Challenges in the hydrodynamics modelling of Floating Offshore Wind Turbines (FOWT)

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TWIND Summer School
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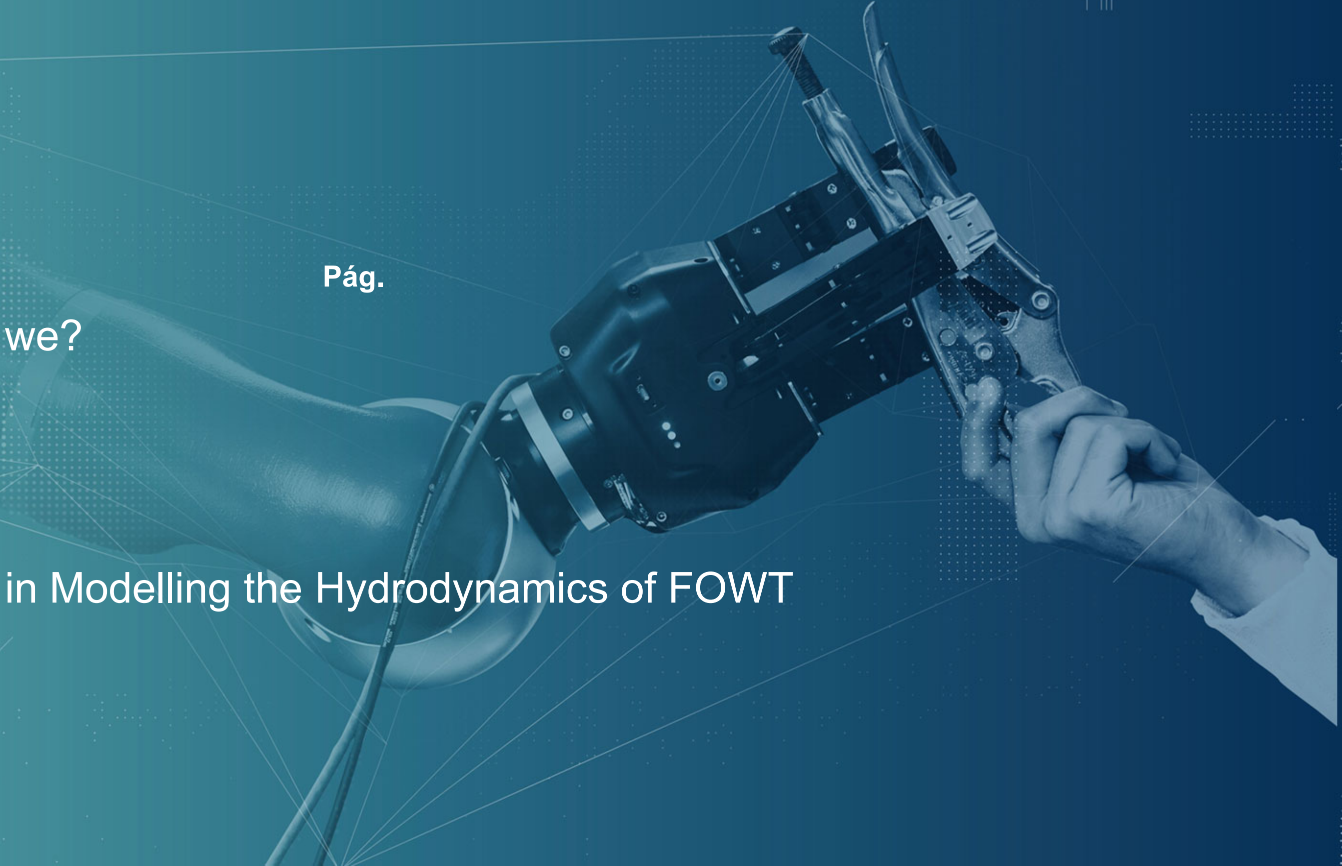


Outline

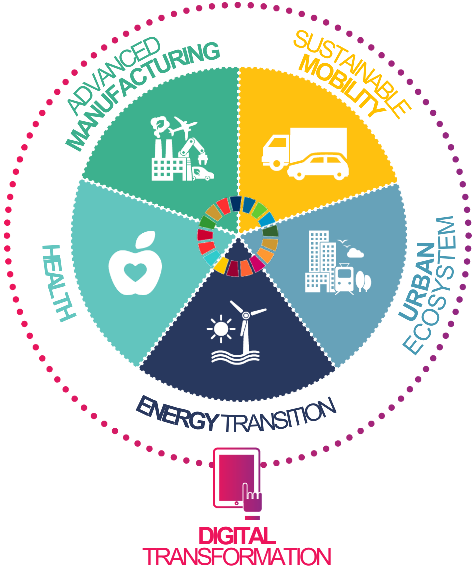
Pág.

TECNALIA:
Who are we?

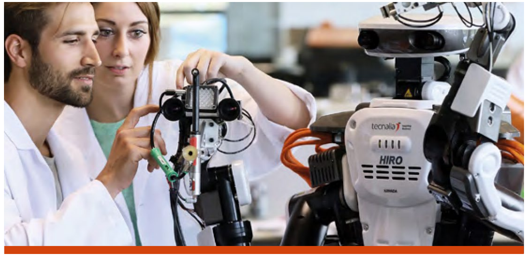
TECNALIA: Who are we?

1st private organisation in Spain in project contracting, participation and leadership under the EU **Horizon 2020** Programme.

SCOPES OF ACTION



IMPACT SERVICES



Laboratory Services

R&D and Innovation Projects

Development of **Investment Opportunities**

> 7.800 CLIENT COMPANIES

(2011 - 2020)

75%
SMEs

25%
Large companies

Benchmark Research and Technological Development Centre in Europe, with **1,472** experts of **31** nationalities, oriented towards transforming technology into GDP to improve People’s quality of life, creating business opportunities in Companies.

Offshore Renewable Energy

- New solutions for installation and O&M
- Optimised designs for reducing costs of foundations and electrical infrastructure
- Test and analysis of materials and components for harsh environments

- Design tools for floating platforms
- Tank testing and numerical analysis
- Analysis and design of mooring systems and electrical connections

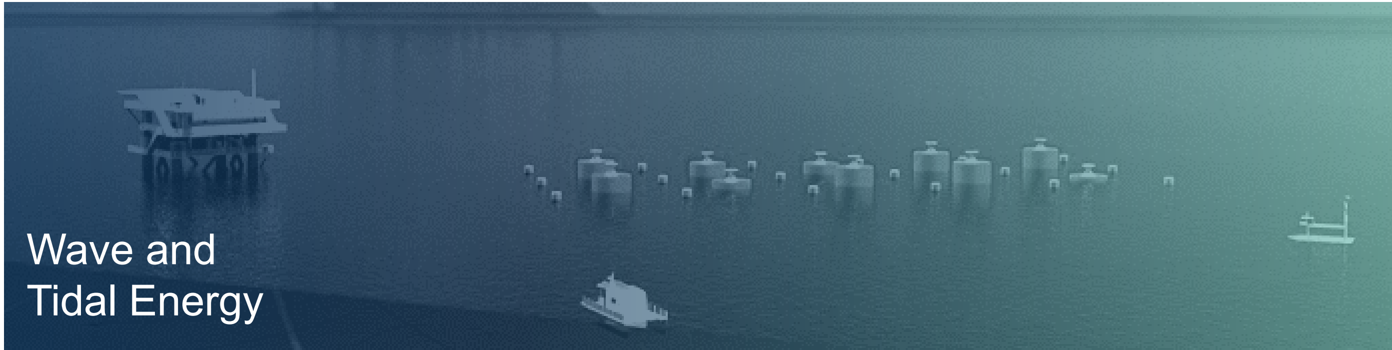
- Design tools for the optimisation of arrays
- Performance assessment
- Optimisation of Power Take-Off and Control systems

tecnalia Inspiring Business

TWIND OFFSHORE WIND ENERGY

Innovations for cost reduction in fixed offshore wind farms

Floating offshore wind turbines



Wave and Tidal Energy

WHO ARE WE?

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Benchmark Research and Technological Development Centre in Europe and Member of **BRTA** (Basque Research and Technology Alliance)

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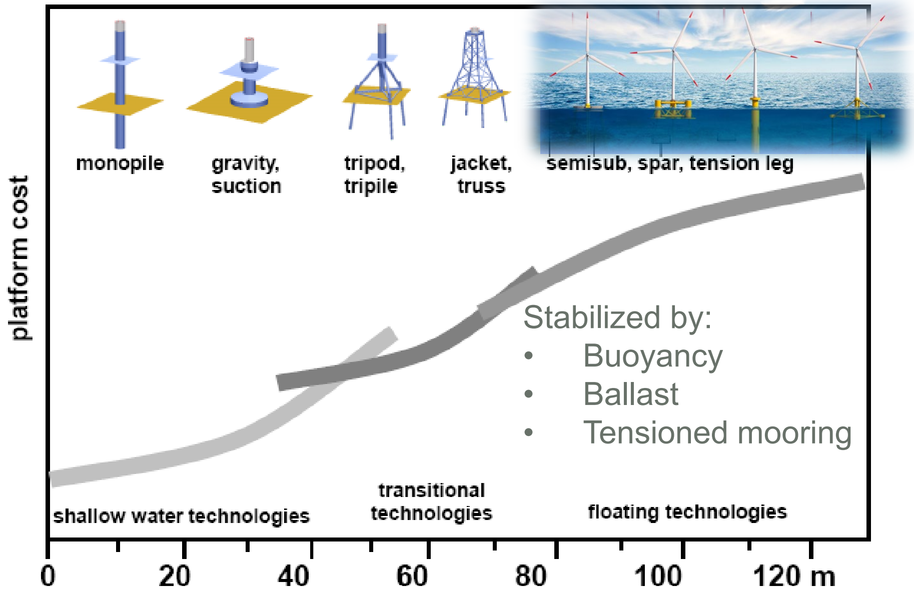
Motivation

FLOATING OFFSHORE WIND: TECHNOLOGIES

Platform technologies vary with water depth



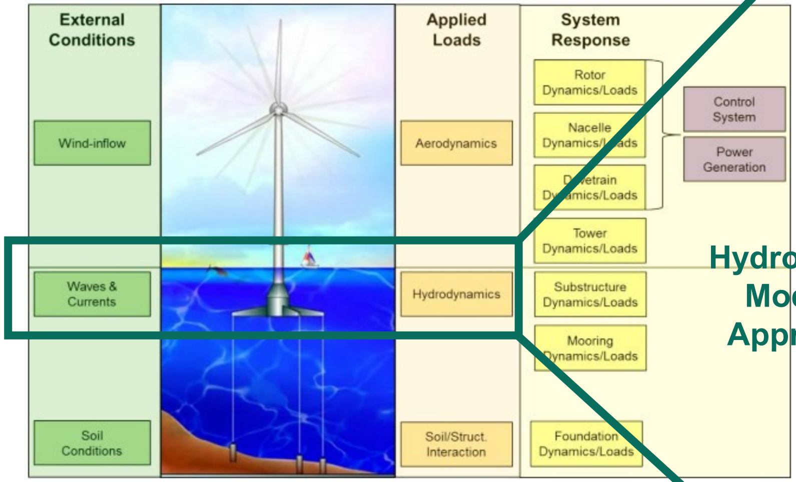
Stabilized by:

- Buoyancy
- Ballast
- Tensioned mooring

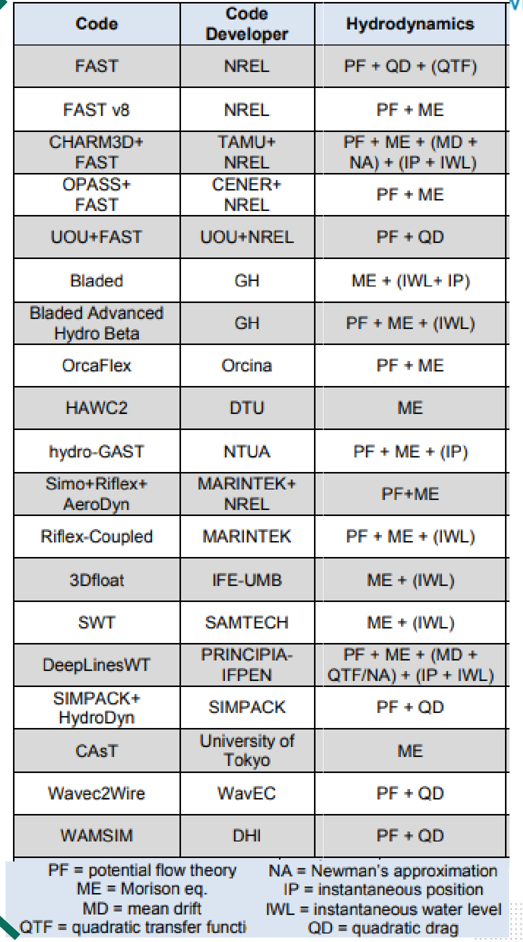
Why “being” FLOATING, then?

- ☐ Economically **more convenient** for deep water
- ☐ It could lead to greater **availability of resource** (Wind power is stronger in the ocean than on land)
- ☐ **Reduced visual impact** from seafront
- ☐ Seismically **isolated**
- ☐ **Reduced risk** due to solitons
- ☐ Exploitation of **oil & gas** already consolidated **experience** in conceptual design of the devices (with several differences...)

FLOATING OFFSHORE WIND: HOW TO MODEL IT?



Hydrodynamic Modelling Approaches



Code	Code Developer	Hydrodynamics
FAST	NREL	PF + QD + (QTF)
FAST v8	NREL	PF + ME
CHARM3D+ FAST	TAMU+ NREL	PF + ME + (MD + NA) + (IP + IWL)
OPASS+ FAST	CENER+ NREL	PF + ME
UOU+FAST	UOU+NREL	PF + QD
Bladed	GH	ME + (IWL+ IP)
Bladed Advanced Hydro Beta	GH	PF + ME + (IWL)
OrcaFlex	Orcina	PF + ME
HAWC2	DTU	ME
hydro-GAST	NTUA	PF + ME + (IP)
Simo+Riflex+ AeroDyn	MARINTEK+ NREL	PF+ME
Riflex-Coupled	MARINTEK	PF + ME + (IWL)
3Dfloat	IFE-UMB	ME + (IWL)
SWT	SAMTECH	ME + (IWL)
DeepLinesWT	PRINCIPIA- IFPEN	PF + ME + (MD + QTF/NA) + (IP + IWL)
SIMPACK+ HydroDyn	SIMPACK	PF + QD
CAsT	University of Tokyo	ME
Wavec2Wire	WavEC	PF + QD
WAMSIM	DHI	PF + QD

PF = potential flow theory
ME = Morison eq.
MD = mean drift
QTF = quadratic transfer functi
NA = Newman's approximation
IP = instantaneous position
IWL = instantaneous water level
QD = quadratic drag

- Excitation from incident waves
- Radiation of outgoing waves from platform motion (including added mass and damping effects)
- Viscous forces

Source : Offshore Code Comparison Collaboration, Continuation within IEA Wind Task 30: Phase II Results Regarding a Floating Semisubmersible Wind System: Preprint (nrel.gov)

Top Four Challenges in Modelling the Hydrodynamics of FOWT

Top FOUR Challenges in modelling FOWT hydrodynamics

1. Modelling the loads with Morison Equation

Model the loads with Morison Equation

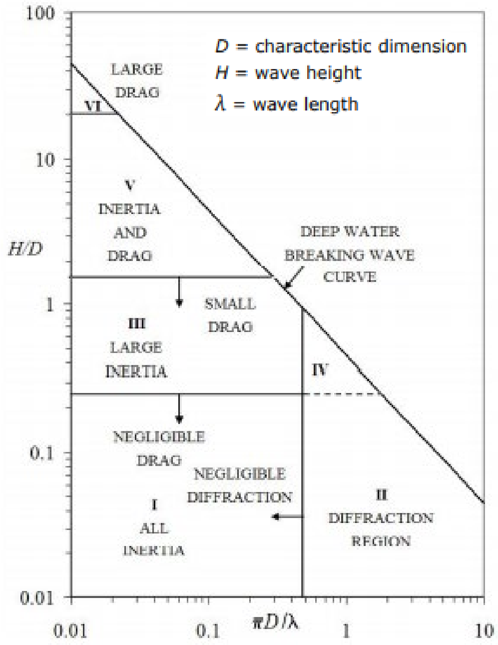
Three basic approaches to wave excitation loads:

- ❑ **Morison formula**
  - Accurate description if drag force is significant
  - Inertia term can be used for small structures (λ/D >5)

- ❑ **Froude-Krylov approximation**
  - Pressures due to incident waves is used on the surface of the structure
  - Applicable for relatively small structures (λ/D>5)

- ❑ **Diffraction theory**
  - Necessary for relative large structures (λ/D<5)
  - Viscous effect not represented

Total wave force consists of components due to drag, inertia and scattering



Source : Wave force regimes (Chakrabarti, 1987)

Model the loads with Morison Equation

$$F= \underbrace{\rho\, C_m V\, \dot{u}}_{\text{Inertia force}} + \underbrace{\frac{1}{2}\rho\, C_d A\; u|u|}_{\text{Drag force}}$$

Froude KrylovK   Hydrodynamic mass

Morison formula –Basic idea:

- Inertia coefficient Cm=1+Ca:
  - Represents changes in the fluid due to the presence of the cylinder under non-viscous potential flow.
  - In a uniformly accelerated fluid, the added mass coefficient is Ca=1
- Drag coefficient Cd:
  - Represents viscous effects due to turbulence wake región behind the cylinder-difficult to predict.
  - Different values of Cd apply for steady flow past the cylinder as opposed to oscillatory flow
- Simple superposition of both effects assumed
- Interaction effects become important for separation <2D between members

F is the total inline force of the object
$\dot{u}$ is the flow acceleration
A cross sectional area of the body perpendicular to the flow direction
V is the volume of the body

For instance for a circular cylinder of diameter D in oscillatory flow, the reference area per unit length is A=D and the cylinder volume per unit cylinder is V= $\frac{\pi}{4}D^2$

$$F= \rho\, C_m \frac{\pi}{4} D^2 V\, \dot{u} + \frac{1}{2}\rho\, C_d D\; u|u|$$

In case the body moves as well, with velocity *v*, the ME becomes:

$$F= \rho\, V\, \dot{u} + \rho C_a V\, (\dot{u} - \dot{v}) + \frac{1}{2}\rho\, C_d A(u - v)\, |u - v|$$

Model the loads with Morison Equation

- Current integrated wind turbine design codes model the loads on **fixed bottom offshore structures** by applying **ME** (However, the best way to model loads depends on the sea state!)
- **ME** not recommenced for modelling loads on **floating offshore wind turbines** (some exceptions, e.g. small braces)

FIXED BOTTOM offshore structures	**FLOATING offshore structures**
Small diameter → waves nor disturbed → diffraction neglected	Diameter large enough for the incident waves to be disturbed → diffraction effects must be included
Viscous drag dominates the drag loading + small motion → wave radiation damping ignored	Sizeable volume + low-frequency rigid modes → significant movement → wave radiation to be considered
Axisymmetric cylindrical structures	Non-axisymmetric structures → added mass-induced coupling between hydrodynamic force and support structure acceleration in all DOFs
Hydrostatic restoring forces neglected	Hydrostatic restoring forces are very important

Top FOUR Challenges in modelling FOWT hydrodynamics

1. Modelling the loads with morison equation

2. **Assume linear hydrodynamics**

Assume Linear Hydrodynamics

In the oil and gas industry the method of accounting for the different sources of hydrodynamic loading is to divide them into separate problems and solve them independently, assuming linear hydrodynamics.

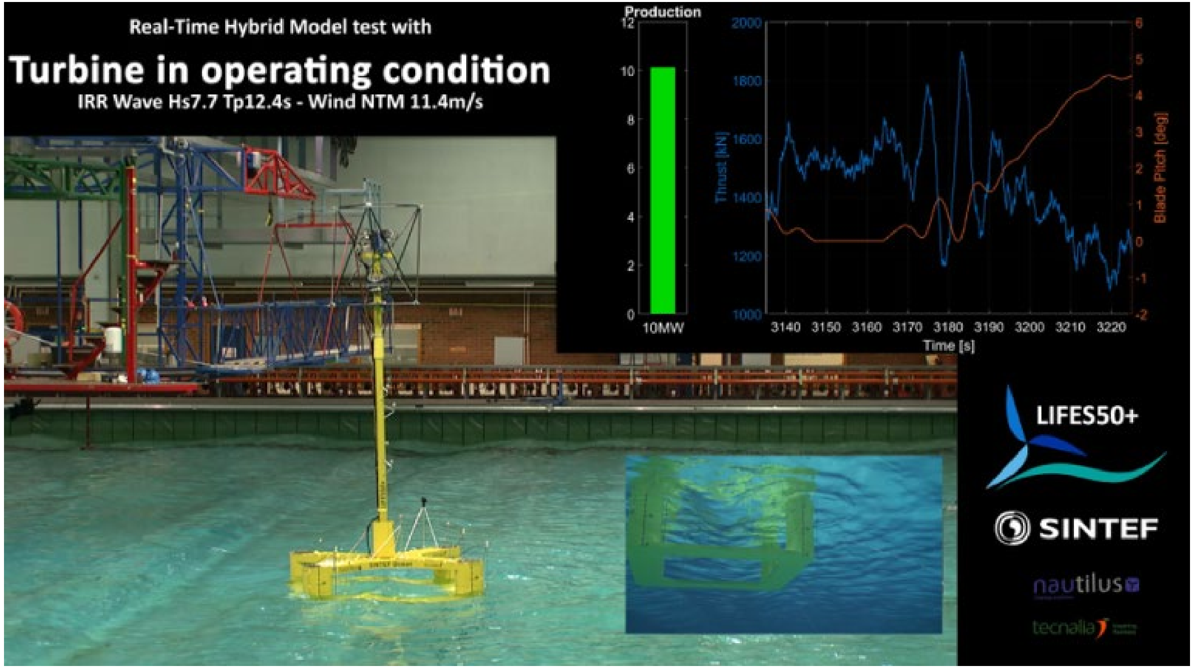
Limitations when applied to FOWT…

- **Requires** the use of **linear Airy wave theory** for the calculation of **wave-particle kinematics**.
    - **Steepsided or breaking waves** found in shallow water **cannot be modeled together with the resulting slap and slam loading.**
- **Potential-flow** theories used in several design tools to calculate hydrodynamic loads were **developed for stationary bodies**, and only are valid when the support structure translational motion is small relative to the wavelength and the rotational motion is less than the wave steepness.
    - **Floating configurations** experience **large translational displacements** relative to the length of the platform, for instance catenary moored systems where there is low resistance to surge and sway.

Assume Linear Hydrodynamics

The **NAUTILUS FS** concept in a tank test campaign under operational conditions.

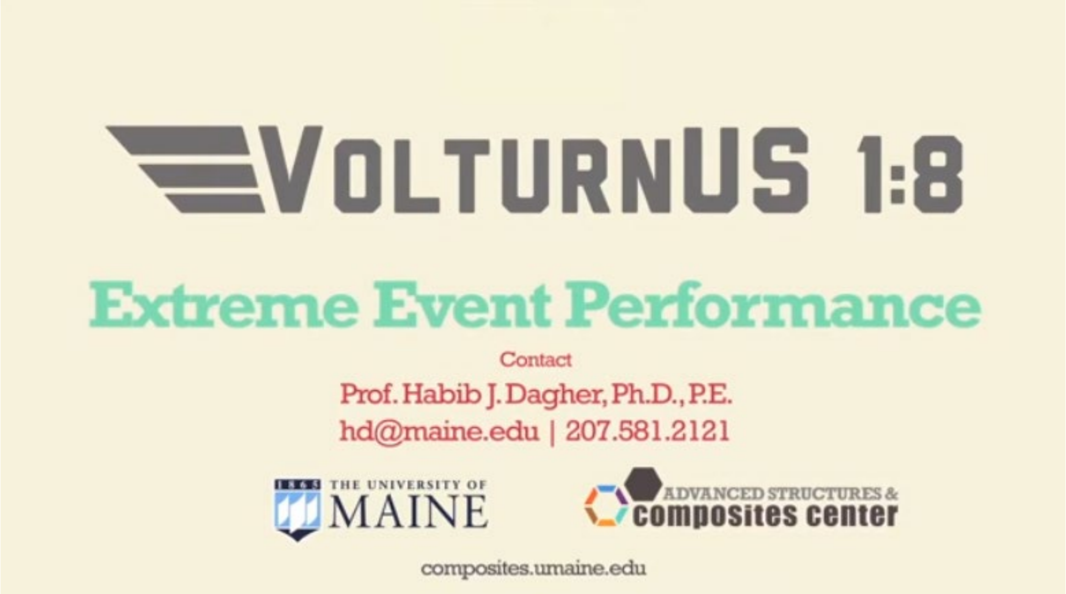
☺ Assumption of linear hydrodynamics valid



Video. Please, check the recordings of the session.

Assume Linear Hydrodynamics

The **VolturnUS** 1:8 experienced 21m equivalent waves in a November 2013 storm off the coast of Castine, Maine!!
☹ Assumption of linear hydrodynamics no valid



VOLTURNUS 1:8

Extreme Event Performance

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THE UNIVERSITY OF MAINE

ADVANCED STRUCTURES & composites center

composites.umaine.edu

[VolturnUS 1:8 Extreme Event Performance November 2013 - Bing video]

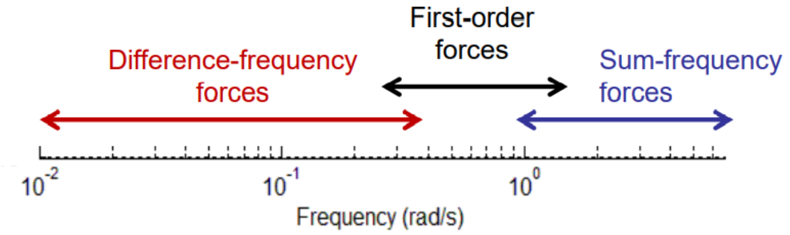
Top FOUR Challenges in modelling FOWT hydrodynamics

1. Modelling the loads with morison equation

2. Assume linear hydrodynamics

3. Assume second order hydrodynamics

Assume Second-Order Hydrodynamics



Second-order hydrodynamic loads are…

- **Proportional to the square of the wave amplitude**
  - Normally being **small in magnitude**
- Have **frequencies equal to both the sum and the difference of the multiple-incident wave frequencies of an irregular sea state**
  - Although the natural frequencies of the structure are designed to be outside the wave energy spectrum, the second-order forces can excite these frequencies→ the **resonant effect** can be important.

Three components of second-order hydrodynamic forces for the diffraction problem:

Mean drift forces Slowly varying drift forces Sum frequency forces

Assume Second-Order Hydrodynamics

Mean drift forces…

- ❑ Result in a **mean offset** of the body relative to its undisplaced position.
- ❑ Typically are an **order of magnitude less than first-order wave excitation forces** (Insignificant compared to mean thrust**).**
- ❑ Are a **combination** of **second-order hydrodynamic pressure due to first-order waves** and the **interaction between first-order motion and the first-order wave field**.
- ❑ The **viscous drag** could add to this force significantly when a **current** is present.
- ❑ The **mooring-line tension** often is related non-linearly to platform displacement, therefore mean drift forces can have an important effect.

Assume Second-Order Hydrodynamics

Slowly varying drift forces…

- ☐ **Persist much longer than the main wave energy spectrum** but still are within the range of horizontal platform motion.
- ☐ **Result from non-linear interactions between multiple waves having different frequencies.**
- ☐ Are **small** as compared to forces at the wave frequency, **but they can cause large displacements in moored floating wind turbines** which can in turn lead to **high loads in the mooring lines**.
- ☐ Can **excite** the **large amplitude resonant translational motion of the floating platform**.

Assume Second-Order Hydrodynamics

Sum frequency forces…

- ❑ Have a **frequency** which is **higher than the wave frequency**
- ❑ Are **small in amplitude**
- ❑ **Arise from** the same source as low-frequency drift forces (**interactions between multiple waves of varying frequency**)
- ❑ Have an **important contribution when analysing “ringing”** behaviour for floating wind turbine configurations such as TLP concepts, which typically have high natural frequencies in heave, roll, and pitch.
- ❑ Potentially can **excite vibration modes of the supported wind turbine**

Assume Second-Order Hydrodynamics

[Ref 1] Lucas, J., UpWind Project: Comparison of a First- and Second-Order Hydrodynamic Results for Floating Offshore Wind Structures, Garrad Hassan & Partners Ltd, Bristol, UK, January 2011

[Ref 2] Line Roald, Jason Jonkman, Amy Robertson, Ndaona Chokani, The Effect of Second-order Hydrodynamics on Floating Offshore Wind Turbines, Energy Procedia, Volume 35, 2013, Pages 253-264, ISSN 1876-6102,

[Ref 3] I Bayati et al 2014. The effects of second-order hydrodynamics on a semisubmersible floating offshore wind turbine. J. Phys.: Conf. Ser. 524 012094

Conclusions:

- **Second order effects are very important for FOWTs**
  - Second-order excitation force in stochastic waves is important in surge and pitch modes, although it still is smaller than the first-order excitation force.
  - The importance of the second-order excitation force decreases for the steeper waves and higher significant wave heights.
  - For semi-submersible platforms, the second-order excitation force is dominant over the first order for less-steep waves and lower significant wave heights for all modes except heave.

- **Even with second-order hydrodynamic terms included the hydrodynamic theory might not completely apply to FOWT…**
  - E.g. the tower flexibility can not be taken into account in diffraction codes (i.e. WAMIT), leading to inaccuracies in the simulation of second-order quantities for structures where the tower flexibility couples to and influences the eigenfrequencies in pitch and roll (i.e. TLPs)..

Top FOUR Challenges in modelling FOWT hydrodynamics

1. Modelling the loads with morison equation

2. Assume linear hydrodynamics

3. Assume second order hydrodynamics

3. Vortex-Induced Vibrations / Motions

Vortex-Induced Vibrations / Motions (VIV /VIM)

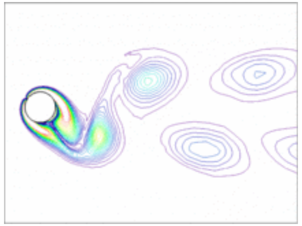
If the structure is flexible these vortices may cause vibrations, leading to stresses and fatigue damage. This motion of the body influences, in turn, the vortex formation process, establishing a feedback mechanism that may lead to stable or unstable dynamic equilibria.

On the hull:

- They increase the global loads
- They may increase the offset (drag effect)

On the moorign lines:

- They may affect fatigue life of the line



Source: Z.-S. Chen and W.-J. Kim, “Numerical investigation of vortex shedding and vortex-induced vibration for flexible riser models,” Int. J. Nav. Archit. Ocean Eng., vol. 2, no. 2, pp. 112–118, Jun. 2010.

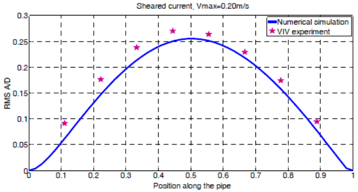


Fig. 1 RMS A/D pattern of cross-flow response along the brass riser span, in the case of sheared current V_{max}=0.20m/s.

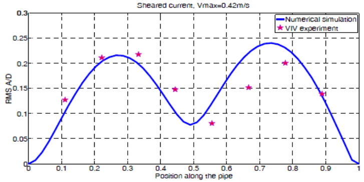


Fig. 2 RMS A/D pattern of cross-flow response along the brass riser span, in the case of sheared current V_{max}=0.42m/s.

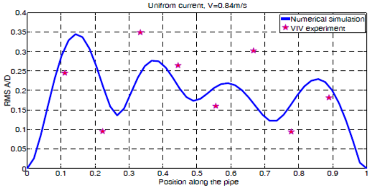
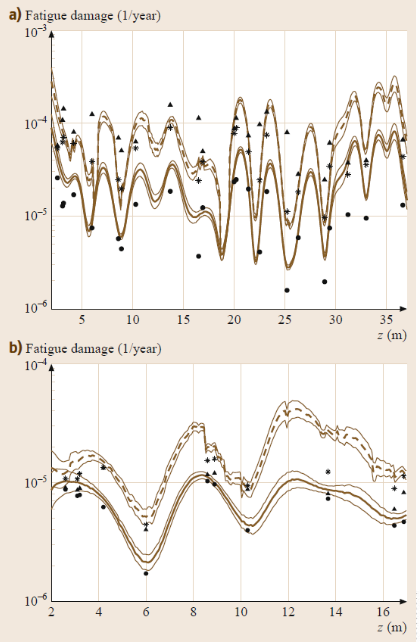
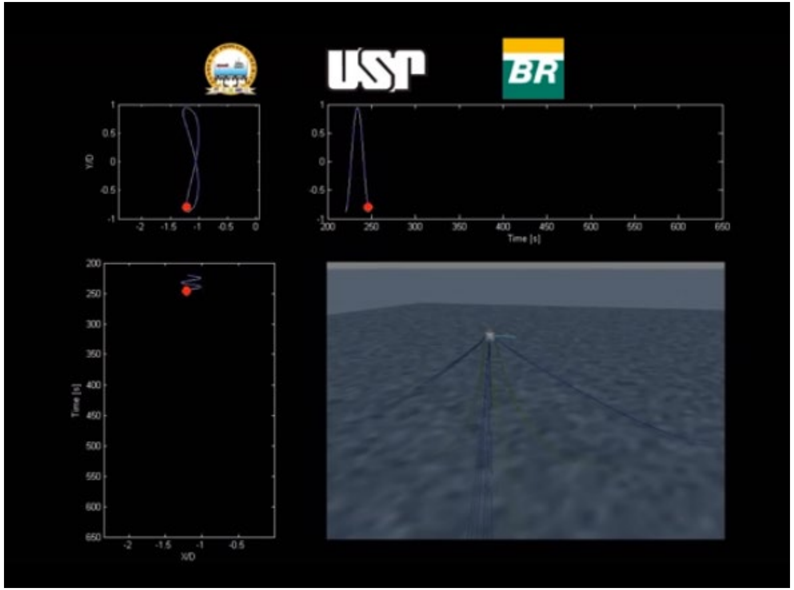


Fig. 3 RMS A/D pattern of cross-flow response along the brass riser span, in the case of uniform current V=0.84m/s.

Source: M. S. Triantafyllou, R. Bourguet, J. Dahl, and Y. Modarres-Sadeghi, “Vortex-Induced Vibrations,” in *Springer Handbook of Ocean Engineering*, Springer, 2016, pp. 819–850.



Vortex-Induced Vibrations / Motions (VIV /VIM)



VIM effects on mooring lines of a monocolumn platform

[VIM (vortex-induced motions) of Monocolumn platform - YouTube]

Conclusions

- For modelling of non-slender floating platforms, hydrodynamic wave diffraction effects must be accounted for to correctly determine the local pressure force and global wave loads.
- Significant platform movements require inclusion of wave radiation forces
- Non-cylindrical elements demand modelling of added mass-induced coupling between hydrodynamic force and support structure acceleration.
- Second-order linear hydrodynamics and VIV/VIM are important when simulating FOWT

- Beyond theoretical and numerical analysis, **validation of advanced modelling techniques with measurement data from full-scale prototypes is of great importance** and is necessary to resolve the challenges; especially when considering a potential new standard for the design of floating offshore wind turbines.

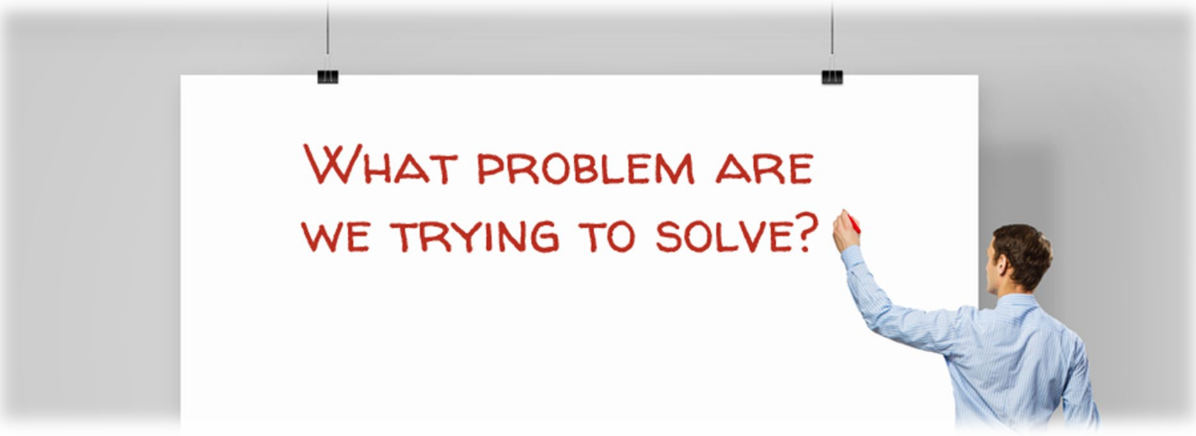
- The **IEA Wind Task 30 Offshore Code Comparison Collaboration Continued, with Correlation and unCertainty (OC6 / 2019-2022)** project (started in 2005 with OC3), also will address some of these modelling challenges.

iea wind

- In the future, advanced FOWT simulation tools will enable more reliable motion, load, and deflection predictions and ultimately will lead to improved designs to utilize the vast amount of wind resource located in deep waters.

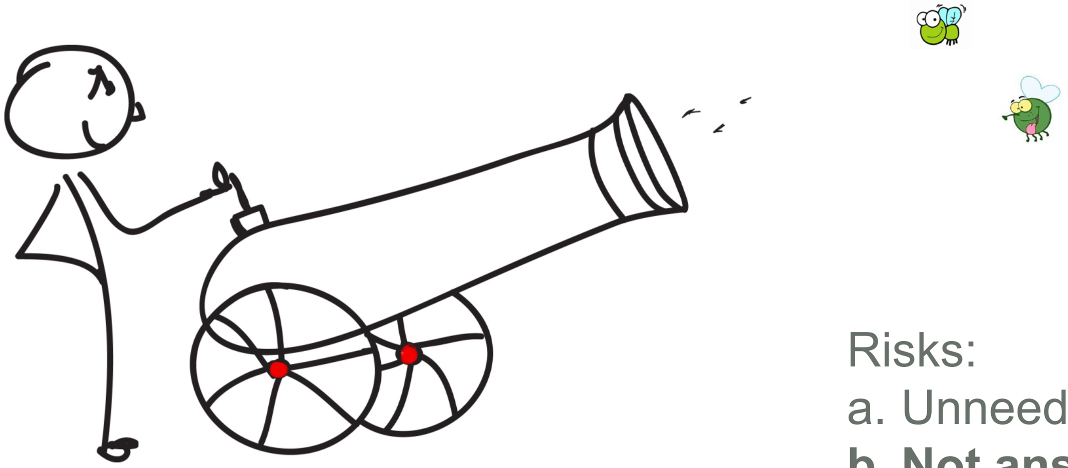
Lessons learnt

Describe the problem properly and identify the outcomes



Problem statement stage is **important**, in order to **focus on the right physics / model to study**.

Use the appropriate numerical model for solving the problem without ‘using sledgehammers to crack nuts’



Risks:

a. Unneeded **computational burden**

b. Not answering to the questions

Interpreting the results of the experimental / numerical study in order to "bark up the right tree"

The **results** of a good experimental campaign or numerical test can be **jeopardised** by a **wrong understanding of what's going on.**

All the problems are important, but some problems are more important than others

Developers must **identify** different **priorities for the problems to be solved** through their experience and look at them from an adecuate perspective.

ESKERRIK ASKO
GRACIAS
THANK YOU
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