Multi Rotor 2024

MRS Modelling in OpenFAST

Hannah Ross

National Renewable Energy Laboratory

Made possible by our sponsors:

MYRIAD Wind Energy Systems

NMIS National Manufacturing Institute Scotland

Statkraft

WIND CATCHING

Organised by:

HAW HAMBURG | CC4E

University of Strathclyde Glasgow

Hosted by:

RENEWABLE DYNAMICS

Supported by:

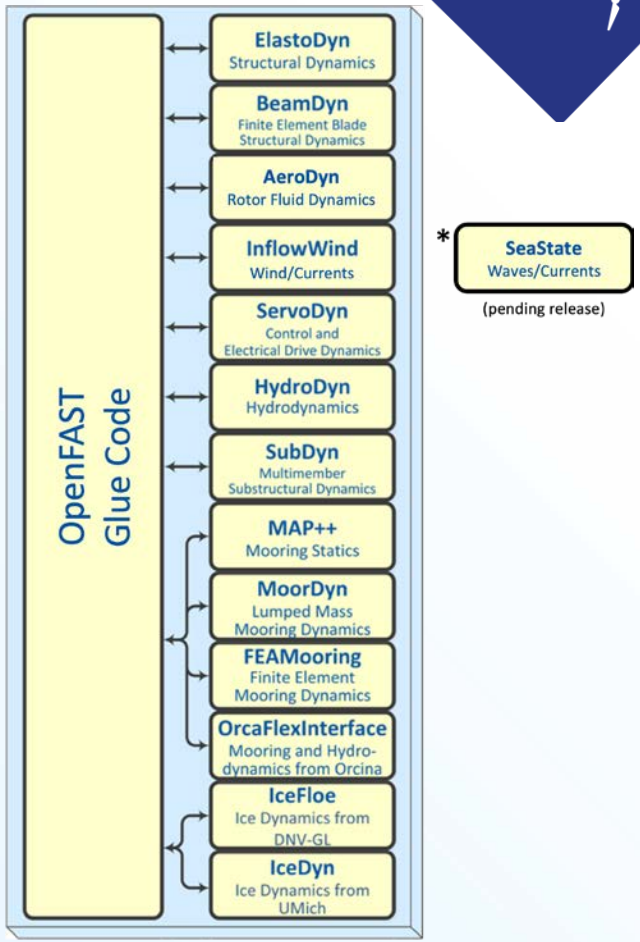
Funded by UK Government

Glasgow City Council

OpenFAST summary

Capabilities

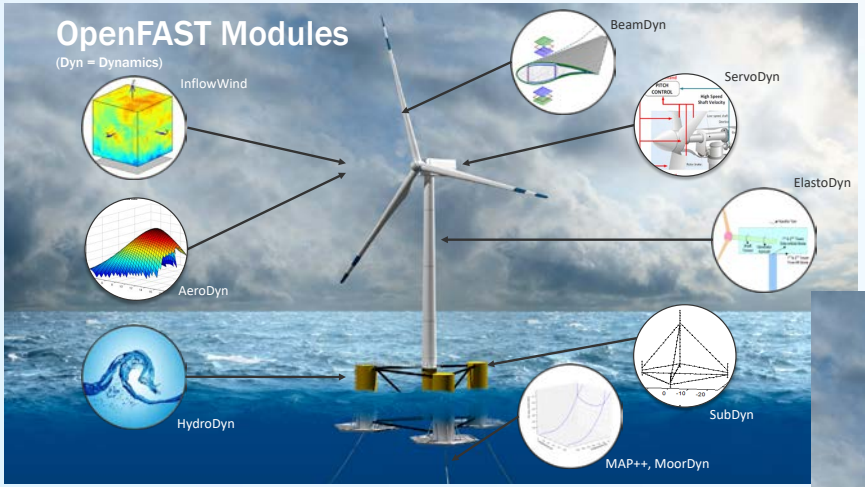
- Models fixed and floating wind and marine turbines
- Computes nonlinear dynamics in the time domain
- Linearizes nonlinear equations and exports state-space models
- Glue code couples independent modules
  - Enables data encapsulation for distinct physics and/or components
  - Glue code can run more than one instance of a module
- Supports substructure flexibility for multi-member support structures
- Tight coupling between structural modules



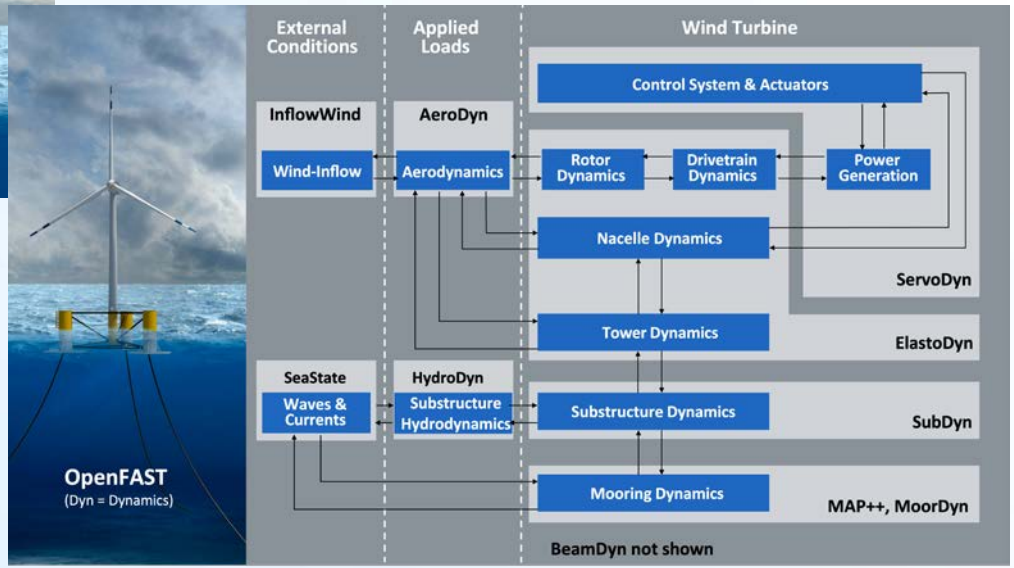
OpenFAST glue code and its modules. *Image by Jason Jonkman, NREL*

NREL Transforming ENERGY

OpenFAST for wind turbines

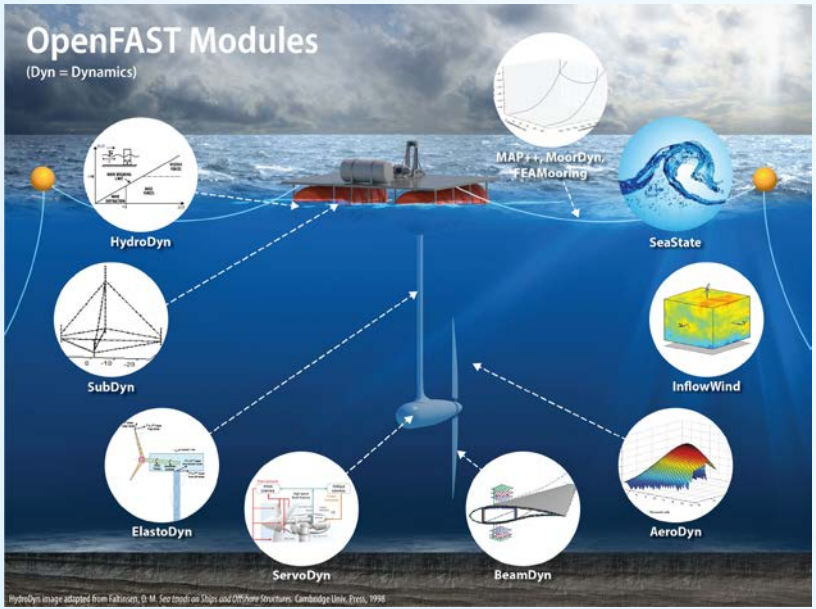


OpenFAST modules for a floating offshore wind turbine.
Image by NREL Communications

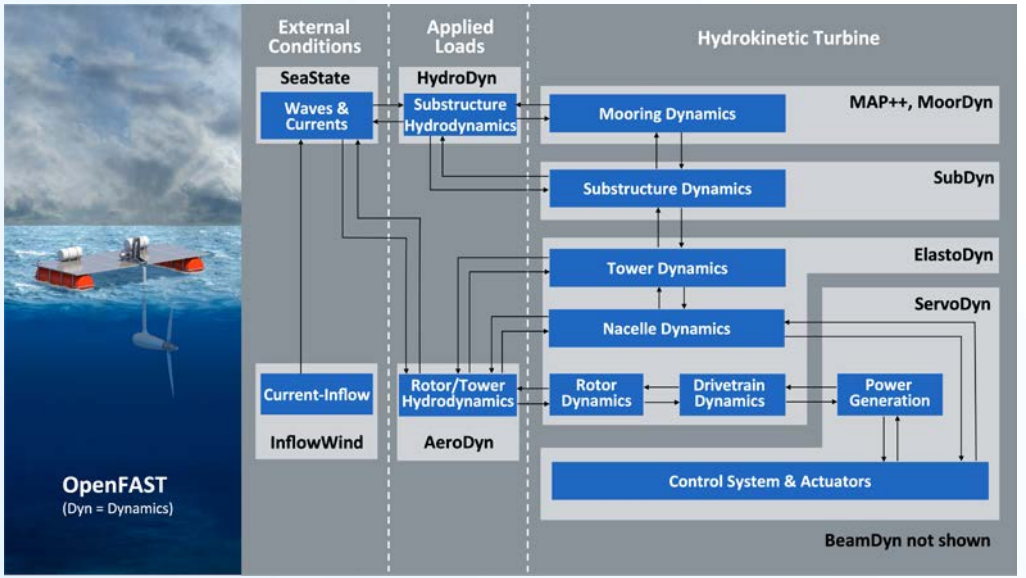


OpenFAST module coupling for a floating offshore wind turbine. *Image by NREL Communications*

OpenFAST for marine turbines



OpenFAST modules for a floating marine turbine.
Image by NREL Communications



OpenFAST module coupling for a floating marine turbine. *Image by NREL Communications*

Multi Rotor 2024

OpenFAST for multi-rotors

Objective

- Simulate coupled aero-hydro-servo-elastic dynamics of multi-rotor systems
  - Land-based, fixed-bottom, and floating offshore wind turbines
  - Fixed and floating marine turbines
- Allow nonlinear time domain simulations and full-system linearization

Example multi-rotor systems (from left to right: Vestas, Nezzy[2], SeaGen, MEGALODON)

NREL Transforming ENERGY

Multi Rotor 2024

OpenFAST for multi-rotors

Existing capabilities

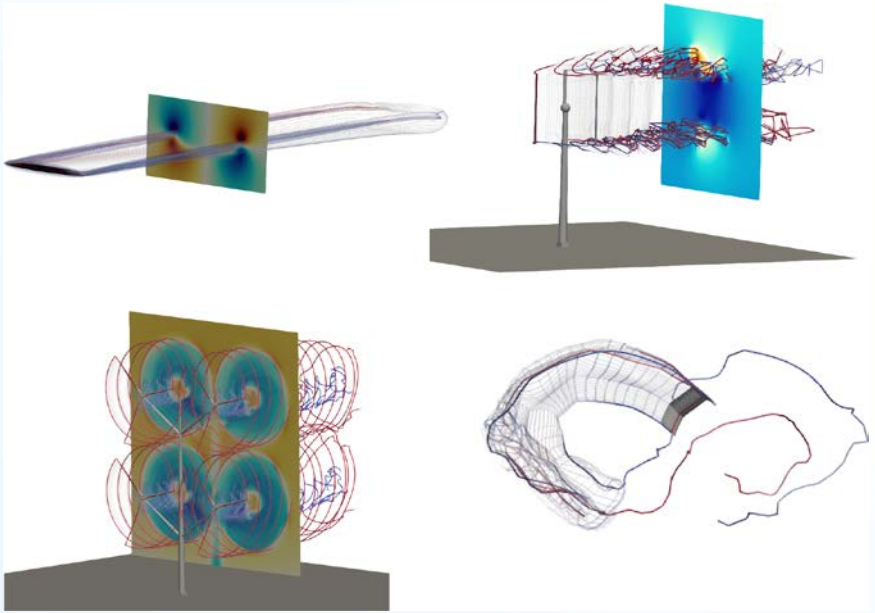
- AeroDyn driver can run multiple rotors

Original AeroDyn driver

- Simulation of horizontal-axis turbines only
- Fixed nacelle position
- Power-law shear profile inflow

Updated AeroDyn driver

- Arbitrary collections of wings, rotors, and towers (including multiple rotors)
- Arbitrary rigid-body motions of lifting surfaces
- Aerodynamic interactions using free vortex wake model (OLAF)



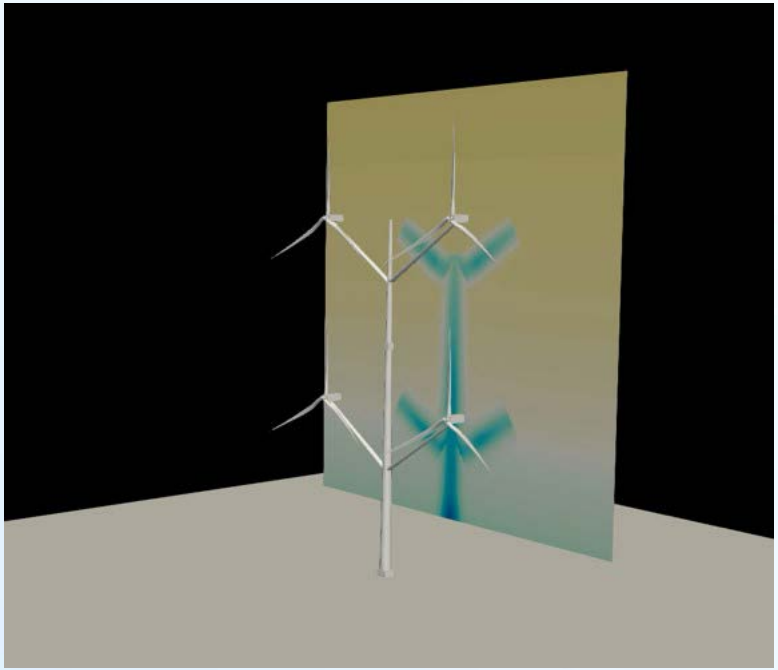
Examples of wind energy concepts to which the AeroDyn driver may be applied: (clockwise from top left) elliptical wing, VAWT, kites, and multi-rotor systems.
Illustration by Emmanuel Branlard

NREL Transforming ENERGY

Branlard, E., Brownstein, I., Strom, B., Jonkman, J., Dana, S., and Baring-Gould, E. I. "A multipurpose lifting-line flow solver for arbitrary wind energy concepts", *Wind Energy Science*, 7, 455–467, 2022.

OpenFAST for multi-rotors

Existing capabilities



Quad-rotor horizontal-axis wind turbine (HAWT) simulated in OLAF.

Illustration by Emmanuel Branlard

Multi Rotor 2024

OpenFAST for multi-rotors

Under development

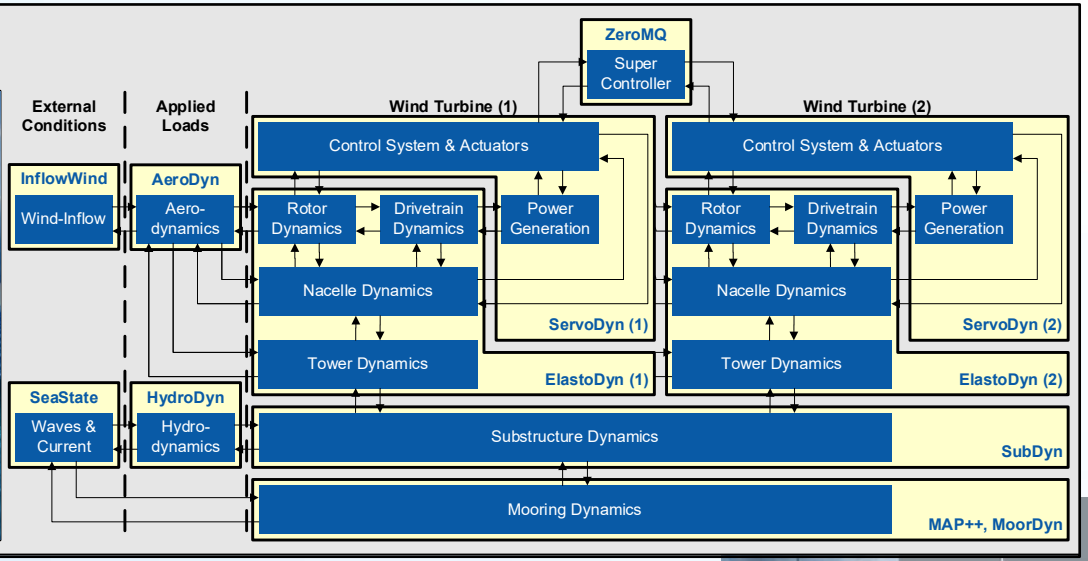
- Define the number of turbines *N* and their origins at the glue-code level
- One rotor, drivetrain, nacelle, and optional tower per turbine
- *N* instances of ElastoDyn model the rotor, drivetrain, nacelle, and tower structural dynamics (one instance per turbine)
- *N* instances of ServoDyn model the turbine control and electrical drive dynamics (one instance per turbine)
- Each turbine has its own degrees of freedom and configuration
- Allow multiple interface joints in SubDyn
- Develop a system-level super controller to allow coordinated control
- Multi-rotor functionalities in AeroDyn coupled to other modules

Distinction from previous work

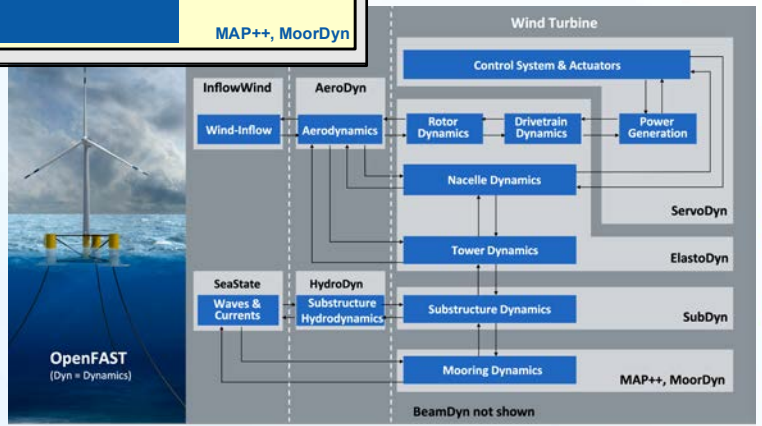
- Modelling of floater hydro-elastics, which may be important for large floaters supporting multiple turbines

NREL
Transforming ENERGY

OpenFAST for multi-rotors



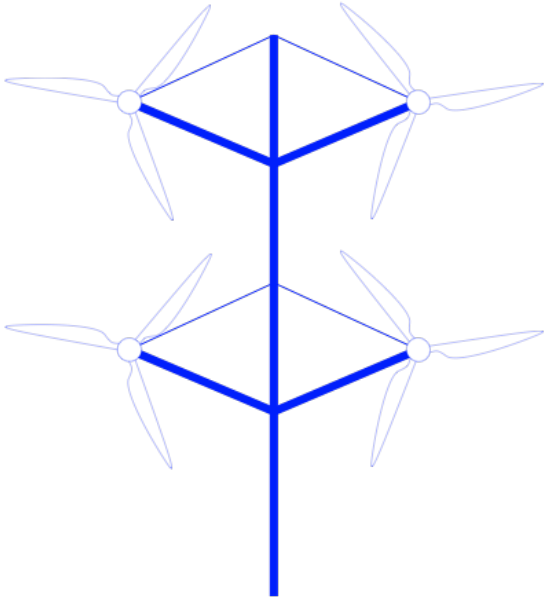
Partitioning of physics into OpenFAST modules for multi-rotor systems (shown with the Hexicon TwinWind concept). *Illustration by Jason Jonkman, NREL*



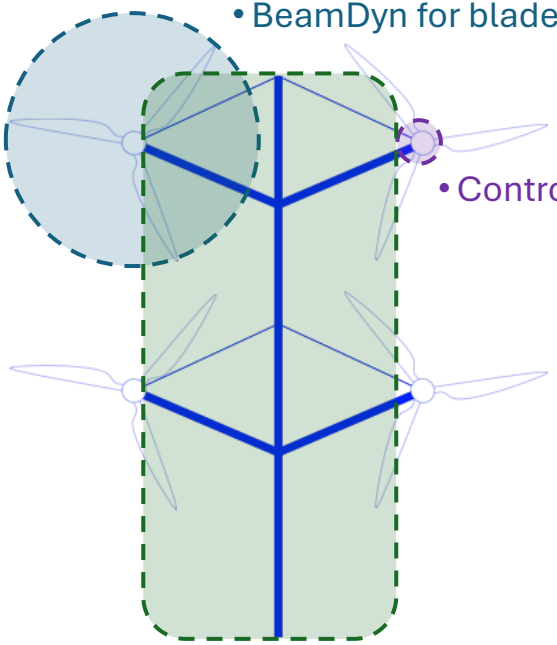
OpenFAST for multi-rotors

Multi Rotor 2024

Multi-rotor land-based wind turbine



Multi-rotor wind turbine concept. *Illustration by Derek Slaughter, NREL*



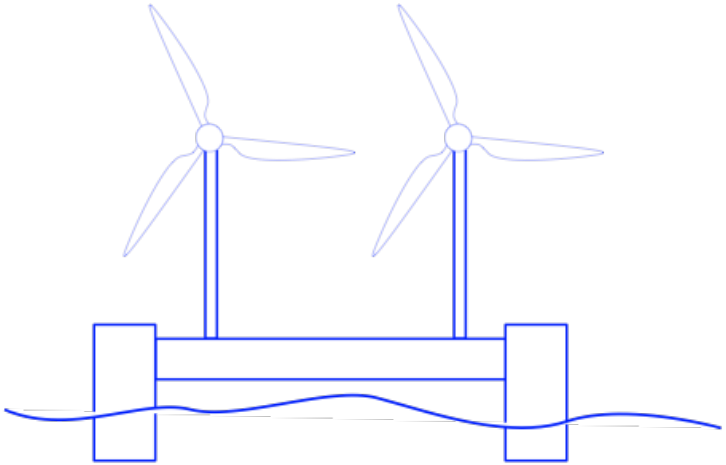
- Rotor aero: AeroDyn
- Rotor structural: ElastoDyn
  - BeamDyn for blades (optional)
- Controls: ServoDyn
- Support structure aero: N/A
- Support structure structural: SubDyn

NREL Transforming ENERGY

OpenFAST for multi-rotors

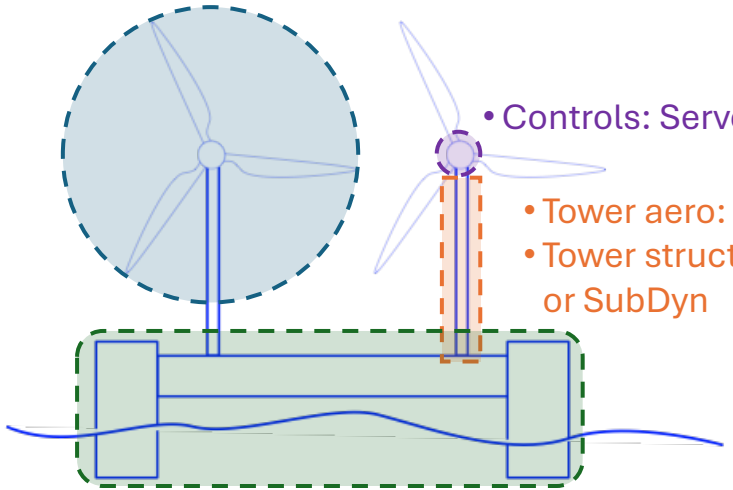
Multi Rotor 2024

Multi-rotor floating offshore wind turbine



Multi-rotor wind turbine concept. *Illustration by Derek Slaughter, NREL*

- Rotor aero: AeroDyn
- Rotor structural: ElastoDyn
  - BeamDyn for blades (optional)



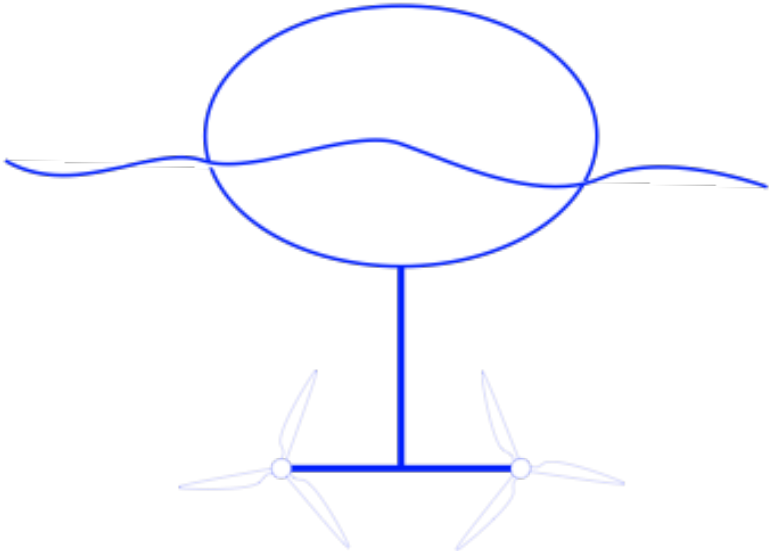
- Controls: ServoDyn
- Tower aero: AeroDyn
- Tower structural: ElastoDyn or SubDyn
- Platform hydro: HydroDyn
- Platform structural: SubDyn

NREL Transforming ENERGY

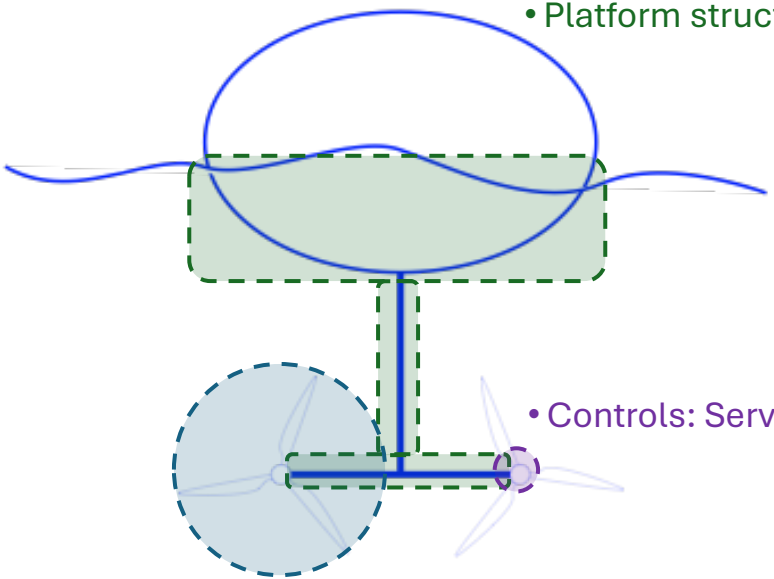
OpenFAST for multi-rotors

Multi Rotor 2024

Multi-rotor floating marine turbine



Multi-rotor marine turbine concept. *Illustration by Derek Slaughter, NREL*



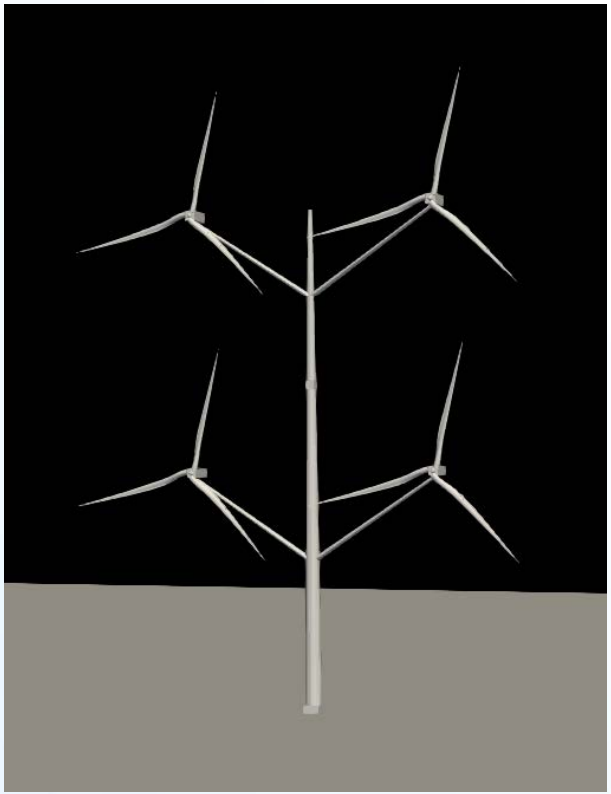
- Platform aero: N/A
- Platform hydro: HydroDyn
- Platform structural: SubDyn
- Controls: ServoDyn
- Rotor aero: AeroDyn
- Rotor structural: ElastoDyn
  - BeamDyn for blades (optional)

NREL Transforming ENERGY

Summary

Conclusions

- OpenFAST can model aero-hydro-servo-elastic dynamics of individual wind and marine turbines
- OpenFAST is being modified to enable coupled simulation of systems with N turbines on a single platform
- Support structure flexibility will enable loads coupling between turbines
- Super controller will allow coordinated control



Quad-rotor HAWT. *Illustration by Emmanuel Branlard*

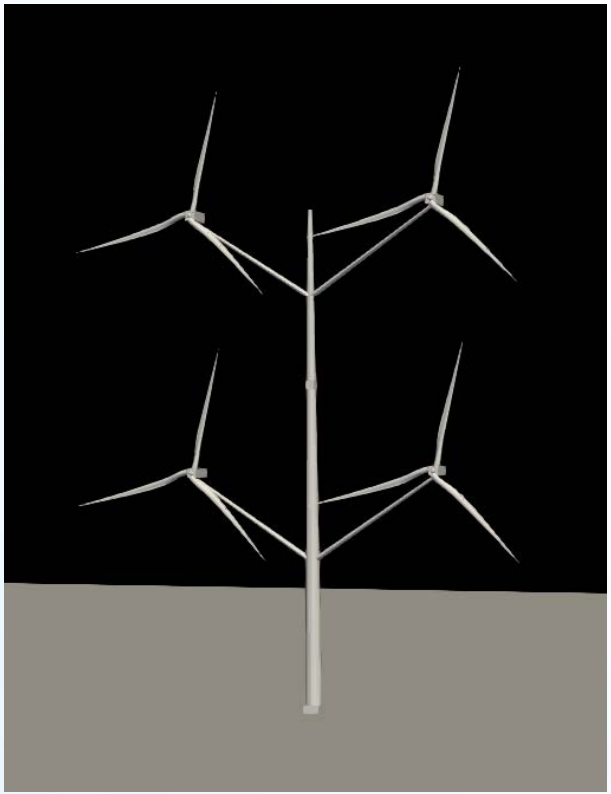
Summary

Timeline

- Next update at NAWEA conference in October by Jason Jonkman
- Tentative release at the end of 2024

Potential future work

- Aerodynamic loading of multi-member support structures
- Vertical-axis turbines
- Yaw control of a superstructure holding multiple rotors
- FAST.Farm for multi-rotor systems



Quad-rotor HAWT. *Illustration by Emmanuel Branlard*

Acknowledgements

- U.S. Department of Energy Water Power Technologies Office
- U.S. Department of Energy Wind Energy Technologies Office
- U.S. Department of Energy Advanced Research Projects Agency – Energy
- Jason Jonkman, Derek Slaughter, Andy Platt

https://github.com/OpenFAST/openfast/tree/main

https://openfast.readthedocs.io/en/main/

NREL team encourages and supports community code contributions

This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by U.S. Department of Energy Wind Energy Technologies Office and U.S. Department of Energy Water Power Technologies Office. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

NREL/PR-5700-90223

Made possible by our sponsors:

MYRIAD Wind Energy Systems

NMIS National Manufacturing Institute Scotland

Statkraft

WIND CATCHING

Organised by:

HAW HAMBURG | CC4E

University of Strathclyde Glasgow

Hosted by:

RENEWABLE DYNAMICS

Supported by:

Funded by UK Government

Glasgow City Council