ICCM23 workshop on 'Modernising Routes to Compliance with Composite Regulations: A Journey towards Virtual Testing and Digital Twinning'

CerTest: enhanced performance and productivity through integration of multi-scale modelling, high-fidelity experimentation and Bayesian learning

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(Not a statistician!!)

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Engineering and Physical Sciences Research Council

1.Challenge

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

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Contents

1. Framework overview
2. C-spar demonstrator
3. CerTest methodology

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2.Process overview

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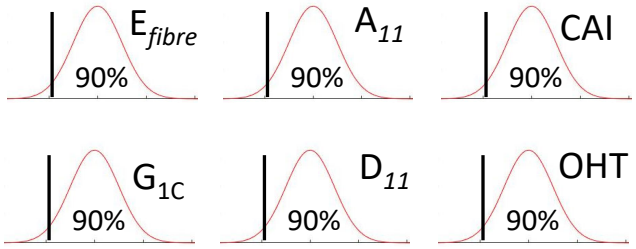
Coupons

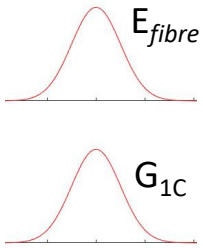
Material | Laminate | Laminate with feature

Current:



CerTest:

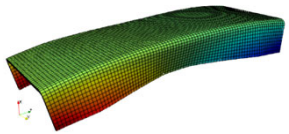
Material



Model/design

Models with no defect and fixed properties

B-basis allowables – single value

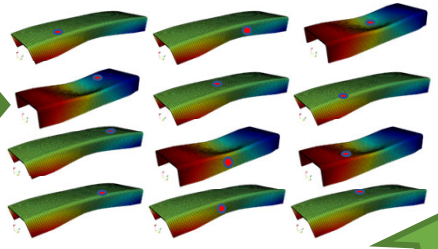


Limited design space

Validation of conservative design

Rapid models with defects and uncertain properties

Full distributions



Wide design space

Test

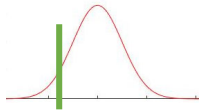
Test pyramid

Single value
Limit load
pass/fail

Most informative test

Reduced Test pyramid

Learning about material & physics



Sufficiently probable strengths
>
limit load

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1. Overview

2. C-spar example description

3. CerTest methodology

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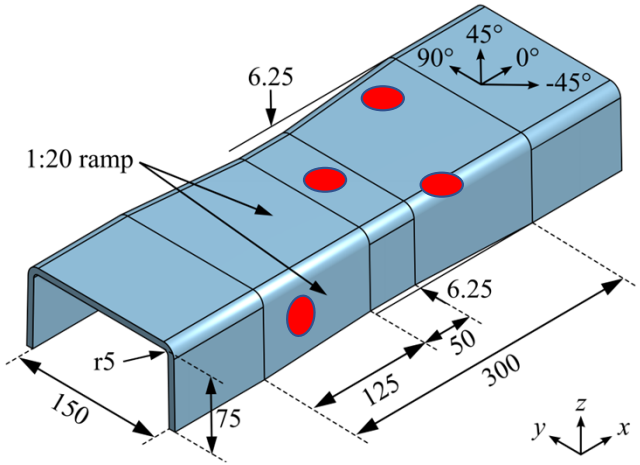
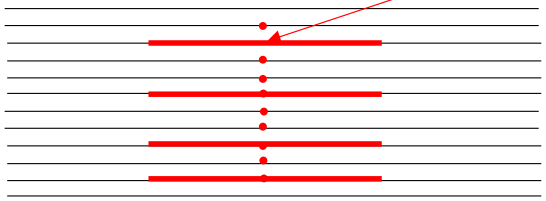
3. C-spar and controlled parameters

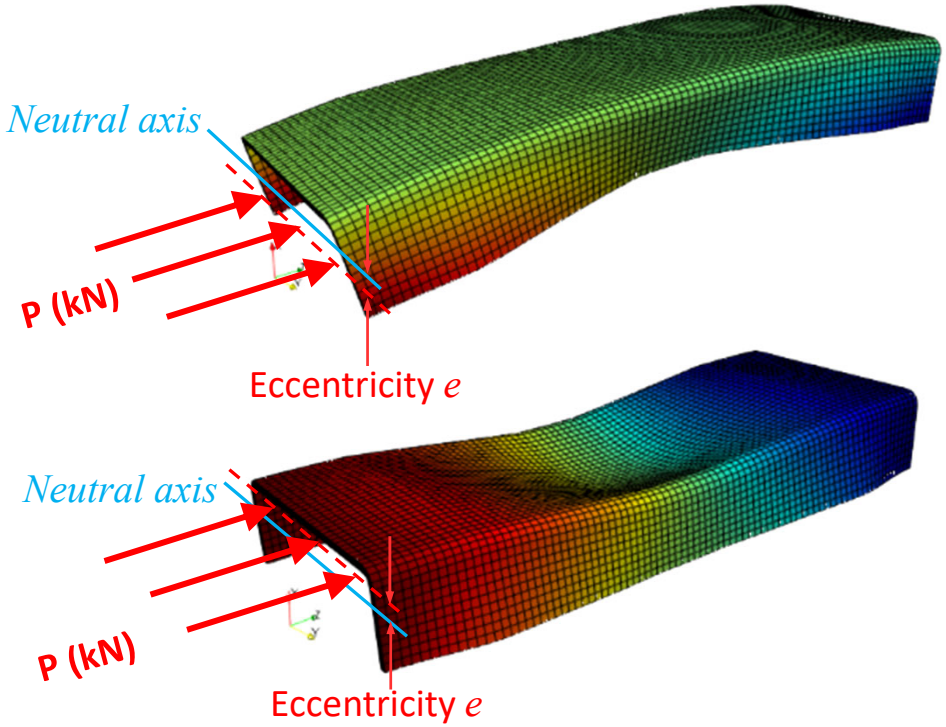
Artificial delamination position (d): "Defect"



Single artificial delamination

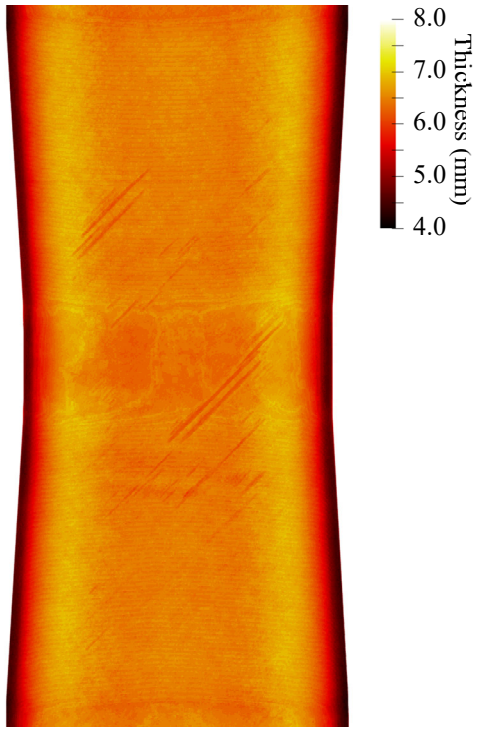


Eccentric loading (e): "Load cases"

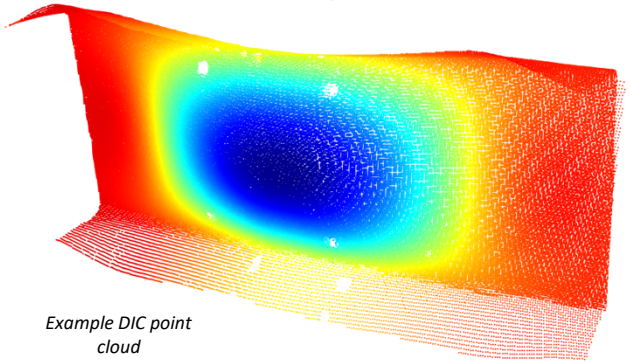


4. C-spar demonstrator - data

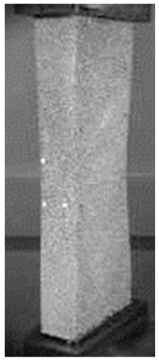
NDE: X-ray CT, CMM, Ultrasound, eddy current



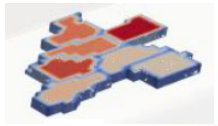
Physical test: DIC

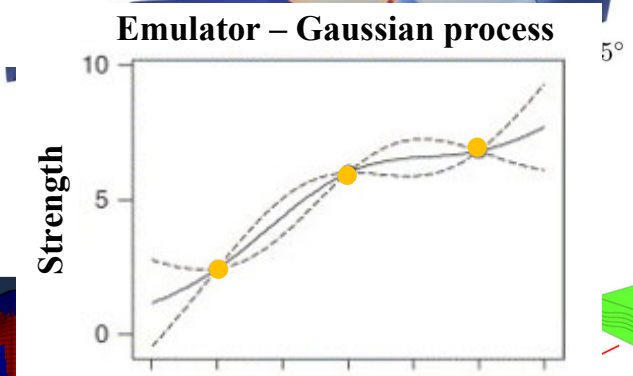


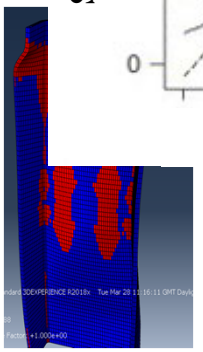
Example DIC point cloud

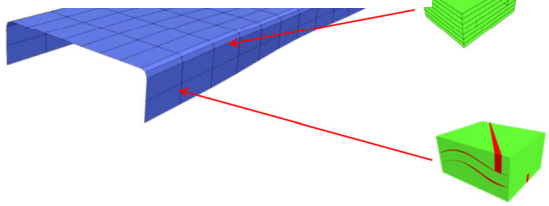


Simulation: DUNE and ABAQUS (FE^2)









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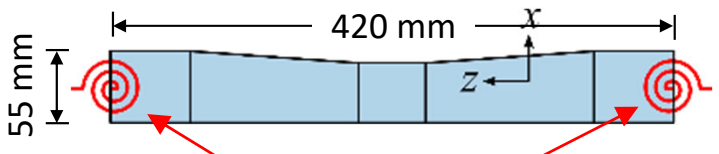
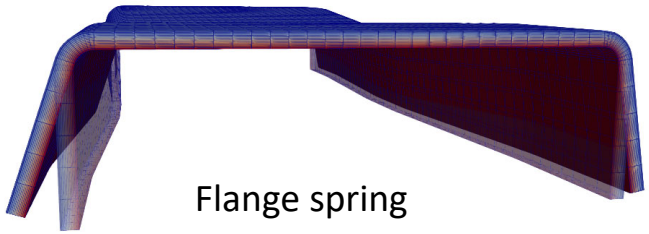
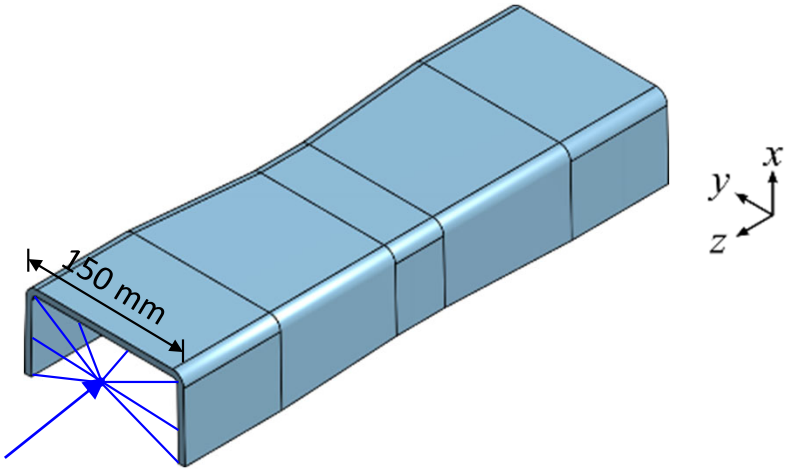
5. Parameter uncertainty - BCs



Torsional springs with stiffness, K, control BC strength

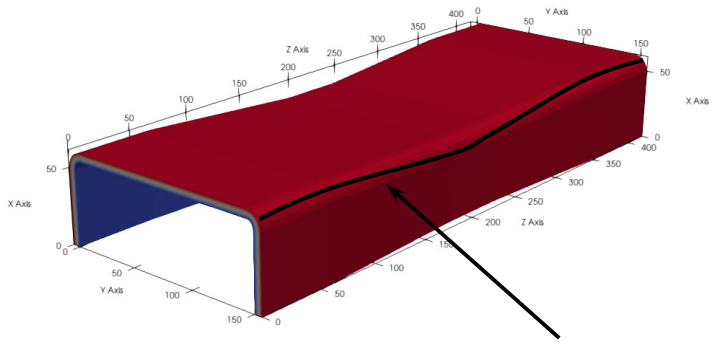


Flange spring



Ends constrained to reference points with beam MPCs

$u_1 = u_2$
$= R_1 = R_3 = 0$



Fibre path owing to conformation with geometry e.g. not straight.

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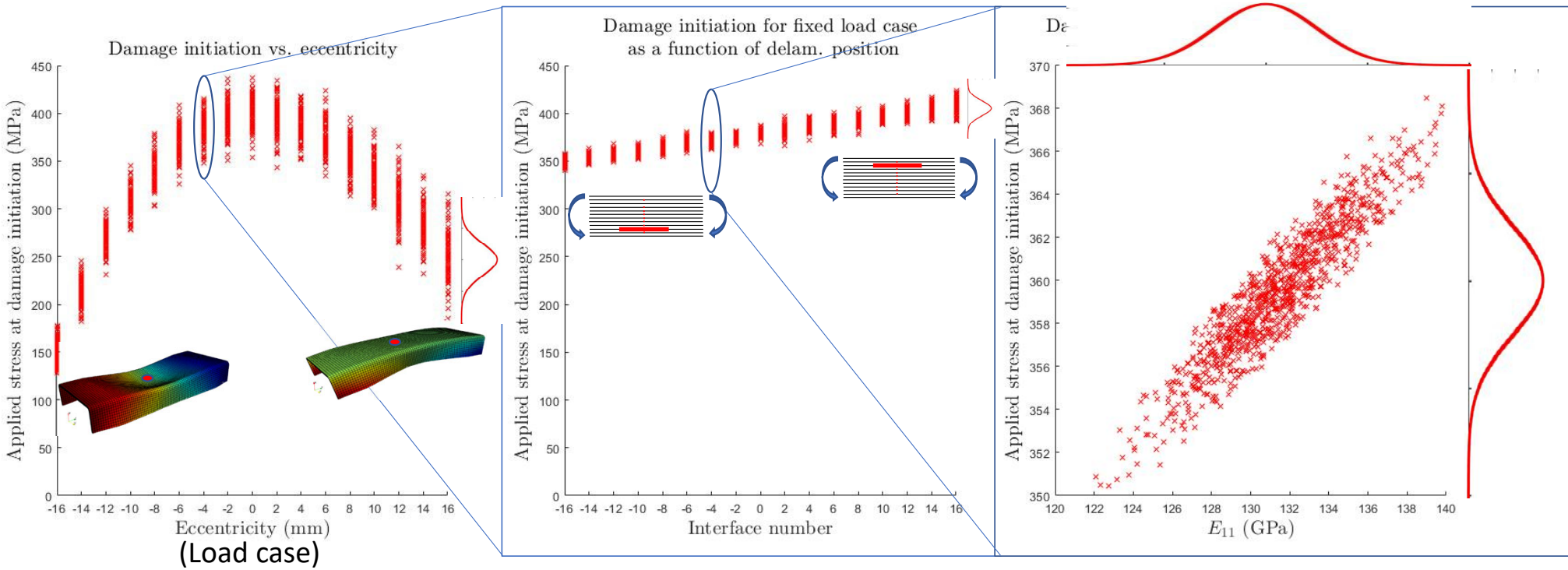
6. Parameter uncertainty - material



(Load case)

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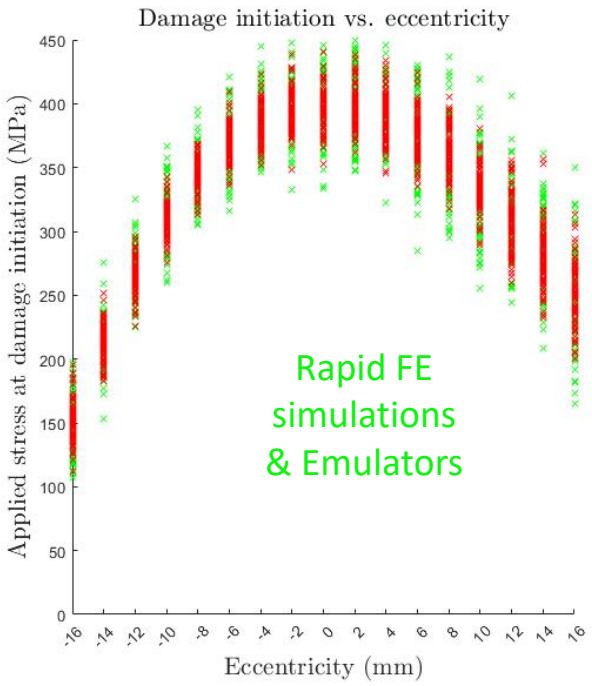
7. Discrepancy model

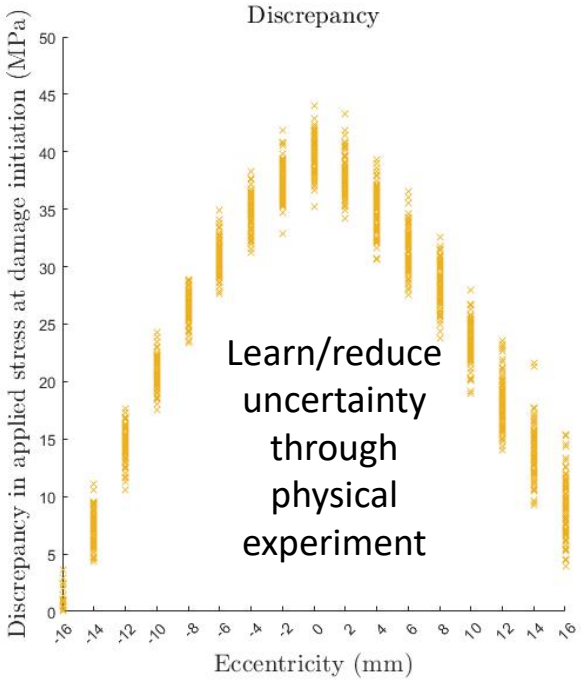
Experiment | Numerical simulation output | Discrepancy | Measurement error

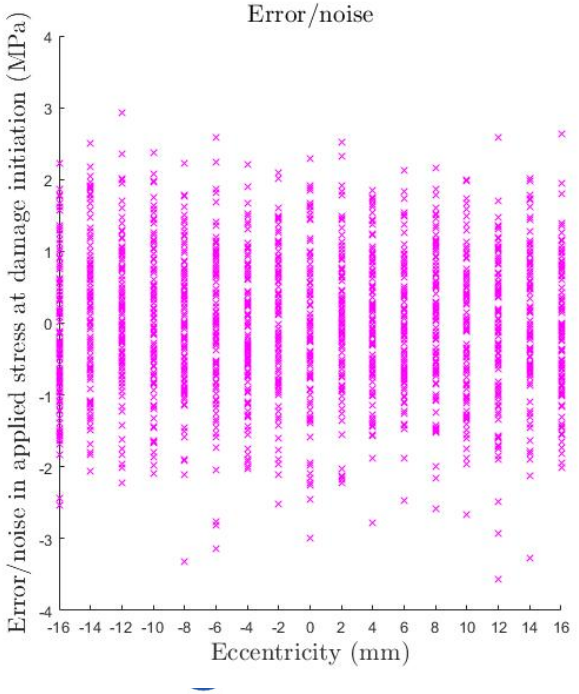
$$y(x_i, \theta^*) = \eta(x_i, \theta^*) + \delta(x_i, \theta^*) + \varepsilon_i$$

Controllable (delamination position and eccentricity)

Uncertain (e.g. modulus, boundary conditions)







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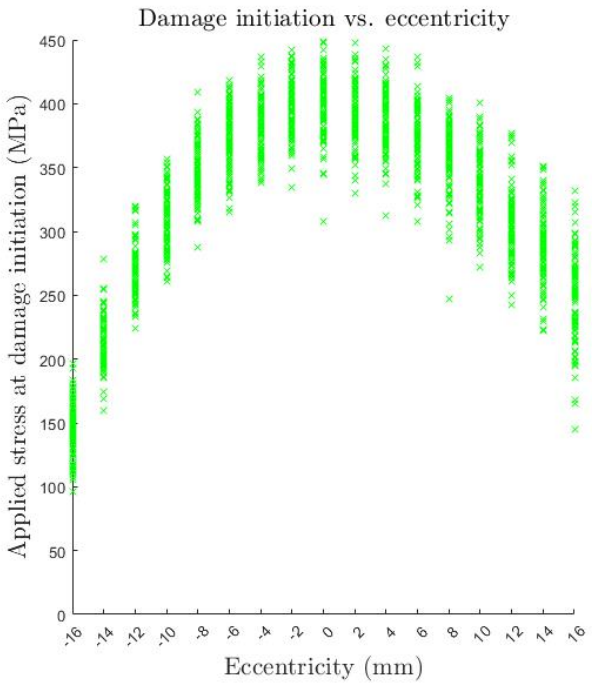
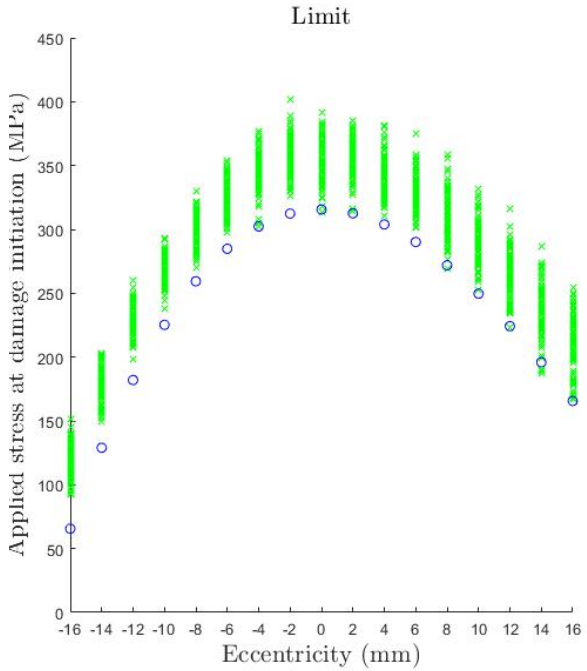
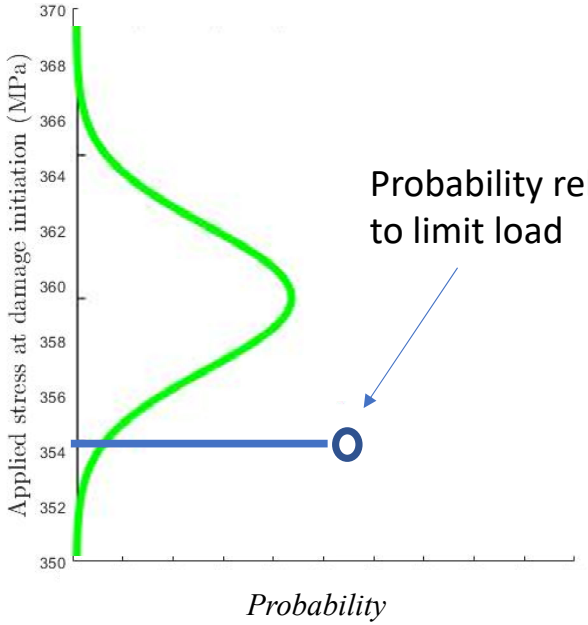
8. Limit load







Probability relevant to limit load

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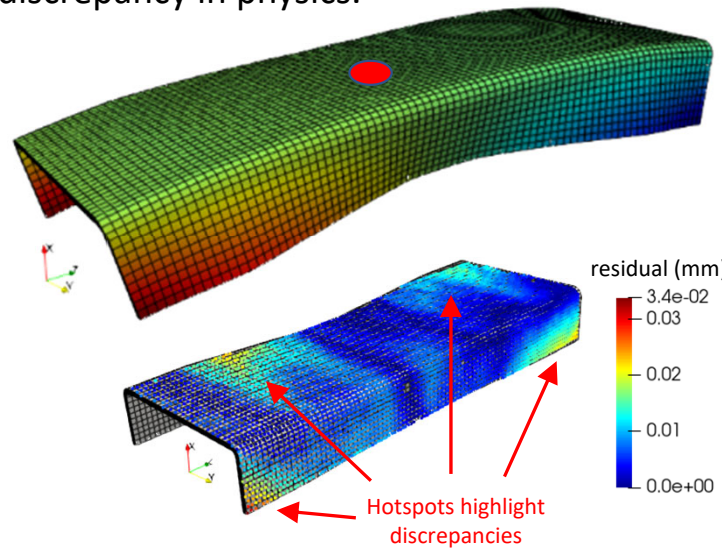
9. Calibration (learning)

Single physical experiment

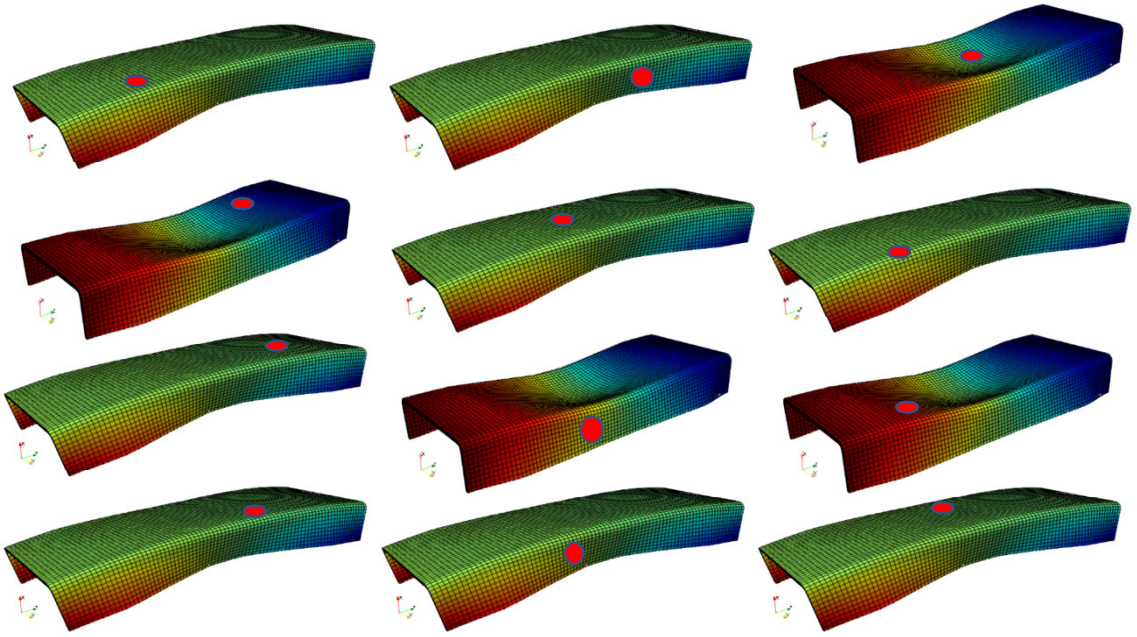
Learn about (via comparison of DIC and simulations), and then employ, property/BC values for the specific part instance to uncover discrepancy in physics.



Residuals of DIC compared with average calibrated model

'All' C-spars with defect under all load cases

Choose tests to learn about and minimise discrepancy in physics as behaviour varies at the part scale.



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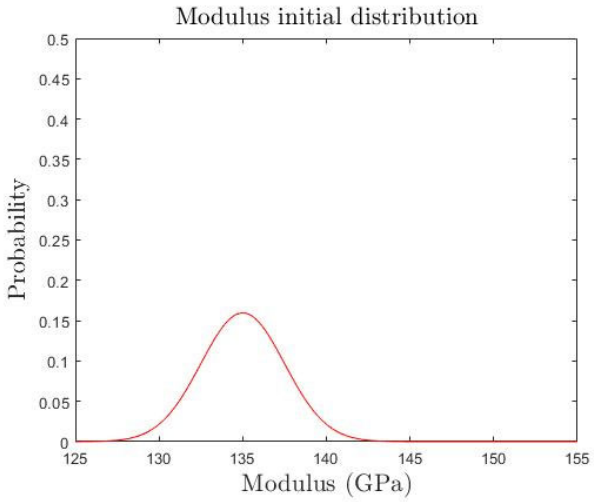
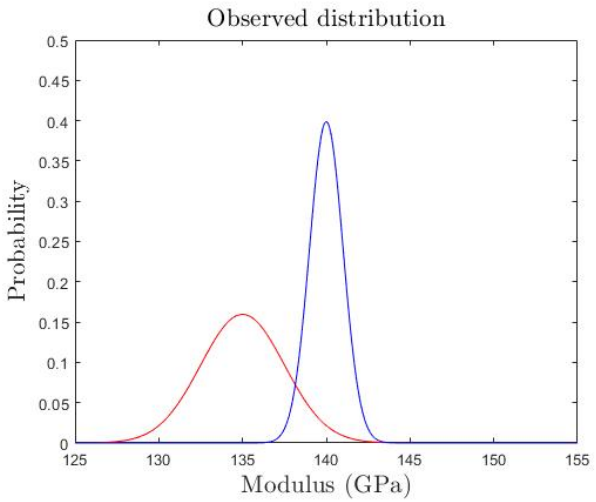
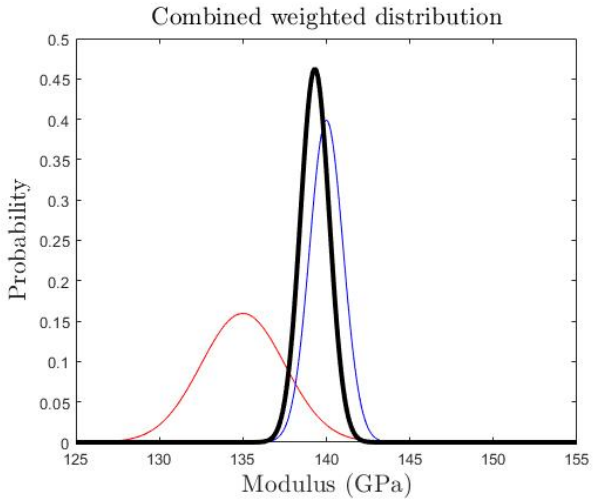
10. Bayesian calibration







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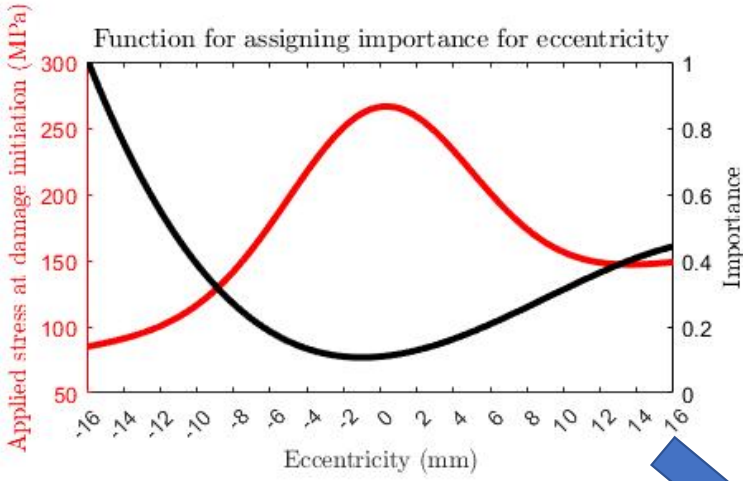
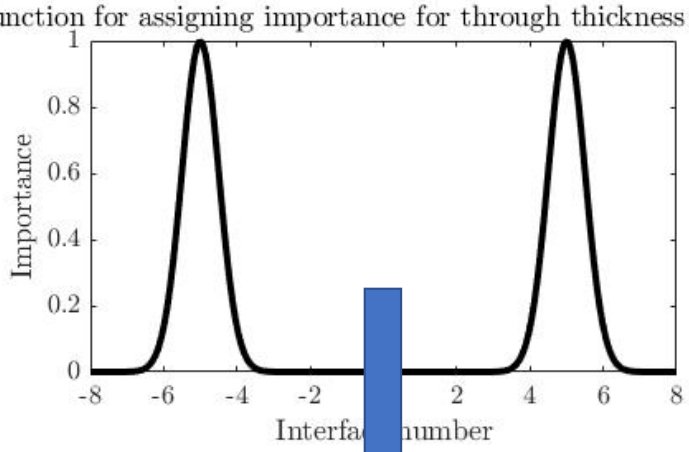
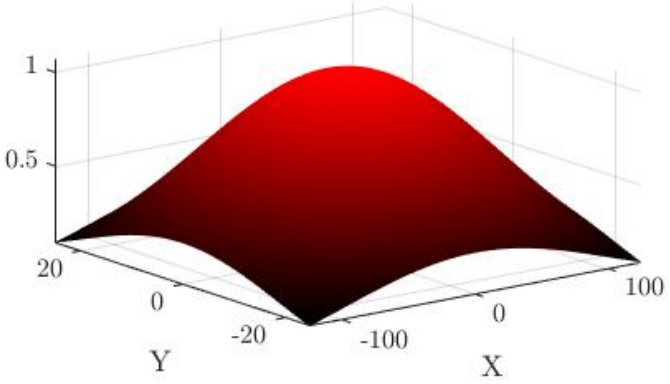
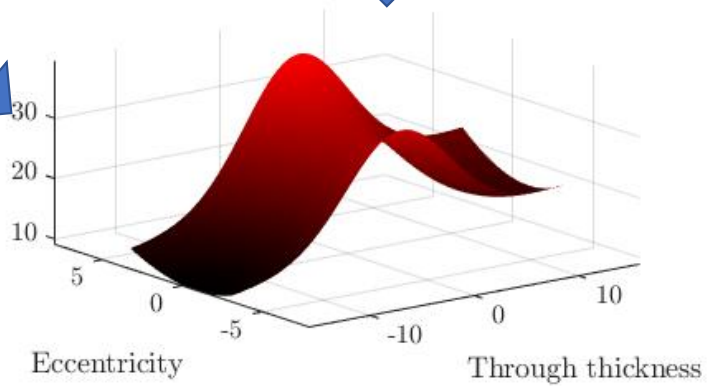
11. Design of experiments & Importance









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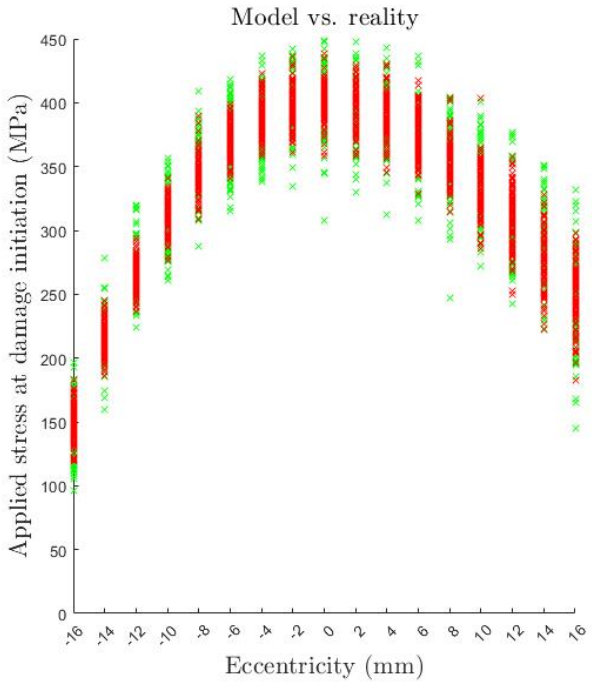
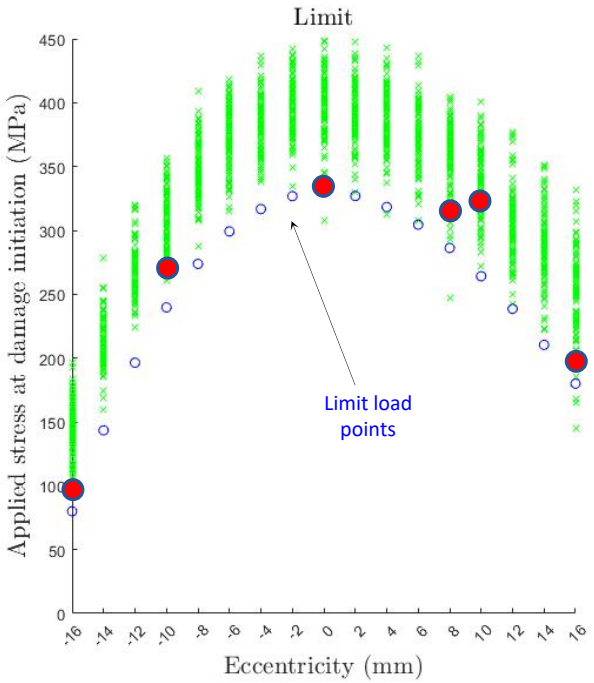
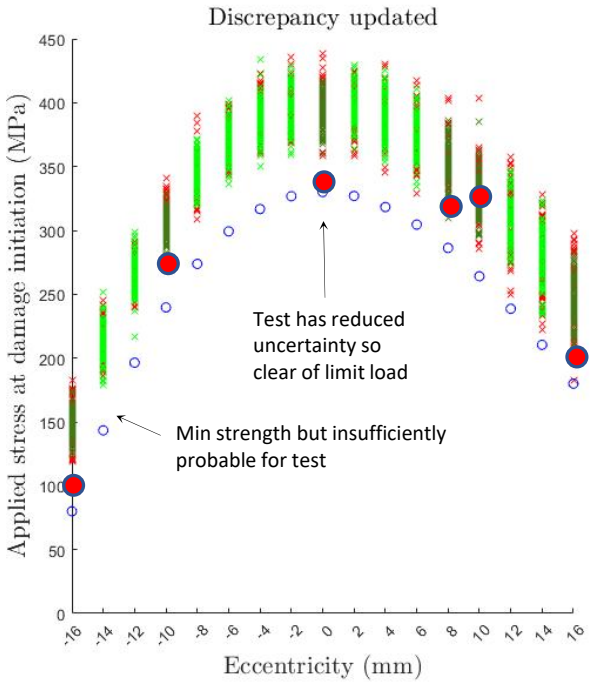
12. Design of experiments & Bayes Update







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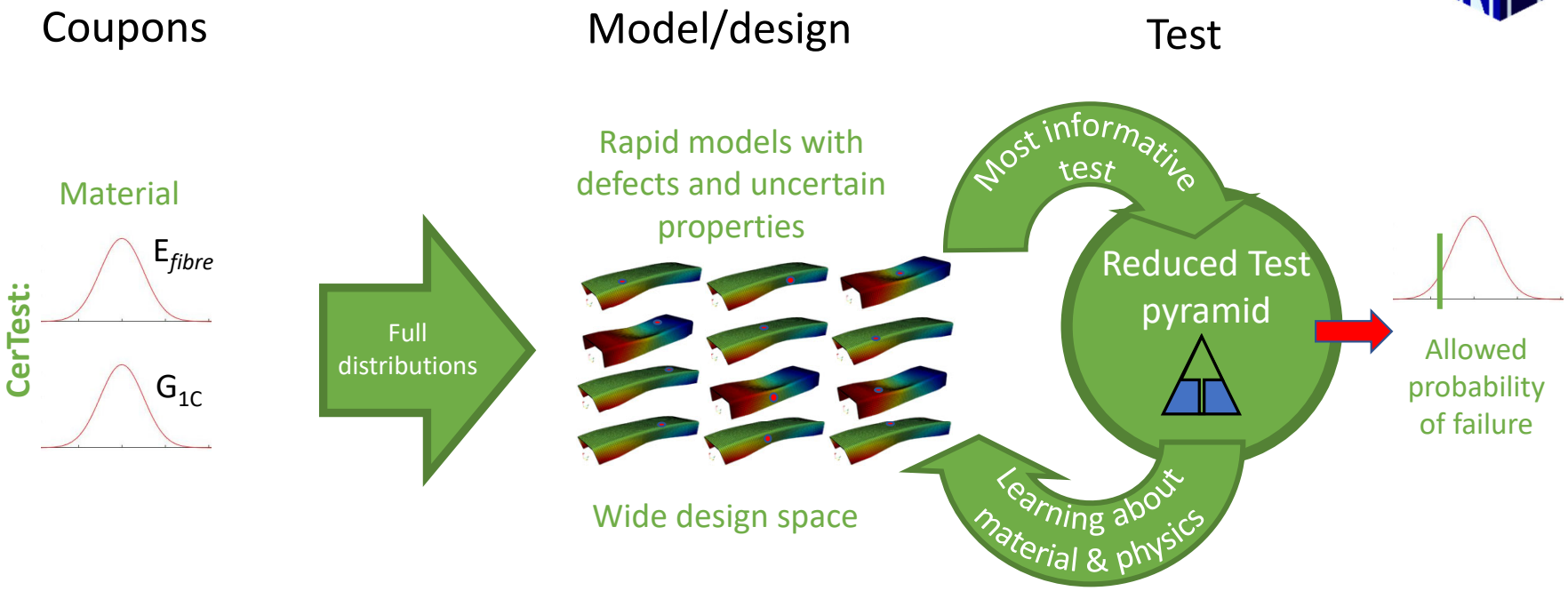
13. Conclusions & future work



Potential to: (a) consider material variability at scale e.g. defects and fibre steering
(b) Understand the impact of process variability on strength – rapid uptake of new materials

14. CerTest Team

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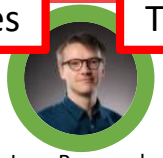
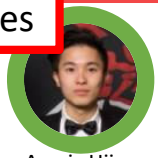
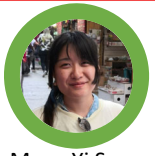
RC1 Multiscale Performance Modelling	 **Richard Butler** R.Butler @bath.ac.uk	 Robert Scheichl R.Scheichl @bath.ac.uk	 Bassam Elsaied bassam.elsaid @bristol.ac.uk	 Tim Dodwell T.Dodwell @exeter.ac.uk	Tues  Jean Benezech Jb3285 @bath.ac.uk	Tues  Aewis Hii aewis.hii @bristol.ac.uk	 Meng Yi Song mengyi.song @bristol.ac.uk	 Georges Cucu Gc16397 @bristol.ac.uk	 Fen Huang fen.huang@ bristol.ac.uk	 Athira Anil Kumar Ss22491@ bristol.ac.uk
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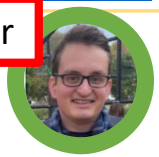
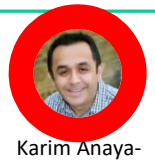
RC3 Data Rich High Fidelity Structural Characterisation	 **Janice Barton** Janice.barton @bristol.ac.uk					Thur  Geir Olafsson geir.Olafsson @bristol.ac.uk	 Tobias Laux tobi.laux@bri stol.ac.uk	 Riccardo Cappello riccardo.Cappello @bristol.ac.uk	 Rafael Ruiz Iglesias rafael.ruiziglesias @bristol.ac.uk	 Emily Leung emily.leung @bristol.ac.uk	 Cynthia Bullock roy.bullock@ bristol.ac.uk
RC4 Integration and Methodology Validation	 **Ole Thomsen** O.Thomsen @bristol.ac.uk	 Andrew Rhead a.t.rhead @bath.ac.uk	 Karim Anaya-Izquierdo k.anaya-izquierdo @bath.ac.uk	 Dave Woods D.Woods @soton.ac.uk		Wed  Carl Scarth C.Scarth @bath.ac.uk	 Sinan Xiao Sx450 @bath.ac.uk		 Thomas Maierhofer Tam48 @bath.ac.uk		