THE EFFECTS OF WIND-INDUCED INCLINATION ON THE DYNAMICS OF FLOATING WIND TURBINES

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Study carried out within the **IDCORE EngD** programme

GdR EMR : journée éolien offshore - Marseille, 9th of Mars, 2016

SUMMARY

- Introduction
- Methodology
  - Coupled time-domain simulation
  - Finite-angle adaptation
- Study of Dutch Tri-floater

  => significant effect of finite inclinations on dynamic response
- Conclusion

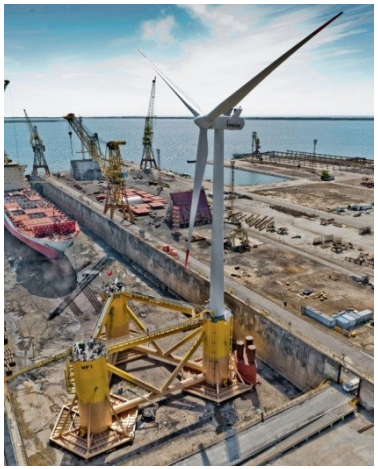
INTRODUCTION
MOTIVATION

- EDF R&D assists EDF EN in the development of pilot projects:
  - Concept selection
  - Risk identification
- Novel technologies and complex environment challenge the existing engineering practices

INTRODUCTION

SEMI-SUBMERSIBLE FLOATER

- Demonstrated technology
- Aerodynamic excitation: FW > oil & gas semi-subs
- MW/t needs to improve => even larger $\frac{T}{\Delta}$?

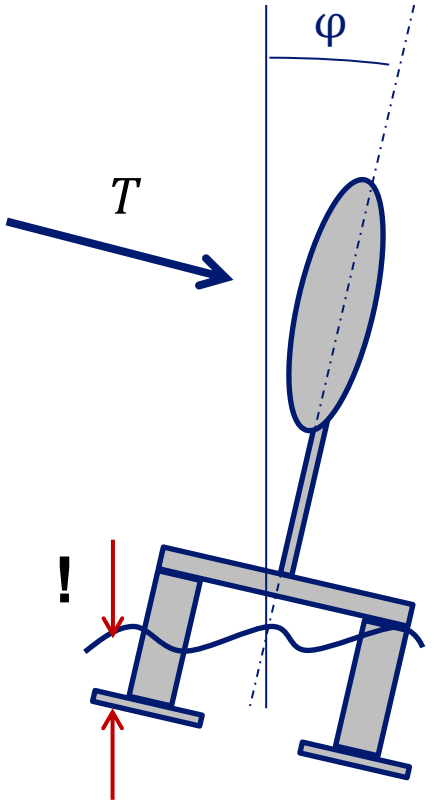


INTRODUCTION

FINITE-ANGLE COUPLING

Admissible φ in the region of 10°

=> significant column excursion

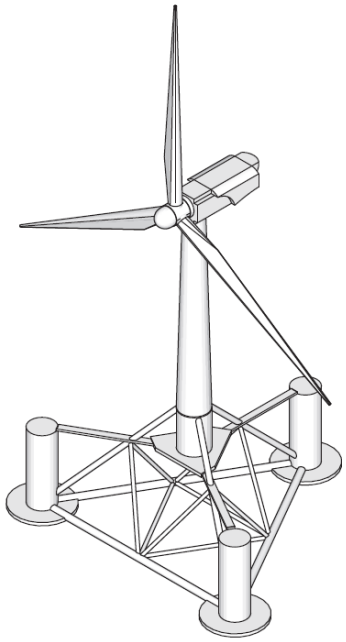


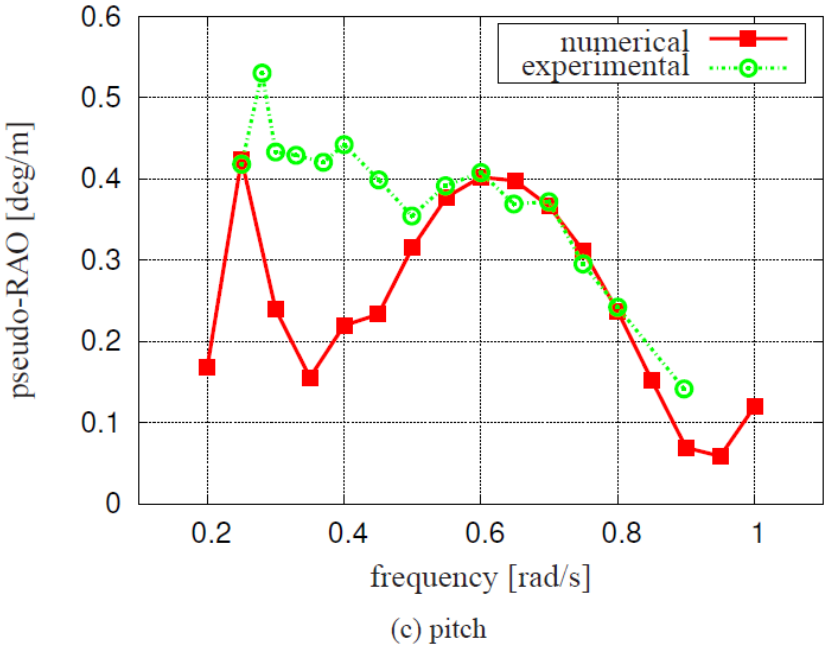
"geometric nonlinearity"

INTRODUCTION

EXPERIMENTAL CLUES

‘Odd’ motion results from basin tests



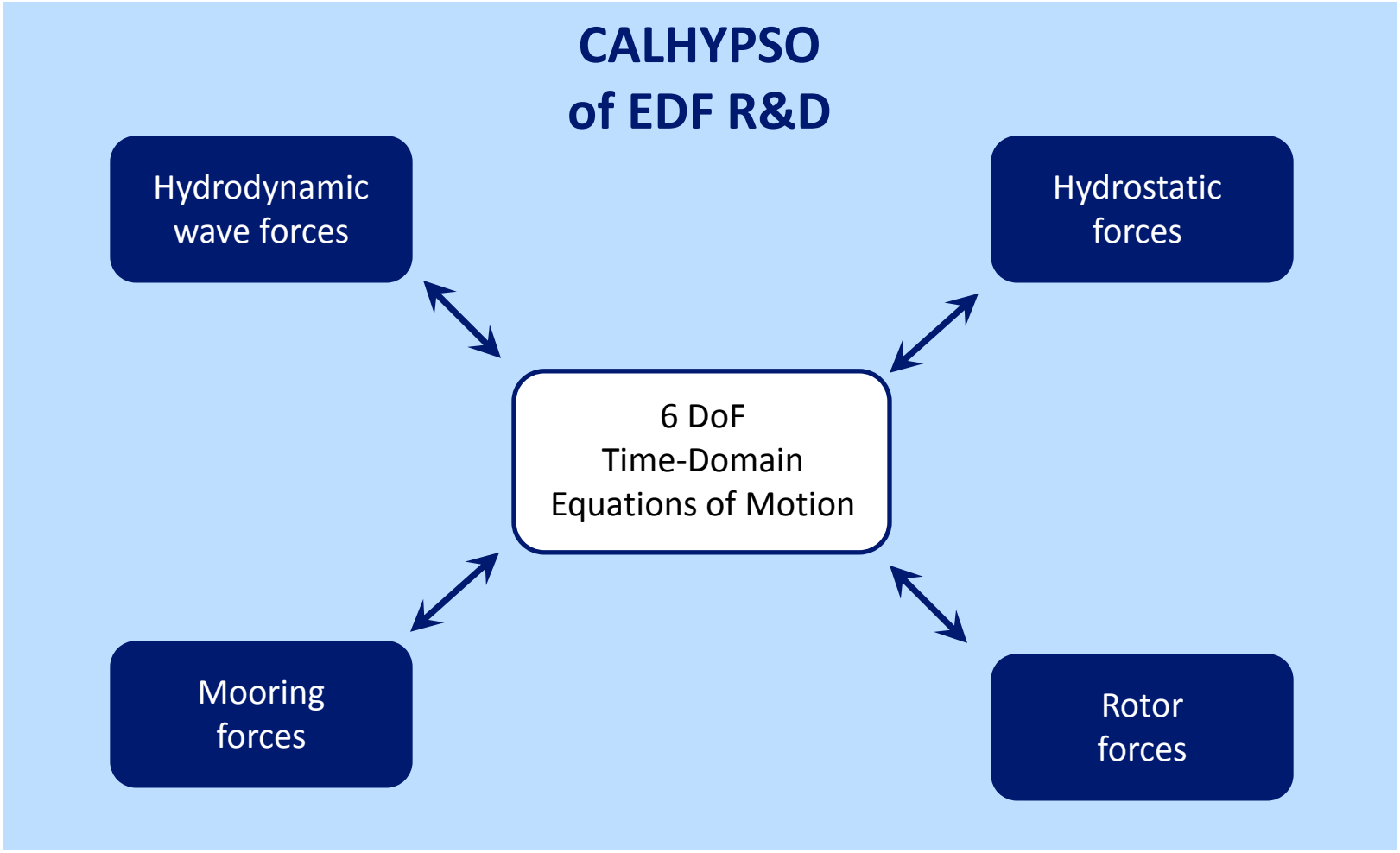


(c) pitch

Philippe et al., ‘**Comparison of simulation and tank test results of a semi-submersible floating wind turbine under wind and wave loads**’, in *Proc. 32nd International Conference on Ocean, Offshore and Arctic Engineering*, Nantes, France, 2013.

METHODOLOGY

COUPLED TIME-DOMAIN SIMULATION



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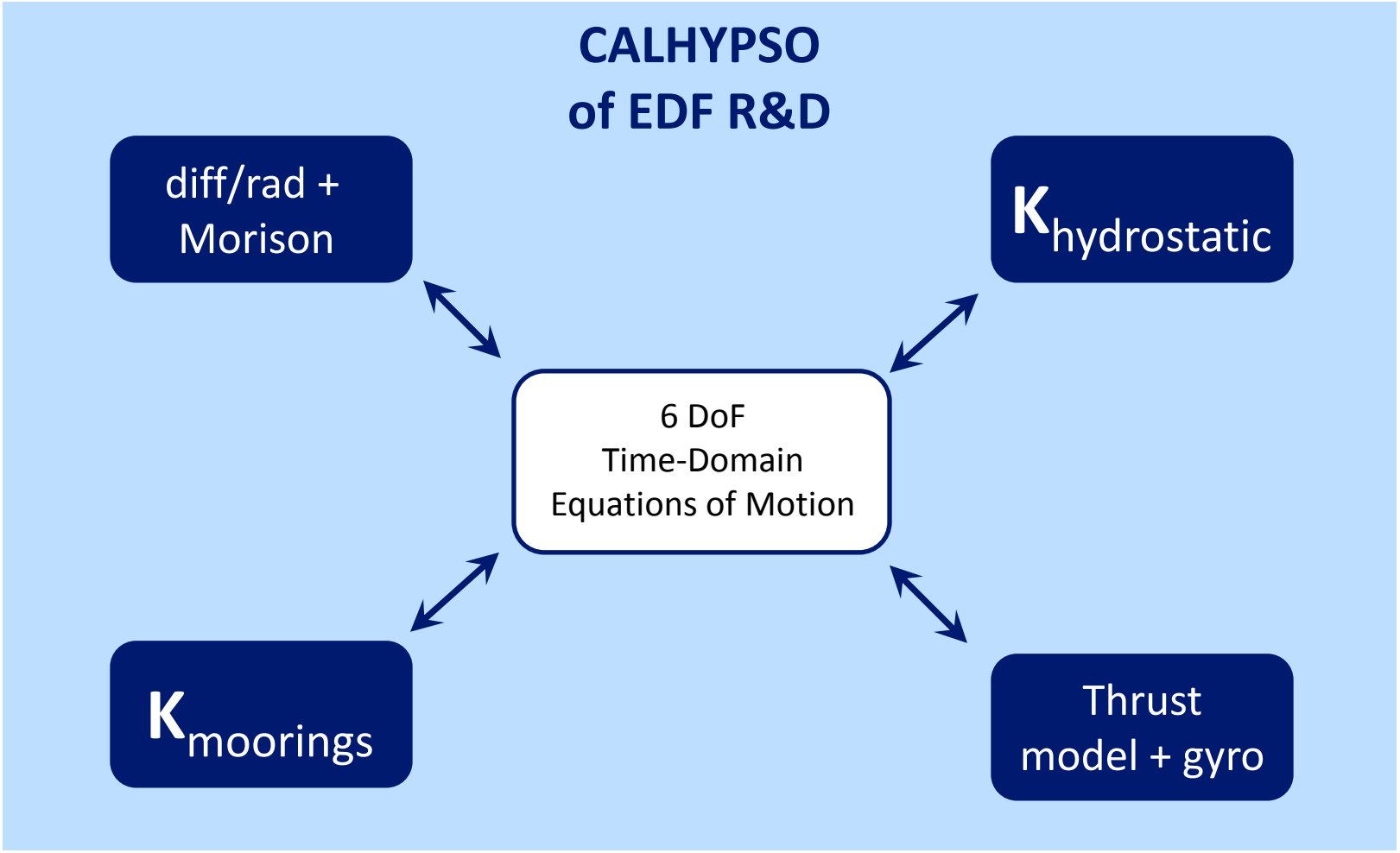

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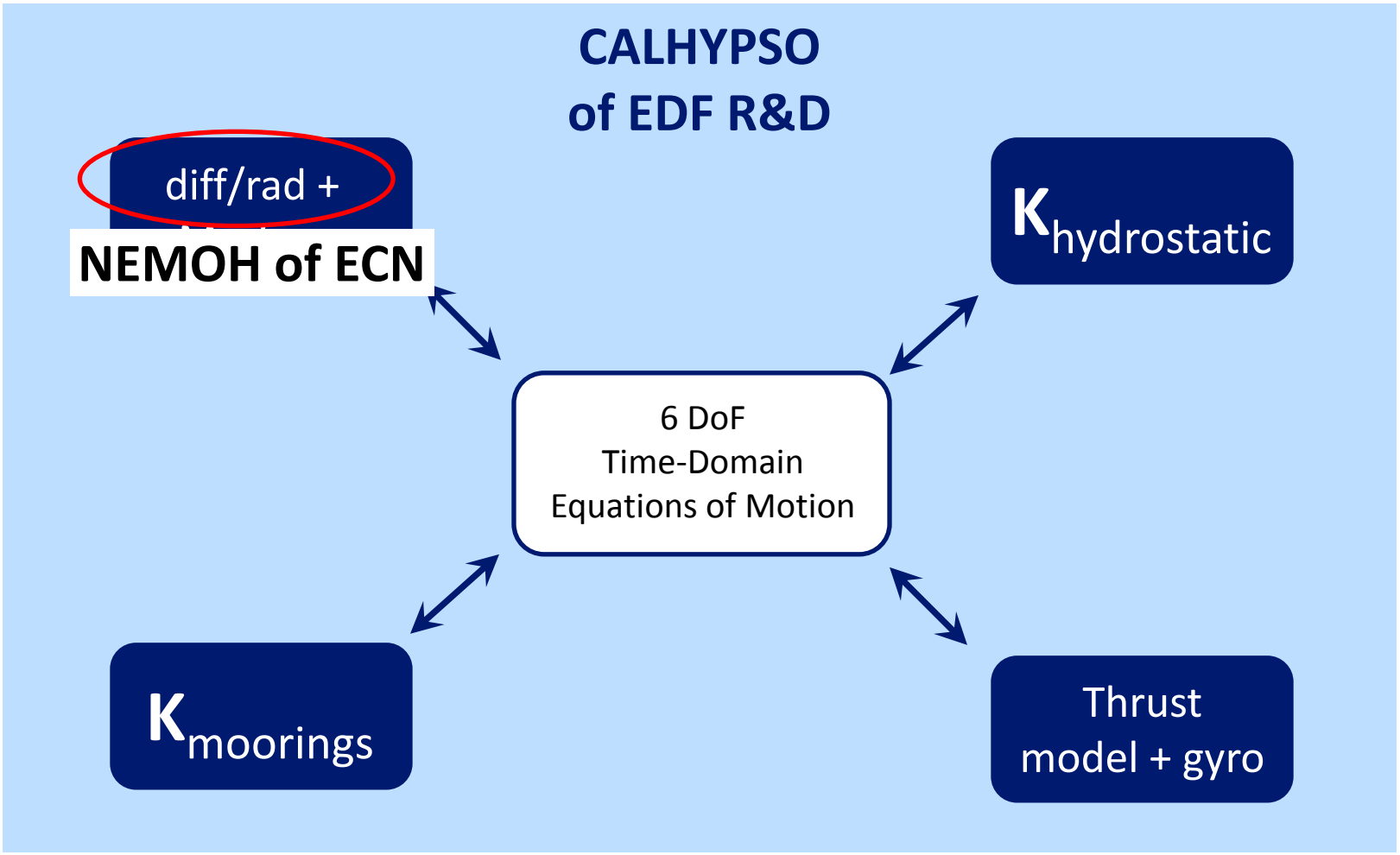

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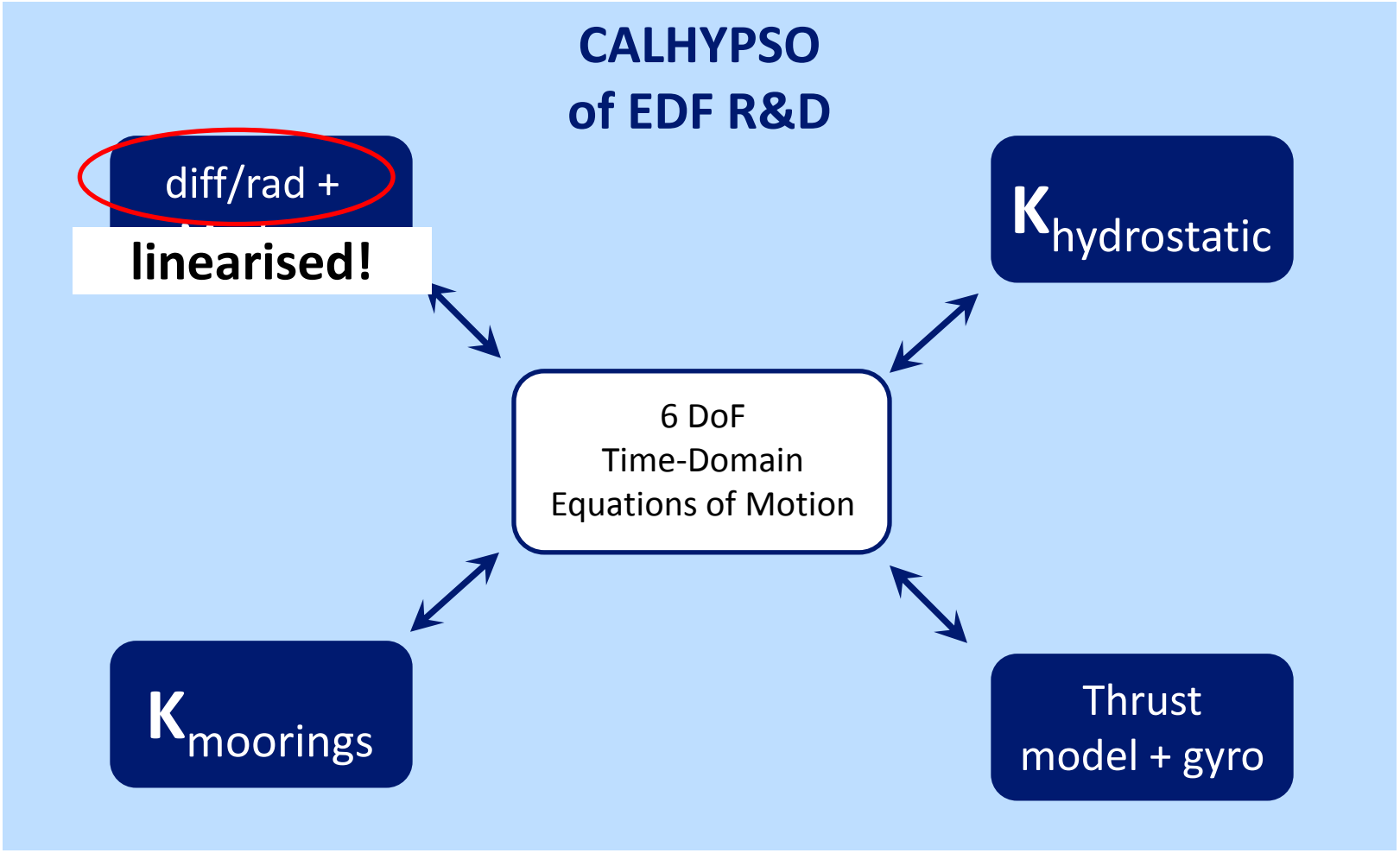
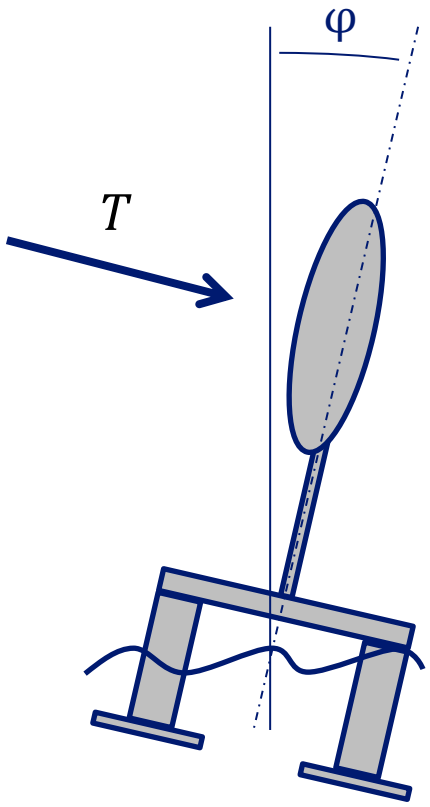


METHODOLOGY

FINITE-ANGLE ADAPTATION

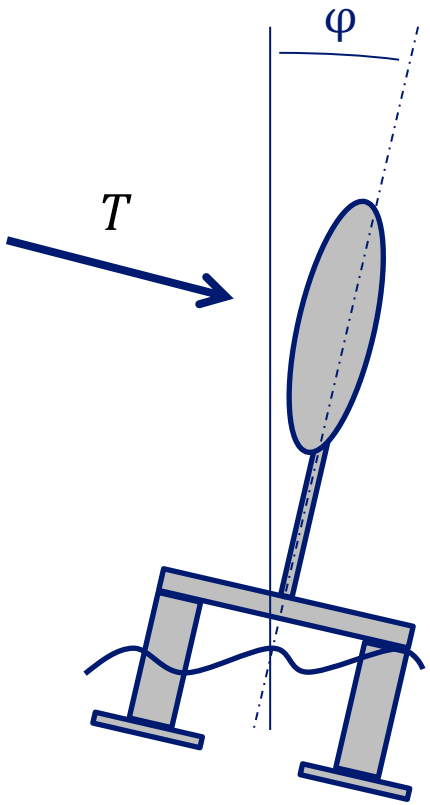
1) Introduce constant wind excitation and find equilibrium angle



METHODOLOGY

FINITE-ANGLE ADAPTATION

1) Introduce constant wind excitation and find equilibrium angle
2) Re-write the system's EoM using this as the undisturbed position



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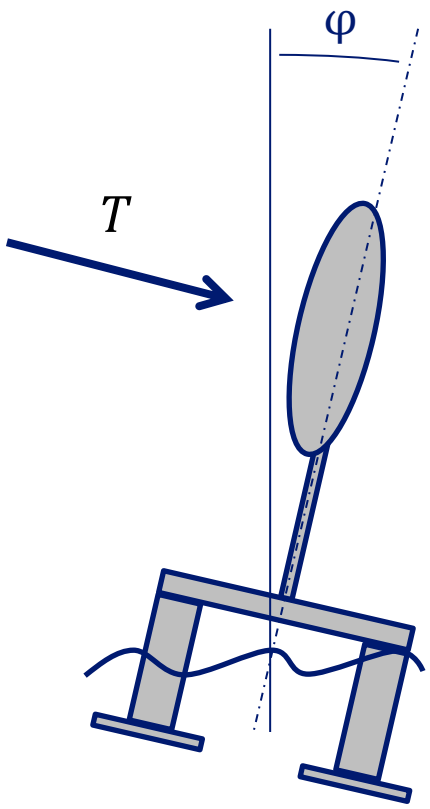

$$\mathbf{M} = \begin{pmatrix} m & 0 & 0 & 0 & mz_C & -my_C \\ & m & 0 & -mz_C & 0 & mx_C \\ & & m & my_C & -mx_C & 0 \\ & & & J_{11} & I_{12} - mx_C y_C & I_{13} - mx_C z_C \\ & \text{sym.} & & & J_{22} & I_{23} - my_C z_C \\ & & & & & J_{33} \end{pmatrix}$$

METHODOLOGY

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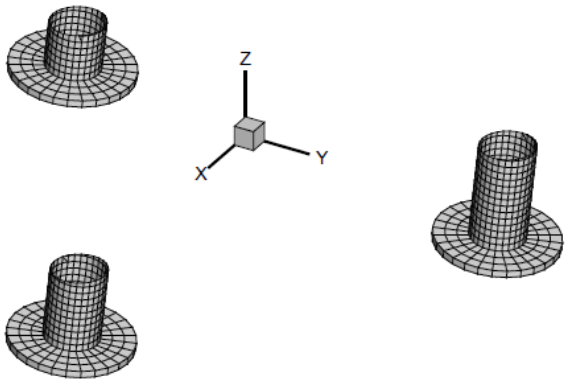
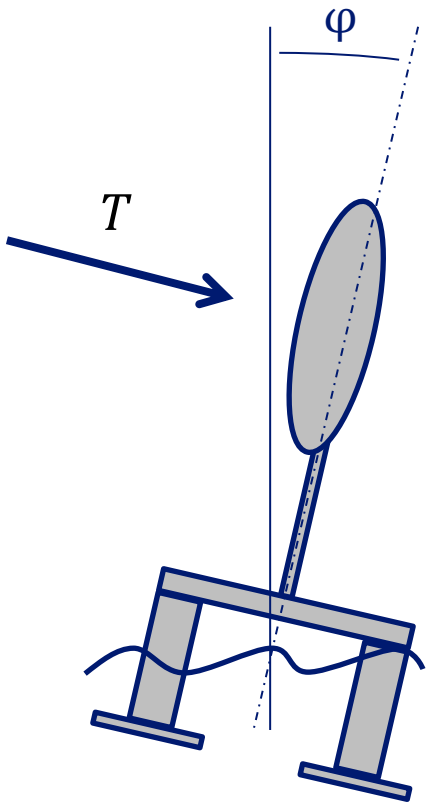
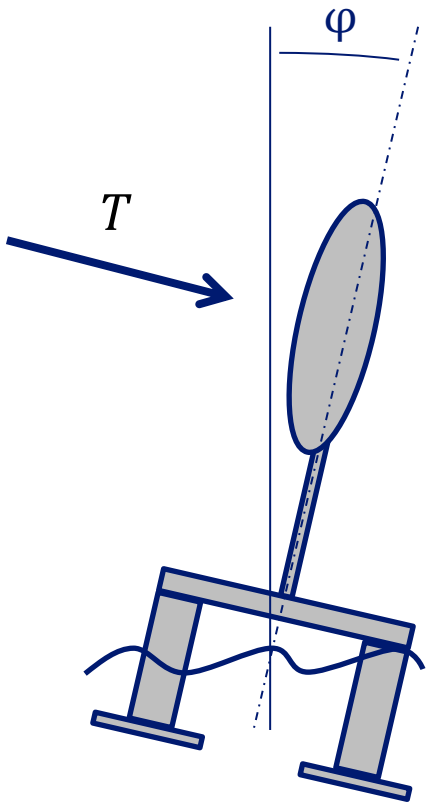




METHODOLOGY

FINITE-ANGLE ADAPTATION

1) Introduce constant wind excitation and find equilibrium angle
2) Re-write the system's EoM using this as the undisturbed position
3) Compute dynamic response in waves around new equilibrium

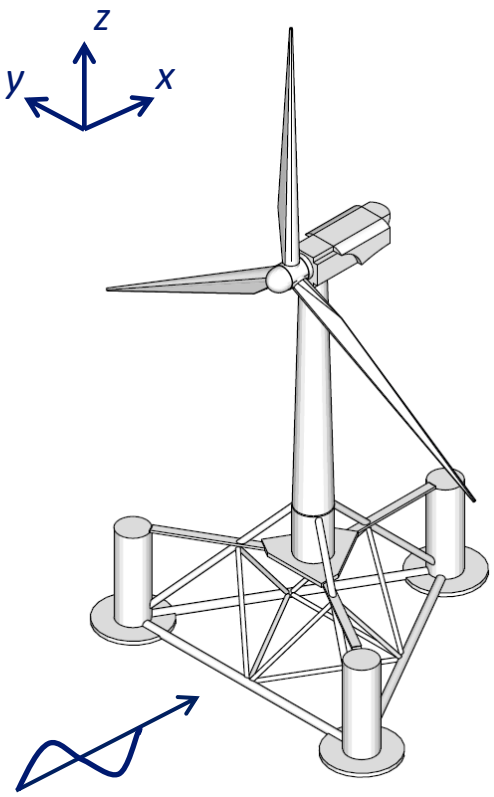


STUDY OF DUTCH TRI-FLOATER

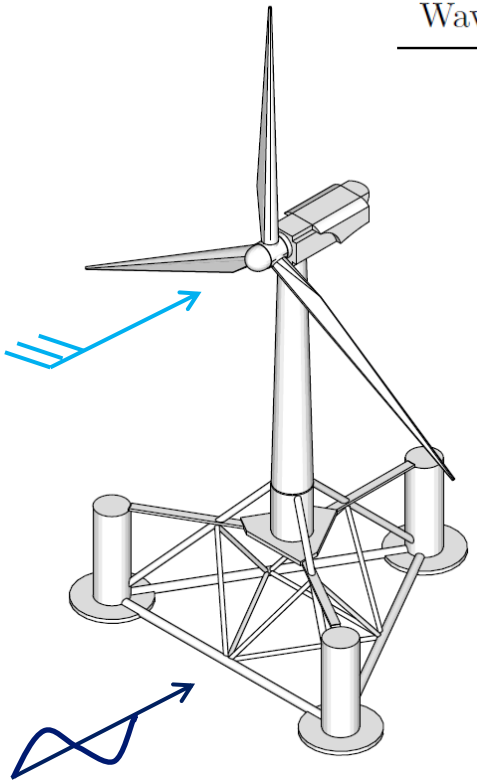
LOADING CASES

Regular waves

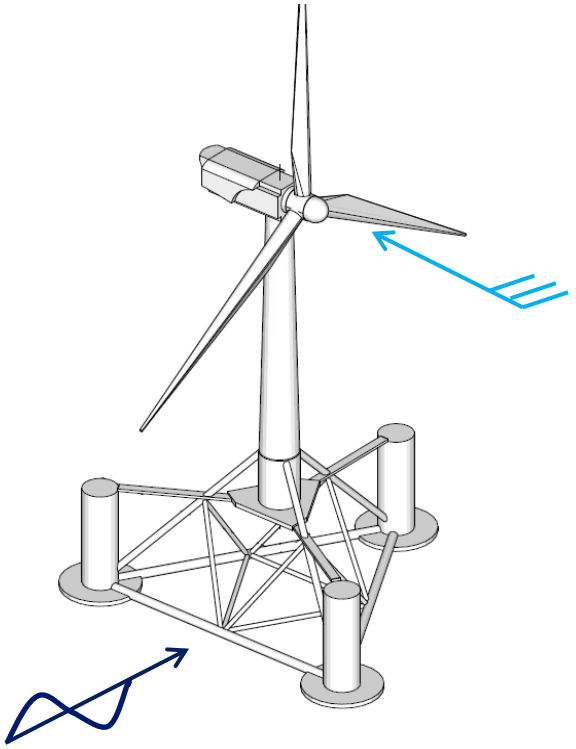
Loading case name	LC0	LCX	LCY
Wind speed [m/s]	0.0	11.4	11.4
Wind direction [deg]	-	0.0	90.0
Turbine operation	parked	rated	rated
Wave height [m]	4.0	4.0	4.0
Wave direction [deg]	0.0	0.0	0.0



LC0



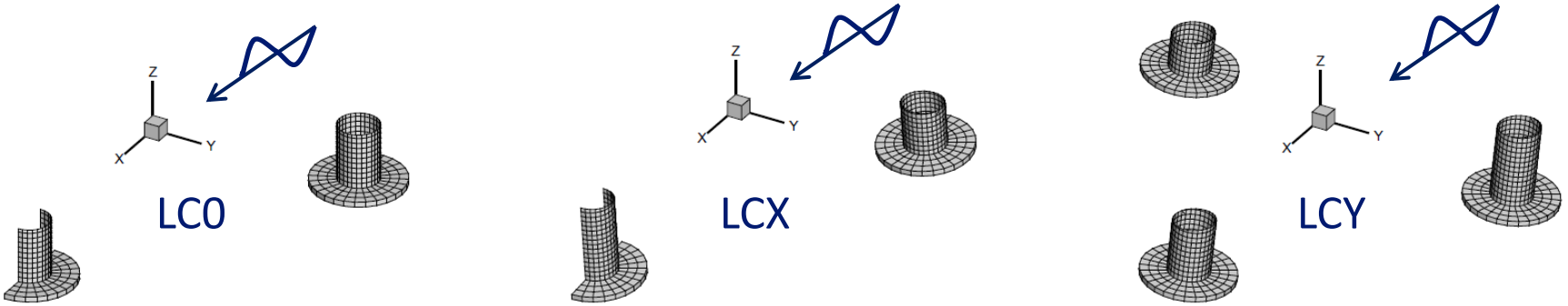
LCX



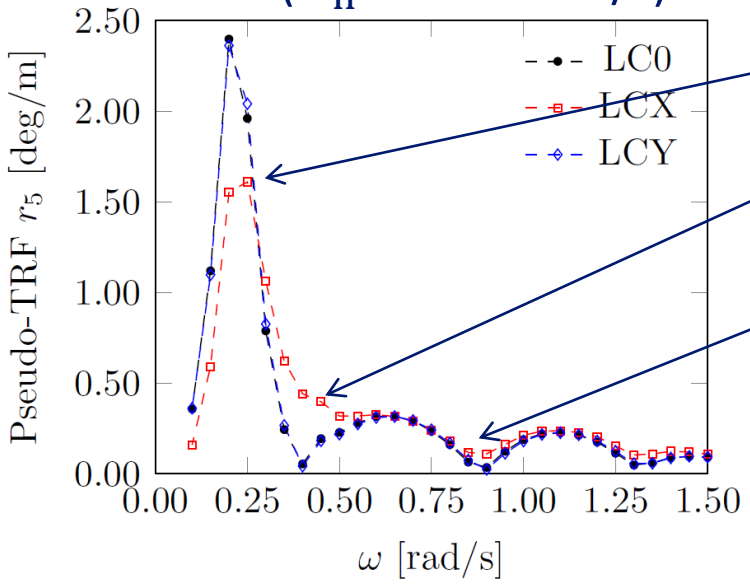
LCY

STUDY OF DUTCH TRI-FLOATER

KEY RESULTS



Pitch ($\omega_n \cong 0.25$ rad/s)



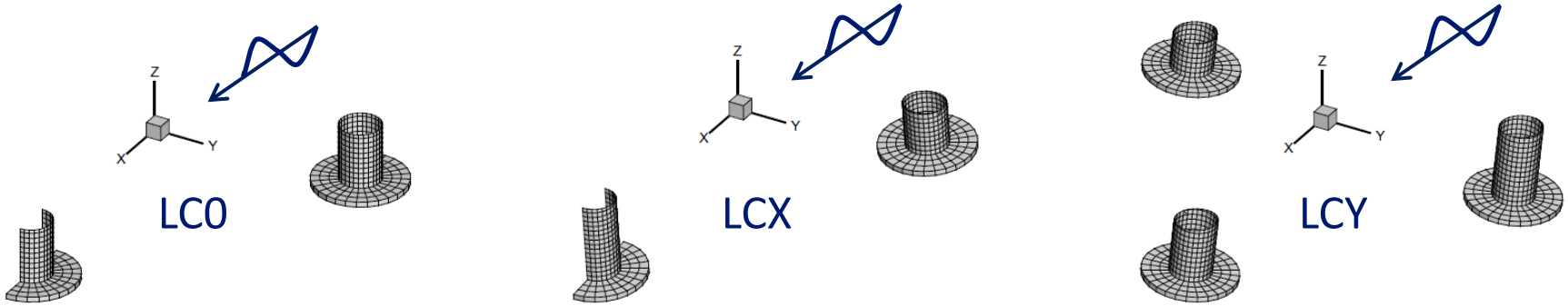
Aerodynamic damping

Column+plate excursion aerodynamic coupling

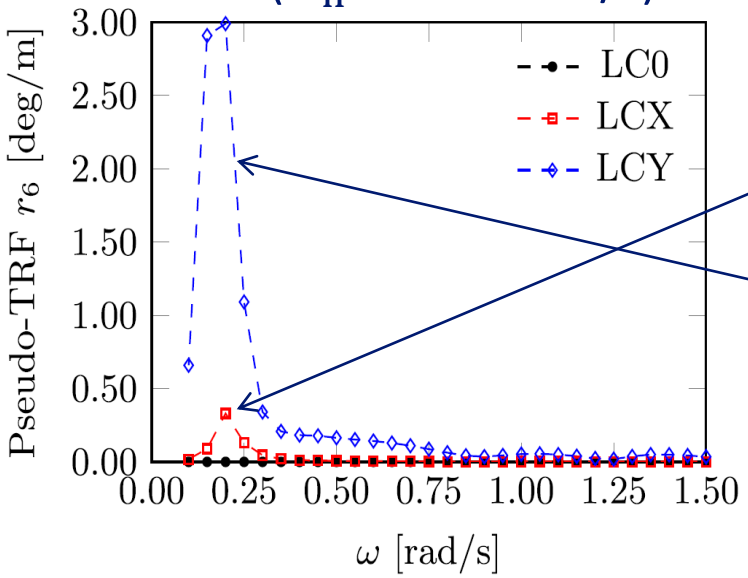
Column+plate excursion

STUDY OF DUTCH TRI-FLOATER

KEY RESULTS



Yaw ($\omega_n \cong 0.18$ rad/s)



Gyroscopic coupling

Column+plate excursion

CONCLUSION

RESULTS

- Inclination coupling significant in presence of **combined wind and waves**
- Invalidates the classic assumptions of offshore models => **challenge in platform design and verification**
- Proposed methodology adaptation was **validated** (VALEF2 project)

PUBLICATION

Antonutti et al., '**The effects of wind-induced inclination on the dynamics of semi-submersible floating wind turbines in the time domain**', *Renewable Energy*, vol. 88, pp. 83–94, 2016.

CONCLUSION

FURTHER WORK

- CALHYPSO now upgraded to solve 6 DoF dynamics in the floating frame
- Geometric nonlinearity may be addressed with higher-order hydro modelling
- Explore finite inclinations for other floater types
- How to accommodate this in probabilistic design?

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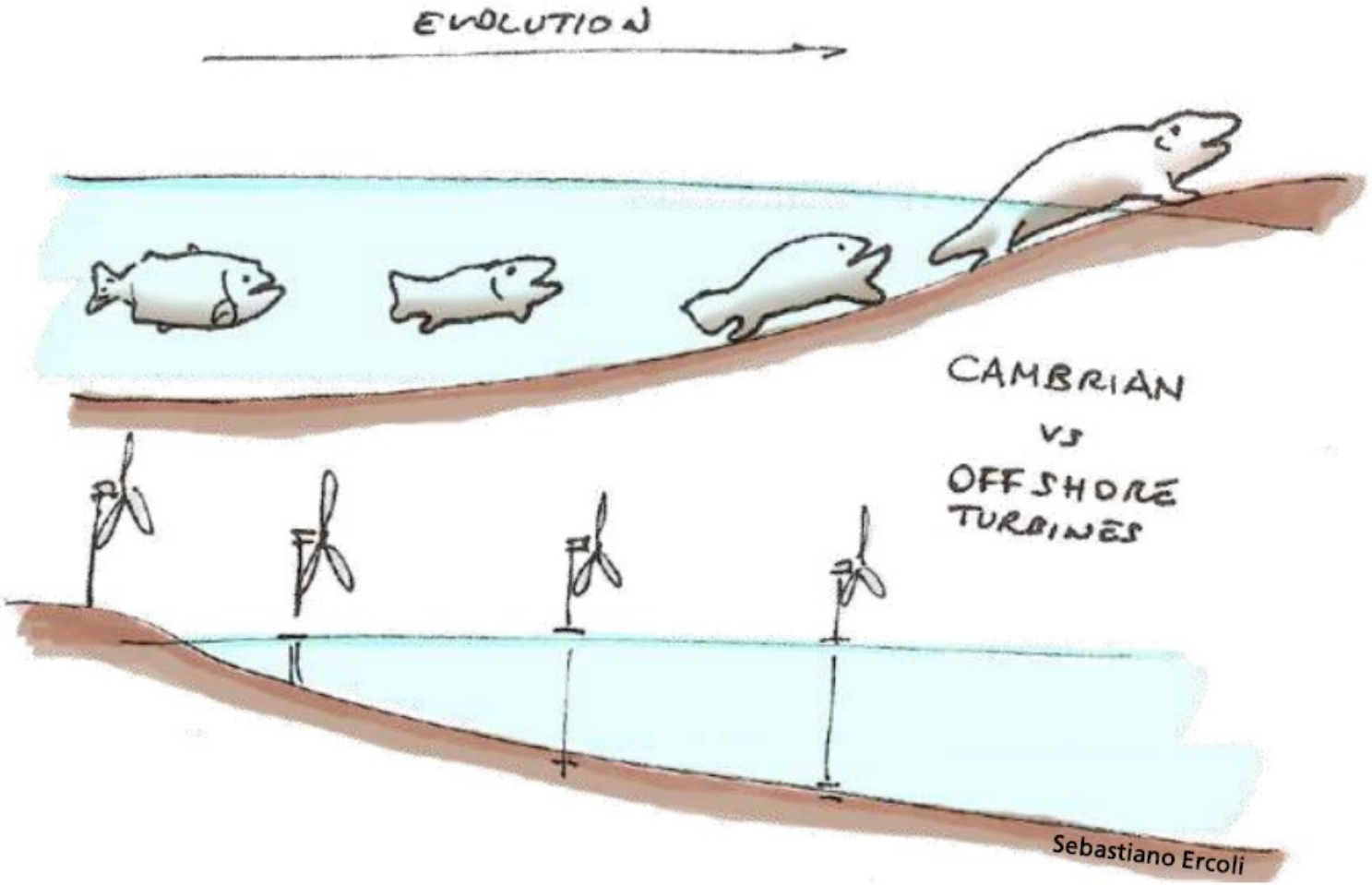
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VS
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TURBINES
Sebastiano Ercoli

Thank you