Integrated Testing and Modelling of Composite Structures – A Journey Towards Virtual Testing and Certification by Analysis

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ECCM21
02-05 July 2024
Nantes - France

Outline

- Background and motivation
- CerTest
- Overview of research challenges and methodology (process flow and how it works?)
- Steps towards demonstration of new methodology
- Summary / Vision

The prize?

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Outline

- Back[illegible]tivation
- Cer[illegible]
- Ove[illegible]s flow an[illegible]
- Steps towards dem[illegible]
- Summary / Vision

The prize?

REDUCED DEVELOPMENT TIME / TIME TO MARKET!

REMOVING/REDUCING BARRIERS TO INNOVATION POSED BY CURRENT PROCESSES

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Background and motivation – what is the problem?

- Mostly tests on coupon and generic element levels of testing pyramid – for certification purposes
- Few test on component/structural detail and full structure levels – but full scale tests are required for certification (very costly and time consuming)
- Full scale & component/structure tests

Background and motivation – what is the problem?

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Background and motivation – what is the problem?

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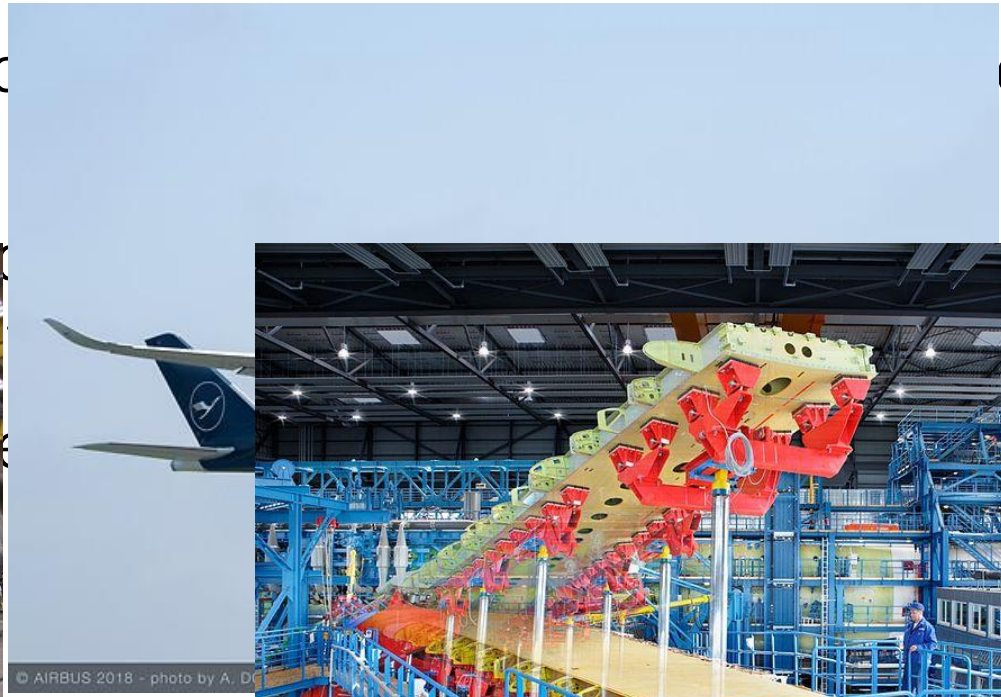

Complience with safety regulations – currently "building block" approach / "testing pyramid"

1. **Coupon:** a small test specimen for evaluation of basic laminate properties or properties of generic structural features
2. **Element:** A generic part of a more complex structural member
3. **Detail/Component:** a non-generic structural element of a more complex structural member
4. **Component/Full structure:** major three-dimensional structure - complete structural representation of a section of the full structure (or the full structure)

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Complience with safety regulations – currently "building block" approach / "testing pyramid"

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2. Elemer
3. Detail/
   memb
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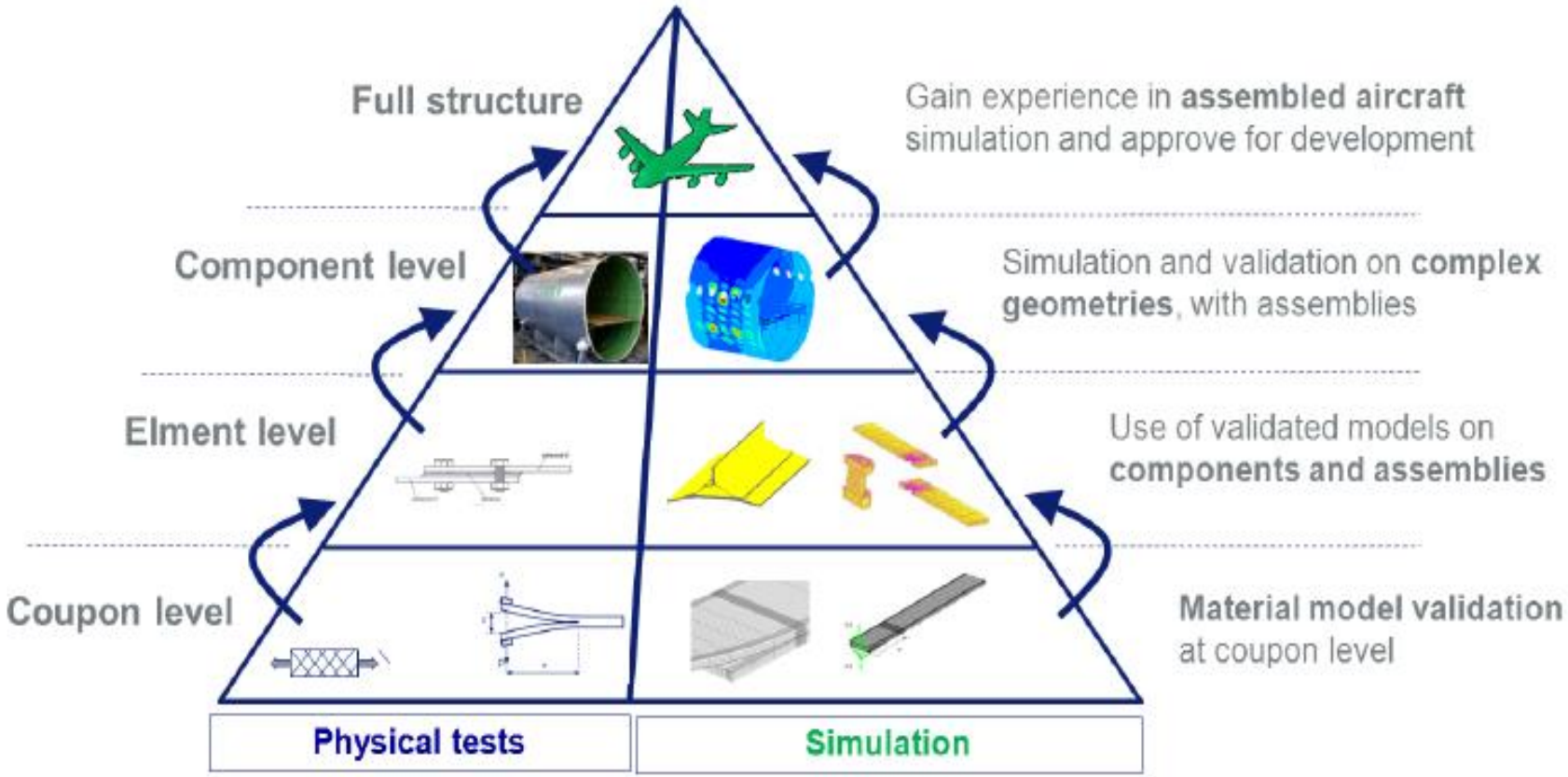

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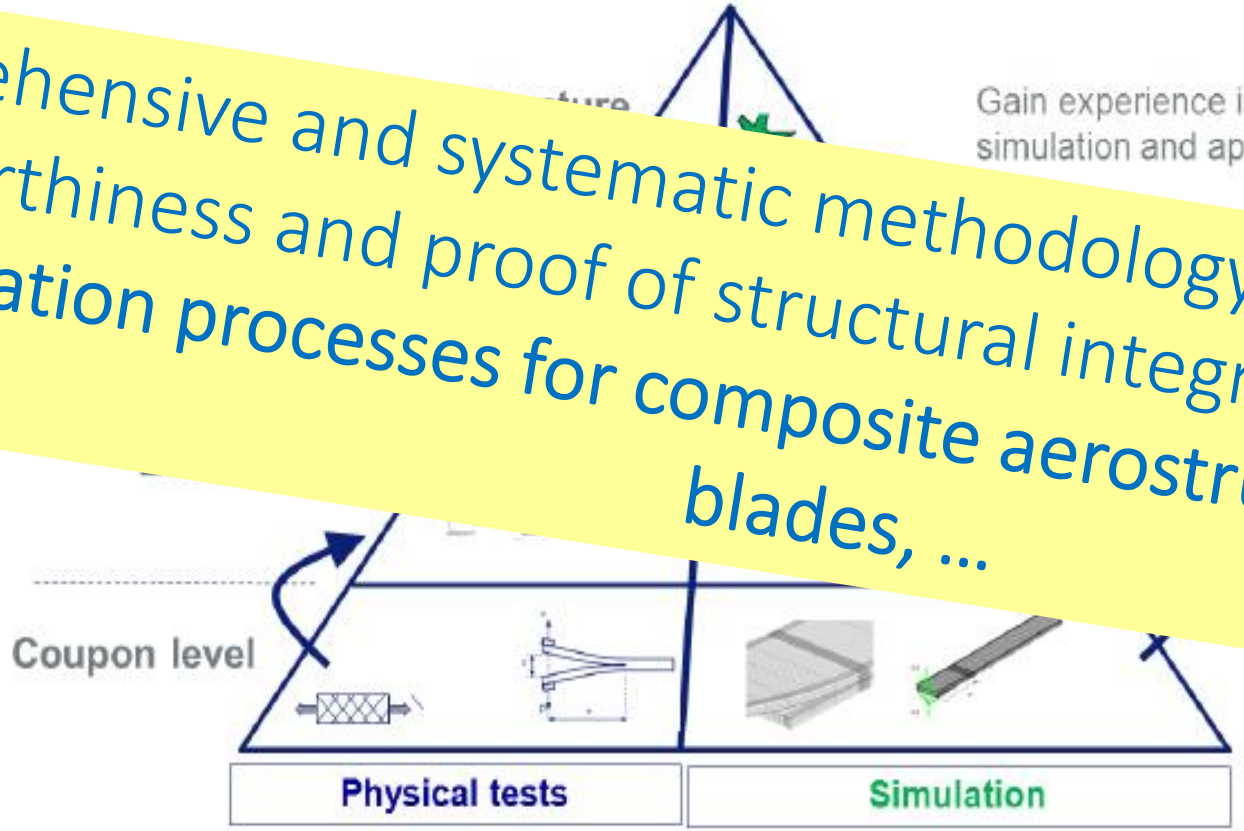
Compliance with safety regulations – currently "building block" approach / "testing pyramid"

Comprehensive and systematic methodology to prove/demonstrate airworthiness and proof of structural integrity - **backbone of the certification processes for composite aerostructures, wind turbine blades, …**



EVIDENCE – limitations to Building Block approach

- Failure models largely based on inputs derived from coupon tests comprising simple, mainly uniaxial, loading modes and unidirectional materials
- Large number of coupon tests to define “allowables” - relatively few tests mid-tier and top-tiers of pyramid (larger length scales)
- *Underlying assumption:* Material properties from tests at the coupon level can be used to define design allowables at greater length scales
- Coupon properties do not represent the “in-situ” properties well
- Transfer/upscaling of ”allowables” from coupon level to higher levels leads to large knock-down factors, lack of understanding of MoS and reliability on structure/system level
- Excessively costly (especially top-tier) and time consuming

Can we do things more efficiently (safer, cheaper, faster)?

- Reduce bottom tier of pyramid?
- Coupon tests still required – but at reduced levels/numbers (how many?)
- Reduce/eliminate top tier of pyramid?
- Modelling & testing integrated – validation: Mid-tiers of pyramid structural scale
- Models used to inform tests – tests used validate/inform models – *Data Fusion* & *Design of Experiments*
- High-fidelity tests – calibration/validation of model predictions
- Models benchmarked/challenged and validated via **SUFFICIENTLY COMPLEX TESTS** (geometry and load complexity) on **structural** length scales

Can we do things more efficiently (safer, cheaper, faster)?

- Redu[illegible] bottom tier of pyramid?
- Cou[illegible] but at reduced levels/numbers (how many?)
- Red[illegible]
- Mo[illegible] scale
- M[illegible] *f*
  Ex
- High-fidelity test[illegible]
- Models benchmarked/challenged and [illegible]etry and load complexity) on **structural** length scales

If successful …

generic methodology/framework would be transferable to other emerging materials/ manufacturing technologies (AM, 3D printing, …)

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CerTest

- Programme Grant: *"Certification for design – Reshaping the Testing Pyramid"*
- Grant award: £6.9M, 2019-2025

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CERTIFICATION FOR DESIGN: RESHAPING THE TESTING PYRAMID

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AIRBUS

BAE SYSTEMS

Rolls-Royce

GKN AEROSPACE

NATIONAL COMPOSITES CENTRE

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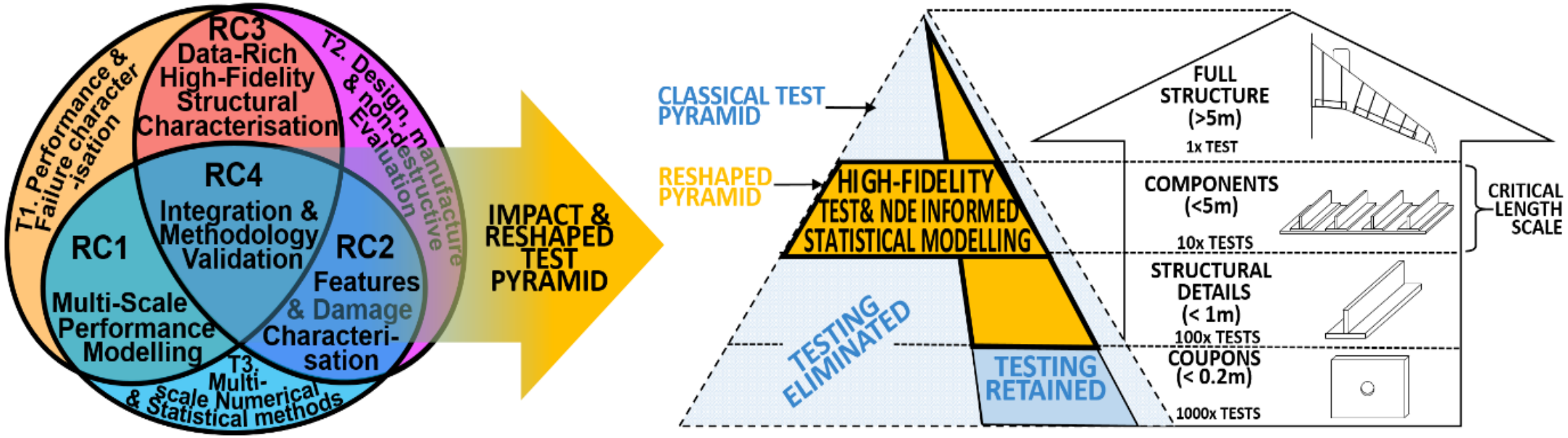
Aim – Development and validation of scientific/engineering tools that will enable VIRTUAL composite structure performance validation - relying on less physical testing and accounting for uncertainty and variability on all levels

Key enabler – integration of multi-scale modelling and high-fidelity data-rich testing on structural scale via Bayesian learning and ”Design of Experiments”



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Aim – De… …ering tools that will enable VIRTUAL composit… …ccounting for uncer…

Key enab… …g on str… …scale via Bayesian learning

Decisive move towards virtual testing and validation (and DIGITAL CERTIFICATION) – reduce reliance on physical testing

CHALLENGE – *UQ = Uncertainty Quantification*:

New statistical frameworks must be created to design, model and test at the component/sub-structure level, safely accounting for uncertainty whilst exploiting new design opportunities including manufacturability

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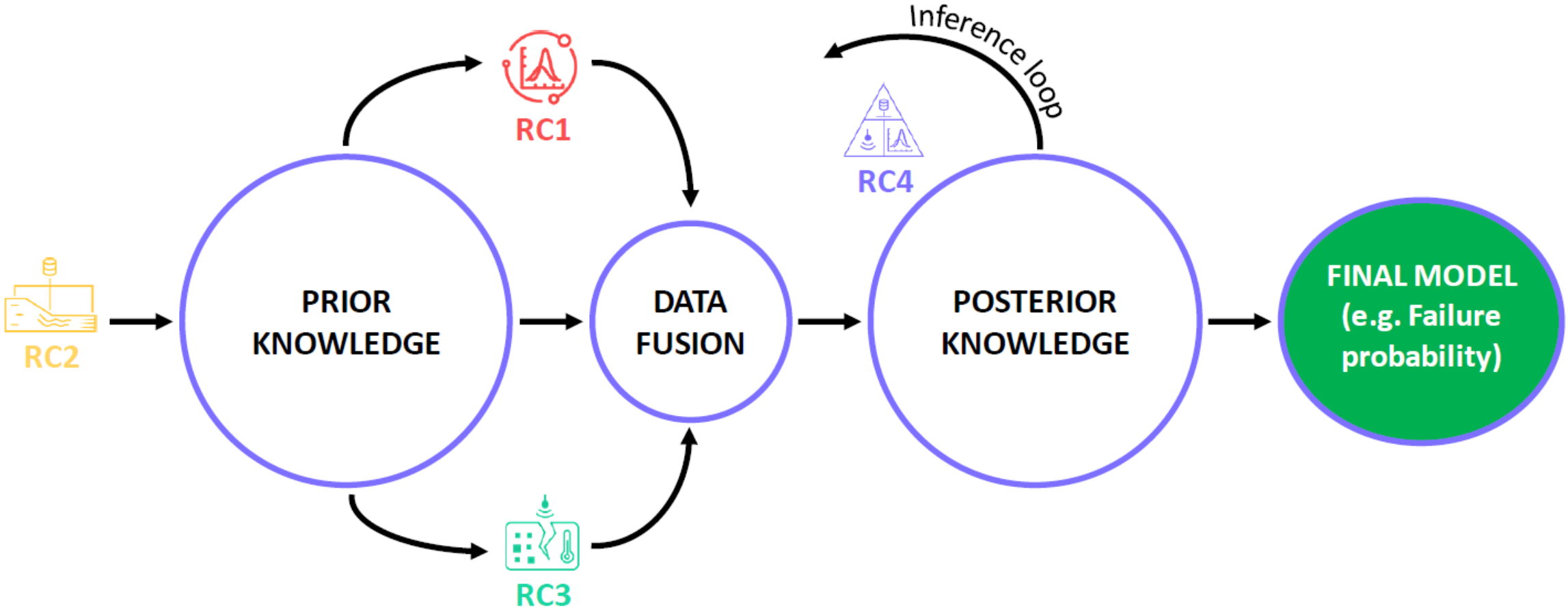
CerTest hypotheses



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Coupons

Model/design

Test

Current:

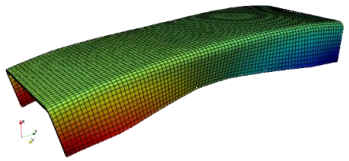
Material: E_{fibre} 90%; G_{1C} 90%

Laminate: A_{11} 90%; D_{11} 90%

Laminate with feature: CAI 90%; OHT 90%

Models with no defects and fixed properties

B-basis allowables – single value



Limited design space

Validation of conservative design

Test pyramid

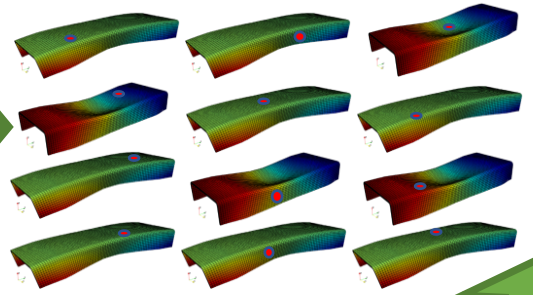
Single value
Limit load
pass/fail

CerTest:

Material: E_{fibre}; G_{1C}

Rapid models with defects and uncertain properties

Full distributions

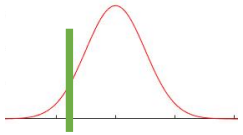


Wide design space

Most informative test

Reduced Test pyramid

Learning about material & physics



Sufficiently probable strengths
>
limit load

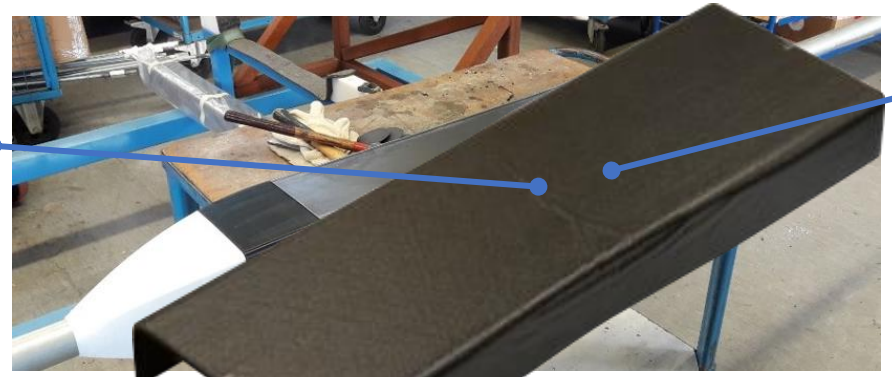
CerTest – steps towards demonstration of methodology

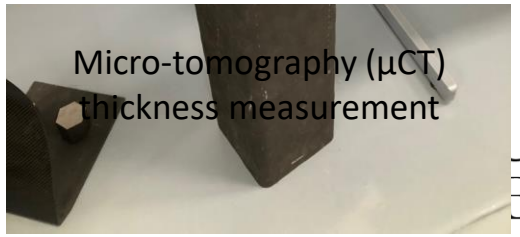
- C-spar with delamination - combined loading – demonstrator: ***Full Bayesian loop and DoE process***
- Larger scale demonstrator – possibly ***"wing-box" like component seeded with manufacturing defects***

CerTest – steps towards demonstration of methodology

- C-spar with delamination - combined loading – demonstrator: ***Full Bayesian loop and DoE process***
- Larger scale demonstrator – possibly ***"wing-box" like com***
  manufacturing defects

Wrinkles





Micro-tomography (µCT) thickness measurement

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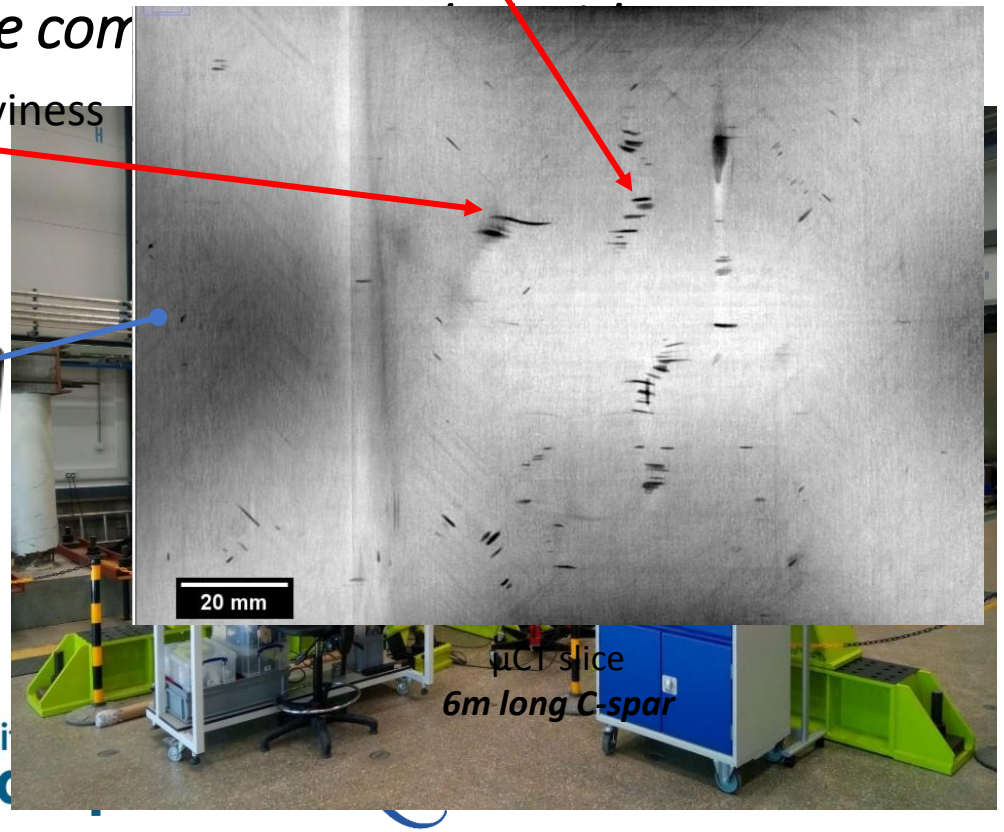
Voids

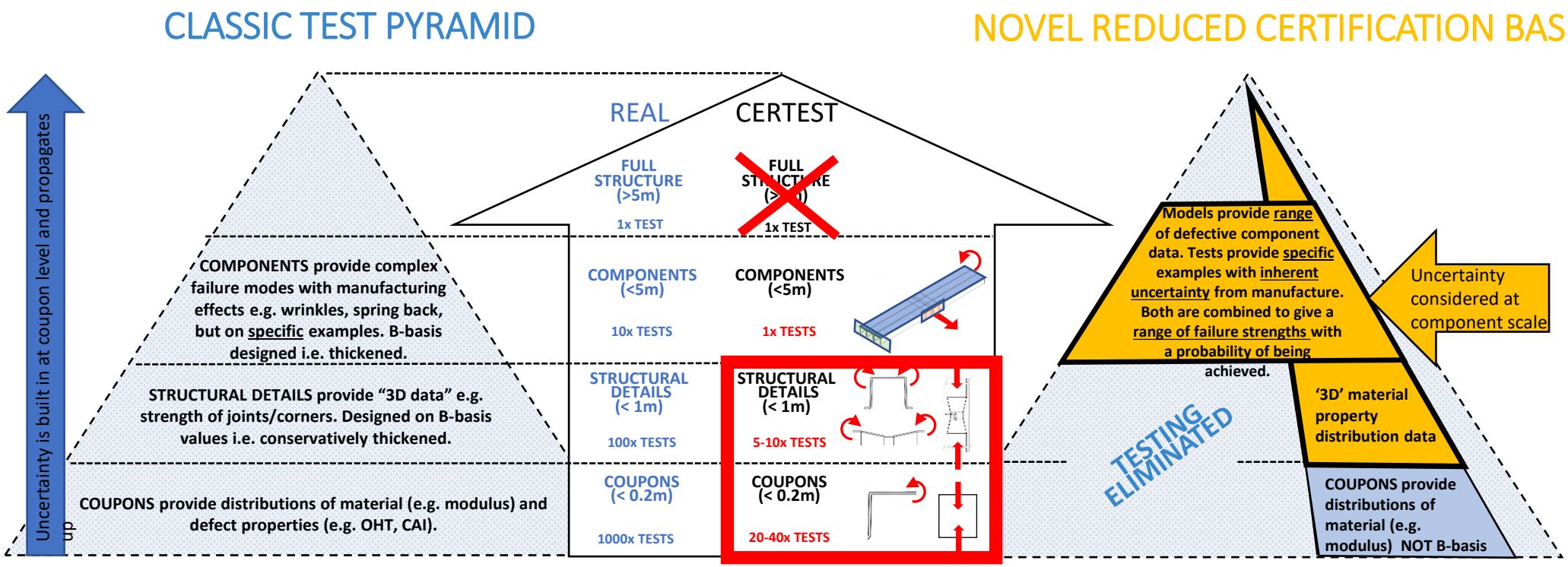
In plane waviness



µCT slice

6m long C-spar

SUMMARY - Competing test pyramids and availability of data



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Tuesday 2nd July 2024, Multiscale modelling – I, Room 2000

- 12:00 An optimal framework for assessing uncertain parameters in large-scale composites using nonlinear MS-GFEM, Jean BÉNÉZECH, University of Bath

Wednesday 3rd July 2024, Special Symposium on Integrated testing and modelling of composite structures – towards virtual testing and certification by analysis – I, Room BC

- 9:30 Integrated testing and modelling of composite structures – a journey towards virtual testing and certification by analysis, Ole THOMSEN, University of Bristol, Bristol Composites Institute, UK
- 9:45 Bayesian Calibration of a Geometrically Nonlinear Finite Element C-spar Model using Digital Image Correlation, Carl SCARTH, University of Bath, UK
- 10:15 Application of second-order multi-scale modelling to composite components with delamination, fibre and matrix damage, Meng Yi SONG, University of Bristol, Bristol Composites Institute, UK
- 10:30 Characterization of micro-structural features in complex parts for use in digital technologies, James KRATZ, University of Bristol, Bristol Composites Institute, UK

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Wednesday 3rd July 2024, 16-17:30 Poster Discussion session, Mezzanine

- Session on "Material and Structural Behavior - Simulation & Testing Electrical properties": P099, *Advancing Understanding of Eddy Currents in Carbon Fiber Reinforced Composites using Through-Transmission Technique*, Atul SHARMA, University of Bristol, Bristol Composites Institute, UK
- Session on "Integrated testing and modelling of composite structures – towards virtual testing and certification by analysis": P197, *A novel method for forming realistic pre-preg wrinkles in an AFP representative setup and their characterization*, Ege ARABUL, University of Bristol, Bristol Composites Institute, UK

Thursday 4th July, Textile composites – II, Club Atlantique

- 12:00 *Implementation of Second-Order Homogenisation using Shell Elements for Woven Composites*, Athira Anil KUMAR, University of Bristol, Bristol Composites Institute, UK

Friday 5th July 2024, Novel test methods – II, Room GH

- 11:30 Considerations and potential for inductive sensing evaluation of carbon fibre composites, Robert HUGHES, University of Bristol, UK

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Questions?

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