FAST for Distributed Wind Turbines

SMART Wind Consortium

Mechanical Subgroup Meeting

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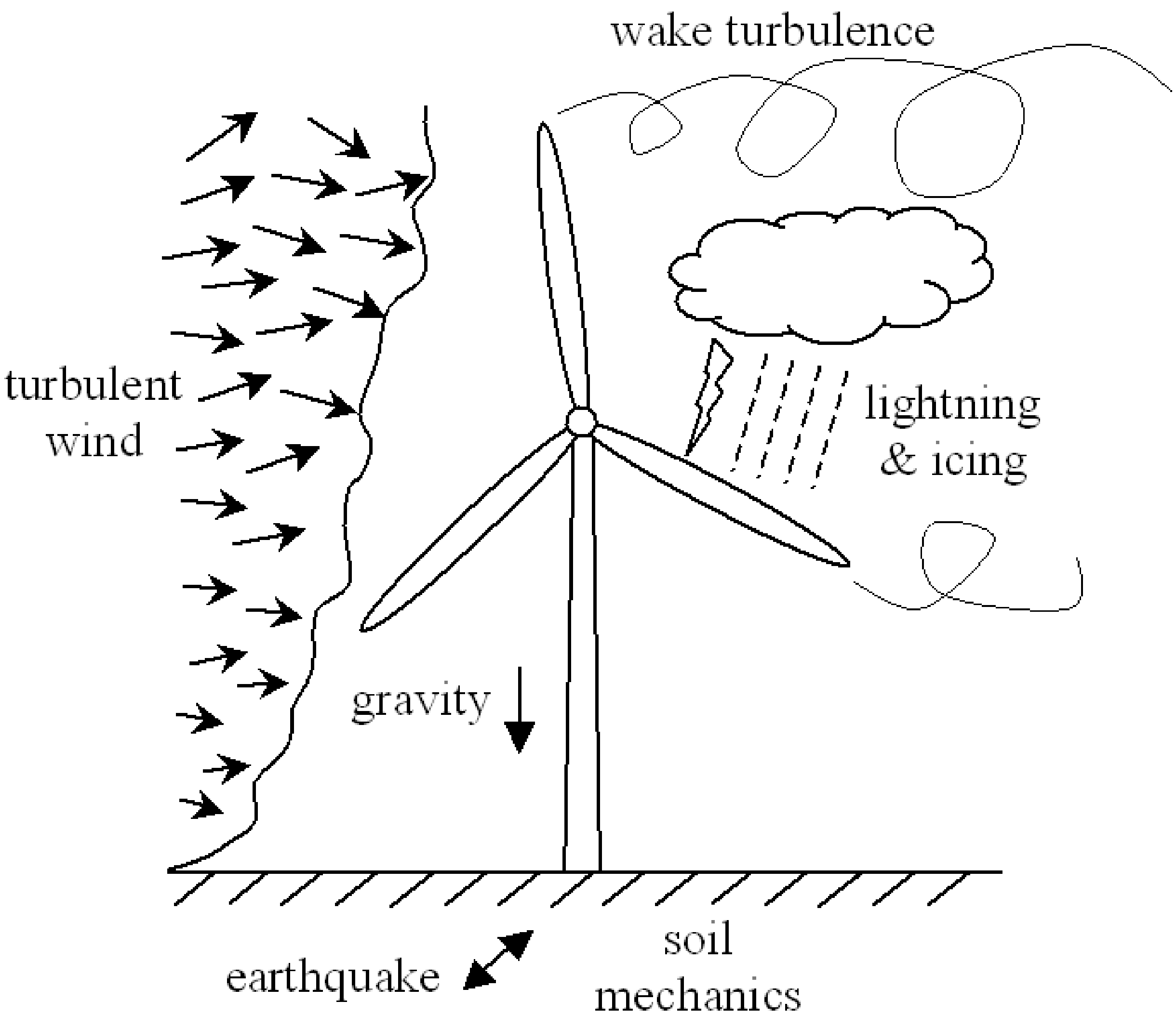
Introduction & Background

Modeling Requirements

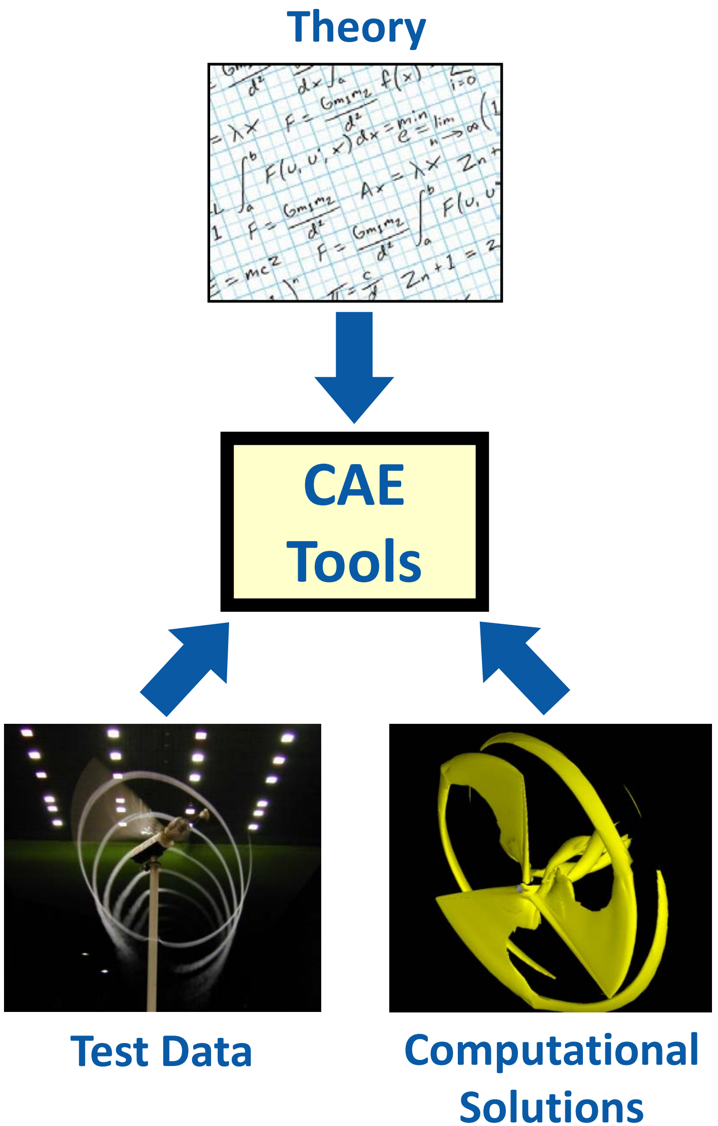


- Coupled aero-servo-elastic interaction
- Wind-inflow:
  - Discrete events
  - Turbulence
- Aerodynamics:
  - Induction
  - Rotational augmentation
  - Skewed wake
  - Dynamic stall
  - Tail vane
- Structural dynamics:
  - Gravity / inertia
  - Elasticity
  - Foundations
- Control system:
  - Yaw, torque, pitch

Introduction & Background

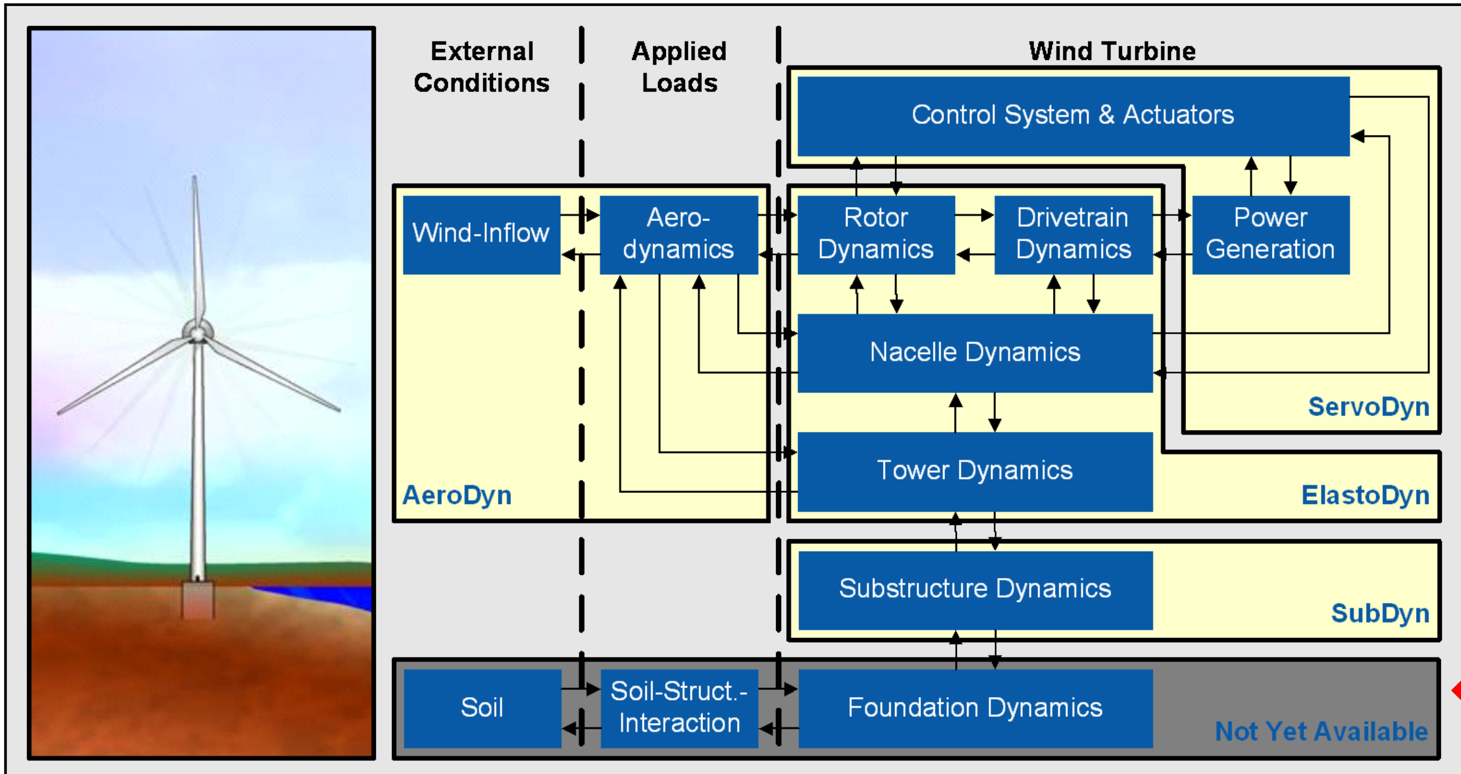
Balance Between Performance & Accuracy

- CAE tools are required for:
  - Conceptual, initial, iterative, & probabilistic design
  - Loads & stability analysis
  - Controls development
  - System-level optimization
  - Development of any new technology innovation
- WT CAE tools are:
  - Nonlinear time-domain multi-physics (aero-hydro-servo-elastic)
  - Capture system-level physics interactions
  - Derived from theory/fundamental laws of physics, with appropriate simplifications & assumptions, & supplemented with computational solutions & test data
  - Not fully predictive, so V&V is fundamental



Introduction & Background

FAST Module Control Volumes – Land-Based



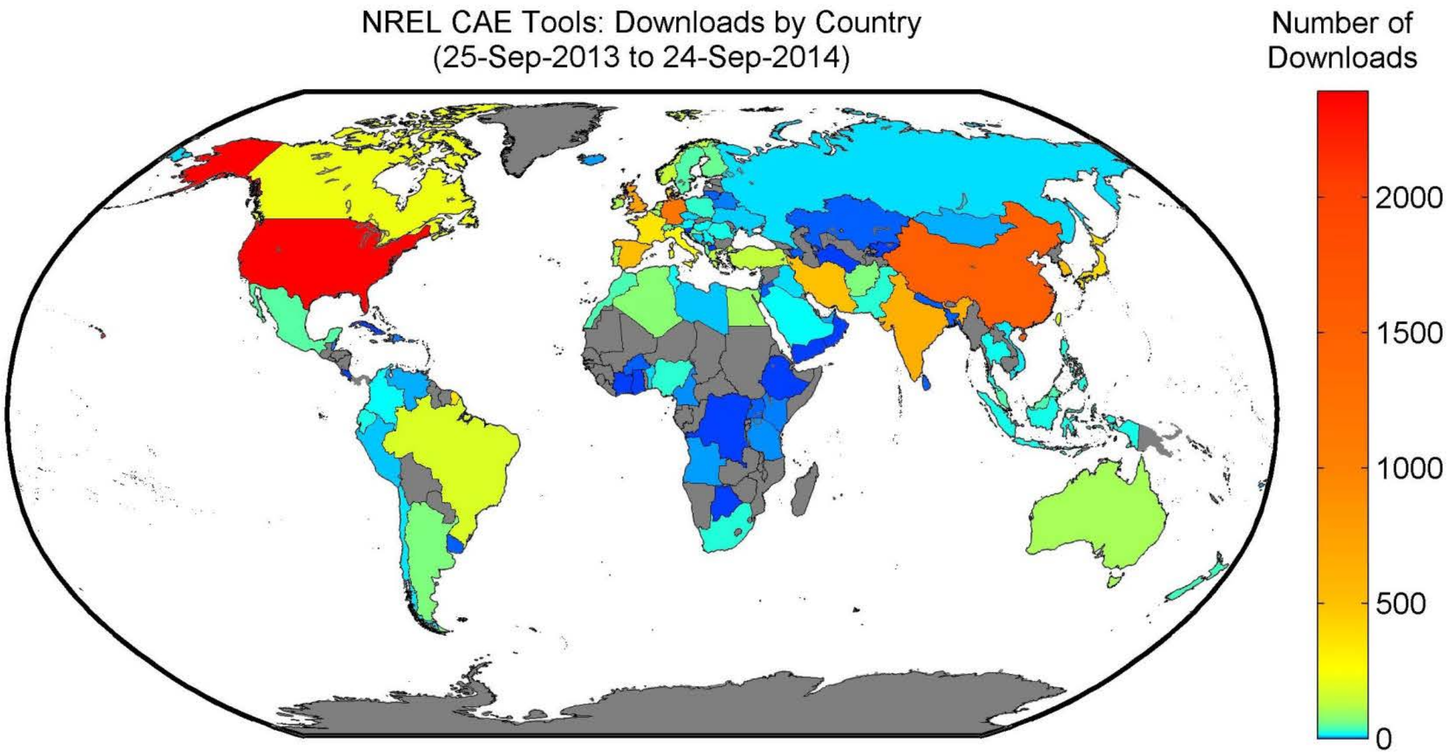
Full-System Level

Component Level

Introduction & Background

Users of NREL-Developed Tools

- Supported by DOE as free, public, open-source products
- Used worldwide by industry, researchers, & academia
- In last 12 months, there have been 12,995 unique downloads by 4,374 users from 1,917 organizations in 114 countries



DWT Challenges & FAST Modeling
What is Furling?

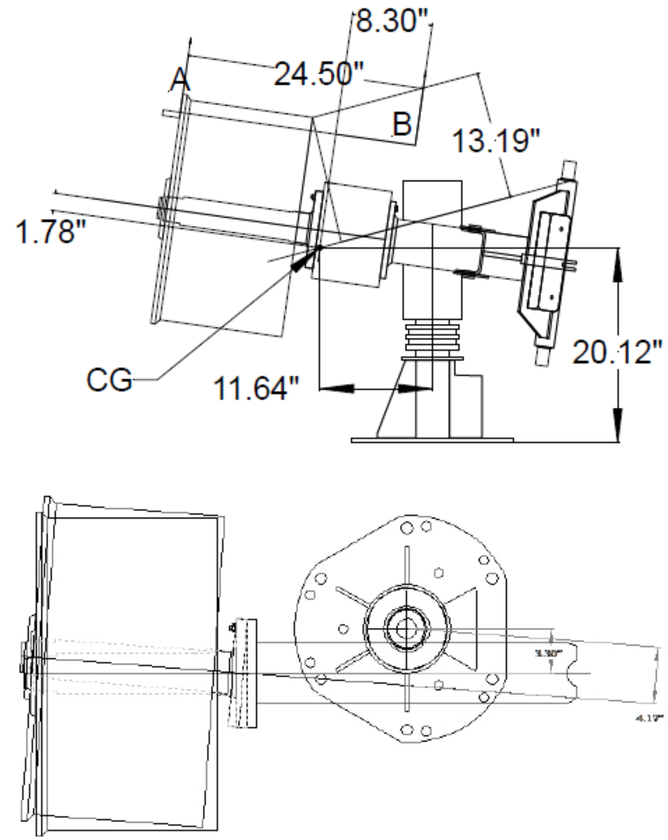
- DWTs often use some form of passive furling control
- Furling is yawing &/or tilting out of the wind to protect against excessive power generation & rotor speeds in high winds
- Furling is achieved by a:
  - Lateral rotor thrust offset from yaw axis
  - Tail vane
  - Furling hinge
- Historically, furling design depended on trial-&-error testing

Whisper H40 by Southwest Windpower

Bergey Excel by Bergey Windpower

DWT Challenges & FAST Modeling
Modeling Challenges of Furling

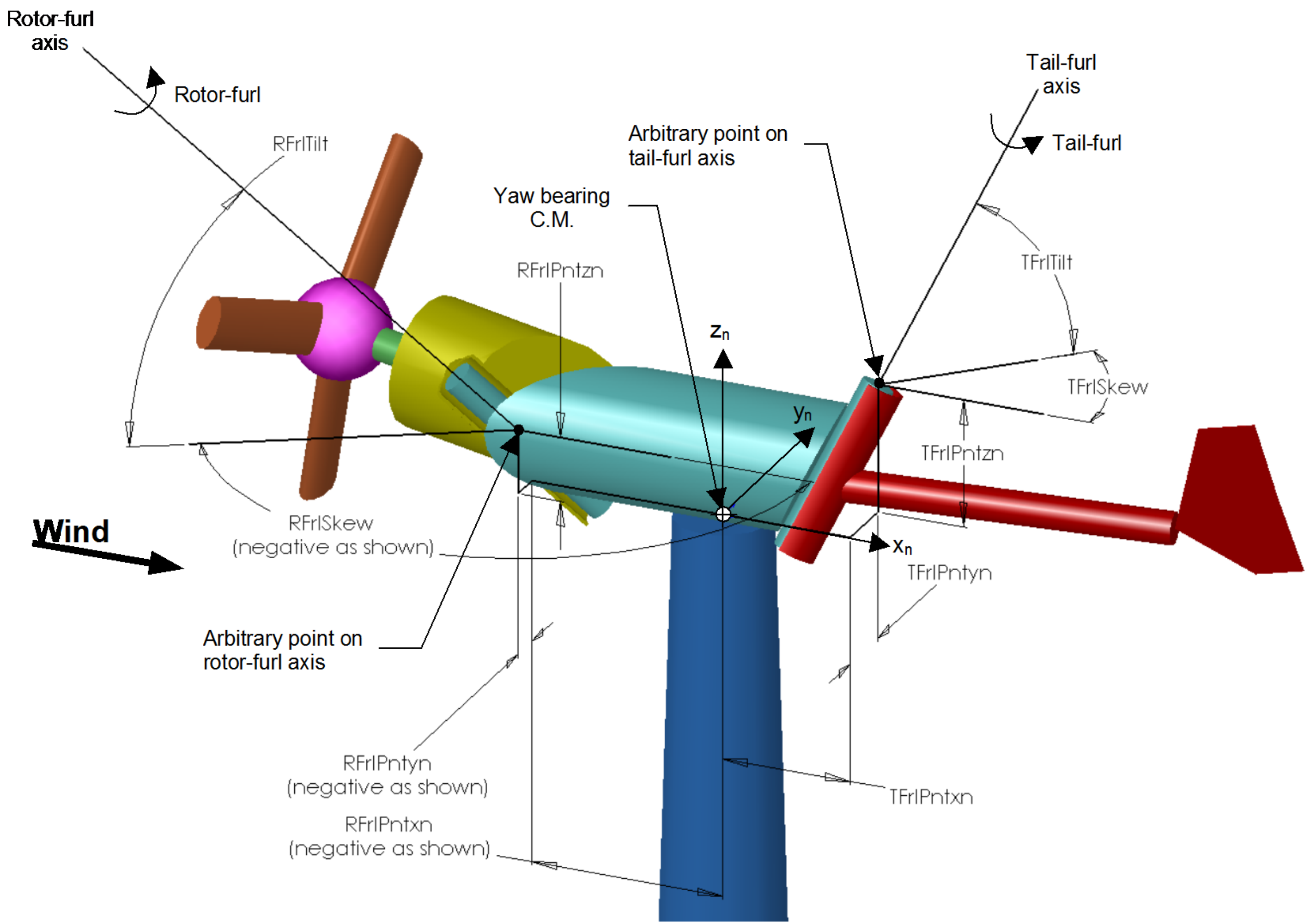
- To enhance design capability, furling functionality added to **FAST** in 2003:
  - Based on recommendations from NWTC Furling Workshop in 2000 & input from DWT community
  - Capability added includes lateral rotor thrust offset; rotor- & tail-furling hinges, springs, dampers, & stops; & tail inertia & aerodynamics
  - **FAST**-to-**ADAMS** capability for furling WTs
  - Capability also useful for non-furling free-yaw turbine with tail vane
- Furling modeling is complicated by effects from:
  - Rotor aerodynamics in highly skewed flow
  - Blade pitch, rotor tilt, & lateral thrust offset
  - Furling hinge configuration & mass balance
  - Tail size, location, & aerodynamic properties
  - Alternator torque characteristics
  - Transient dynamics



Generator, Shaft, & Furl Configuration of the Small Wind Research Turbine (SWRT)

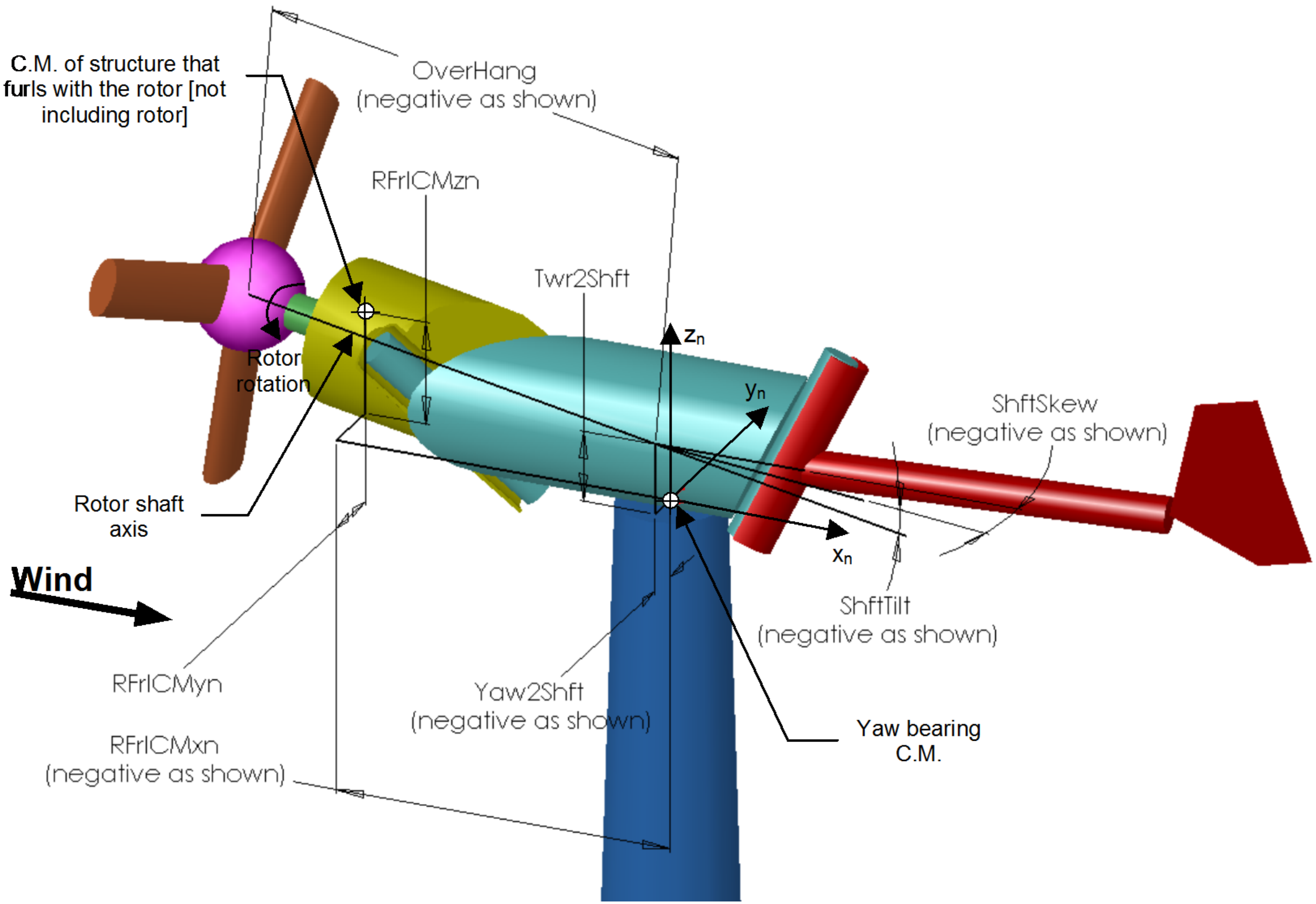
DWT Challenges & FAST Modeling

Furling Capability – Layout of Furl Axes



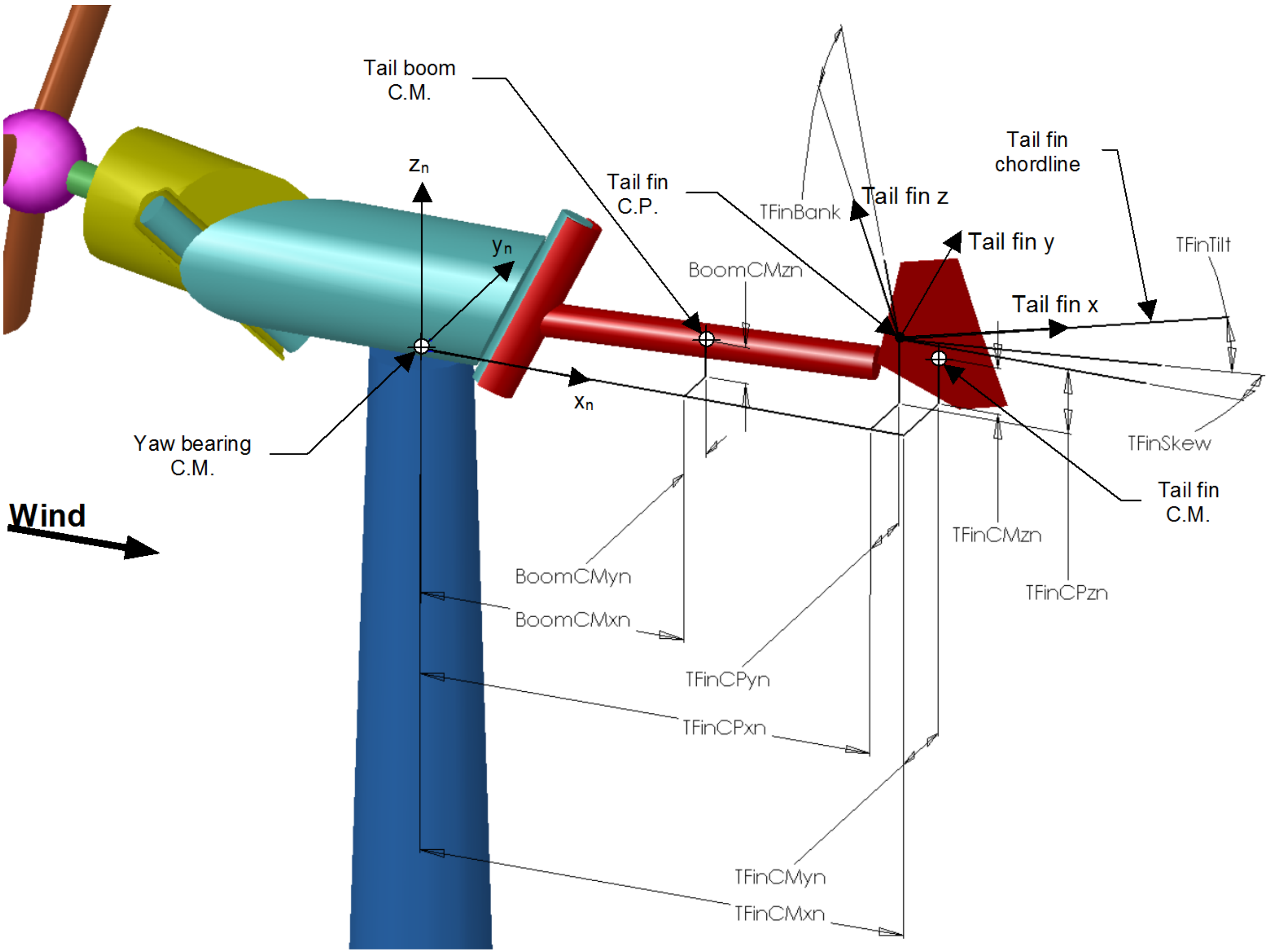
DWT Challenges & FAST Modeling

Furling Capability – Rotor-Furling Properties



DWT Challenges & FAST Modeling

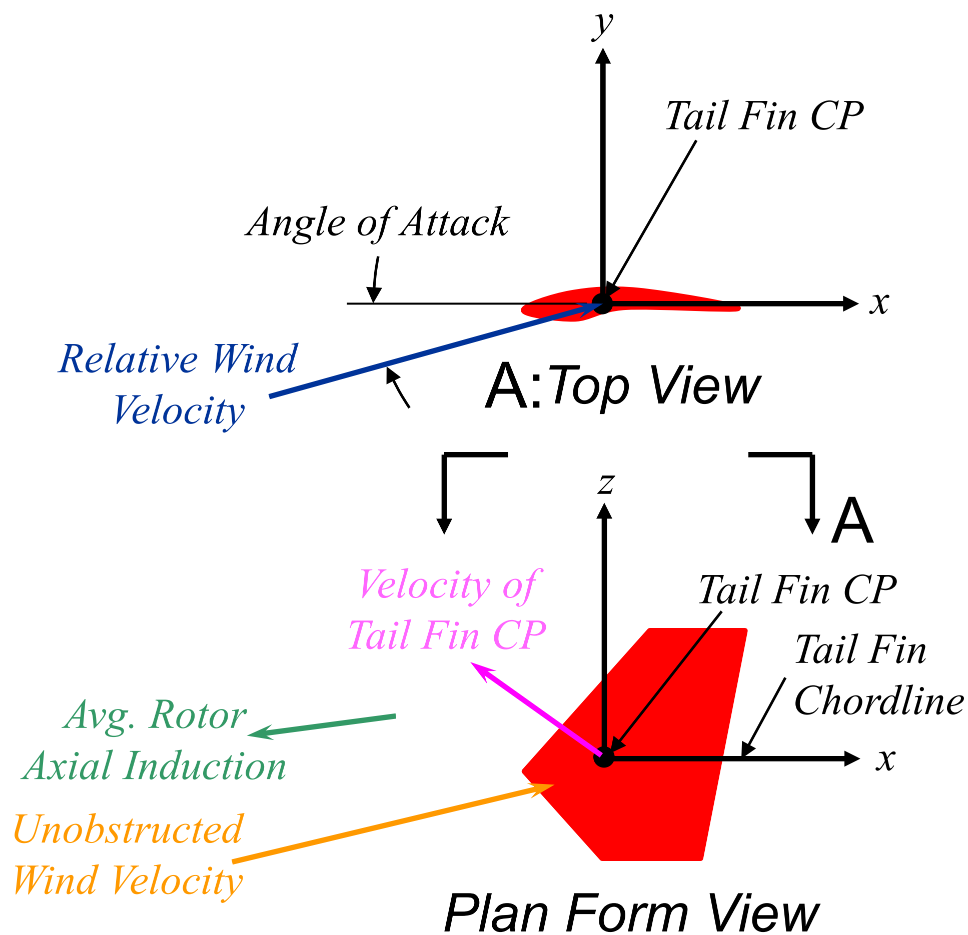
Furling Capability – Tail-Furling Properties



DWT Challenges & FAST Modeling

Furling Capability – Aerodynamics

- Rotor aerodynamics unchanged:
  - Uses **AeroDyn**
- Tail vane aerodynamic loads obtained from simple computed data:
  - Relative wind velocity
  - Angle of attack
  - Airfoil table lookup
  - Local dynamic pressure



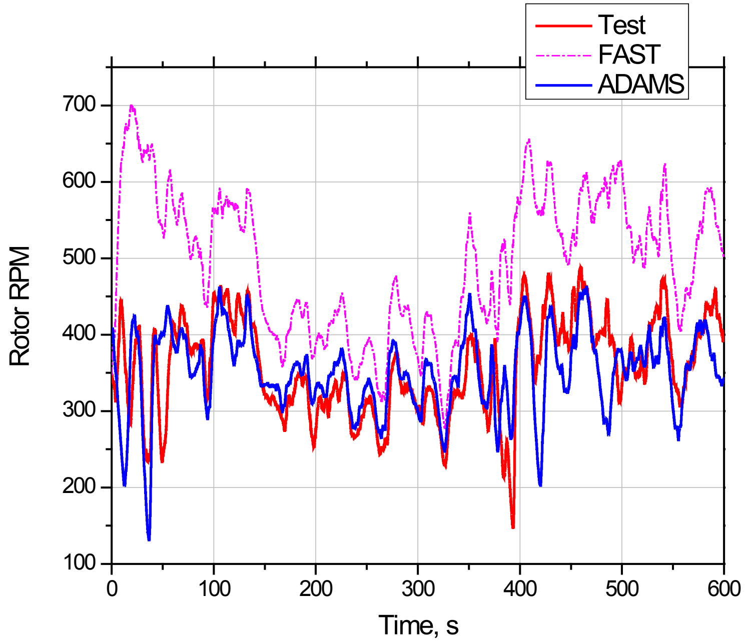
$$
\begin{aligned}
relative\ wind\ velocity = {} & unobstructed\ wind\ velocity\ @\ tail\ \ fin\ CP \\
& - velocity\ of\ \ tail\ \ fin\ CP \\
& - avg.\ rotor\ axial\ induction
\end{aligned}
$$

Optional account of wake

DWT Challenges & FAST Modeling

Verification & Validation

- Verified via comparisons against **MSC.ADAMS**
- Validated against comparisons to SWRT experiment
- Conclusions:
  - Model captures key furling response (mean thrust & yaw)
  - Model misses some values:
    - RPM consistently over-predicted in high winds
    - Peak thrust under-predicted
  - Discrepancies due to:
    - Airfoil data
    - Wake aerodynamics
    - IEC instead of actual turbulence input
    - No blade torsion
    - Difficulty modeling nonlinear components e.g. furl damper



*SWRT in high winds – **ADAMS** has Blade Torsion, **FAST** doesn't*

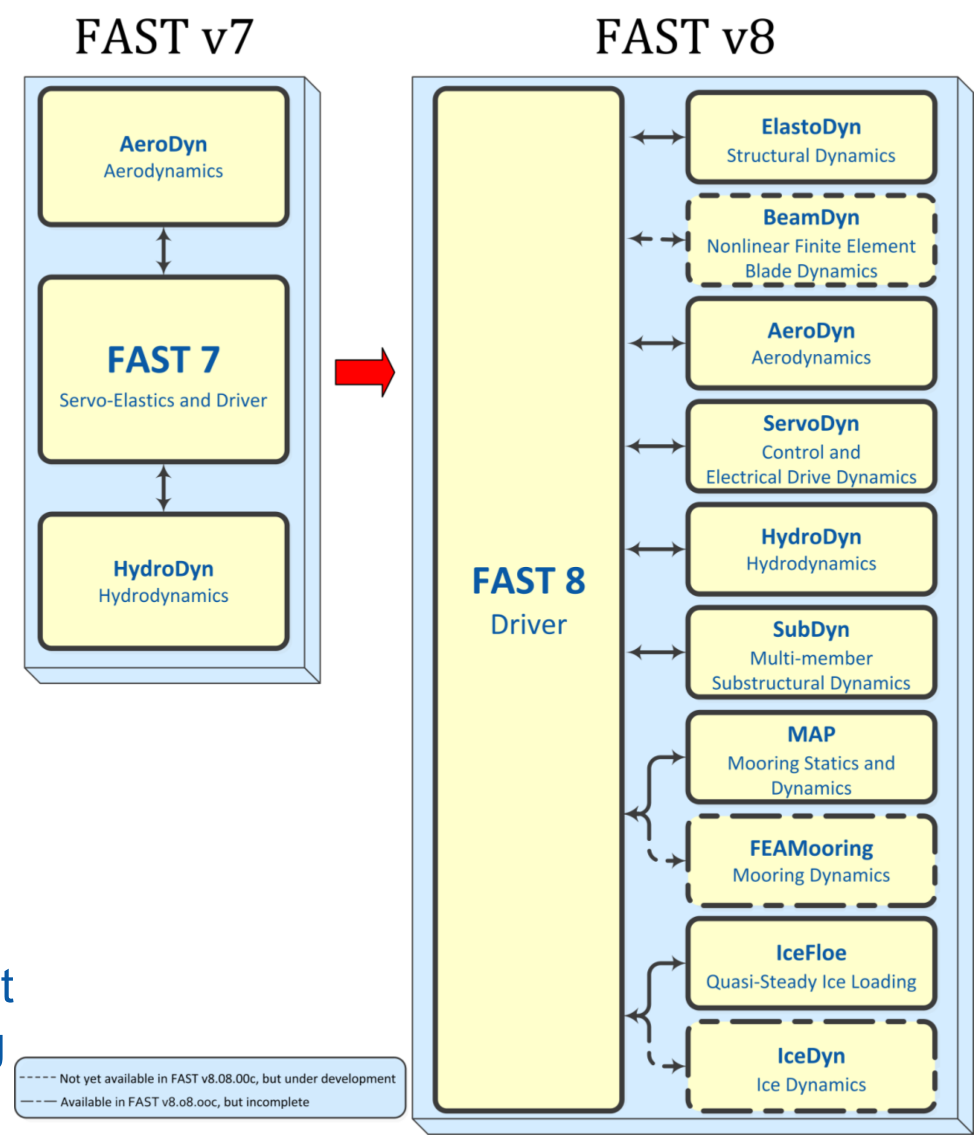
Jonkman, JM & Hansen, AC (2005) "Development and Validation of an Aeroelastic Model of a Small Furling Wind Turbine." *AIAA ASM*, 10–13 January 2005, Reno, NV. AIAA-2005-0970; NREL/CP-500-39589.

Corbus, D; Hansen, AC; & Minnema, J (2006) "Effect of Blade Torsion on Modeling Results for the Small Wind Research Turbine (SWRT)". JSEE, Vol. 128, pp 481-486.

FAST Modularization Framework

Recent Developments

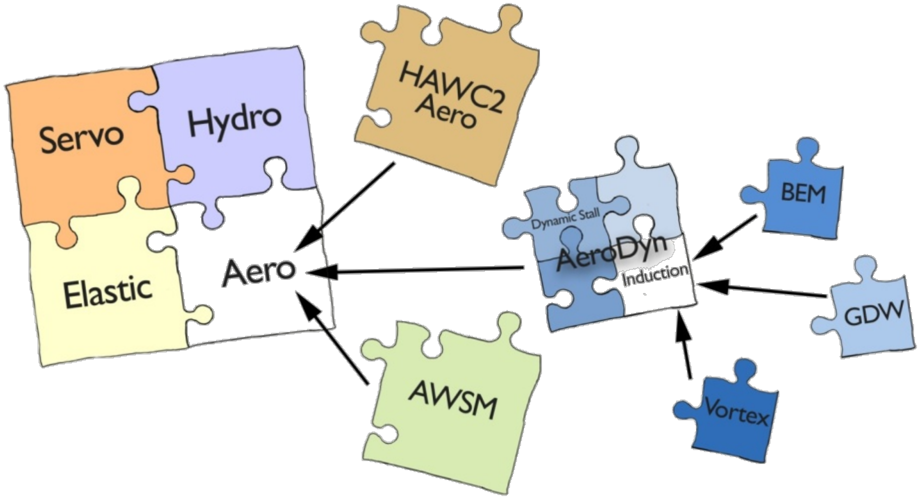
- Recently **FAST** & its various modules have been converted to a new modularization framework
- Splitting of **FAST** into:
  - **FAST** driver (glue) code
  - **ElastoDyn** module for structural dynamics
  - **ServoDyn** module for controller & electrical drive
- Introduction of:
  - **SubDyn** module for multi-member substructure structural dynamics
  - **MAP** module for mooring quasi-statics
  - **IceFloe** for sea ice
  - New **AeroDyn** & **HydroDyn** features
- First releases of v8 have focused on framework & new offshore features, but improved aero-elastics are forthcoming
- Tail aero not yet available in v8

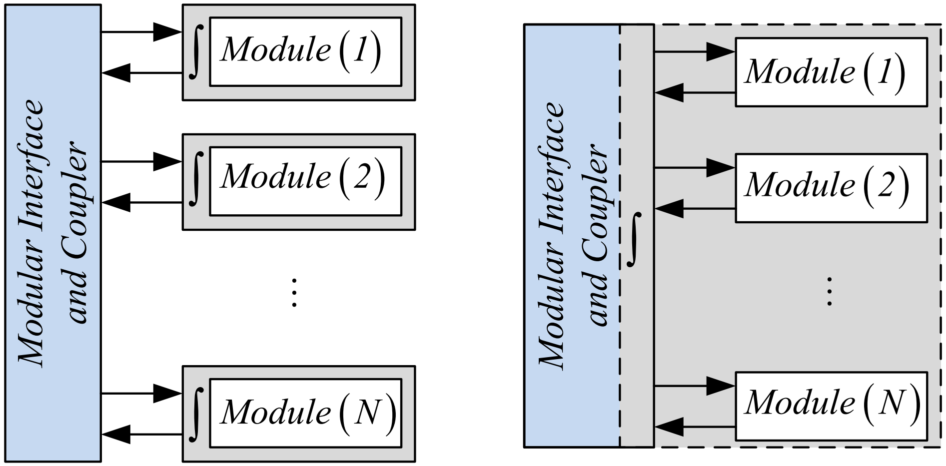


FAST Modularization Framework

Distinguishing Characteristics

- Range of modeling fidelity through coupling of a variety of modules
- Mapping between module-independent time & spatial discretizations
- Multiple coupling schemes & integration/solver options
- Nonlinear time-domain simulation, operating-point determination, & linearization
- Module data encapsulation & dynamic allocation
- Module solution in series or parallel
- Save/retrieve capability
- Pathway towards development community



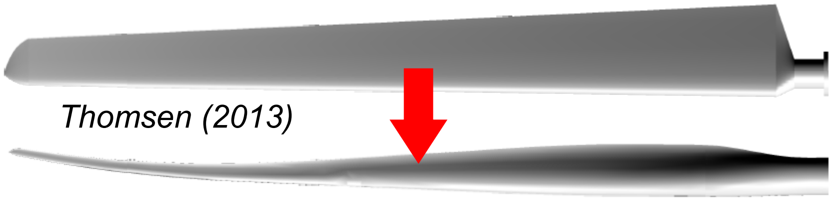


Loose- (Left) & Tight- (Right) Coupling Schemes

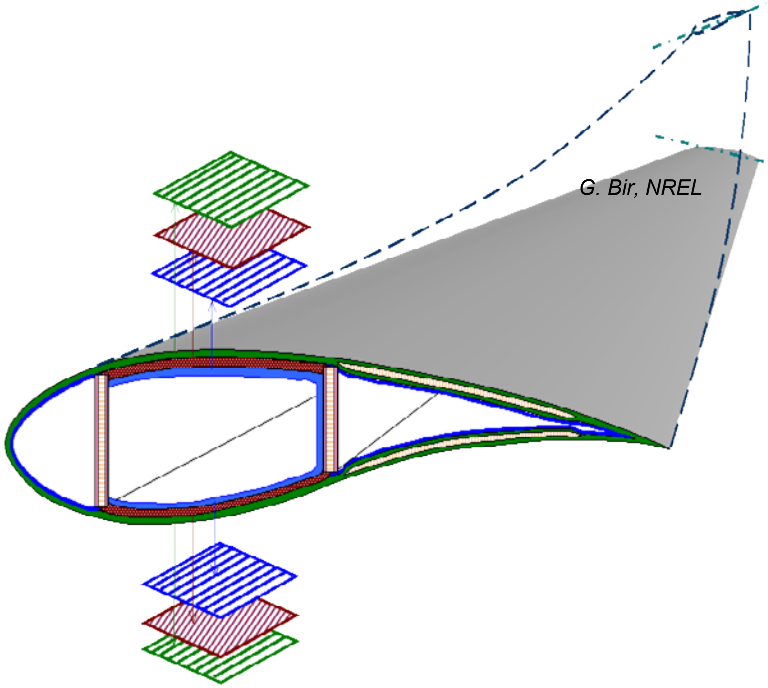
FAST Modularization Framework

Current & Planned Work Pertinent to DWT

- Further framework development
- **AeroDyn** overhaul:
  - BEM with skewed wake
  - GDW
  - Unsteady airfoil aero
  - Aero influence & loading apart from rotor (tower, nacelle/hub, tail)
  - Nonstraight blades
- **BeamDyn** development:
  - Anisotropic material couplings
  - Geometric nonlinearities (GEBT)
  - Nonstraight blades
  - Phase I – Spectral finite element
  - Phase II – Improved modal method
- **MATLAB/Simulink** interface



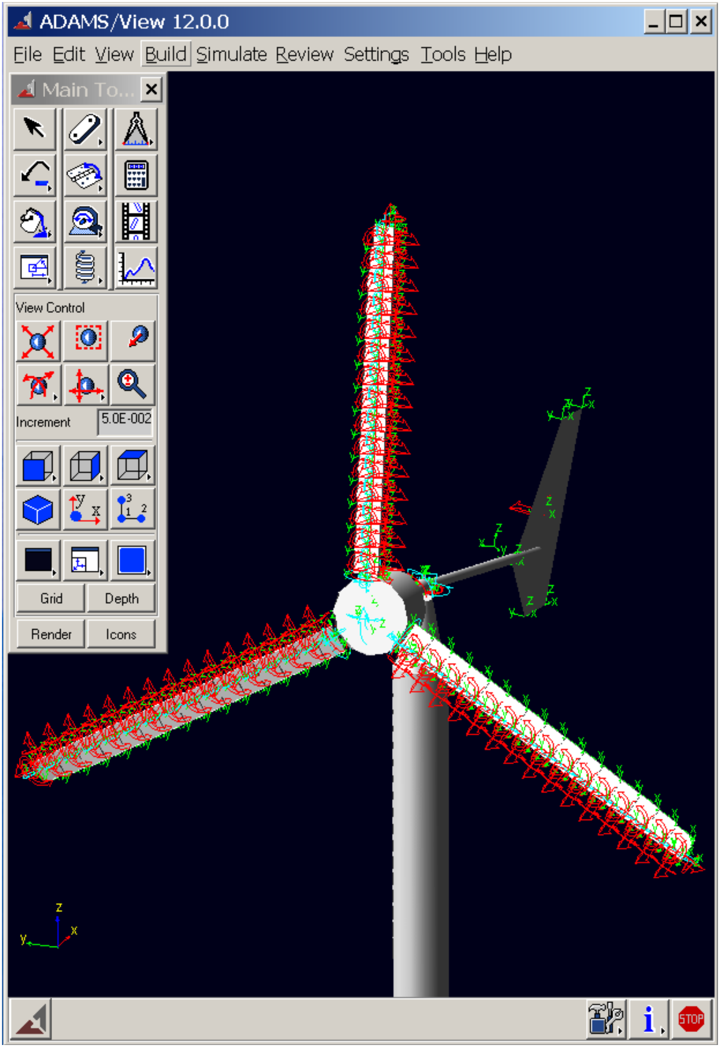
Advancement in Blade Design



Blade Twist Induced By Anisotropic Layup

Conclusions & Outlook
Summary

- CAE tools are required to address design challenges, so that WTs are:
  - Innovative
  - Optimized
  - Reliable
  - Cost-effective
- **FAST** considers furling dynamics for DWT:
  - Lateral rotor thrust offset
  - Tail vane (not yet in v8)
  - Furling DOFs, springs, dampers, & stops
- Improvements are needed for better model predictive furling accuracy:
  - Experiments & HFM focused on wake & tail aero in highly skewed & transient conditions



***MSC.ADAMS** Model of SWRT*

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More information @: https://nwtc.nrel.gov

Carpe Ventum!

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