatial nodes in Y direction for wind data interpolation (-) [>=2]
33 17 ..... NZ_High ..... Number of high-resolution spatial nodes in Z direction for wind data interpolation (-) [>=2]
34 "InflowWind.dat" ..... InflowFile ..... Name of file containing InflowWind module input parameters (quoted string)

```

TMax – Supersedes TMax in OpenFAST model(s)

FAST.Farm Input File

```
1  --- FAST.Farm FOR OpenFAST INPUT FILE ---
2  Sample FAST.Farm input file
3  --- SIMULATION CONTROL ---
4  False ..... Echo ..... Echo input data to <RootName>.ech? (flag)
5  FATAL ..... AbortLevel ..... Error level when simulation should abort (string) {"WARNING", "SEVERE", "FATAL"}
6  2000.0 ..... TMax ..... Total run time (s) [>=0.0]
7  1 ..... Mod_AmbWind ..... Ambient wind model (switch) {1: high-fidelity precursor in VTK format, 2: one InflowWind module, 3: multiple ins
8  2 ..... Mod_WaveField ..... Wave field handling (switch) {1: use individual HydroDyn inputs without adjustment, 2: adjust wave phases based
9  0 ..... Mod_SharedMooring ..... Shared mooring system model (switch) {0: None, 3=MoorDyn}}
10 --- SHARED MOORING SYSTEM --- [used only for Mod_SharedMoor>0]
11 "" ..... SharedMoorFile ..... Name of file containing shared mooring system input parameters (quoted string) [used only when Mod_SharedMooring
12 0.04 ..... DT_Mooring ..... Time step for farm-level mooring coupling with each turbine (s) [used only when Mod_SharedMooring > 0]
13 False ..... WrMooringVis ..... Write shared mooring visualization, at the global FAST.Farm time step (-) [used only for Mod_SharedMooring = 3]
14 --- AMBIENT WIND: PRECURSOR IN VTK FORMAT --- [used only for Mod_AmbWind=1]
15 2.0 ..... DT_Low-VTK ..... Time step for low-resolution wind data input files; will be used as the global FAST.Farm time step (s) [>0.0]
16 0.333333 ..... DT_High-VTK ..... Time step for high-resolution wind data input files (s) [>0.0]
17 "Y:\Wind\Public\Projects\Projects_F\FAST.Farm\AmbWind\steady" ..... WindFilePath ..... Path name to VTK wind data files from precursor (string)
18 False ..... ChkWndFiles ..... Check all the ambient wind files for data consistency? (flag)
19 --- AMBIENT WIND: INFLOWWIND MODULE --- [used only for Mod_AmbWind=2 or 3]
20 2.0 ..... DT_Low ..... Time step for low-resolution wind data interpolation; will be used as the global FAST.Farm time step (s) [>0.0]
21 0.333333 ..... DT_High ..... Time step for high-resolution wind data interpolation (s) [>0.0]
22 300 ..... NX_Low ..... Number of low-resolution spatial nodes in X direction for wind data interpolation (-) [>=2]
23 300 ..... NY_Low ..... Number of low-resolution spatial nodes in Y direction for wind data interpolation (-) [>=2]
24 35 ..... NZ_Low ..... Number of low-resolution spatial nodes in Z direction for wind data interpolation (-) [>=2]
25 5.0 ..... X0_Low ..... Origin of low-resolution spatial nodes in X direction for wind data interpolation (m)
26 5.0 ..... Y0_Low ..... Origin of low-resolution spatial nodes in Y direction for wind data interpolation (m)
27 5.0 ..... Z0_Low ..... Origin of low-resolution spatial nodes in Z direction for wind data interpolation (m)
28 10.0 ..... dX_Low ..... Spacing of low-resolution spatial nodes in X direction for wind data interpolation (m) [>0.0]
29 10.0 ..... dY_Low ..... Spacing of low-resolution spatial nodes in Y direction for wind data interpolation (m) [>0.0]
30 10.0 ..... dZ_Low ..... Spacing of low-resolution spatial nodes in Z direction for wind data interpolation (m) [>0.0]
31 16 ..... NX_High ..... Number of high-resolution spatial nodes in X direction for wind data interpolation (-) [>=2]
32 16 ..... NY_High ..... Number of high-resolution spatial nodes in Y direction for wind data interpolation (-) [>=2]
33 17 ..... NZ_High ..... Number of high-resolution spatial nodes in Z direction for wind data interpolation (-) [>=2]
34 "InflowWind.dat" ..... InflowFile ..... Name of file containing InflowWind module input parameters (quoted string)
```

Mod_AmbWind – Ambient wind model:

- 1) High-fidelity precursor
- 2) Single InflowWind (simple, TurbSim, Mann)
- 3) Multiple InflowWind (low- and high-res. Domains)

FAST.Farm Input File

```
1  --- FAST.Farm FOR OpenFAST INPUT FILE ---
2  Sample FAST.Farm input file
3  --- SIMULATION CONTROL ---
4  False ..... Echo ..... Echo input data to <RootName>.ech? (flag)
5  FATAL ..... AbortLevel ..... Error level when simulation should abort (string) {"WARNING", "SEVERE", "FATAL"}
6  2000.0 ..... TMax ..... Total run time (s) [>=0.0]
7  1 ..... Mod_AmbWind ..... Ambient wind model (switch) {1: high-fidelity precursor in VTK format, 2: one InflowWind module, 3: multiple ins
8  2 ..... Mod_WaveField ..... Wave field handling (switch) {1: use individual HydroDyn inputs without adjustment, 2: adjust wave phases based
9  0 ..... Mod_SharedMooring ..... Shared mooring system model (switch) {0: None, 3=MoorDyn}}
10 --- SHARED MOORING SYSTEM --- [used only for Mod_SharedMoor>0]
11 "" ..... SharedMoorFile ..... Name of file containing shared mooring system input parameters (quoted string) [used only when Mod_SharedMooring
12 0.04 ..... DT_Mooring ..... Time step for farm-level mooring coupling with each turbine (s) [used only when Mod_SharedMooring > 0]
13 False ..... WrMooringVis ..... Write shared mooring visualization, at the global FAST.Farm time step (-) [used only for Mod_SharedMooring = 3]
14 --- AMBIENT WIND: PRECURSOR IN VTK FORMAT --- [used only for Mod_AmbWind=1]
15 2.0 ..... DT_Low-VTK ..... Time step for low-resolution wind data input files; will be used as the global FAST.Farm time step (s) [>0.0]
16 0.333333 ..... DT_High-VTK ..... Time step for high-resolution wind data input files (s) [>0.0]
17 "Y:\Wind\Public\Projects\Projects_F\FAST.Farm\AmbWind\steady" ..... WindFilePath ..... Path name to VTK wind data files from precursor (string)
18 False ..... ChkWndFiles ..... Check all the ambient wind files for data consistency? (flag)
19 --- AMBIENT WIND: INFLOWWIND MODULE --- [used only for Mod_AmbWind=2 or 3]
20 2.0 ..... DT_Low ..... Time step for low-resolution wind data interpolation; will be used as the global FAST.Farm time step (s) [>0.0]
21 0.333333 ..... DT_High ..... Time step for high-resolution wind data interpolation (s) [>0.0]
22 300 ..... NX_Low ..... Number of low-resolution spatial nodes in X direction for wind data interpolation (-) [>=2]
23 300 ..... NY_Low ..... Number of low-resolution spatial nodes in Y direction for wind data interpolation (-) [>=2]
24 35 ..... NZ_Low ..... Number of low-resolution spatial nodes in Z direction for wind data interpolation (-) [>=2]
25 5.0 ..... X0_Low ..... Origin of low-resolution spatial nodes in X direction for wind data interpolation (m)
26 5.0 ..... Y0_Low ..... Origin of low-resolution spatial nodes in Y direction for wind data interpolation (m)
27 5.0 ..... Z0_Low ..... Origin of low-resolution spatial nodes in Z direction for wind data interpolation (m)
28 10.0 ..... dX_Low ..... Spacing of low-resolution spatial nodes in X direction for wind data interpolation (m) [>0.0]
29 10.0 ..... dY_Low ..... Spacing of low-resolution spatial nodes in Y direction for wind data interpolation (m) [>0.0]
30 10.0 ..... dZ_Low ..... Spacing of low-resolution spatial nodes in Z direction for wind data interpolation (m) [>0.0]
31 16 ..... NX_High ..... Number of high-resolution spatial nodes in X direction for wind data interpolation (-) [>=2]
32 16 ..... NY_High ..... Number of high-resolution spatial nodes in Y direction for wind data interpolation (-) [>=2]
33 17 ..... NZ_High ..... Number of high-resolution spatial nodes in Z direction for wind data interpolation (-) [>=2]
34 "InflowWind.dat" ..... InflowFile ..... Name of file containing InflowWind module input parameters (quoted string)
```

Mod_WaveField – Wave field handling:

- 1) Waves in each OpenFAST model are independent
- 2) Waves propagate across wind farm

FAST.Farm Input File

```

1  --- FAST.Farm FOR OpenFAST INPUT FILE ---
2  Sample FAST.Farm input file
3  --- SIMULATION CONTROL ---
4  False ..... Echo ..... Echo input data to <RootName>.ech? (flag)
5  FATAL ..... AbortLevel ..... Error level when simulation should abort (string) {"WARNING", "SEVERE", "FATAL"}
6  2000.0 ..... TMax ..... Total run time (s) [>=0.0]
7  1 ..... Mod_AmbWind ..... Ambient wind model (switch) {1: high-fidelity precursor in VTK format, 2: one InflowWind module, 3: multiple ins
8  2 ..... Mod_WaveField ..... Wave field handling
9  0 ..... Mod_SharedMooring ..... Shared mooring system
10 --- SHARED MOORING SYSTEM --- [used only for Mod_SharedMooring]
11 "" ..... SharedMoorFile ..... Name of file containing mooring data
12 0.04 ..... DT_Mooring ..... Time step for farm mooring
13 False ..... WrMooringVis ..... Write shared mooring visualization
14 --- AMBIENT WIND: PRECURSOR IN VTK FORMAT --- [used only for Mod_AmbWind]
15 2.0 ..... DT_Low-VTK ..... Time step for low-resolution wake meandering
16 0.333333 ..... DT_High-VTK ..... Time step for high-resolution turbulent wind excitation
17 "Y:\Wind\Public\Projects\Projects_F\FAST.Farm\AmbWind\st
18 False ..... ChkWndFiles ..... Check all the ambient wind files
19 --- AMBIENT WIND: INFLOWWIND MODULE --- [used only for Mod_AmbWind]
20 2.0 ..... DT_Low ..... Time step for low-resolution wake meandering
21 0.333333 ..... DT_High ..... Time step for high-resolution turbulent wind excitation
22 300 ..... NX_Low ..... Number of low-resolution wake meandering
23 300 ..... NY_Low ..... Number of low-resolution wake meandering
24 35 ..... NZ_Low ..... Number of low-resolution wake meandering
25 5.0 ..... X0_Low ..... Origin of low-resolution wake meandering
26 5.0 ..... Y0_Low ..... Origin of low-resolution wake meandering
27 5.0 ..... Z0_Low ..... Origin of low-resolution wake meandering
28 10.0 ..... dX_Low ..... Spacing of low-resolution wake meandering

```

Low-resolution time step should be sufficient to resolve wake meandering time scales

High-resolution time step should be sufficient to resolve turbulent wind excitation

$$DT_{Low} \leq \frac{C_{Meander} D_{wake}}{10V_{hub}}$$

$$DT_{High} \leq \frac{1}{2f_{max}}$$

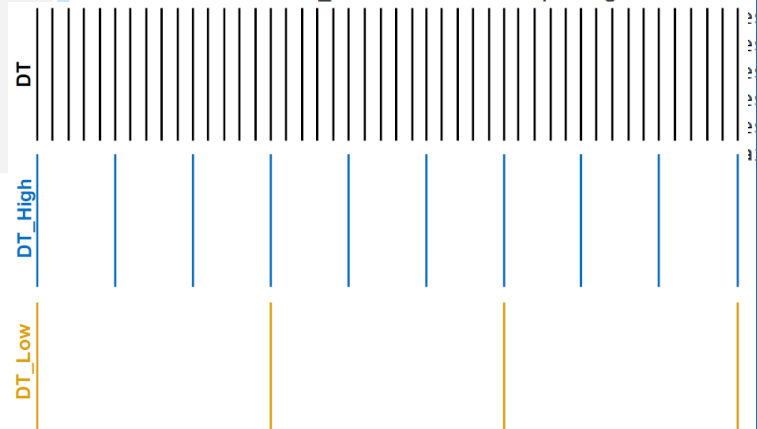
$C_{Meander} \approx 2$ (DEFAULT = 1.9)

$D_{Wake} \approx D$

Curled wake may need smaller DT_{Low}

DT_{High} must be an integer divisor of DT_{Low}

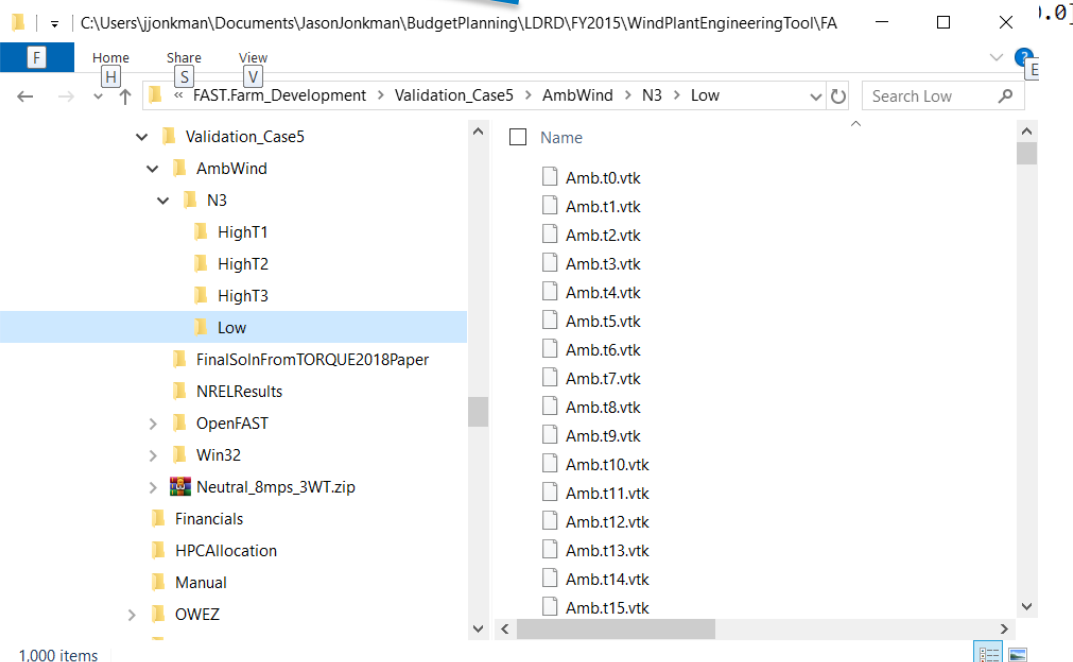
DT in OpenFAST be an integer divisor of DT_{Low}



FAST.Farm Input File

```

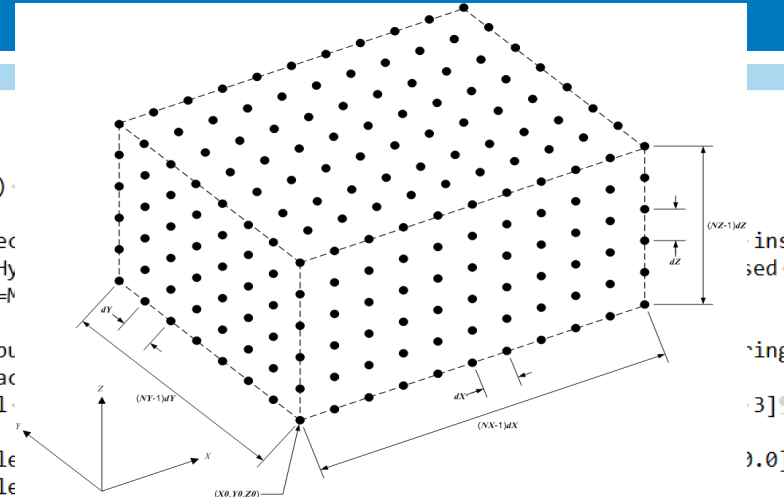
1  --- FAST.Farm FOR OpenFAST INPUT FILE ---
2  Sample FAST.Farm input file
3  --- SIMULATION CONTROL ---
4  False ..... Echo ..... Echo input data to <RootName>.ech? (flag)
5  FATAL ..... AbortLevel ..... Error level when simulation should abort (string) {"WARNING", "SEVERE", "FATAL"}
6  2000.0 ..... TMax ..... Total run time (s) [≥0.0]
7  1 ..... Mod_AmbWind ..... Ambient wind model (switch) {1: high-fidelity precursor in VTK format, 2: one InflowWind module, 3: multiple ins
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9  0 ..... Mod_SharedMooring ..... Shared mooring system model (switch) {0: None, 3=MoorDyn}
10 --- SHARED MOORING SYSTEM --- [used only for Mod_SharedMoor>0]
11 "" ..... SharedMoorFile ..... Name of file containing shared mooring system input parameters (quoted string) [used only when Mod_SharedMooring
12 0.04 ..... DT_Mooring ..... Time step for farm-level mooring coupling with each turbine (s) [used only when Mod_SharedMooring > 0]
13 False ..... WrMooringVis ..... Write shared mooring visualization, at the global FAST.Farm time step (-) [used only for Mod_SharedMooring = 3]
14 --- AMBIENT WIND: PRECURSOR IN VTK FORMAT --- [used only for Mod_AmbWind=1]
15 2.0 ..... DT_Low-VTK ..... Time step for low-resolution wind data input files ; will be used as the global FAST.Farm time step (s) [≥0.0]
16 0.333333 ..... DT_High-VTK ..... Time step for high-resolution wind data input files (s) [≥0.0]
17 "Y:\Wind\Public\Projects\Projects\F\FAST.Farm\AmbWind\steady" ..... WindFilePath ..... Path name to VTK wind data files from precursor (string)
18 False ..... ChkWndFiles ..... Check all the ambient wind files for data consistency? (flag)
19 --- AMBIENT WIND: INFLOWWIND MODULE --- [used only for Mod_AmbWind=2 or 3]
20 2.0 ..... DT_Low ..... Time step for low-resolution
21 0.333333 ..... DT_High ..... Time step for high-resolution
22 300 ..... NX_Low ..... Number of low-resolution
23 300 ..... NY_Low ..... Number of low-resolution
24 35 ..... NZ_Low ..... Number of low-resolution
25 5.0 ..... X0_Low ..... Origin of low-resolution
26 5.0 ..... Y0_Low ..... Origin of low-resolution
27 5.0 ..... Z0_Low ..... Origin of low-resolution
28 10.0 ..... dX_Low ..... Spacing of low-resolution
29 10.0 ..... dY_Low ..... Spacing of low-resolution
30 10.0 ..... dZ_Low ..... Spacing of low-resolution
31 16 ..... NX_High ..... Number of high-resolution
32 16 ..... NY_High ..... Number of high-resolution
33 17 ..... NZ_High ..... Number of high-resolution
34 "InflowWind.dat" ..... InflowFile ..... Name of file containing I
  
```



FAST.Farm Input File

```

1  --- FAST.Farm FOR OpenFAST INPUT FILE ---
2  Sample FAST.Farm input file
3  --- SIMULATION CONTROL ---
4  False ..... Echo ..... Echo input data to <RootName>.ech? (flag)
5  FATAL ..... AbortLevel ..... Error level when simulation should abort (string)
6  2000.0 ..... TMax ..... Total run time (s) [>=0.0]
7  1 ..... Mod_AmbWind ..... Ambient wind model (switch) {1: high-fidelity prec
8  2 ..... Mod_WaveField ..... Wave field handling (switch) {1: use individual Hy
9  0 ..... Mod_SharedMooring ..... Shared mooring system model (switch) {0: None, 3=M
10 --- SHARED MOORING SYSTEM --- [used only for Mod_SharedMooring=0]
11 "" ..... SharedMooringFile ..... Name of file containing shared mooring system input
12 0.04 ..... DT_Mooring ..... Time step for farm-level mooring coupling with each
13 False ..... WrMooringVis ..... Write shared mooring visualization, at the global
14 --- AMBIENT WIND: PRECURSOR IN VTK FORMAT --- [used only for Mod_AmbWind=1]
15 2.0 ..... DT_Low-VTK ..... Time step for low-resolution wind data input file
16 0.333333 ..... DT_High-VTK ..... Time step for high-resolution wind data input file
17 "Y:\Wind\Public\Projects\Projects\F\FAST.Farm\A
18 False ..... ChkWndFiles ..... Check all
19 --- AMBIENT WIND: INFLOWWIND MODULE --- [used o
20 2.0 ..... DT_Low ..... Time step
21 0.333333 ..... DT_High ..... Time step
22 300 ..... NX_Low ..... Number o
23 300 ..... NY_Low ..... Number o
24 35 ..... NZ_Low ..... Number o
25 5.0 ..... X0_Low ..... Origin o
26 5.0 ..... Y0_Low ..... Origin o
27 5.0 ..... Z0_Low ..... Origin o
28 10.0 ..... dX_Low ..... Spacing o
29 10.0 ..... dY_Low ..... Spacing o
30 10.0 ..... dZ_Low ..... Spacing o
31 16 ..... NX_High ..... Number o
32 16 ..... NY_High ..... Number o
33 17 ..... NZ_High ..... Number o
34 "InflowWind.dat" ..... InflowFile ..... Name of f
  
```



Low-resolution domain should extend wherever wakes may reside ($3 D_{Rotor}$ boundaries), except downstream

Low-resolution spatial resolution should be sufficient for adequate spatial averaging

$$DS_{Low} \leq \frac{C_{meander} D_{wake} V_{hub}}{150 \frac{m}{s}} = \frac{DT_{Low} V_{hub}^2}{15 \frac{m}{s}}$$

$S = X, Y, \text{ or } Z$

Curled wake may need smaller DS_{Low}

Set velocities to NaN for any point below the ground

FAST.Farm Input File

```

1  --- FAST.Farm FOR OpenFAST INPUT FILE ---
2  Sample FAST.Farm input file
3  --- SIMULATION CONTROL ---
4  False ..... Echo ..... Echo input data to <RootName>.ech? (flag)
5  FATAL ..... AbortLevel ..... Error level when simulation should abort (string) {"WARNING", "SEVERE", "FATAL"}
6  2000.0 ..... TMax ..... Total run time (s) [>=0.0]
7  1 ..... Mod_AmbWind ..... Ambient wind model (switch) {1: high-fidelity precursor in VTK format, 2: one InflowWind module, 3: multiple ins
8  2 ..... Mod_WaveField ..... Wave field handling (switch) {1: use individual HydroDyn inputs without adjustment, 2: adjust wave phases based
9  0 ..... Mod_SharedMooring ..... Shared mooring system model (switch) {0: None, 3=MoorDyn}}
10 --- SHARED MOORING SYSTEM --- [used only for Mod_SharedMoor>0]
11 "" ..... SharedMoorFile ..... Name of file containing shared mooring system input parameters (quoted string) [used only when Mod_SharedMooring
12 0.04 ..... DT_Mooring ..... Time step for farm-level mooring coupling with each turbine (s) [used only when Mod_SharedMooring > 0]
13 False ..... WrMooringVis ..... Write shared mooring visualization, at the global FAST.Farm time step (-) [used only for Mod_SharedMooring = 3]
14 --- AMBIENT WIND: PRECURSOR IN VTK FORMAT --- [used only for Mod_AmbWind=1]
15 2.0 ..... DT_Low-VTK ..... Time step for low-resolution wind data input files ; will be used as the global FAST.Farm time step (s) [>0.0]
16 0.333333 ..... DT_High-VTK ..... Time step for high-resolution wind data input files (s) [>0.0]
17 "Y:\Wind\Public\Projects\Projects_F\FAST.Farm\AmbWind\steady" ..... WindFilePath ..... Path name to VTK wind data files from precursor (string)
18 False ..... ChkWndFiles ..... Check all the ambient wind files for data consistency? (flag)
19 --- AMBIENT WIND: INFLOWWIND MODULE --- [used only for Mod_AmbWind=2 or 3]
20 2.0 ..... DT_Low ..... Time step for low-resolution wind data interpolation; will be used as the global FAST.Farm time step (s) [>0.0]
21 0.333333 ..... DT_High ..... Time step for high-resolution wind data interpolation (s) [>0.0]
22 300 ..... NX_Low ..... Number of low-resolution spatial nodes in X direction for wind data interpolation (-) [>=2]
23 300 ..... NY_Low ..... Number of low-resolution spatial nodes in Y direction for wind data interpolation (-) [>=2]
24 35 ..... NZ_Low ..... Number of low-resolution spatial nodes in Z direction for wind data interpolation (-) [>=2]
25 5.0 ..... X0_Low ..... Origin of low-resolution spatial nodes in X direction for wind data interpolation (m)
26 5.0 ..... Y0_Low ..... Origin of low
27 5.0 ..... Z0_Low ..... Origin of low
28 10.0 ..... dX_Low ..... Spacing of low
29 10.0 ..... dY_Low ..... Spacing of low
30 10.0 ..... dZ_Low ..... Spacing of low
31 16 ..... NX_High ..... Number of high
32 16 ..... NY_High ..... Number of high
33 17 ..... NZ_High ..... Number of high
34 "InflowWind.dat" ..... InflowFile ..... Name of file co

```

When using TurbSim or Mann:

- Recommend generating periodic winds
- Recommend aligning full-field grid w/ low- and high-resolution domain points
- Recommend PropagationDir = 0°, ±90°, or 180°
- Importance of transverse coherence
- HubHt / GridHeight issue in TurbSim
- X / Time problem in Mann

FAST.Farm Input File

```

35 --- WIND TURBINES ---
36 1 NumTurbines Number of wind turbines (-) [≥1] [last 6 columns below used only for Mod_AmbWind=2 or 3]
37 WT_X WT_Y WT_Z WT_FASTInFile X0_High Y0_High Z0_High dX_High dY_High dZ_High
38 (m) (m) (m) (string) (m) (m) (m) (m) (m) (m)
39 605.0 1500.0 0.0 "Y:\Wind\Public\Projects\Projects_F\FAST.Farm\MasterModel\FAST\Test18.fst" 525.0 1425.0 5.0 10.0 10.0 10.0
40 --- WAKE DYNAMICS ---
41 1 Mod_Wake Switch between wake formulations (switch) {1:Polar, 2:Curl, 3:Cartesian}
42 126.0 RotorDiamRef Reference turbine rotor diameter for wake calculations (m) [≥0.0]
43 5.0 dr Radial increment of the wake plane finite-difference grid (m) [≥0.0]
44 40 NumRadii Number of radii in the wake plane finite-difference grid (-) [≥2]
45 140 NumPlanes Number of wake planes (-) [≥2]
46 DEFAULT f_c Cutoff (corner) frequency of the low-pass time-filter for the wake advection, deflection, and meandering model
47 DEFAULT C_HwkDfl_O Calibrated parameter in the correction for wake deflection defining the horizontal offset at the rotor
48 DEFAULT C_HwkDfl_OY Calibrated parameter in the correction for wake deflection defining the horizontal offset at the rotor scaled wi
49 DEFAULT C_HwkDfl_x Calibrated parameter in the correction for wake deflection defining the horizontal offset scaled wi
50 DEFAULT C_HwkDfl_xY Calibrated parameter in the correction for wake deflection defining the horizontal offset scaled wi
51 DEFAULT C_NearWake Calibrated parameter for the near-wake correction (-) [≥1.0 and <2.5] or DEFAULT [DEFAULT=1.8]
52 DEFAULT k_vAmb Calibrated parameters for the influence of ambient turbulence in the eddy viscosity (set of 5 parameters: k, FMI
53 DEFAULT k_vShr Calibrated parameters for the influence of the shear layer in the eddy viscosity (set of 5 parameters: k, FMI
54 DEFAULT Mod_WakeDiam Wake diameter calculation model (switch) {1: rotor diameter, 2: velocity based, 3: mass-flux based, 4: momentum-
55 DEFAULT C_WakeDiam Calibrated parameter for wake diameter calculation (-) [≥0.0 and <0.99] or DEFAULT [DEFAULT=0.95] [unused for Mo
56 DEFAULT Mod_Meander Spatial filter model for wake meandering (-) (switch) {1: uniform, 2: truncated jinc, 3: windowed jinc} or DEFAU
57 DEFAULT C_Meander Calibrated parameter for wake meandering (-) [≥1.0] or DEFAULT [DEFAULT=1.9]
58 --- CURLED-WAKE PARAMETERS [only used if Mod_Wake=2 or 3] ---
59 DEFAULT Swirl Flag to include swirl velocities in wake (flag) [DEFAULT=TRUE]
60 DEFAULT k_VortexDecay Vortex decay constant for curl (-) [DEFAULT=0.0001]
61 DEFAULT NumVortices The number of vortices in the curled wake model (-) [DEFAULT=100]
62 DEFAULT sigma_D The width of the vortices in the curled wake model non-dimensionalized by rotor diameter (-) [DEFAULT=0.2]
63 DEFAULT FilterInit Switch to filter the initial wake plane deficit and select the number of grid points for the filter (switch) {0:
64 DEFAULT k_vCurl Calibrated parameter for scaling the eddy viscosity in the curled wake model (-) [≥0] or DEFAULT [DEFAULT=2.0]
65 DEFAULT Mod_Projection Switch to select how the wake plane velocity is projected in AWAE (switch) {1: keep all components, 2: project a
66 --- WAKE-ADDED TURBULENCE ---
67 2 WAT Switch between wake-added turbulence box options (switch) {0: no wake added turbulence, 1: predefined turbulence
68 "../WAT_MannBoxDB/FFDB_D100_512x512x64.u" WAT_BoxFile Filepath to the file containing the u-component of the turbulence box (either predefined or use
69 512, 512, 64 WAT_NxNyNz Number of points in the x, y, and z directions of the WAT_BoxFile (-) [used only if WAT=2, derived value
70 5.0, 5.0, 5.0 WAT_DxDyDz Distance between points in the x, y, and z directions of the WAT_BoxFile (m) [used only if WAT=2, derived value
71 DEFAULT WAT_ScaleBox Flag to scale the input turbulence box to zero mean and unit standard deviation at every node (flag) [DEFAULT=Fa
72 DEFAULT WAT_k_Def Calibrated parameters for the influence of the maximum wake deficit on wake-added turbul
73 DEFAULT WAT_k_Grad Calibrated parameters for the influence of the radial velocity gradient of the wake deficit on wake-added turbul

```


FAST.Farm Input File

```

35 --- WIND_TURBINES ---
36 1 NumTurbines ..... Number of wind turbines (-) [≥1] ..... [last 6 columns below used only for Mod_AmbWind=2 on
37 WT_X WT_Y WT_Z WT_FASTInFile ..... X0_High Y0_High Z0_High dX_High dY_High dZ_High
38 (m) (m) (m) (string) ..... (m) (m) (m) (m) (m) (m)
39 605.0 1500.0 0.0 "Y:\Wind\Public\Projects\Projects_F\FAST.Farm\MasterModel\FAST\Test18.fst" 525.0 1425.0 5.0 10.0 10.0 10.0
40 --- WAKE_DYNAMICS ---
41 1 Mod_Wake ..... Switch between wake formulations (switch) {1:Polar, 2:Curl, 3:Cartesian}
42 126.0 RotorDiamRef ..... Reference turbine rotor diameter for wake calculations (m) [≥0.0]
43 5.0 dr ..... Radial increment of the wake plane finite-difference grid (m) [≥0.0]
44 40 NumRadii ..... Number of radii in the wake plane finite-difference grid (-) [≥2]
45 140 NumPlanes ..... Number of wake planes (-) [≥2]
46 DEFAULT f_c ..... Cutoff (corner) frequency of the low-pass time-filter for the wake advection, deflection, and meandering model
47 DEFAULT C_HwkDfl_O ..... Calibrated parameter in the correction for wake deflection defining the horizontal offset at the rotor
48 DEFAULT C_HwkDfl_OY ..... Calibrated parameter in the correction for wake deflection defining the horizontal offset at the rotor scaled wi
49 DEFAULT C_HwkDfl_x ..... Calibrated parameter in the correction for wake deflection defining the horizontal offset ..... scaled wi
50 DEFAULT C_HwkDfl_xY ..... Calibrated parameter in the correction for wake deflection defining the horizontal offset ..... scaled wi
51 DEFAULT C_NearWake ..... Calibrated parameter for the near-wake correction (-) [≥1.0 and <2.5] or DEFAULT [DEFAULT=1.8]
52 DEFAULT k_vAmb ..... Calibrated parameters for the influence of ambient turbulence in the eddy viscosity (set of 5 parameters: k, FMI
53 DEFAULT k_vShr ..... Calibrated parameters for the influence of the shear layer ..... in the eddy viscosity (set of 5 parameters: k, FMI
54 DEFAULT Mod_WakeDiam ..... Wake diameter calculation model (switch) {1: rotor diameter, 2: velocity based, 3: mass-flux based, 4: momentum-
55 DEFAULT C_WakeDiam ..... Calibrated parameter for wake diameter calculation (-) [≥0.0 and <0.99] or DEFAULT [DEFAULT=0.95] [unused for Mo
56 DEFAULT Mod_Meander ..... Spatial filter model for wake meandering (-) (switch) {1: uniform, 2: truncated jinc, 3: windowed jinc} or DEFAU
57 DEFAULT C_Meander ..... Calibrated parameter for wake meandering (-) [≥1.0] or DEFAULT [DEFAULT=1.9]
58 --- CURLED-WAKE_PARAMETERS [only used if Mod_Wake=2 or 3] ---
59 DEFAULT Swirl ..... Flag to include swirl velocities in wake (flag) [DEFAULT=TRUE]
60 DEFAULT k_VortexDecay ..... Vortex decay constant for curl (-) [DEFAULT=0.0001]
61 DEFAULT NumVortices ..... The number of vortices in the curled wake model (-) [DEFAULT=100]
62 DEFAULT sigma_D ..... The width of the vortices in the curled wake model non-dimensionalized by rotor diameter (-) [DEFAULT=0.2]
63 DEFAULT FilterInit ..... Switch to filter the initial wake plane deficit and select the number of grid points for the filter (switch) {0:
64 DEFAULT k_vCurl ..... Calibrated parameter for scaling the eddy viscosity in the curled wake model (-) [≥0] or DEFAULT [DEFAULT=2.0]
65 DEFAULT Mod_Projection ..... Switch to select how the wake plane velocity is projected in AWAE (switch) {1: keep all components, 2: project a
66 --- WAKE-ADDED_TURBULENCE ---
67 2 WAT ..... Switch between wake-added turbulence box options (switch) {0: no wake added turbulence, 1: predefined turbulence
68 "../WAT_MannBoxDB/FFDB_D100_512x512x64.u" WAT_BoxFile ..... Filepath to the file containing the u-component of the turbulence box (either predefined or use
69 512, 512, 64 WAT_NxNyNz ..... Number of ..... points in the x, y, and z directions of the WAT_BoxFile (-) [used only if WAT=2, derived value
70 5.0, 5.0, 5.0 WAT_DxDyDz ..... Distance between ..... BoxFile (m) [used only if WAT=2, derived value
71 DEFAULT WAT_ScaleBox ..... Flag to scale t ..... standard deviation at every node (flag) [DEFAULT=Fa
72 DEFAULT WAT_k_Def ..... Calibrated parameters for the influence of the maximum ..... wake deficit on wake-added turbul
73 DEFAULT WAT_k_Grad ..... Calibrated parameters for the influence of the radial velocity gradient of the wake deficit on wake-added turbul

```

Origin of each wind turbine

FAST.Farm Input File

```

35 --- WIND TURBINES ---
36 1 NumTurbines Number of wind turbines (-) [>=1] [last 6 columns below used only for Mod_AmbWind=2 or 3]
37 WT_X WT_Y WT_Z WT_FASTInFile X0_High Y0_High Z0_High dX_High dY_High dZ_High
38 (m) (m) (m) (string) (m) (m) (m) (m) (m) (m)
39 605.0 1500.0 0.0 "Y:\Wind\Public\Projects\Projects_F\FAST.Farm\MasterModel\FAST\Test18.fst" 525.0 1425.0 5.0 10.0 10.0 10.0
40 --- WAKE DYNAMICS ---
41 1 Mod_Wake Switch between wake formulations (switch) {1:Polar, 2:Curl, 3:Cartesian}
42 126.0 RotorDiamRef Reference turbine rotor diameter for wake calculations (m) [>0.0]
43 5.0 dr Radial increment of the wake plane finite-difference grid (m) [>0.0]
44 40 NumRadii Number of radii in the wake plane finite-difference grid (-) [>=2]
45 140 NumPlanes Number of wake planes (-) [>=2]
46 DEFAULT f_c Cutoff (corner) frequency of the low-pass time-filter for the wake advection, deflection, and meandering model
47 DEFAULT C_HwkDfl_O Calibrated parameter in the correction for wake deflection defining the horizontal offset at the rotor
48 DEFAULT C_HwkDfl_OY Calibrated parameter in the correction for wake deflection defining the horizontal offset at the rotor scaled wi
49 DEFAULT C_HwkDfl_x Calibrated parameter in the correction for wake deflection defining the horizontal offset scaled wi
50 DEFAULT C_HwkDfl_xY Calibrated parameter in the correction for wake deflection defining the horizontal offset scaled wi
51 DEFAULT C_NearWake Calibrated parameter for the near-wake correction (-) [>1.0 and <2.5] or DEFAULT [DEFAULT=1.8]
52 DEFAULT k_vAmb Calibrated parameters for the influence of ambient turbulence in the eddy viscosity (set of 5 parameters: k, FMI
53 DEFAULT k_vShr Calibrated parameters for the influence of the shear layer in the eddy viscosity (set of 5 parameters: k, FMI
54 DEFAULT Mod_WakeDiam Wake diameter calculation model (switch) {1: rotor diameter, 2: velocity based, 3: mass-flux based, 4: momentum-
55 DEFAULT C_WakeDiam Calibrated parameter for wake diameter calculation (-) [>0.0 and <0.99] or DEFAULT [DEFAULT=0.95] [unused for Mo
56 DEFAULT Mod_Meander Spatial filter model for wake meandering (-) (switch) {1: uniform, 2: truncated jinc, 3: windowed jinc} or DEFAUL
57 DEFAULT C_Meander Calibrated parameter for wake meandering (-) [>=1.0] or DEFAULT [DEFAULT=1.9]
58 --- CURLED-WAKE PARAMETERS [only used if Mod_Wake=2 or 3] ---
59 DEFAULT Swirl Flag to include swirl velocities in wake (flag) [DEFAULT=TRUE]
60 DEFAULT k_VortexDecay Vortex decay constant for curl (-) [DEFAULT=0.0001]
61 DEFAULT NumVortices The number of vortices in the curled wake model (-) [DEFAULT=100]
62 DEFAULT sigma_D The width of the vortices in the curled wake model non-dimensionalized by rotor diameter (-) [DEFAULT=0.2]
63 DEFAULT FilterInit Switch to filter the initial wake plane deficit and select the number of grid points for the filter (switch) {0:
64 DEFAULT k_vCurl Calibrated parameter for scaling the eddy viscosity in the curled-wake model (-) [>=0] or DEFAULT [DEFAULT=2.0]
65 DEFAULT Mod_Projection Switch to select how the wake plane velocity is projected in AWAE (switch) {1: keep all components, 2: project a
66 --- WAKE-ADDED TURBULENCE ---
67 2 WAT Switch between WAT and WAT_BoxFile
68 "../WAT_MannBoxDB/FFDB_D100_512x512x64.u" WAT_BoxFile
69 512, 512, 64 WAT_NxNyNz Number of vortices in the WAT model
70 5.0, 5.0, 5.0 WAT_DxDyDz Distance between vortices in the WAT model
71 DEFAULT WAT_ScaleBox Flag to scale the WAT model
72 DEFAULT WAT_k_Def Calibrated parameter for the WAT model
73 DEFAULT WAT_k_Grad Calibrated parameter for the WAT model

```

Each turbine needs a set of OpenFAST input files

When using Bladed-style controllers, distinct controllers are required for each turbine

FAST.Farm Input File

```

35 --- WIND TURBINES ---
36 1 NumTurbines ..... Number of wind turbines (-) [≥1] ..... [last 6 columns below used only for Mod_AmbWind=2 on
37 WT_X WT_Y WT_Z WT_FASTInFile ..... X0_High Y0_High Z0_High dX_High dY_High dZ_High
38 (m) (m) (m) (string) ..... (m) (m) (m) (m) (m) (m)
39 (FAST.Farm\MasterModel\FAST\Test18.fst" 525.0 1425.0 5.0 10.0 10.0 10.0
40
41 formulations (switch) {1:Polar, 2:Curl, 3:Cartesian}
42 rotor diameter for wake calculations (m) [≥0.0]
43 the wake plane finite-difference grid (m) [≥0.0]
44 the wake plane finite-difference grid (-) [≥2]
45 nes (-) [≥2]
46 frequency of the low-pass time-filter for the wake advection, deflection, and meandering model [
47 er in the correction for wake deflection defining the horizontal offset at the rotor .....
48 er in the correction for wake deflection defining the horizontal offset at the rotor scaled wi
49 er in the correction for wake deflection defining the horizontal offset ..... scaled wi
50 er in the correction for wake deflection defining the horizontal offset ..... scaled wi
51 er for the near-wake correction (-) [≥1.0 and <2.5] or DEFAULT [DEFAULT=1.8]
52 ers for the influence of ambient turbulence in the eddy viscosity (set of 5 parameters: k, FMI
53 ers for the influence of the shear layer ... in the eddy viscosity (set of 5 parameters: k, FMI
54 ilation model (switch) {1: rotor diameter, 2: velocity based, 3: mass-flux based, 4: momentum-
55 er for wake diameter calculation (-) [≥0.0 and <0.99] or DEFAULT [DEFAULT=0.95] [unused for Mo
56 el for wake meandering (-) (switch) {1: uniform, 2: truncated jinc, 3: windowed jinc} or DEFAU
57 or DEFAULT [DEFAULT=1.9]
58
59 ULT=TRUE]
60
61 DEFAULT=100]
62 n-dimensionalized by rotor diameter (-) [DEFAULT=0.2]
63 select the number of grid points for the filter (switch) {0:
64 n the curled-wake model (-) [≥0] or DEFAULT [DEFAULT=2.0]
65 cted in AWAE (switch) {1: keep all components, 2: project a
66
67 tch) {0: no wake added turbulence, 1: predefined turbulence
68 u-component of the turbulence box (either predefined or use
69 of the WAT_BoxFile (-) [used only if WAT=2, derived value
70 of the WAT_BoxFile (m) [used only if WAT=2, derived value
71 nd unit standard deviation at every node (flag) [DEFAULT=Fa
72 m ..... wake deficit on wake-added turbul
73 velocity gradient of the wake deficit on wake-added turbul

```

High-resolution domain should extend around each wind turbine

High-resolution spatial resolution should be sufficient for turbulent wind excitation

$$DS_{High} \leq c_{max}$$

c_{max} = max chord length

$S = X, Y, \text{ or } Z$

FAST.Farm Input File

```

35 --- WIND TURBINES ---
36 1 NumTurbines Number of wind turbines (-) [>=1] [last 6 columns below used only for Mod_AmbWind=2 or 3]
37 WT_X WT_Y WT_Z WT_FASTInFile X0_High Y0_High Z0_High dX_High dY_High dZ_High
38 (m) (m) (m) (string) (m) (m) (m) (m) (m) (m)
39 605.0 1500.0 0.0 "Y:\Wind\Public\Projects\Projects_F\FAST.Farm\MasterModel\FAST\Test18.fst" 525.0 1425.0 5.0 10.0 10.0 10.0
40 --- WAKE DYNAMICS ---
41 1 Mod_Wake Switch between wake formulations (switch) {1:Polar, 2:Curl, 3:Cartesian}
42 126.0 RotorDiamRef Reference turbine rotor diameter for wake calculations (m) [>0.0]
43 5.0 dr Radial increment of the wake plane finite-difference grid (m) [>0.0]
44 40 NumRadRad Number of radii in the wake plane finite-difference grid (-) [>=2]
45 140 NumPlanes Number of wake planes (-) [>=2]
46 DEFAULT f_c Cutoff (corner) frequency of the low-pass time-filter for the wake advection, deflection, and meandering model
47 DEFAULT C_HwkDfl_0 Calibrated parameter in the correction for wake deflection defining the horizontal offset at the rotor
48 DEFAULT C_HwkDfl_0Y Calibrated parameter in the correction for wake deflection defining the horizontal offset at the rotor scaled wi
49 DEFAULT C_HwkDfl_x Calibrated parameter in the correction for wake deflection defining the horizontal offset scaled wi
50 DEFAULT C_HwkDfl_xY Calibrated parameter in the correction for wake deflection defining the horizontal offset scaled wi
51 DEFAULT C_NearWake Calibrated parameter for the near-wake correction (-) [>1.0 and <2.5] or DEFAULT [DEFAULT=1.8]
52 DEFAULT k_vAmb Calibrated parameters for the influence of ambient turbulence in the eddy viscosity (set of 5 parameters: k, FMI
53 DEFAULT k_vShr Calibrated parameters for the influence of the shear layer in the eddy viscosity (set of 5 parameters: k, FMI
54 DEFAULT Mod_WakeDiam Wake diameter calculation model (switch) {1: rotor diameter, 2: velocity based, 3: mass-flux based, 4: momentum-
55 DEFAULT C_WakeDiam Calibrated parameter for wake diameter calculation (-) [>0.0 and <0.99] or DEFAULT [DEFAULT=0.95] [unused for Mo
56 DEFAULT Mod_Meander Spatial filter model for wake meandering (-) (switch) {1: uniform, 2: truncated jinc, 3: windowed jinc} or DEFAU
57 DEFAULT C_Meander Calibrated parameter for wake meandering (-) [>=1.0] or DEFAULT [DEFAULT=1.9]
58 --- CURLED-WAKE PARAMETERS [only used if Mod_Wake=2 or 3] ---
59 DEFAULT Swirl Flag to include swirl velocities in wake (flag) [DEFAULT=TRUE]
60 DEFAULT k_VortexDecay Vortex decay constant for curl (-) [DEFAULT=0.0001]
61 DEFAULT NumVortices The number of vortices in the curled wake model (-) [DEFAULT=100]
62 DEFAULT sigma_D The width of the vortices in the curled wake model non-dimensionalized by rotor diameter (-) [DEFAULT=0.2]
63 DEFAULT FilterInit Switch to filter the initial wake plane deficit and select the number of grid points for the filter (switch) {0:
64 DEFAULT k_vCurl Calibrated parameter for scaling the eddy viscosity in the curled-wake model (-) [>=0] or DEFAULT [DEFAULT=2.0]
65 DEFAULT Mod_Projection Switch to select how the wake plane velocity is projected in AWAE (switch) {1: keep all components, 2: project a
66 --- WAKE-ADDED TURBULENCE ---
67 2 WAT Switch between wake-added turbulence box options (switch) {0: no wake added turbulence, 1: predefined turbulence
68 "../WAT_MannBoxDB/FFDB_D100_512x512x64.u" WAT_BoxFile Filepath to the file containing the u-component of the turbulence box (either predefined or use
69 512, 512, 64 WAT_NxNyNz Number of
70 5.0, 5.0, 5.0 WAT_DxDyDz Distance between
71 DEFAULT WAT_ScaleBox Flag to scale t
72 DEFAULT WAT_k_Def Calibrated para
73 DEFAULT WAT_k_Grad Calibrated para

```

Mod_Wake – Wake formulation:

1) Polar

2) Curl

3) Cartesian (curl without vortices)

FAST.Farm Input File

```

35 --- WIND TURBINES ---
36 1 NumTurbines Number of wind turbines (-) [≥1] [last 6 columns below used only for Mod_AmbWind=2 on]
37 WT_X WT_Y WT_Z WT_FASTInFile X0_High Y0_High Z0_High dX_High dY_High dZ_High
38 (m) (m) (m) (string) (m) (m) (m) (m) (m) (m)
39 605.0 1500.0 0.0 "Y:\Wind\Public\Projects\Projects_F\FAST.Farm\MasterModel\FAST\Test18.fst" 525.0 1425.0 5.0 10.0 10.0 10.0
40 --- WAKE DYNAMICS ---
41 1 Mod_Wake Switch between wake formulations (switch) {1:Polar, 2:Curl, 3:Cartesian}
42 126.0 RotorDiamRef Reference turbine rotor diameter for wake calculations (m) [≥0.0]
43 5.0 dr Radial increment
44 40 NumRadii Number of radii
45 140 NumPlanes Number of wake planes
46 DEFAULT f_c Cutoff (corner)
47 DEFAULT C_HwkDfl_0 Calibrated parameter
48 DEFAULT C_HwkDfl_0Y Calibrated parameter
49 DEFAULT C_HwkDfl_x Calibrated parameter
50 DEFAULT C_HwkDfl_xY Calibrated parameter
51 DEFAULT C_NearWake Calibrated parameter
52 DEFAULT k_vAmb Calibrated parameter
53 DEFAULT k_vShr Calibrated parameter
54 DEFAULT Mod_WakeDiam Wake diameter

```

Each wake plane should extend well beyond the rotor and sufficiently resolve the wake deficit

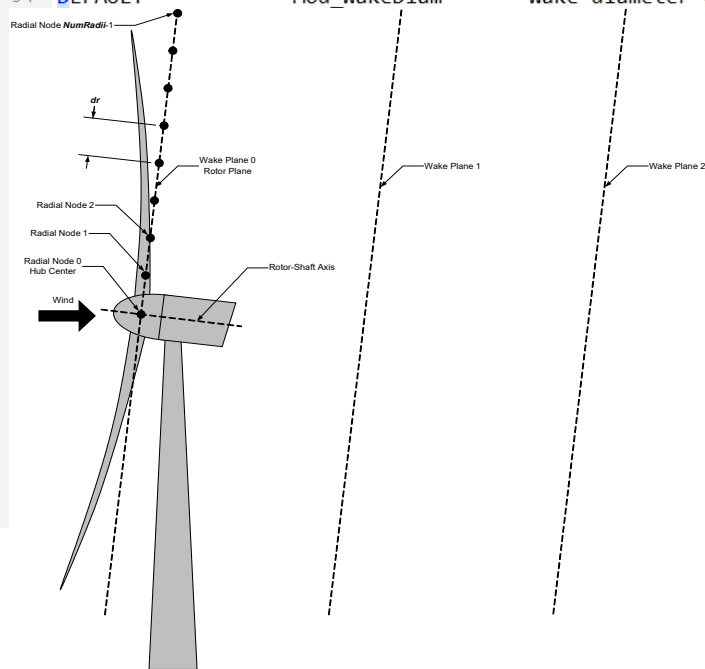
$$dr \leq \frac{D_{Rotor}}{15}$$

$$NumRadii \approx \frac{3D_{Rotor}}{2dr} + 1$$

The wake planes should extend a sufficient distance downstream (so that the wake deficit decays)

$$NumPlanes \geq \frac{XDist_{Low}}{DT_{Low} V_{bar}} = \frac{10XDist_{Low}}{C_{Meander} D_{wake} (1 - \frac{\bar{a}}{2})}$$

$$V_{bar} \approx V_{hub} (1 - \frac{\bar{a}}{2})$$



FAST.Farm Input File

```

35 --- WIND TURBINES ---
36 1 NumTurbines ..... Number of wind turbines (-) [≥1] ..... [last 6 columns below used only for Mod_AmbWind=2 or
37 WT_X WT_Y WT_Z WT_FASTInFile ..... X0_High Y0_High Z0_High dX_High dY_High dZ_High
38 (m) (m) (m) (string) ..... (m) (m) (m) (m) (m) (m)
39 605.0 1500.0 0.0 "Y:\Wind\Public\Projects\Projects_F\FAST.Farm\MasterModel\FAST\Test18.fst" 525.0 1425.0 5.0 10.0 10.0 10.0
40 --- WAKE DYNAMICS ---
41 1 Mod_Wake ..... Switch between wake formulations (switch) {1:Polar, 2:Curl, 3:Cartesian}
42 126.0 RotorDiamRef ..... Reference turbine rotor diameter for wake calculations (m) [≥0.0]
43 5.0 dr ..... Radial increment of the wake plane finite-difference grid (m) [≥0.0]
44 40 NumRadii ..... Number of radii in the wake plane finite-difference grid (-) [≥2]
45 140 NumPlanes ..... Number of wake planes (-) [≥2]
46 DEFAULT f_c ..... Cutoff (corner) frequency of the low-pass time-filter for the wake advection, deflection, and meandering model
47 DEFAULT C_HwkDfl_O ..... Calibrated parameter in the correction for wake deflection defining the horizontal offset at the rotor
48 DEFAULT C_HwkDfl_OY ..... Calibrated parameter in the correction for wake deflection defining the horizontal offset at the rotor scaled wi
49 DEFAULT C_HwkDfl_x ..... Calibrated parameter in the correction for wake deflection defining the horizontal offset ..... scaled wi
50 DEFAULT C_HwkDfl_xY ..... Calibrated parameter in the correction for wake deflection defining the horizontal offset ..... scaled wi
51 DEFAULT C_NearWake ..... Calibrated parameter for the near-wake correction (-) [≥1.0 and <2.5] or DEFAULT [DEFAULT=1.8]
52 DEFAULT k_vAmb ..... Calibrated parameters for the influence of ambient turbulence in the eddy viscosity (set of 5 parameters: k, FMI
53 DEFAULT k_vShr ..... Calibrated parameters for the influence of the shear layer ..... in the eddy viscosity (set of 5 parameters: k, FMI
54 DEFAULT Mod_WakeDiam ..... Wake diameter calculation model (switch) {1: rotor diameter, 2: velocity based, 3: mass-flux based, 4: momentum-
55 DEFAULT C_WakeDiam ..... Calibrated parameter for wake diameter calculation (-) [≥0.0 and <0.99] or DEFAULT [DEFAULT=0.95] [unused for Mo
56 DEFAULT Mod_Meander ..... Spatial filter model for wake meandering (-) (switch) {1: uniform, 2: truncated jinc, 3: windowed jinc} or DEFAUL
57 DEFAULT C_Meander ..... Calibrated parameter for wake meandering (-) [≥1.0] or DEFAULT [DEFAULT=1.9]
58 --- CURLED-WAKE PARAMETERS [only used if Mod_Wake=2 or 3] ---
59 DEFAULT Swirl ..... Flag to include swirl velocities in wake (flag) [DEFAULT=TRUE]
60 DEFAULT k_VortexDecay ..... Vortex decay constant for curl (-) [DEFAULT=0.0001]
61 DEFAULT NumVortices ..... The number of vortices in the curled wake model (-) [DEFAULT=100]
62 DEFAULT sigma_D ..... The width of the vortices in the curled wake model non-dimensionalized by rotor diameter (-) [DEFAULT=0.2]
63 DEFAULT FilterInit ..... Switch to filter the initial wake plane deficit and select the number of grid points for the filter (switch) {0:
64 DEFAULT k_vCurl ..... Calibrated parameter for scaling the eddy viscosity in the curled-wake model (-) [≥0] or DEFAULT [DEFAULT=2.0]
65 DEFAULT Mod_Projection ..... Switch to select how the wake plane velocity is projected in AWAE (switch) {1: keep all components, 2: project a
66 --- WAKE-ADDED TURBULENCE ---
67 2 WAT ..... Switch between wake-added turbulence box options (switch) {0: no wake added turbulence, 1: predefined turbulence
68 "../WAT_MannBoxDB/FFDB_D100_512x512x64.u" WAT_BoxFile ..... Filepath to the file containing the u-component of the turbulence box (either predefined or use
69 512, 512, 64 WAT_NxNyNz ..... Number of ..... points in the x, y, and z directions of the WAT_BoxFile (-) [used only if WAT=2, derived value
70 5.0, 5.0, 5.0 WAT_DxDyDz ..... Distance between points in the x, y, and z directions of the WAT_BoxFile (m) [used only if WAT=2, derived value
71 DEFAULT WAT_ScaleBox ..... Flag to scale t ..... [DEFAULT=Fa
72 DEFAULT WAT_k_Def ..... Calibrated para ..... added turbul
73 DEFAULT WAT_k_Grad ..... Calibrated para ..... added turbul

```

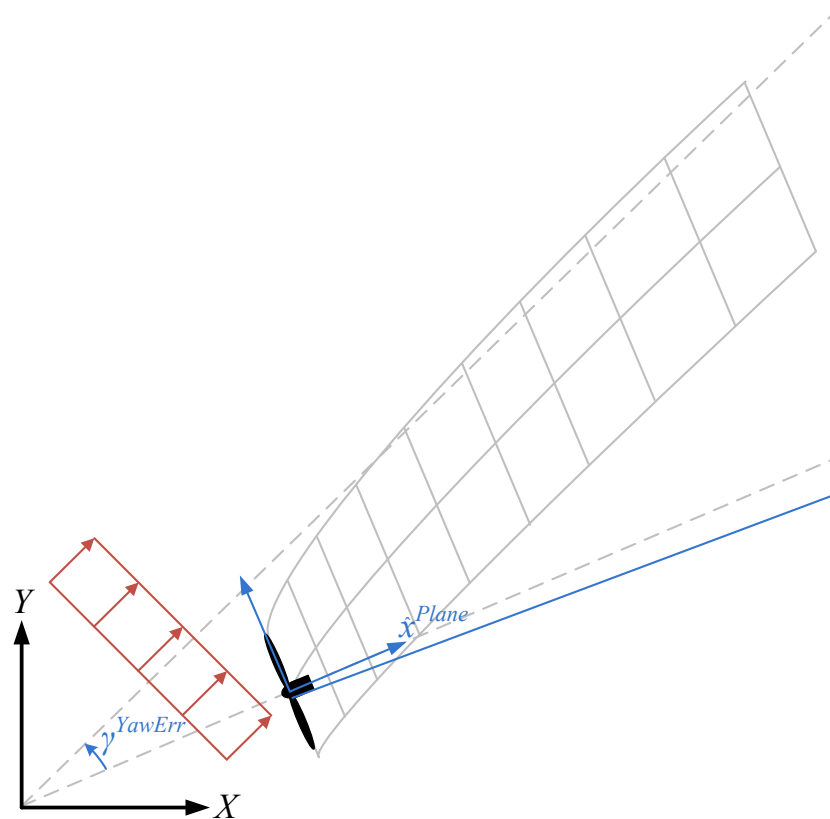
Calibration parameters effecting wake dynamics that could be calibrated better for a given case

FAST.Farm Input File

```

35 --- WIND-TURBINES ---
36 1 ..... NumTurbines ..... Number of wind turbin
37 WT_X WT_Y WT_Z WT_FASTInFile .....
38 (m) (m) (m) (string) .....
39 605.0 1500.0 0.0 "Y:\Wind\Public\Projects\Projects_F\FA
40 --- WAKE DYNAMICS ---
41 1 ..... Mod_Wake ..... Switch between wake f
42 126.0 ..... RotorDiamRef ..... Reference turbine rot
43 5.0 ..... dr ..... Radial increment of t
44 40 ..... NumRadii ..... Number of radii in th
45 140 ..... NumPlanes ..... Number of wake planes
46 DEFAULT ..... f_c ..... Cutoff (corner) frequ
47 DEFAULT ..... C_HwkDfl_0 ..... Calibrated parameter
48 DEFAULT ..... C_HwkDfl_0Y ..... Calibrated parameter
49 DEFAULT ..... C_HwkDfl_x ..... Calibrated parameter
50 DEFAULT ..... C_HwkDfl_xY ..... Calibrated parameter
51 DEFAULT ..... C_NearWake ..... Calibrated parameter
52 DEFAULT ..... k_vAmb ..... Calibrated parameters
53 DEFAULT ..... k_vShr ..... Calibrated parameters
54 DEFAULT ..... Mod_WakeDiam ..... Wake diameter calcula
55 DEFAULT ..... C_WakeDiam ..... Calibrated parameter
56 DEFAULT ..... Mod_Meander ..... Spatial filter model
57 DEFAULT ..... C_Meander ..... Calibrated parameter
58 --- CURLED-WAKE PARAMETERS [only used if Mod_Wake=2 or 3] ---
59 DEFAULT ..... Swirl ..... Flag to include swirl
60 DEFAULT ..... k_VortexDecay ..... Vortex decay constant
61 DEFAULT ..... NumVortices ..... The number of vortice
62 DEFAULT ..... sigma_D ..... The width of the vort
63 DEFAULT ..... FilterInit ..... Switch to filter the
64 DEFAULT ..... k_vCurl ..... Calibrated parameter for scaling the eddy viscosity in the curled-wake model (-) [>=0] or DEFAULT [DEFAULT=2.0]
65 DEFAULT ..... Mod_Projection ..... Switch to select how the wake plane velocity is projected in AWAE (switch) {1: keep all components, 2: project a
66 --- WAKE-ADDED TURBULENCE ---
67 2 ..... WAT ..... Switch between wake-added turbulence box options (switch) {0: no wake added turbulence, 1: predefined turbulence
68 "../WAT_MannBoxDB/FFDB_D100_512x512x64.u" WAT_BoxFile ..... Filepath to the file containing the u-component of the turbulence box (either predefined or use
69 512, 512, 64 ..... WAT_NxNyNz ..... Number of ..... points in the x, y, and z directions of the WAT_BoxFile (-) [used only if WAT=2, derived value
70 5.0, 5.0, 5.0 ..... WAT_DxDyDz ..... Distance between points in the x, y, and z directions of the WAT_BoxFile (m) [used only if WAT=2, derived value
71 DEFAULT ..... WAT_ScaleBox ..... Flag to scale the input turbulence box to zero mean and unit standard deviation at every node (flag) [DEFAULT=Fa
72 DEFAULT ..... WAT_k_Def ..... Calibrated parameters for the influence of the maximum ..... wake deficit on wake-added turbul
73 DEFAULT ..... WAT_k_Grad ..... Calibrated parameters for the influence of the radial velocity gradient of the wake deficit on wake-added turbul

```



r Mod_AmbWind=2 or
 dY_High dZ_High
 (m) (m)
 10.0 10.0

meandering model [
 the rotor
 the rotor scaled wi
 scaled wi
 scaled wi
]
 parameters: k, FMI
 parameters: k, FMI
 based, 4: momentum-
 .95] [unused for Mo
 owed jinc} or DEFAU

DEFAULT=0.2]
 filter (switch) {0:
 filter (switch) {0:

FAST.Farm Input File

Figure 1 is a line plot showing the normalized velocity deficit F (y-axis) versus the normalized distance x/D (x-axis). The y-axis ranges from 0 to 1.2, and the x-axis ranges from 0 to 20. Four curves are plotted:

- F_1 (blue line): Starts at $F \approx 0.2$ for $x/D < 2$, then drops sharply to $F \approx 0$ at $x/D \approx 2$.
- F_2 (red line): Starts at $F \approx 0.05$ for $x/D < 2$, then drops sharply to $F \approx 0$ at $x/D \approx 2$.
- F_{vAmb} (green line): Starts at $F \approx 1.0$ for $x/D < 2$, then decreases gradually to $F \approx 0.9$ at $x/D = 20$.
- F_{vShr} (purple line): Starts at $F \approx 0.2$ for $x/D < 2$, then decreases gradually to $F \approx 0.9$ at $x/D = 20$.

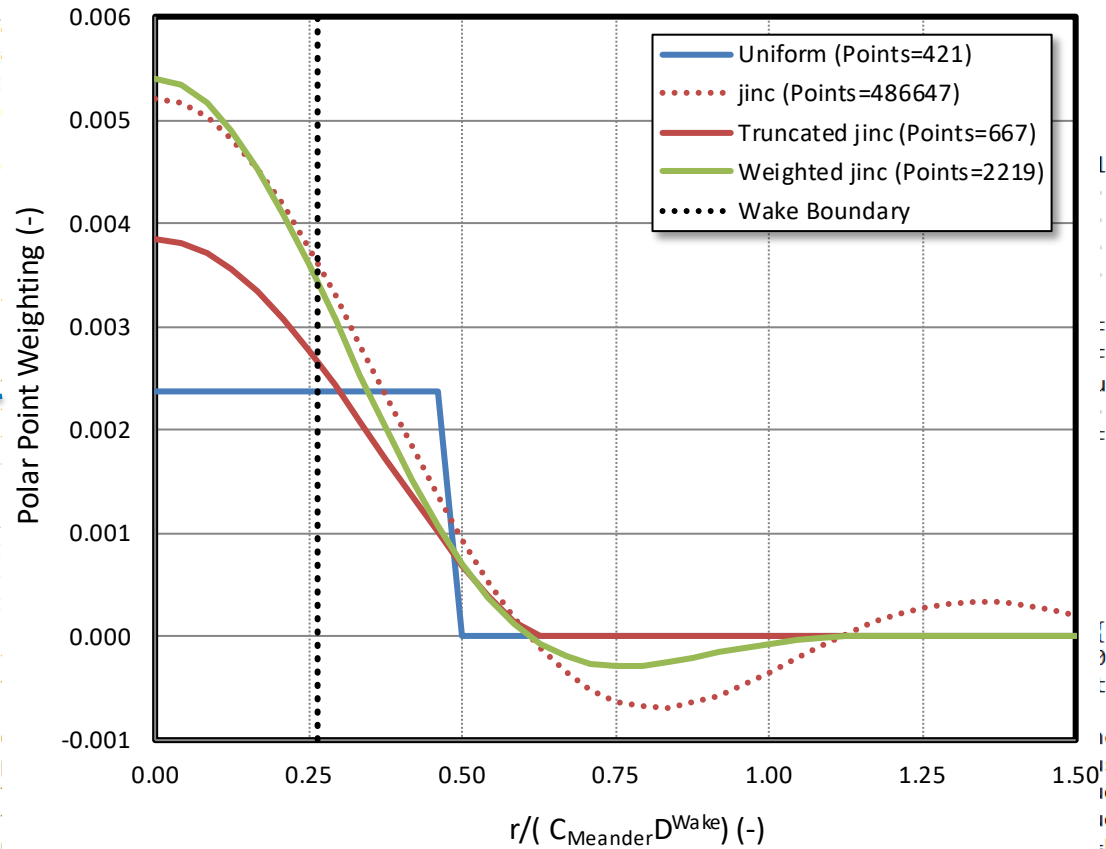
FAST.Farm Input File

```

35 --- WIND TURBINES ---
36 1 NumTurbines Number of wind turbines (-) [≥1] [last 6 columns below used only for Mod_AmbWind=2 or 3]
37 WT_X WT_Y WT_Z WT_FASTInFile X0_High Y0_High Z0_High dX_High dY_High dZ_High
38 (m) (m) (m) (string)
39 605.0 1500.0 0.0 "Y:\Wind\Public\Projects\Projects_F\FA
40 --- WAKE DYNAMICS ---
41 1 Mod_Wake Switch between wake f
42 126.0 RotorDiamRef Reference turbine rot
43 5.0 dr Radial increment of t
44 40 NumRadii Number of radii in th
45 140 NumPlanes Number of wake planes
46 DEFAULT f_c Cutoff (corner) frequ
47 DEFAULT C_HwkDfl_0 Calibrated parameter
48 DEFAULT C_HwkDfl_0Y Calibrated parameter
49 DEFAULT C_HwkDfl_x Calibrated parameter
50 DEFAULT C_HwkDfl_xY Calibrated parameter
51 DEFAULT C_NearWake Calibrated parameter
52 DEFAULT k_vAmb Calibrated parameters
53 DEFAULT k_vShr Calibrated parameters
54 DEFAULT Mod_WakeDiam Wake diameter calcula
55 DEFAULT C_WakeDiam Calibrated parameter
56 DEFAULT Mod_Meander Spatial filter model
57 DEFAULT C_Meander Calibrated parameter
58 --- CURLED-WAKE PARAMETERS [only used if Mod_Wake=2 or 3] ---
59 DEFAULT Swirl Flag to include swirl
60 DEFAULT k_VortexDecay Vortex decay constant
61 DEFAULT NumVortices The number of vortice
62 DEFAULT sigma_D The width of the vort
63 DEFAULT FilterInit Switch to filter the
64 DEFAULT k_vCurl Calibrated parameter
65 DEFAULT Mod_Projection Switch to select how
66 --- WAKE-ADDED TURBULENCE ---
67 2 WAT Switch between wake-a
68 "../WAT_MannBoxDB/FFDB_D100_512x512x64.u" WAT_BoxFile File
69 512, 512, 64 WAT_NxNyNz Number of poin
70 5.0, 5.0, 5.0 WAT_DxDyDz Distance between poin
71 DEFAULT WAT_ScaleBox Flag to scale the input turbulence box to zero mean and unit standard deviation at every node (flag) [optional: Fa
72 DEFAULT WAT_k_Def Calibrated parameters for the influence of the maximum wake deficit on wake-added turbul
73 DEFAULT WAT_k_Grad Calibrated parameters for the influence of the radial velocity gradient of the wake deficit on wake-added turbul

```

Normalized Polar Point Weighting

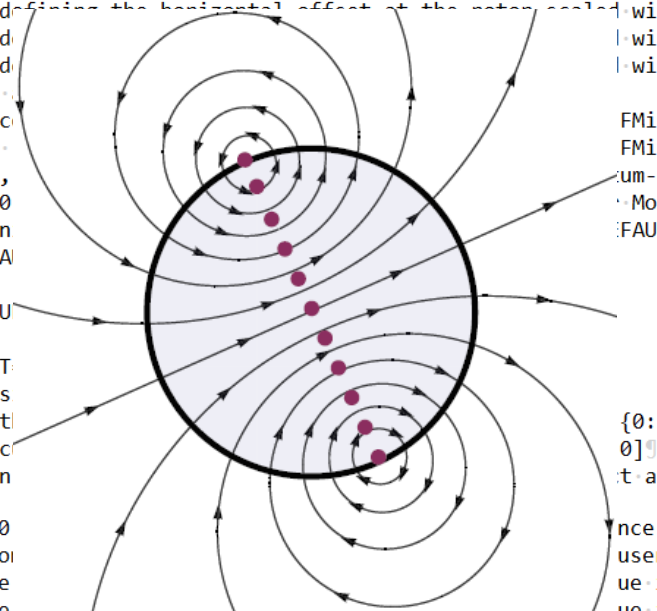


FAST.Farm Input File

```

35 --- WIND TURBINES ---
36 1 NumTurbines Number of wind turbines (-) [>=1] [last 6 columns below used only for Mod_AmbWind=2 or 3]
37 WT_X WT_Y WT_Z WT_FASTInFile X0_High Y0_High Z0_High dX_High dY_High dZ_High
38 (m) (m) (m) (string) (m) (m) (m) (m) (m) (m)
39 605.0 1500.0 0.0 "Y:\Wind\Public\Projects\Projects_F\FAST.Farm\MasterModel\FAST\Test18.fst" 525.0 1425.0 5.0 10.0 10.0 10.0
40 --- WAKE DYNAMICS ---
41 1 Mod_Wake Switch between wake formulations (switch) {1:Polar, 2:Curl, 3:Cartesian}
42 126.0 RotorDiamRef Reference turbine rotor diameter for wake calculations (m) [>0.0]
43 5.0 dr Radial increment of the wake plane finite-difference grid (m) [>0.0]
44 40 NumRadii Number of radii in the wake plane finite-difference grid (-) [>=2]
45 140 NumPlanes Number of wake planes (-) [>=2]
46 DEFAULT f_c Cutoff (corner) frequency of the low-pass time-filter for the wake advection, deflection, and meandering model
47 DEFAULT C_HwkDfl_O Calibrated parameter in the correction for wake deflection defining the horizontal offset at the rotor
48 DEFAULT C_HwkDfl_OY Calibrated parameter in the correction for wake deflection defining the horizontal offset at the rotor
49 DEFAULT C_HwkDfl_x Calibrated parameter in the correction for wake deflection defining the horizontal offset at the rotor
50 DEFAULT C_HwkDfl_xY Calibrated parameter in the correction for wake deflection defining the horizontal offset at the rotor
51 DEFAULT C_NearWake Calibrated parameter for the near-wake correction (-) [>1.0]
52 DEFAULT k_vAmb Calibrated parameters for the influence of ambient turbulence
53 DEFAULT k_vShr Calibrated parameters for the influence of the shear layer
54 DEFAULT Mod_WakeDiam Wake diameter calculation model (switch) {1: rotor diameter,
55 DEFAULT C_WakeDiam Calibrated parameter for wake diameter calculation (-) [>0.0]
56 DEFAULT Mod_Meander Spatial filter model for wake meandering (-) (switch) {1: un
57 DEFAULT C_Meander Calibrated parameter for wake meandering (-) [>=1.0] or DEFA
58 --- CURLED-WAKE PARAMETERS [only used if Mod_Wake=2 or 3] ---
59 DEFAULT Swirl Flag to include swirl velocities in wake (flag) [DEFAULT=TRUE]
60 DEFAULT k_VortexDecay Vortex decay constant for curl (-) [DEFAULT=0.0001]
61 DEFAULT NumVortices The number of vortices in the curled wake model (-) [DEFAULT=
62 DEFAULT sigma_D The width of the vortices in the curled wake model non-dimes
63 DEFAULT FilterInit Switch to filter the initial wake plane deficit and select t
64 DEFAULT k_vCurl Calibrated parameter for scaling the eddy viscosity in the c
65 DEFAULT Mod_Projection Switch to select how the wake plane velocity is projected in
66 --- WAKE-ADDED TURBULENCE ---
67 2 WAT Switch between wake-added turbulence box options (switch) {0
68 "../WAT_MannBoxDB/FFDB_D100_512x512x64.u" WAT_BoxFile Filepath to the file containing the u-compo
69 512, 512, 64 WAT_NxNyNz Number of points in the x, y, and z directions of the
70 5.0, 5.0, 5.0 WAT_DxDyDz Distance between points in the x, y, and z directions of the
71 DEFAULT WAT_ScaleBox Flag to scale the input
72 DEFAULT WAT_k_Def Calibrated parameters f
73 DEFAULT WAT_k_Grad Calibrated parameters f

```



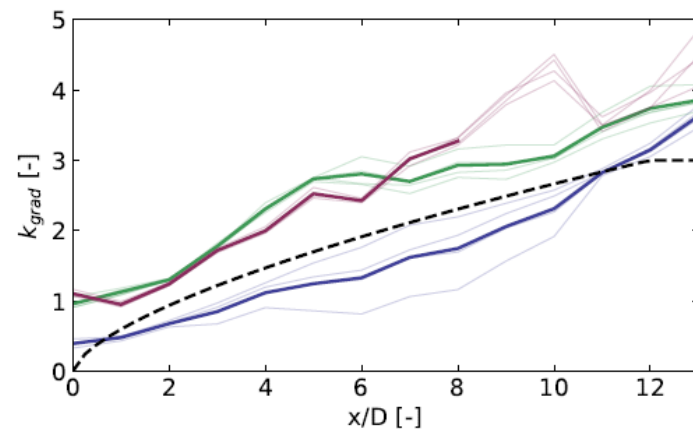
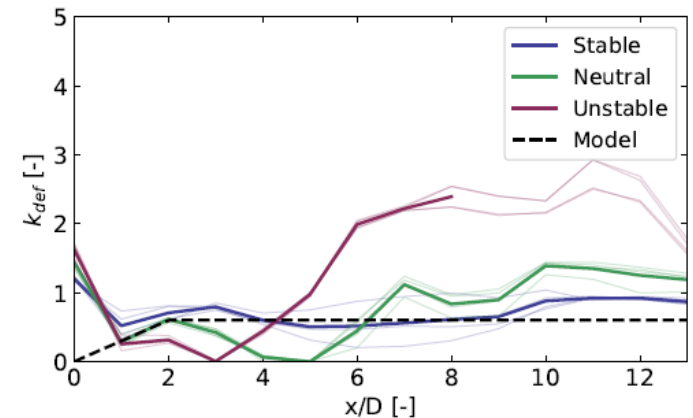
Curled Default curled wake parameters should be OK, although $k_VortexDecay$ and k_vCurl could be calibrated better for a given case

FAST.Farm Input File

```

35 --- WIND TURBINES ---
36 1 NumTurbines Number of wind turbines (-) [≥1]
37 WT_X WT_Y WT_Z WT_FASTInFile
38 (m) (m) (m) (string)
39 605.0 1500.0 0.0 "Y:\Wind\Public\Projects\Projects_F\FAST.Farm\MasterModel\FAST\Test
40 --- WAKE DYNAMICS ---
41 1 Mod_Wake Switch between wake formulations (switch) {1: Polar; 2: Prandtl; 3:
42 126.0 RotorDiamRef Reference turbine rotor diameter for wake calculation (m)
43 5.0 dr Radial increment of the wake plane finite-difference method (m)
44 40 NumRadii Number of radii in the wake plane finite-difference method
45 140 NumPlanes Number of wake planes (-) [≥2]
46 DEFAULT f_c Cutoff (corner) frequency of the low-pass time-filter (Hz)
47 DEFAULT C_HwkDfl_O Calibrated parameter in the correction for wake deflection
48 DEFAULT C_HwkDfl_OY Calibrated parameter in the correction for wake deflection
49 DEFAULT C_HwkDfl_x Calibrated parameter in the correction for wake deflection
50 DEFAULT C_HwkDfl_xY Calibrated parameter in the correction for wake deflection
51 DEFAULT C_NearWake Calibrated parameter for the near-wake correction
52 DEFAULT k_vAmb Calibrated parameters for the influence of ambient turbulence
53 DEFAULT k_vShr Calibrated parameters for the influence of the shear
54 DEFAULT Mod_WakeDiam Wake diameter calculation model (switch) {1: rotor; 2:
55 DEFAULT C_WakeDiam Calibrated parameter for wake diameter calculation
56 DEFAULT Mod_Meander Spatial filter model for wake meandering (-) (switch)
57 DEFAULT C_Meander Calibrated parameter for wake meandering (-) [≥1.0]
58 --- CURLED-WAKE PARAMETERS [only used if Mod_Wake=2 or 3] ---
59 DEFAULT Swirl Flag to include swirl velocities in wake (flag) [DEFAULT=0]
60 DEFAULT k_VortexDecay Vortex decay constant for curl (-) [DEFAULT=0.0001]
61 DEFAULT NumVortices The number of vortices in the curled wake model (-)
62 DEFAULT sigma_D The width of the vortices in the curled wake model (m)
63 DEFAULT FilterInit Switch to filter the initial wake plane deficit and
64 DEFAULT k_vCurl Calibrated parameter for scaling the eddy viscosity
65 DEFAULT Mod_Projection Switch to select how the wake plane velocity is projected
66 --- WAKE-ADDED TURBULENCE ---
67 2 WAT Switch between wake-added turbulence box options (switch) {1: Mann; 2:
68 "../WAT_MannBoxDB/FFDB_D100_512x512x64.u" WAT_BoxFile Filepath to the wake-added
69 512, 512, 64 WAT_NxNyNz Number of points in the wake-added turbulence box
70 5.0, 5.0, 5.0 WAT_DxDyDz Distance between points in the wake-added turbulence
71 DEFAULT WAT_ScaleBox Flag to scale the input box dimensions
72 DEFAULT WAT_k_Def Calibrated parameters for the wake-added turbulence
73 DEFAULT WAT_k_Grad Calibrated parameters for the wake-added turbulence

```



Predefined isotropic wake-added turbulence box should be sufficient for any case
WAT_k_Def and WAT_k_Grad could be calibrated better for a given case

FAST.Farm Input File

```
74 -- VISUALIZATION ---
75 False ..... WrDisWind ..... Write low- and high-resolution disturbed wind data to <RootName>.Low.Dis.t<n>.vtk etc.? (flag)
76 1 ..... NOutDisWindXY ..... Number of XY planes for output of disturbed wind data across the low-resolution domain to <RootName>.Low.DisXY<n>
77 90.0 ..... OutDisWindZ ..... Z coordinates of XY planes for output of disturbed wind data across the low-resolution domain (m) [1 to NOutDisW
78 9 ..... NOutDisWindYZ ..... Number of YZ planes for output of disturbed wind data across the low-resolution domain to <RootName>/Low.DisYZ<n>
79 600.0, 978.0, 1104.0, 1230.0, 1356.0, 1482.0, 1608.0, 1734.0, 1860.0 ..... OutDisWindX ..... X coordinates of YZ planes for output of disturbed wind data
80 1 ..... NOutDisWindXZ ..... Number of XZ planes for output of disturbed wind data across the low-resolution domain to <RootName>/Low.DisXZ<n>
81 1500.0 ..... OutDisWindY ..... Y coordinates of XZ planes for output of disturbed wind data across the low-resolution domain (m) [1 to NOutDisW
82 20.0 ..... WrDisDT ..... Time step for disturbed wind visualization output (s) [>0.0] or DEFAULT [DEFAULT=DT_Low or DT_Low-VTK] [unused f
83 --- OUTPUT ---
84 True ..... SumPrint ..... Print summary data to <RootName>.sum? (flag)
85 99999.9 ..... ChkptTime ..... Amount of time between creating checkpoint files for potential restart (s) [>0.0]
86 200.0 ..... TStart ..... Time to begin tabular output (s) [>=0.0]
87 1 ..... OutFileFmt ..... Format for tabular (time-marching) output file (switch) {1: text file [<RootName>.out], 2: binary file [<RootNam
88 True ..... TabDelim ..... Use tab delimiters in text tabular output file? (flag) {uses spaces if False}
89 "ES10.3E2" ..... OutFmt ..... Format used for text tabular output, excluding the time channel. Resulting field should be 10 characters. (quot
90 DEFAULT ..... OutAllPlanes ..... - Output all wake planes at all time steps. [DEFAULT=False]
91 20 ..... NOutRadii ..... Number of radial nodes ..... for wake output for an individual rotor (-) [0 to 20]
92 0, 1, 2, 3, 4, 5, 7, 9, 11, 13, 15, 16, 17, 18, 19, 21, 24, 28, 33, 39 ..... OutRadii ..... List of radial nodes ..... for wake output for an individ
93 9 ..... NOutDist ..... Number of downstream distances for wake output for an individual rotor (-) [0 to 9]
94 0.0, 378.0, 504.0, 630.0, 756.0, 882.0, 1008.0, 1134.0, 1260.0 ..... OutDist ..... List of downstream distances for wake output for an individ
95 1 ..... NWindVel ..... Number of points for wind output (-) [0 to 9]
96 600.0 ..... WindVelX ..... List of coordinates in the X direction for wind output (m) [1 to NWindVel] [unused for NWindVel=0]
97 1500.0 ..... WindVelY ..... List of coordinates in the Y direction for wind output (m) [1 to NWindVel] [unused for NWindVel=0]
98 90.0 ..... WindVelZ ..... List of coordinates in the Z direction for wind output (m) [1 to NWindVel] [unused for NWindVel=0]
99 ..... OutList ..... The next line(s) contains a list of output parameters. See OutListParameters.xlsx for a listing of available ou
100 "RtAxsXT1", RtAxsYT1", RtAxsZT1"
101 "RtPosXT1", RtPosYT1", RtPosZT1"
102 "YawErrT1"
103 "TIAmbT1"
104 END of input file (the word "END" must appear in the first 3 columns of this last OutList line)
105
```

FAST.Farm Input File

```

74  -- VISUALIZATION ---
75  False ..... WrDisWind ..... Write low- and high-resolution disturbed wind data to <RootName>.Low.Dis.t<n>.vtk etc.? (flag)
76  1 ..... NOutDisWindXY ..... Number of XY planes for output of disturbed wind data across the low-resolution domain to <RootName>.Low.DisXY<n>
77  90.0 ..... OutDisWindZ ..... Z coordinates of XY planes for output of disturbed wind data across the low-resolution domain (m) [1 to NOutDisW
78  9 ..... NOutDisWindYZ ..... Number of YZ planes for output of disturbed wind data across the low-resolution domain to <RootName>/Low.DisYZ<n>
79  600.0, 978.0, 1104.0, 1230.0, 1356.0, 1482.0, 1608.0, 1734.0, 1860.0 ..... OutDisWindX ..... X coordinates of YZ planes for output of disturbed wind data
80  1 ..... NOutDisWindXZ ..... Number of XZ planes for output of disturbed wind data across the low-resolution domain to <RootName>/Low.DisXZ<n>
81  1500.0 ..... OutDisWindY ..... Y coordinates of XZ planes for output of disturbed wind data across the low-resolution domain (m) [1 to NOutDisW
82  20.0 ..... WrDisDT ..... Time step for disturbed wind visualization output (s) [>0.0] or DEFAULT [DEFAULT=DT_Low or DT_Low-VTK] [unused f
83  --- OUTPUT ---
84  True ..... SumPrint ..... Print summary data to <RootName>.sum? (flag)
85  99999.9 ..... ChkptTime ..... Amount of time between creating checkpoint files for potential restart (s) [>0.0]
86  200.0 ..... TStart ..... Time to begin tabular output (s) [>=0.0]
87  1 ..... OutFileFmt ..... Format for tabular (time-marching) output file (switch) {1: text file [<RootName>.out], 2: binary file [<RootNam
88  True ..... TabDelim ..... Use tab delimiters in text tabular output file? (flag) {uses spaces if False}
89  "ES10.3E2" ..... OutFmt ..... Format used for text tabular output, excluding the time channel. Resulting field should be 10 characters. (quot
90  DEFAULT ..... OutAllPlanes ..... Output all wake planes at all time steps. [DEFAULT=False]
91  20 ..... NOutRadii ..... Number of radial nodes ..... for wake output for an individual rotor (-) [0 to 20]
92  0, 1, 2, 3, 4, 5, 7, 9, 11, 13, 15, 16, 17, 18, 19, 21, 24, 28, 33, 39 ..... OutRadii ..... List of radial nodes ..... for wake output for an individ
93  9 ..... NOutDist ..... Number of downstream distances for wake output for an individual rotor (-) [0 to 9]
94  0.0, 378.0, 504.0, 630.0, 756.0, 882.0, 1008.0, 1134.0, 1260.0 ..... OutDist ..... List of downstream distances for wake output for an individ
95  1 ..... NWindVel ..... Number of points for wind output (-) [0 to 9]
96  600.0 ..... WindVelX ..... List of coordinates in the X direction for wind output (m) [1 to NWindVel] [unused for NWindVel=0]
97  1500.0 ..... WindVelY ..... List of coordinates in the Y direction for wind output (m) [1 to NWindVel] [unused for NWindVel=0]
98  90.0 ..... WindVelZ ..... List of coordinates in the Z direction for wind output (m) [1 to NWindVel] [unused for NWindVel=0]
99  ..... OutList ..... The next line(s) contains a list of output parameters. See OutListParameters.xlsx for a listing of available ou
100 "RtAxsXT1", RtAxsYT1", RtAxsZT1"
101 "RtPosXT1", RtPosYT1", RtPosZT1"
102 "YawErrT1"
103 "TIAmbT1"
104 END of input file (the word "END" must appear in the first 3 columns of this last OutList line)
105

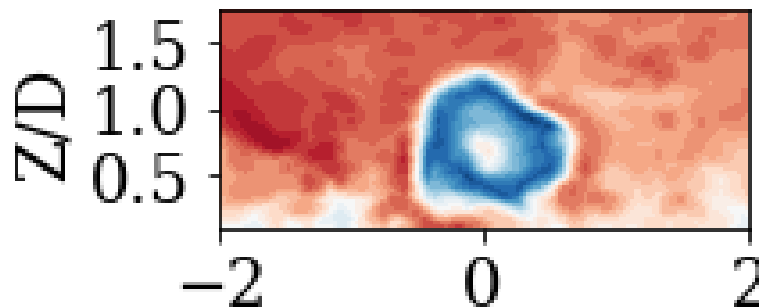
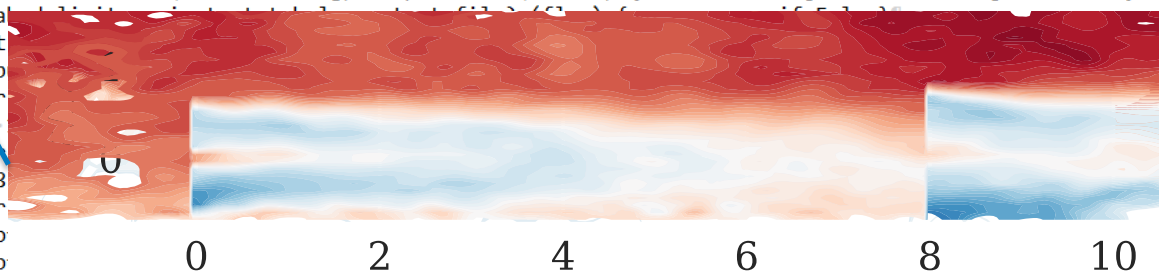
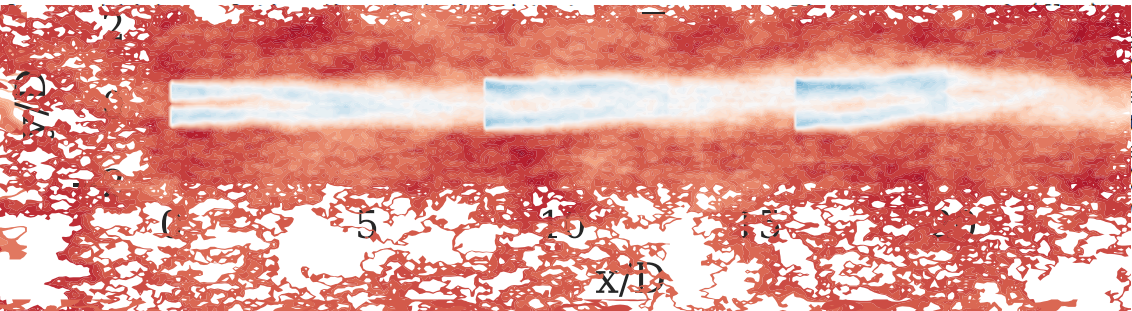
```

Creates a lot of data!

FAST.Farm Input File

```

74  -- VISUALIZATION ---
75  False ..... WrDisWind ..... Writ
76  1 ..... NOutDisWindXY ..... Numb
77  90.0 ..... OutDisWindZ ..... Z co
78  9 ..... NOutDisWindYZ ..... Numb
79  600.0, 978.0, 1104.0, 1230.0, 1356.0, 1482 .....
80  1 ..... NOutDisWindXZ ..... Numb
81  1500.0 ..... OutDisWindY ..... Y co
82  20.0 ..... WrDisDT ..... Time
83  --- OUTPUT ---
84  True ..... SumPrint ..... Prin
85  99999.9 ..... ChkptTime ..... Amou
86  200.0 ..... TStart ..... Time to begin tabular output (s) [>=0.0]
87  1 ..... OutFileFmt ..... Format for tabular (time-marching) output file (switch) {1: text file [<RootName>.out], 2: binary file [<RootName>.out]}
88  True ..... TabDelim ..... Use ta
89  "ES10.3E2" ..... OutFmt ..... Format
90  DEFAULT ..... OutAllPlanes ..... Outp
91  20 ..... NOutRadii ..... Number
92  0, 1, 2, 3, 4, 5, 7, 9, 11, 13, 15, 16, 17 .....
93  9 ..... NOutDist ..... Number
94  0.0, 378.0, 504.0, 630.0, 756.0, 882.0, 1008 .....
95  1 ..... NWindVel ..... Number
96  600.0 ..... WindVelX ..... List o
97  1500.0 ..... WindVelY ..... List o
98  90.0 ..... WindVelZ ..... List o
99  ..... OutList ..... The nex
100  "RtAxsXT1" ..... , RtAxsYT1 ..... , RtAxsZT1 .....
101  "RtPosXT1" ..... , RtPosYT1 ..... , RtPosZT1" .....
102  "YawErrT1" .....
103  "TIAmbT1" .....
104  END of input file (the word "END" must appear
105  ;
  
```



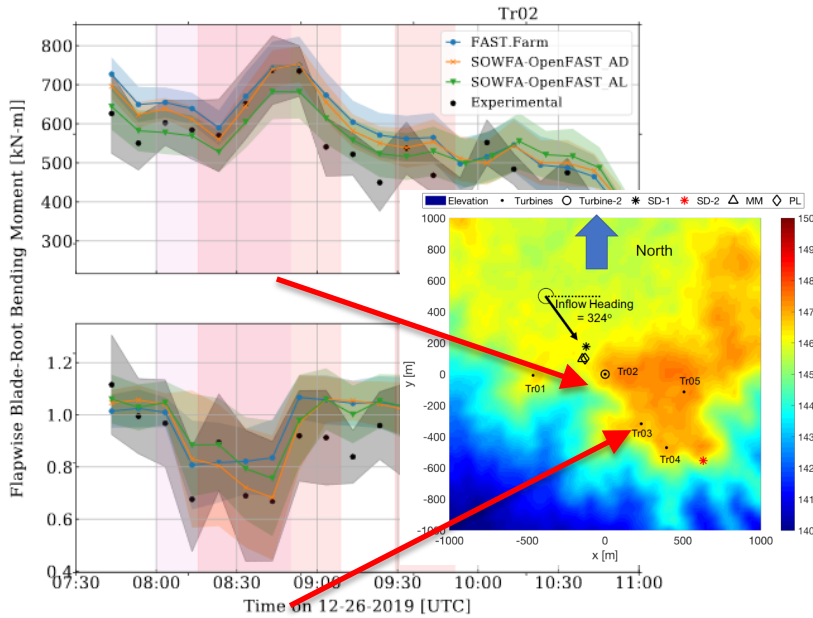
FAST.Farm Input File

```
74 -- VISUALIZATION ---
75 False ..... WrDisWind ..... Write low- and high-resolution disturbed wind data to <RootName>.Low.Dis.t<n>.vtk etc.? (flag)
76 1 ..... NOutDisWindXY ..... Number of XY planes for output of disturbed wind data across the low-resolution domain to <RootName>.Low.DisXY<n>
77 90.0 ..... OutDisWindZ ..... Z coordinates of XY planes for output of disturbed wind data across the low-resolution domain (m) [1 to NOutDisW
78 9 ..... NOutDisWindYZ ..... Number of YZ planes for output of disturbed wind data across the low-resolution domain to <RootName>/Low.DisYZ<n>
79 600.0, 978.0, 1104.0, 1230.0, 1356.0, 1482.0, 1608.0, 1734.0, 1860.0 ..... OutDisWindX ..... X coordinates of YZ planes for output of disturbed wind data
80 1 ..... NOutDisWindXZ ..... Number of XZ planes for output of disturbed wind data across the low-resolution domain to <RootName>/Low.DisXZ<n>
81 1500.0 ..... OutDisWindY ..... Y coordinates of XZ planes for output of disturbed wind data across the low-resolution domain (m) [1 to NOutDisW
82 20.0 ..... WrDisDT ..... Time step for disturbed wind visualization output (s) [>0.0] or DEFAULT [DEFAULT=DT_Low or DT_Low-VTK] [unused f
83 --- OUTPUT ---
84 True ..... SumPrint ..... Print summary data to <RootName>.sum? (flag)
85 99999.9 ..... ChkptTime ..... Amount of time between creating checkpoint files for potential restart (s) [>0.0]
86 200.0 ..... TStart ..... Time to begin tabular output (s) [>=0.0]
87 1 ..... OutFileFmt ..... Format for tabular (time-marching) output file (switch) {1: text file [<RootName>.out], 2: binary file [<RootNam
88 True ..... TabDelim ..... Use tab delimiters in text tabular output file? (flag) {uses spaces if False}
89 "ES10.3E2" ..... OutFmt ..... Format used for text tabular output, excluding the time channel. Resulting field should be 10 characters. (quot
90 DEFAULT ..... OutAllPlanes ..... - Output all wake planes at all time steps. [DEFAULT=False]
91 20 ..... NOutRadii ..... Number of radial nodes ..... for wake output for an individual rotor (-) [0 to 20]
92 0, 1, 2, 3, 4, 5, 7, 9, 11, 13, 15, 16, 17, 18, 19, 21, 24, 28, 33, 39 ..... OutRadii ..... List of radial nodes ..... for wake output for an individ
93 9 ..... NOutDist ..... Number of downstream distances for wake output for an individual rotor (-) [0 to 9]
94 0.0, 378.0, 504.0, 630.0, 756.0, 882.0, 1008.0, 1134.0, 1260.0 ..... OutDist ..... List of downstream distances for wake output for an individ
95 1 ..... NWindVel ..... Number of points for wind output (-) [0 to 9]
96 600.0 ..... WindVelX ..... List of coordinates in the X direction for wind output (m) [1 to NWindVel] [unused for NWindVel=0]
97 1500.0 ..... WindVelY ..... List of coordinates in the Y direction for wind output (m) [1 to NWindVel] [unused for NWindVel=0]
98 90.0 ..... WindVelZ ..... List of coordinates in the Z direction for wind output (m) [1 to NWindVel] [unused for NWindVel=0]
99 ..... OutList ..... The next line(s) contains a list of output parameters. See OutListParameters.xlsx for a listing of available ou
100 "RtAxsXT1", RtAxsYT1", RtAxsZT1"
101 "RtPosXT1", RtPosYT1", RtPosZT1"
102 "YawErrT1"
103 "TIAmbT1"
104 END of input file (the word "END" must appear in the first 3 columns of this last OutList line)
105
```

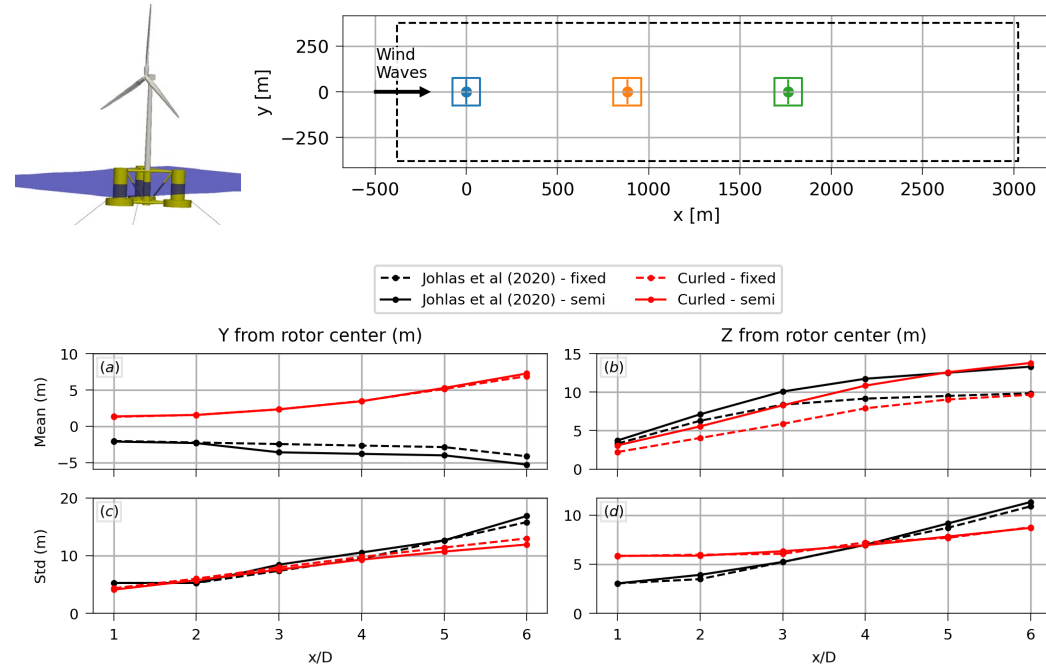
Examples 1-3

Recent FAST.Farm V&V and Applications

Recent/Ongoing FAST.Farm V&V

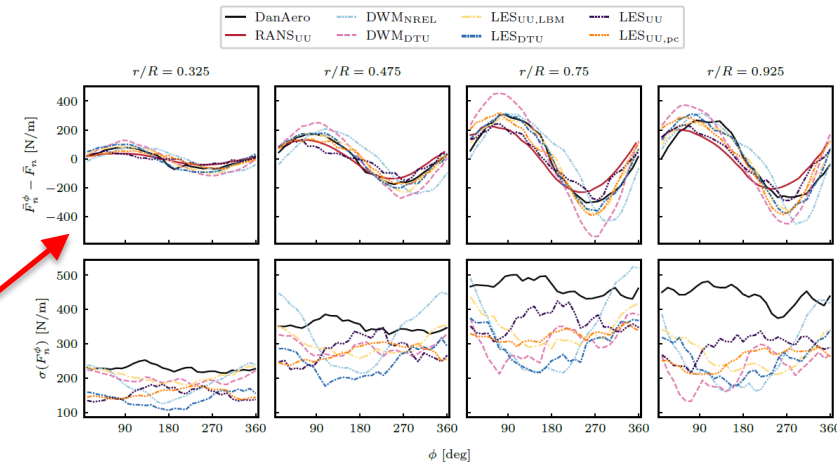
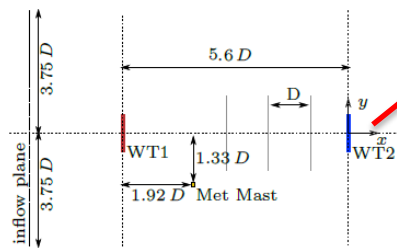
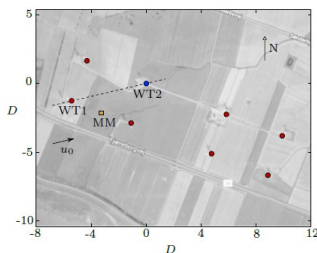


FAST.Farm, SOWFA, and Data Over a Diurnal Evolution with Wake Steering

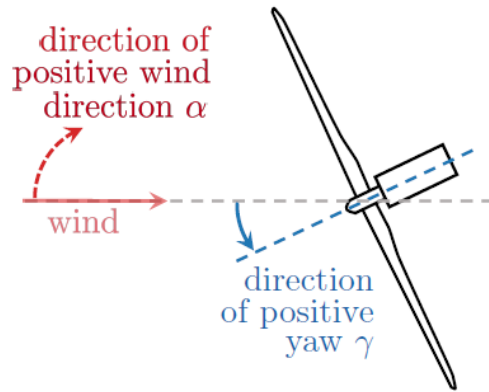


FAST.Farm Versus LES (SOWFA) for FOWT

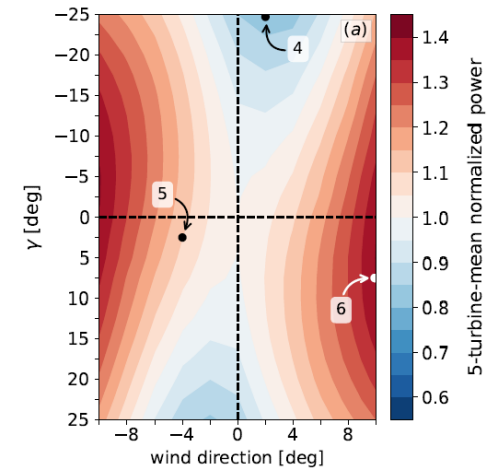
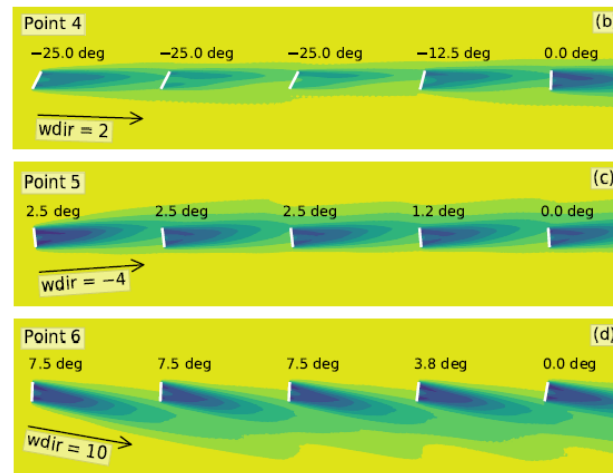
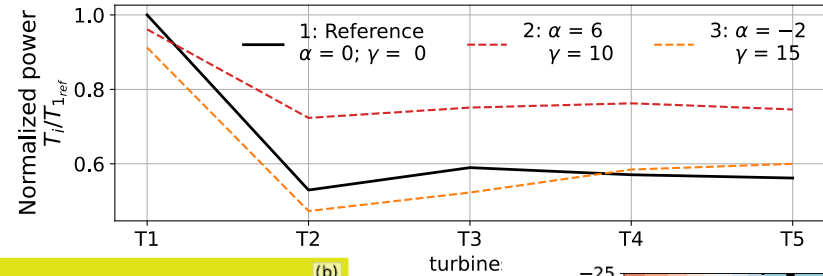
*Waked-Inflow
WP of IEA
Wind Task 29
(DanAero)*



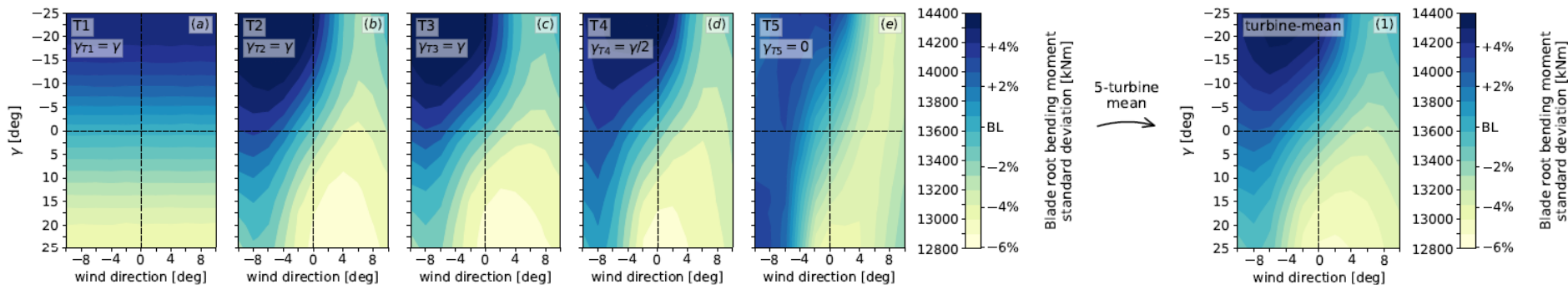
Recent/Ongoing Applications: Impact of Wake Steering on Loads



Yaw and Wind Direction Conventions

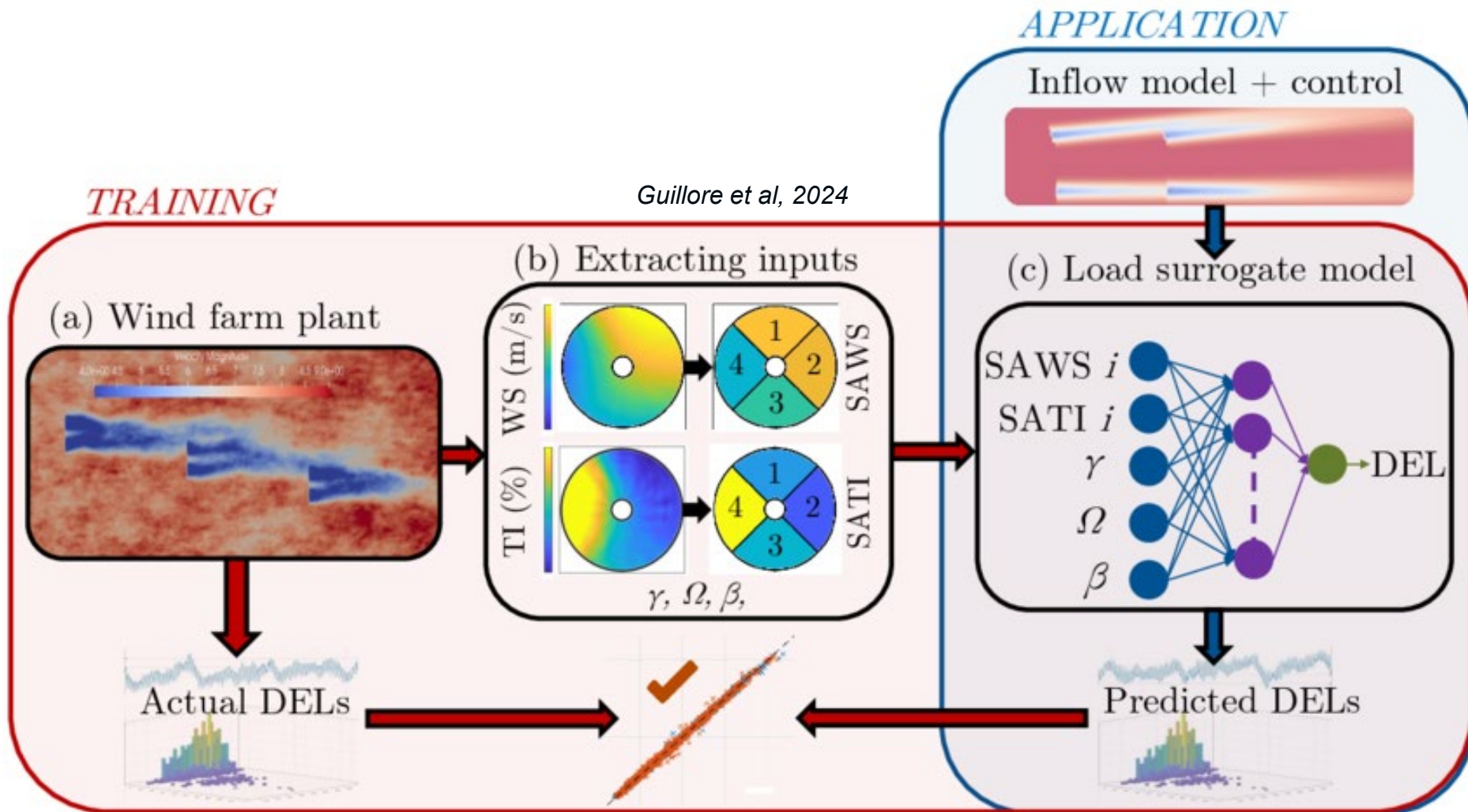


Normalized Power of Each Turbine (Top) and Five-Turbine Mean (Right)

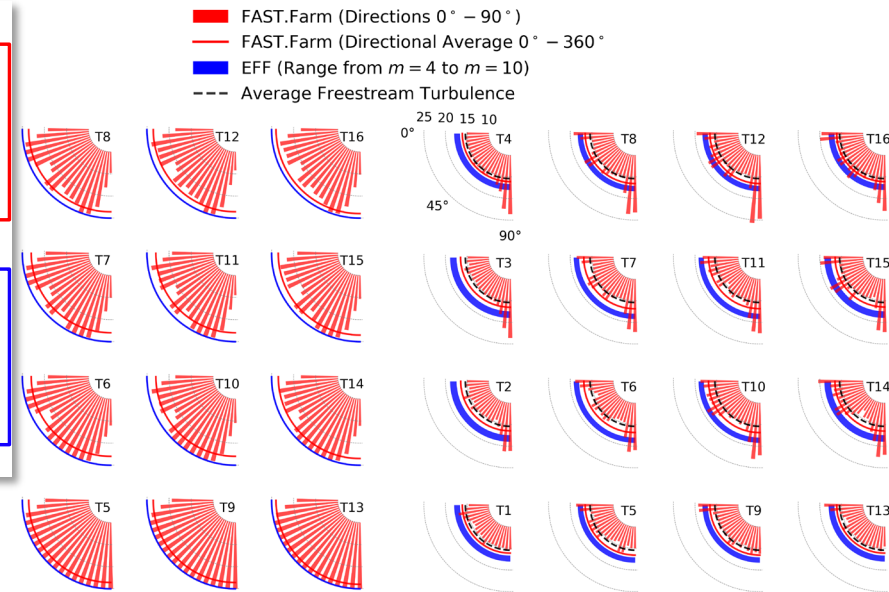
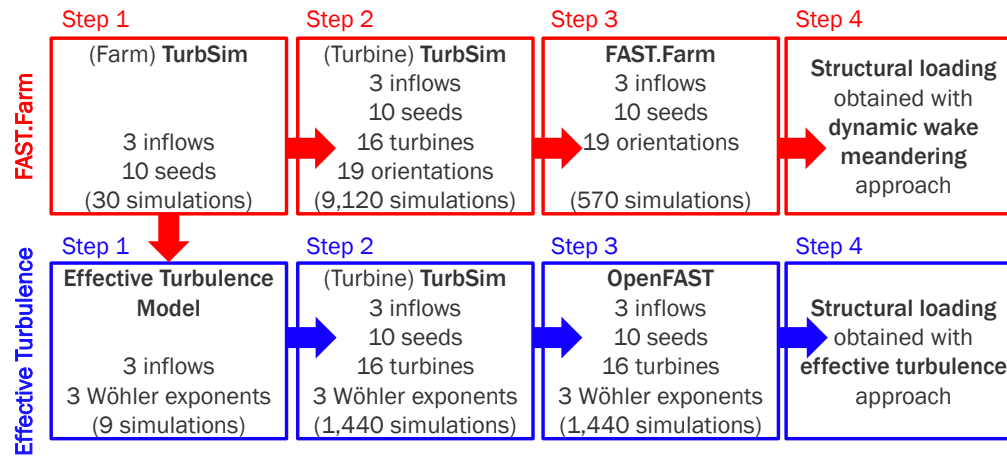


Blade-Root Bending of Each Turbine (Left) and Five-Turbine Mean (Right)

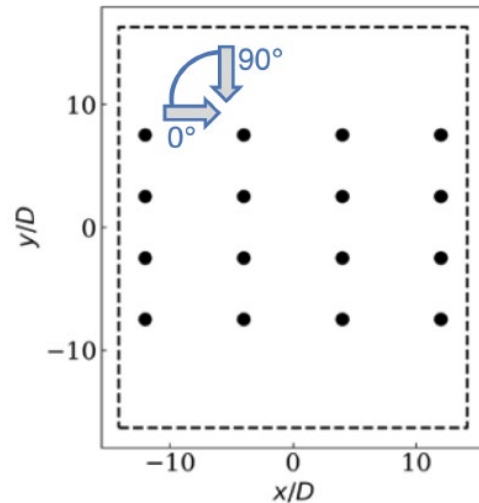
Recent/Ongoing Applications: Use of FAST.Farm for Wake-Loads Surrogate



Difference in Fatigue Assessment Obtained with IEC Effective Turbulence Versus FAST.Farm

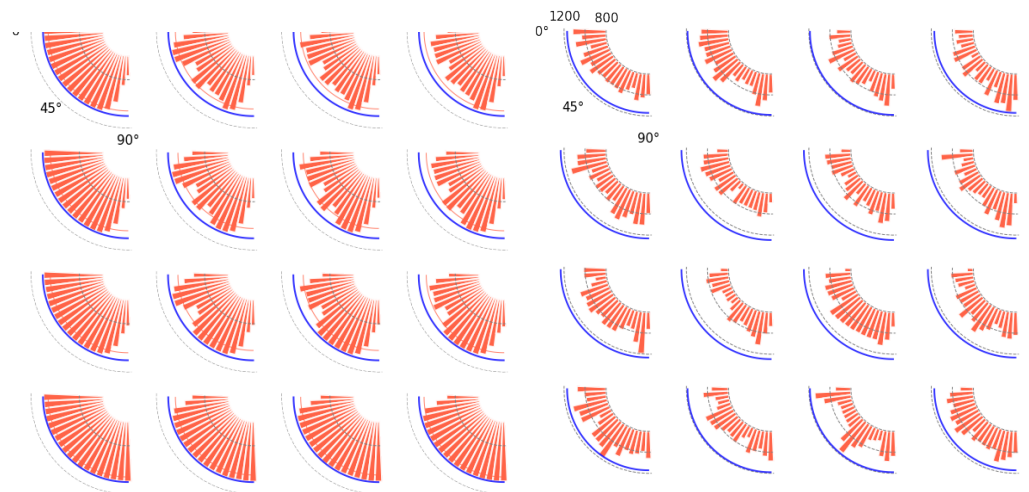


Simulation Approaches – FAST.Farm (Top) and Effective Turbulence (EFF, Bottom)



4x4, 5Dx8D Wind Farm of NREL 5-MW Turbines

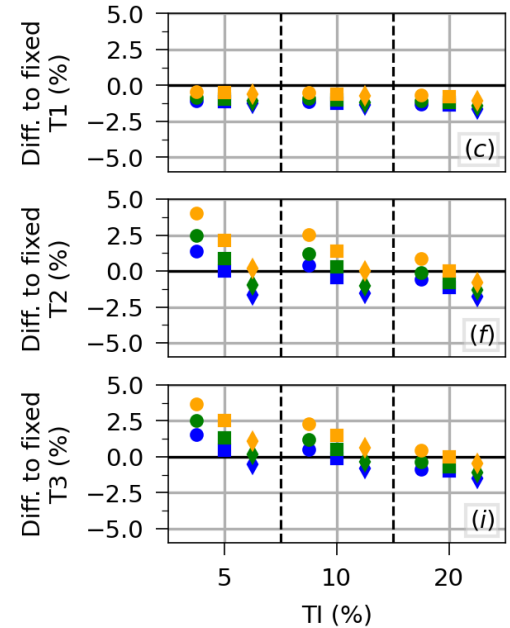
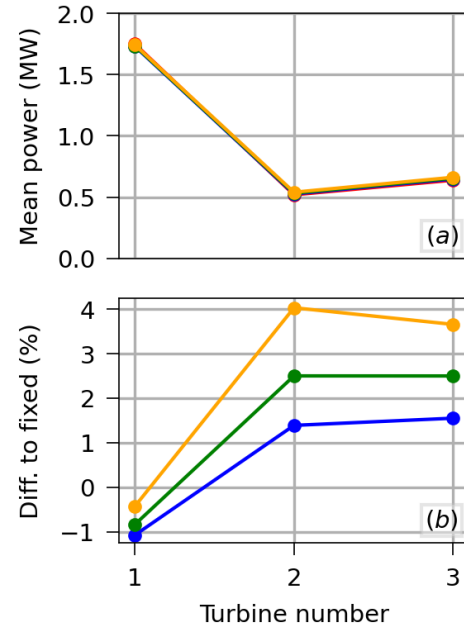
Hub-Height Wind Speed Mean (Left) and TI (Right)



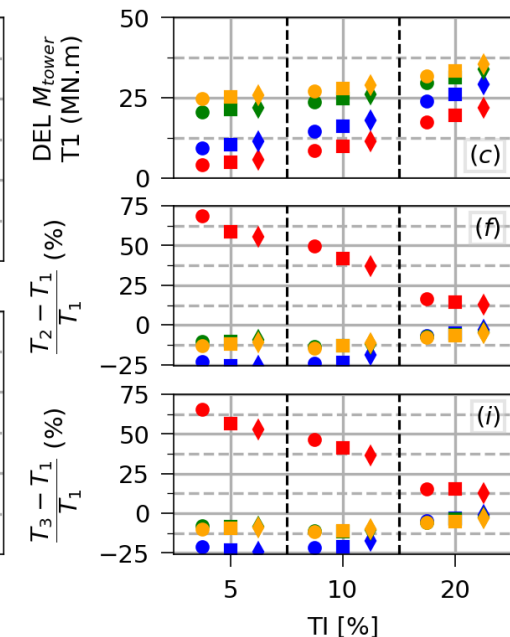
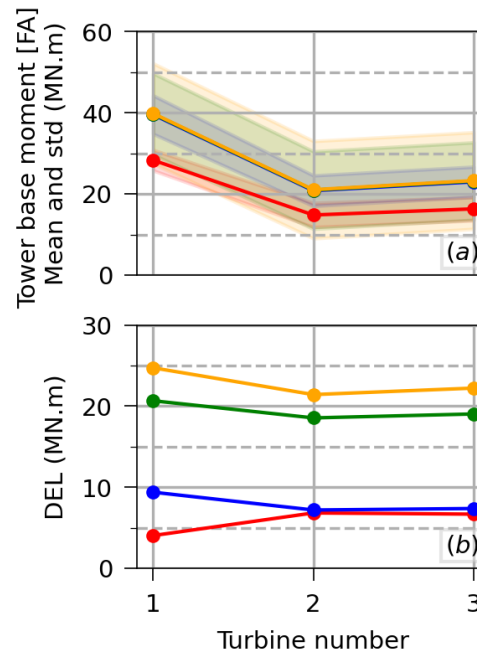
Blade-Root Bending Mean (Left) and Std. (Right)

Use of FAST.Farm for FOWT-Wake Interactions

- FOWT-wake interactions explored for a small farm
- Results dictated by interplay of:
 - Wind and wave-induced floater motion
 - Heel angle of floater
 - Shift of tower natural frequency



Generator Power at 8 m/s



Tower-Base Moment at 8 m/s

Outlook

FAST.Farm Accuracy Gaps

Known Limitations

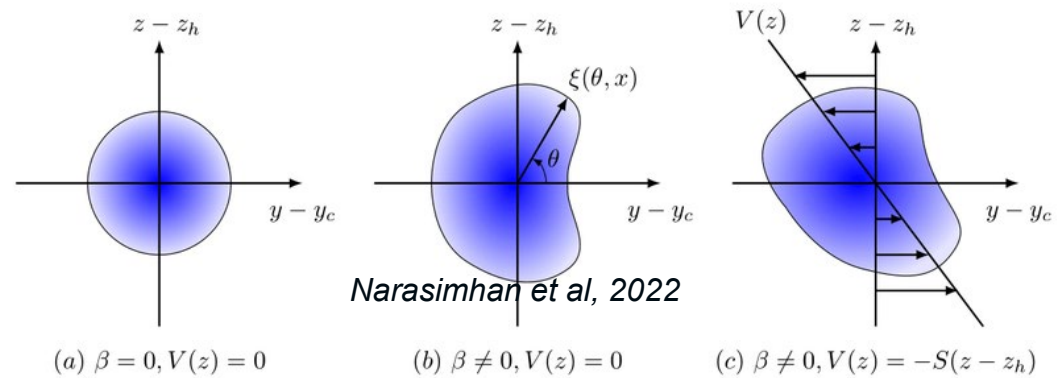
- ✓ High thrust → • High thrust correction
- ✓ Skewed flow → • Curled wake
- ✓ Low ambient turbulence → • Wake-added turbulence
- ❑ High shear and veer → • Ongoing
- ❑ Near wake (<3D) → • Work starting soon
- ❑ Floater-induced wake pulsations
- ❑ Turbulence-induced wake distortion
- ❑ Large wind farm effects (blockage, deep array, gravity waves)

Unknown Limitations

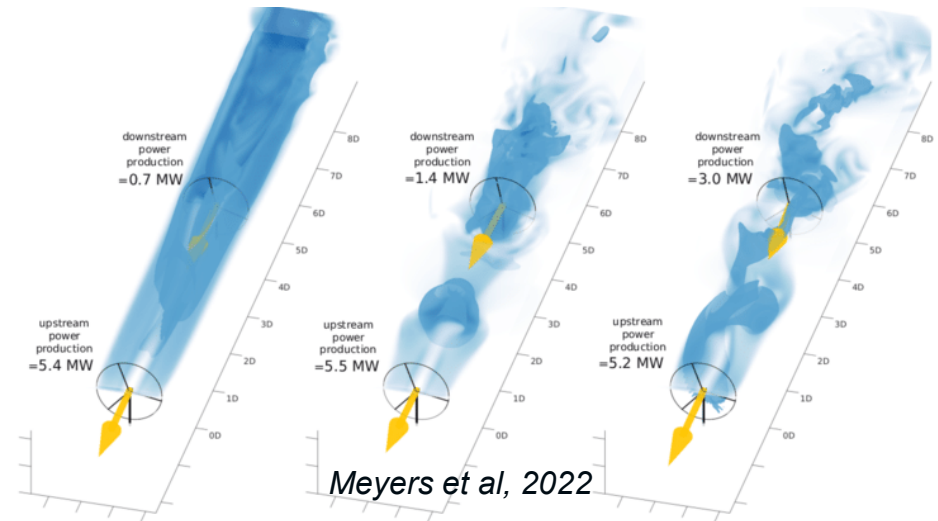
- ❑ Helix-induced wake pulsations
 - ❑ Ground / surface effects
 - ❑ Eddy viscosity dependence
 - ❑ Transient events and gusts
 - ❑ Cluster wakes
- • Future developments and V&V

Future Pathways – Improved Physics

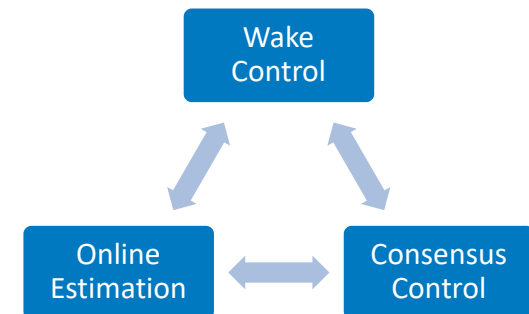
- ✓ Improvements for high shear and veer
- ❑ Ground / surface effects
- ❑ Near-to-far wake transition
- ❑ Turbulence-induced wake distortion
- ❑ Improved eddy-viscosity formulation
- ❑ Improved wake dynamics for FOWT
- ❑ Helix-induced pulsations
- ❑ Improved transient events
- ❑ Wind Farms with different turbines
- ✓ Wave-excitation of shared moorings
- ❑ Large-farm effects (blockage, deep array)
- ❑ Cluster wakes
- ✓ Reference super controller
- ❑ Farm-Level LiDAR



Wakes Without and With Skew and Veer



Baseline, Pulsed, and Helix Wake Control



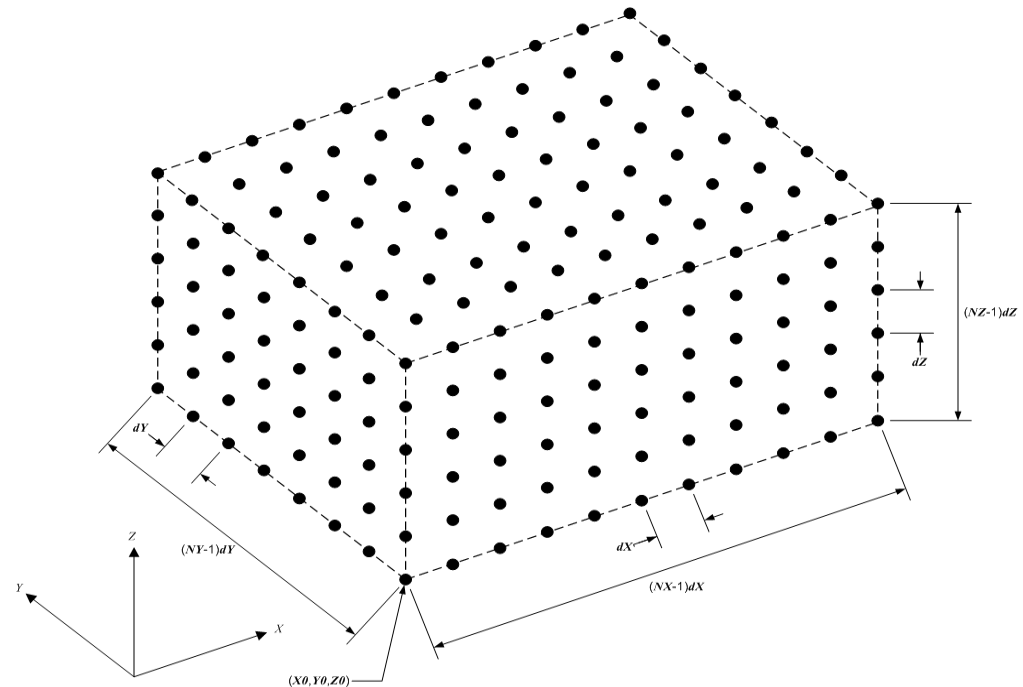
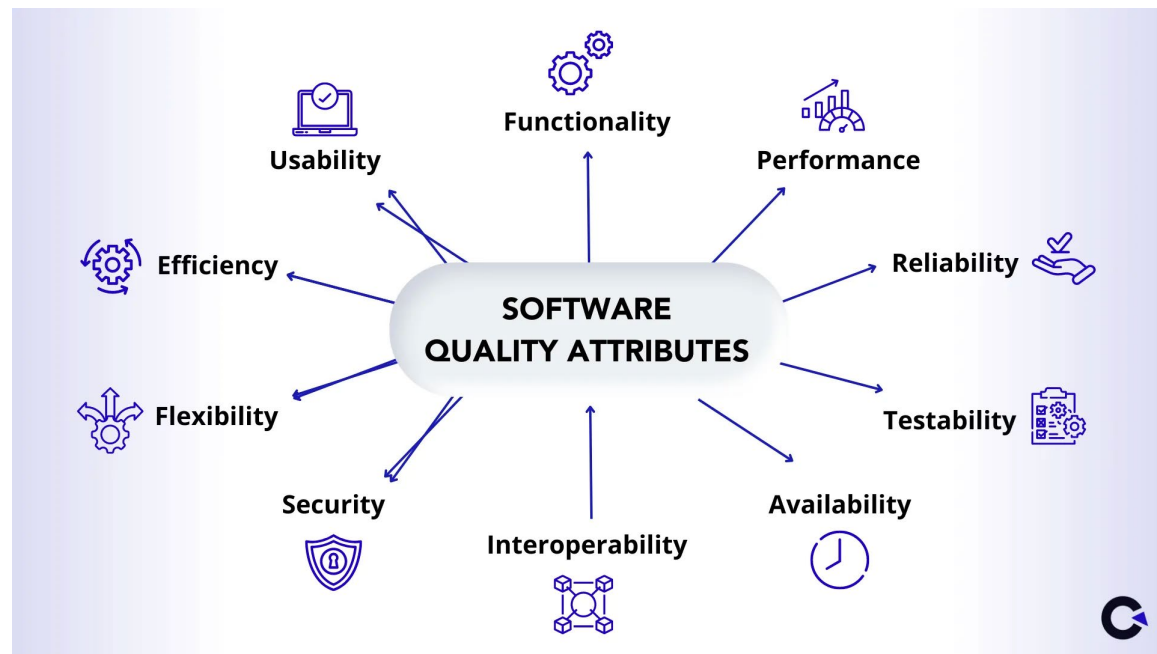
Future Pathways – Computational Efficiency

- ✓ Improve integrator in the curled wake model
- ✓ Partitioned low-resolution domain
- ✓ Ambient wind data in alternative format
- ✓ Regions of wake influence
- ☐ Hybrid inflow generation
- ☐ MPI parallelization



Future Pathways – Usability

- ✓ Develop loads surrogates
- ❑ Decouple hub height from grid in TurbSim
- ❑ Alignment of domains with wind direction
- ❑ Support to shut off specific turbines
- ❑ Overhaul the OpenFAST Toolbox
- ❑ TurbSim/FAST.Farm domain misalignment warnings
- ❑ Spatial-temporal discretization defaults



Carpe Ventum!

Access FAST.Farm @: <https://github.com/OpenFAST>

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www.nrel.gov

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