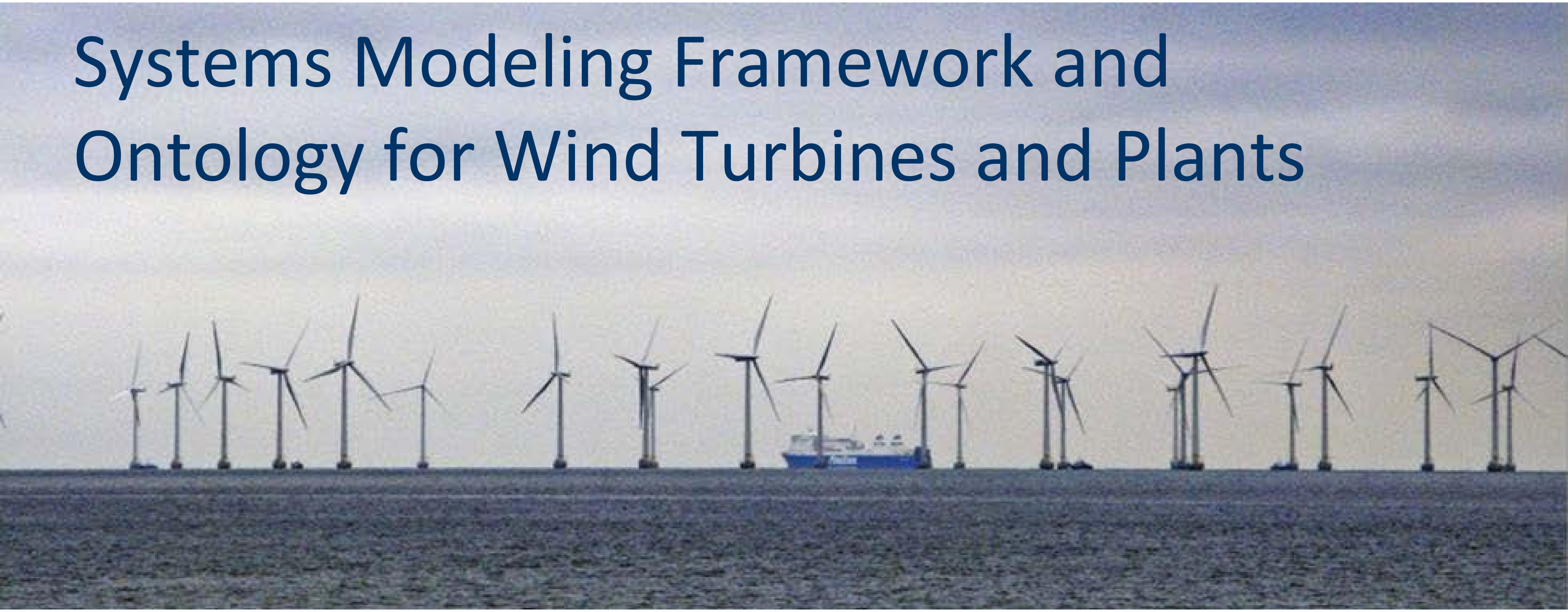
IEA Wind Task 37



Systems Modeling Framework and Ontology for Wind Turbines and Plants

Katherine Dykes, Frederik Zahle, Karl Merz, Mike McWilliam, Pietro Bortolotti, et al.

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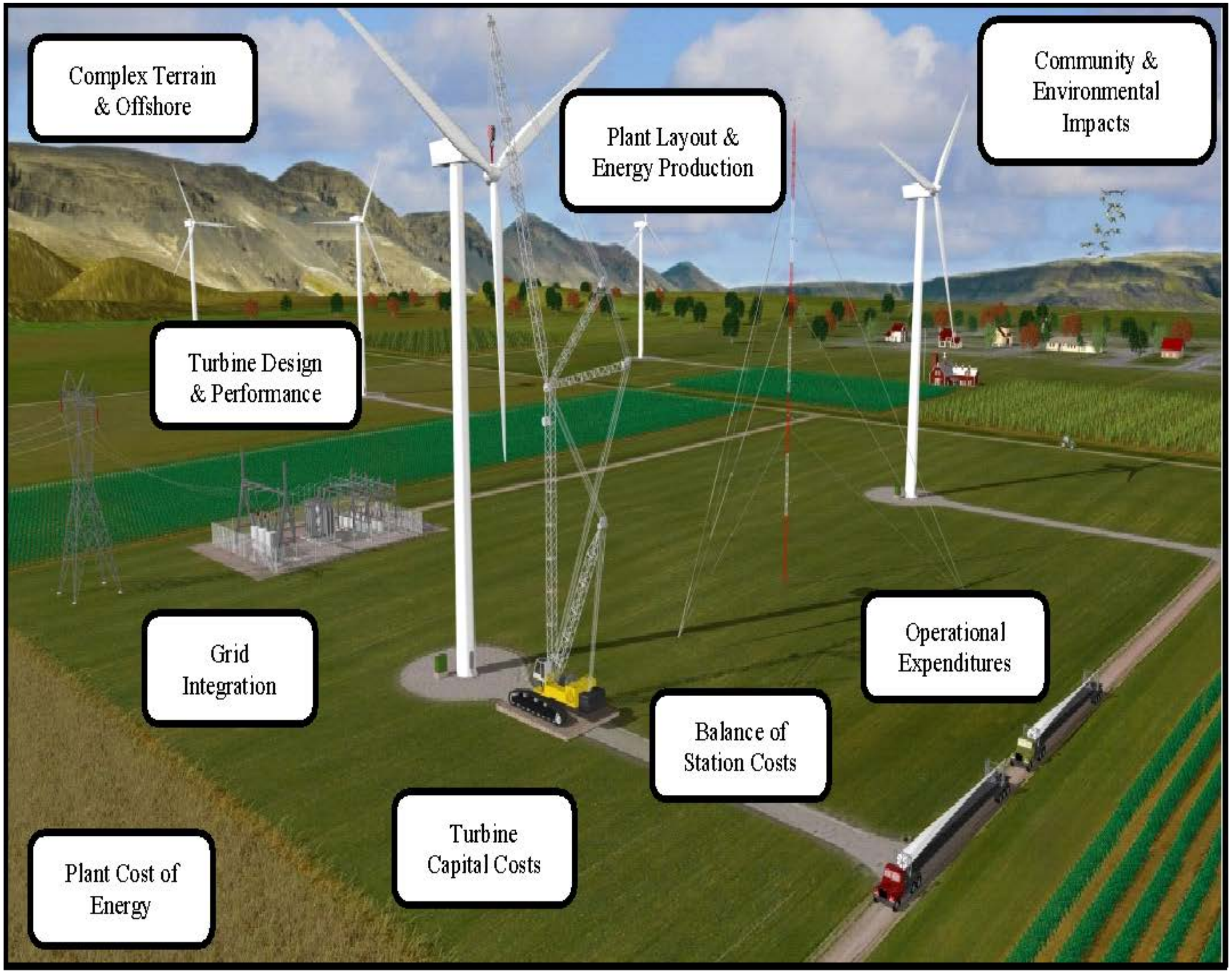
Outline

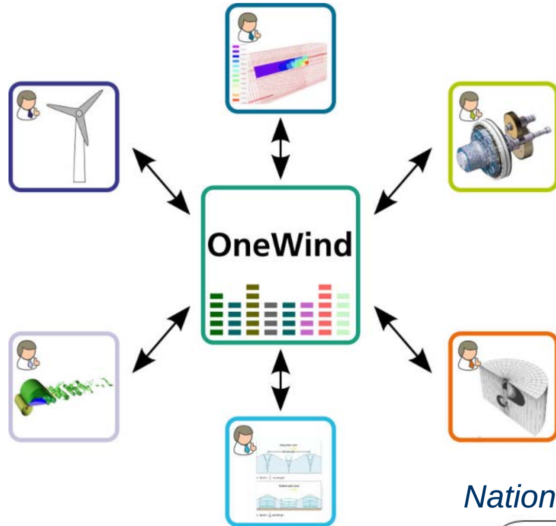
- Overview of International Energy Agency (IEA) Wind Task 37
- System modeling framework development

Background: A Wind Plant as a Complex and Highly Interconnected System



Background: MDAO for Wind

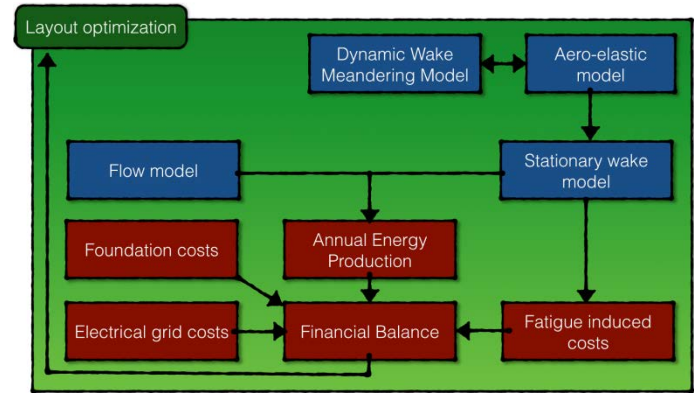
- Efforts to apply multidisciplinary design, analysis, and optimization (MDAO) of wind plants are growing
- **IEA Wind Task 37** seeks to align and develop best practices for MDAO at turbine and plant levels*



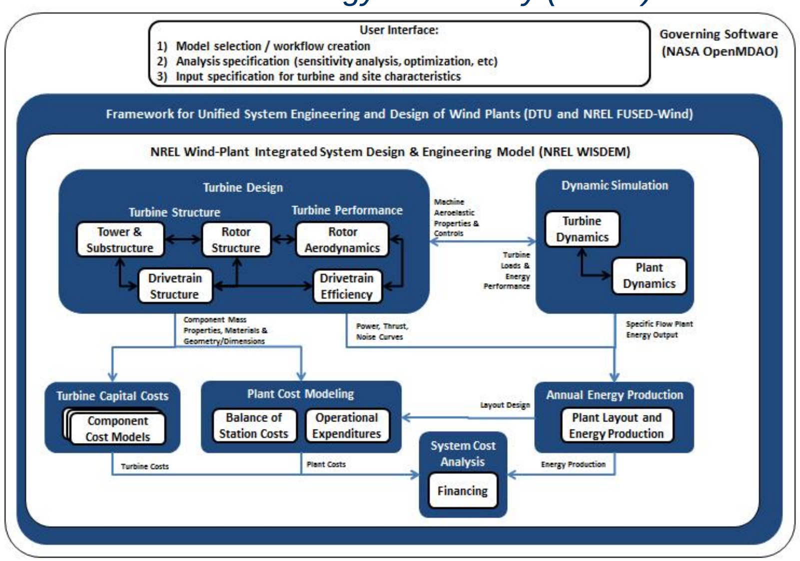
Fraunhofer IWES

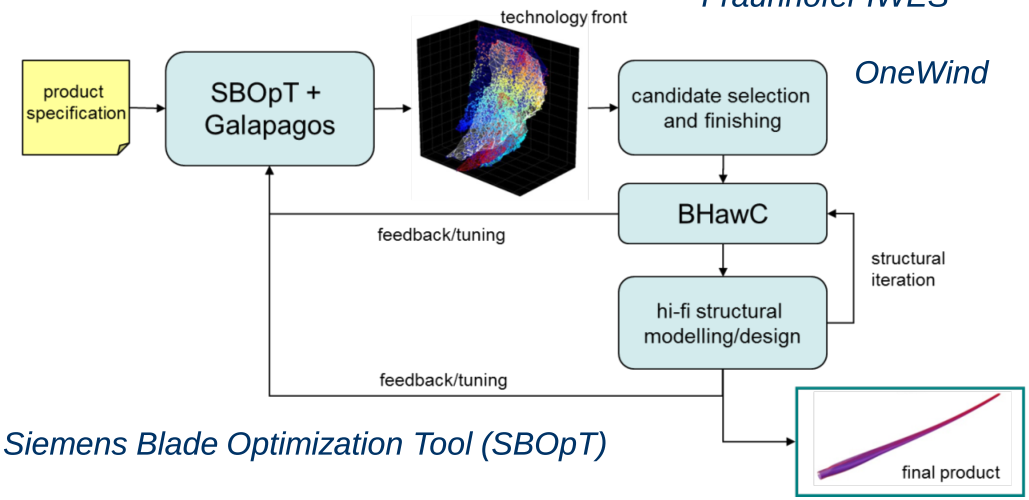
OneWind

Technical University of Denmark (DTU) TopFarm



National Renewable Energy Laboratory (NREL) WISDEM





Siemens Blade Optimization Tool (SBOpT)

*** For more examples of integrated research, development, and demonstration (RD&D) initiatives, see the IEA Wind Topical Expert Meeting #80 proceedings.**

IEA Wind Task 37: Objectives

- Project objectives and outcomes:
  - Improve quality of systems engineering by practitioners through development of best practices and benchmarking exercises
  - Promote general knowledge and demonstrate value of systems engineering tools and methods, as applied to wind energy RD&D.

- Current Term: 2016–2018 (began January 2016)

IEA Wind Task 37: Goals

- Specific task goals:
  - Promote general knowledge and understanding of systems engineering tools and methods and the overall value of these to wind energy RD&D
  - Improve quality of systems engineering by practitioners
  - Enable better communication between researchers and practitioners in different disciplines
  - Enable system-level analysis, including technology evaluation, multidisciplinary design, analysis and optimization, multifidelity modeling, and uncertainty analysis and quantification
  - Promote enhanced design of wind turbines and plants through the use of systems engineering tools and methods.

IEA Wind Task 37: Work Package Overview

- Work Package 1 (WP1): Guidelines for integrated wind turbine and plant software frameworks
  - *This presentation*
  - *1:00 pm: (related project) OWGraph: A Graph Database for the Offshore Wind Domain, Quaeghebeur*

- WP2: Series of reference turbine and plant designs for supporting integrated analysis activities
  - *10:40 am: IEA Wind Task 37 3.X Megawatt (MW) Land-Based Wind Turbine, Bortolotti*
  - *14:40 pm: Aerostructural Design of DTU 10-MW Wind Turbine Rotor, Zahle*

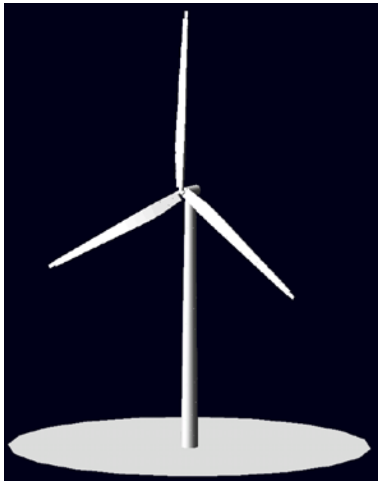
- WP3: Best practice recommendations on MDAO as applied to wind systems
  - *2:40 pm: The Aerodynamic Wind Turbine Design Optimization Case Study for IEA Wind Task 37, McWilliam*

IEA Wind Task 37: Work Packages

- **WP1: Guidelines on a common framework for integrated RD&D of wind energy systems**
  - Addresses the task goals by creating guidelines for a common conceptual architecture for wind turbine and plant modeling and analysis. This allows:
    - More seamless integration of wind turbine and plant models between different stakeholders
    - More transparent ways to communicate about capabilities of different models and differences between models.
  - Key activities include:
    - Survey of existing frameworks and MDAO work
    - Development of framework requirements
    - Development of common framework guidelines for turbines and plants.

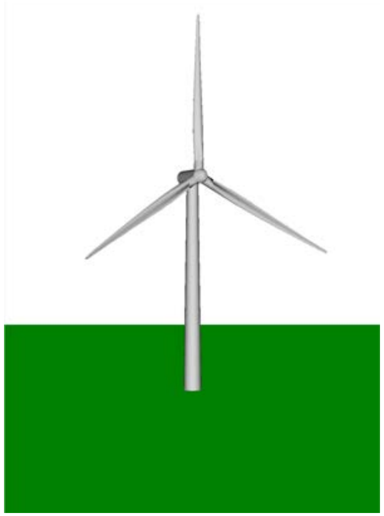
IEA Wind Task 37: Work Packages

- **WP2: Reference Wind Energy Systems**
  - Addresses task goals by providing RD&D community with a set of turbines and plants to use as starting points for various system-level analyses.



NREL 5-MW Reference Turbine

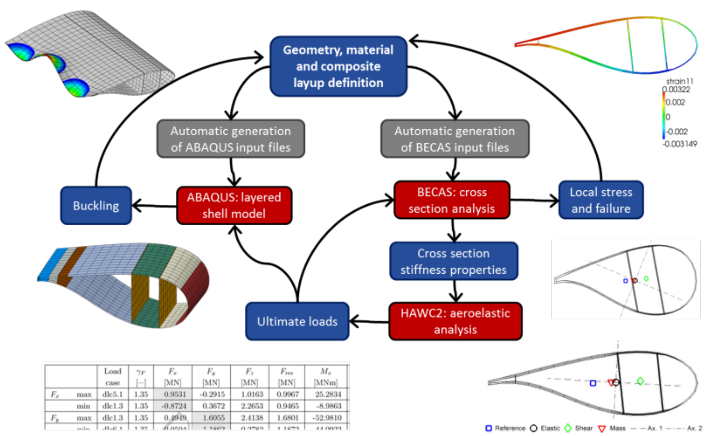
  - Key activities include:
    - Determining target reference system markets
    - Determining specific turbines/plants for development and design requirements
    - Developing reference turbines (3 suggested)
    - Developing reference plants (3 suggested).



DTU 10-MW Reference Turbine

IEA Wind Task 37: Work Packages

- **WP3: Benchmarking MDAO activities at different system levels**
  - Addresses task goals by benchmarking activities which will exercise frameworks, reference wind energy systems, and help inform best practices in MDAO for wind energy systems.



Example Aerostructural MDAO for DTU 10-MW Reference Turbine

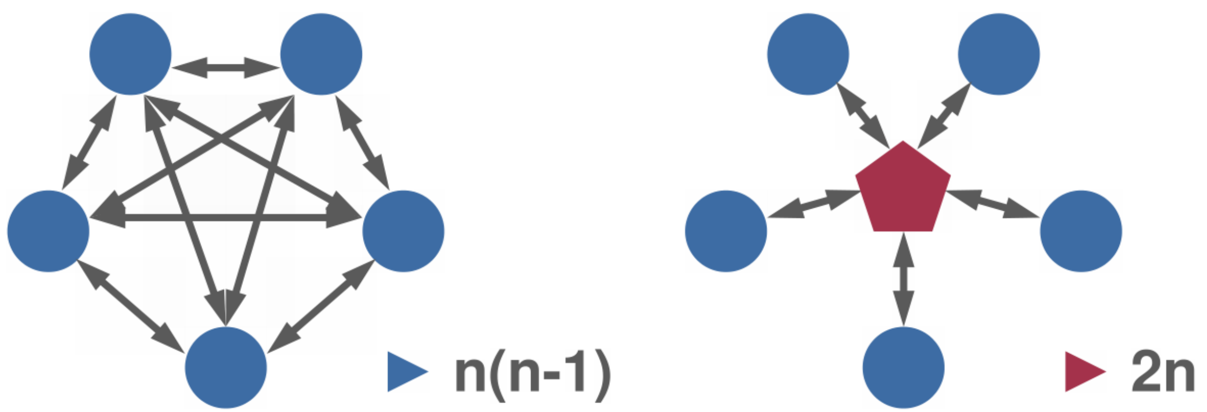
  - Key activities include:
    - Establishing benchmarking scope based on WP1
    - Selecting benchmarking cases and establishing evaluation criteria and process
    - Performing MDAO benchmarking for wind turbines (target 3)
    - Performing MDAO benchmarking for wind plants (target 3).

WP1: Guidelines on a common framework for integrated RD&D of wind energy systems

WP1: Foundations

- For WP1, existing efforts were considered, including:
  - FUSED-Wind (Framework for Unified Systems Engineering and Design of Wind Plants): DTU Wind Energy / NREL collaboration to allow for interchange of models in a workflow
  - CPACS (Common Parametric Aircraft Configuration Schema): Hosted by DLR and gaining traction within aviation community.

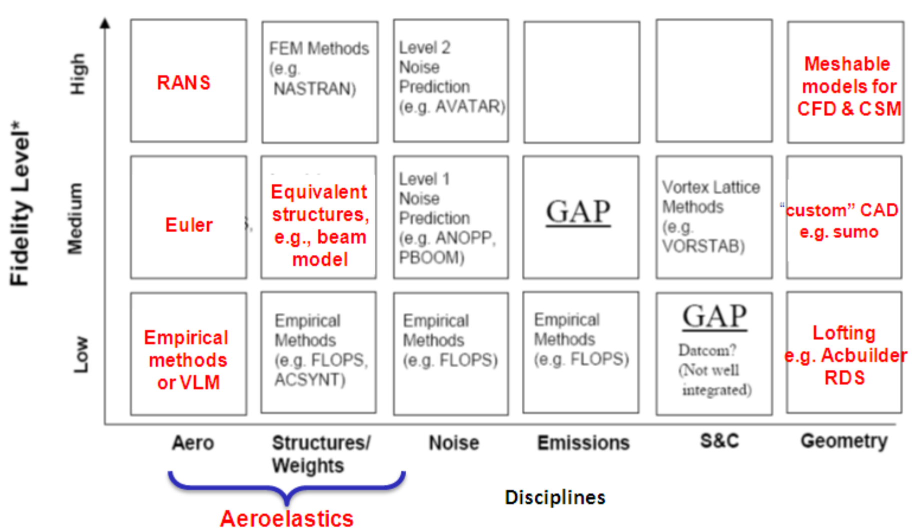
- Advantage is to reduce model translation burden when several stakeholders are involved in a design process.



Source: CPACS website https://software.dlr.de/p/cpacs/home/

WP1: Process

- Initial process for framework development:
  1. Catalog multidisciplinary design and analysis tools for wind turbine and plant applications
  2. Develop discipline-fidelity matrices for the wind turbine and plant
  3. Cross-walk modeling frameworks to matrices
  4. Select most common discipline-fidelity combinations for guideline development
  5. Develop guidelines for chosen discipline-fidelity combinations.



CPACS discipline-fidelity matrix Source: Rizzi et al., 2012

WP1: Framework Catalogue

- Many MDAO efforts for wind turbines exist in the research community and commercially
  - Included so far for turbine: Cp-Max (TUM), HAWTOPT2 (DTU), WISDEM (NREL), BladeOASIS (CENER), Turbine Architect (DNV GL), OneWind Modelica Library (Fraunhofer)
  - Included so far for plant: WISDEM (NREL), TOPFARM (DTU), OpenWind (AWS)

Basic Information			MDAO Characteristics	
Framework Name	**Organizations Involved**	**Description**	**Disciplines included - subsystems**	**Disciplines included - physics**
Cp-Max	TU Munich, Politecnico di Milano	Integrated design of wind turbine components with system dynamics analysis. Integration with cost models for cost optimization.	Rotor aerodynamics, rotor and tower structures, aerostructural integrated design, optimal selection of composite materials, tuning of model based controller	BEM/Dynamic Inflow, multibody analysis, 2D FE blade sectional analysis (ANBA), full 3D FEM blade model
FUSED-Wind / WISDEM - Turbine	NREL	A general systems engineering toolset for wind energy for both turbine and plant applications; built on FUSED-Wind framework and the OpenMDAO software environment	Rotor (aerodynamics, structure), Drivetrain (structure and electrical performance), Tower (structure), Offshore support structure (monopile, jacket, floating spar), Aero-structural integration, Costs (turbine), Financing	BEM, cross-sectional blade analysis, simple FEM for blade and support structure, aereoelastic simulation, empirical / parametric cost models
FUSED-Wind / HAWTOPT2	DTU Wind Energy	Multidisciplinary optimization tool built around the aeroelastic solvers HAWC2 and HAWCStab2 and the cross-sectional FE solver BECAS. HAWTOpt2 uses OpenMDAO to define the workflow and dataflow and interface to optimizers. Uses FUSED-Wind to define the turbine parameterization.	Fully coupled design of blade aerodynamic shape and internal structure, controller tuning, frequency placement	Turbine (aeroelastically modelled, BEM non-linear beams), Blade (FE cross section code), Tower (FE cross-section code)
Turbine.Architect	DNVGL	combined loads, yield, engineering & cost models for LCoE-based optimization and probabilistic analysis	loads, turbine design :engineering optimization algorithms for blade, hub, nacelle-structural, yaw bearing & system, flanges, bolted connections, tower, monopile, jacket, floater. power curve calculation. AEP/wake. BOP cost: installation, cable, foundation and other BoP cost models (on&offshore), OpEx estimation, finance	BEM, wave loads, eddy-viscosity wake, structural yield & fatigue limit states evaluation, numerical optimization
BladeOASIS	CENER	Blade Optimal Aero-Structural Integrated Solutions. Simultaneous optimization of wind turbine blade aerodynamics and structure, that can be coupled with an aeroelastic code for dynamic simulation. Optimization performed based on a variety of optimization functions involving AEP, CP, CT, BladeMass, COE.	Fully coupled Blade Aerodynamic Shape and Blade Structural Design; Upwind and Downwind rotor design; Energy Production; Aeroelastic load simulations; Cost evaluation.	BEM, cross-sectional blade analysis, aereoelastic simulation, empirical / parametric cost models
OneWind Modelica Library	Fraunhofer IWES	Integrated design of wind turbine components with multi-physics system dynamics analysis.	Onshore structures (Rotor, Blades, Hub, Nacelle, Drivetrain, Generator, Tower), Offshore support structures (Monopile, Tripod, Jacket, Semi-Submersible, Spa-Buoy, Mooring lines), Operating Control, Wind, Waves, Sea-Ice	Aerodynamics, aero-elasticity, fully coupled load analysis

WP1: Framework Disciplines

- Development of fidelity-discipline matrices for wind turbine and plant modeling
  - Wind turbine rotor, drivetrain components, and tower
  - Wind plant energy production, balance of system, operations and maintenance, and financing.

Fidelity

High-fidelity time resolved turbulence modelled computational fluid dynamics (CFD)		3-D solid				
Blade-resolved CFD	Time resolved large-eddy simulations CFD	3-D shell				
Actuator line CFD	Vortex methods	Super-element		Supervisory controllers		
Actuator disc CFD	DWM	Elemental non-linearity (GEBT)	Generalized 6x6	Safety protection functions		
Vortex methods	Engineering unsteady 3-D (Veers/Mann)	Multi-body (linear/non-linear)	Timoshenko	Load mitigation		Full BOM and manufacturing process flow
Blade Element Momentum	Unsteady uniform	Modal	Euler	Power/speed regulation		Empirical design-based
Look-up table CT&Power	Steady inflow	Rigid	Analytical solid	Prescribed operation	Semi-empirical	Empirical parametric
Rotor aero	**Inflow aero**	**Structures**	**Cross-section structures**	**Controls**	**Acoustics**	**Cost**

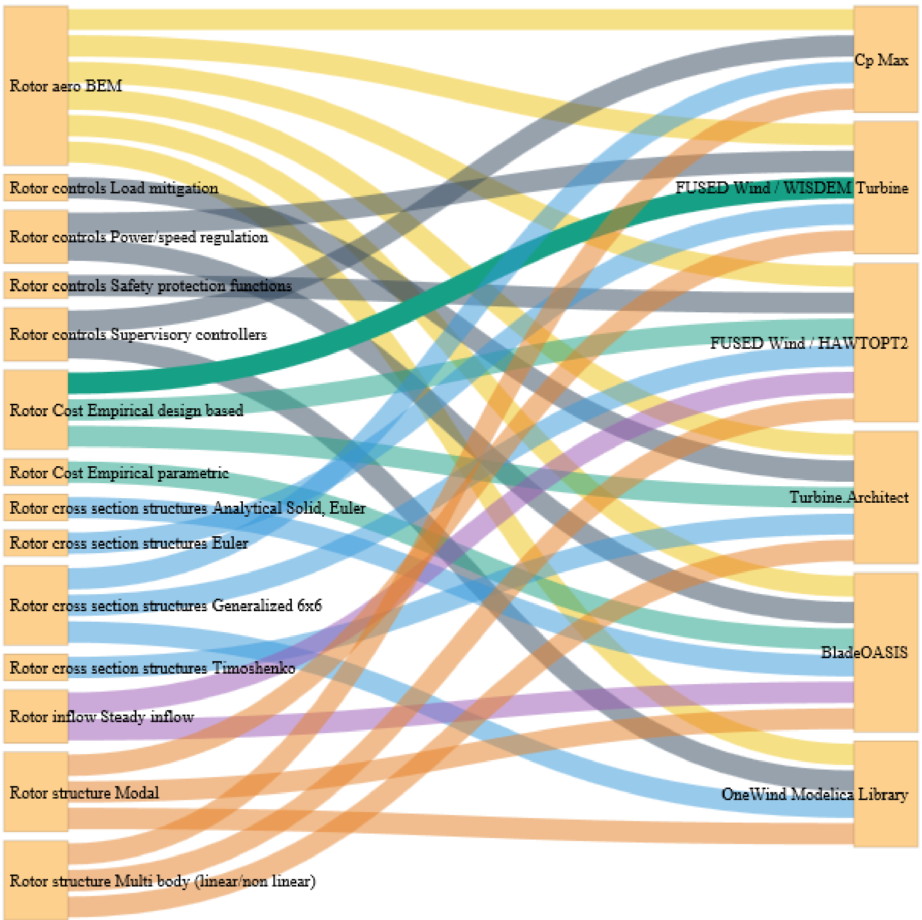
Disciplines (Rotor)

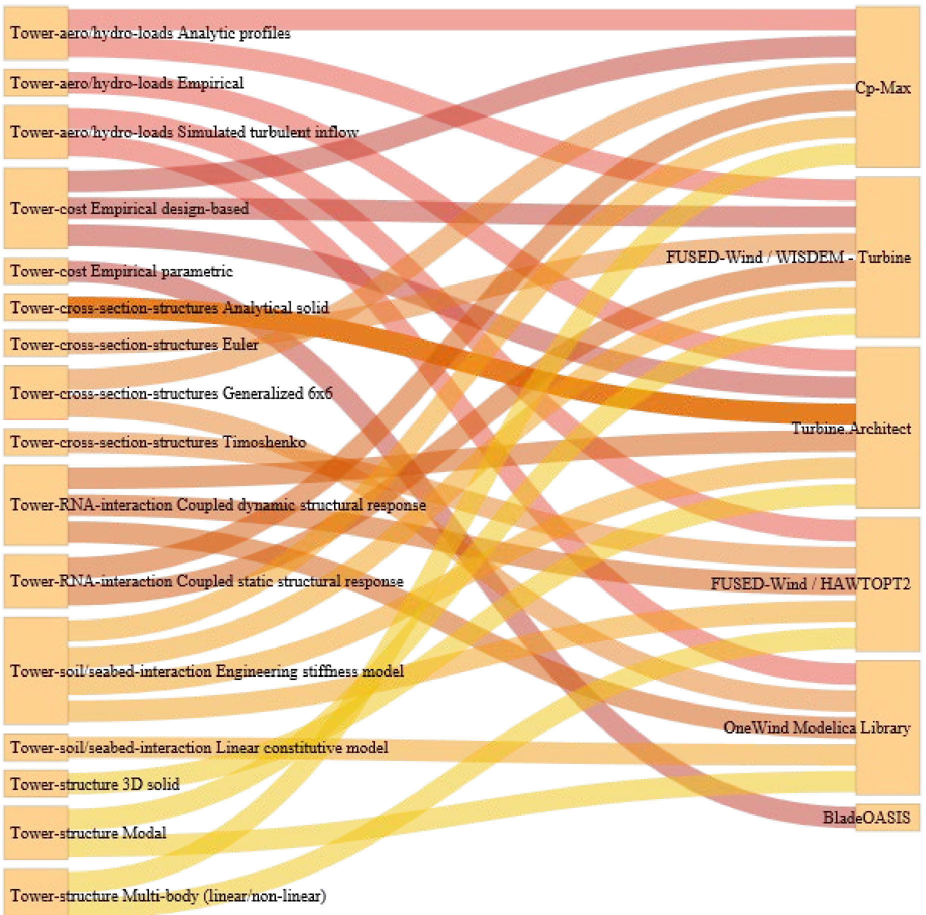
Unsteady 3-D finite element analysis					
3-D shell					
Super-element		LES			
Elemental non-linearity (GEBT)	Generalized 6x6	URANS			
Multi-body (linear/non-linear)	Timoshenko	RANS	Nonlinear constitutive model	Coupled dynamic structural response	
Modal	Euler	Simulated turbulent inflow	Linear constitutive model	Coupled static structural response	Full BOM and manufacturing process flow
Rigid	Analytical solid	Analytic profiles	Engineering stiffness model	Fixed moments of inertia and forces	Empirical design-based
Empirical	Empirical	Empirical	Rigid	Empirical	Empirical parametric
Structures	**Cross-section structures**	**Aero/Hydro Loads**	**Soil**	**RNA**	**Cost**

Disciplines (Tower)

WP1: Framework Cross-Walk

- Initial cross-walk of model catalogue shows most common disciplines





WP1: Framework Development

- Selected rotor blade element momentum (BEM) as test case for initial framework development.
- Chose YAML for interchange data format
  - YAML is a human-friendly data serialization standard for all programming languages
    - Works with Python, C/C++, etc
    - Much easier to read than XML
    - Better at representing hierarchical information than comma-separated value (CSV) files.
- Developed YAML for BEM model via WP3.1 aerodynamic optimization case study.

Summary and Next Steps

- IEA Wind Task 37 established to support wind energy systems engineering and integrated system modeling.
- WP1 on frameworks seeks to develop CPACS-style guidelines for wind energy system modeling.
- Development of initial framework underway for most common fidelity and discipline combinations.
- Join us!
  - Next annual meeting September 11–12, 2017, at DTU
  - 4th biennial Wind Energy Systems Engineering Workshop: http://www.conferencemanager.dk/SEworkshop2017

Thank You

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