EuroCC@Türkiye – METU RÜZGEM

CFD and Performance Simulations of Wind Turbines

Hydrodynamic Analysis of Floating Wind Turbines

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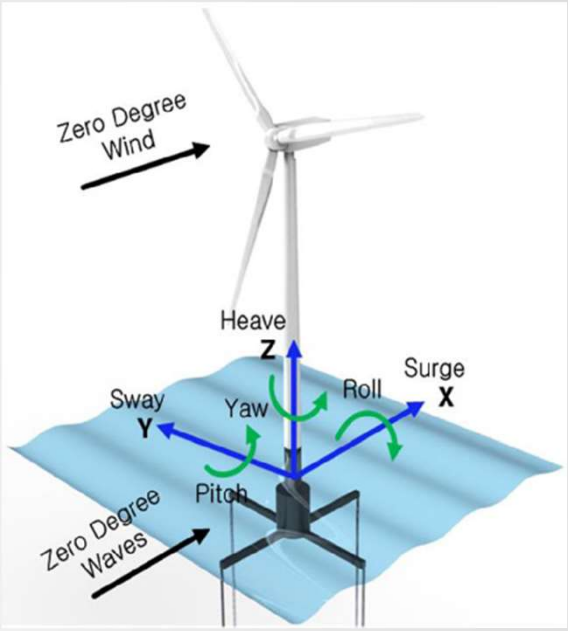
Supervisor: Assoc. Prof. Dr. Elif Oğuz

Outline

- Introduction
- Floater Design Concerns
- Conceptual Design Approaches
- Numerical Methods for Fluid Flow
- Panel Method Outputs
- Panel Method Codes
- Second Part – HAMS Application

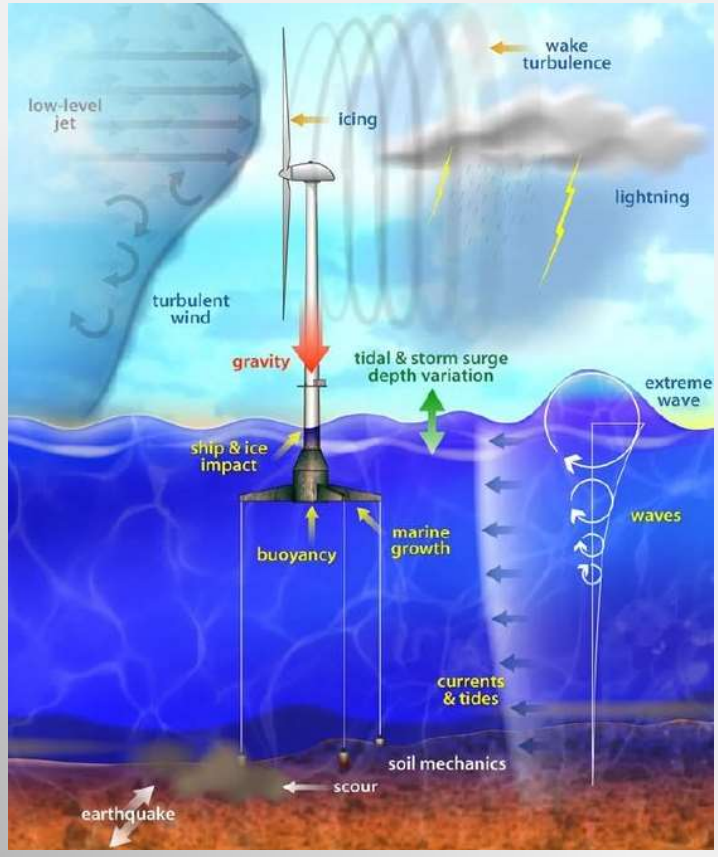
Introduction
Offshore Wind Turbine Foundations

(DHIgroup, 2021)

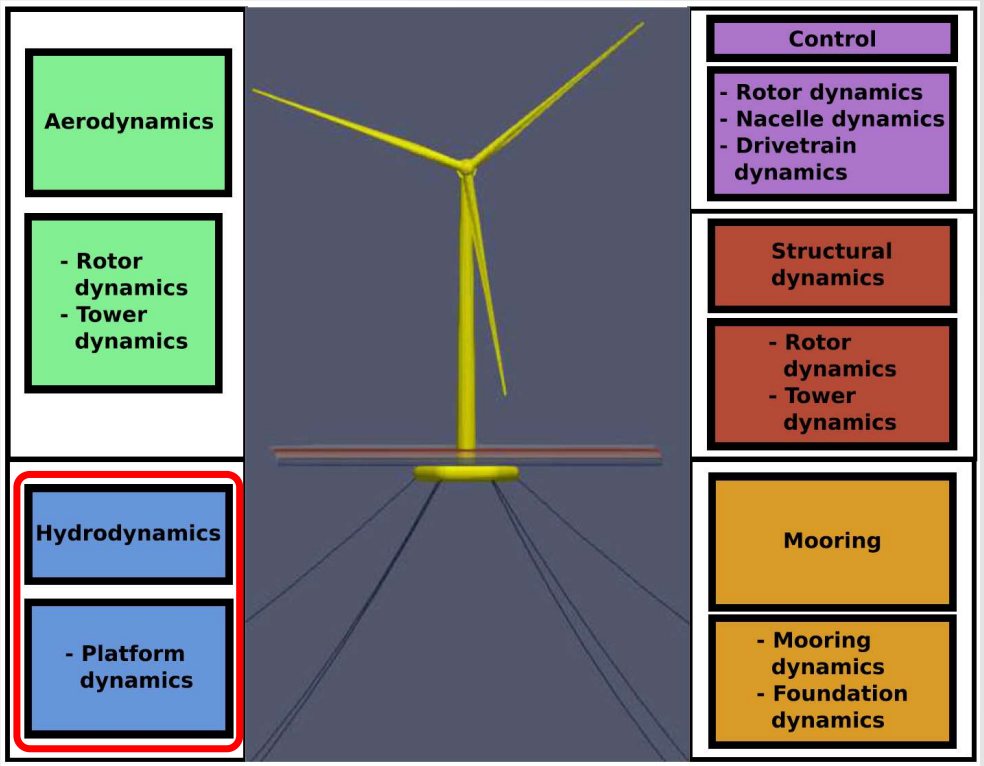


(Toan Tran et al., 2015)

Introduction
Coupled Dynamics of Floating Wind Turbines



(Jonkman, 2005)



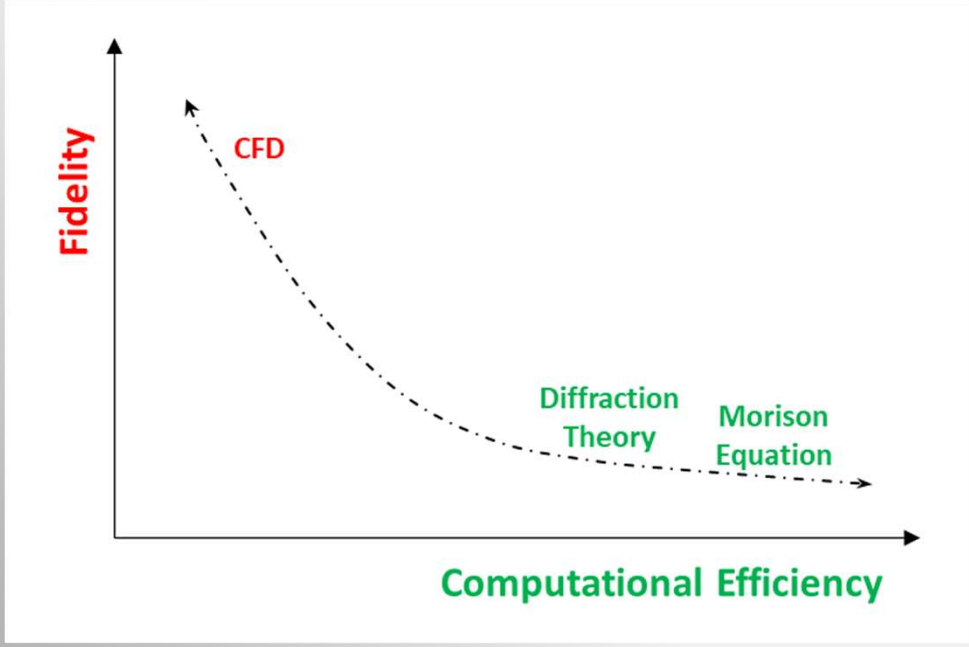
(Faraggiana et al., 2022)

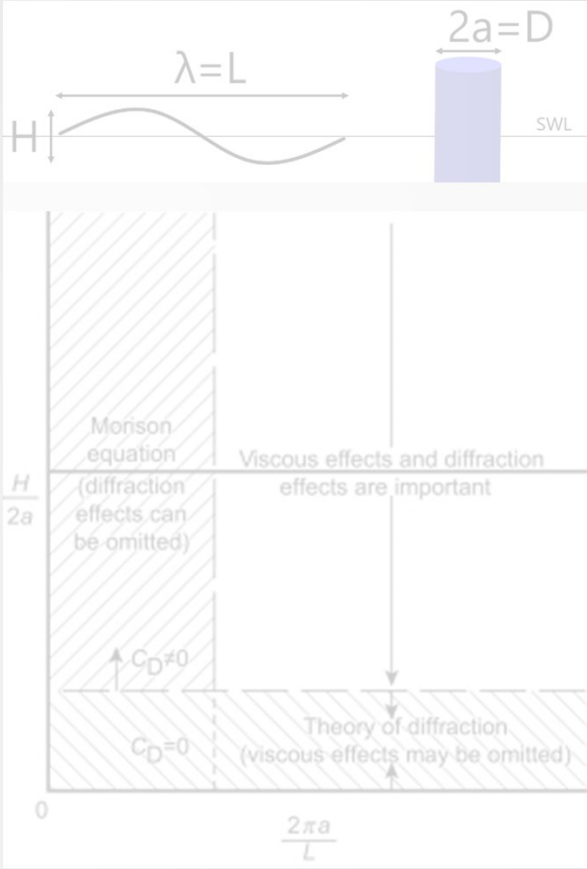
Floater Design Concerns

Fidelity – Computational Efficiency Relation

Hydrodynamic design order:

Detailed<Basic<Conceptual





(Fang & Duan, 2014)

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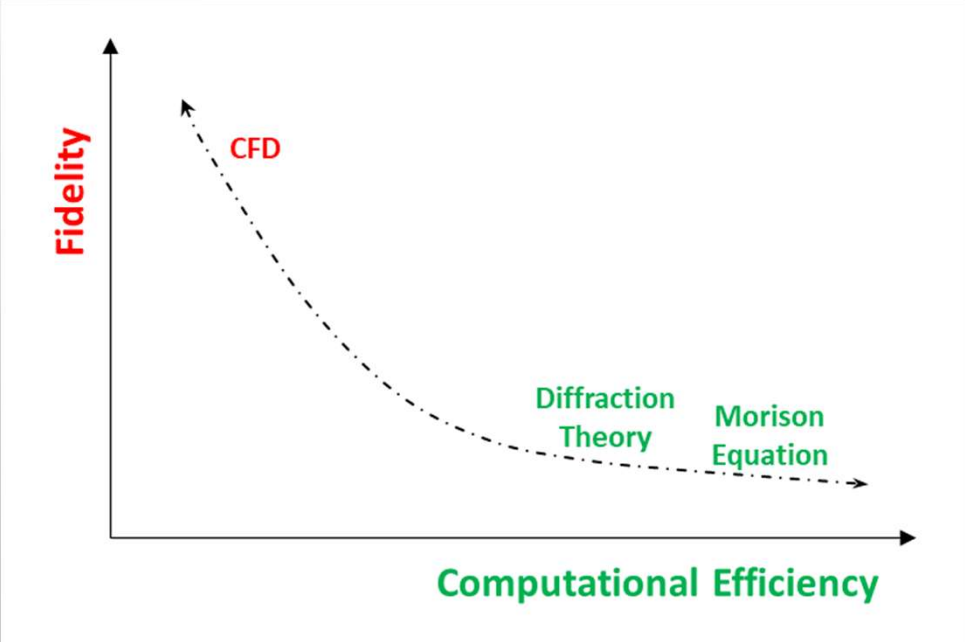
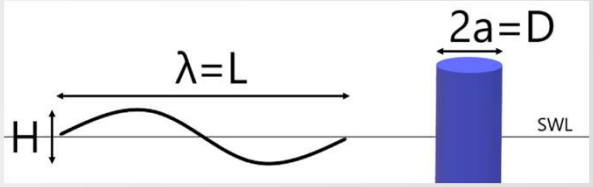
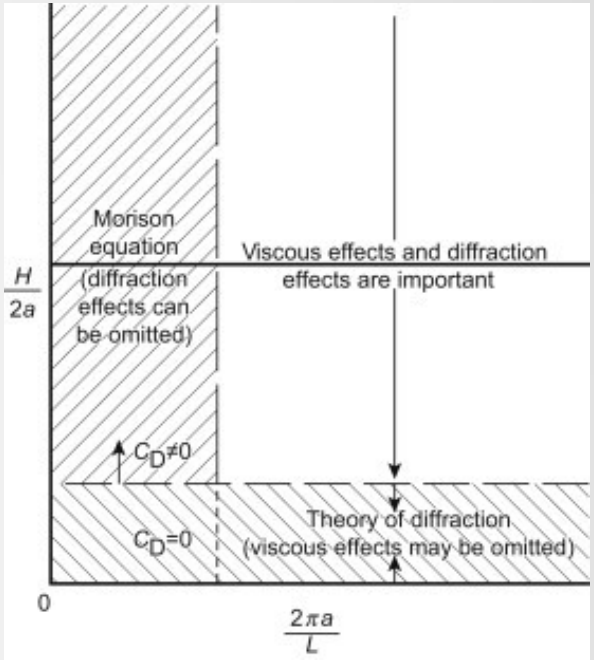




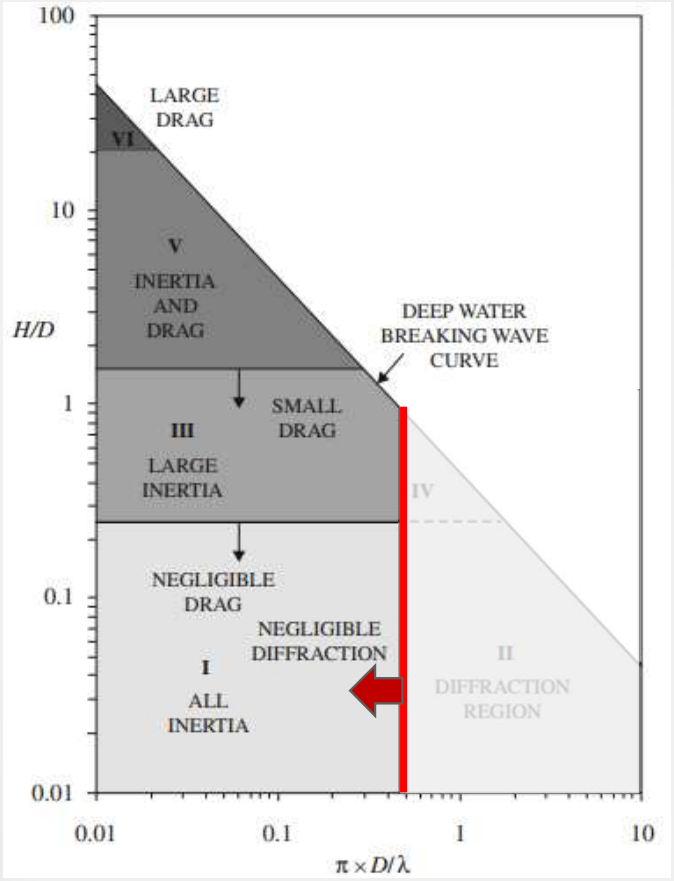


(Fang & Duan, 2014)

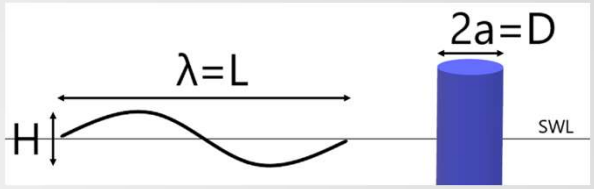
Conceptual Design Approaches
Morison Equation

Morison Equation

$$F = \underbrace{\rho C_m V \dot{u}}_{F_I} + \underbrace{\frac{1}{2}\rho C_d A u|u|}_{F_D},$$



(Chakrabarti, 1987)



Diffraction Theory

$$\nabla^2\varphi = \frac{\partial^2\varphi}{\partial x^2} + \frac{\partial^2\varphi}{\partial y^2} + \frac{\partial^2\varphi}{\partial z^2} = 0$$

Conceptual Design Approaches
Diffraction Theory

Morison Equation

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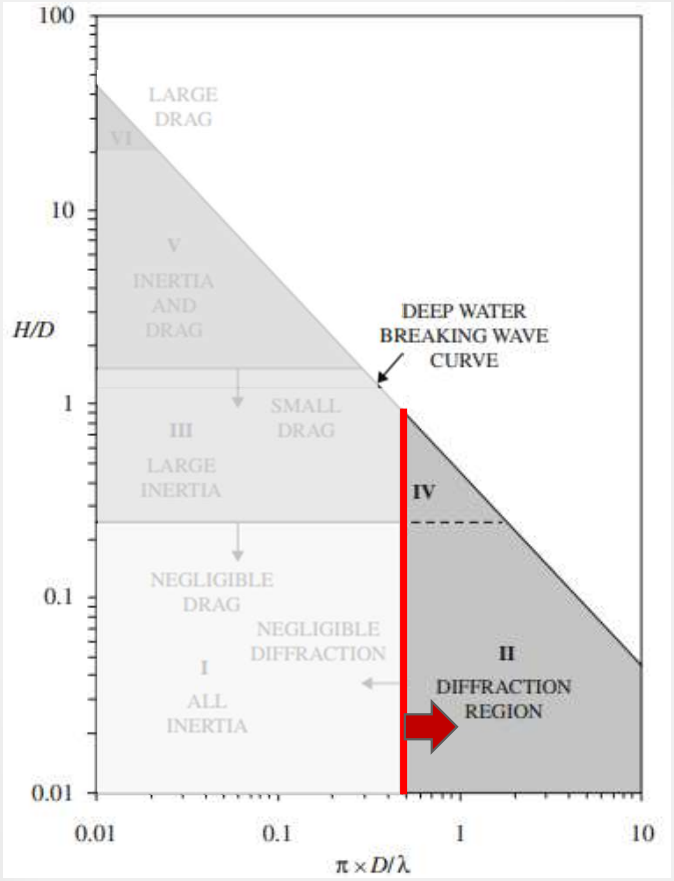

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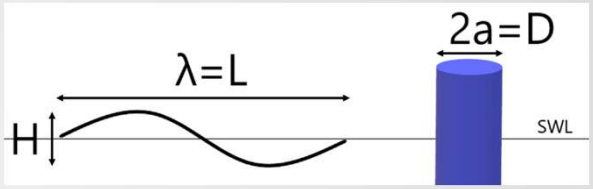


Diffraction Theory

$$\nabla^2\varphi = \frac{\partial^2\varphi}{\partial x^2} + \frac{\partial^2\varphi}{\partial y^2} + \frac{\partial^2\varphi}{\partial z^2} = 0$$

Conceptual Design Approaches

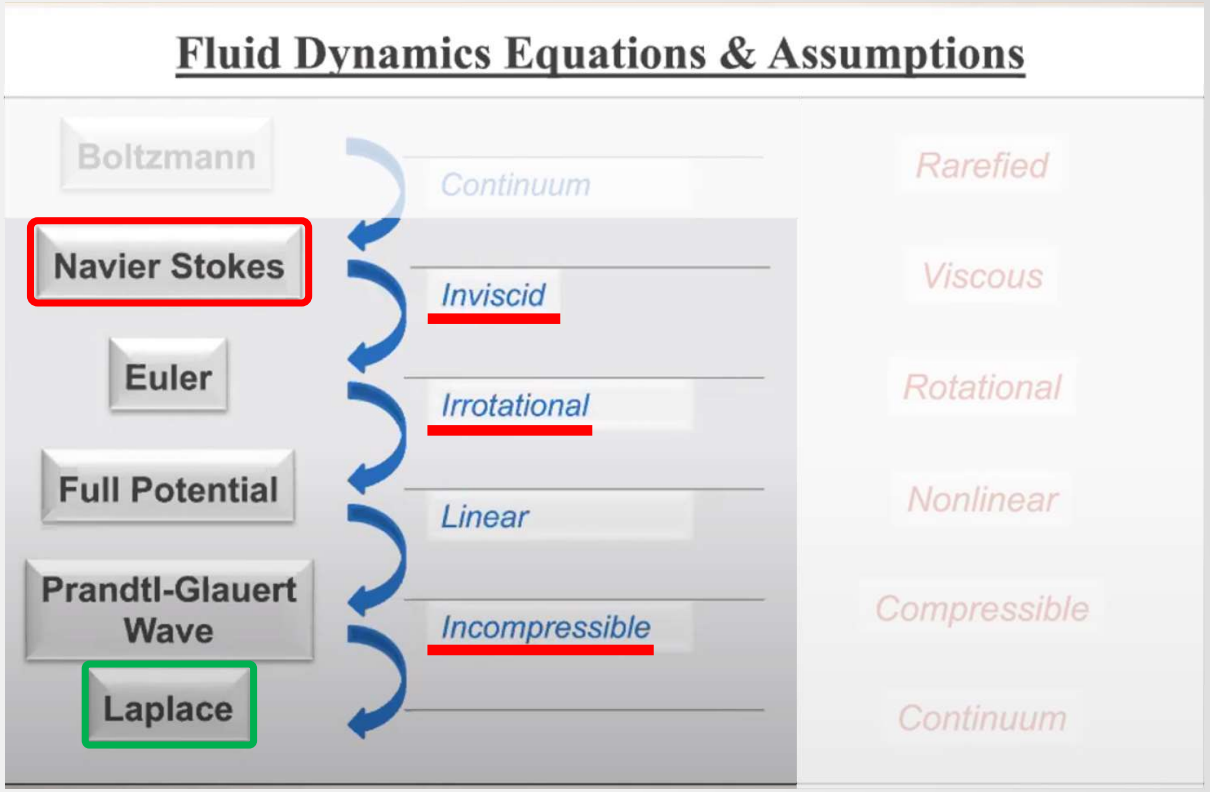
Diffraction Theory - Assumptions

Fidelity & Details

Computing Cost

CFD

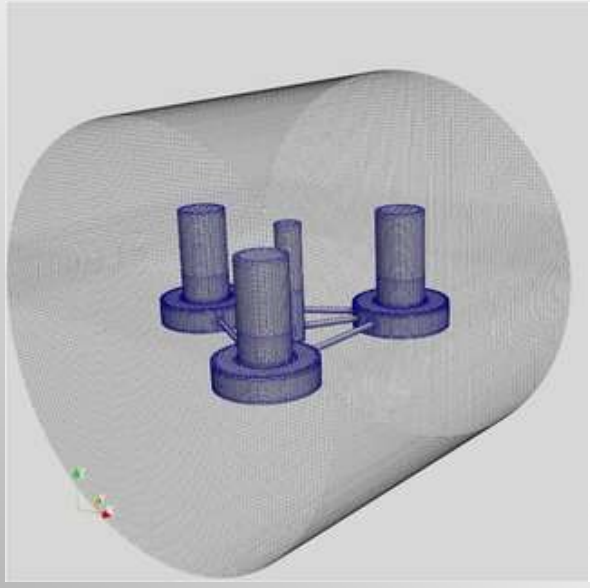
Diffraction Theory



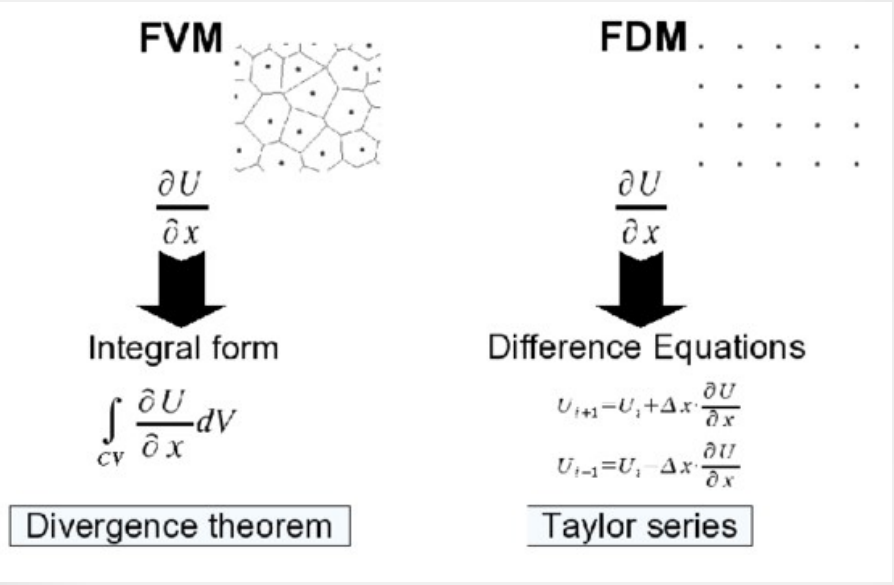
https://docs.truba.gov.tr/education/cfd/index.html

Numerical Methods for Fluid Flow

Panel Method – BEM applied to fluid dynamics



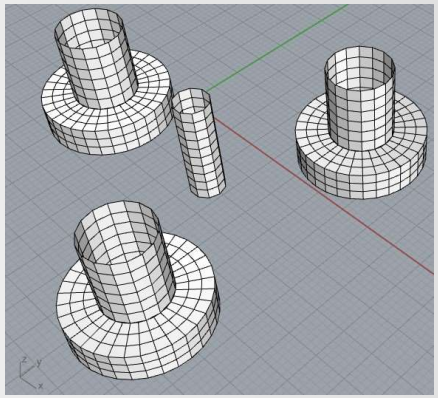
(Zhou et al., 2019)



(Milbradt & Abed, 2008)

Panel Method

$$\nabla^2 \varphi = 0$$

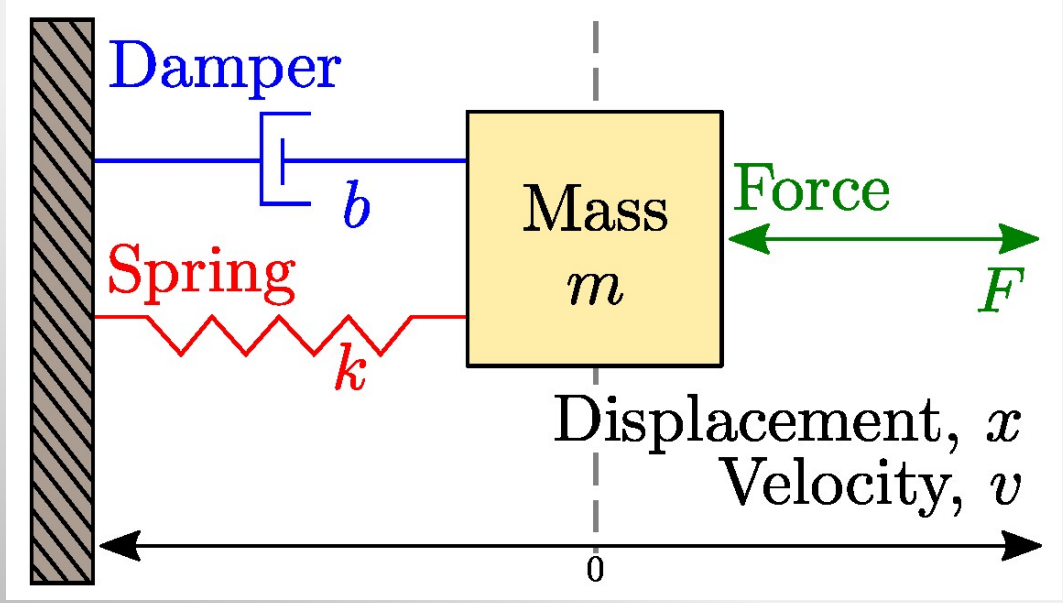


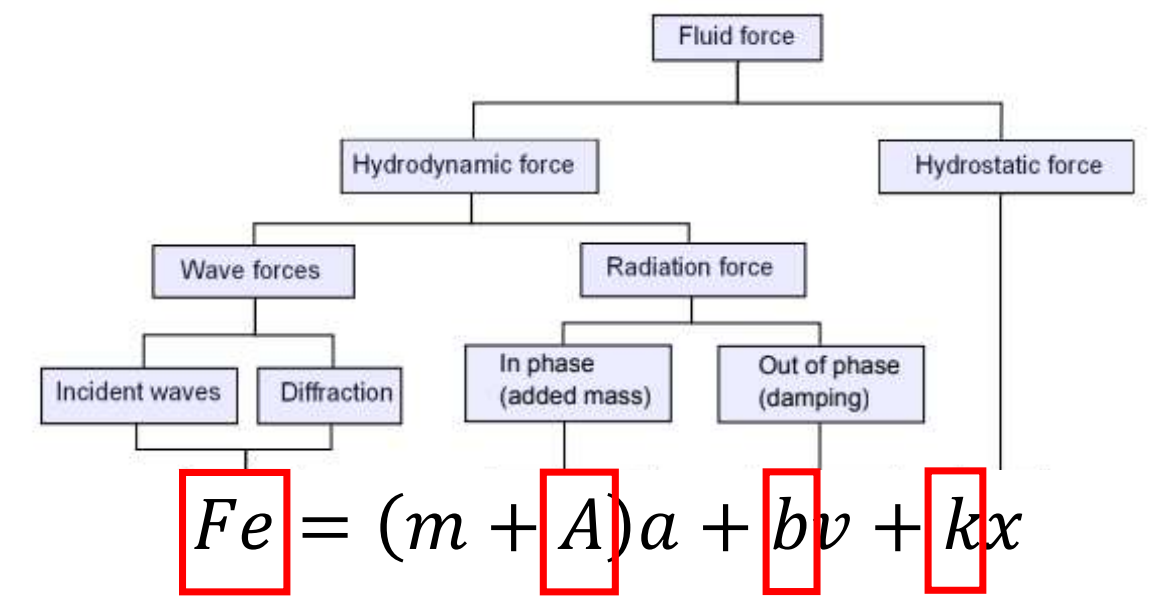
Numerical Methods for Fluid Flow

Panel Method – BEM applied to fluid dynamics

Aspect	FVM	FDM	Panel Method (BEM)
Domain	Control volumes	Entire domain	Boundary only
Mesh Generation	Control volume-based	Grid-based	Boundary-based
Governing Equations	PDEs	PDEs	Integral equations
Boundary Conditions	Integrated over CVs	Applied at nodes	Integral equations
Unknowns	Cell averages	Node values	Boundary values
Numerical Stability	CFL condition	CFL condition	Stable
Solution Approach	Iterative	Direct or Iterative	Direct (LU decomposition, etc.)
Applicability	General	General	Boundary value problems

Panel Method Outputs
Motion Dynamics





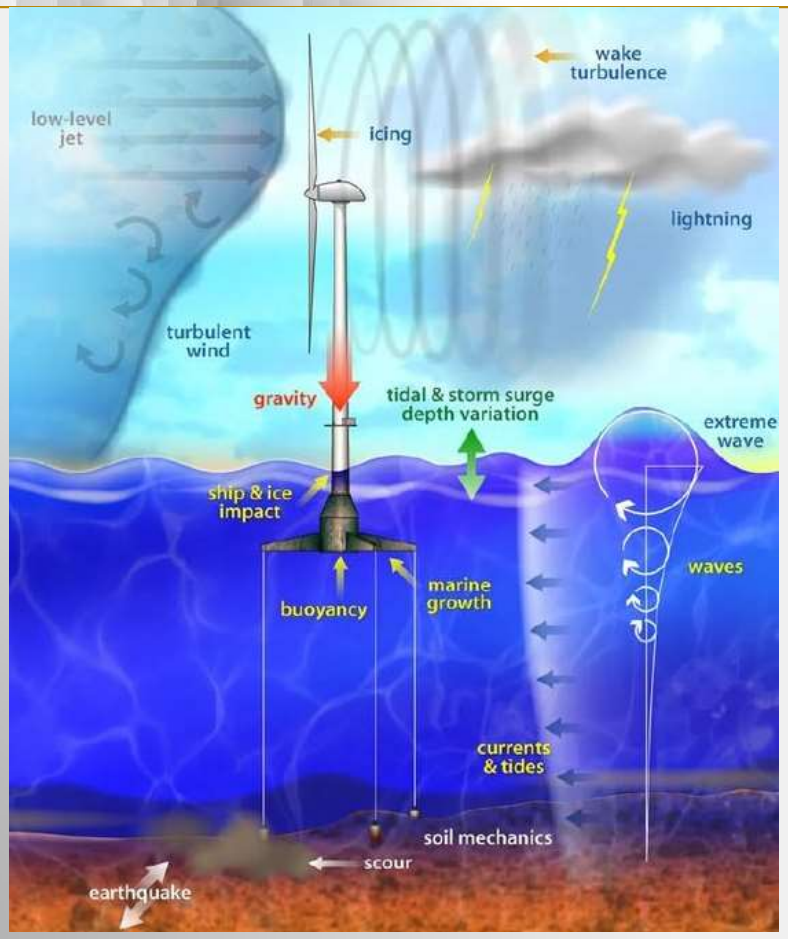
$$\frac{Fe}{(m + A)a + bv + kx} = RAO$$

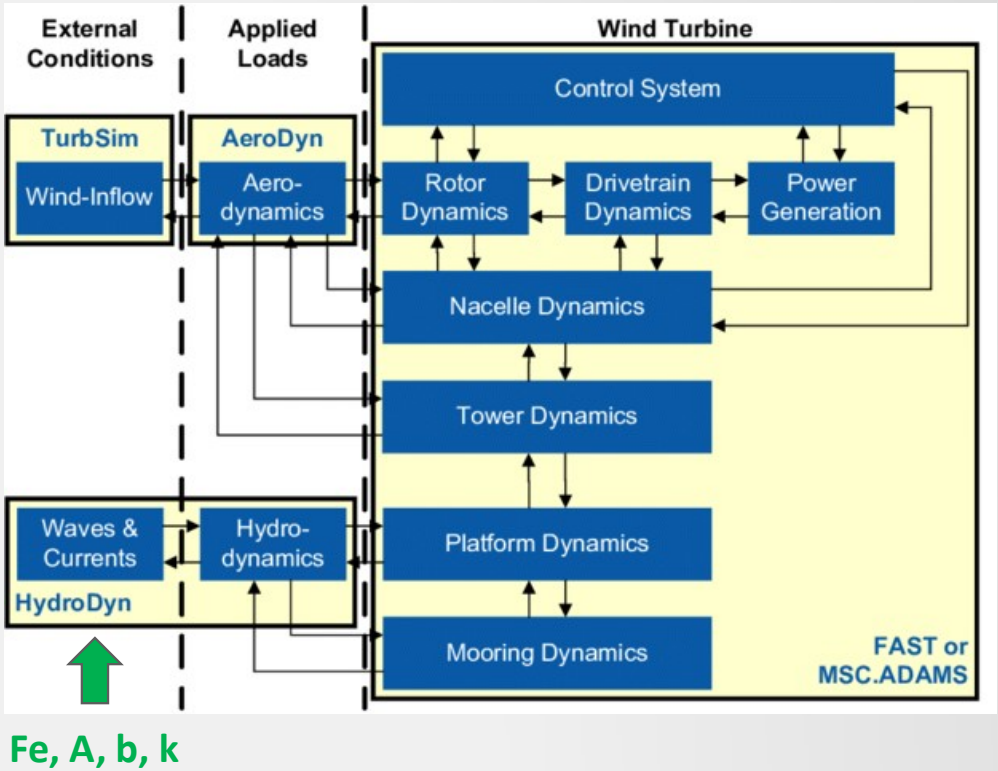
(Cruz-Duarte et al., 2020)

(Cheng et al., 2017)

Panel Method Outputs

OpenFAST Modules

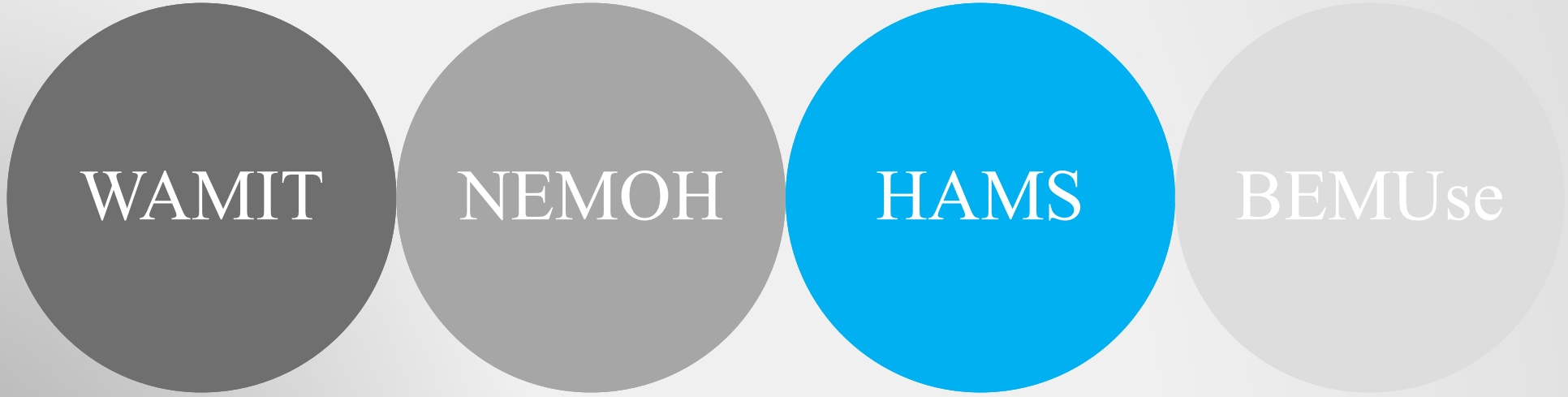




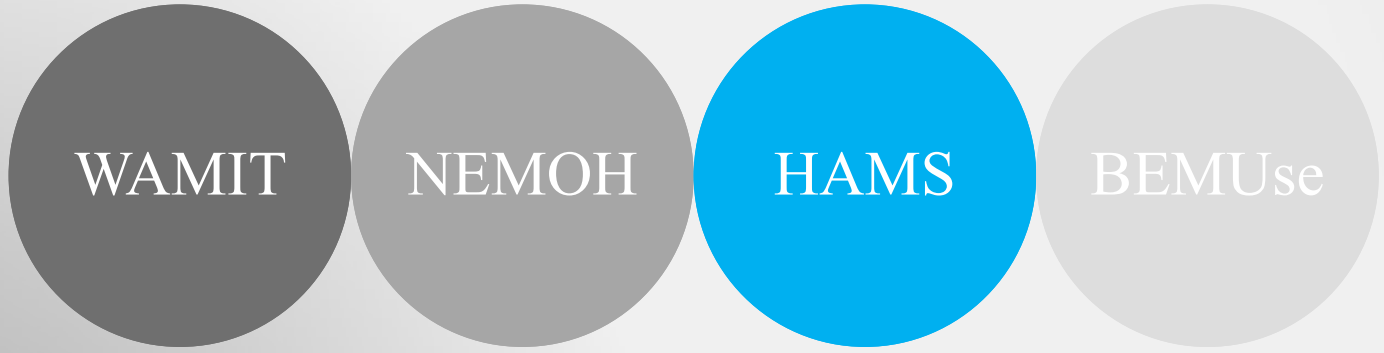
Fe, A, b, k

(Jonkman, 2005)

Panel Method Codes



Panel Method Codes
Comparative Study



- Mesh study
- Hydrodynamic coefficient comparison
- Resultant motion comparison with FAST
- Spectral-density based analysis on resultant motion data

Panel Method Codes
Comparative Study - Conclusions

Results more deviate about natural frequencies of the platforms

Resultant motion differences are statistically insignificant

Open Source Codes can be used in FWT platform dynamics

Panel Method Codes
Comparative Study - Publications

Ucar, M., Uzunoglu, E., Oguz, E. (2021). "*Comparison and Evaluation of Open-Source Panel Method Codes against Commercial Codes", Proceedings of 2nd International Congress on Ship and Marine Technology, e-ISBN: 978-605-01-0713-5, 2021*

Ucar, M., Uzunoglu, E., Oguz, E. (2022). "*Comparison and Evaluation of Open-Source Panel Method Codes against Commercial Codes",* GMO Journal of Ship and Marine Technology, DOI: 10.54926/gdt.1106386

Ucar, M., Hmedi, M., Uzunoglu, E., Oguz, E. (2023). Effect of Panel Method Codes in Estimating the time-domain responses of Floating Wind Turbines [Under-review]. Civil Engineering Faculty, Middle East Technical University.

HAMS Hydrodynamic Modeling Test Case

Application Part

Modeling Phases

Pre-process

Process

Post-process

Modeling Phases

Pre-process

- Mesh generation and Transfer
- Hydrostatic stiffness matrix definiton (k)
- Control file definiton

Process

- Run the executive file

Post-process

- .1 file contains Added Mass & Radiation Damping
- .3 file contains Excitation Force
- Using BemRosetta

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Pre-process

Mesh generation and Transfer

- Create the mesh with Rhino
- Export the file in .gdf extension
- Use MeshTran to obtain .pnl files

Hydrostatic stiffness matrix definiton (k)

- Copy restoring matrix from Hydrostatic.in file

Control file definiton

- Follow the instructions given in the Manual file

Pre-process

Mesh generation and Transfer	• Create the mesh with Rhino • Export the file in .gdf extension • Use MeshTran to obtain .pnl files
Hydrostatic stiffness matrix definiton (k)	• Copy restoring matrix from Hydrostatic.in file
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Post-process

.1 file contains the Added Mass & Radiation Damping	• You may handle the data with Excell or any code
.3 file contains Excitation Force	• You may handle the data with Excell or any code
Using BemRosetta	• Graphical User Interface • Quick mesh check & healing • Easy data handling

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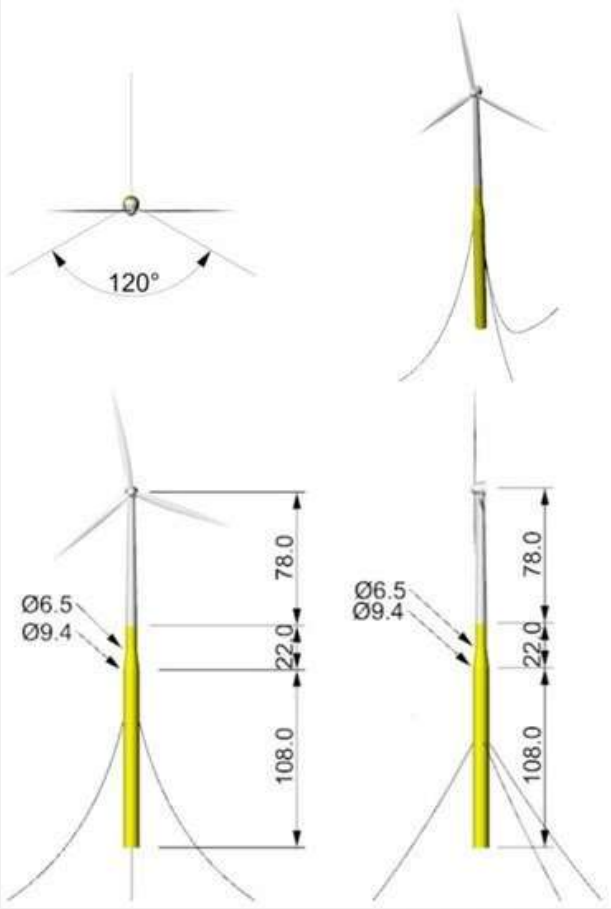
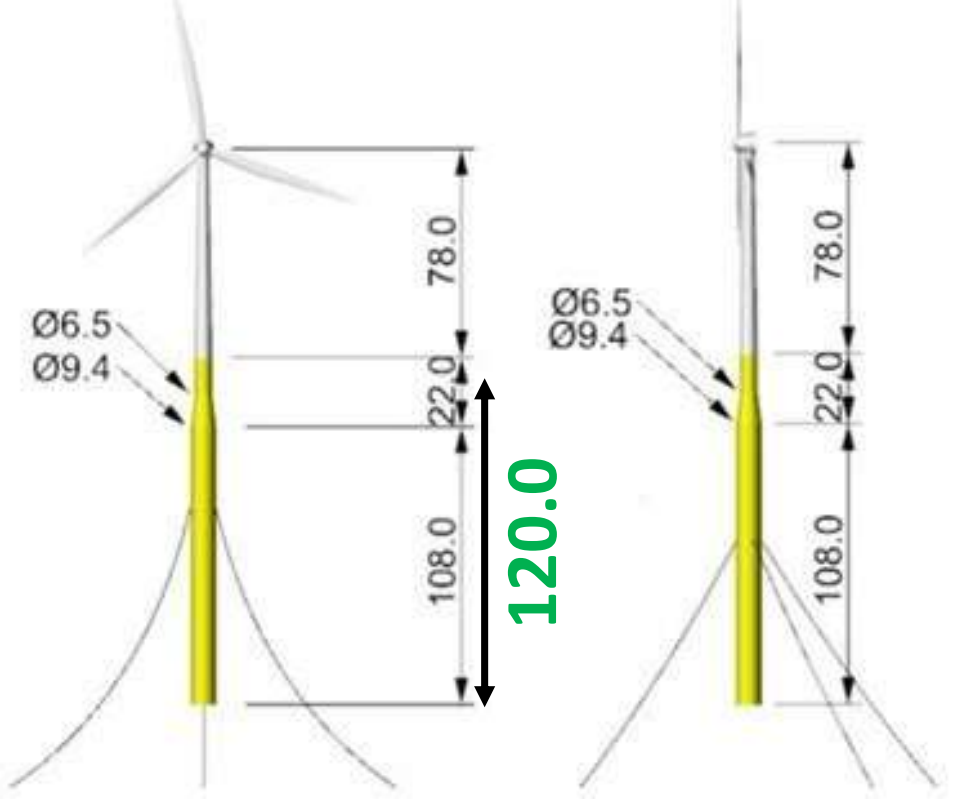
OC3 Hywind Spar Buoy




Ø6.5
Ø9.4
78.0
22.0
108.0
120.0
Ø6.5
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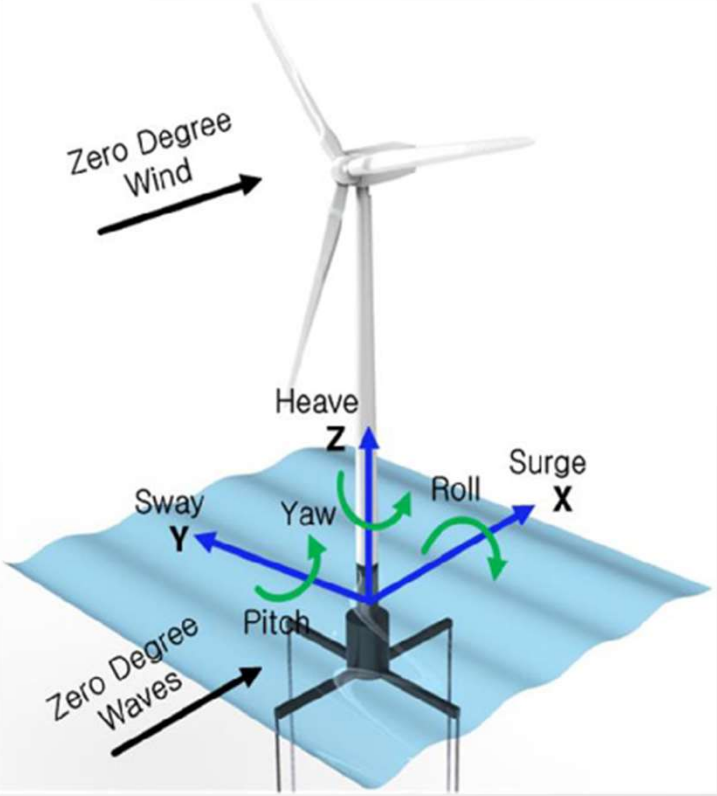
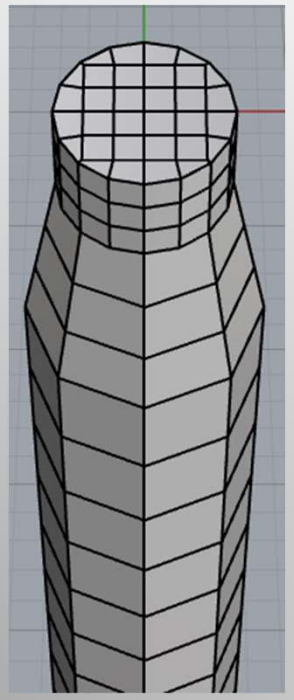
78.0
22.0
108.0

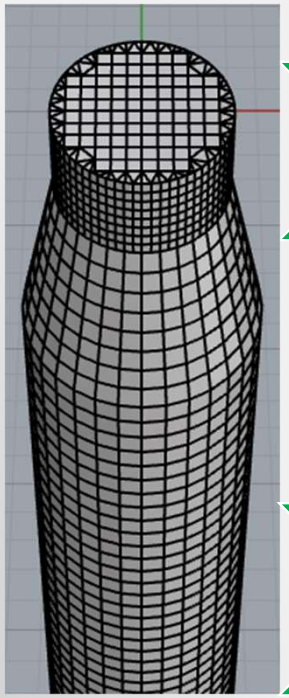

Zero Degree
Wind
Heave
Z
Surge
X
Sway
Y
Yaw
Roll
Pitch
Zero Degree
Waves

Mesh Study

M1



M4



Volumetric Representation

M1	M2	M3	M4
90%	96%	98.9%	99.4%

Precision-Convergence

1-M1/M4	1-M2/M4	1-M3/M4	1-M4/M4
5.52%	2.42%	0.41%	

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- Cruz-Duarte, J. M., Rosales-García, J. J., & Correa-Cely, C. R. (2020, March 4). Entropy Generation in a Mass-Spring-Damper System Using a Conformable Model. *Symmetry*, *12*(3), 395. https://doi.org/10.3390/sym12030395
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Thank you for listening