REAL TIME HYBRID MODELLING

APPLIED TO A
FLOATING OFFSHORE WIND TURBINE

USING
A DUCTED FAN

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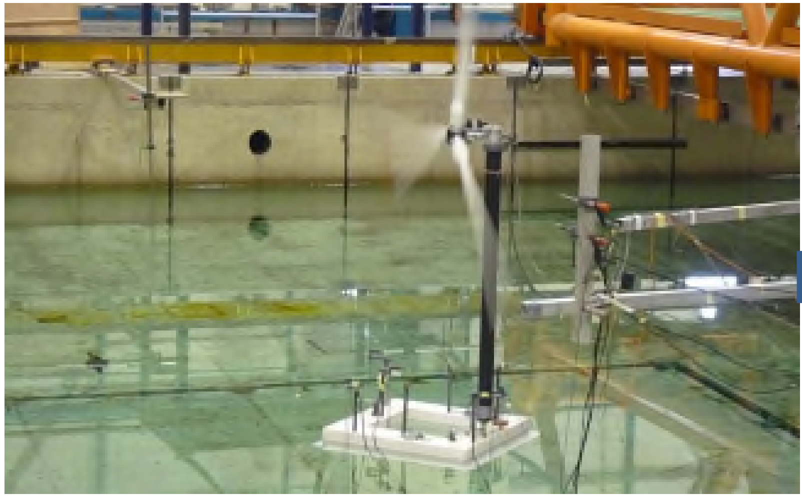
INTRODUCTION

- Basin model tests consist in
  - Modelling the complete system at a reduced scale
  - Submit it to site environmental conditions (waves, wind & current)
  - Measure quantities of interest (motions, accelerations, mooring tensions…)
- They are usually carried out at FOWT design stage to
  1. Measure quantities difficult to capture numerically (viscous effects…)
  2. Validate the design

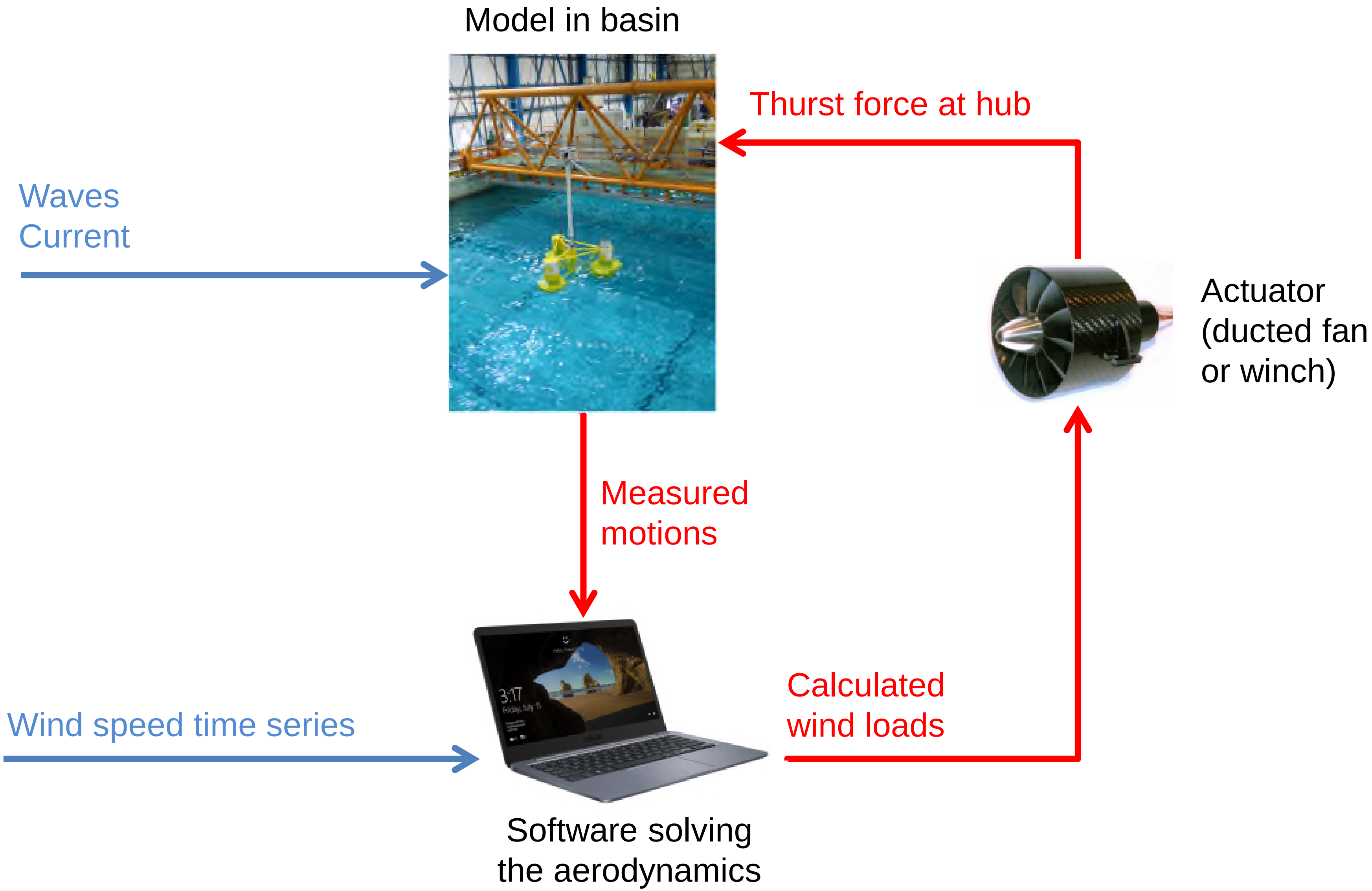


INTRODUCTION

- For FOWT modelling in basin, 2 scaling laws shall be used but are not compatible
  - Froude similitude for the hydrodynamics (submerged part)
  - Reynolds similitude for the aerodynamics (emerged part)
- 3 alternatives can be used

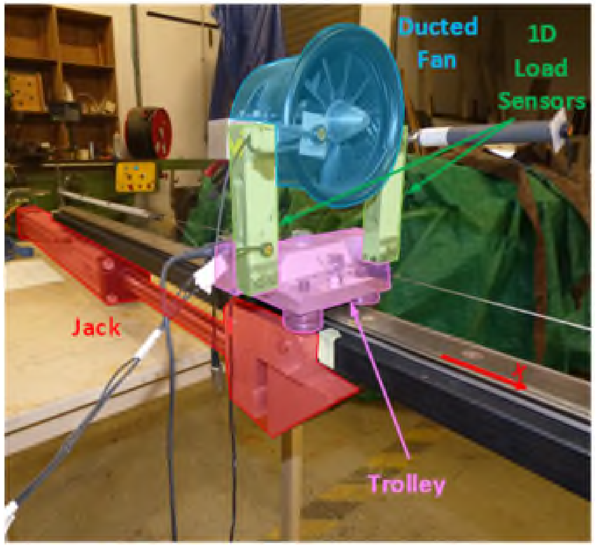
Hydro	Aero	Pro & Cons
In basin	In basin With wind	Uncertain
In basin	Numerically Afterwards	Does not allow « third party » control
In basin	In basin Numerically	So called « RTHM » The best technical choice

RTHM APPLIED TO FOWT



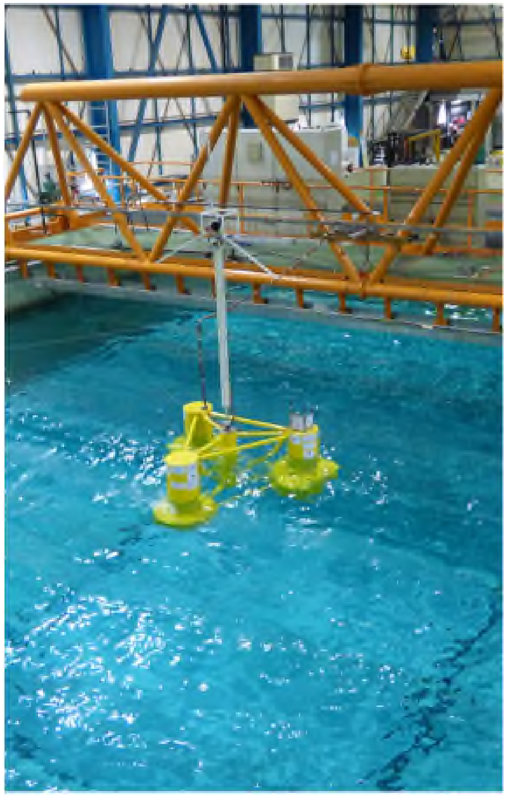
THE JIP

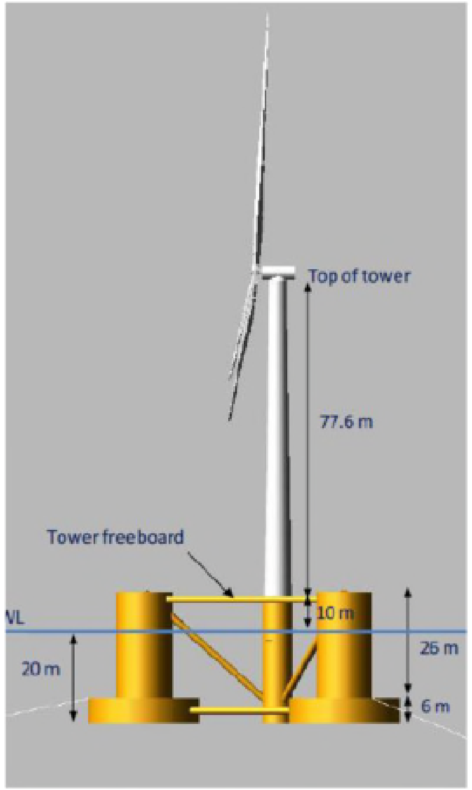
- RTHM has already been applied to FOWT's
- But more "feedbacks" are still needed
- A JIP was initiated by OCEANIDE & PRINCIPIA in 2019 to clarify
  - How reliable and robust such a methodology is
  - How it shall be specified / controlled
  - Which accuracy / gain compared to other methodologies can be expected
  - …
- The program included
  - Development
  - Qualification on a bench outside basin (static + dynamic tests)
  - Application to a "real" case (tests in basin)
  - Synthesis & recommendations
- The presentation will focus on a few results



CASE STUDY

- Floater : DeepCwind (OC4)
- Turbine : NREL 5MW
- Actuator : ducted fan
- Scale : 1/32
- Software : DeepLinesWind

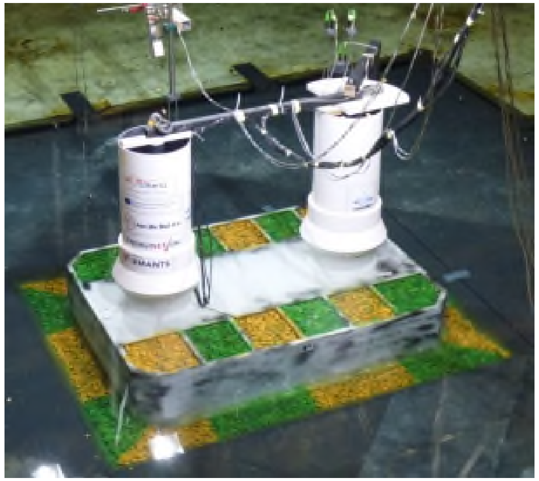




	Global COG location			Mass	Inertia at global COG	Radius of gyration
	X (m)	Y (m)	Z (m)	(t)	I_{yy} (t.m²)	(m)
Floater	0.00	0.00	6.52	13 659	7.070E+06	-
Tower	0.00	0.00	63.38	245	8.650E+05	-
RNA	-0.46	0.00	110.11	349	3.522E+06	-
Total measured	-0.01	0.00	10.04	14 253	1.146E+07	28.35
Total specified	-0.01	0.00	10.06	14 260	1.129E+07	28.14
Deviation (%)	-	-	-0.2%	0.0%	1.5%	0.8%

OCEANIDE FACILITY DESCRIPTION

- BGO FIRST basin : 40m x 16m x 0 to 4,8m
- Waves + Current + Wind capabilities
- Operated by Oceanide since 1998
- Located France, in « Côte d'Azur »



Kieggers Flak

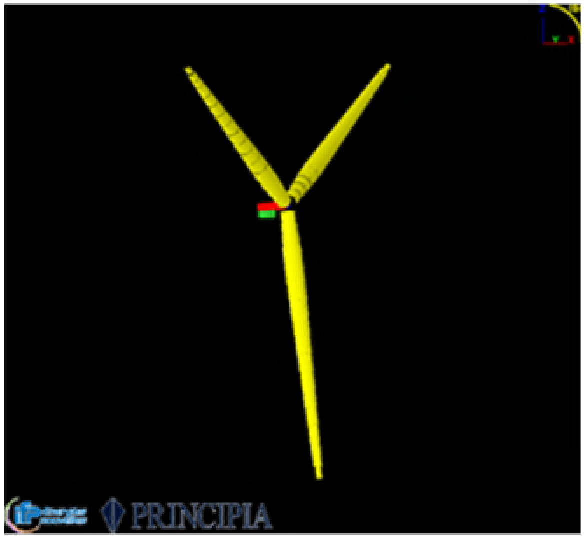
Eolfloat

PGL

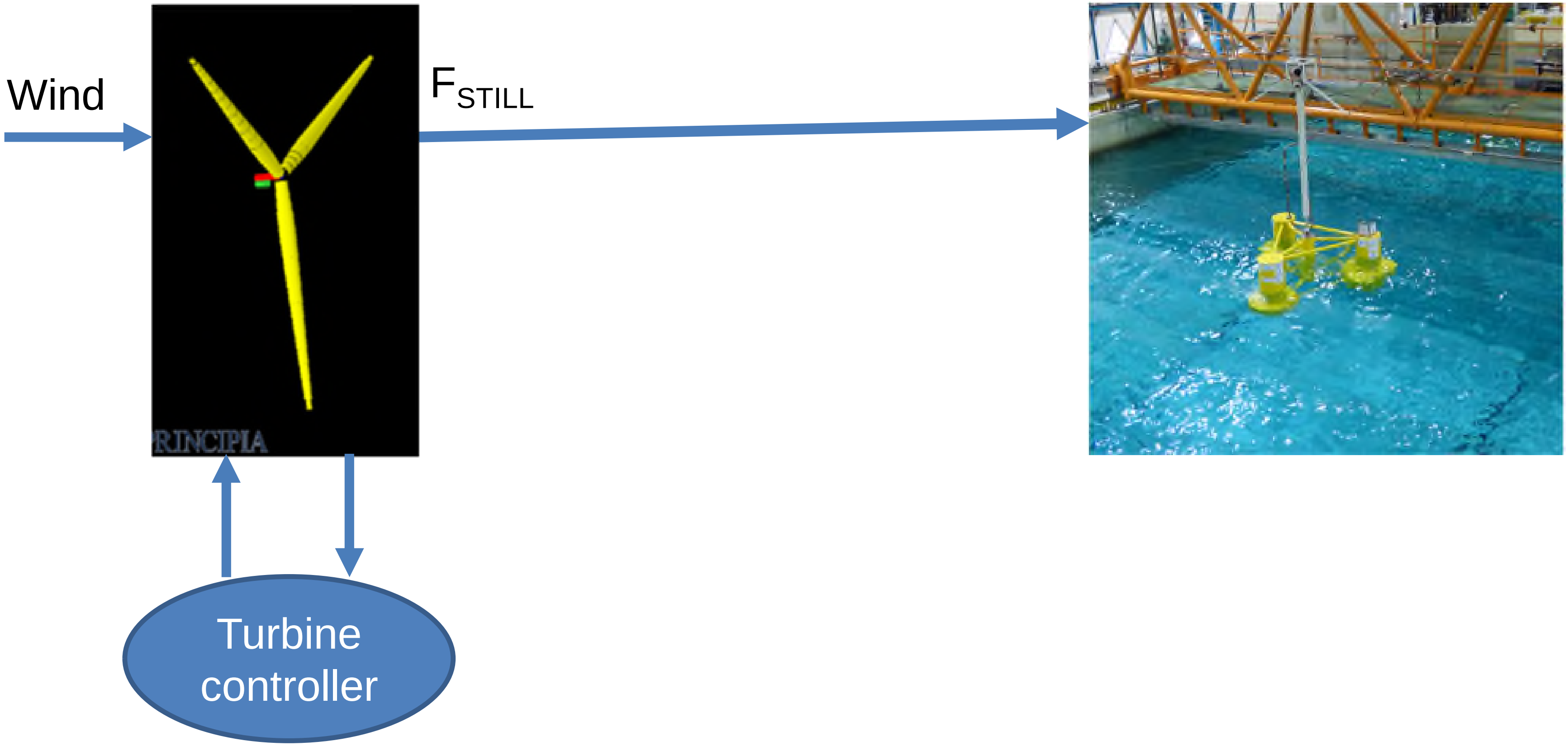
Fécamp

SOFTWARE DESCRIPTION

- Software DeepLinesWind operated by Principia
- Computing the aerodynamic loads with
  - Full 3D turbulent wind (in time and space)
  - Rigid blades & mast
- Using
  - NREL controller
  - Real-Time measured 6D motions / speeds / accelerations at hub

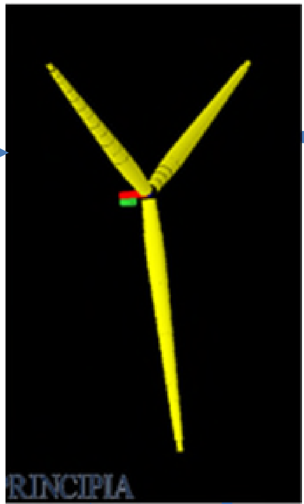


STEP 1 : OPEN LOOP



One way coupling

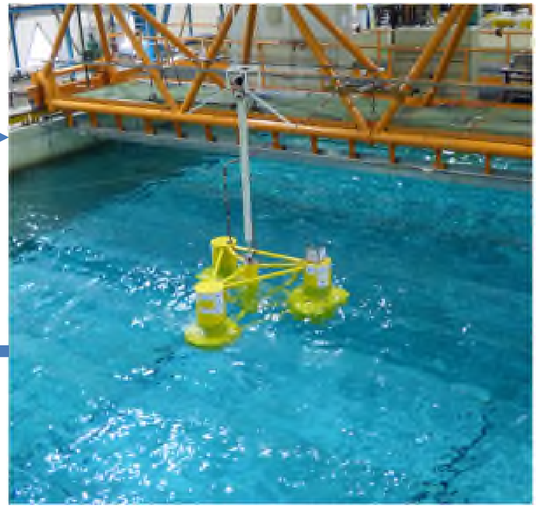
Wind



F_{STILL}

Simplified formulae

F_{COR}



measured motions

Turbine controller

$$F(t) = \alpha \left(V_{wind}(t) - V_{hub}(t) \right)^2$$

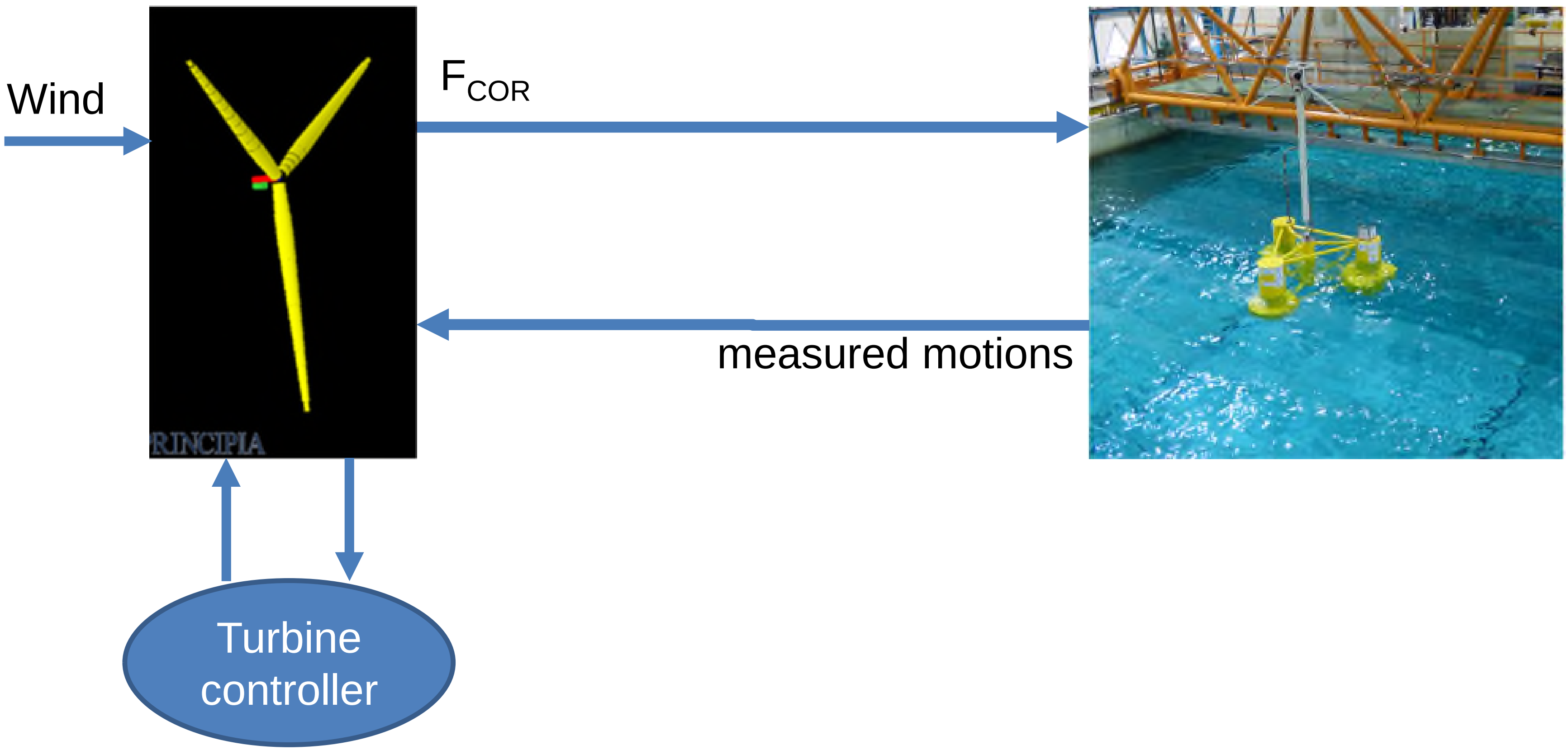
$$F(t) \sim \alpha V_{wind}(t)^2 - 2\,\alpha\, \overline{V_{wind}}\, V_{hub}(t)$$

$$F_{COR}(t) \sim F_{STILL}(t) - 2\, \frac{\overline{F_{STILL}}}{\overline{V_{wind}}^2}\, \overline{V_{wind}}\, V_{hub}(t)$$

$$F_{COR}(t) \sim FSTILL(t) - \beta\, V_{hub}(t)$$

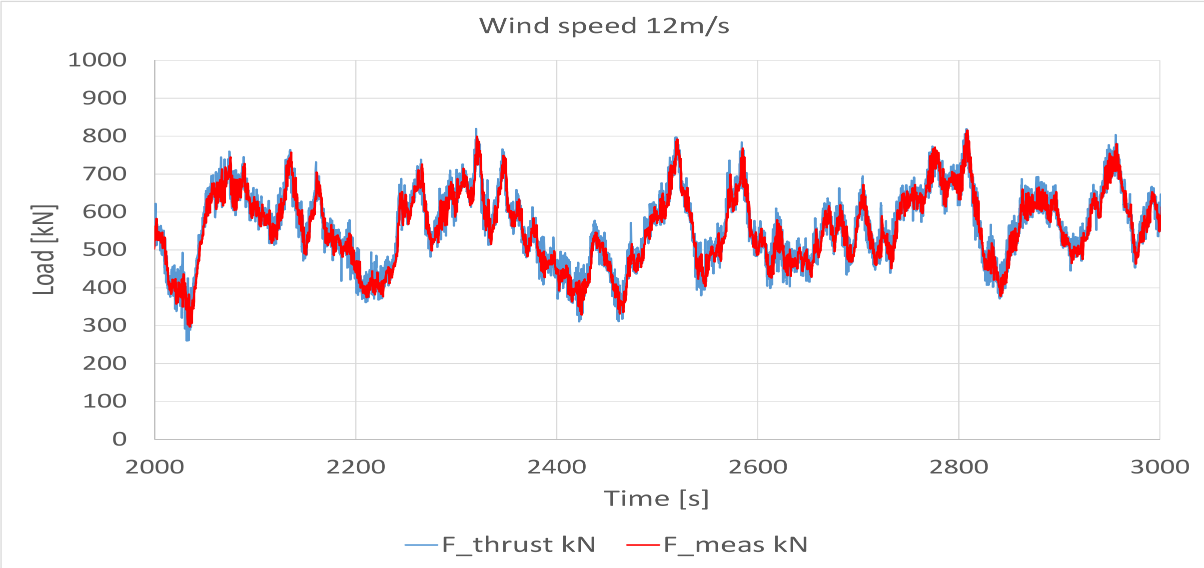
2 ways coupling but turbine controller not in the loop

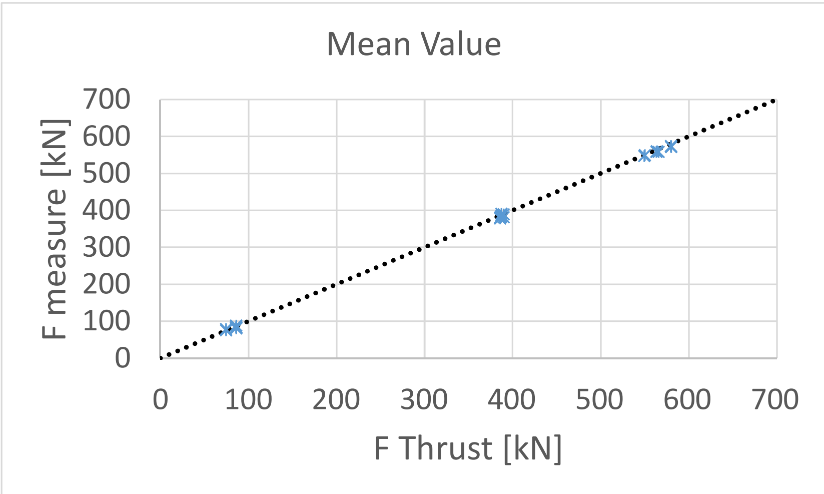
STEP 3 : COMPLETE LOOP

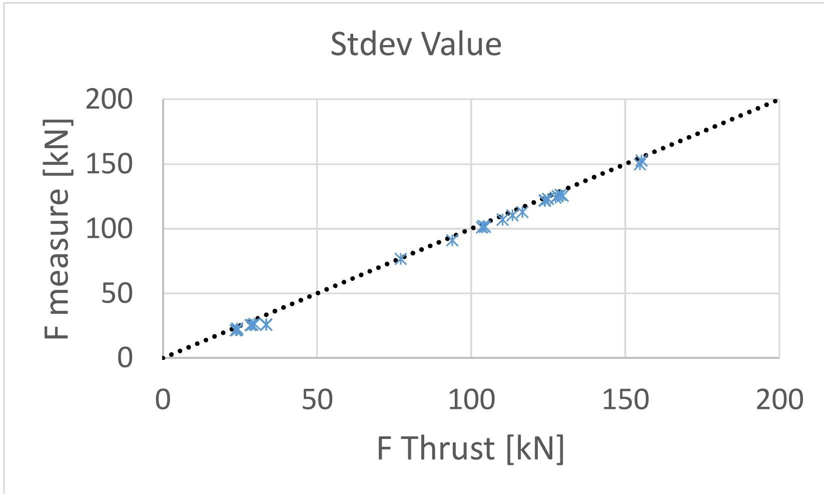


➡ 2 ways coupling with turbine controller in the loop

DUCTED FAN PERFORMANCE



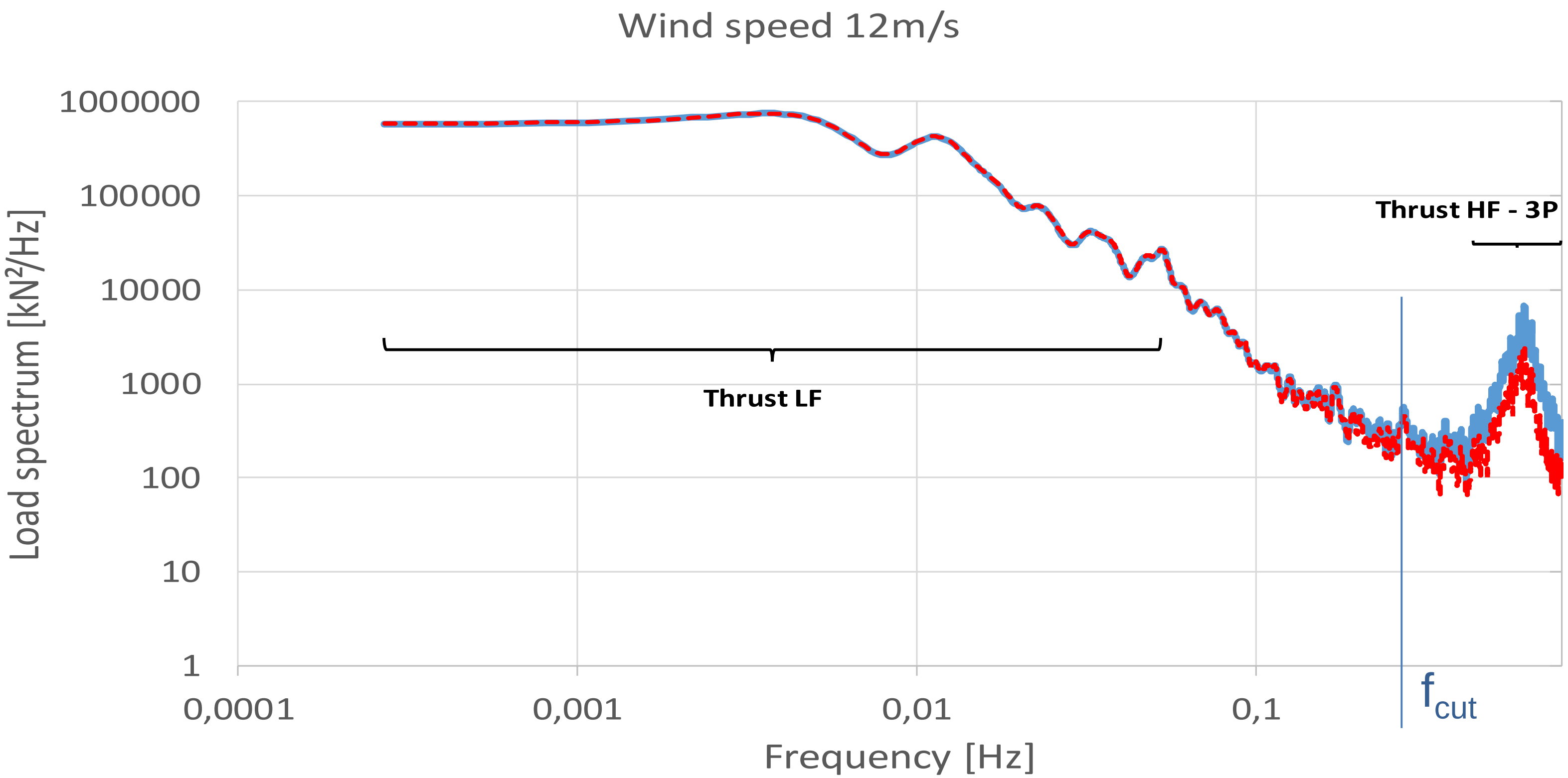




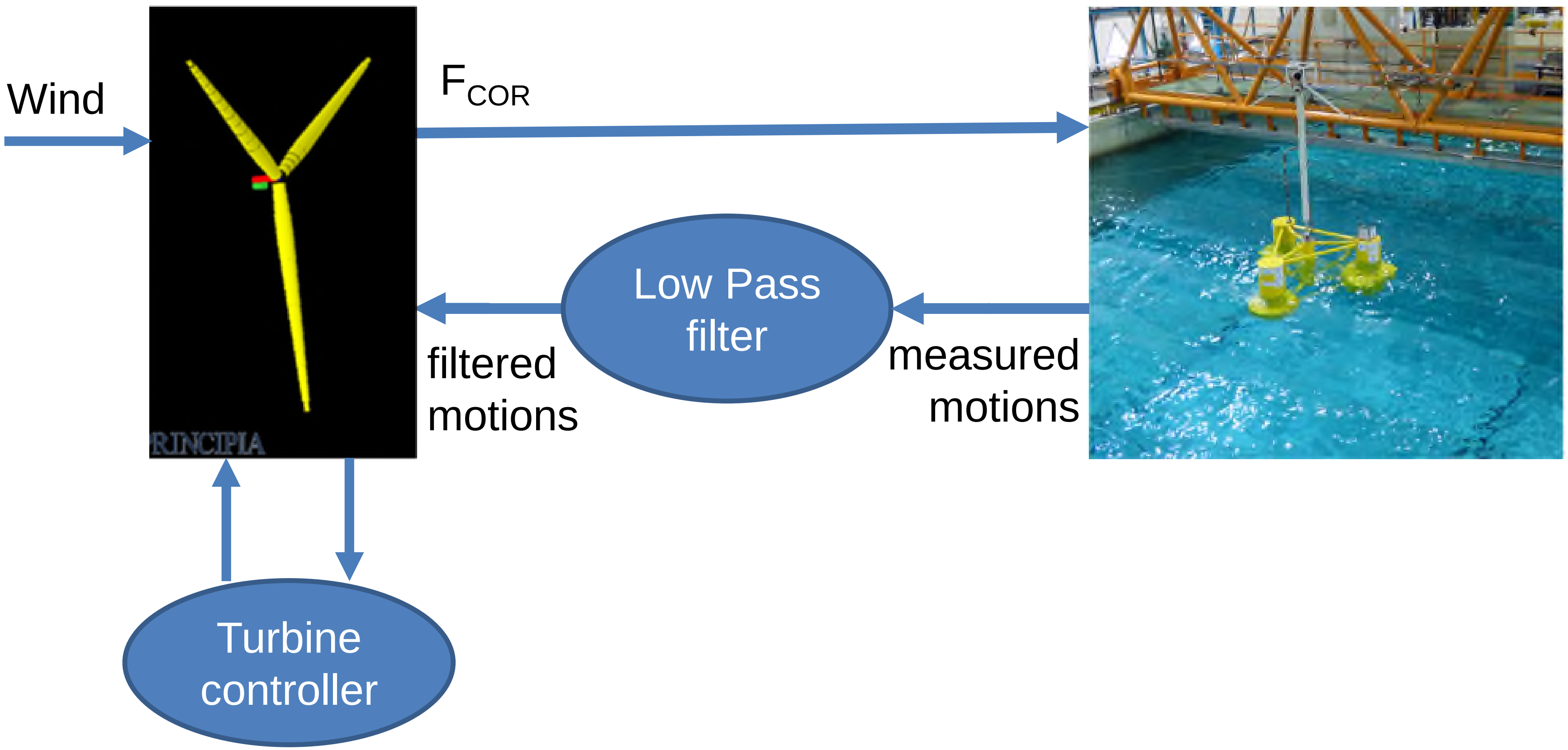
DUCTED FAN PERFORMANCE

- Obtained
  - after measurement of the ducted fan transfer function (TF) in static
  - application of the load time series in basin on the floating FOWT, without PID

=> Very good repeatibility, and no influence of floater motions on fan TF



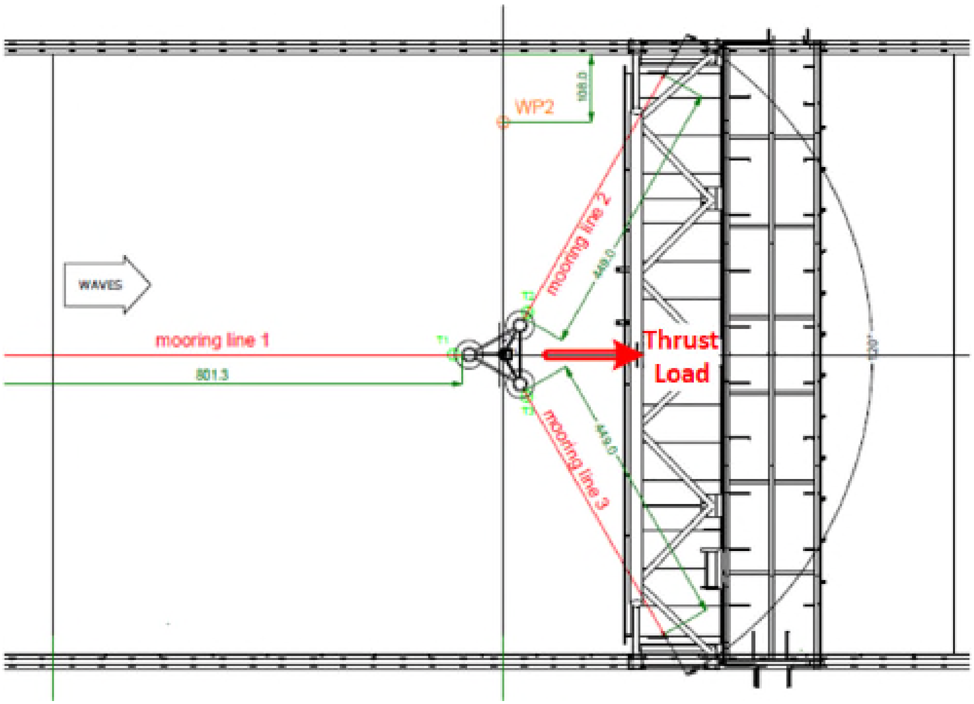
STEP 3 : MODIFIED COMPLETE LOOP



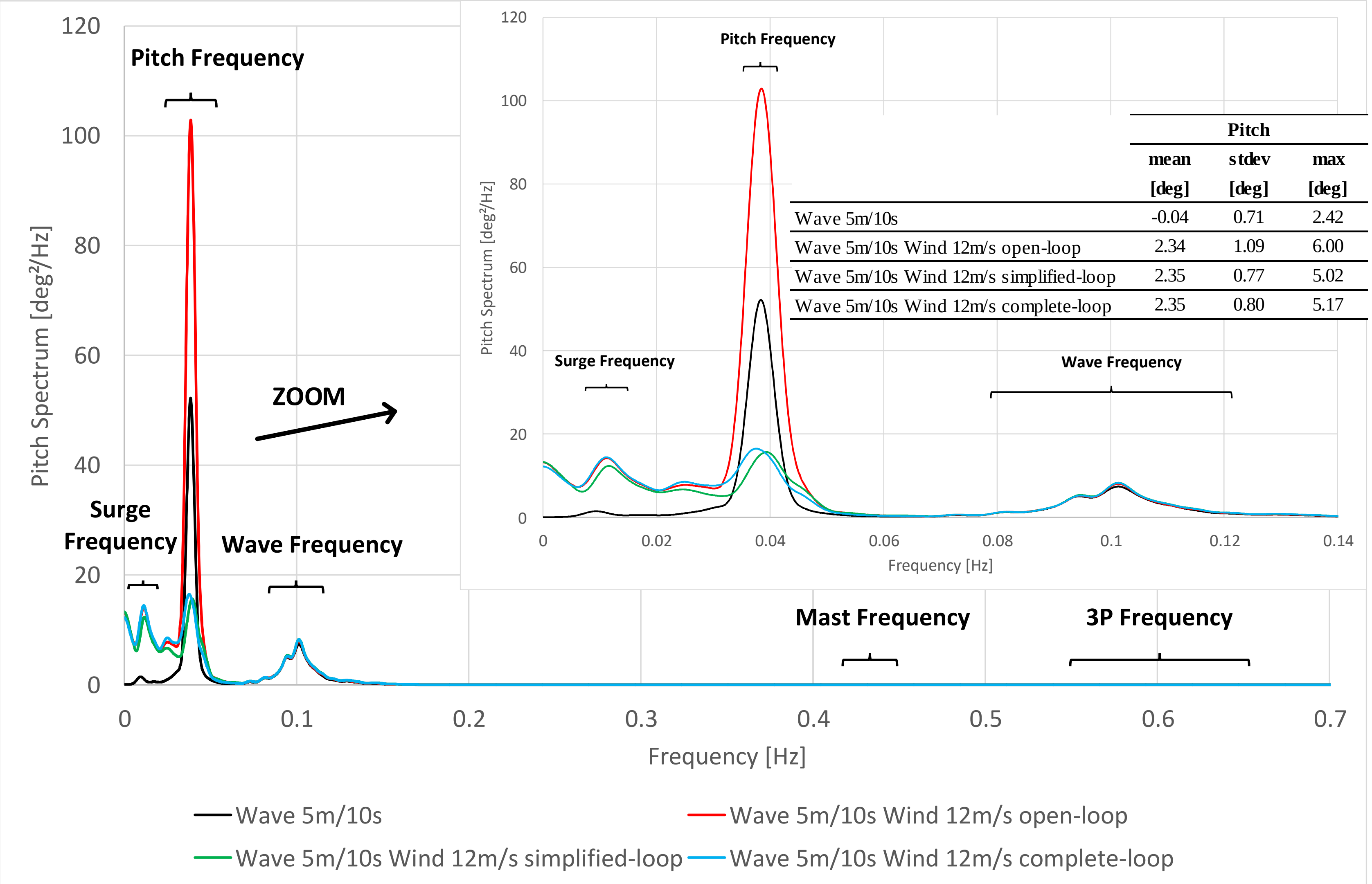
- LF & WF in the loop
- HF (1P, 3P…) imposed

SOME RESULTS

- Results are presented hereafter
  - For each of the 3 different steps : open-loop, simplified loop, modified complete loop
  - For 2 different Hs : 5m and 10m
  - For 1 speed : 12m/s (rated speed, the one for which the turbine controller is the most active)
  - For collinear wind / waves

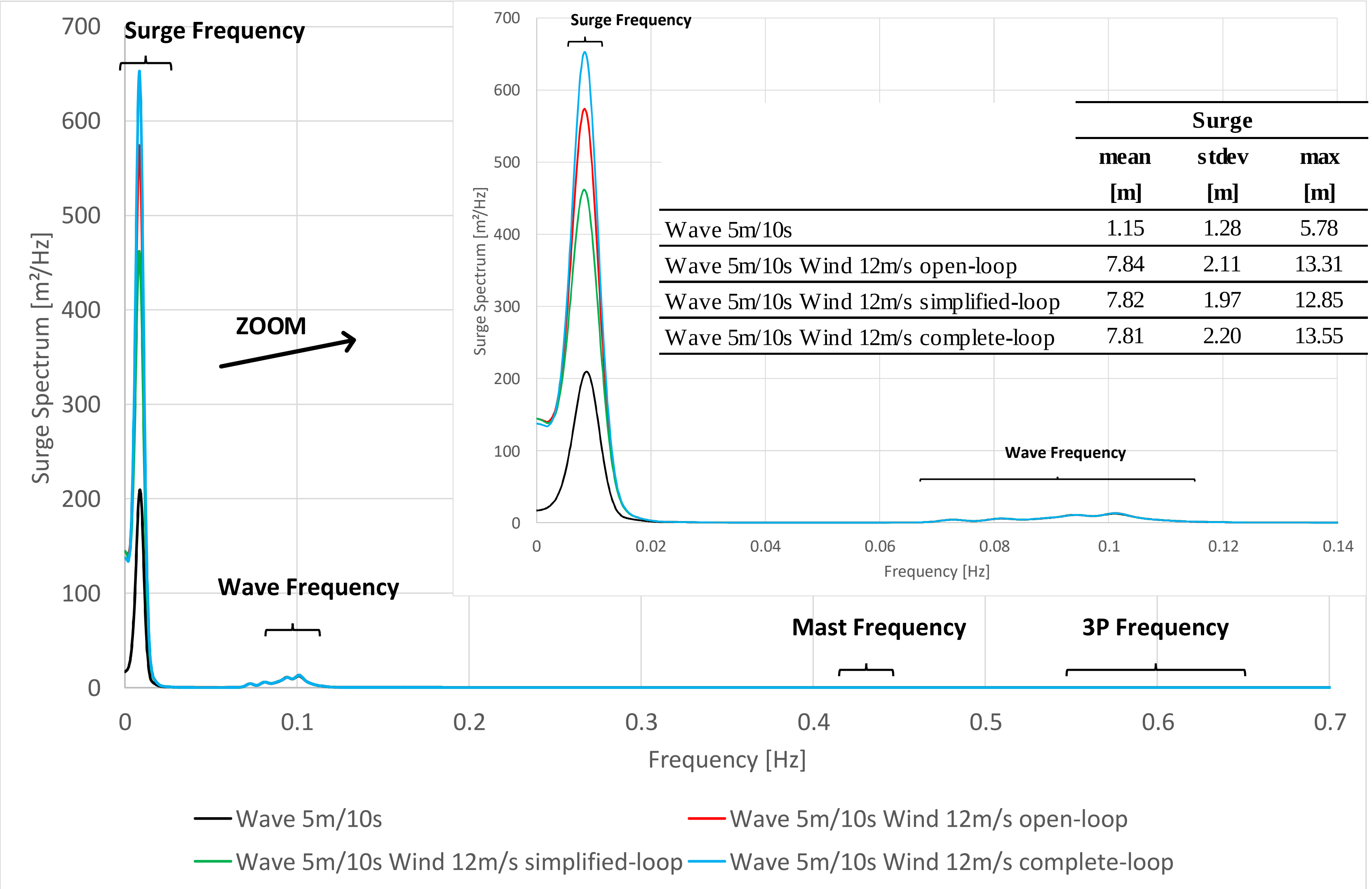


FLOATER PITCH RESPONSE



	Pitch mean [deg]	Pitch stdev [deg]	Pitch max [deg]
Wave 5m/10s	-0.04	0.71	2.42
Wave 5m/10s Wind 12m/s open-loop	2.34	1.09	6.00
Wave 5m/10s Wind 12m/s simplified-loop	2.35	0.77	5.02
Wave 5m/10s Wind 12m/s complete-loop	2.35	0.80	5.17

FLOATER SURGE RESPONSE



	Surge		
	mean [m]	stdev [m]	max [m]
Wave 5m/10s	1.15	1.28	5.78
Wave 5m/10s Wind 12m/s open-loop	7.84	2.11	13.31
Wave 5m/10s Wind 12m/s simplified-loop	7.82	1.97	12.85
Wave 5m/10s Wind 12m/s complete-loop	7.81	2.20	13.55

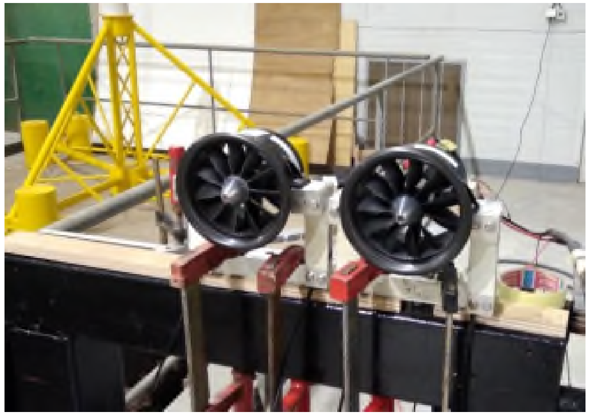
CONCLUSION

- RTHM technique has been qualified by Oceanide/Principia on a typical FOWT using a ducted fan and DeepLinesWind software

- Extensive qualification tests have shown very good performances
  - Thurst force is applied with an accuracy of 1%, very good repeatability
  - Software-in-the-loop can be used for LF and WF
  - For HF (1P, 3P modes), loads can be imposed, but further work is required if Software-in-the-loop is needed at such frequencies (main interest is for TLP type floaters)

- The system was designed to be extended to more DOFs. Couplings are less than 2% even for very closeby ducted fans.

Turbune 1 (N)	Turbine 3 alone (N)	Turbine 3 aside Turbine 1 (N)	Diff (%)
10	7,73	7,73	0,0%
10	18,35	18,25	-0,5%
10	28,85	28,52	-1,1%
17	7,73	7,76	0,4%
17	18,35	18,31	-0,2%
17	28,85	28,33	-1,8%
30	7,73	7,71	-0,3%
30	18,35	18,15	-1,1%
30	28,85	28,72	-0,5%



CONCLUSION

- WF floater response is governed by Waves
- Wind loads have a significant impact on floater LF response
- OPEN LOOP : conservative in most cases
- SIMPLIFIED LOOP : can provide good results => this can be an interesting alternative when the turbine controller is not fixed yet or not available
- COMPLETE LOOP : requires turbine controller

These conclusions are based on a few results on an oversized floater (DeepCwind model + NREL 5MW). Couplings should be larger for a more competitive floater but similar trends are expected

CONCLUSION

- This project was initiated in April. 2019 and will be completed in March. 2020
- The authors wish to thank **Doris Group, Engie, Saipem** and **Technip France** for their financial & technical support during this JIP
- A second phase is under discussion, new comers are welcome
- See also OMAE2020-18076
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