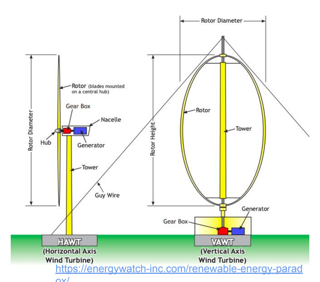
Investigating the Impact of Region 2 Operation on Spar, Barge, and Semi-sub Offshore Wind Turbine Platforms using OpenFAST

Susannah Smith

Introduction- Wind Turbines



- Renewable Energy
  - Increase in Renewable Energy Research
    - Caused by extensive fossil fuel use
  - Solution -
    - Turbines (1)
- Wind Turbines-Mechanical energy converted to electricity (1)

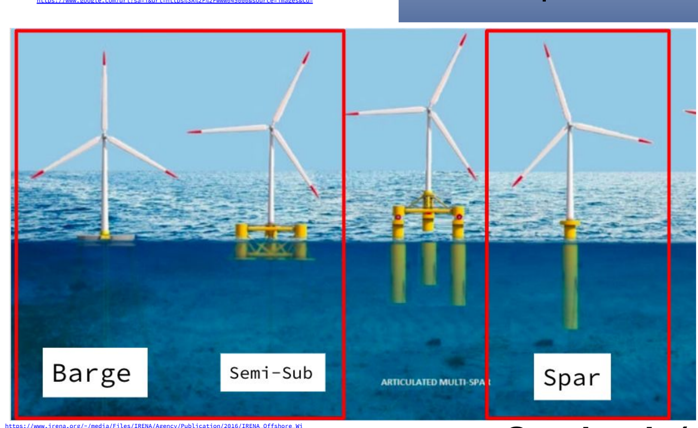
Horizontal axis
- Blades rotate around axis parallel to ground
- Most used/commercially available
- Upwind or downwind turbines (1)

Vertical axis
- Axis is perpendicular to the ground (2)
- Darrieus rotor

Onshore
- Proven technology
- Simple to install
- Noise Pollution, eye sores (1)

Offshore
- Offshore wind speeds tend to be faster and steadier than on land (3)
- Installation difficult and costly
- Coastal areas have high energy needs
- Out of the way

FOWT
- 3 Types of Foundations(4)
  - Barge
  - Semi-Sub
  - Spar



Barge (4)
- Platform supported by mooring lines
  - Large surface area
- Buoyancy Stabilized
- Steel or concrete hull
- 30 meters

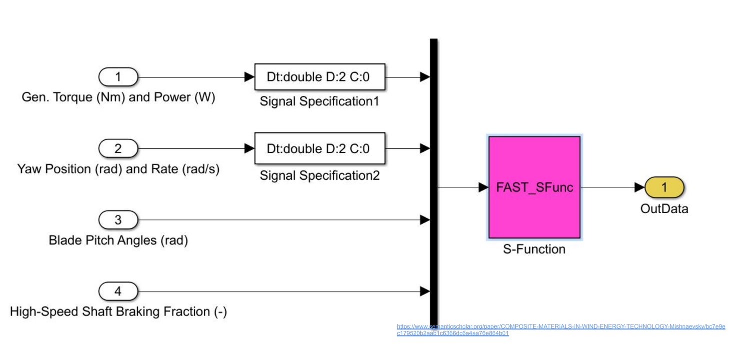
Spar (5)
- Cylinder floats vertically in the water
- Ballast tanks in the base of the cylinder volume.
- Weighted at the base
- 100 meters

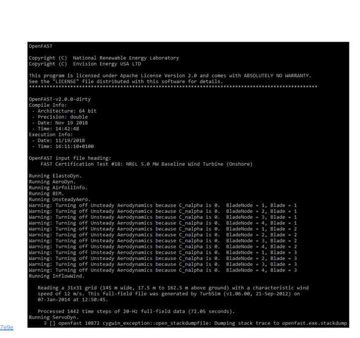
Semi-sub (4,5)
- Partly submerged to provide
  - Localization
  - Stability
- Avoid large wave loads by utilizing smaller tubulars (columns) in splash zone
- 40 meters

Introduction- OpenFAST

- FLORIS
- WISDEM
- SOWFA
- FAST (6,9)

- Fatigue, Aerodynamics, Structures,and Turbulence (1, 9, 6)
  - Simulates HAWTs
- FAST joins
  - Aerodynamics model (9,10)
  - Hydrodynamics models for offshore structures
  - Control and electrical system dynamics models
  - Structural dynamics models





Literature Review

- Turbine blades usually made of **composite material**, the base and other mechanisms are mostly **steel** or **iron**

Mishnaevsky, L., Branner, K., Petersen, H., Beauson, J., Mcgugan, M., & Sørensen, B. (**2017**). Materials for Wind Turbine Blades: An Overview. Materials, 10(11), 1285. doi:10.3390/ma10111285

- Linearization in **OpenFAST** -as ***accurate*** as **FAST v.7**

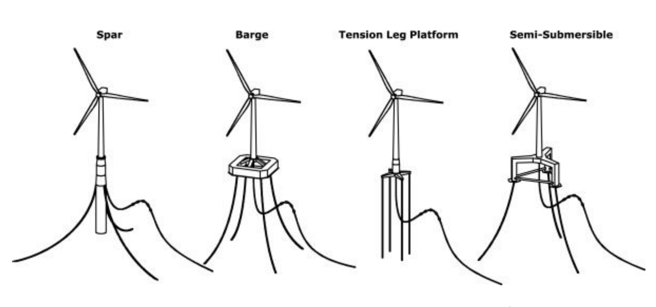
N Johnson, J Jonkman, A Wright , G Hayman, and A Robertson **2019** Verification of Floating Offshore Wind Linearization Functionality in OpenFAST.https://iopscience.iop.org/article/10.1088/1742-6596/13

- OpenFAST substructure: Rigid body with hydrodynamic loads at a point, Predicts the **global response** of the floating substructure. Not the **structural loads** in individual parts.

Jason Jonkman, Rick Damiani, Emmanuel Branlard, Matthew Hall, Amy Robertson, and Greg Hayman **(2019).** Substructure Flexibility and Member- Level Load Capabilities for Floating Offshore Wind Turbines in OpenFAST

Gap in the Research

- Region 2 operation
- Unexplored capabilities



Hypothesis

Out of the spar, barge, and semi-sub foundations, the spar will best be able to withstand region 2 wind in deep water because of weight distribution and shape.

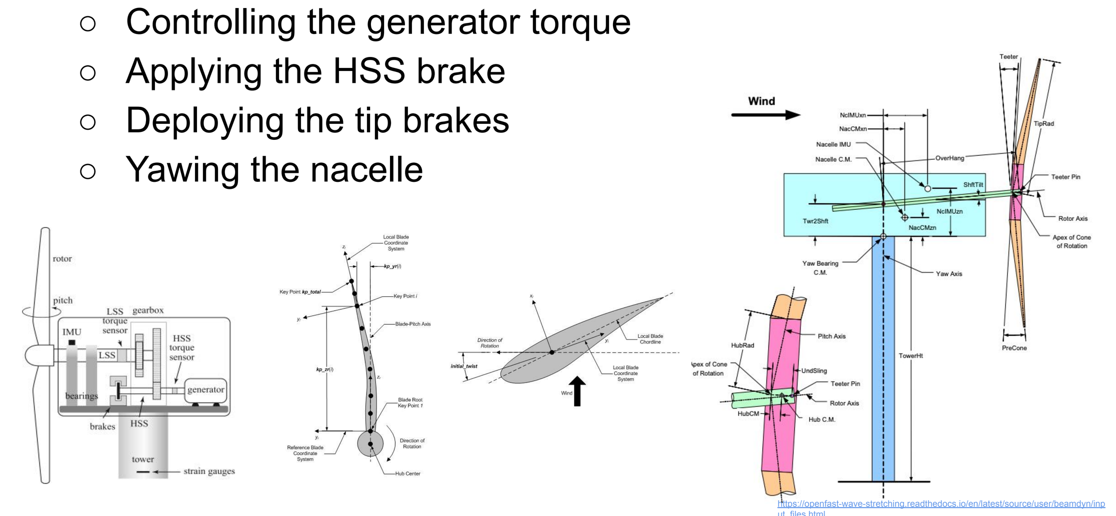
Methods- Simulation

- Two different forms of operation/ analysis modes
  - Simulation
  - Linearization

Simulation

- **Aerodynamic and structural response** to wind-inflow conditions is determined in time.
- Active controls modified
- Predict both the extreme and fatigue **loads** of HAWT
- Windows executable program file or DLL interfaced with Simulink

- **Nine rigid bodies**
  - Earth, support platform, base plate, nacelle, armature, gears, hub, tail, and structure furling with the rotor
- **Four flexible bodies**
  - Tower, two blades, and drive shaft
- Through 22 degrees of freedom (DOFs).
- **Controls**: (7)
- Setting appropriate input parameters in the Turbine Control section of the primary input file
  - Pitching the blades
  - Controlling the generator torque
  - Applying the HSS brake
  - Deploying the tip brakes
  - Yawing the nacelle

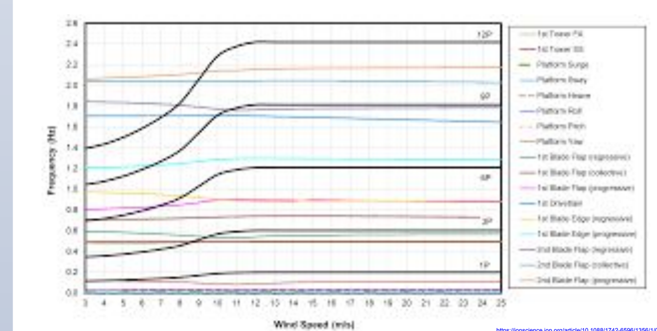


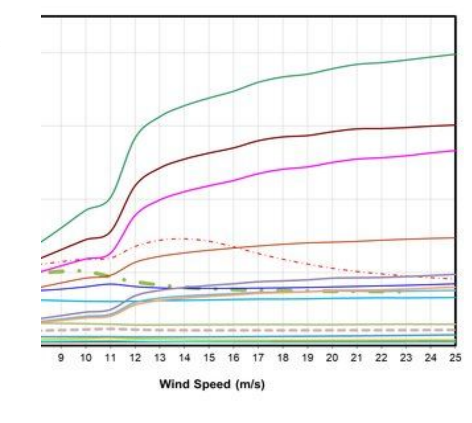
Methods- Linearization

Linearization

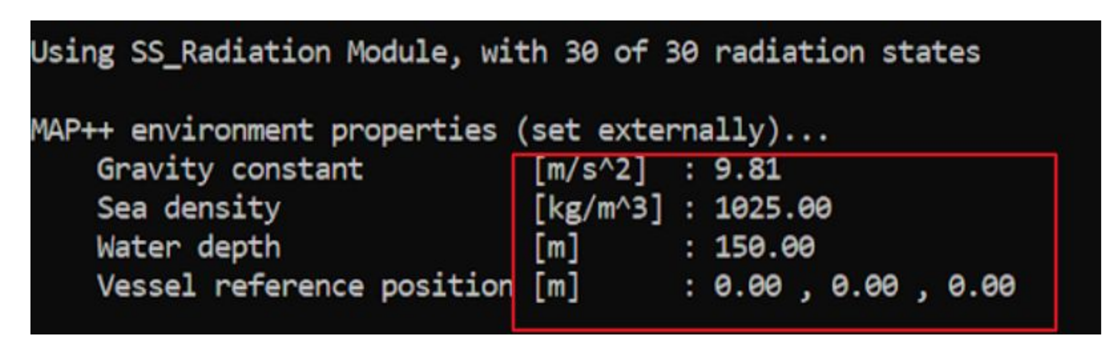
- Extracting linearized representations of the complete **nonlinear** aeroelastic wind turbine modeled
- Aid in controls design and analysis

- Find steady state solution
- FAST linearizes the complete nonlinear aeroelastic model about the operating point
- Post processing script file in PDAP





Results



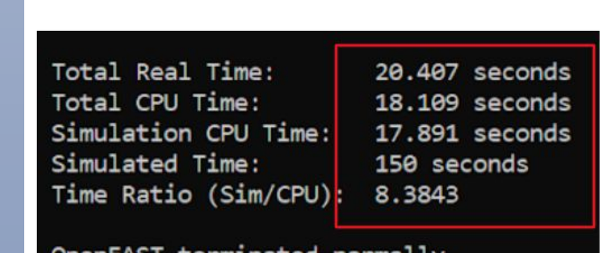
```
Using SS_Radiation Module, with 30 of 30 radiation states

MAP++ environment properties (set externally)...
    Gravity constant          [m/s^2]  : 9.81
    Sea density               [kg/m^3] : 1025.00
    Water depth               [m]      : 150.00
    Vessel reference position [m]      : 0.00 , 0.00 , 0.00
```

Spar:

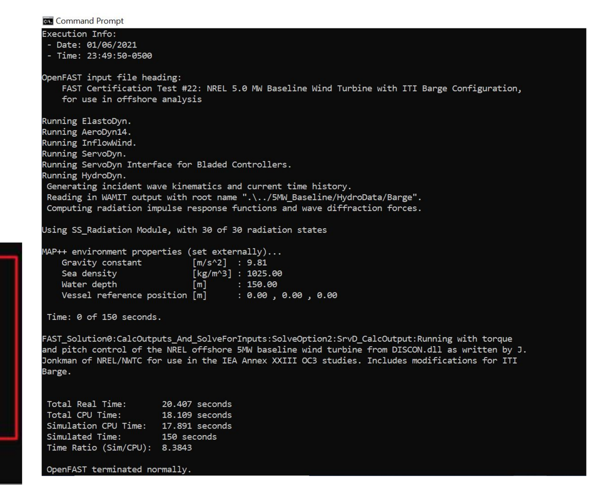
Total Real Time: 17.458 seconds
Total CPU Time: 17.453 seconds
Simulation CPU Time: 17.234 seconds
Simulated Time: 150 seconds
Time Ratio (Sim/CPU): 8.7035

Barge:



```
Total Real Time:       20.407 seconds
Total CPU Time:        18.109 seconds
Simulation CPU Time:   17.891 seconds
Simulated Time:        150 seconds
Time Ratio (Sim/CPU):  8.3843

OpenFAST terminated normally.
```



Discussion

- In real time, spar ran quicker than barge
  - Spar time ratio (Sim/CPU)= 8.7035
  - Barge time ratio (Sim/CPU)=8.3843
- reducing the number of analysis nodes in the various FAST modules and/or disabling features
- disable features/ structural DOFs, increase the simulation time step(s), which will further increase the speed.
- Generating Campbell Diagram with Matlab
  - represents a system's response spectrum as a function of its oscillation regime
- I expect the spar turbine to withstand high speed winds because the foundation is denser and more secure
  - Withstand great depths
- Limitations of depth, materials, cost
  - Different locations, special events

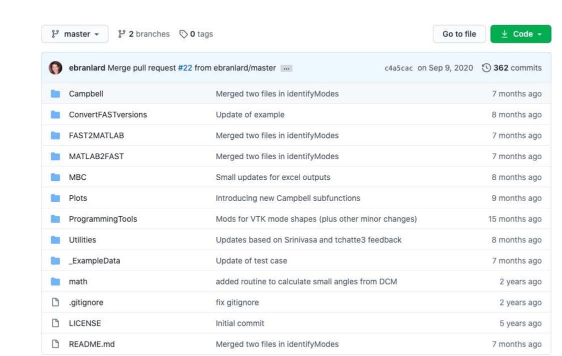
Conclusion

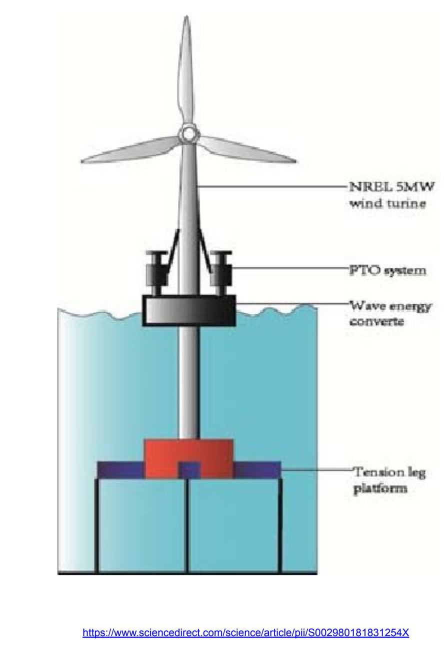
Out of the spar, barge, and semi-sub foundations, the spar will best be able to withstand region 2 wind in deep water because of weight distribution and shape.

Currently inconclusive, however previous literature and results thus far are in support of hypothesis.

Future Research

- Other foundations like a TLP
- Region 1 and 3 wind
- Special events
- New foundations





Acknowledgments

I'd like to thank
- My Science Research teacher, Ms. Gillian Rinaldo
- My mentor, Mr. Sam Roach
- My parents, Science Research peers, and friends

Sources

1. Borg, M., & Collu, M. (2014). A Comparison on the Dynamics of a Floating Vertical Axis Wind Turbine on Three Different Floating Support Structures. Energy Procedia, 53, 268-279. doi:10.1016/j.egypro.2014.07.236
2. Broekel, T., & Alfken, C. (2015). Gone with the wind? The impact of wind turbines on tourism demand. Energy Policy, 86, 506-519. doi:10.1016/j.enpol.2015.08.005
3. Energy efficiency and renewable energy sources. Common international terminology. (n.d.). doi:10.3403/30269797
4. Galiev, S. U. (2020). Wind-Induced Waves and Wind–Wave Resonance. Evolution of Extreme Waves and Resonances, 349-362. doi:10.1201/9781003038504-14
5. Hall, M., Buckham, B., & Crawford, C. (2013). Evaluating the importance of mooring line model fidelity in floating offshore wind turbine simulations. Wind Energy, 17(12), 1835-1853. doi:10.1002/we.1669
6. Jamil, M., Parsa, S., & Majidi, M. (1995). Wind power statistics and an evaluation of wind energy density. Renewable Energy, 6(5-6), 623-628. doi:10.1016/0960-1481(95)00041-h
7. tanding and minimizing wind turbine operation and maintenance costs. doi:10.2172/882048
8. Wind Turbine Blade Design Requirements. (2010). Wind Turbine Technology, 135-160. doi:10.1201/9781439815076-7
9. Byrne, Byron & Houlsby, Guy. (2004). Foundations for offshore wind turbines. Philosophical transactions. Series A, Mathematical, physical, and
10. Verification of Floating Offshore Wind Linearization Functionality in OpenFAST
11. N Johnson, J Jonkman, A Wright , G Hayman, and A Robertson 2019 https://iopscience.iop.org/article/10.1088/1742-6596/1356/1/012022/pdf
12. Substructure Flexibility and Member-level load capabilities for floating offshore wind turbines in OpenFAST Jason Jonkman, Rick Damiani, Emmanuel Branlard, Matthew Hall, Amy Robertson, and Greg Hayman 2019 https://www.nrel.gov/docs/fy20osti/74380.pdf
13. A review of foundations of offshore wind energy convertors: Current status and future perspectives
14. Ki-YongOh, Woochul Namb, Moo SungRyu, Ji-Young Kim, Bogdan I. Epureanu 2018 https://www.sciencedirect.com/science/article/pii/S136403211830025X?via%3Dihub