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Innovative Winds: Digital Twins and ML at Siemens Energy

Jeppe Funk Kirkegaard - Digital, Features & Fleet
7th Wind Energy Systems Engineering Workshop, Risø, Denmark
December 2024

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I have a masters in mechanical engineering from AAU, started my professional career designing armored vehicles, have since taken an MBA, certified Senior PM and has been with SGRE since 2011.

Several roles as project manager for technology, warranty and new product development projects.

Engineering line manager for blades structural department and since 2022 leading Digital, Features & Fleet for R&D.

Digital innovation fills the hole between the operational technologies (such as SCADA) and IT (operational and support focus) and sitting in R&D is focused on subjects such as design tools, digital twins, AI/ML and VR.

Feature & Fleet are the product development programs for new features going across turbine platforms – both for active products and for the legacy fleet.

Why Digital Twins and ML?

Challenge:

- Wind turbine design models are growing to a point where HPC compute capacity increasingly is becoming a bottle neck restricting design iterations and prolonging time2market for new products.
- Legacy design methods and standards are focused on individual turbines in an IEC framework, this assumption is becoming increasingly wrong as the wind farms and rotor sizes are increasing.
- The amount of historic turbine data available is in the PB scale and beyond the traditional means of processing it - leading to a lost opportunity for improvement.

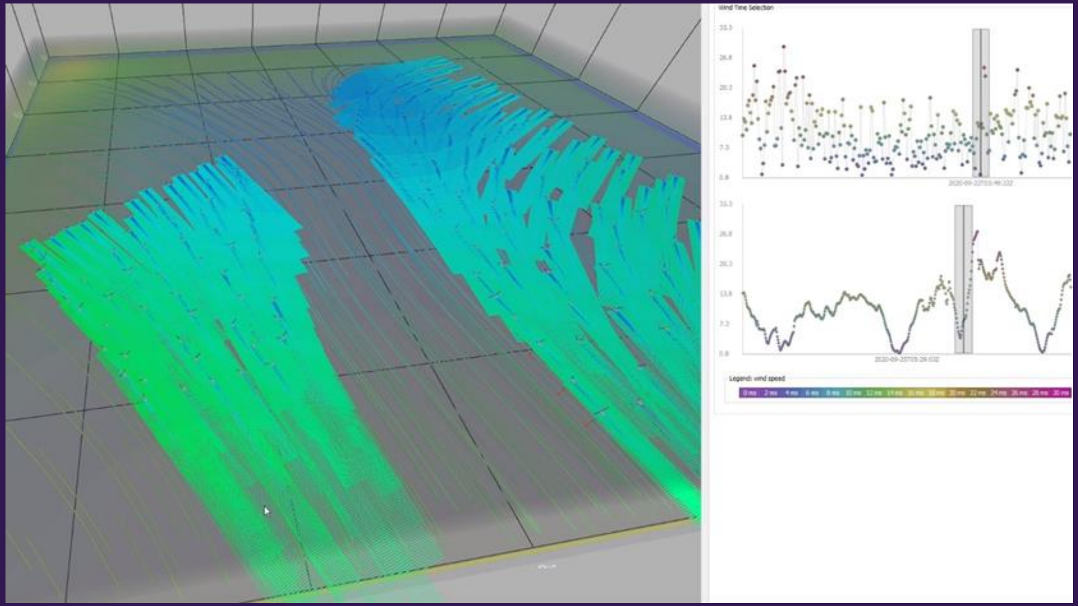
Answer:

- Use surrogate models for scoping and design iterations limiting the use of the full model – this leads to speed up of many orders of magnitude and allows for farm wide computations.
- Create systems that can consume data at scale supporting a change from use-as-designed to designed-as-used and an authoritative modelling paradigm.

E-Twin

R-Class inputs and Farm level modelling

Digital Engineering Strategy

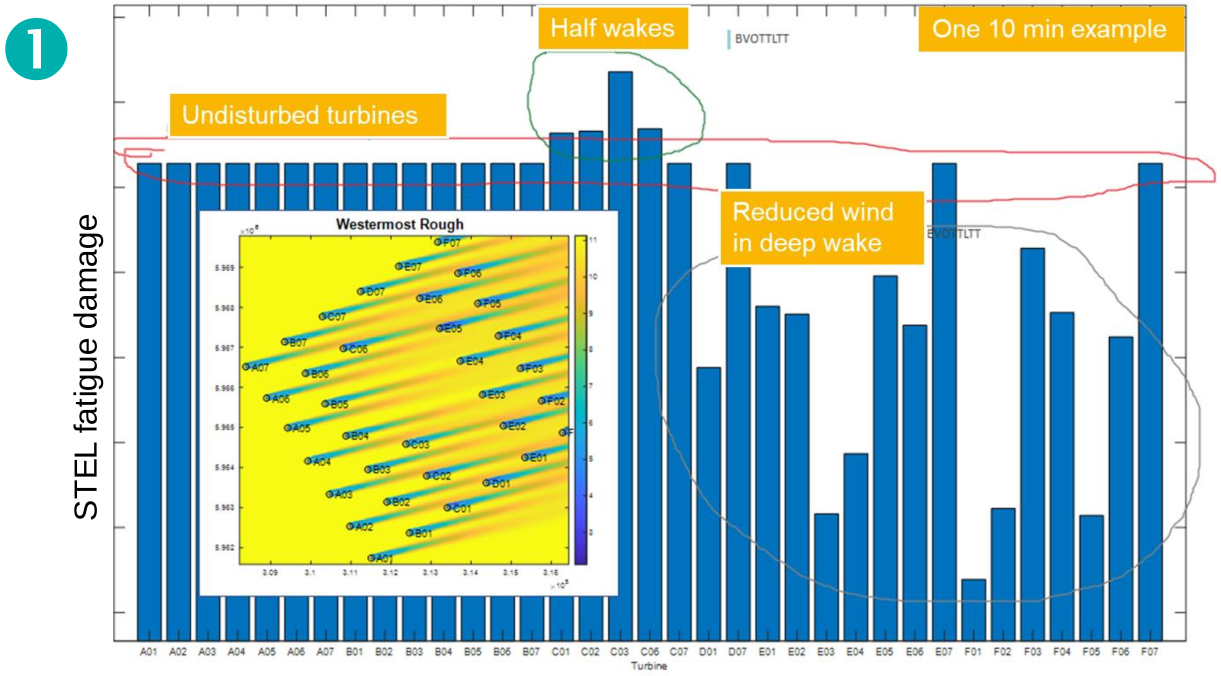


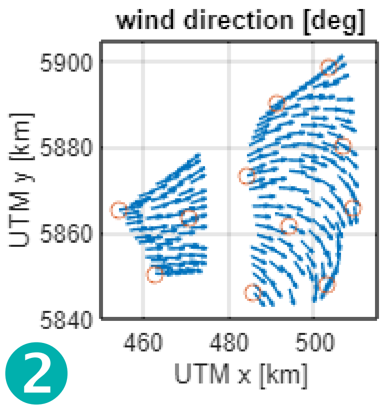
Why are farm wide calculations important?

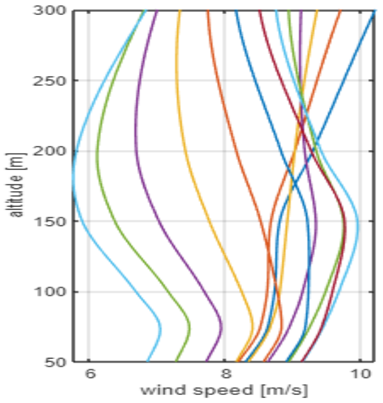
Aero-elastic codes used for design only cover an individual turbine and is computationally heavy.

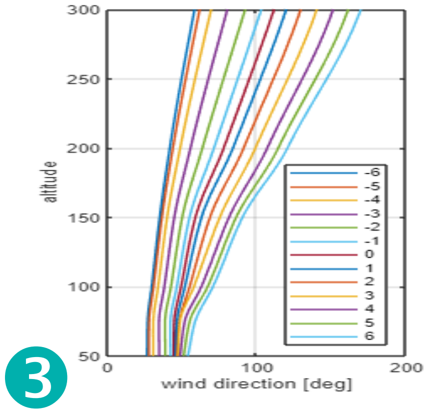
1. This is very far from the reality – turbines are affecting each other by wakes
2. Modern offshore farms are large enough that the wind fields are varying across them.
3. Current designs are driven by IEC standards – they are far from the actual offshore wind conditions

E-Twin wants to address these issues by pursuing R-class as input to calculation – the Real conditions that turbines are subjected to.









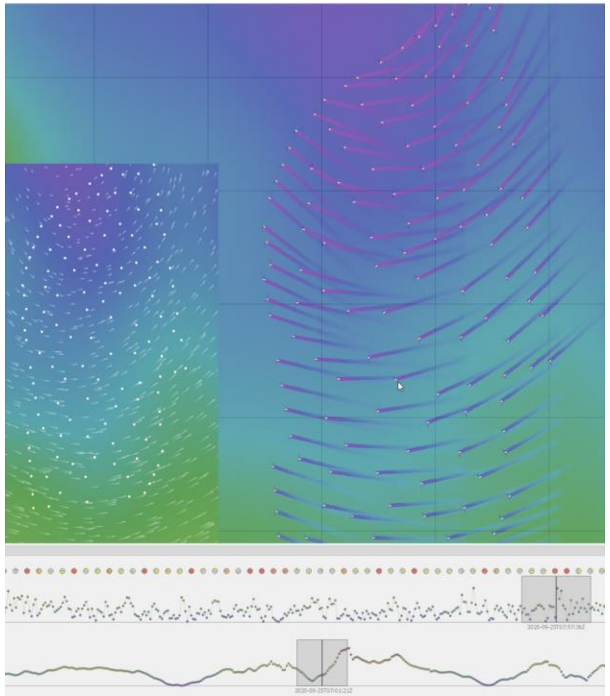
E-Twin Workflow

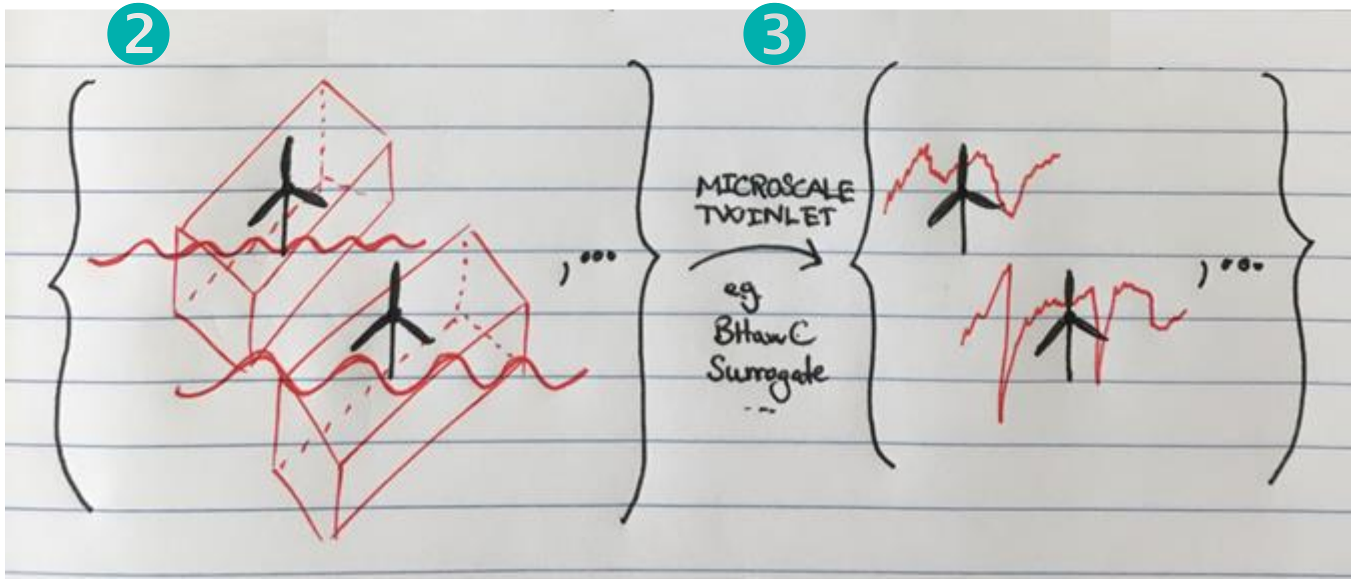
A typical workflow begins by **configuring** a wind farm: farm layout, water depth, turbine configuration, etc.

1. **Query** or otherwise produce mesoscale environment data and **enrich** it if necessary.
2. **Realize** microscale wind fields and wave loads from mesoscale environment data.
3. Use an engine to **map** wind and waves to turbine response timeseries:
   - *BHawC (our in-house aero-hydro-servo-elastic code, running approximately in real time)*
   - *Trained twinlet (surrogate model of a subset of BHawC, orders of magnitudes faster)*

Surrogate models currently being applied

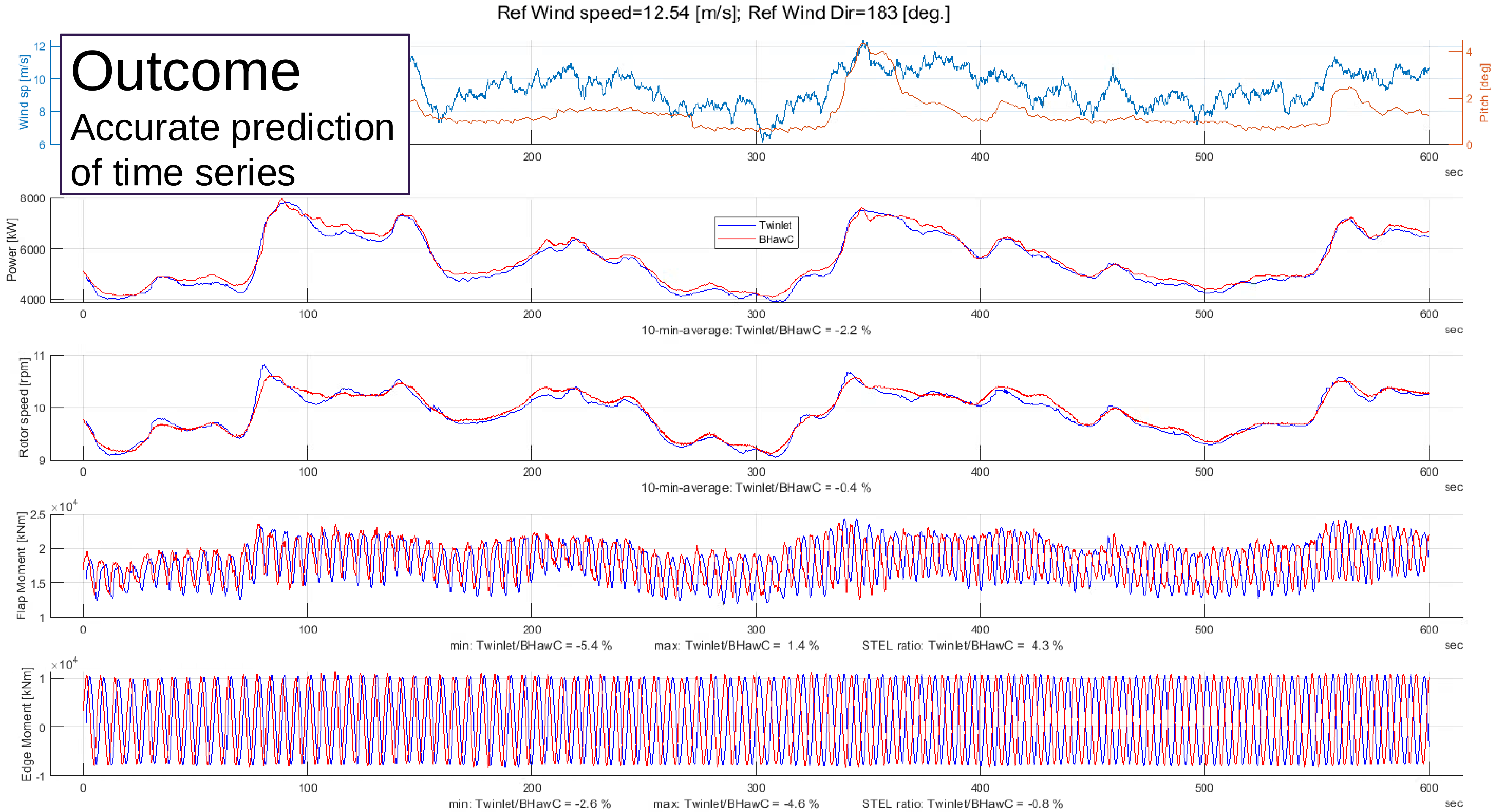
- *Parametrized families of regression models*
- *Long Short-Term Memory models*





Outcome

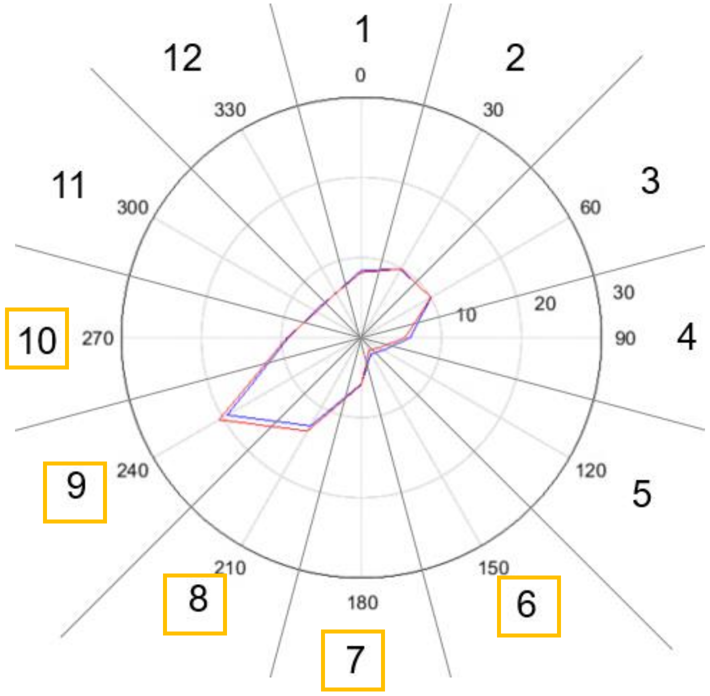
Accurate prediction of time series

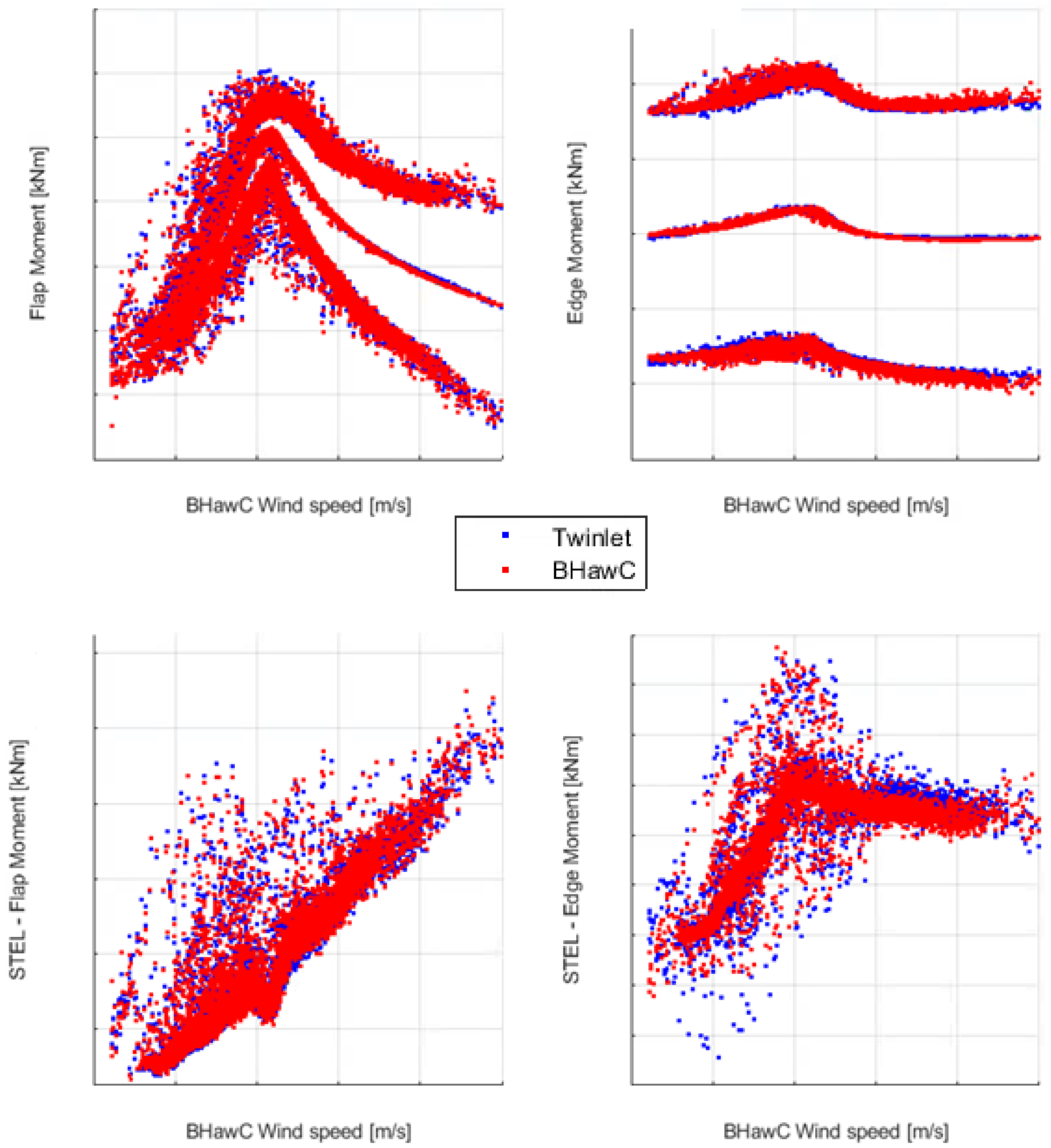


Outcome

Accurate prediction of statistical quantities through prediction of the underlying time series

Compute is currently ~1000x faster depending on model





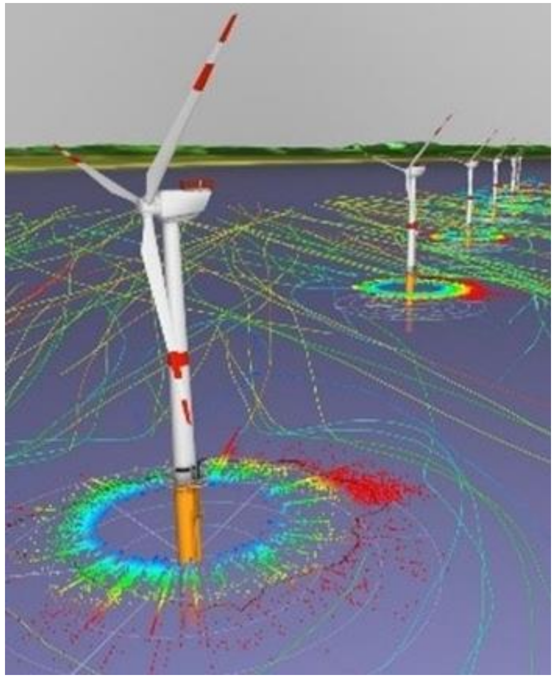
Authoritative Models through MDT Metamodels

Digital Engineering Strategy

Objective of Authoritative Models

We build authoritative models where we trust our technology work enough to shrink real-world activities by expanding digital ones

1. Models are built and validated in the technology phase
2. Models needs to be **integrated it in our E2E tools and processes**
3. Benefits are harvested in the design and prototype phase

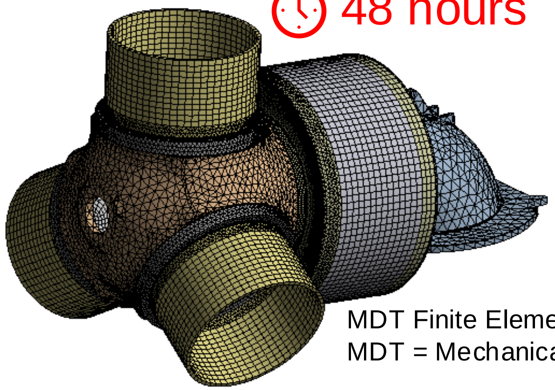


Truly authoritative models are a long-term goal and will take several generations of refinement

Operational Tools – Meta Models

A model of the model…

48 hours



MDT Finite Element Model
MDT = Mechanical Drive Train

MDT
Load Case´s

400 GB

MDT
Load Case

Component
Load Case´s

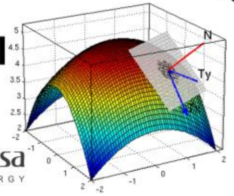
500 GB	500 GB	500 GB	500 GB	500 GB	500 GB
Submodel Load case	Submodel Load case	Submodel Load case	Submodel Load case	Submodel Load case	Submodel Load case
Stator Pl.	Rotor House	Hub	Anti O. Ring	Bedframe	other

~12.5 million nodes
+30 components

3.000 GB

*MDT load case = 2.5 GB
*Submdl load case = 3.0 GB

Meta Model Creator



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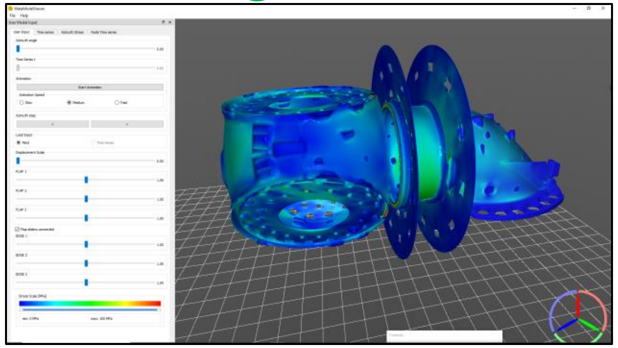
<1 GB

0.01 seconds

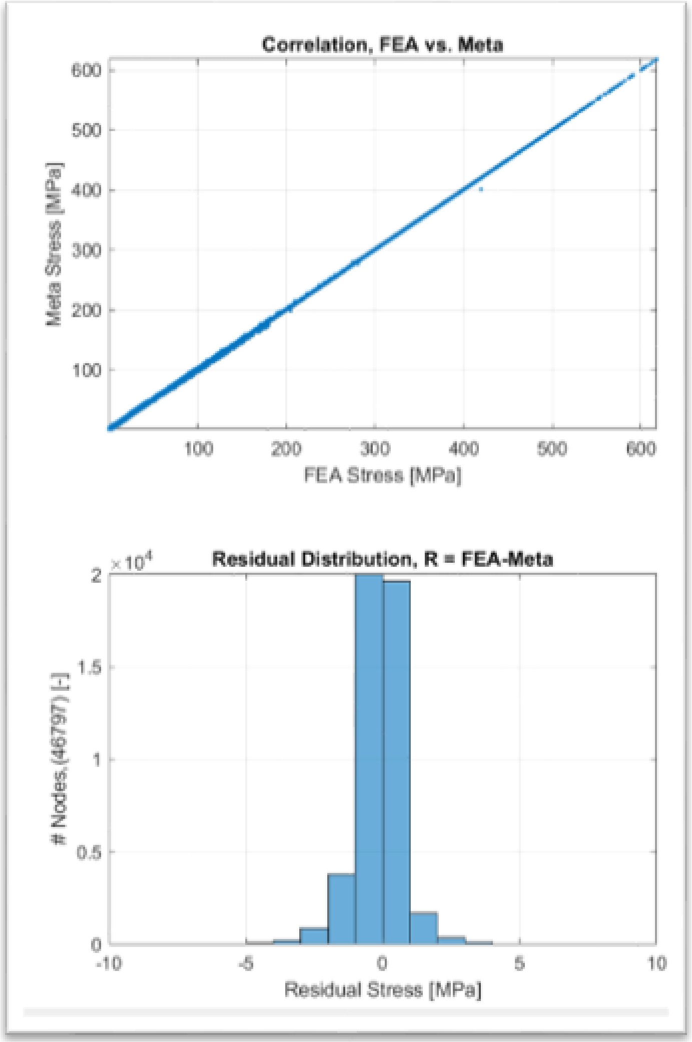


Meta Model Viewer

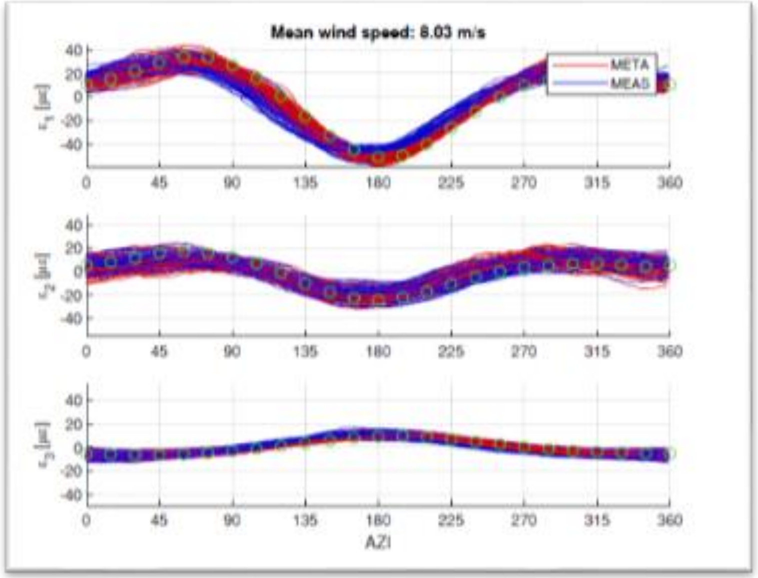
Design Workflow – Meta Models

Meta Models are...

Validated against FEA



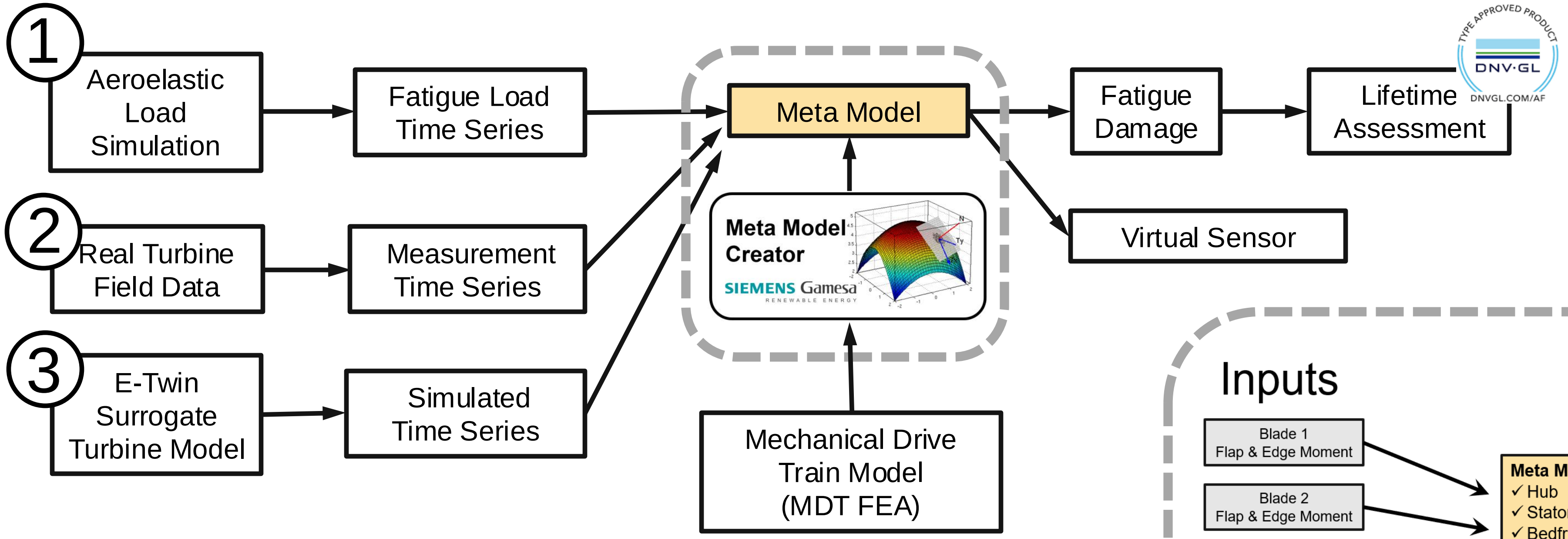
Validated against measurements

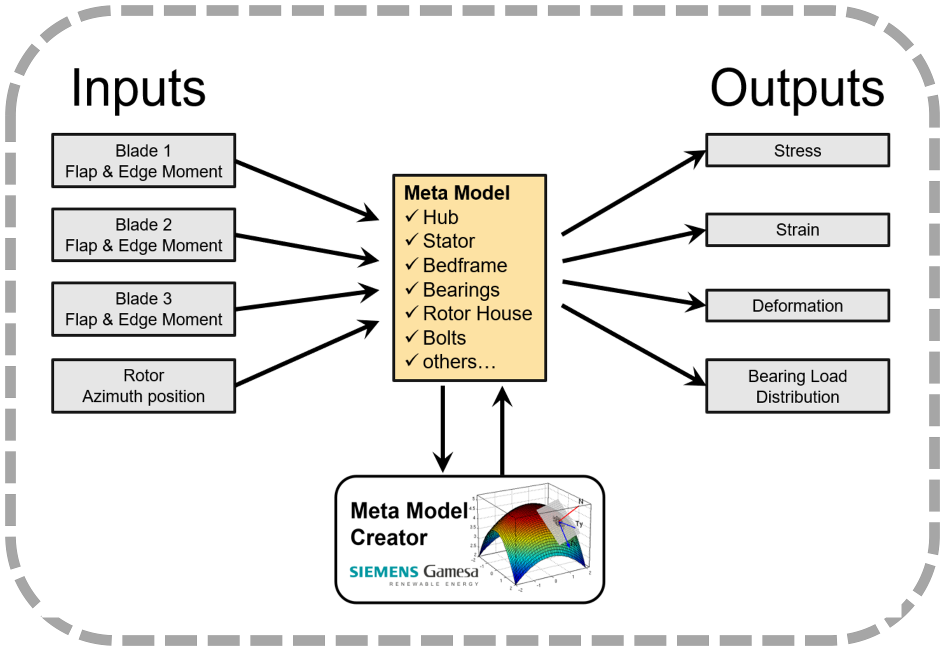


On this component **75** Strain Gauge locations are defined, data stored, analyzed and documented in a fully automated workflow

Design Workflow – Fatigue Assessment

Apply design workflow in other domains…





- Primary purposes of Meta models are:
  - Lifetime assessments of structural components
  - Operational daily use for design -> wider use of already created models
- Tool chain is highly automated and fully integrated with validation activities

Data and Digital Twins

Digital Engineering Strategy

Digital Twins in an Operational Context

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The digital twin environment (DTE) has several components:

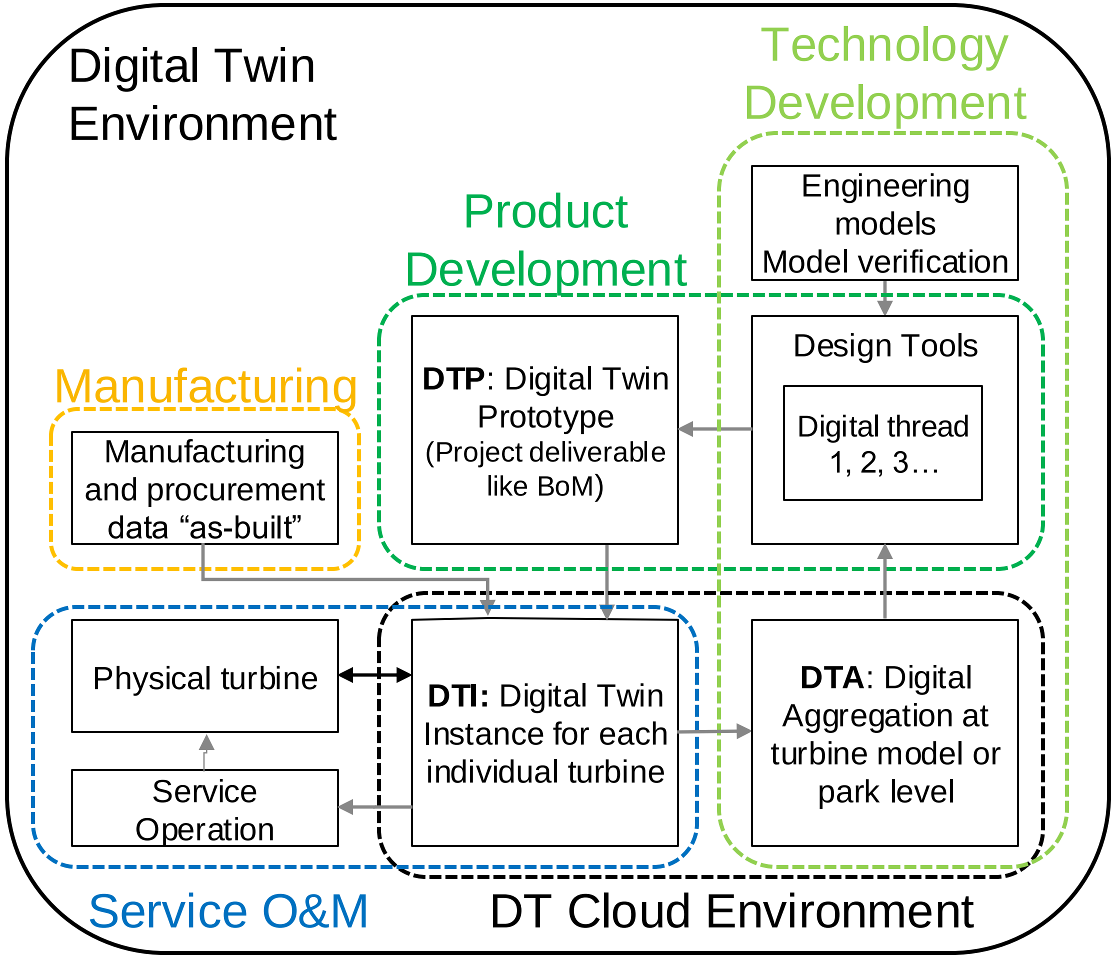
Digital Twin Prototype (DTP)
- Engineering models describing the physical product coupled with sensor inputs
- A **validated** deliverable from the design process

Digital Twin Instance (DTI)
- Individual instance of a product after manufacture – ie. each turbine in a park
- Contains as-built and in-use information to enrich it compared to the DTP
- The digital twin may or may not give feedback to the turbine controller, but never in real time as it resides in separate environment – often with a cloud architecture

Digital Twin Aggregate (DTA)
- Aggregation of DTI data to park, turbine or component level to facilitate analytics and hopefully valuable insights to technology development

Digital Thread
- A stream of data covering the full value chain for a DTI (mostly for a given subsystem or component)
- Example: The blade bearing model will combine as-built data on raceway hardness with turbine sensor inputs to calculate fatigue damage and remaining lifetime

What do we get out of Digital Twins? Feedback loops providing relevant insights:
- Service O&M has the fastest feedback loop – direct value
- Product Development has a medium duration loop - design assumptions
- Technology development is long term feedback loop – **authoritative models**



Digital Twin – an operational platform in SGRE

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1. Web frontend with model upload, compiler and execution scheduler – select data from more than 70.000 turbines
   - Supports Matlab, Python and Julia models -> reuse design models as much as possible
   - Model examples:
     - Structural fatigue for hotspots
     - Blade bearing damage
     - Yaw friction virtual sensor

2. Backend runner in Azure which pulls data from Data warehouse, computes and stores the output data
   - Execution example: For 100 turbines a day of data takes 10min to compute
   - Data IO is currently larger bottleneck than compute…

3. Outputs can be consumed by business tools like PowerBI, used in various analytic suites or directly in Matlab by engineers