Research objectives: My main research goal is to provide more accurate estimates of extreme hydrodynamic and aerodynamic loads on offshore wind turbines (OWTs), specifically wave and wind loads during hurricanes. To this end, I propose to numerically simulate OWTs subjected to extreme wind and waves using computational fluid dynamics (CFD). This research aims to advance basic understanding of OWT loads by answering the questions:

1. How do extreme hydrodynamic and aerodynamic loads on OWTs vary for different support structures and hurricane characteristics?
2. How do OWTs (especially floating OWTs) respond to hurricane wind and waves?

Motivation: To meet the federal goal of 20% electricity from wind energy by 2030, the U.S. wind industry must expand to include offshore wind development. Offshore wind offers several advantages over onshore wind, including the mitigation of aesthetic and land use issues, as well as the utilization of abundant, high-quality offshore wind resources in proximity to population centers [1]. However, wind farms off the eastern and southern U.S. coast could be destroyed by hurricanes, unless their support structures are designed with such extreme loads in mind [2]. These designs require accurate load data, but experimental data is mostly unavailable due to the lack of OWTs in hurricane-prone areas. So, current OWT simulations find hydrodynamic and aerodynamic loads using simple empirical models, which are much less accurate than CFD [3]. This inaccuracy is catastrophic when designing OWTs to withstand hurricanes, so using CFD to better predict extreme loads will inform more robust OWT designs.

Methods: To generate hydrodynamic and aerodynamic loads typical of hurricanes, I will numerically simulate OWTs subjected to extreme, hurricane-like wind and waves. These simulations will be done in the CFD software Converge from Convergent Science. Unlike most CFD software, Converge doesn't require user-made meshes, which means researchers can complete simulations faster. Converge's adaptive automatic meshing also improves solution accuracy for moving objects like floating OWTs, since the grid resolution adapts where necessary. Converge could also fix stability issues found when modeling floating OWTs in other CFD software like OpenFOAM [4].

I will first identify hurricane parameters characteristic of the U.S. coast, focusing on areas where OWT development is likely. I will then validate my predicted hydrodynamic and aerodynamic loads against experimental and numerical data: CFD-based numerical data for non-extreme waves is available from Benitz [4], while proprietary experimental data for loads from Hurricane Irene is available from industry collaborators. Aerodynamic loads will be validated against the open literature for onshore wind turbines. Finally, I will create databases of hydrodynamic and aerodynamic loads corresponding to various hurricane parameters for several support structure types.

The predicted non-hurricane hydrodynamic loads will be validated for some OWT structures prior to the beginning of the proposed project: the proposed team (detailed below) is currently collaborating on a 1-year project on OWTs in breaking waves, which includes validating the predicted hydrodynamic loads on non-floating structures against numerical data and experimental data from industry partners.

Deliverables: The main deliverables of the project and their estimated times of completion are:

1. Identify representative hurricane characteristics for the U.S. coast (2 months),
2. Validate aerodynamic loads against experimental data (3 months),
3. Validate hydrodynamic loads against experimental and numerical data (5 months),
4. Generate hydrodynamic and aerodynamic load databases for various hurricane parameters for non-floating structures (12 months) and floating structures (14 months).

Collaborations: This work will involve collaboration between University of Massachusetts faculty from two departments, as well as collaboration with industry partners (Convergent Science and others in development). Dr. David Schmidt and Dr. Matt Lackner (Mechanical Engineering) have previously studied hydrodynamic loads on OWTs [3,4], and have access to the computing resources necessary for CFD. Dr. Schmidt also worked in Converge on other applications, and his long relationship with Convergent Science enables their collaboration and assistance in introducing hydrodynamics and aerodynamics as new applications. Dr. Sanjay Arwade (Civil Engineering) brings expertise in OWT support structures and hurricanes' impacts on OWTs.

Intellectual merit: The proposed project furthers basic scientific understanding of OWT loads, introduces better software for OWT modeling, and provides better data for structural models of OWTs. First, using CFD to study extreme hydrodynamic and aerodynamic loads on OWTs will improve fundamental understanding of how OWT support structures behave during hurricanes, which is currently hindered by overly simple models and a lack of experimental data. Second, this project will validate a faster, more accurate CFD software for OWTs and other ocean engineering applications. Third, this research will provide more accurate loads used in OWT structural analysis, like that done by civil engineers. These results will be distributed at wind energy and CFD conferences, in journal articles, and in my PhD dissertation.

Broader impacts: By providing more accurate hydrodynamic and aerodynamic hurricane loads for use in structural OWT models, the proposed project allows for better designs of OWTs that can withstand hurricanes. Hurricane-resistant OWTs lower the risks of offshore wind, encouraging the widespread development of offshore wind energy in the U.S. and other hurricane-prone countries. In this way, the proposed research contributes to the growth of renewable energy on the national and global scale.

References

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