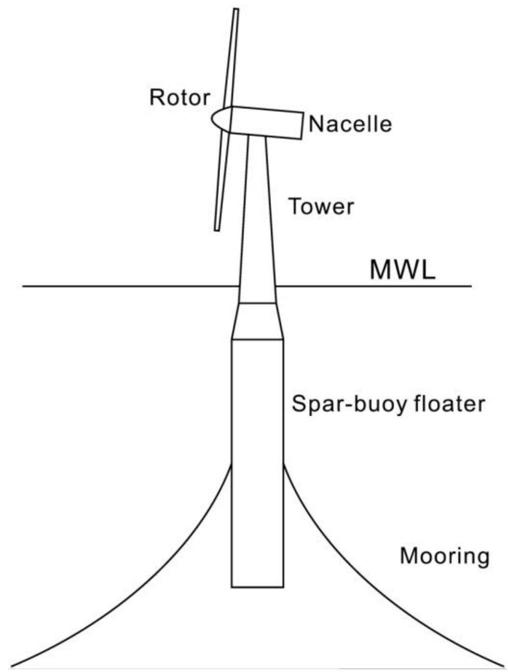
OE44185 – Project Deadline: 13/06/2025

Modelling a Floating wind turbine

Introduction:

This project is designed to apply and deepen your understanding of computational modeling techniques in offshore and dredging engineering. You will use the principles learned in the "Numerical Methods for Offshore and Dredging Engineering" course to develop a numerical simulation of a Floating Offshore Wind Turbine (FOWT) system. The focus will be on the OC3 phase-IV spar-buoy concept, incorporating structural and hydrodynamic modeling to analyze its dynamic behavior under offshore environmental conditions.



This project emphasizes hands-on numerical experimentation and algorithm development. You will work with Python or MATLAB to develop and validate your simulation. Additionally, following the FAIR principles, you will ensure that your computational work is transparent, reproducible, and scientifically rigorous.

The project is divided into two main parts, each with specific requirements and objectives related to structural analysis and flow characterization.

Part 1. Structural analysis

The project will require you to construct a simplified yet representative 2D model of the FOWT system, considering different structural elements with appropriate mechanical approximations. The wind turbine itself will be modeled using the NREL 5MW reference turbine, and the mooring system will consist of catenary mooring lines.

Structural model

To pass the course, the model should include the following key aspects:

- A point mass representation for the Rotor-Nacelle Assembly (RNA)
- A thin beam model for the wind turbine tower
- A rigid body formulation for the floating spar-buoy
- Spring/damper system to represent mooring system with properties taken from a quasi-static analysis

For a maximum grade, the model should include:

- Coupled axial-bending model for the turbine tower
- Geometrically nonlinear strings to represent the mooring system
- (optionally) extension to model the floater as a flexible beam

Hydrodynamic/Aerodynamic force estimation

Throughout this project, you will implement numerical methods to account for offshore environmental forces such as wind, waves, and currents. Your simulation will be expected to capture key system responses and provide insights into the dynamic behavior of the floating wind turbine. The model should include the following hydrodynamic/aerodynamic forces:

- Wave loading:
  - Linear wave theory (Airy waves) as a baseline approach for regular waves.
  - Morison force (inertia and drag terms, including added mass and added damping)
- Wind loading:
  - Equivalent thrust force at the nacelle (constant)
- Current loading:
  - Mean forces computed from Part 2.

For a maximum grade, you should include the following forces:

- Wave loading:
  - Irregular waves
- Wind loading:
  - Time dependent thrust force
- Current loading:
  - Time dependent force computed from Part 2.

Structural dynamic analysis

With the structural model and the hydrodynamic/aerodynamic force estimation you can assess the dynamics of the structure. Your dynamic assessment should include:

- Identification of natural frequencies and modes of the structure
- Dynamic response of the structure at key locations (nacelle, COG, …)
- Dynamic response of the structure using a reduced order model with few relevant modes.

Part 2. Computational Fluid Dynamics

Current loading model

To pass the course, the 2D model should include the following key aspects:

- A square cylinder with no-slip boundaries
- An inlet with a specified velocity and zero gradient boundary for pressure
- An outlet with zero gradients for the velocity and fixed values for the pressure
- Stress free boundaries at the upper and lower walls
- A routine to compute the viscous and pressure forces on the cylinder

For a maximum grade, the model should include:

- The possibility to use periodic boundary conditions on all walls and force the flow
- The possibility to model circular cylinders using a volume-penalization method
- The possibility to increase the resolution around the cylinder

Current loading analysis

With the current loading model, you can assess the forces on the cylinder. Your assessment should include:

- The computation of the pressure and viscous drag coefficients as function of inlet velocity
- An analysis of the Strouhal number for transient cases
- Comparison with literature values and reflection on possible model improvements

Deliverables:

As a final deliverable you should write a report that does not exceed 15 pages with the sections described below. Together with the report you need to provide an executable file, or notebook, that can reproduce the results reported in the document.

<u>Section 1. Model Definition :</u>

- Obtain dimensions and design the model. Higher complexity in the geometry definition, higher grade (inclusion of all elements has maximum grade).
- Describe governing equations and characteristic loading, including (possibly) time-dependent wave/wind/current loading.

<u>Section 2. Numerical Methods:</u>

- Derive discrete formulation using Finite Element Method (structure) and Finite Volumes (currents). Inclusion of terms not discussed in class will be valued positively if their inclusion is properly justified.
- Detail geometry discretization, Finite Element space, shape functions, weak form, boundary conditions, and loading.
- Justify all your choices.

Section 3. Numerical Schemes:

- Implement the discrete formulation, utilizing appropriate time discretization methods. You can use the notebooks given in the lectures as starting point. More efficient implementations will be valued positively.

Section 4. Results Analysis:

- Validate structural deformations with literature data.
- Conduct convergence study (in space) and analyse time stepping.
- Analyze response based on literature's operating conditions.
- Perform modal analysis and relate mode shapes/frequencies to loading conditions.

Additional Requirements:

- Justify choices and provide supporting references.
- Supplement findings with relevant graphics.

Assessment Criteria:

- Quality of the final model (10 points).
- Correct definition and derivation of numerical model (30 points).
- Correct implementation of numerical model (10 points).
- Correct analysis of results, including convergence, validation, and response assessment (50 points).

The report and supporting code should be submitted through “Assignments” in Brightspace. The due date is **Friday 13/06/2025 at 23:59.**