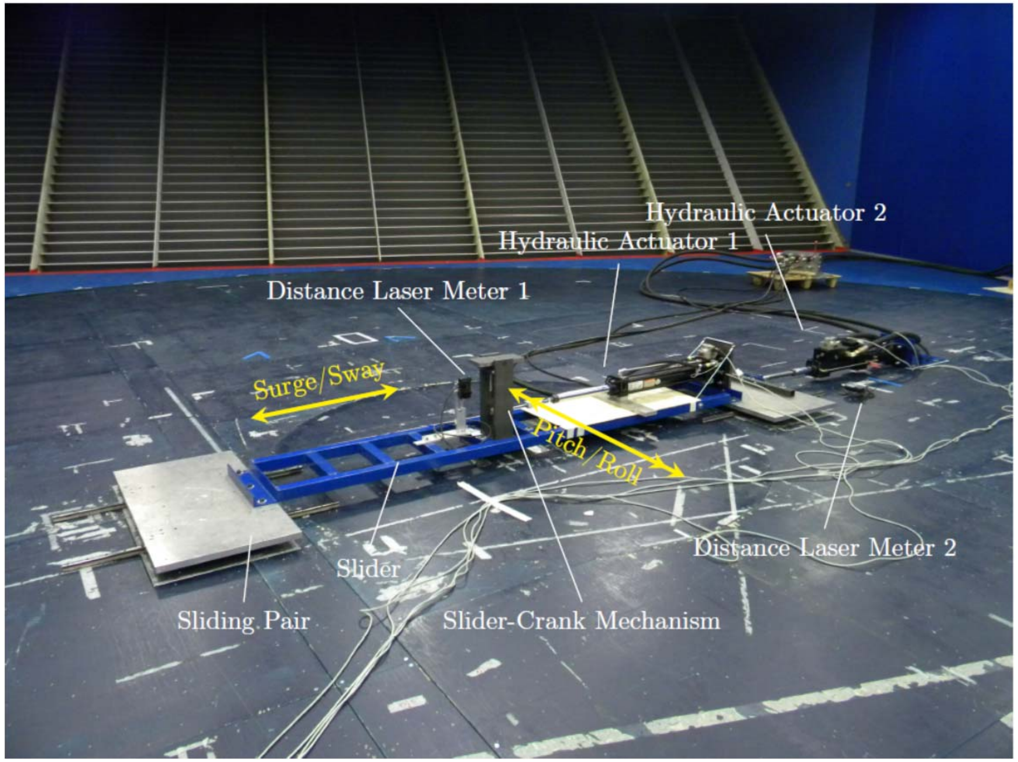
# Unsteady Aerodynamics Of FOWT:
# Toward Experimental Validation Of Equivalent Lumped-element Models

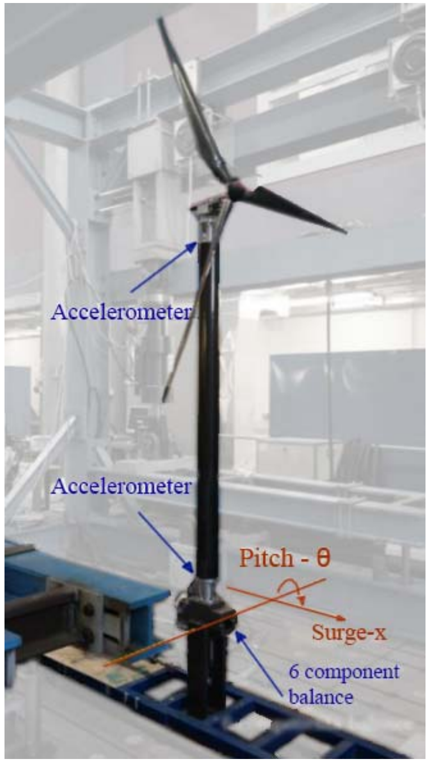
Ilmas Bayati, Luca Bernini, Alberto Zasso

Department of Mechanical Engineering

# 2DoF Setup

- Polimi WT 2011 Test of Vestas V52 (may 2011)
- Surge imposed motion
- 1/25 geometric blade scale  D=2.1m  Ω=2.5Hz

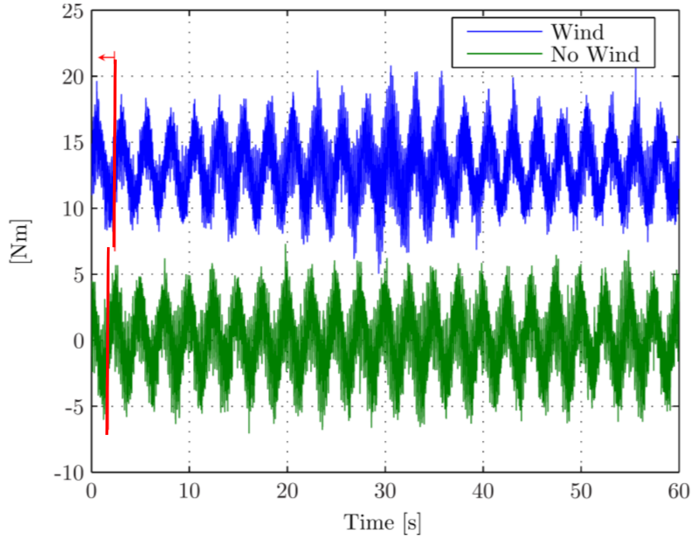


# 2DoF Setup
# experimental Session

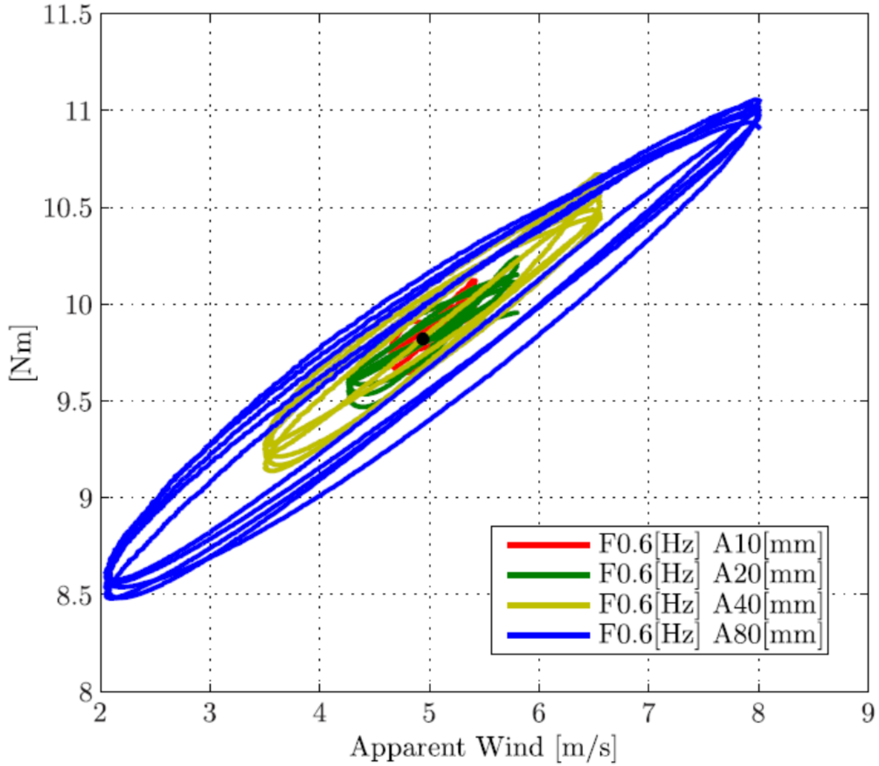
- **Steady** configuration
- **Unsteady** configuration:
  Surge and Pitch Sine waves
  - **Wind/No Wind** measuremenents
  - Inertial Forces **subtraction**

| Frequency (f) | [Hz] | 0.2 | 0.4 | 0.6 | 1 |
|---|---|---|---|---|---|
| Amplitude (A) | [mm] | 10 | 20 | 40 | 80 |
| Wind Speed (W) | [m/s] | 4.5 | 5 | 5.5 | 6 |




# 2DoF Setup
# Previous Experimental Session

- Aerodynamic Histeresis registered
- Dimension and shape of cycle depends on dynamic conditions
- **Does FAST/Aerodyn predict this behaviour?**




Example of histeretic cycles:
aerodynamic pitch moment

# Modelling
# Imposed Motion In FAST

## User Input File

- Platform Dof: Surge and Pitch
- Additional Damping and Stiffness matrices

***HydroDyn.dat***

## FAST 8 custom version

Definition of a control force at the tower's base to get an imposed motion

$$FORCE = K\_add \cdot (PtfmDisp - X) + C\_add \cdot (PtfmVel - XD)$$

***HydroDyn_input.f90***
***HydroDyn_Types.f90***
***HydroDyn.f90***

*K_add* and *C_add* :
**parameters** of the **oscillator**
f >10*f imposed motion
h =1

*K_add* and *C_add*
*(see FAST7/Seismic module)*

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## DYNIN

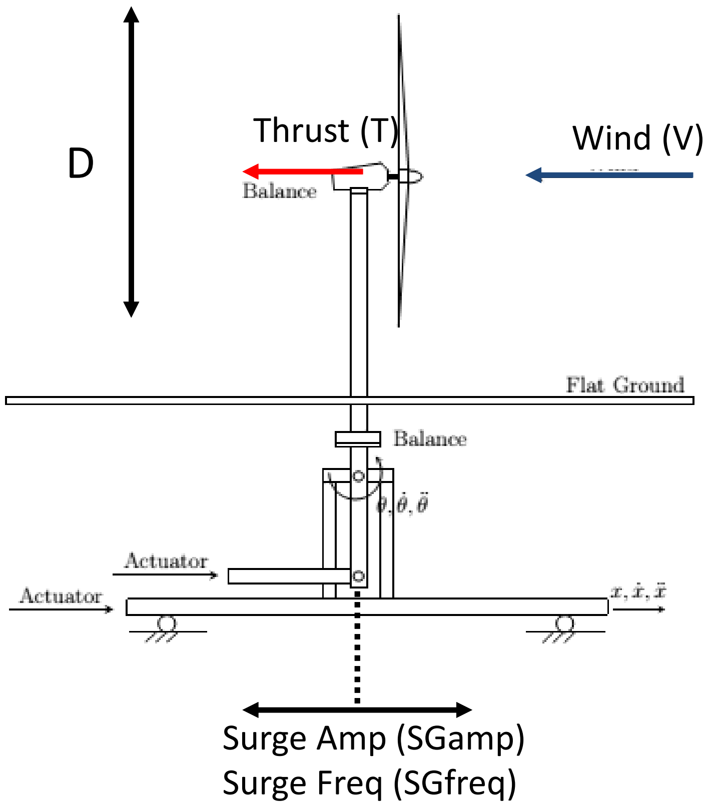
**G**eneralized **D**ynamic **W**ake **(GDW)** = acceleration potential method

- Does not require iterative process
  - More **general pressure distribution** accross rotor
  - Fully nonlinear implementation:
    **turbulence and spatial variation of inflow**
  - **Inherent modelling** of:
    - Dynamic wake effect
    - Tip losses
    - Skewed wake

Accounting for **time lag** in the **induced velocity** created by vorticity shed from blades and convected downstream

# Nomeclature

Experimental/Numerical test scheme




Variable definition

$x$ → surge motion displacement

$\dot{x}$ → surge motion velocity

$V_A = V + \dot{x}$ → Apparent wind

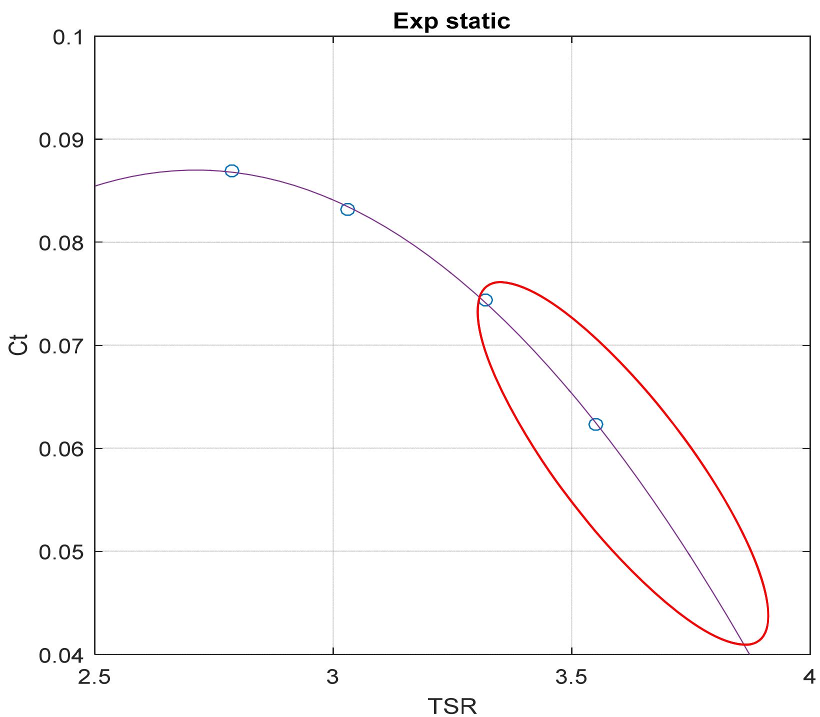
$Ct = \dfrac{T}{0{,}5\rho V_a(\frac{\pi D^2}{4})}$ → Thrust coefficient

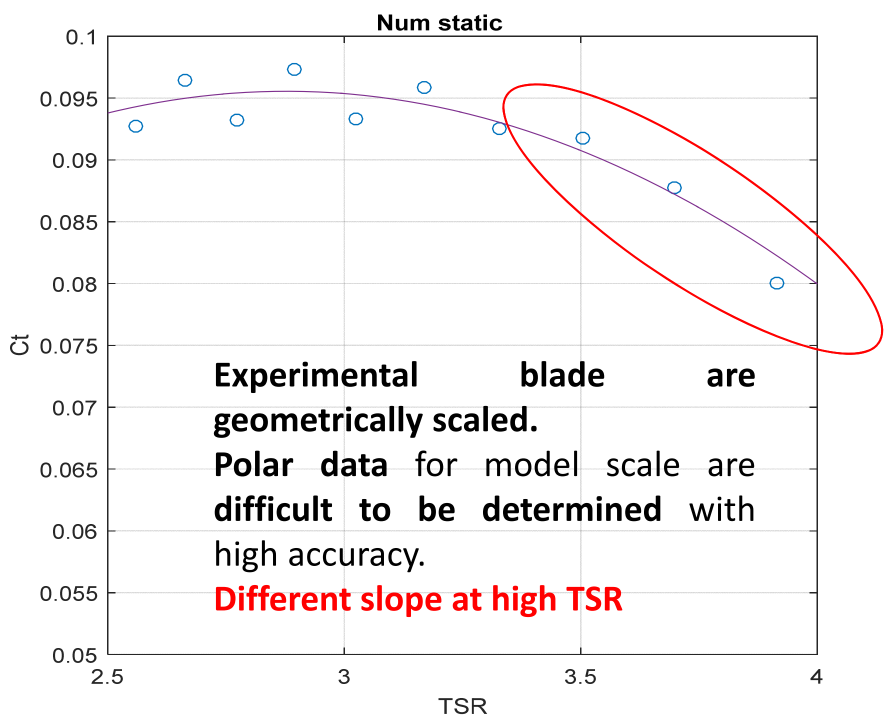
$TSR = \dfrac{\Omega D/2}{V}$ → Nominal tip speed ratio

tsr= $\dfrac{\Omega D/2}{V_A}$ → Effective tip speed ratio

# Experimental vs Numerical results

## Static thrust




**Experimental blade are geometrically scaled.**
**Polar data** for model scale are **difficult to be determined** with high accuracy.
**Different slope at high TSR**

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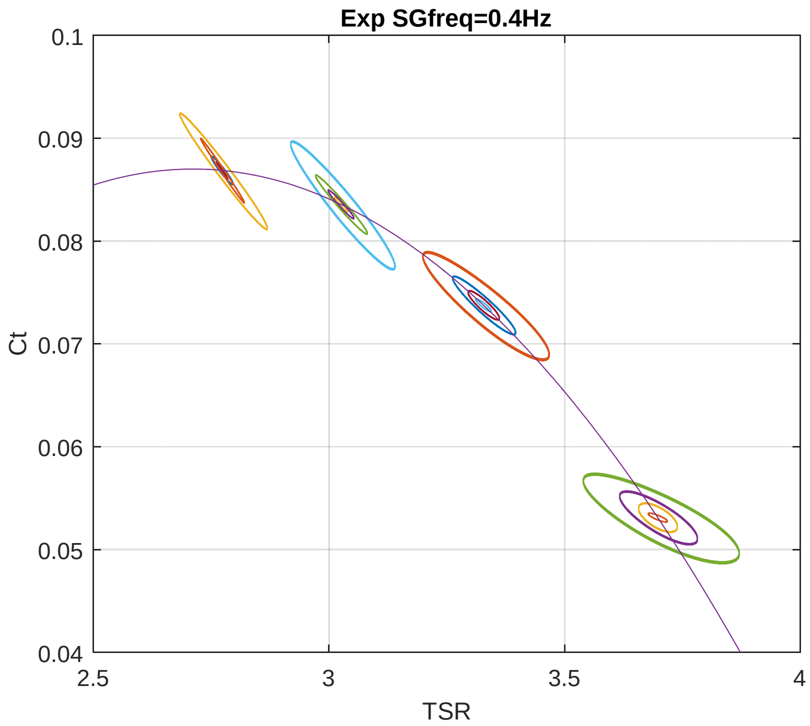
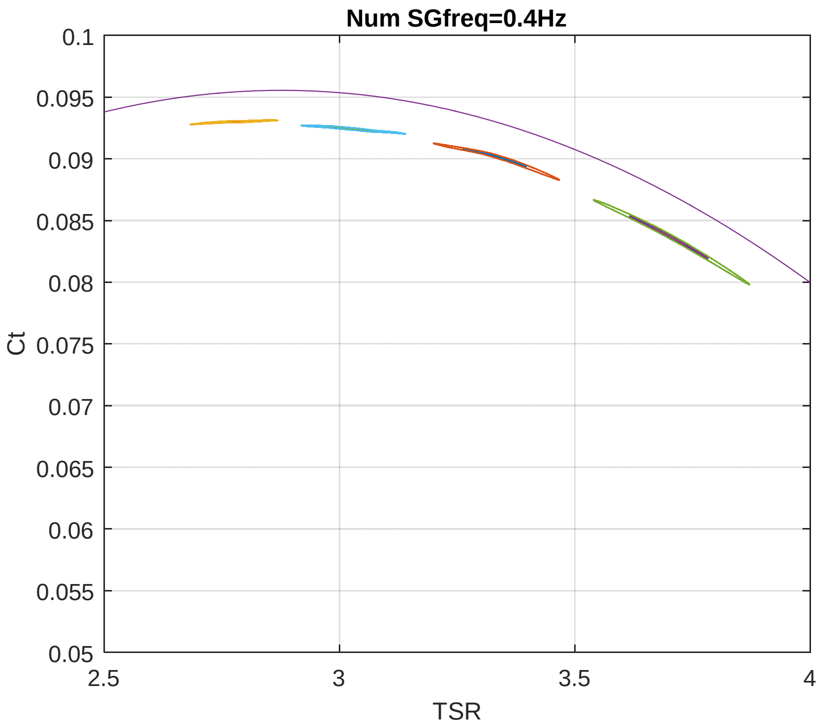
# Experimental vs Numerical results

Dynamic results

- Surge motion frequency 0.4Hz
- Various amplitude

- Agreement Experimental & Numerical
  → Dissipative Hysteresis cycles
- Disagreement in the time delay value i.e.
  → amplitude of hysteresis cycles

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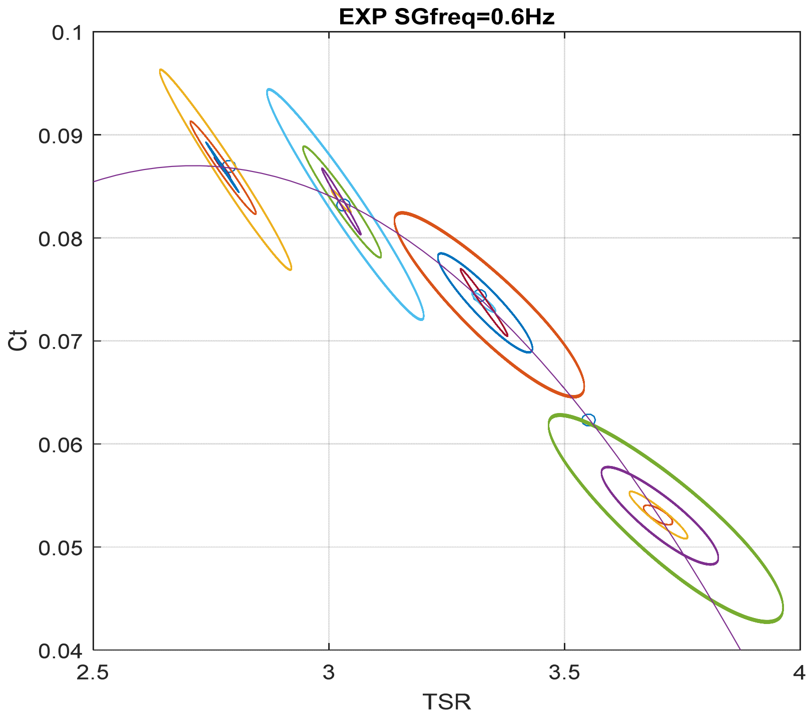
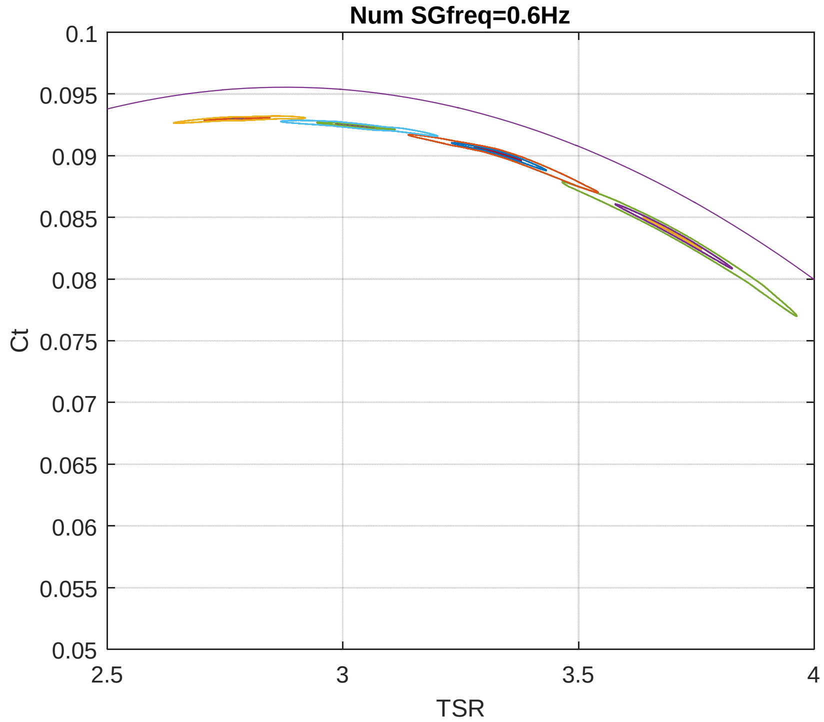
# Experimental vs Numerical results

Dynamic results

- Surge motion frequency 0.6Hz
- Various amplitude

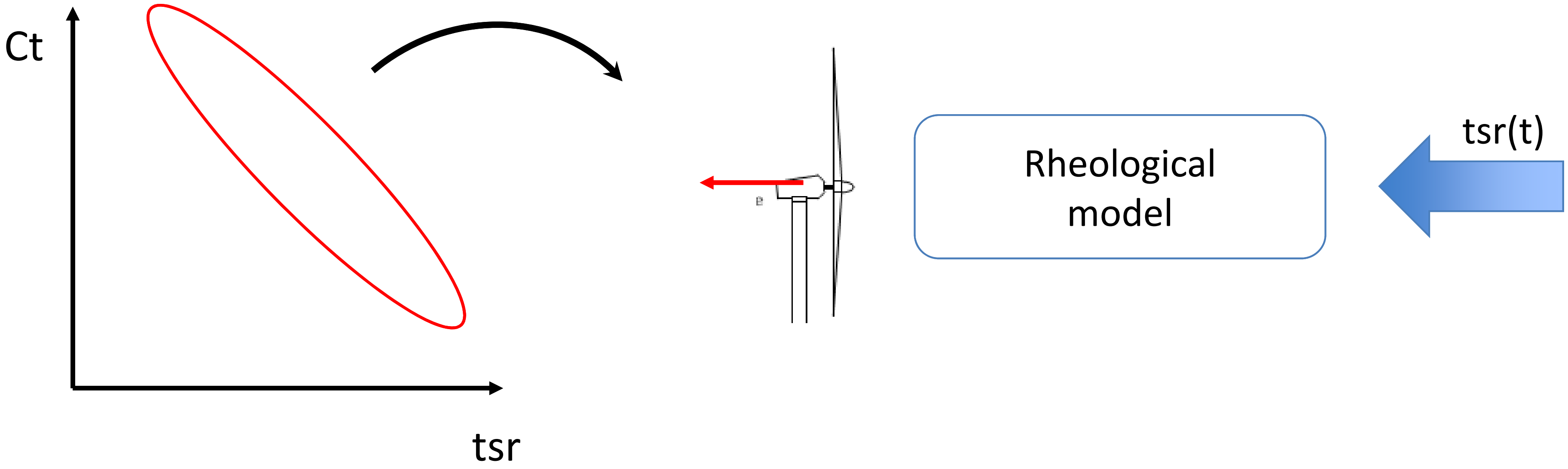
- Agreement Experimental & Numerical → Larger Hysteresis cycles
- GDW underestimates the hysteresis effects



# Lumped-element model: advantages

- SS model aero (control, integrated with hydro)
- Different parameters (wt verification) relationship with wind/sea states (nominal condition for simulations)
- Large wind farms control

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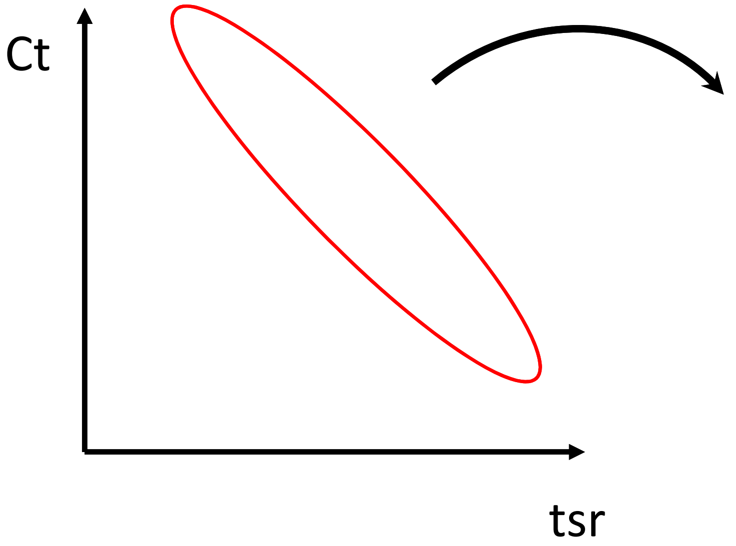
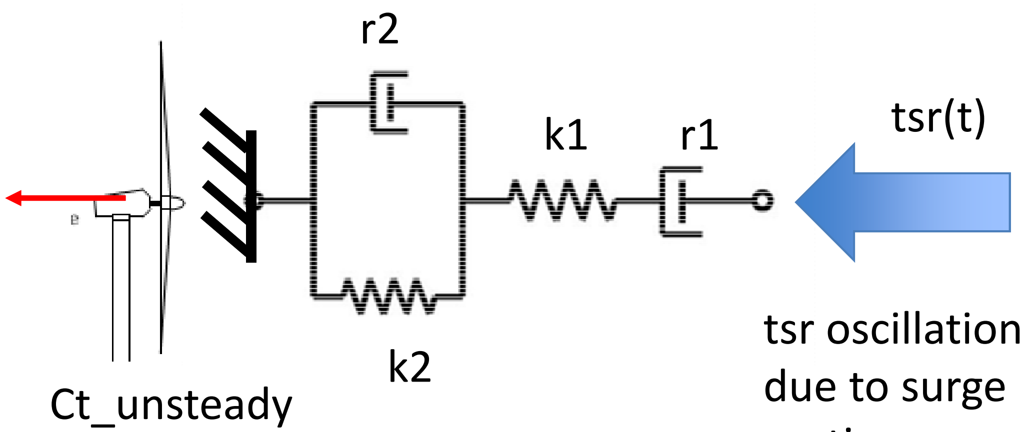
# Proposed lumped model

Objective:
Model the unsteady turbine response to platform motion




Maxwell + Voigt



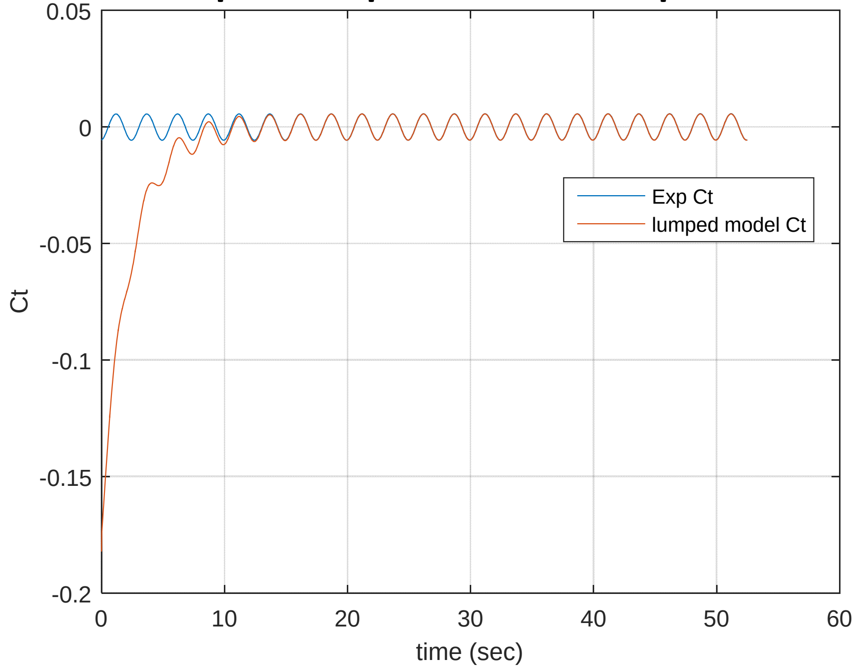

Ct=Ct_static(TSR)+Ct_unsteady(tsr)

# Proposed lumped model

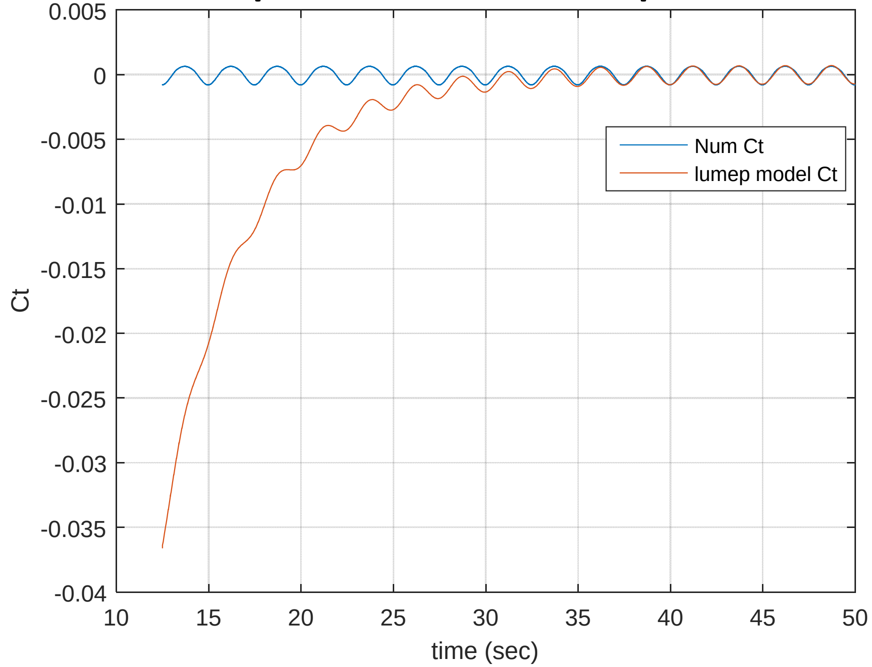
Good results for turbine thrust unsteady modelling both for numerical and experimental data.

**Parameters identification is required**

## Example of experimental data prediction




## Example of numerical data prediction

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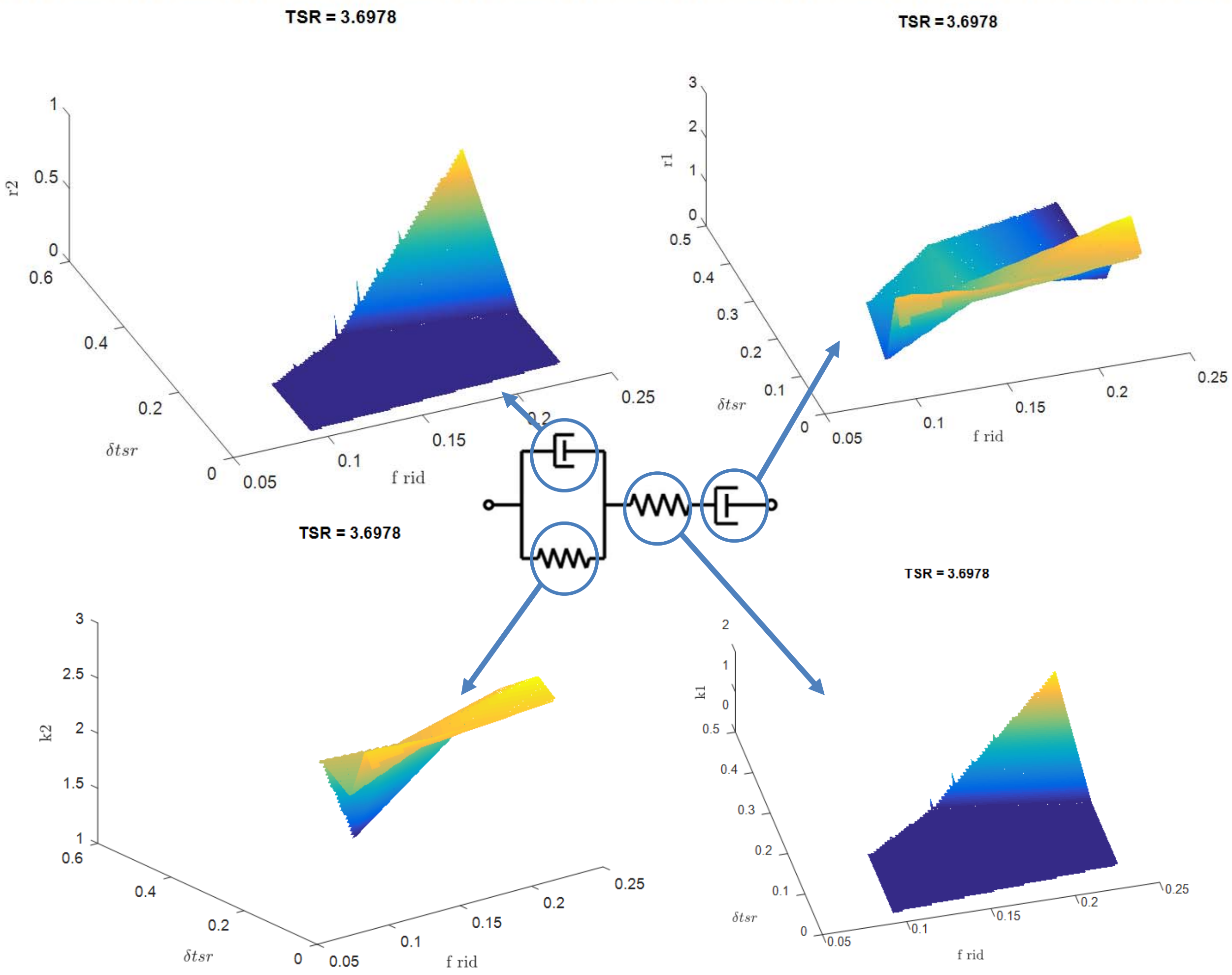
# Lumped model identification




**Lumped model parameter**
Are identified via **quadratic error minimization** for each nominal TSR working condition.
Model parameters function of **reduced frequency and amplitude** of the surge motion

$$f_{rid} = \frac{SGfreq \cdot D/2}{V}$$

$$Amp_{tsr} = \frac{\Delta(tsr)}{2}$$

# LIFES 50+ Project

2011 PoliMi tests

2016-17 PoliMi LIFES50+ tests

1st LIFES50+ deliverable for Polimi

is the validation of **steady/unsteady** AeroDyn for FOWT

The 2011 Polimi wind tunnel tests were used as preliminary set of data for the numerical and experimental comparison

# LIFES50+ A novel hybrid real time approach (Hardware-In-The-Loop)

Aerodynamics (real) + Hydrodinamics (computed)

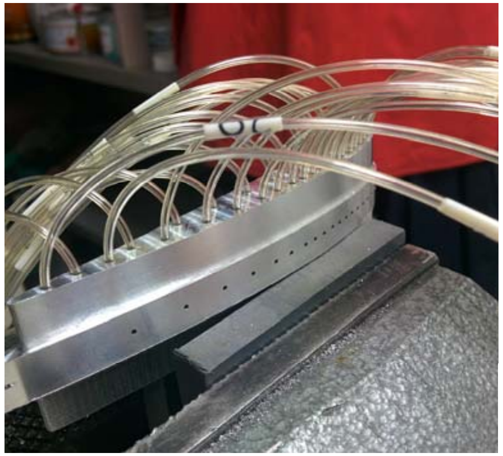
Aerodynamics (Computed) + Hydrodinamics (Real)

Force Input through controlled cables

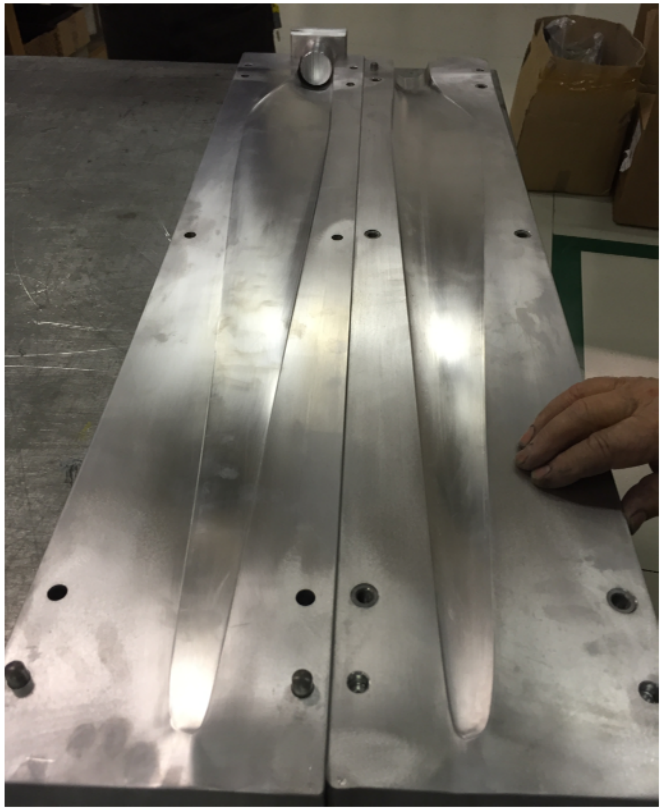
- Less constrictive scaling issues
- Exploiting the advantages of each test facility

# LIFES50+
# Aeroelastic Model Blade Design: DTU 10 MW

PoliMi &DTU Airfoil Characterization
LowRe Wind Tunnel

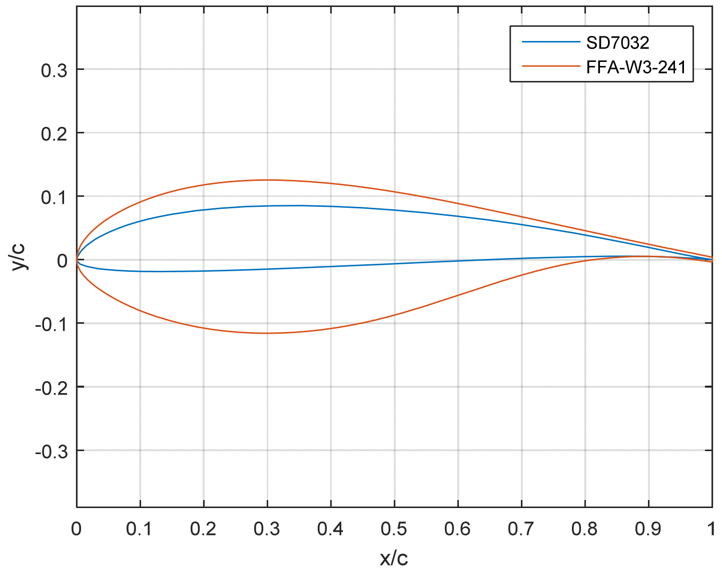


Selig SD7032 Airfoil

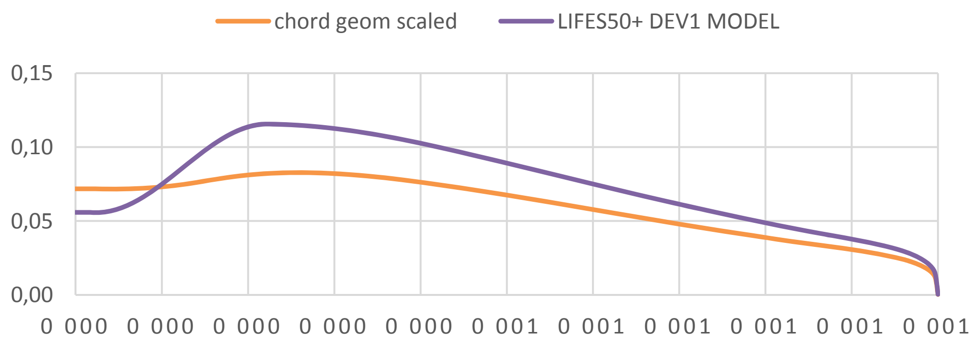


# LIFES50+
# Aeroelastic Model Blade Design: DTU 10 MW

Aerodynamic Scaling




Different airfoil used in WT




Model chord is different from the geometrically scaled. Account for polar Reynolds dependency

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# Design and verification Tools

Since LIFES50+ will be a multidisciplinary project (Aero, Hydro, Structural, Control,…). Advanced simulation tools both for design and verification are actually under implementation at Polimi.

- Fast (aero-servo-hydro)
- Adams (Multibody)
- AdWimo (AeroDyn+Adams)

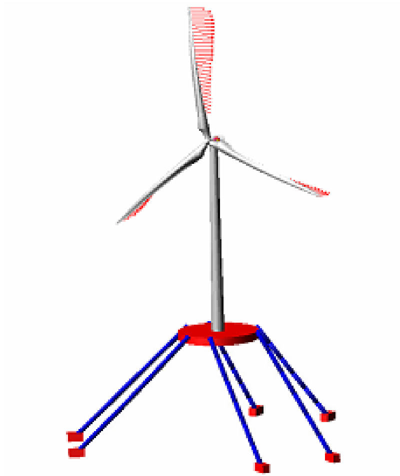

Figure 1: Coupled flexible multibody model the robot and the FOWT.

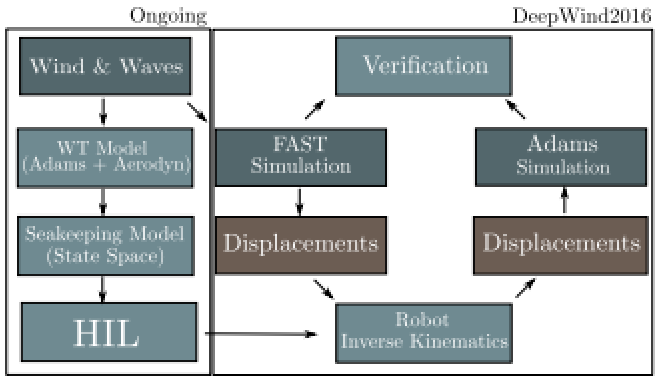


Figure 3: Numerical methodology.

*A design support multibody tool for assessing the dynamic capabilities of a wind tunnel 6DoF/HIL setup*. ***Belloli-Giberti-Fiore DeepWind Poster***