WINDTRUE:
UQ for wind turbine rotor aeroelasticity

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Matchmaking day, 14 February 2019

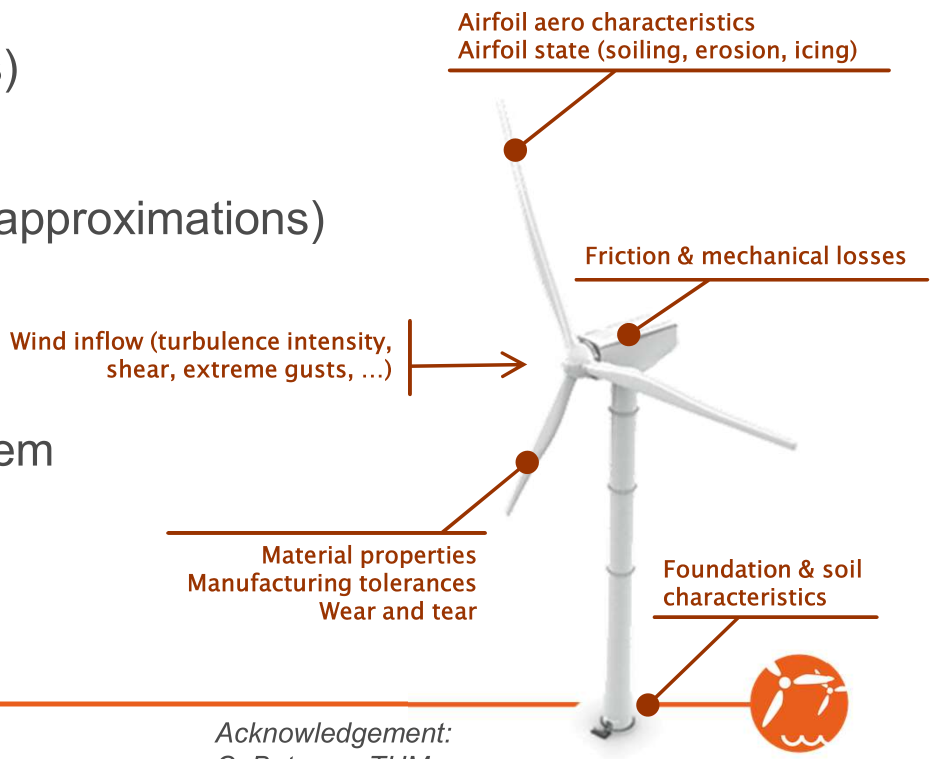
Project overview

- Participants: TNO (coordinator), DNV-GL, Suzlon Energy (Suzlon), Center of Mathematics and Informatics (CWI)
- Project period: January 1st 2019 - December 31st 2020
- Total project budget: 441 kEuro (341 kEuro TKI subsidy)

Partners	Role in the project
TNO	Project coordinator Aerodynamic and Aero-elastic modelling
Suzlon Energy B.V. (Suzlon)	Aerodynamic and Aero-elastic modelling
DNV GL Netherlands B.V.	Aerodynamic and Aero-elastic modelling
CWI	Uncertainty quantification expert

Motivation: Uncertainties in Wind Turbine Modeling

- Sources of uncertainty:
  - Uncertainty in the model parameters
  - Uncertainty in the inputs (e.g., wind conditions)
  - Structural uncertainty (model inadequacy)
  - Algorithmic uncertainty (numerical errors and approximations)
  - Experimental testing uncertainty
- Types of uncertainty:
  - Aleatory: due to stochastic nature of the problem
  - Epistemic: due to a lack of knowledge



Acknowledgement:
C. Botasso, TUM

Goal and approach

- Goal:
  - Develop calibrated aerodynamic models with a *quantified level of uncertainty*
- Approach:
  - Determine main uncertain model (and input) parameters and assess effect on model response.
  - Calibrate the uncertain model parameters with measurements.
- Based on **DanAero** field measurements which are made available in IEA Task 29 by DTU
  - Courtesy to DanAero consortium: DTU, LM, Vestas, Siemens, Dong Energy

Pressure and inflow measurements on the NM80 turbine in the Tjaereborg wind farm

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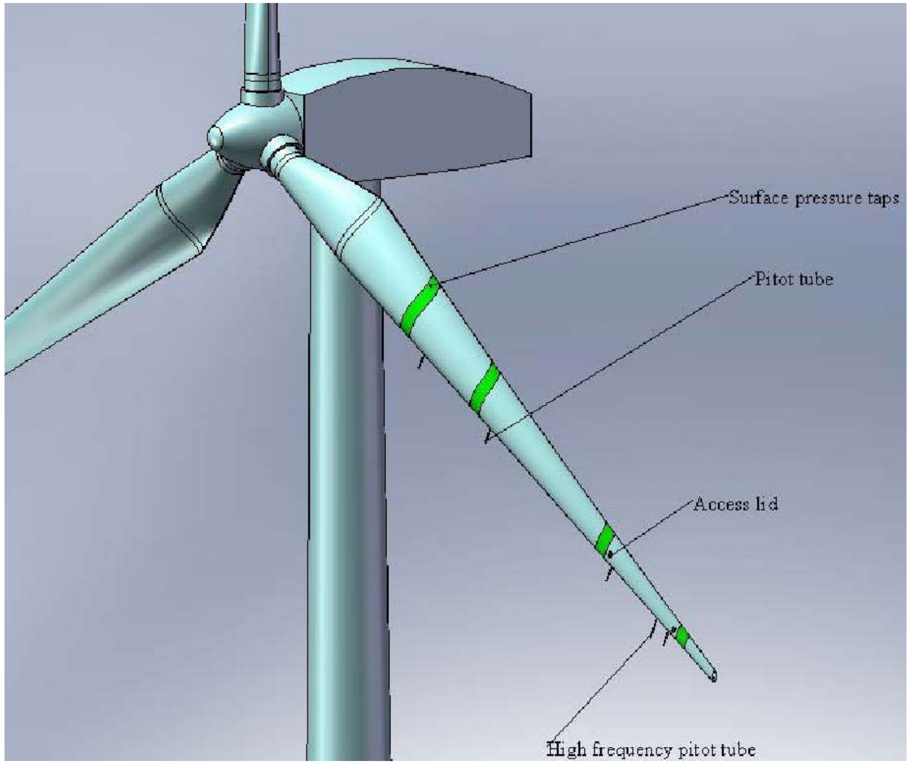
- Surface **pressure** and **inflow** measured at 4 radial stations (100 Hz)
- The outboard station is also instrumented with 60 microphones for **high frequency** surface pressure measurements (50kHz)
- Accelerometers, blade root moments, tower moments, yaw angle, rotational speed, pitch angle, azimuth angle (35 Hz)
- **Meteo** mast data at 7 heights (35 Hz)
- Measurements from June to September 2009



Pressure and inflow measurements on the NM80 turbine in the Tjaereborg wind farm

Pressure and microphone holes

five hole pitot tubes

Measurement campaigns

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Table 3 Overview of campaigns showing 1) the minimum of the 10min mean wind speed from the mast, 2) the maximum of the 10min mean wind speed from the mast, 3) minimum mean wind speed from the nacelle, 4) maximum mean wind speed from the nacelle,5) minimum mean wind direction from the mast, 6) maximum mean wind direction from the mast,7) the number of runs containing a complete setup of all sensors, 8) possible comments and 9) a status whether the data is included in the data set or not.

Measurement day	Min mean WSP	Max mean WSP	Min mean nac WSP	Max mean nac WSP	Min mean Wdir	Max mean Wdir	Number of 10-min series	Comment	Status
20090716	5.3	6.4	4.0	6.0	228	263	25	First measurement day	Included
20090721	5.5	8.9	4.1	7.7	245	259	26		Included
20090806	3.2	6.5	2.5	6.6	111	200	26		Included
20090807	3.9	7.7	5.7	7.8	102	128	24	Pressure reference for surface pressure measurements broke down	Included
20090812	-	-	-	-	-	-	-	Repair of pressure reference	Not included
20090814	3.3	5.3	4.2	5.3	270	319	5		Included
20090818	5.0	9.0	5.0	9.9	263	279	25		Included
20090819	5.9	9.3	4.5	9.3	128	179	49		Included
20090827	-	-	-	-	-	-	-	Mounting of high frequency equipment	Not included
20090901	9.4	13.7	7.1	13.4	153	252	45	Rain on sensors at the end of day	Included
20090909	4.0	7.2	4.9	6.4	289	330	8	High frequency tests. More tests exists without pressure measurements	Included
20090910	4.7	9.8	5.0	9.6	285	325	18	Test of aerodynamic devices	Included
20090911	5.9	9.1	6.1	8.6	278	327	24	LIDAR measurement of inflow in the EU project TOPFARM. Last measurement day	Included

In Table 4 an identification number (ID number) is shown in connection to an intended configuration of the wind turbine. The reason for using the word *intended* is, that different conditions in the atmosphere and in the wind turbine setup can cause the configuration to be different from the intentions.

Table 4 Identification numbers connected to intended wind turbine configuration.

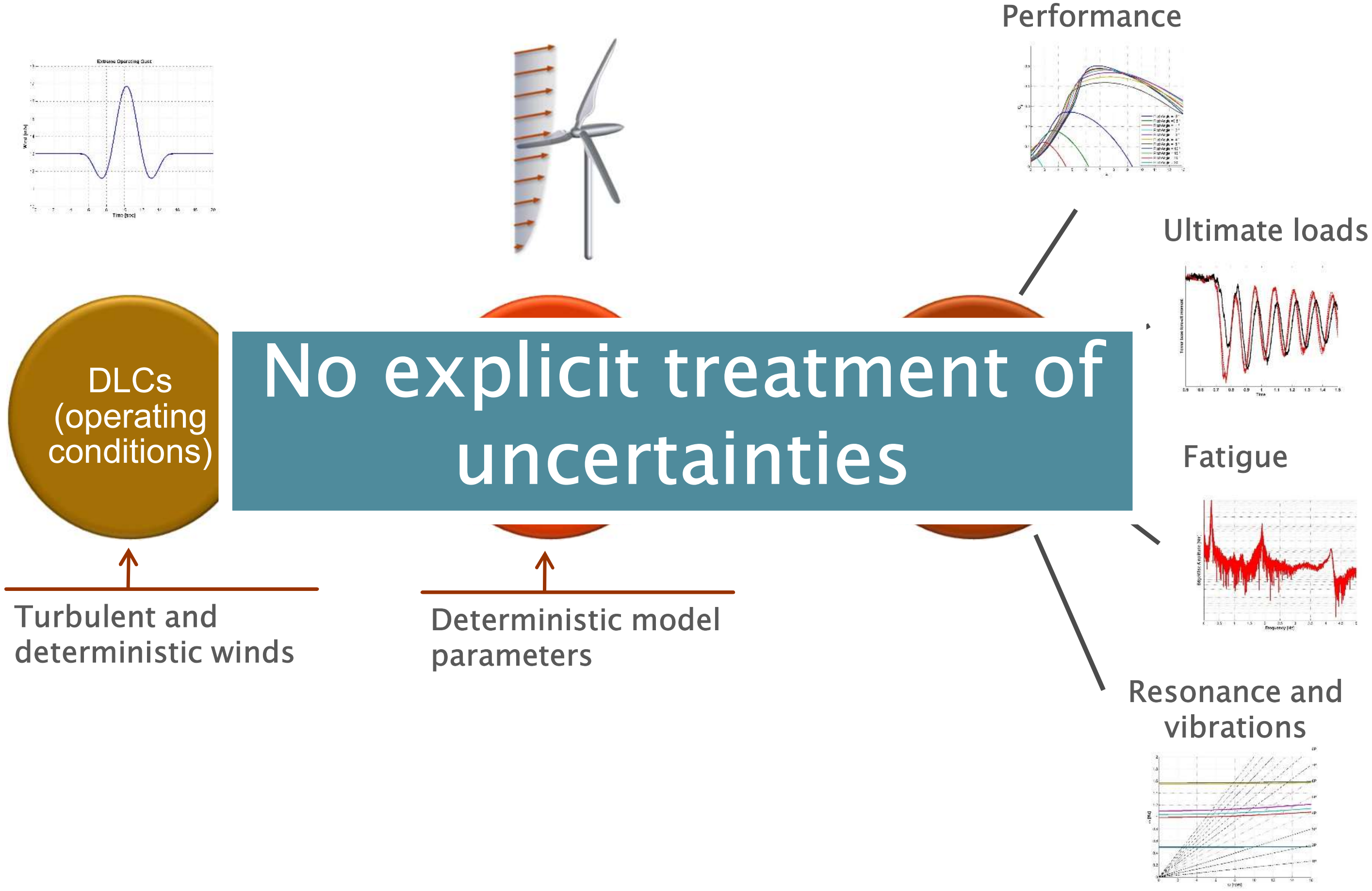
ID number	Configuration
1	Normal operation, yaw=0
2	Pitch=-1, constant RPM, yaw=0
3	Pitch=-4.5, constant RPM, yaw=0
4	Normal operation, yaw=+/-10
5	Pitch=-1, constant RPM, yaw=+/-10
6	Pitch=-4.5, constant RPM, yaw=+/-10
7	Normal operation, yaw=+/-20
8	Pitch=-1, constant RPM, yaw=+/-20
9	Pitch=-4.5, constant RPM, yaw=+/-20
10	Normal operation, yaw=+/-30
11	Pitch=-1, constant RPM, yaw=+/-30
12	Pitch=-4.5, constant RPM, yaw=+/-30
13	Normal operation, yaw=+/-40
14	Pitch=-1, constant RPM, yaw=+/-40
15	Pitch=-4.5, constant RPM, yaw=+/-40
16	Normal operation, yaw=+/-50
17	Pitch=-1, constant RPM, yaw=+/-50
18	Pitch=-4.5, constant RPM, yaw=+/-50
19	Stand still
20	Pitch step

in total 275 10 min. time series

Work packages and tasks

- WP1: Quantification of uncertainty in models and their input
- WP2: Calibration of uncertain parameters in aero-elastic models

Wind turbine design



Uncertainty propagation

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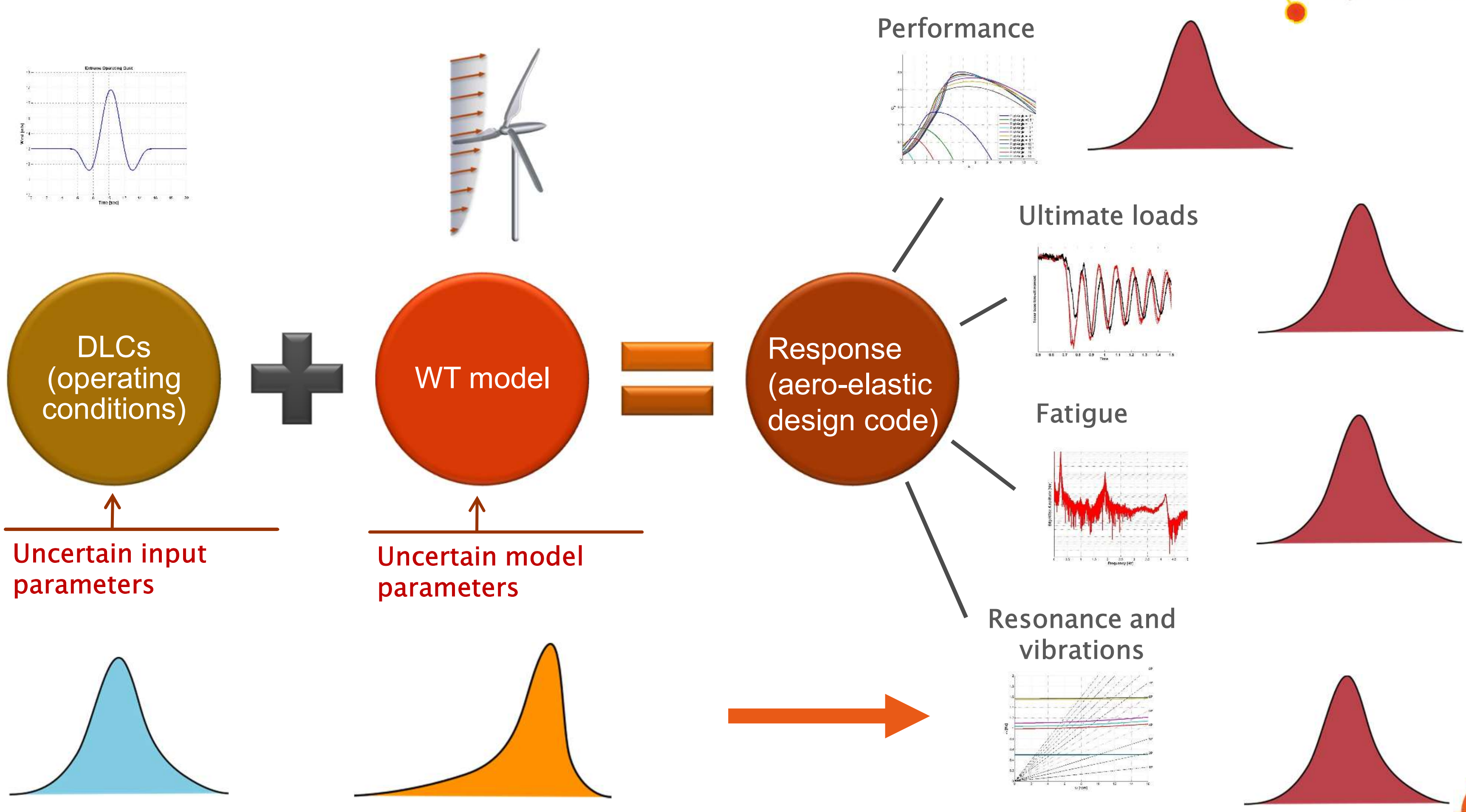

Example: uncertainty in ultimate loads

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Mean wind speed
Turbulence intensity
Wind direction

Mean wind speed
Significant wave height
Peak spectral period

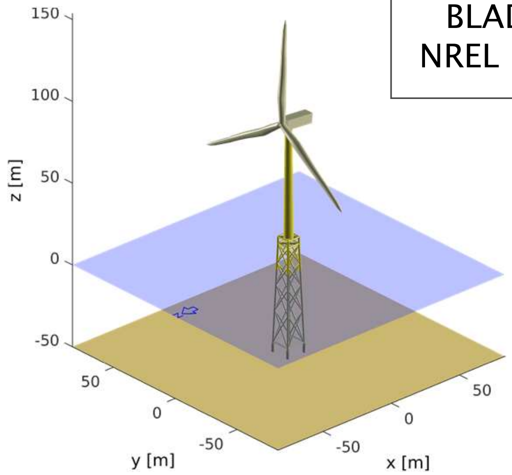
(Design Load Case 1.1)

Model parameters

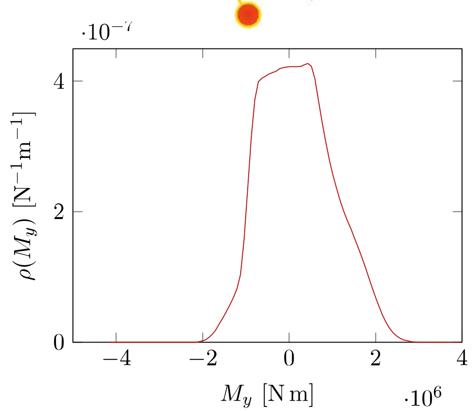
Wind field

Wave field

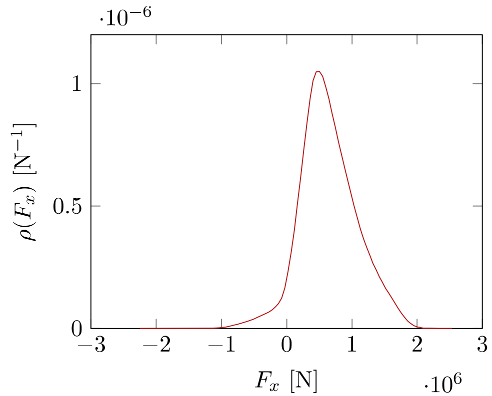
BLADED
NREL 5 MW



x100 to construct surrogate model



Moment on jacket base



Force on hub

van den Bos, Sanderse, Blonk, Bierbooms and van Bussel, *Efficient ultimate load estimation for offshore wind turbines using interpolating surrogate models*, Journal of Physics: Conference Series 1037:6, 2018.

WP1: Quantifying model uncertainty

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- Identify uncertainties in the DANAERO measurements
  - T1.1: Investigate the uncertainty in the measured output data of the DANAERO experiments.
  - T1.2: Develop a reference BEM model to statistically reproduce the DANAERO measurements.
- Characterize uncertainties in aerodynamic (sub)models of BEM
  - T1.3: Model-based global sensitivity analysis of ultimate and fatigue loads using Morris screening and Sobol' indices.
  - T1.4: Measurement-based aerodynamic sub-model assessment by means of skill scores.

Model calibration

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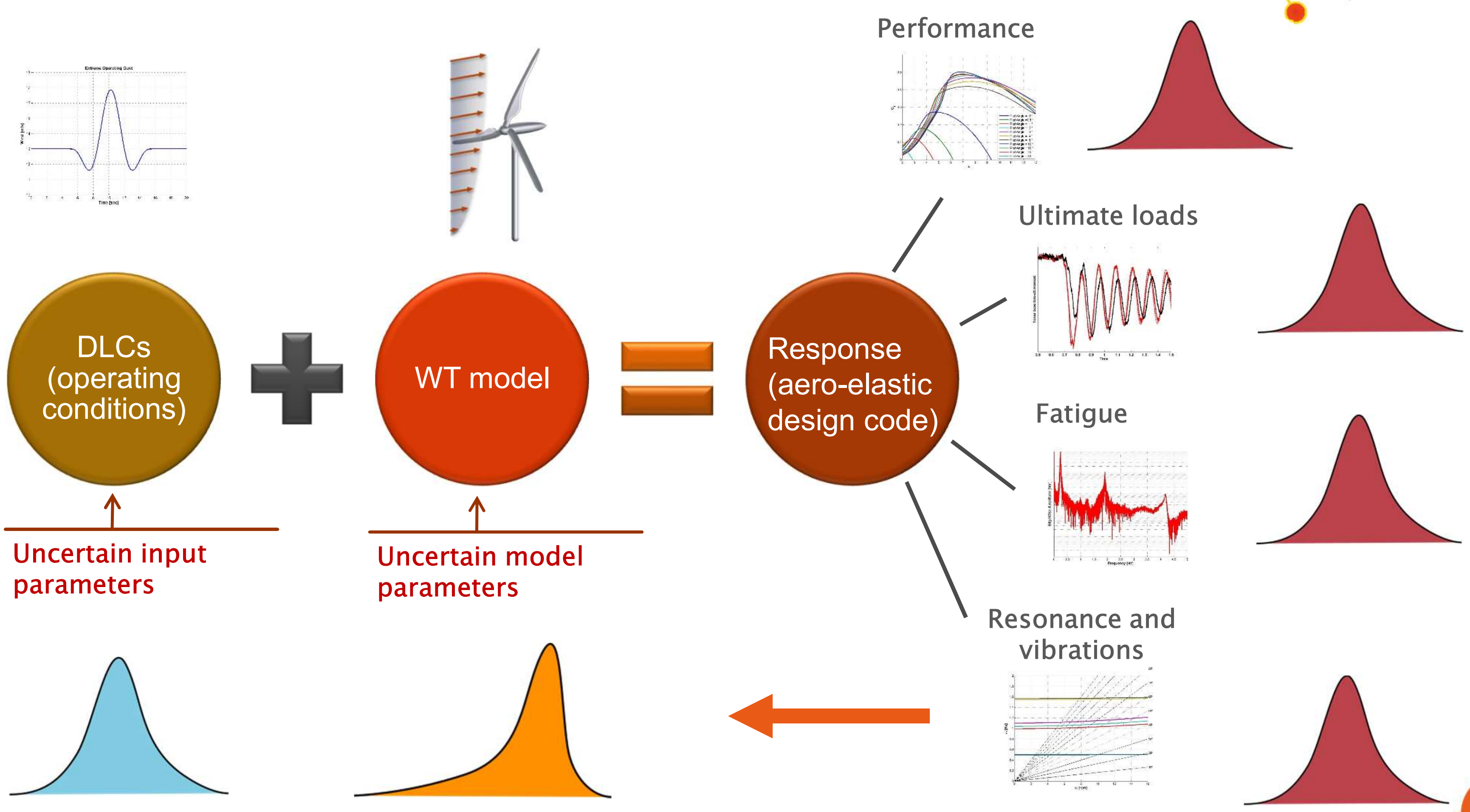
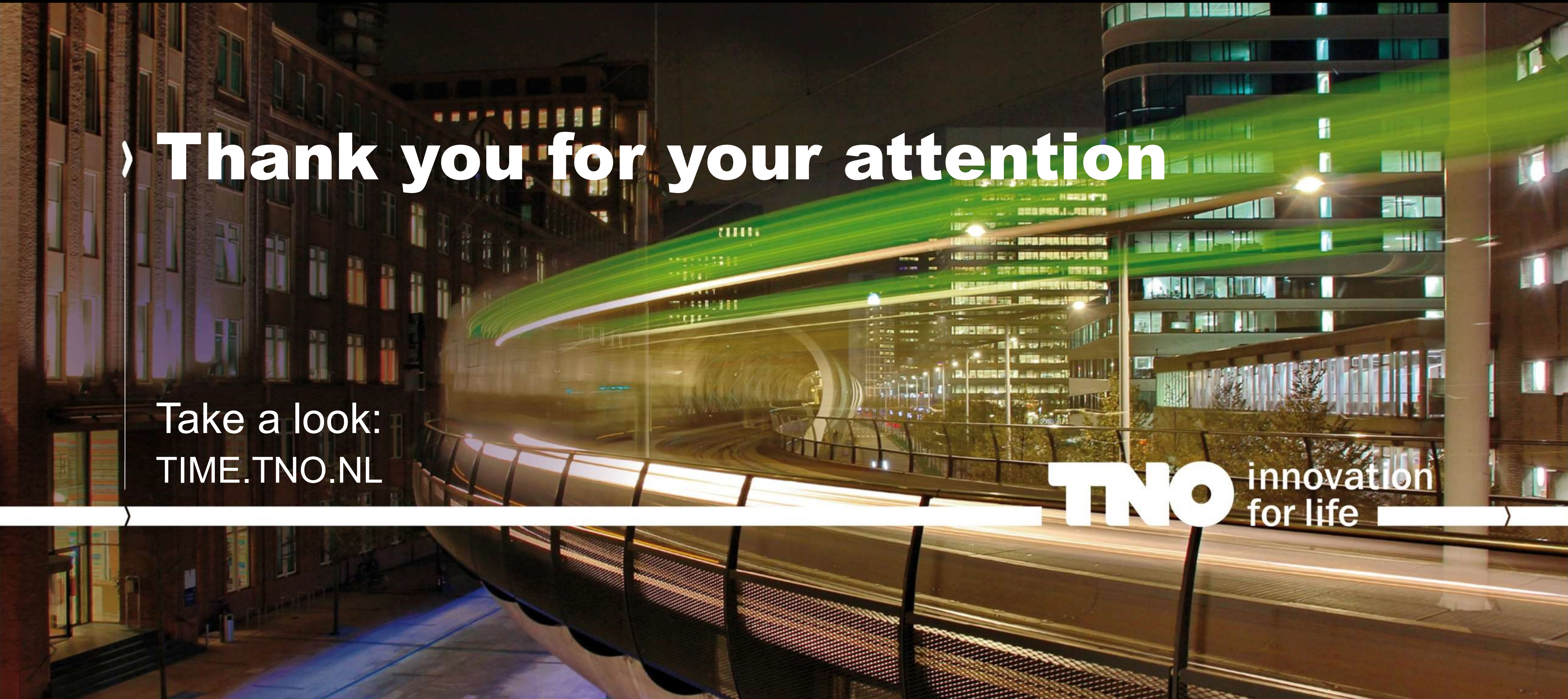


WP2: Aeroelastic model calibration

- Calibration of aeroelastic models using DANAERO measurement data and surrogate models
  - Bayesian model calibration
  - Speed up: replace full aero-elastic model with surrogate model



Thank you for your attention

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