U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

# Integrated Systems Design and Analysis Offshore Wind
# Project ID #T10



Amy Robertson

National Renewable Energy Laboratory (NREL)


Right photo credit: Amy Robertson, NREL

# FY17-FY18 Wind Office Project Organization

“Enabling Wind Energy Options Nationwide”

| Technology Development | Market Acceleration & Deployment |
| --- | --- |
| Atmosphere to Electrons | Stakeholder Engagement, Workforce Development, and Human Use Considerations |
| Offshore Wind | Environmental Research |
| Distributed Wind | Grid Integration |
| Testing Infrastructure | Regulatory and Siting |
| Standards Support and International Engagement | |
| Advanced Components, Reliability, and Manufacturing | |

Analysis and Modeling (cross-cutting)

# Project Overview

## #10: Integrated Systems Design and Analysis; Offshore Wind

### Project Summary

Offshore wind has a significant potential to provide power to regions of the country where other sustainable energy sources are not readily available, or where space on land is constrained. While offshore wind costs have been decreasing on a global basis, innovative and optimized offshore wind technologies have the potential to reduce costs further. Without validated design tools, rapid technology innovation and the resulting cost reduction in the offshore wind industry will not happen.

### Project Objective & Impact

The core of this work is centered on the international Offshore Code Comparison, Collaboration, Continued, with Correlation (OC5) project, run under International Energy Agency (IEA) Wind Task 30. The objective of the work is to enable the rapid technology innovation of offshore wind systems and reduce cost through validation, improvement, and user training on the tools used to design these systems.

### Project Attributes

**Project Principal Investigator(s)**

Amy Robertson
Fabian Wendt
Jason Jonkman
Philipp Mucha

**DOE Lead**

Alana Duerr (Mike Derby)

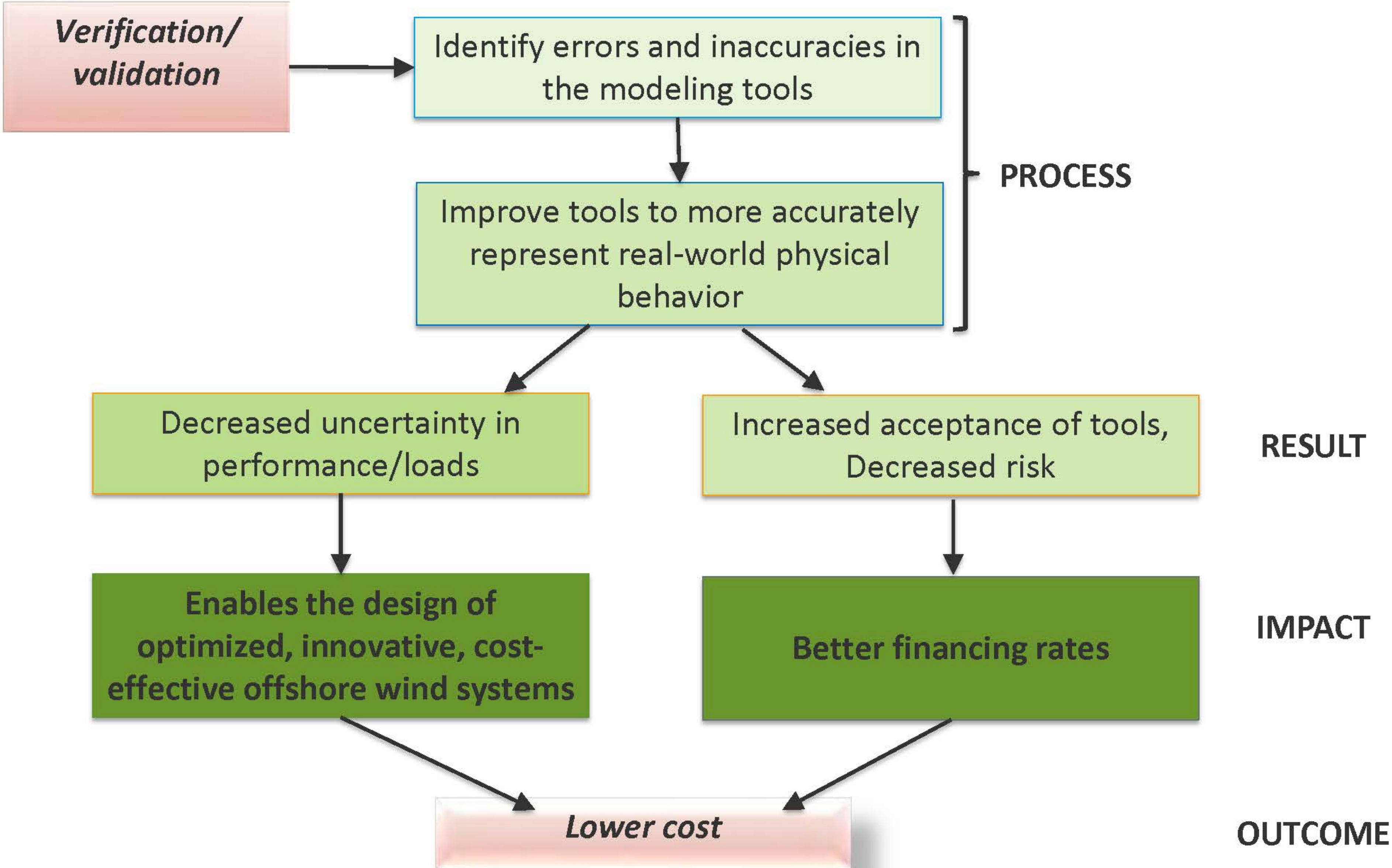
**Project Partners/Subs**

**OC5 project group** - including offshore wind designers, consultants, certifiers, developers, and research institutions.
**Major contributors:** Fraunhofer IWES, DNV GL, Norwegian University of Science and Technology, Technical University of Denmark, MARIN, OWEC Tower, Senvion.

**Project Duration**

FY17 – FY19

# Technical Merit and Relevance



# Approach and Methodology

- Coupled offshore wind design tools validated through a series of campaigns examining different configurations
- Validation achieved by comparing simulated loads/motion against measurements from a test campaign
  - **OC5** (2014-2018)
- Results from different tools show advantages/ disadvantages of modeling approaches
- Tools improved and research and development (R&D) topics identified based on findings from the project

**OC5**

*Photo by DHI [1]*

**Phase I**
2014-2015

*Photo by Andy Goupee, Univ. of Maine, 19576*

**Phase II**
2015-2016

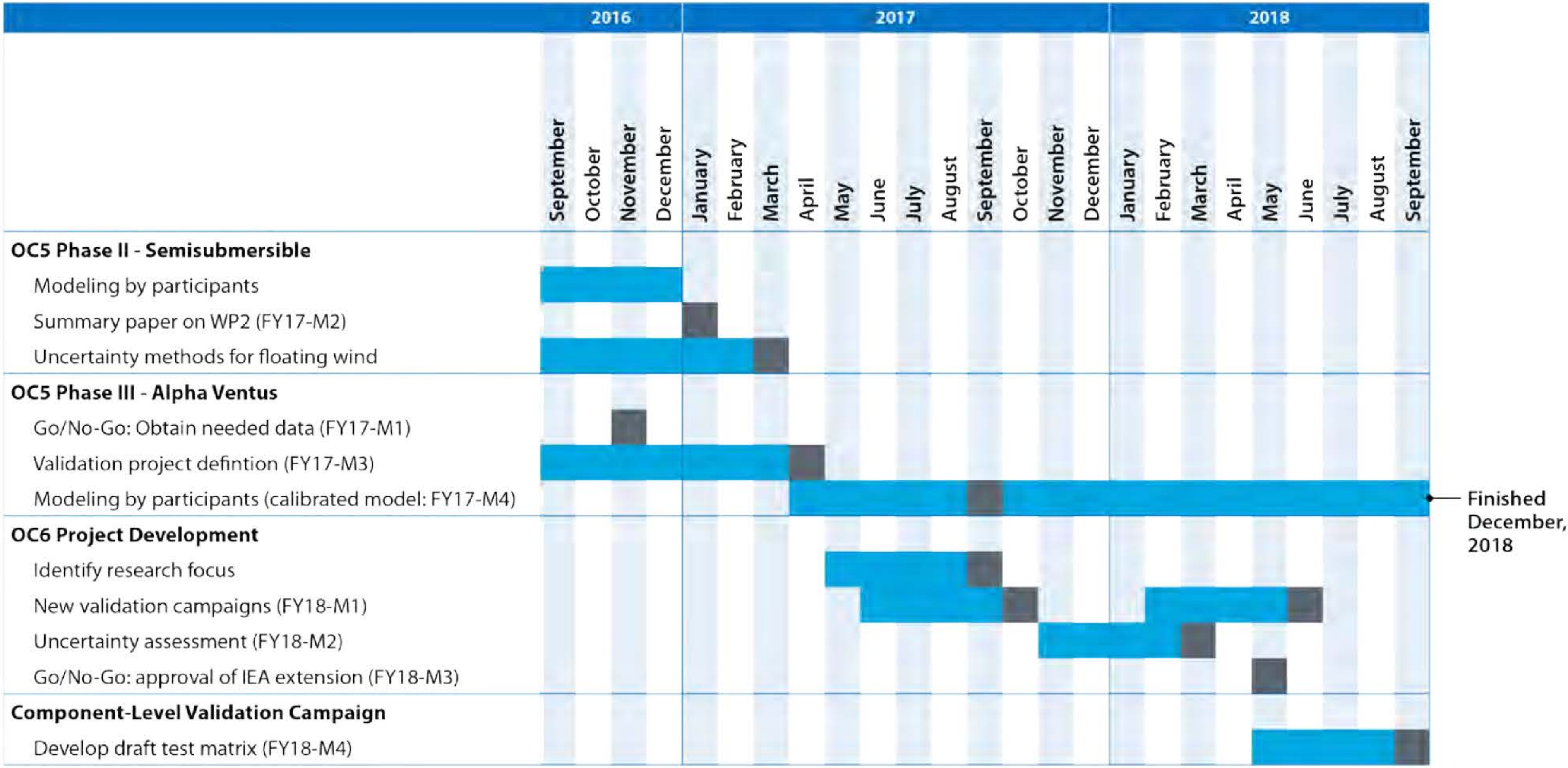
*Photo by Gary Norton, NREL, 27360*

**Phase III**
2017-2018

**OC5 led by NREL and Fraunhofer IWES**
Coordinates numerous offshore wind modeling activities to more quickly advance simulation tools to enable the design of more cost-effective, innovative solutions

1. Bredmose, H ; Slabiak, P ; Sahlberg-Nielsen, L ; Schlütter, F (2013) "Dynamic Excitation of Monopiles by Steep and Breaking Waves: Experimental and Numerical Study", *Proc. 32nd Int. Conference on Ocean, Offshore and Arctic Engineering* (OMAE 2013), 2013, Nantes, DOI: http://dx.doi.org/10.1115/OMAE2013-10948.

# Accomplishments and Progress: Overview



# Accomplishments and Progress: OC5 Phase III

- **OC5 Phase III: Validation of alpha ventus jacket loads**
- **First time: full-scale, open-ocean, commercial system**
  - PROS:
    - Realistic metocean conditions
    - Complex structure
    - No scaling issues
  - CONS
    - IP issues; mitigated by approximate turbine properties and controller – tuned against a model with full properties
    - Time measurements of wind/waves at the structure not possible.
    - Significant support from turbine and support structure designers, and research at Alpha Ventus consortium (RAVE)

Popko, W.; Huhn, M.; Robertson, A.; et al. (2018). "Verification of a Numerical Model of the Offshore Wind Turbine from the Alpha Ventus Wind Farm Within OC5 Phase III," Presented at the Ocean, Offshore and Arctic Engineering Conference, June 2018.

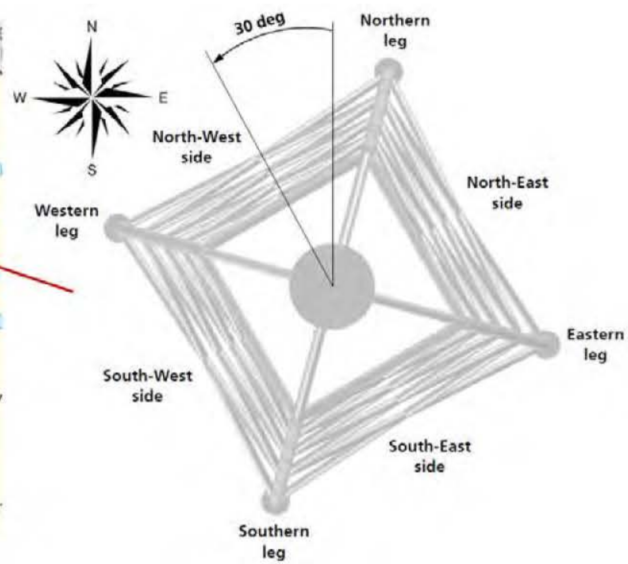





Photo credit: Gary Norton, NREL, 27360

# Accomplishments and Progress: OC5 Phase III

- **Findings:**
  - Simulated strains and accelerations agreed reasonably well with measurements for operational cases, idling, shut-down, and a yaw maneuver.
  - Need good quality check of sensors – inconsistencies in data provided by RAVE
  - Turbine response sensitive to:
    - controller and airfoil properties
    - wind characteristics beyond turbulence (e.g., coherence and shear)
    - damping
- **Deliverable:** Summary conference paper to be presented at 38th International Conference on Ocean, Offshore & Arctic Engineering in FY19

**Tools:** FAST v8, Bladed V4.8, HAWC2, DeepLinesWind V5R4, ASHES, DIEGO, FloaWDyn, NK-UTWind, MoWiT, SAMCEF Wind Turbines, SIMA, Simpack

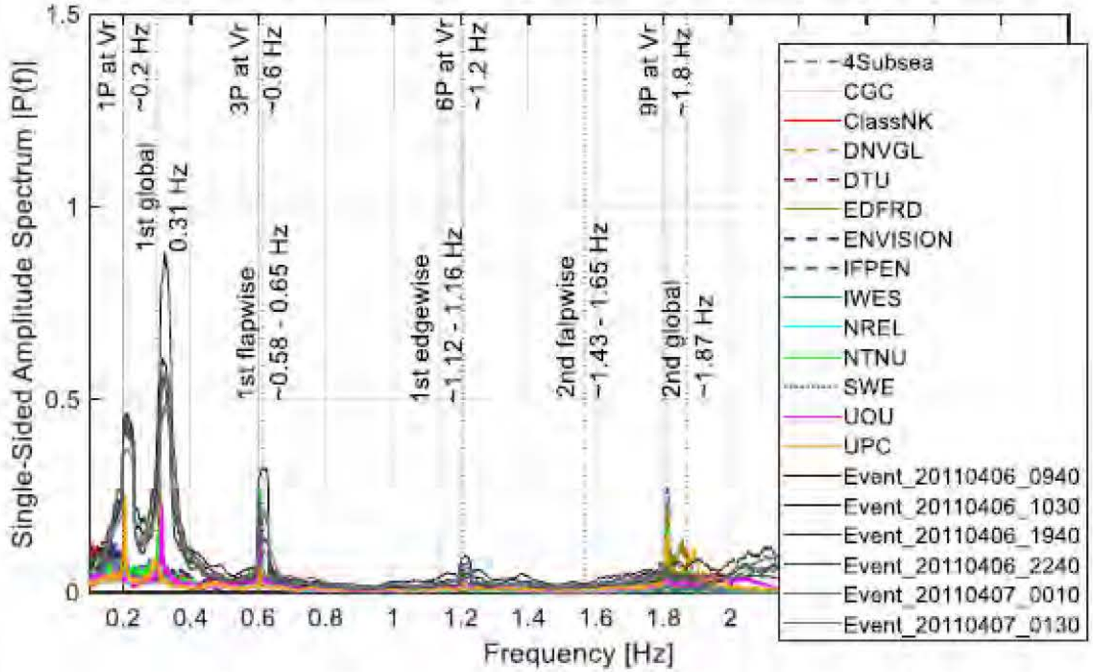



Figure: Spectrum of aggregated strain time series of 6 seeds at KP_2021 (Eastern leg, bottom)

**Participants submitting results:** Fraunhofer IWES, NREL, University of Stuttgart, OWEC Tower, Technical University of Demark, EDF Renewables, IFP Energies Nouvelles, Principia, Nippon Kaji Kyokai (ClassNK), 4Subsea, Norwegian University of Science and Technology, Simis AS, University of Ulsan, Polytechnic University Catalonia, Siemens Industry Software, Envision, Chinese General Certification, and DNV GL

# Accomplishments and Progress:
## Phenomena Identification Ranking Table (PIRT)

| Fixed-Bottom | Importance | Physics Understand | Model Adequacy | Validation Needs |
|---|---|---|---|---|
| **Fluid Dynamics** | | | | |
| 2D wave elevation variation in farm | L | M | L | L |
| Short-crested waves | M | H | M | H |
| Ability to model real spectra/ directionality | M | M | M | M |
| **Environment-Structure Interaction** | | | | |
| Multi-body flow interaction | M | M | L | H |
| Breaking/steep wave loads | H | M | L | H |
| VIV/VIM - substructure | L | L | L | H |
| Viscous load model | M | M | M | H |
| Member-level loads (including concrete) | H | H | M | M |
| Wave current-body interaction | M | M | L | L |
| Soil/structure interaction | H | M | L | H |
| Marine growth influence on loads | M | H | H | L |
| Multi-scale | H | M | H | H |

- **Based on work performed in previous OC projects, PIRT developed to guide future validation work.**
- **Developed by OC5 members at IEA Wind TEM #88 – October 2017**

| Floating | Importance | Physics Understand | Model Adequacy | Validation Needs |
|---|---|---|---|---|
| **Fluid Dynamics** | | | | |
| Short-crested waves | M | H | M | H |
| Low-frequency wind spectra/coherence | H | M | L | H |
| Ability to model real spectra/directionality | M | M | M | M |
| **Environment-Structure Interaction** | | | | |
| Nonlinear excitation – diff/sum/mean | H | M | M | H |
| Multi-body flow interaction | H | M | L | H |
| Breaking/steep wave loads | L | M | L | H |
| VIV/VIM - substructure | M | L | L | H |
| Viscous load model | H | M | M | H |
| Potential combined with viscous | H | M | M | H |
| Member-level loads (including concrete) | H | H | L | M |
| Instantaneous position for wave loads | H | M | H | H |
| Wave current-body interaction | H | M | L | M |
| Nonlinear hydrostatics + Froude-Krylov | H | M | L | M |
| Influence of elasticity on motion | M | H | L | M |
| Aerodynamic applicability under motion | H | L | M | H |
| Marine growth influence on loads | L | H | H | L |
| Multi-scale | H | M | H | H |
| Sloshing (ballasting, holes) | H | M | L | H |
| **Controls** | | | | |
| Negative damping from blade pitching | H | H | H | H |
| **Moorings/Cables** | | | | |
| Seabed friction – mooring | H | H | M | L |
| Wave forcing – mooring loads | H | H | H | L |
| Line hysteresis (mooring/cable) | H | M | M | L |

# Accomplishments and Progress:

## New Validation Campaigns

- **In OC5 Phase II,** tools under-predicted motion/loads of semisubmersible when subjected to wave loading
- **Phenomenon at issue:** nonlinear force created by wave components interacting, which can excite the natural frequencies of the system and cause large motions

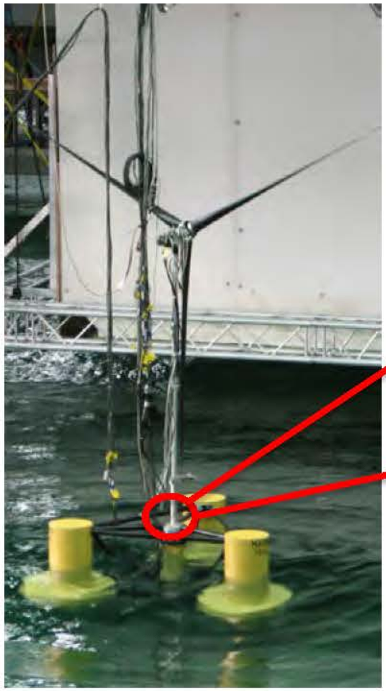
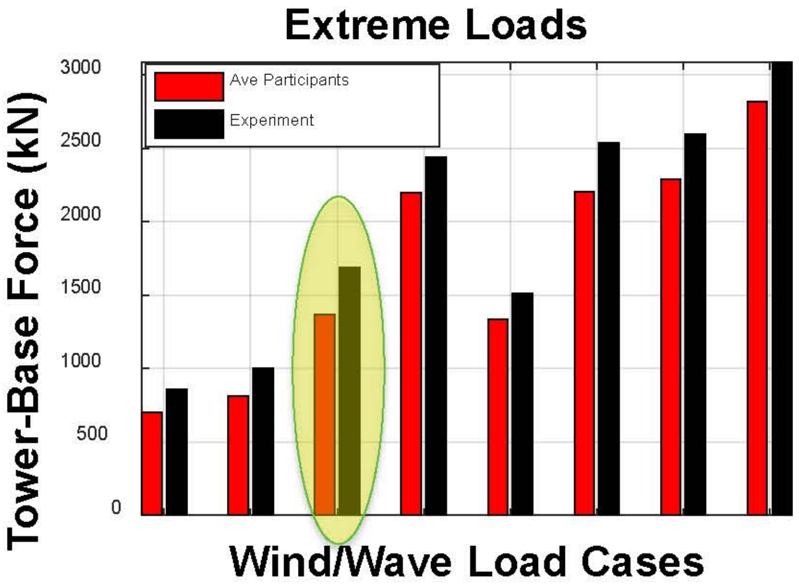
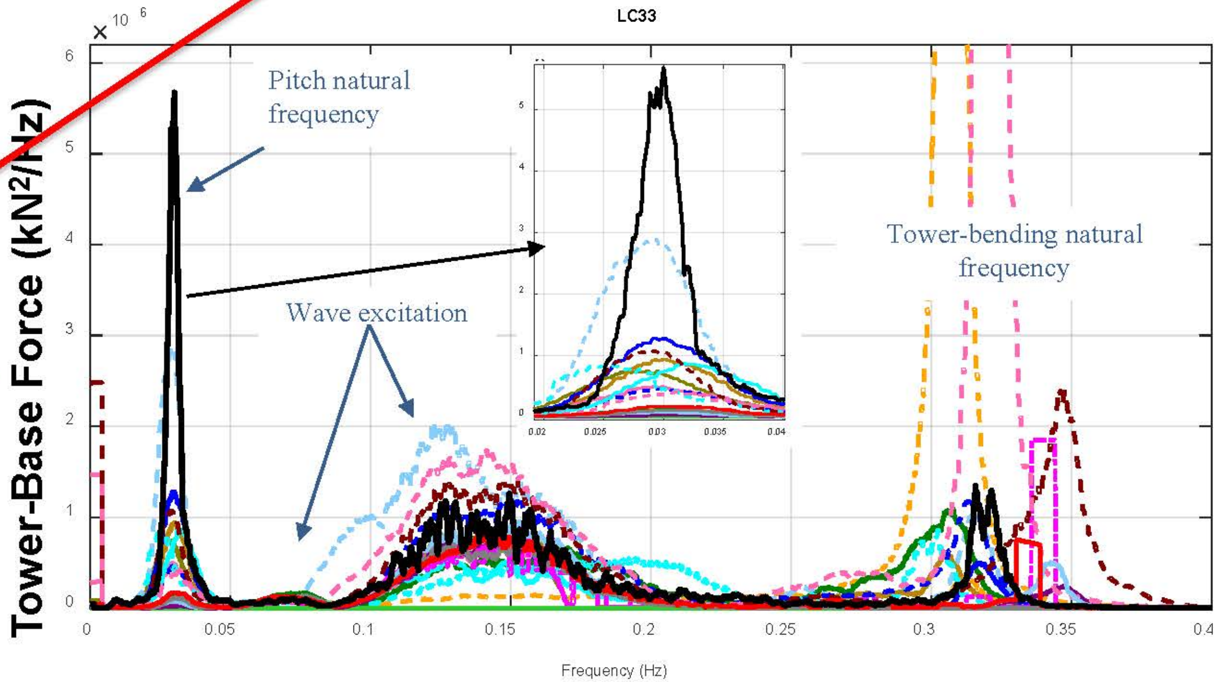


*Photo by Andy Goupee, Univ. of Maine, 19576*



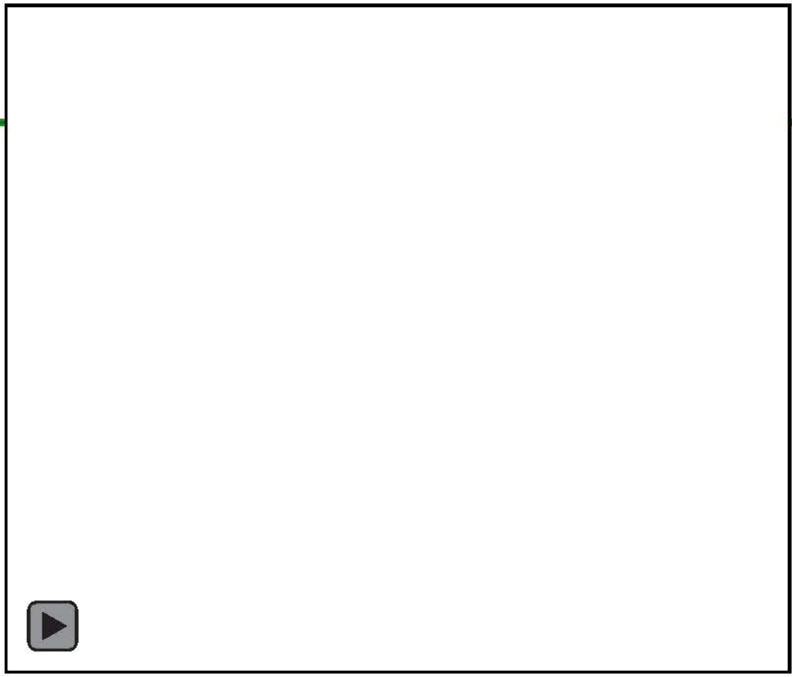



# Accomplishments and Progress:

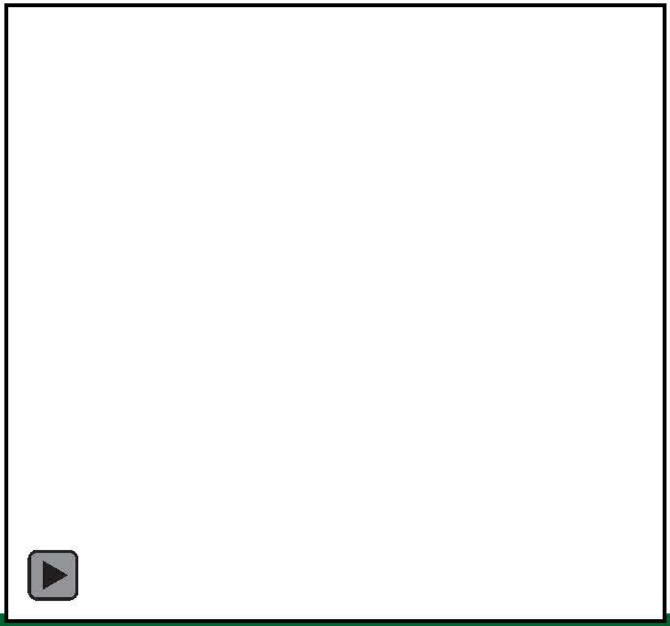
## New Validation Campaigns

- **New validation campaigns** performed to understand phenomenon (at MARIN Concept Basin in the Netherlands):
  - **Moored (Oct 2017):**
    - Focus on assessing uncertainty in measurements
    - Simplified system
      - No turbine, rigid tower, simple mooring
    - Funded by MaRINET2
  - **Fixed (June 2018):**
    - Focus on breaking apart hydrodynamic components
    - Fixed system under wave loading, and forced motion
    - Funded by MARIN and NREL
- **Data to be analyzed in OC6 project** (Offshore Code Comparison Collaborative, Continued, with Correlation, and unCertainty)

*Video by Amy Robertson, NREL*



*Video by Amy Robertson, NREL*



# Accomplishments and Progress

- **Slipped milestones and schedule**
  - All milestones were completed within the specified time.
- **Go/no-go decision points**
  - FY17-M1: Was needed data to perform OC5 Phase III received? Go
  - FY18-M3: Was Approval of IEA Task 30 extension (OC6) granted? Go
- **Project Schedule:**
  - OC5: Jan. 2014 – Dec. 2018
  - New validation campaigns:
    - Oct. 2017
    - June 2018
- **Issues Addressed:**
  - Delays in getting data for Phase III, as well as issues with data quality/uncertainty
  - Extended project schedule and enlisted additional help and expertise

**Notable achievements in this 2-year period:**

- ✓ OC5 Phase II Work Package
  - Published in the Energy Procedia journal
- ✓ Verification for OC5 Phase III
  - Published in Conference on Ocean Offshore & Arctic Engineering (OMAE) 2018 conference paper
- ✓ Two new validation campaigns at MARIN
- ✓ Experimental uncertainty assessment of floating validation campaign
  - Published in OMAE 2018 conf. paper
- ✓ Approval of the IEA Wind Task 30 extension, OC6 (Offshore Code Comparison Collaboration, Continued, with Correlation, and unCertainty)
- ✓ Phenomenon Identification Ranking Table
- ✓ New linearization capability for floating wind systems in OpenFAST
- ✓ Test matrix for a new component-level validation campaign
  - To be performed in FY19

# Communication, Coordination, and Commercialization

*The *OC3-OC5 projects have led to dramatic improvements in model accuracy of industry design tools as the comparisons and lessons learned have helped identify deficiencies and needed improvements.*

- **Tangible Results:**
  - Improvement of industry design tools based on findings from project
  - Specifications on how to best approach offshore wind modeling
  - Public benchmark problems (designs/data) for further research
  - 6 conf. papers, 2 journal articles, and 2 NREL publications
- **Semi-monthly teleconferences and bi-annual meetings for OC5**
  - 195 people,78 organizations in 20 different countries have participated; including offshore wind designers, consultants, certifiers, developers, and research institutions.
- **Outreach:**
  - Topical Experts Meeting – IEA Wind Task 29, 30, and 31 – to identify future focus areas
  - Industry outreach meeting – June 2018 – input on OC6 focus areas
  - Presentations at conferences: International Offshore Wind Technology Conference, AWEA Offshore, International Partnering Forum
- **Integration with related European offshore wind projects:**
  - LIFES 50+: Optimization/qualification of innovative floating designs
  - Floating Wind Joint Industry Project: Recommended practice for floating wind model development and validation
  - INNWIND: Component design for 10-20 MW offshore wind systems
  - WEAMAC: West Atlantic Marine Energy Center on Floating Wind

- ***173 citations of the 7 summary papers from OC3-OC5***
- ***235 citations for other NREL papers focused on OC4-OC5***

**OC3 = Offshore Code Comparison Collaboration (2005-2009)*
**OC4 = Offshore Code Comparison Collaboration, Continued (2010-2014)*

# Upcoming Project Activities

- **OC5**
  - Phase III concluded in Dec 2018 – closing the OC5 project
- **OC6**
  - 4-year project: Jan 2019 – Dec 2022
  - Will integrate project into A2e's Data Access Portal (DAP)
    - Will house all OC project work here (OC3 – OC6)
- **Component-Level Validation Campaign**
  - Better understand hydrodynamic loading on offshore wind system components
  - Testing will be performed in FY19 at a U.S. facility
  - Data will be uploaded to DAP

https://a2e.energy.gov/about/dap