INNTERESTING

INNOVATIVE FUTURE-PROOF TESTING METHODS FOR RELIABLE CRITICAL COMPONENTS IN WIND TURBINES

FINAL MEETING
BILBAO

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ikerlan

MEMBER OF BASQUE RESEARCH & TECHNOLOGY ALLIANCE

OUTLINE

1 INTRODUCTION

2 WHAT WE HAVE LEARNED

3 BRIEF REVIEW OF THE RESULTS

4 CONCLUSIONS

CONSORTIUM

INNTERESTING

3 COUNTRIES

4.8 M€ BUDGET

8 PARTICIPANTS

36 MONTHS

Technical Advisory Group

GE Renewable Energy

Lindø Offshore Renewables Center

CATAPULT Offshore Renewable Energy

SIEMENS Gamesa RENEWABLE ENERGY

DNV·GL

IBERDROLA

Vestas

sirris driving industry by technology

Finland

moventas GEARED FOR NEW ENERGY

VTT

Belgium

KU LEUVEN

SIEMENS Ingenuity for life

vito

Spain

ikerlan

LAULAGUN bearings

Cluster Energía BASQUE ENERGY CLUSTER

PROJECT TIMELINE

January 2020
kick-off meeting
LEUVEN

PANDEMIC SITUATION DUE TO COVID

June 2022
FINLAND

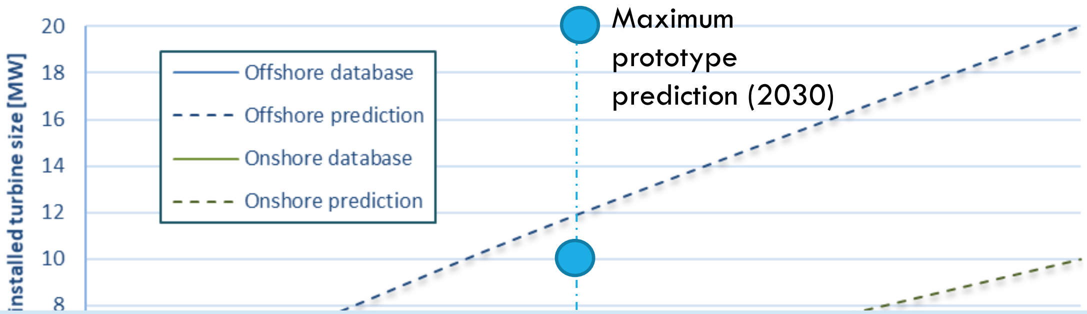
December 2022 BILBAO

Analysis of the future of wind energy at the level of tests and component sizes

WORK PACKAGE 1 : DELIVERABLE D1.1 (**JANUARY- JUNE 2020**)

In this task the *technical*, *environmental* and *social* requirements of the future wind turbines (2030-2050), and more precisely for bearings and gearboxes for large wind turbines were defined.

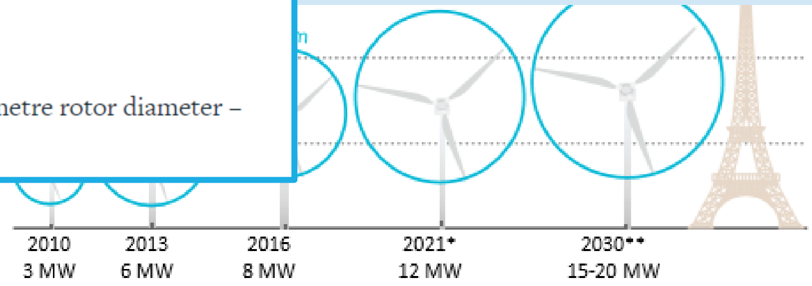
*"GE Renewable Energy's Haliade-X prototype wind turbines starts operating at **14 MW**" (October 2021)*



*"MingYang Smart Energy will deploy two wind turbines that will each have a capacity of **16.6 MW** at the MingYang Yangjiang Qingzhou Four offshore wind farm, which is in the South China Sea." (February 2022)*

CSSC Haizhuang eyes 18MW offshore wind turbine

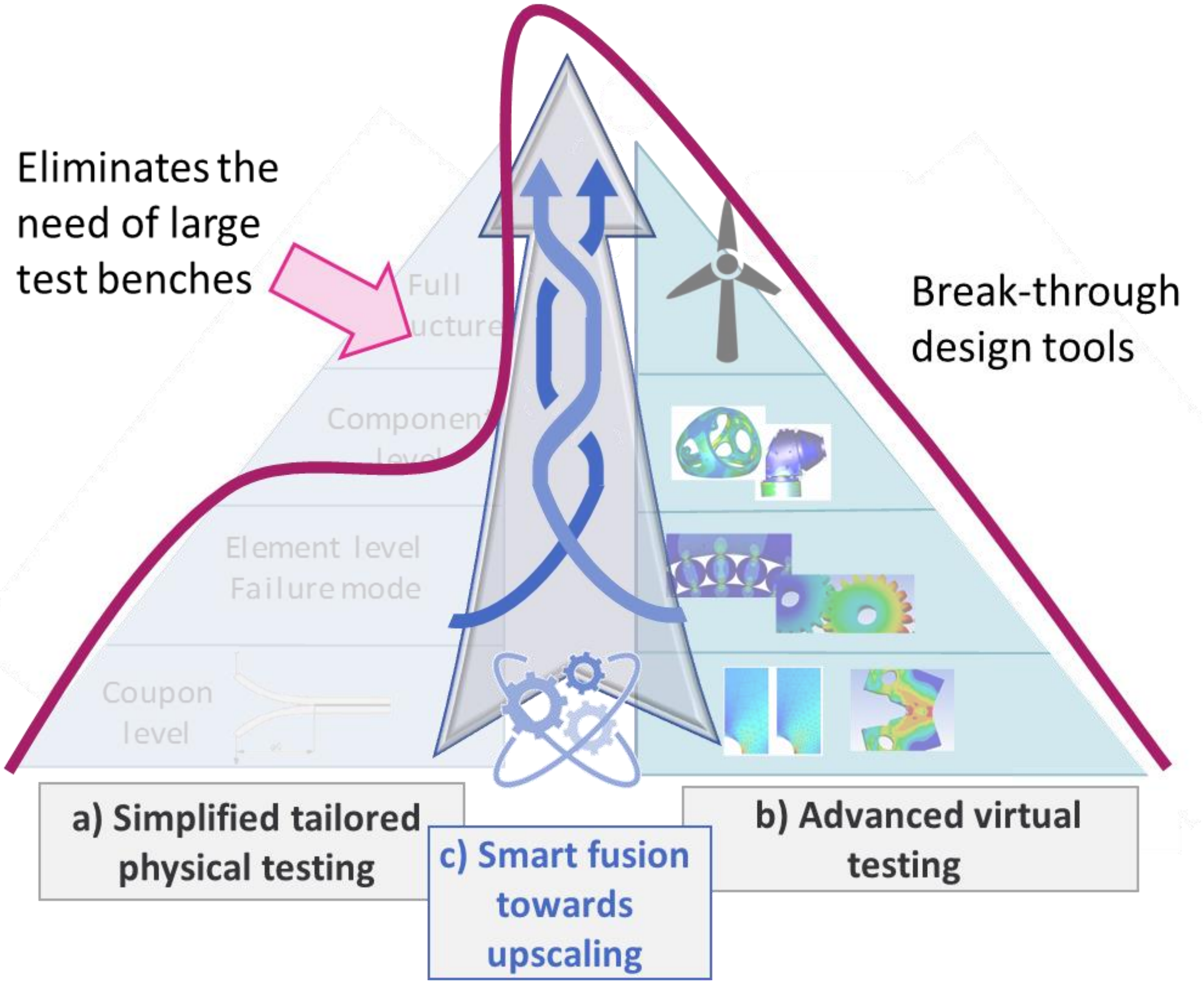
Chinese industrial manufacturing giant CSSC Haizhuang is developing an 18MW offshore wind turbine with a 260-metre rotor diameter – possibly the largest rotor unveiled by a turbine maker to date.



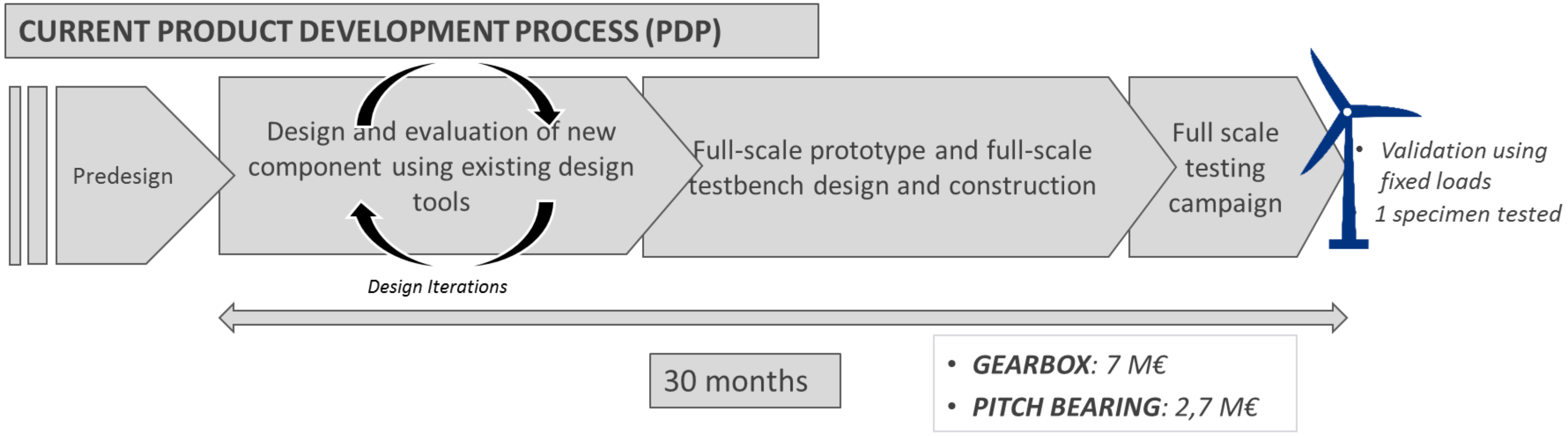
- https://electrek.co/2022/02/22/a-chinese-company-is-building-a-colossal-16-mw-offshore-wind-turbine/
- https://www.evwind.es/2021/10/05/ge-renewable-energys-haliade-x-prototype-wind-turbines-starts-operating-at-14-mw/82663

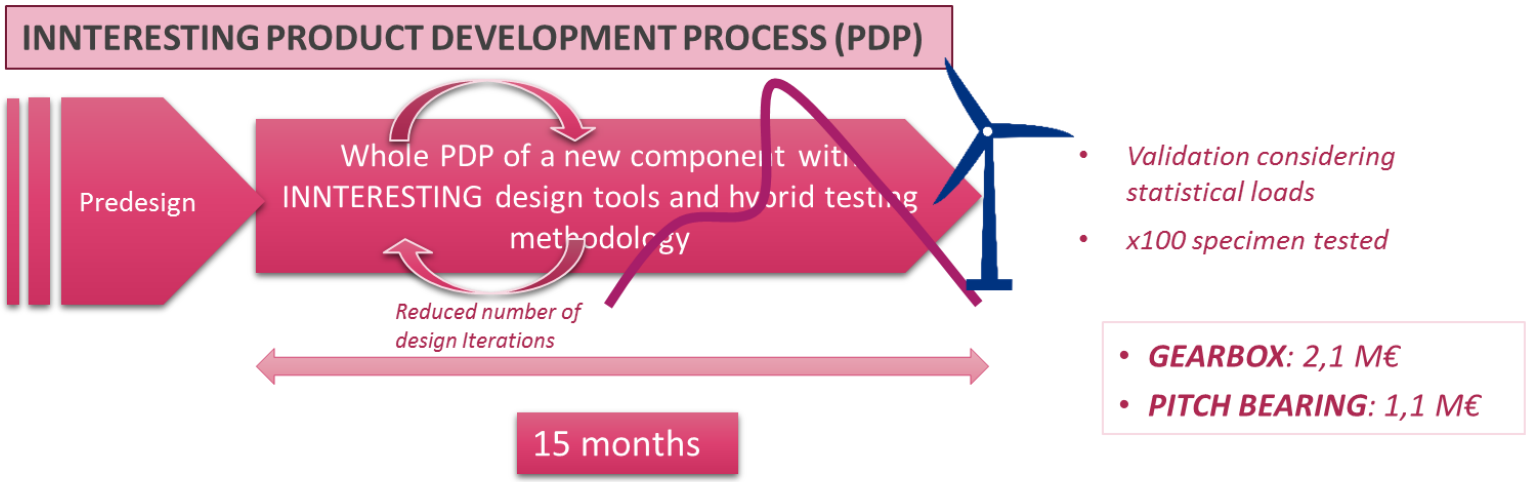
Technological approach

INNTERESTING HYBRID TESTING METHODOLOGY



INNTERESTING IMPACT ON THE PRODUCT DEVELOPMENT PROCESS

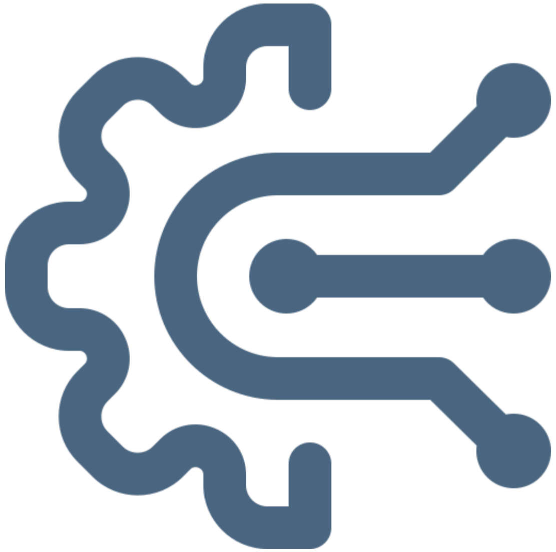




FINAL TRL → 5

In the future it is necessary to work on standards and legislation

What we have learned



ADVANCES OF THE METHODOLOGIES DEVELOPED DURING THE INNTERESTING PROJECT

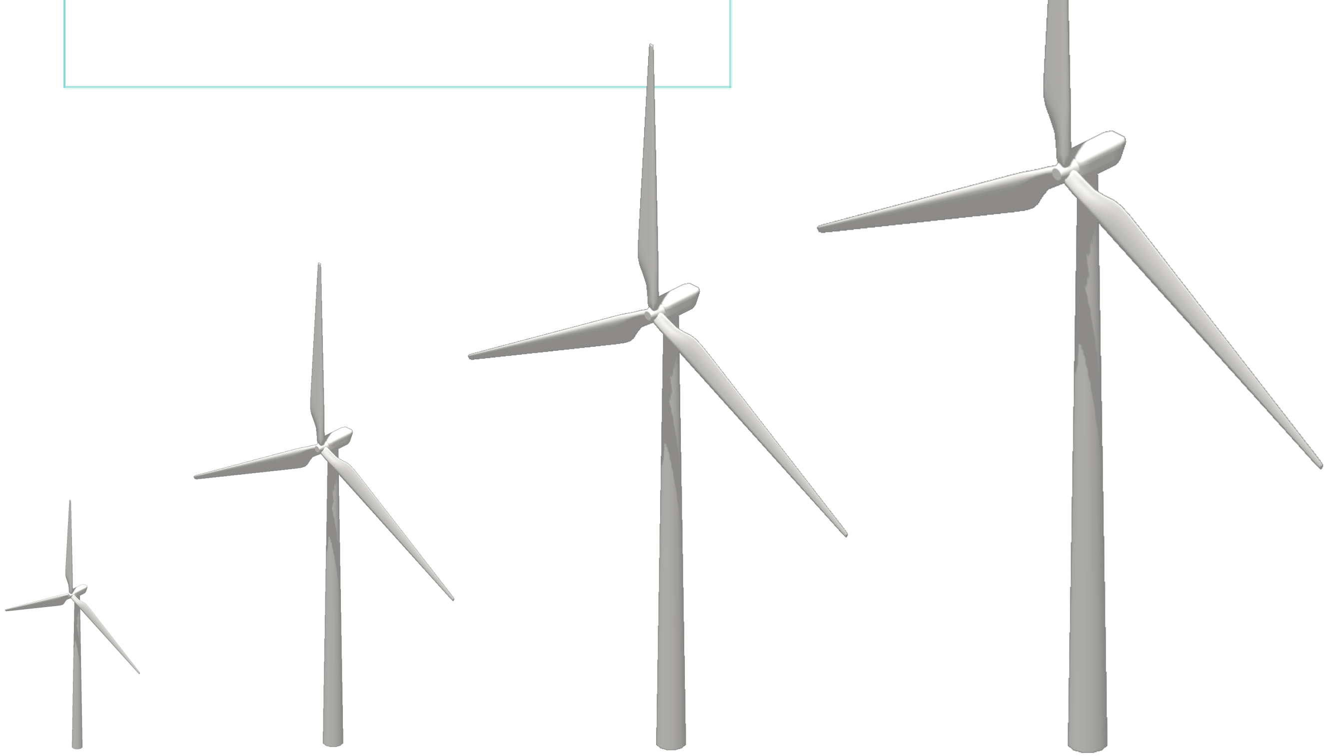
Need of larger/more expensive test benches

The INNTERESTING project aims to develop a novel hybrid methodology and breakthrough design tools to assess reliability of larger wind turbine critical components without the need of building larger test benches in the future

Standards
Regulations…

It is not possible to avoid large test benches… **(But do they need to be 1:1?)**

The INNTERESTING APPROACH can be an additional supplement to acquire knowledge more efficiently



PROBLEMS THAT WE CAN OVERCOME BY USING THIS METHODOLOGY
THE KNOWLEDGE OF THE VARIABLES CAN HELP…

Failures in field

Maintenance, unexpected events…

The design is correct for the known failure modes!!!!

Manufacturing process effect on the structural reliability

Material´s variability

Scale effect on the structural reliability

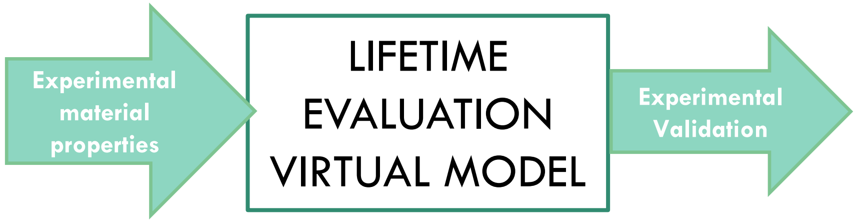
INNTERESTING

- Improve manufacturing processes
- Improve and optimize component´s designs
- Test definition/test campaign
- Probability of failure of the components instead of deterministic damage value.

PROBLEMS THAT WE CAN OVERCOME BY USING THIS METHODOLOGY

Damage calculation methodologies, virtual models for specific failure modes:

- **Difficulty of material characterization inputs and validation**



- Polished surfaces => modifications of the curves to the real roughness values.
- Residual stresses on the Surface: might affect
- Material from real components?
- Direction of the loading is the same?
- Conservative synthetic curves

Simplified tailored tests reduce the uncertainties coming from the material´s characterization

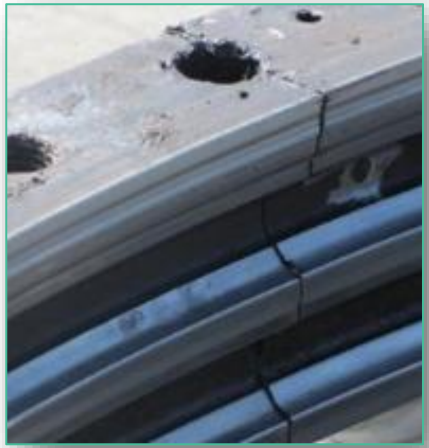
PROBLEMS THAT WE CAN OVERCOME BY USING THIS METHODOLOGY

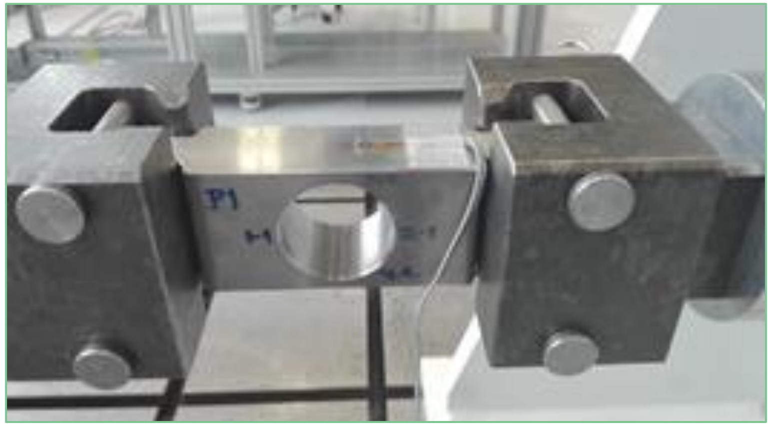
Damage calculation methodologies, virtual models for specific failure modes:

- **Difficulty of material characterization inputs and validation**

Experimental material properties → LIFETIME EVALUATION VIRTUAL MODEL → Experimental Validation

Ring structural failure





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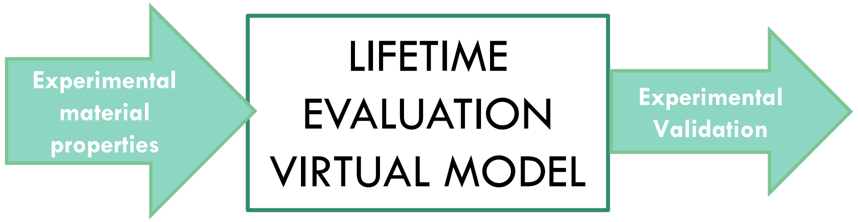
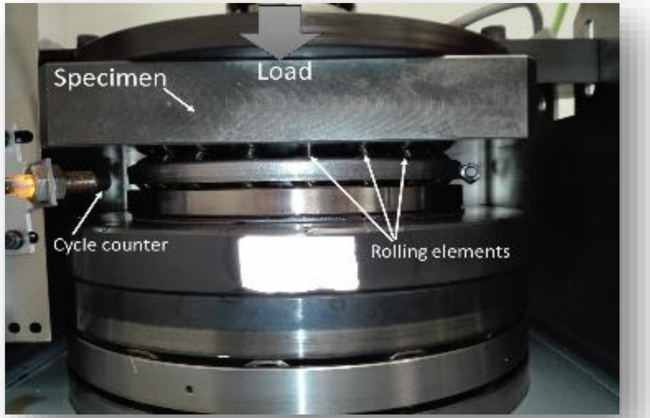


Rolling contact fatigue

Tensile tests
Torsion tests
Hardened layer?



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PROBLEMS THAT WE CAN OVERCOME BY USING THIS METHODOLOGY

SIZE EFFECT IN MATERIAL/COMPONENT:

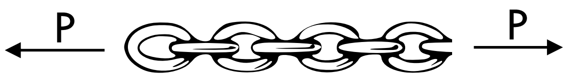
If we have a **chain with many links**

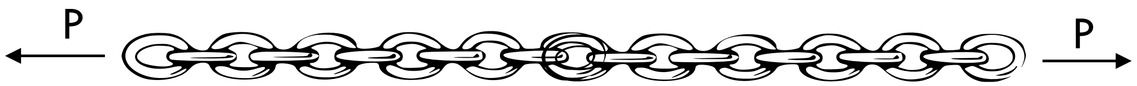
The strength of each link can be represented using a distribution function: Weibull distribution

$$P_{fail} = 1 - exp\left[-\left(\frac{GP-\lambda}{\delta_{ref}}\right)^{\beta}\right]$$

Weakest link principle: Global survival probability of a chain can be calculated as the product of the survival probabilities of each link.

Chain with many links of different strength (coming from the same statistical distribution): The classical theory of size effect has been statistical.

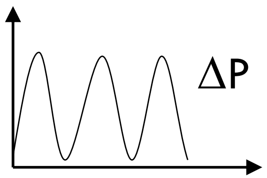


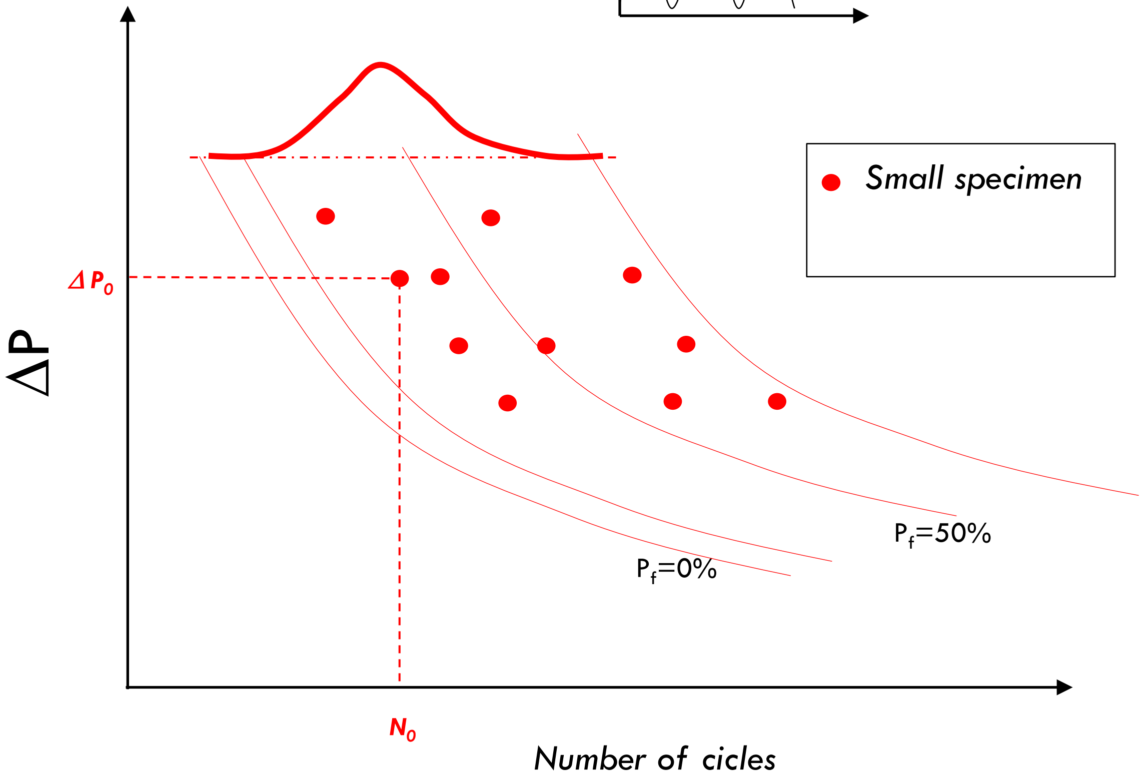


- Same material
- Same manufacturing process
- Same Surface roughness

AND WHAT IS HAPPENING WITH THE FATIGUE?

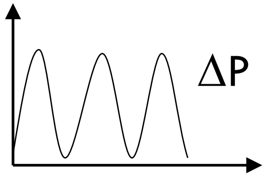
FATIGUE CURVES

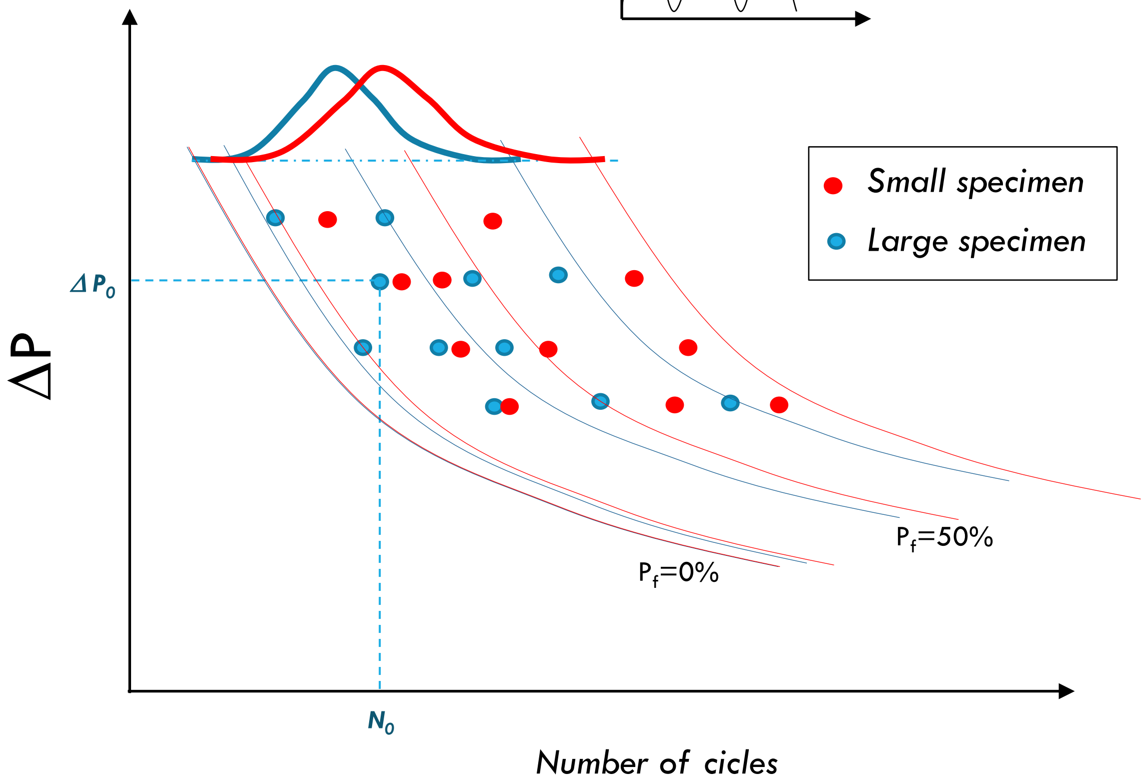




How are fatigue curves affected by the scale effect?

FATIGUE CURVES





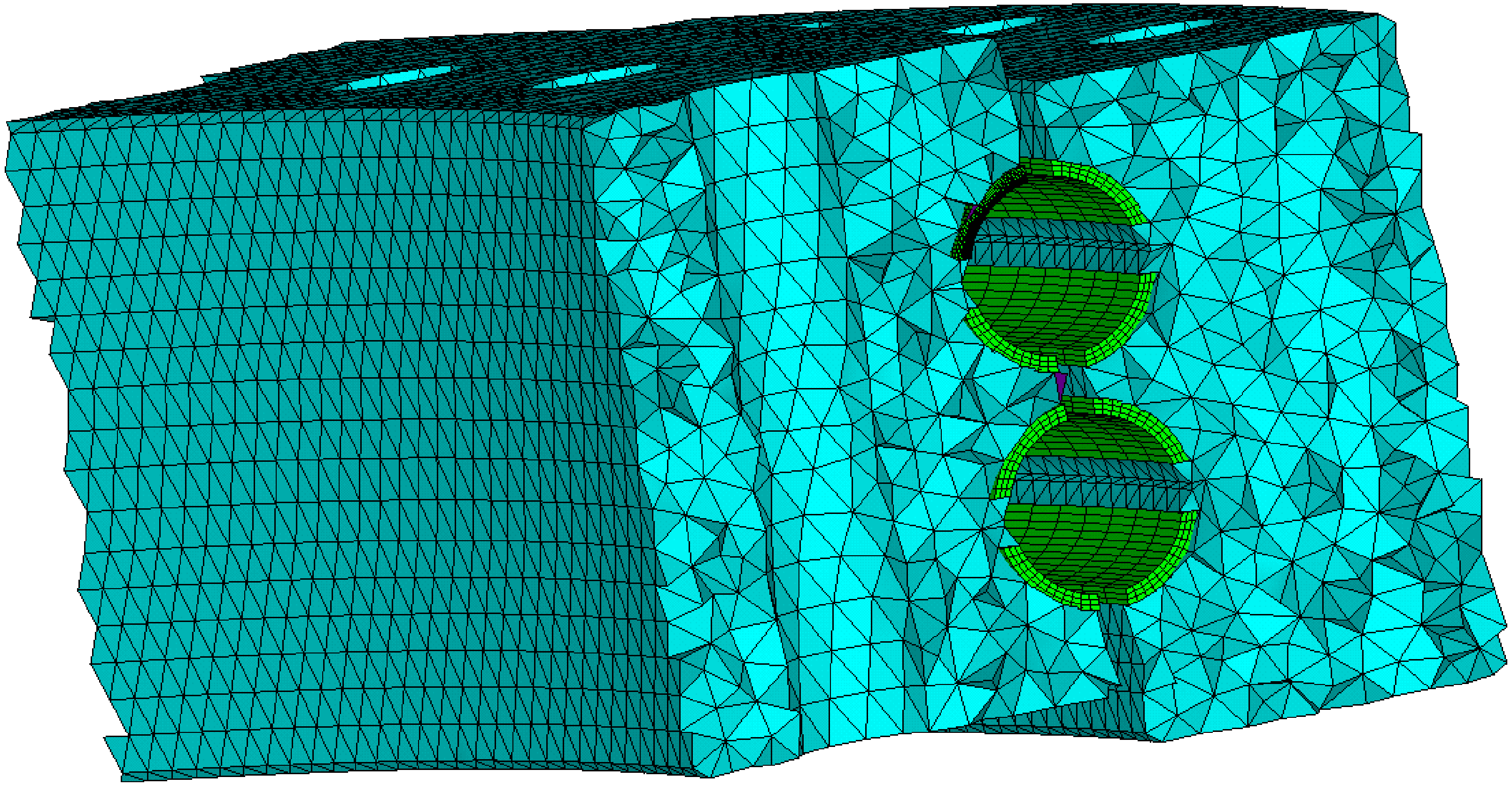
How are fatigue curves affected by the scale effect?

At the same stress/load/pressure level, the probability of failure for the large specimen is higher than the probability for a small specimen

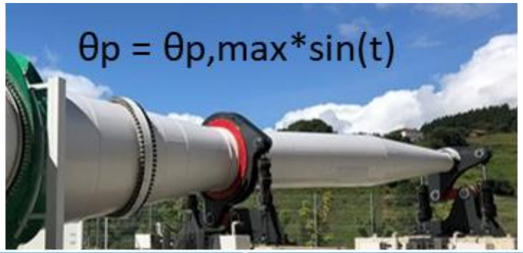
If we do not considere this effect and we design the components based on the small specimen curves, it is not conservative!!

The reason why the scatter in smaller specimens is so high

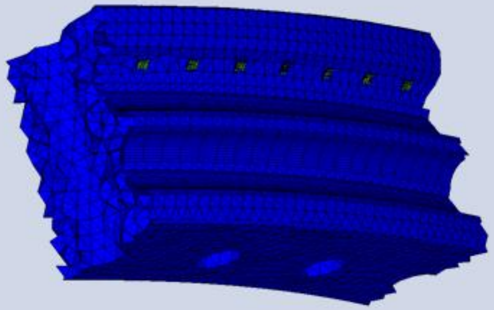
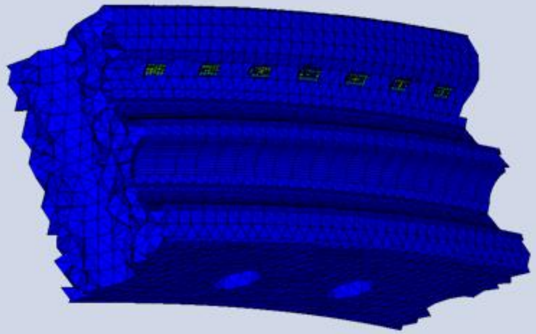
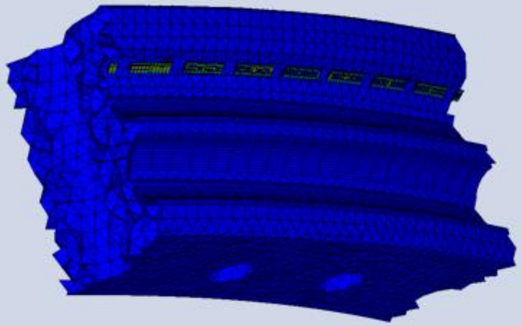
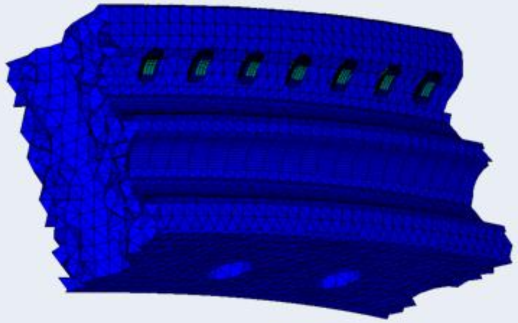
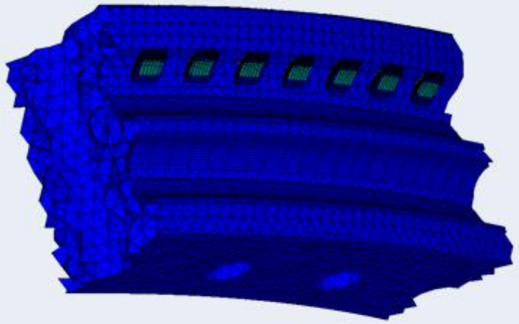
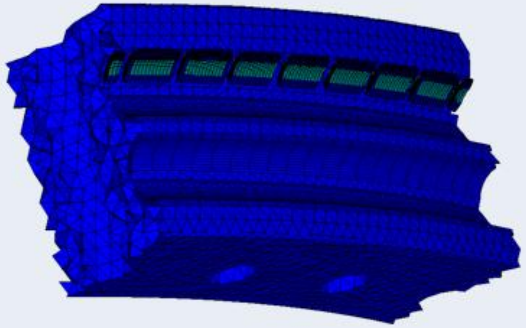
DAMAGE VS. PROBABILITY OF FAILURE



DAMAGE VS. PROBABILITY OF FAILURE



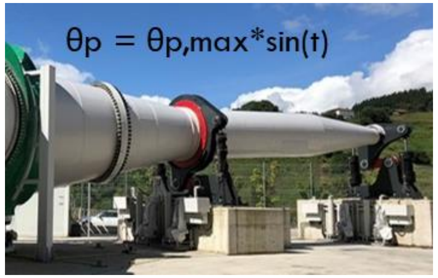
- Results for different short pitch-rotations: 0.5º, 1.5º, 2º.

	θp,max = 0.5º	θp,max = 1.5º	θp,max = 2º
Damage			
Failure probability			

DAMAGE VS. PROBABILITY OF FAILURE

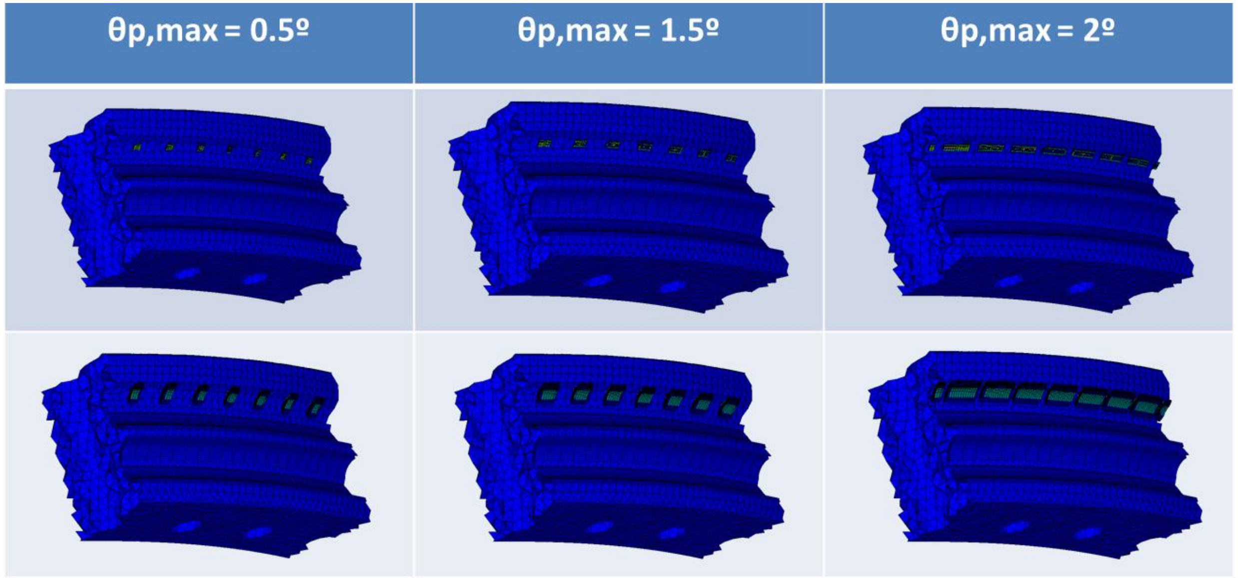
- Results for different short pitch-rotations: 0.5°, 1.5°, 2°.

Pitch rotation	Maximum damage (location)	Maximum local failure probability (location)	Global failure probability
θp,max = 0.5°	**0.572**	0.017%	**33.7%**
θp,max = 1.5°	**0.577**	0.017%	**53.2%**
θp,max = 2°	**0.577**	0.017%	**78.6%**



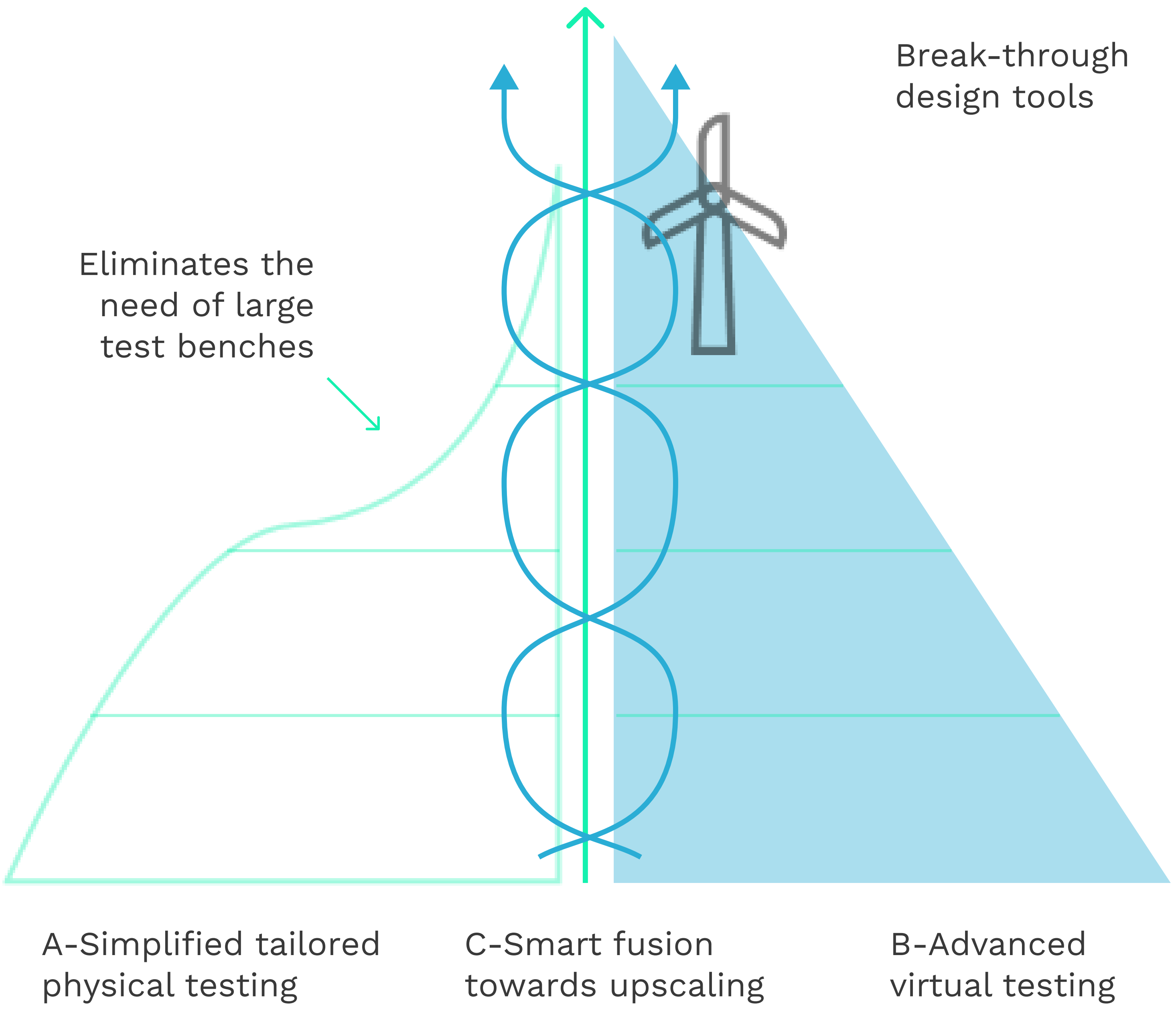
Damage

Failure probability



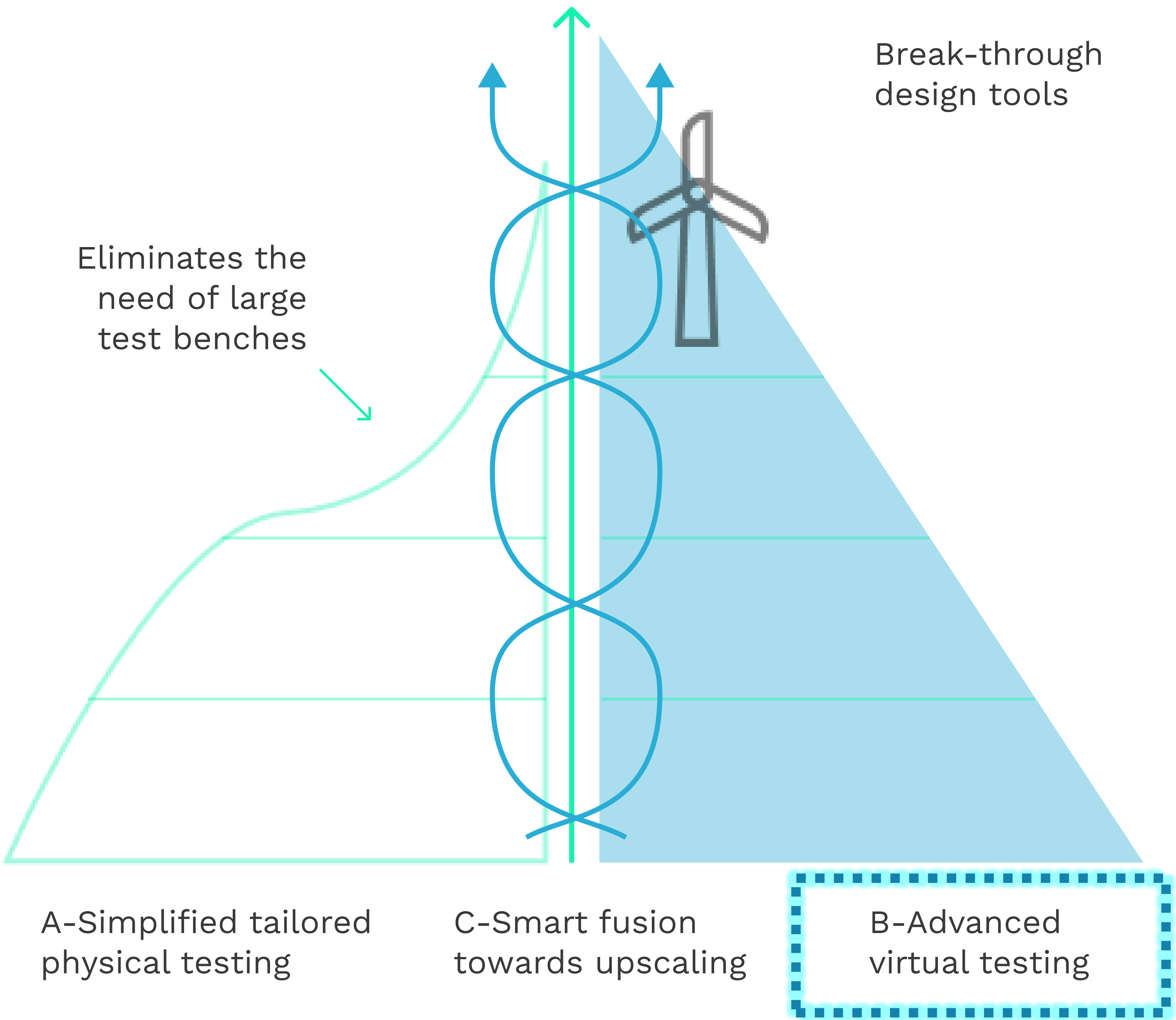
INNTERESTING Results

RESULTS



Break-through
design tools
Eliminates the
need of large
test benches
A-Simplified tailored
physical testing
C-Smart fusion
towards upscaling
B-Advanced
virtual testing

RESULTS



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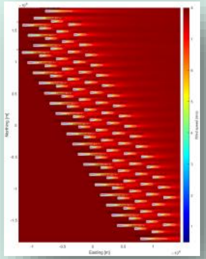
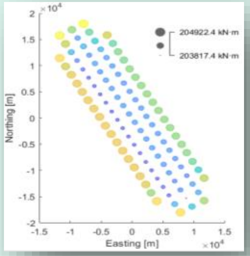
PROBABILISTIC LOAD CALCULATION METHODS

Developed a numerical approach to quantify stochastically the pitch bearing fatigue del variability between WTGs of a wind farm





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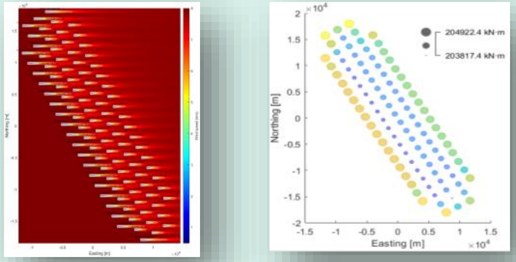
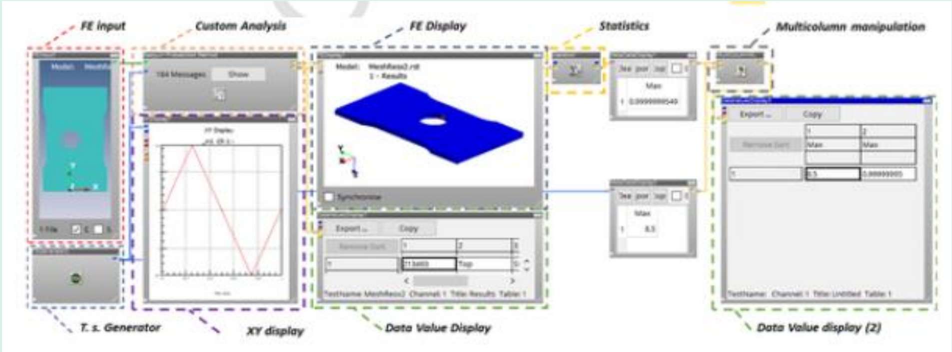


RELIABILITY PREDICTION METHODS FOR WT COMPONENTS

Developed a stochastic numerical approach for estimating global WT structure fatigue probability of failure



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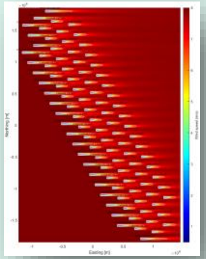

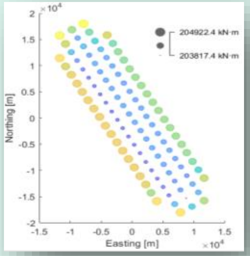

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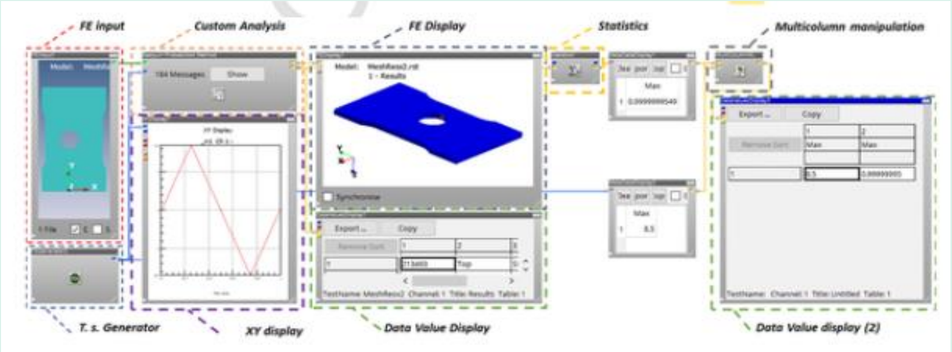
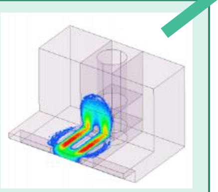


MANUFACTURING AND MATERIAL EFFECTS ON WIND TURBINE COMPONENT LIFETIME

A fast Multiphysics simulation methodology for induction hardening process is developed



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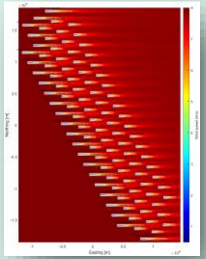

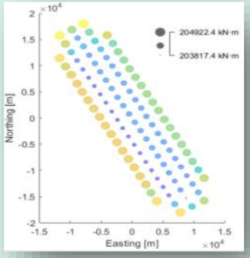

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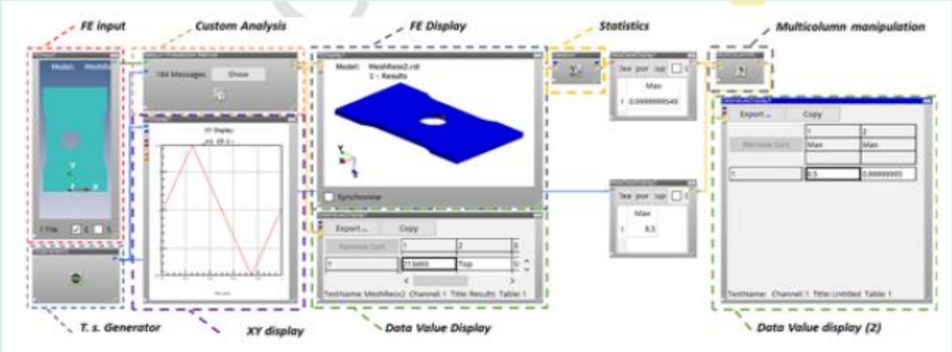

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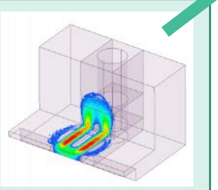

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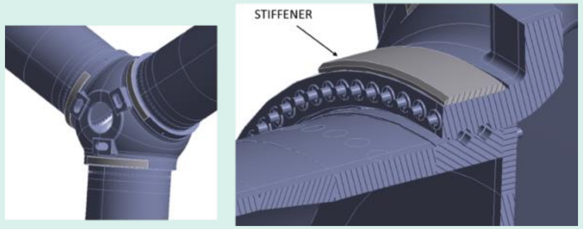

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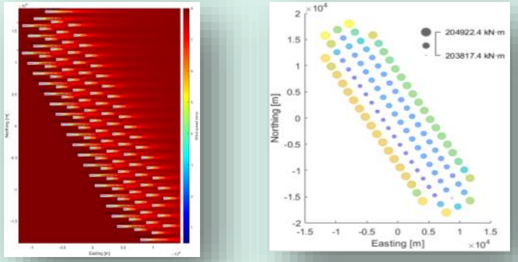

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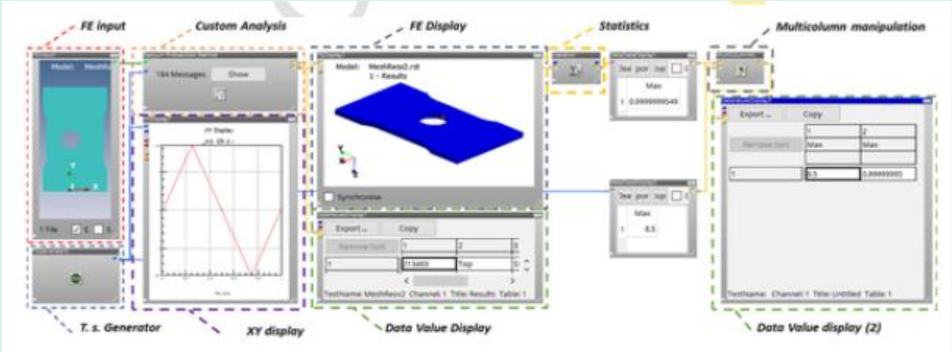

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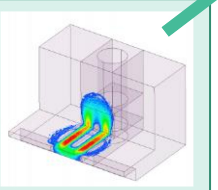

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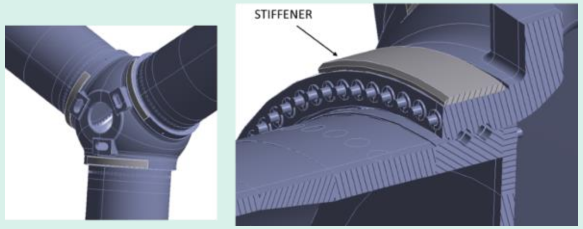

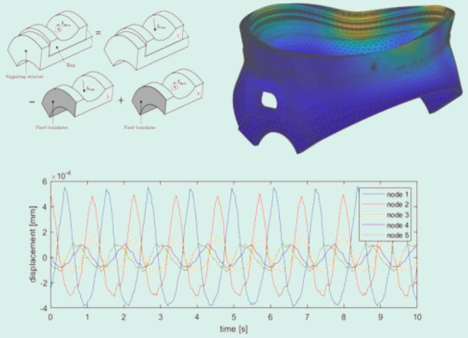

DEVELOPMENT OF SCALABLE PITCH MULTI BODY BEARING MODELS

Focused on the development of analytical models and flexible multibody models for 4 and 8 point of contact ball bearings

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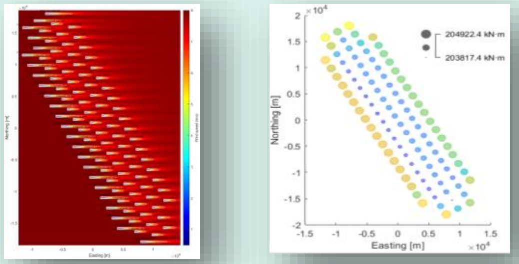

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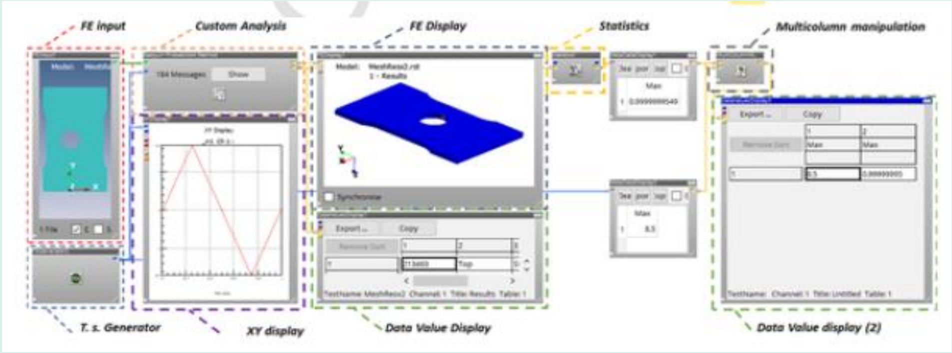

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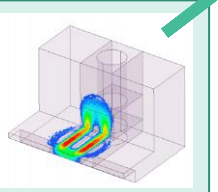
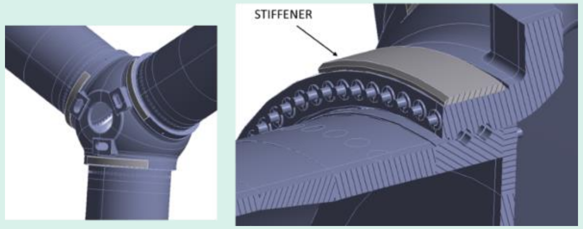
A fast Multiphysics simulation methodology for induction hardening process is developed



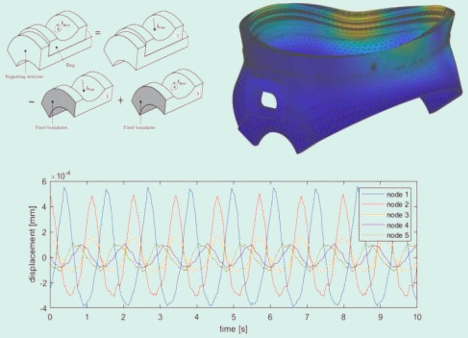
RELIABILITY METHODS FOR LIFETIME EXTENSION OF EXISTING PITCH BEARINGS:

A design procedure to define life extension solution (based on a patented idea)



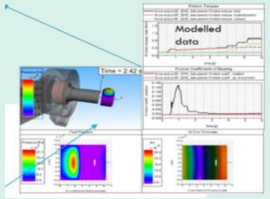
DEVELOPMENT OF SCALABLE PITCH MULTI BODY BEARING MODELS

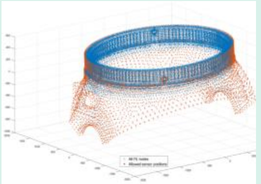
Focused on the development of analytical models and flexible multibody models for 4 and 8 point of contact ball bearings



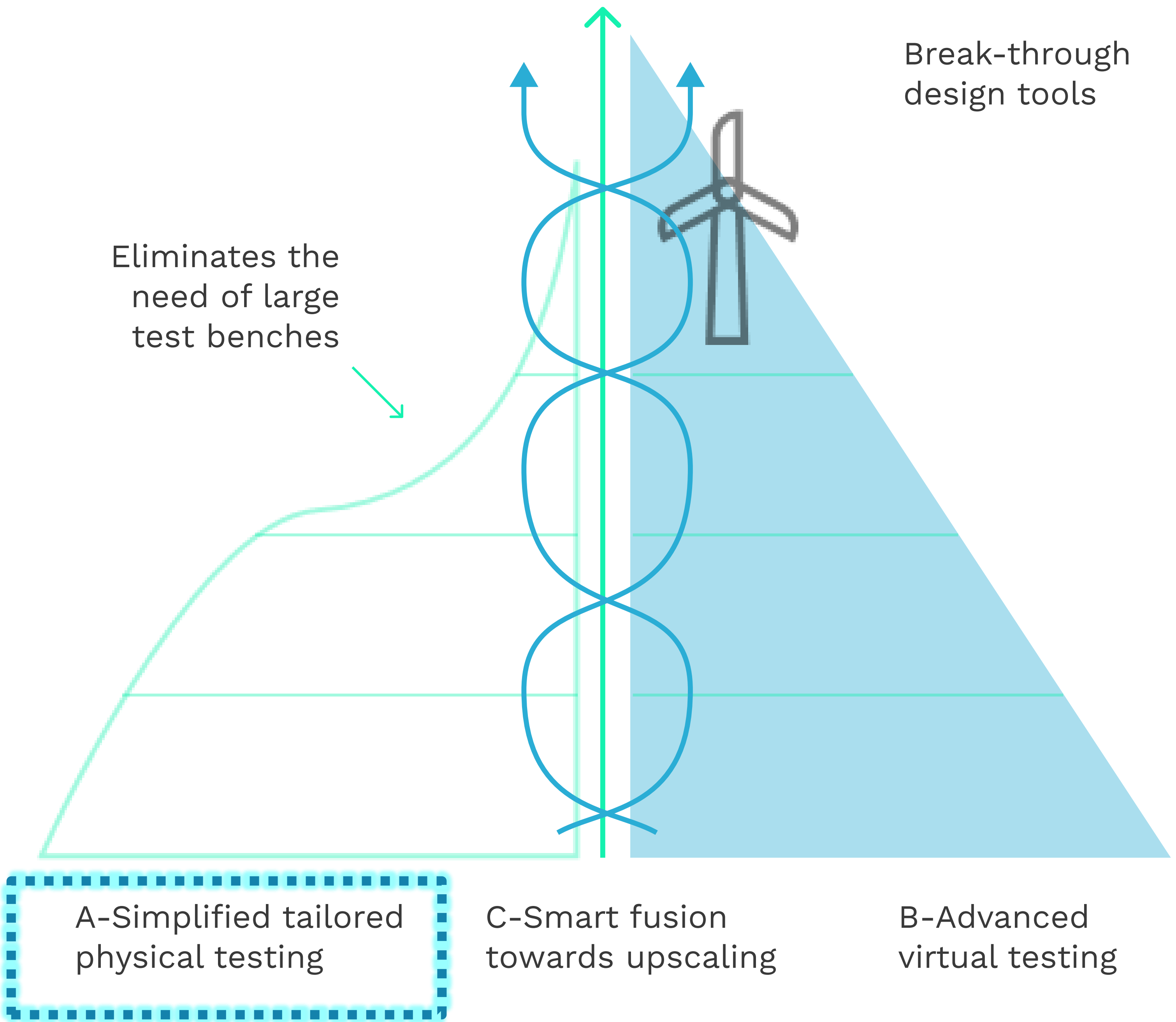
SENSOR SELECTION TECHNIQUE

Developed a sensor selection technique to automatically suggest sensor sets for the estimation of the loads on a pitch bearing and monitor the sensors to monitor the lubricant film thickness in the journal bearing of the gearbox





RESULTS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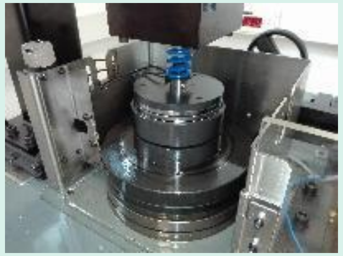
SIMPLIFIED TAILORED PHYSICAL TESTING



EXPERIMENTAL CHARACTERIZATION OF THE MANUFACTURING EFFECT ON THE FATIGUE PROPERTIES

Induction hardening process effect on the fatigue properties

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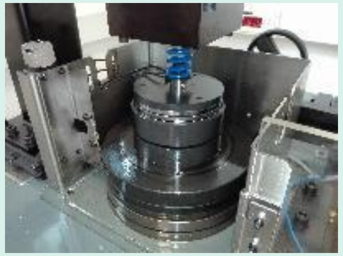

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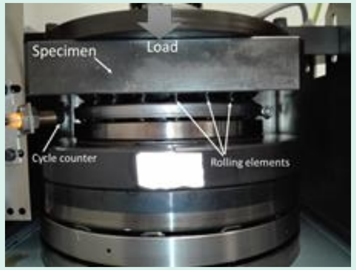
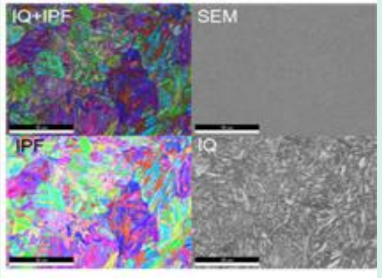
CONTACT FATIGUE FAILURE MODES: ROLLING CONTACT FATIGUE

Analysis of the RCF failure mode with flat smaller samples





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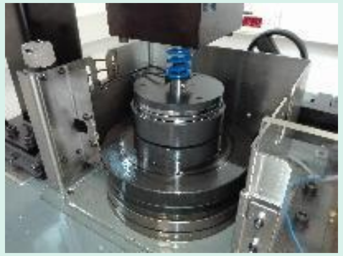

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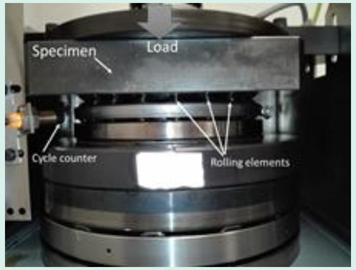
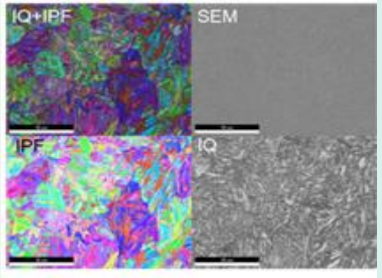
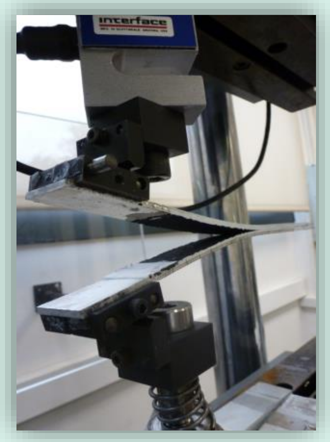
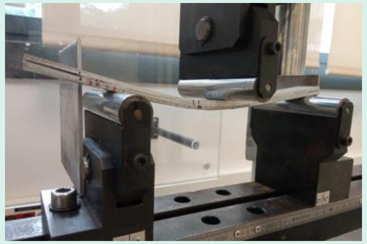






CHARACTERIZATION OF REPAIRS SOLUTIONS adhesive material characterization that will be used for the CS3 (patented idea)



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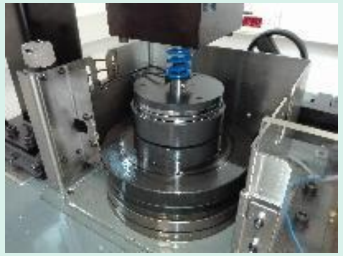

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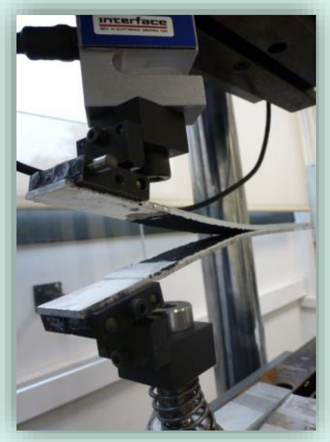

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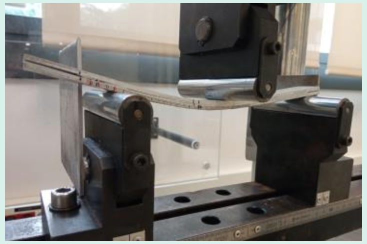

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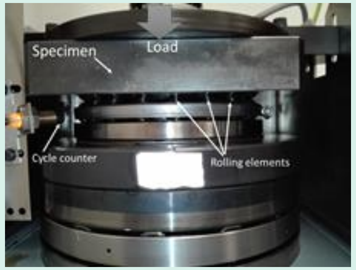
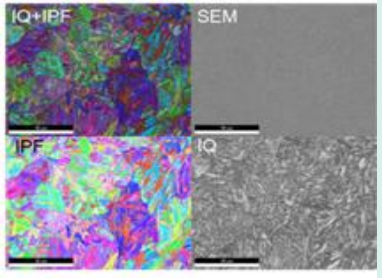
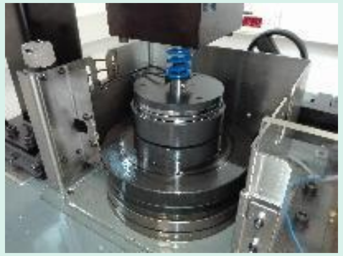




STRUCTURAL FATIGUE FAILURE TESTING FOR WIND TURBINE COMPONENTS

Simplified bolt hole tests using the bearing material. This is linked to the reliability prediction virtual methods

SIMPLIFIED TAILORED PHYSICAL TESTING



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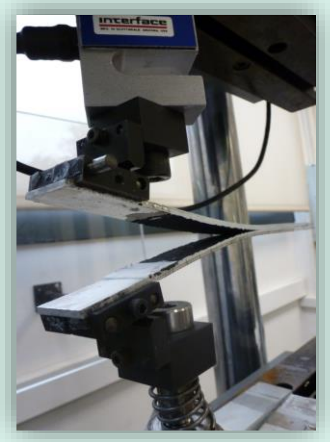

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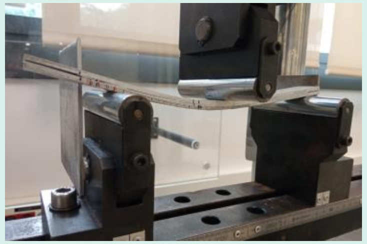
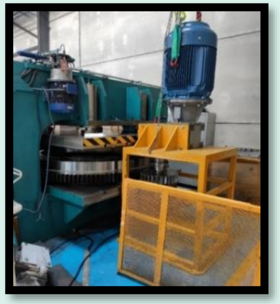


NEW PITCH BEARING CONCEPT VALIDATION TEST



CS1 novel roller concept is validated in a 400 Tn test bench

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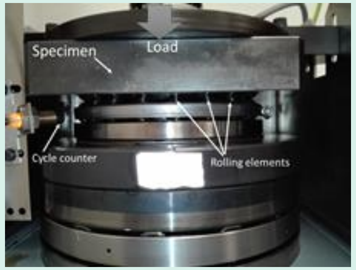

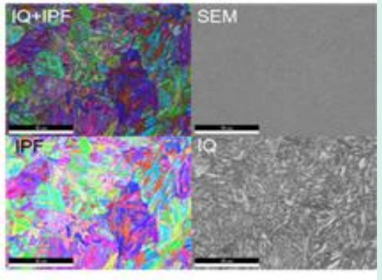

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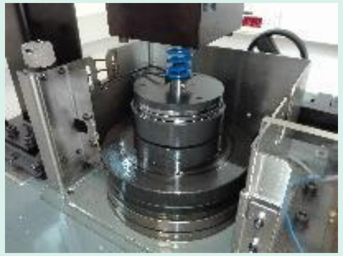

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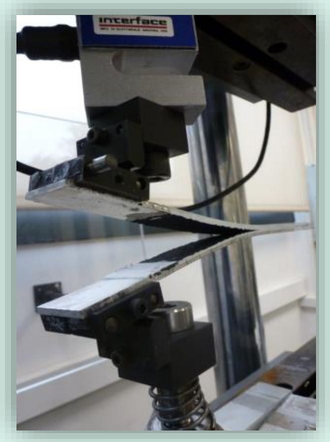

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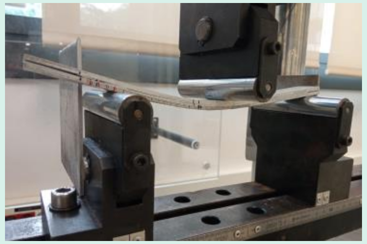

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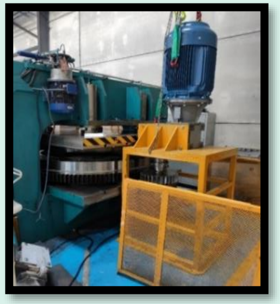

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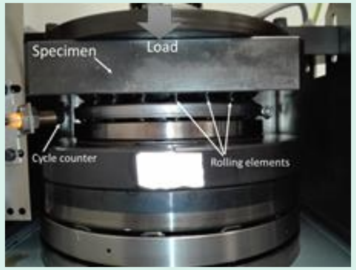

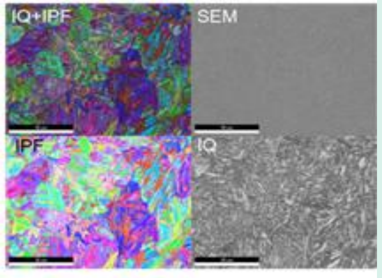

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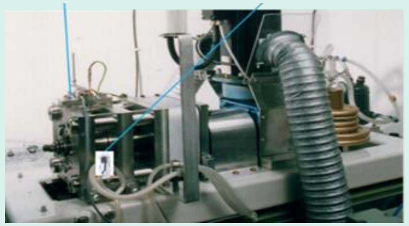
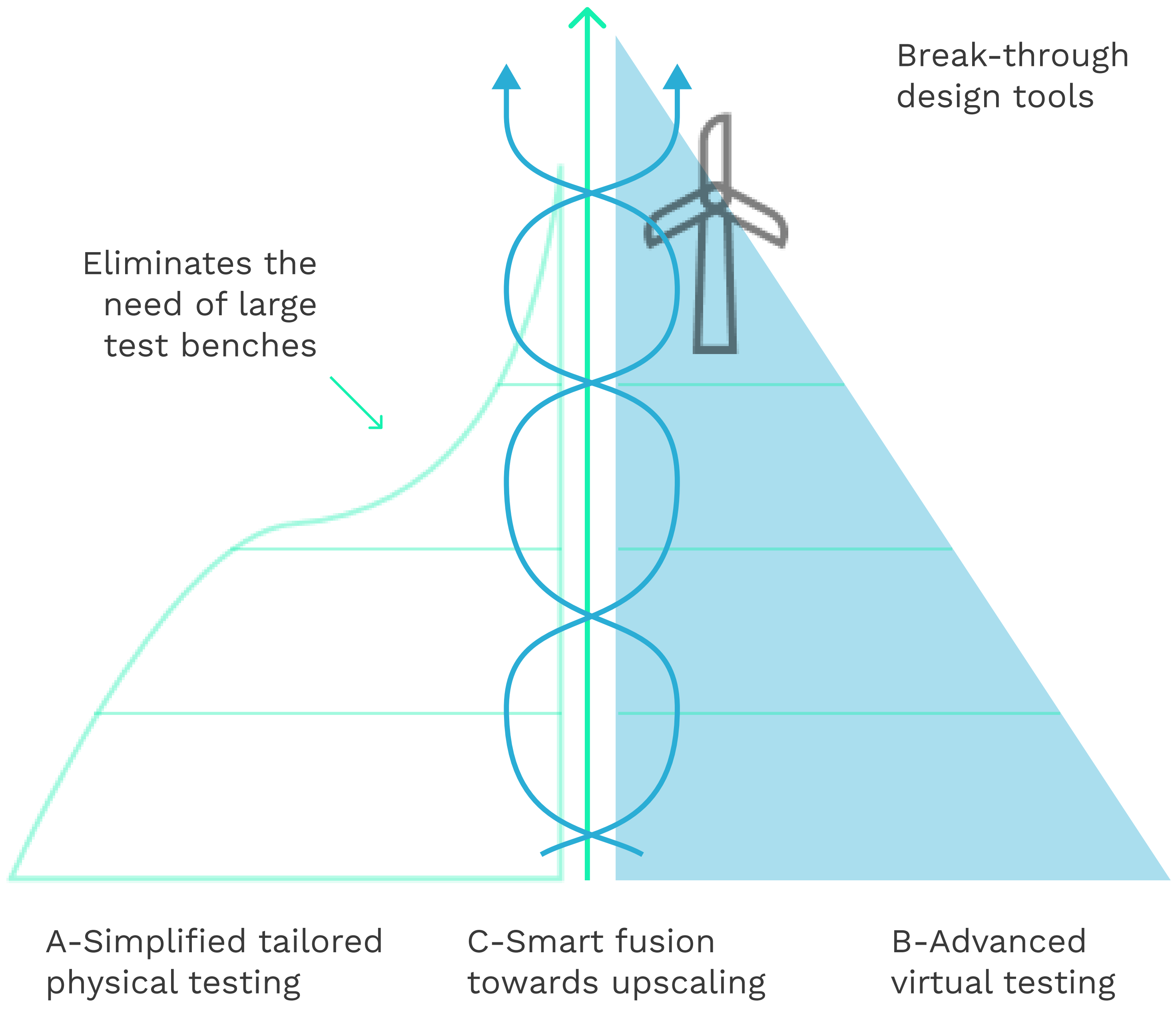
LABORATORY-SCALE TESTS FOR JOURNAL BEARING CONCEPT

Analysis of the failure cases of the journal bearing concept using new type of materials



RESULTS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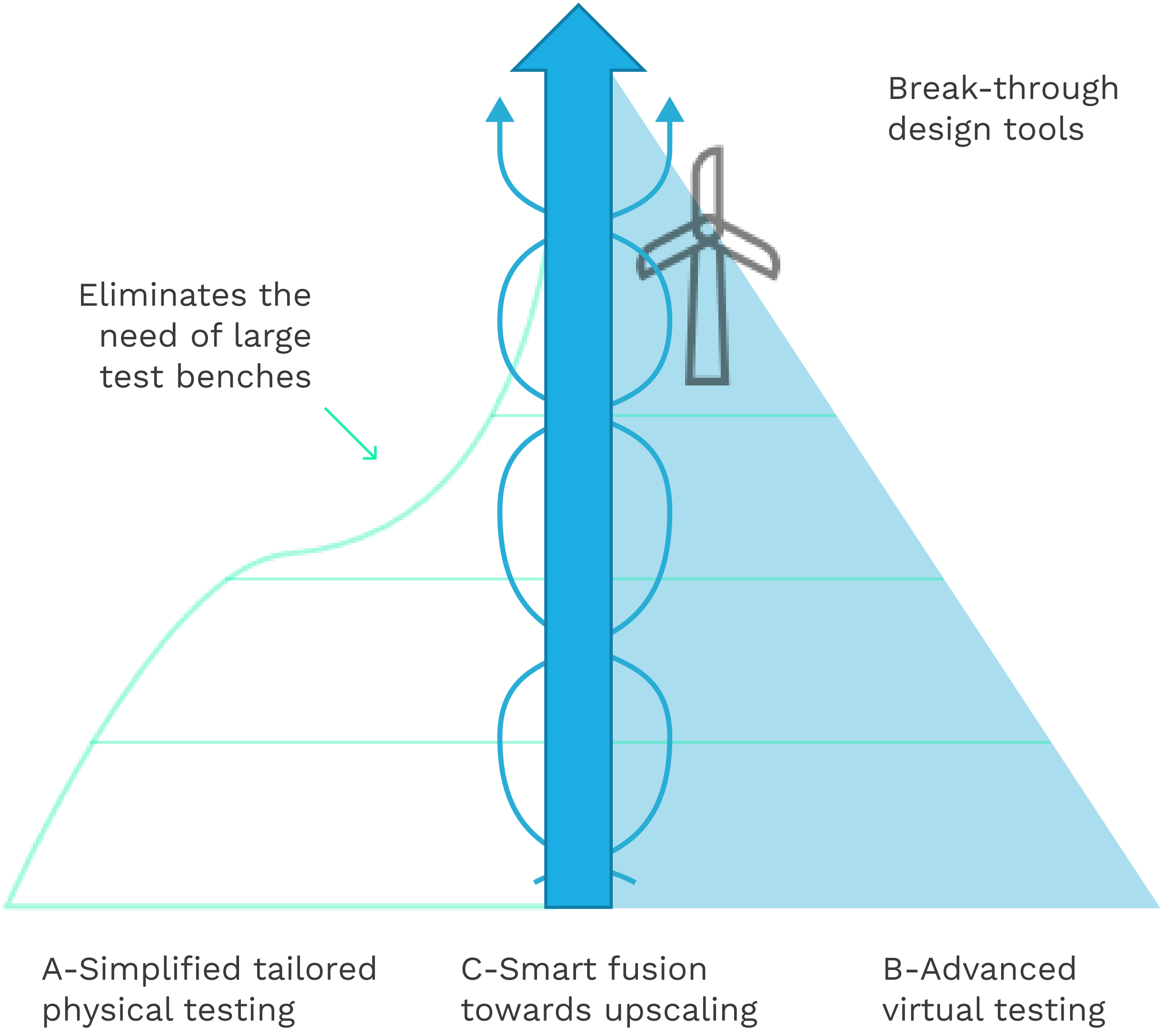
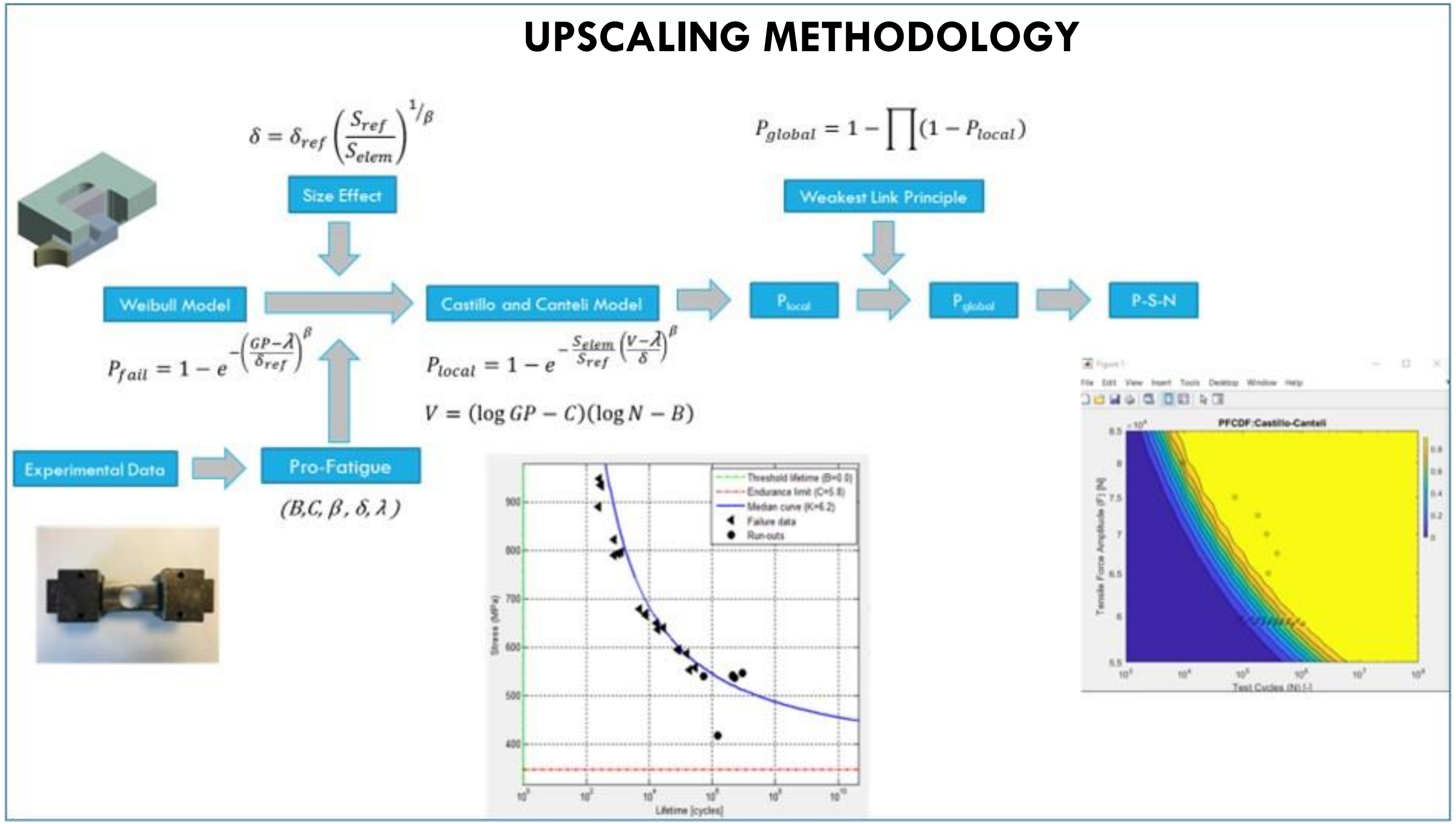
UPSCALING TECHNIQUES



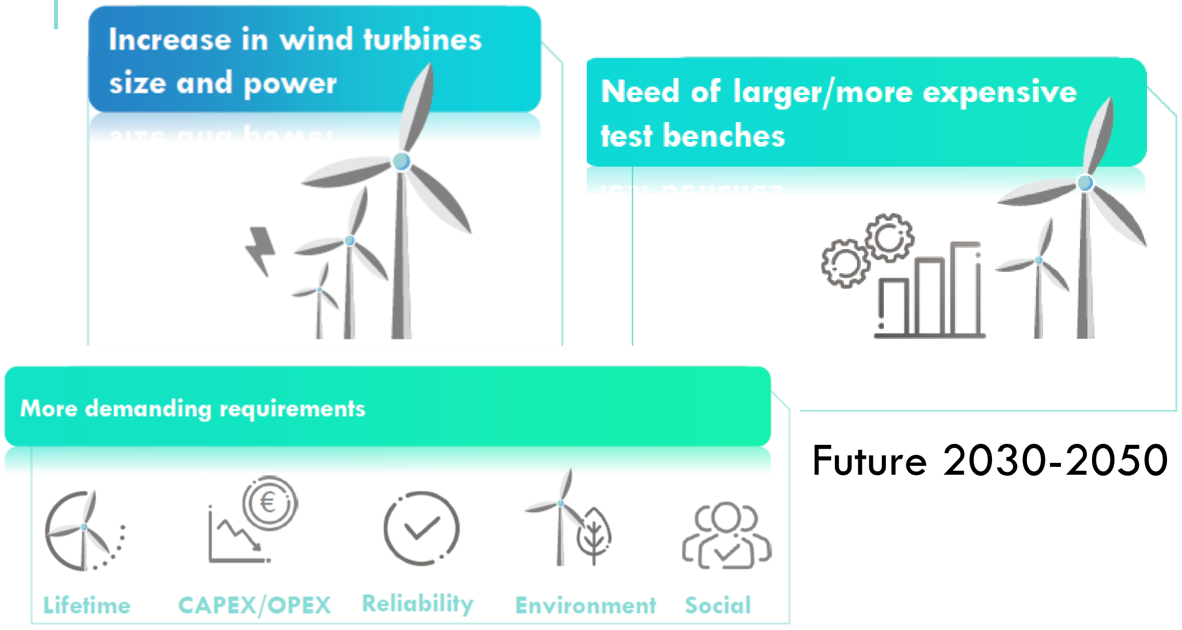
UPSCALING METHODOLOGY WORKFLOW



Conclusions, future lines and possible developments based on what has been learned

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 851245

REVIEW OF THE OBJECTIVES



Future 2030-2050

The INNTERESTING Project aims to develop a novel hybrid methodology and breakthrough design tools to assess reliability of larger wind turbine critical components without the need of building larger tests benches in the future

Objectives:

- develop design tools
- bring two new ground-breaking designs of real wind turbine components to a TRL-4
  - Case Study 1
  - Case Study 2
  - Case Study 3
- reduce the environmental and economic impacts
- Replication of project results to other components and sectors

FINAL TECHNICAL CONCLUSIONS

- ✓ For each case study the INNTERESTING APROACH is developed: the methodology is validated.

- ✓ The INNTERESTING APPROACH not only test or validate the component:
  - Provides knowledge about **material´s variability, manufacturing processes effect** and **specific failure modes** that otherwise would be very expensive to obtain.

- ✓ The downscale tests are a tendency (cheaper/faster): upscaling techniques are necessary
  → otherwise the **new designs will be non-conservative.**

- ✓ A New concept should be included in the industry: **probability of failure of the components**
  → instead of deterministic damage value.

- ✓ The new technologies, artificial intelligence, machine learning… can be used for prediction:
  → but understanding what is happening physically is really important!

MORE RESEARCH IN UPSCALING TECHNIQUES MUST BE DONE

FUTURE TREND

THANK YOU!

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