# Towards virtual validation (certification) of composite structures – rethinking the testing pyramid approach

*Ole Thybo Thomsen (with thanks to CerTest team)*

Bristol Composites Institute, University of Bristol, Bristol, UK

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CERTIFICATION FOR DESIGN: RESHAPING THE TESTING PYRAMID
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University of Bath
University of Southampton
University of Exeter

# Outline

- Background and motivation – what is the problem?
- CerTest
- Overview of research challenges and methodology
- Steps towards demonstration of new methodology
- CerTest outreach & dissemination

*The prize?*

# Outline

- Background and motivation – what is the problem?
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- (…nd methodology
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REDUCED DEVELOPMENT TIME / TIME TO MARKET!

REMOVING/REDUCING BARRIERS TO INNOVATION POSED BY CURRENT PROCESSES

*The prize?*

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# Background and motivation – is there a 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 – wind blade  (LM Wind Power) & wing (Airbus)

# Background and motivation – is there a problem?

generic ... d – for



# *Complience with safety regulations – currently using ‘building block’ / ‘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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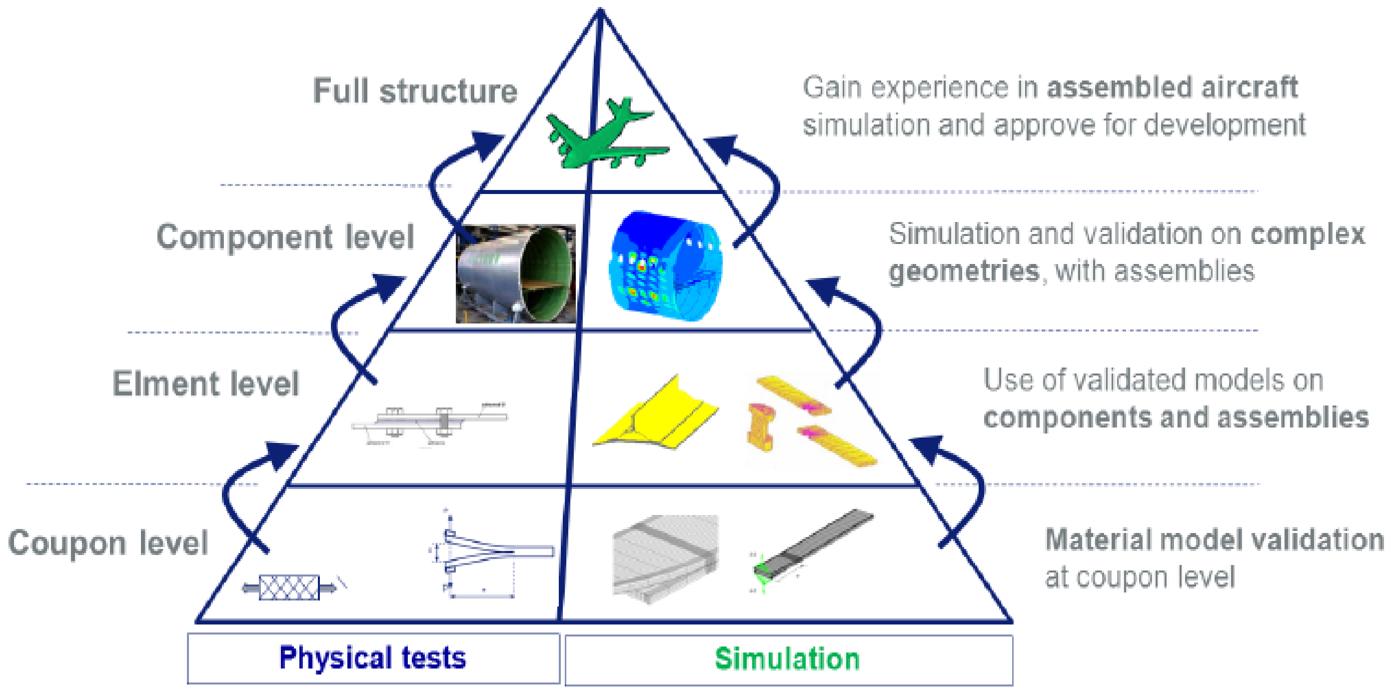
# *Complience with safety regulations – currently using ‘building block’ / ‘testing pyramid’*

1. Coupon: … ies or properti…
2. Element …
3. Detail/C… …x structural member…
4. Compon… …te structural represen…



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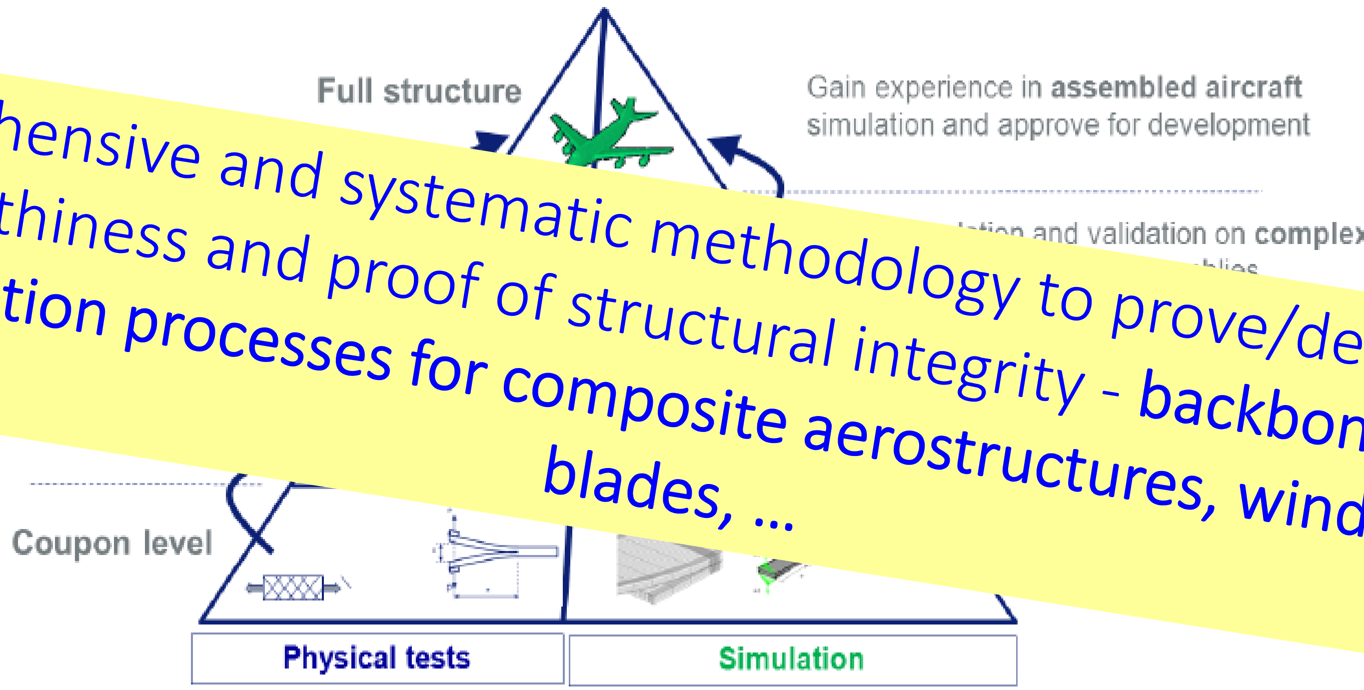


Comprehensive and systematic methodology to prove/demonstrate airworthiness and proof of structural integrity - **backbone of the certification processes for composite aerostructures, wind turbine blades, …**

# *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, reduced time)?*

- Reduce bottom tier of pyramid?
- Coupon tests (probably) 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



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# *Can we do things more efficiently (safer, cheaper, reduced time)?*

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



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# CerTest

composites-certest.com

- Programme Grant: *'Certification for design – Reshaping the Testing Pyramid' (CerTest)*
- Grant award: £6.9M over 5 years (2019-2024)

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University of Bristol · University of Bath · University of Southampton · University of Exeter

Airbus · BAE Systems · Rolls-Royce · GKN Aerospace

National Composites Centre · cfms · The Alan Turing Institute

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Close interaction with EASA

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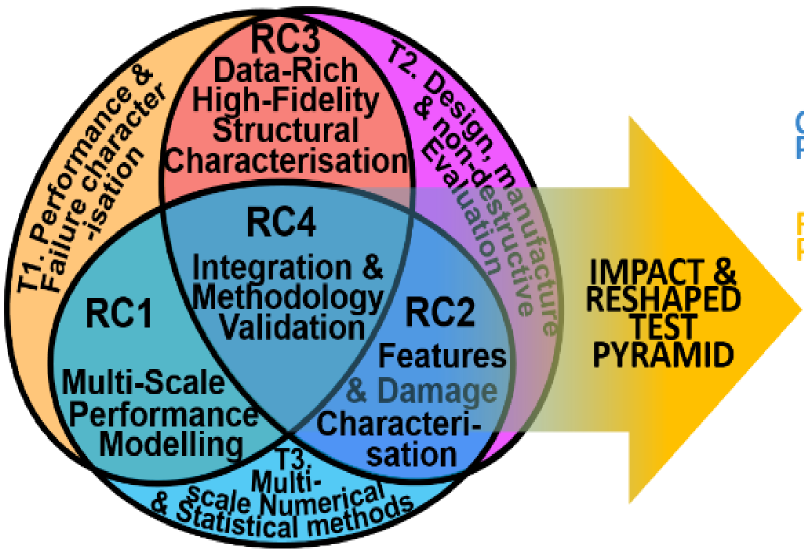
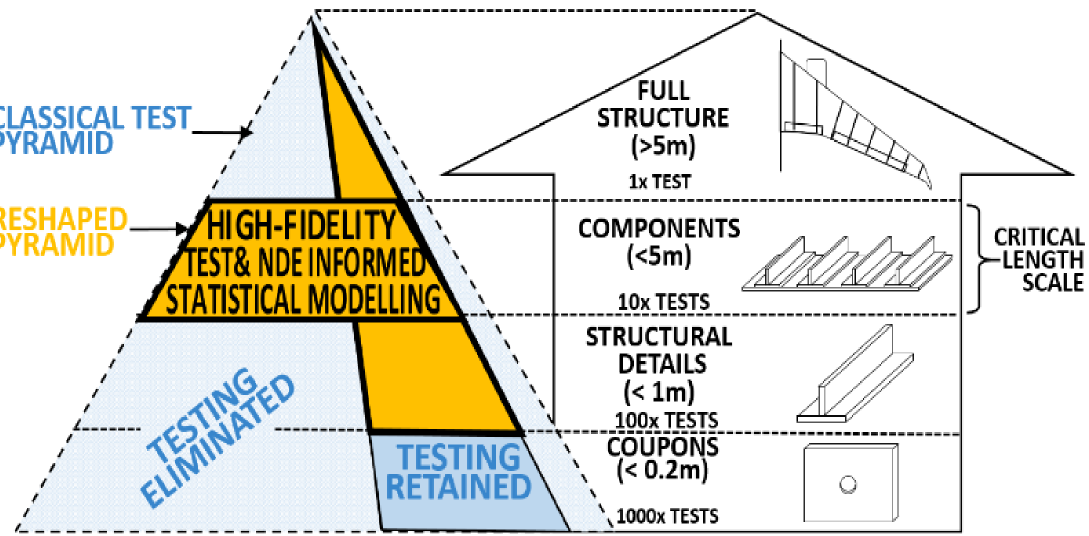
**Aim** – Development and validation of scientific/engineering tools that will enable VIRTUAL composite structure performance validation - relying on less physical testing and accounting for uncertainty and variability on all levels

**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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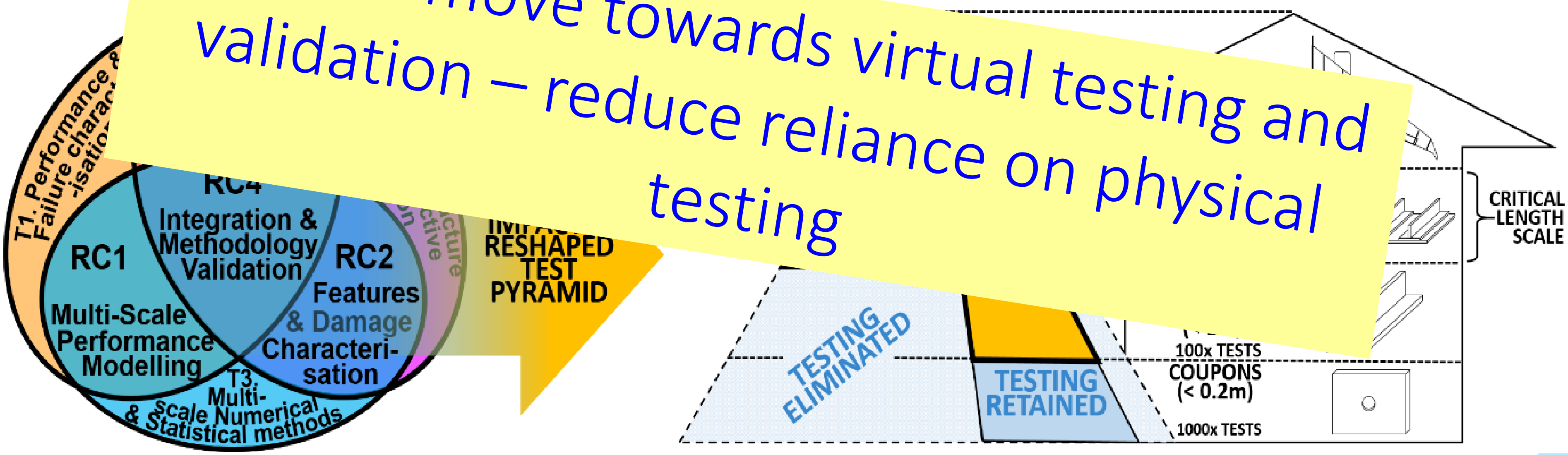
**Decisive move towards virtual testing and validation – reduce reliance on physical testing**

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# Overview of research challenges and methodology

RC1
Multi-scale Performance Modelling

RC2
Features and Damage Characterisation

RC3
Data-rich High Fidelity Structural Characterisation

RC4
Integration and Methodology Validation

- RC1 – lead: Richard Butler (Bath)

  Focus: Multi-scale statistical modelling framework incorporating Bayesian statistics – load response & damage (HPC & surrogate models/GPEs)

- RC2 – lead: Stephen Hallett (Bristol)

  Focus: NDE toolset for damage & intrinsic meso-scale features, as-designed & deviations from design - knowledge base of structurally important features and in-service damage

- RC3 – lead: Janice Barton (Bristol)
  - Focus: Data-rich experimental techniques - evolving stress/strain due to features, defects and damage - high-fidelity data-rich testing - complex loading

- RC4 – lead: Ole Thomsen (Bristol)
  - Focus: Integration of data-rich experimental procedures and statistical and multi-scale models - Bayesian Learning and DoE techniques

# Overview of research challenges and methodology

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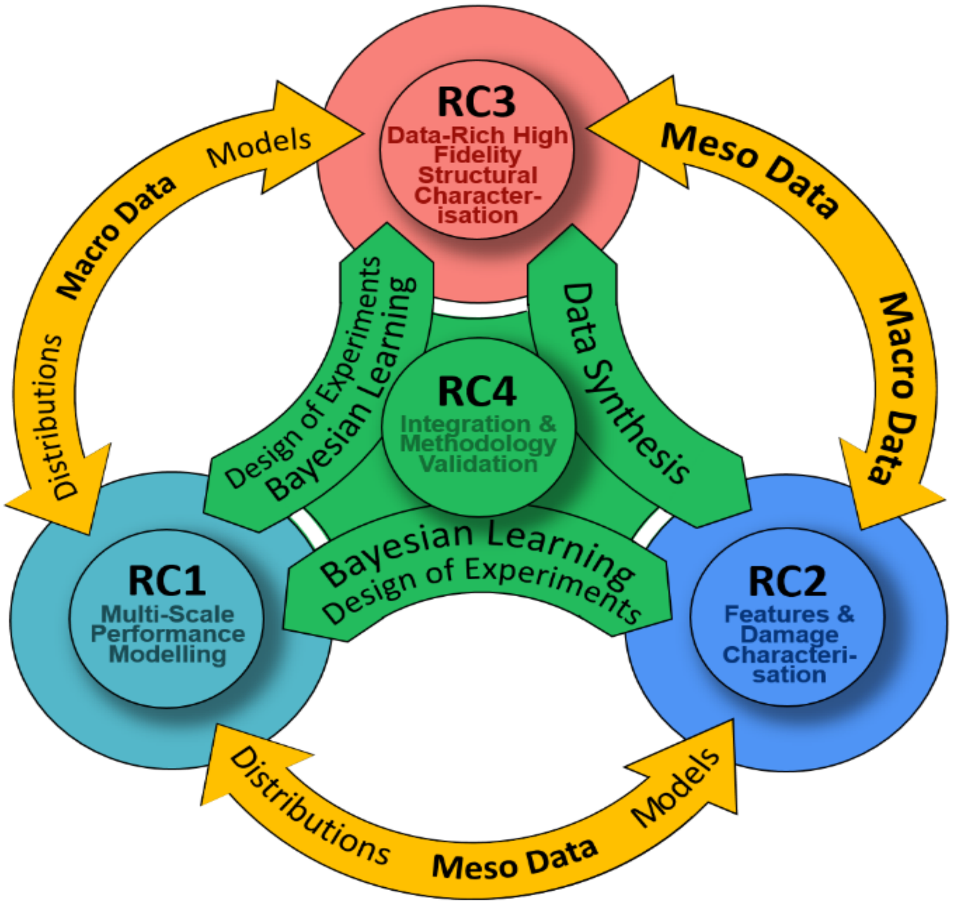


Data-ric
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# *CerTest hypotheses*

- Reliance on physical testing can be reduced by developing the mid-tiers of the testing pyramid
- Mid-tier length scales - characterised by complexity wrt. material composition, geometric features and load states - model benchmarking and validation can be conducted via sufficiently realistic/complex complex sub-structure and component tests
- Merger/fusion of physical test and modelling data is conducted via a Bayesian inference process or looping – leading to model/performance validation (certification)

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# *CerTest hypotheses*

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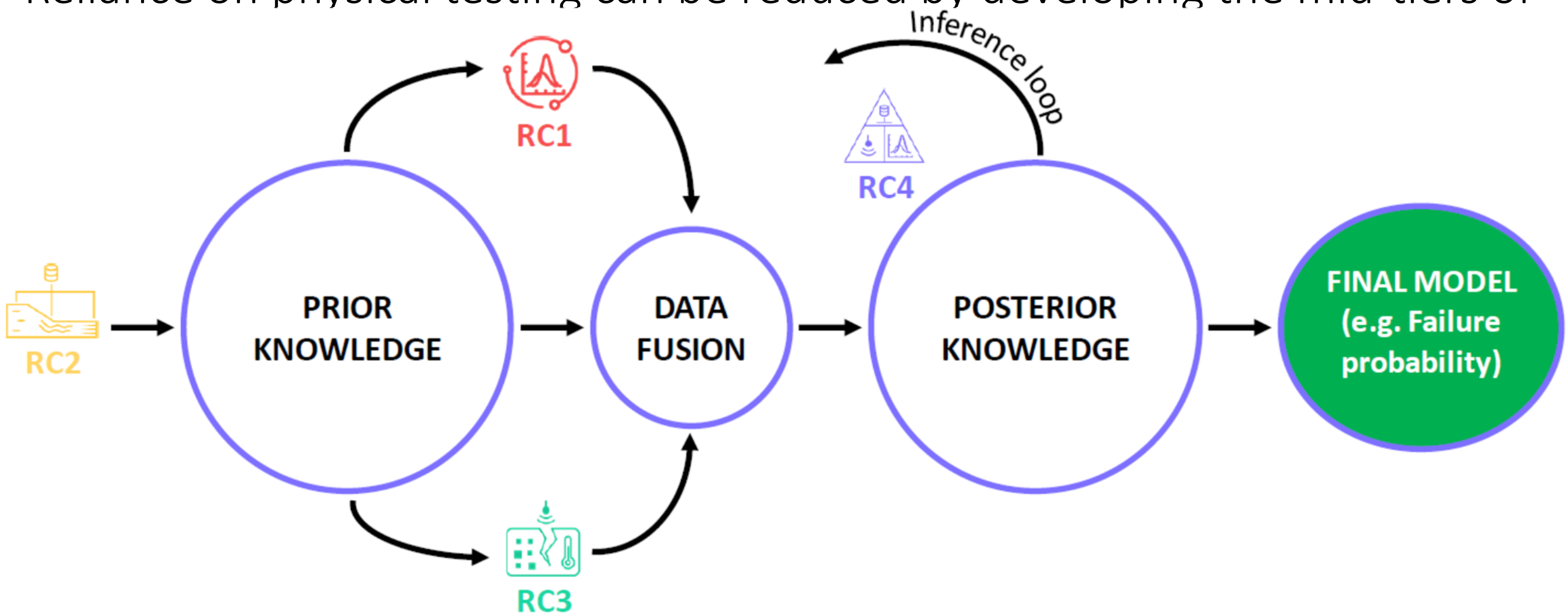


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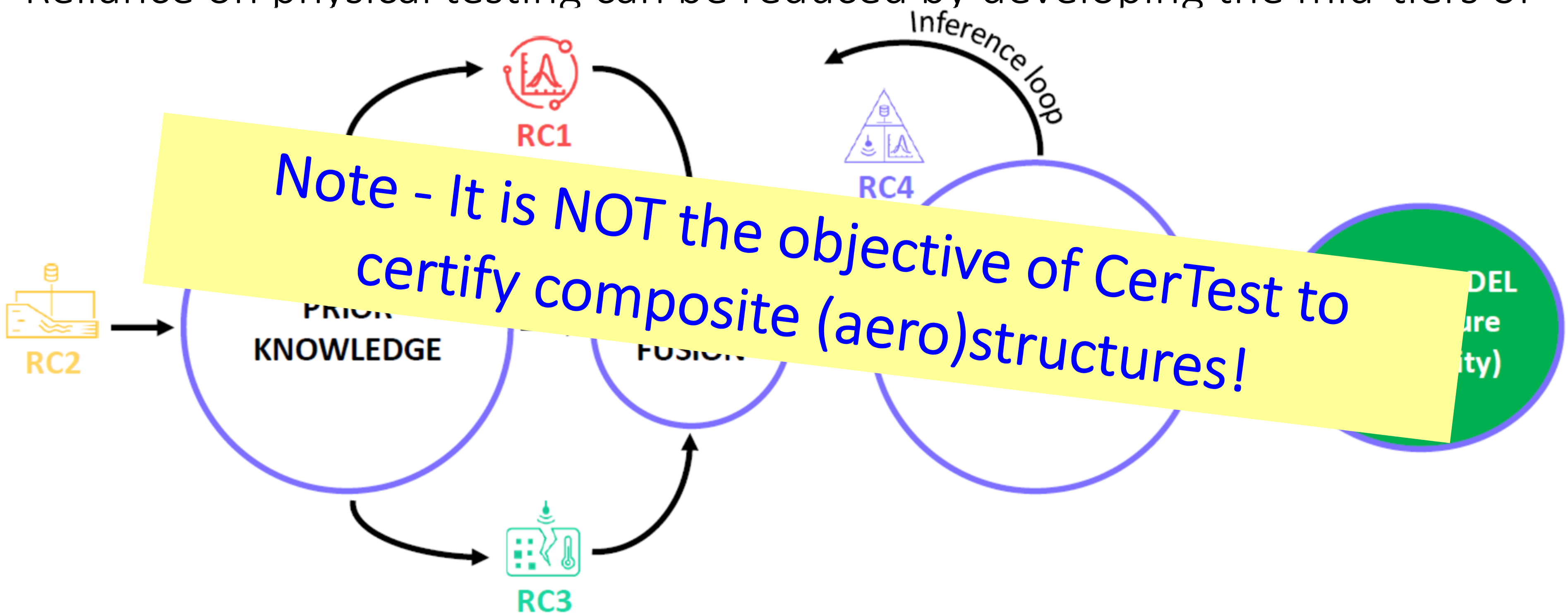


Note - It is NOT the objective of CerTest to certify composite (aero)structures!

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# *CerTest demonstrators*

Purpose:

- Demonstration and validation of the statistical methods - sequential implementation approach
- Implementation of the full Bayesian learning procedure

Initial demonstrators:

- Sufficiently develop/validate the developed scientific methods (RC1-RC4) to enable delivery off the demonstrator cases (CFRP C-spar, MAF specimen)

Composite aero-structure “like” demonstrators:

- Proven difficult to define/select suitable composite aerostructure components/substructures provided by industry partners – confidentiality, IP, ownership to data, …
- Chosen approach: focus on aero-structure “like” demonstrators with seeded defects (wrinkles, delaminations)

# *CerTest demonstrators*

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## RC4 – Integration & Methodology Validation

- Bayesian learning & Design of Experiments (DoE)
- Critical CerTest element to enable Virtual Testing/Validation (Certification)

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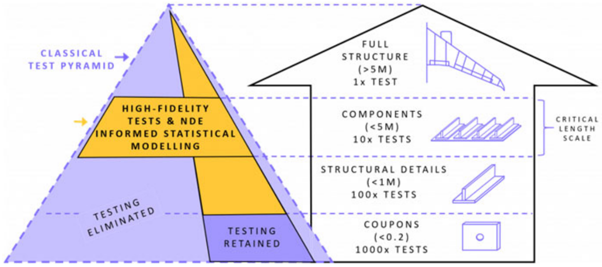
# *Goal: validating new aircraft with minimum effort*


+

Design load envelope




- Which experiments to conduct…
- Which models to run…

*…to demonstrate airworthiness (safety)?*

*…to get the most out of reduced number of tests?*

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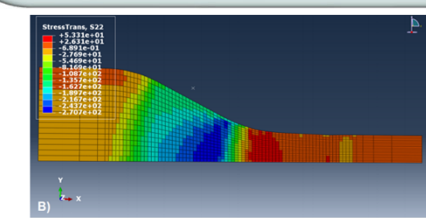
# *Probability = accounting for uncertainty*

## Measurement uncertainty

- Repeated testing
- Is the testing machine/rig well calibrated to measure displacement/load?
- Is the specimen aligned correctly? boundary uncertainty
- **Probability distribution for measurements**

## Model uncertainty

- How good a Mechanics model represent the true physical testing process?
- Can we model failure of a composite part, including meso-scale defects?
- **Can we consider two or more models at once?**




## Parameter uncertainty

- Mechanics models have parameters for which we do not know the right value!
- Material properties can also be uncertain
- **Probability distribution for parameters that reflects engineering knowledge!**

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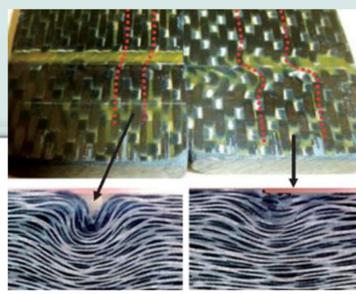
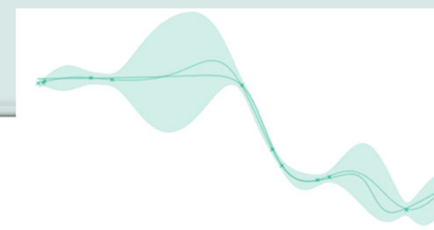
## Manufacturing uncertainty

- Is the manufactured specimen within tolerance? Thickness, etc.
- Are there any relevant defects?
- **Probability distribution for defects shape, location, etc.**



## Computational uncertainty

- FE models are too expensive so we cannot run them at all parameter values!
- **Can we “estimate” quickly what we can compute exactly slowly?**



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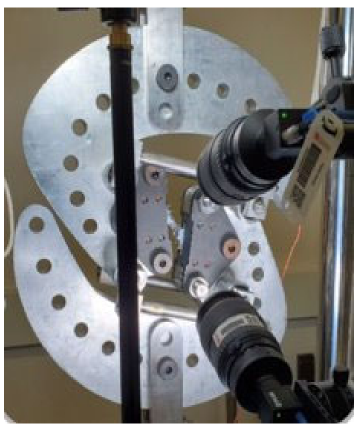
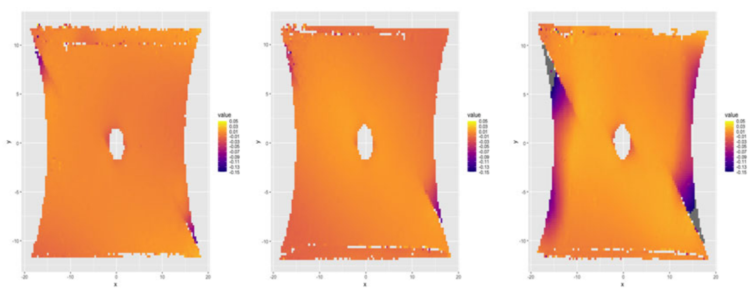
# CerTest – steps towards demonstration of new methodology

- Initial trial/demonstration of Bayesian process and DoE – *ongoing*

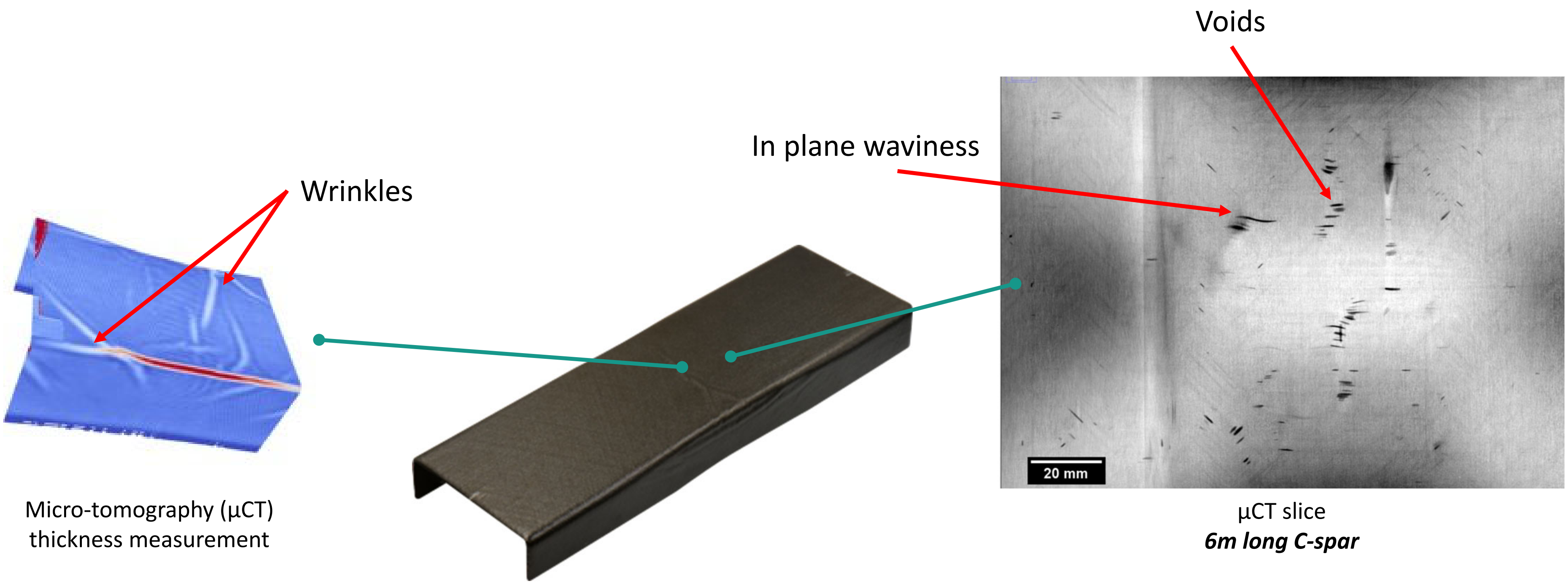
*Initial development of Bayesian DoE process:*

Modified Arcan Fixture (MAF) testing – open hole multidirectional CFRP laminate coupon tests – Question of interest = damage initiation and failure ("strength")





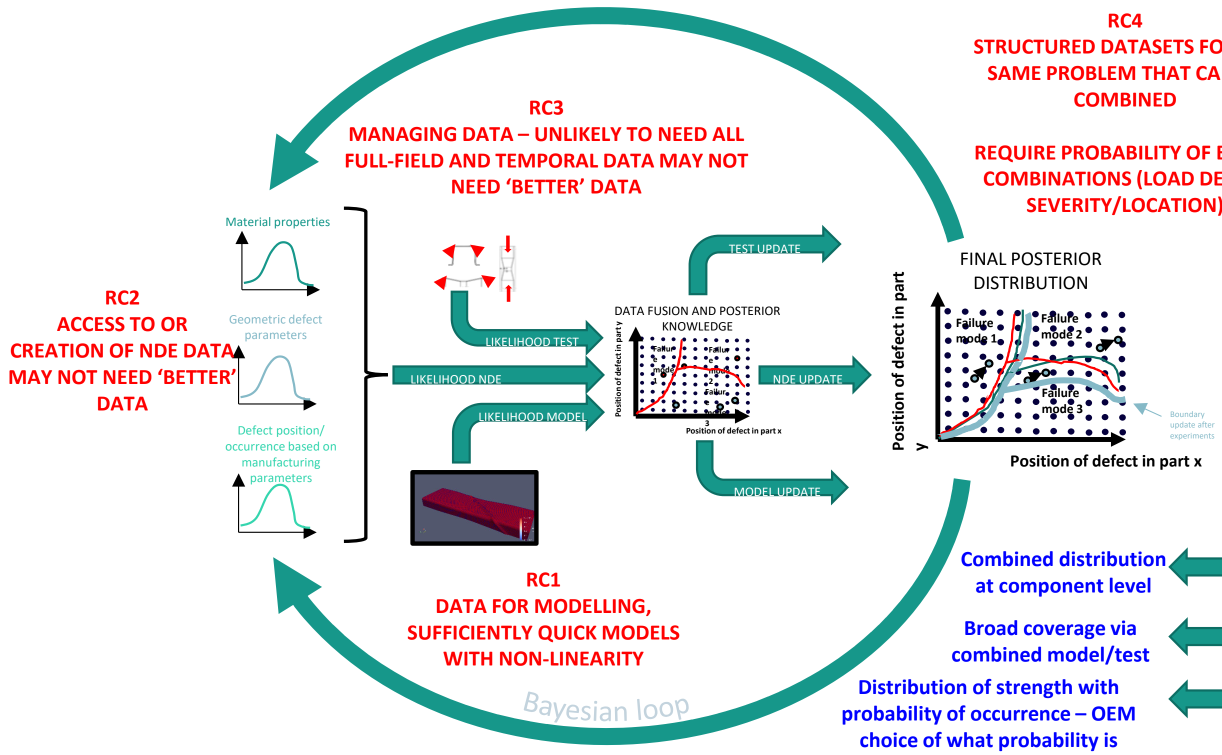
- C-spar with delamination - combined loading – demonstrator: *Full Bayesian loop and DoE process*




Micro-tomography (µCT) thickness measurement

µCT slice
***6m long C-spar***

- C-spar with delamination - combined loading – demonstrator: *Full Bayesian loop and DoE process*

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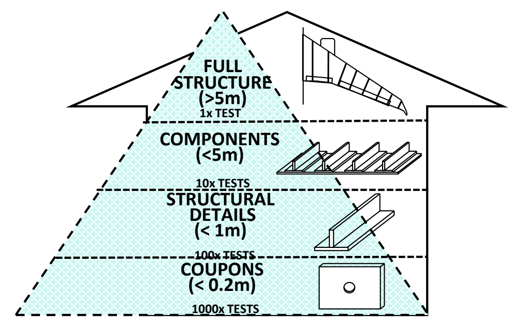


| | | |
|---|---|---|
| Combined distribution at component level | Uncertainty | Built in at material level 'single' value |
| Broad coverage via combined model/test | Failure modes | Single failure mode isolated and confirmed by test |
| Distribution of strength with probability of occurrence – OEM choice of what probability is acceptable which determines strength | Output | Single failure strength proven to meet load levels, required design is conservative. |



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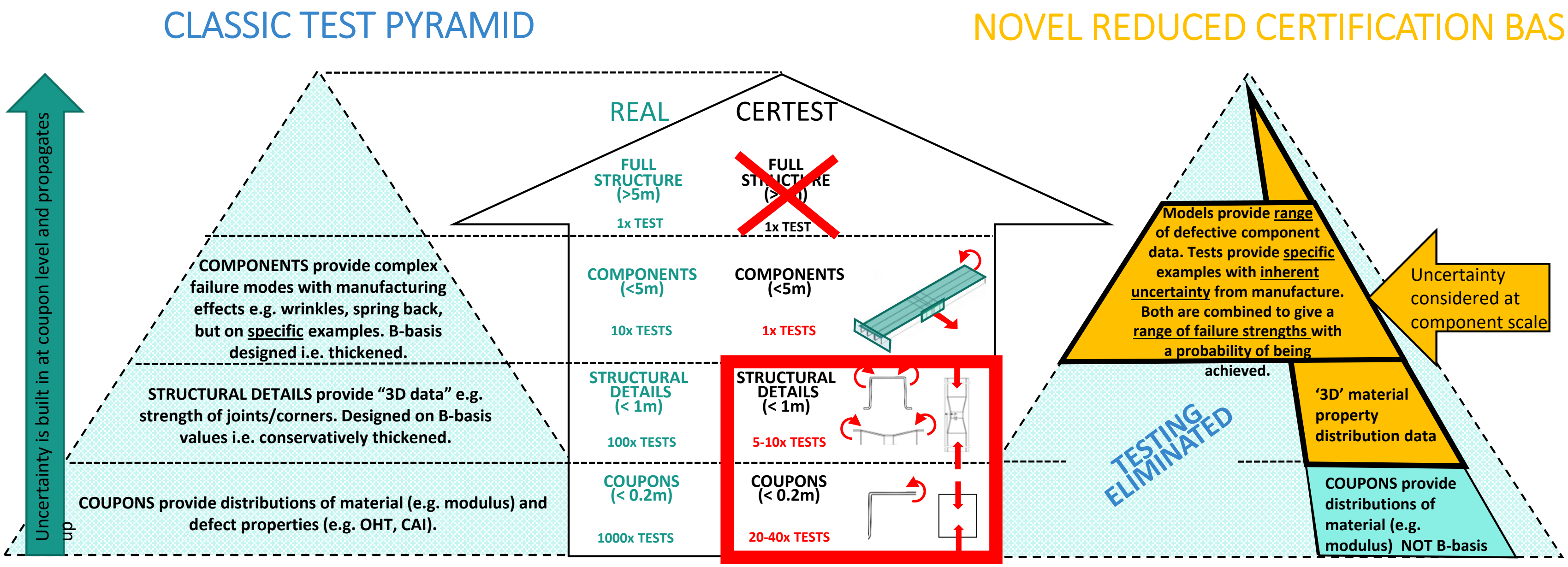
- C-spar with delamination - combined loading – demonstrator: ***Full Bayesian loop and DoE process***
- Larger scale demonstrator – ***"wing-box" like component seeded with manufacturing defects (NCC)***
  - Full Bayesian loop and Doe process will (probably) NOT be conducted (*CerTest 2?)*
  - Focus on RC1 (multi-scale modelling), RC2 (defect/damage), RC3 (high-fidelity structure test, imaging, hybrid test, data fusion)
  - Large scale component/substructure test – LSTL/NIL Southampton

LSTL/National Infrastructure Lab - Southampton

Courtesy: Dr Andrew Rhead

UNIVERSITY OF BATH

# *Competing test pyramids and availability of data - VISION*

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# *CerTest outreach & dissemination*

- Website: [www.composites-certest.com](http://www.composites-certest.com)

  Updates, events, research output/publications, workshops, open positions ...
- ICCM23, 30 July – 4 July 2023, Workshop & panel session on

  ‘Modernising Routes to Compliance with Composites Regulations: A Journey towards Virtual Testing and Digital Twinning’

  Speakers and panellists from academia, industry (aerospace, wind, construction) and regulators (EASA, DNV)
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# *Thank you for your attention. Questions?*

Contact: o.thomsen@bristol.ac.uk

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*Project partners:*

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