STRUCTURES

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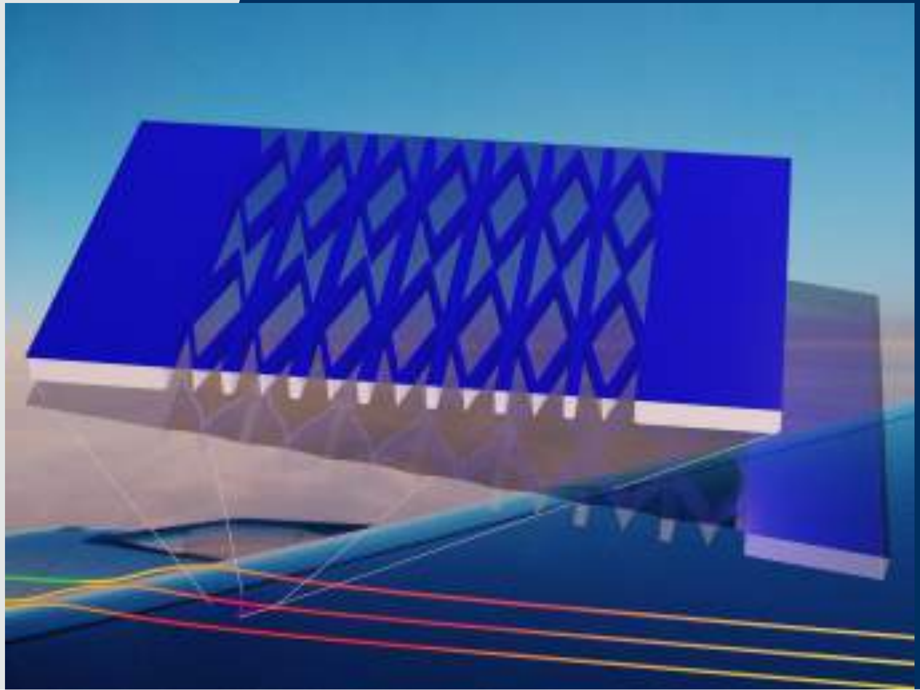
ADVANCED COMPOSITES COLLABORATION FOR INNOVATION & SCIENCE

GATOR Morphing aircraft skins

Rafael Heeb, Michael Dicker, Fabrizio Scarpa, Ben K. S. Woods



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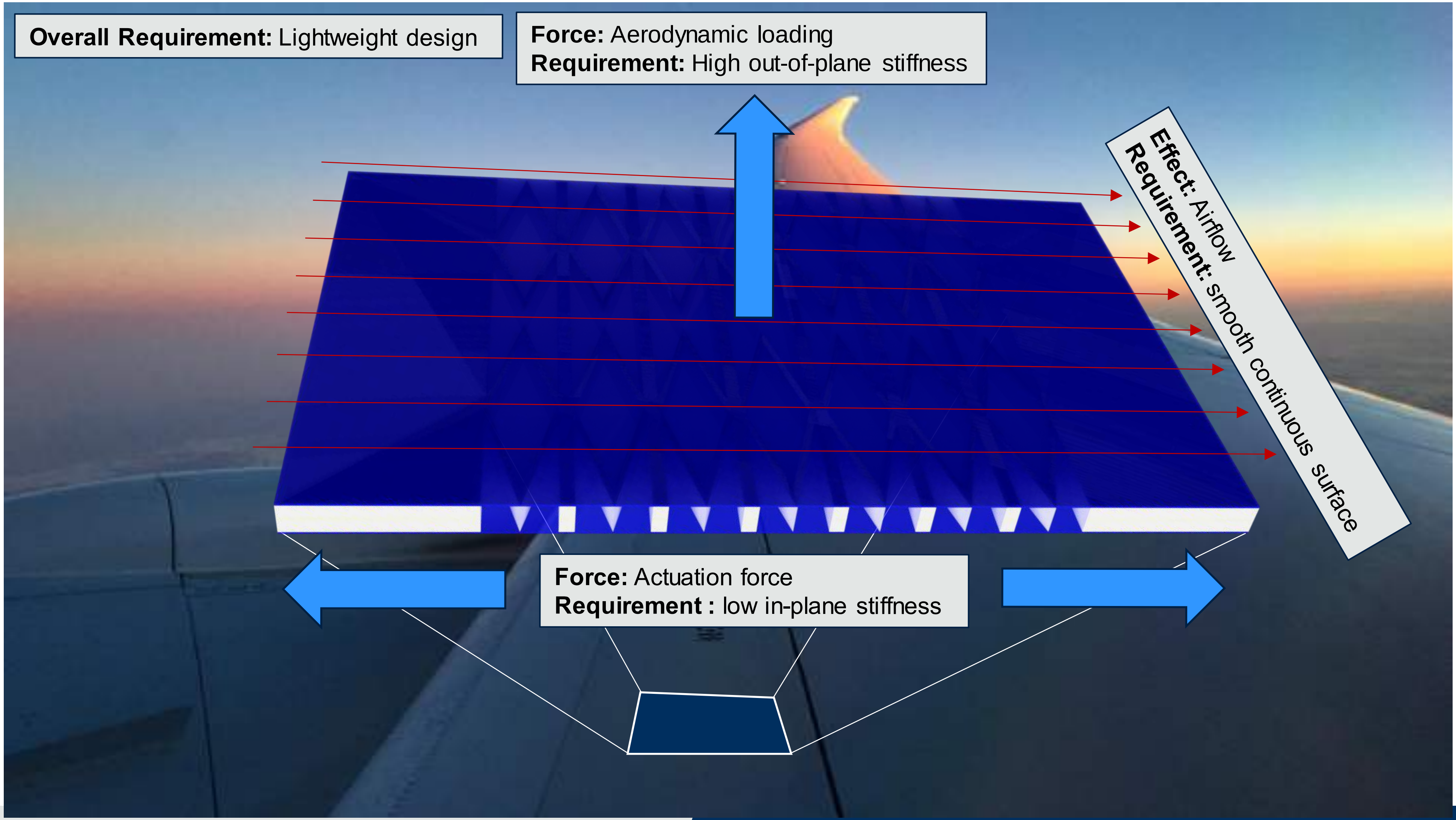
Skin requirements



Overall Requirement: Lightweight design

Force: Aerodynamic loading
Requirement: High out-of-plane stiffness

Effect: Airflow
Requirement: smooth continuous surface

Force: Actuation force
Requirement : low in-plane stiffness

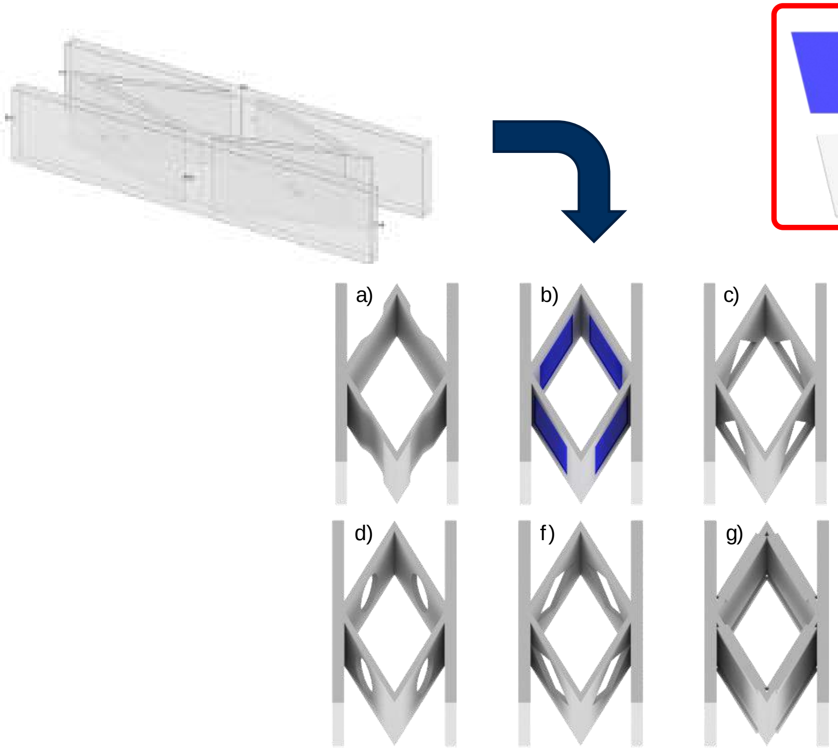
GATOR morphing aircraft skins

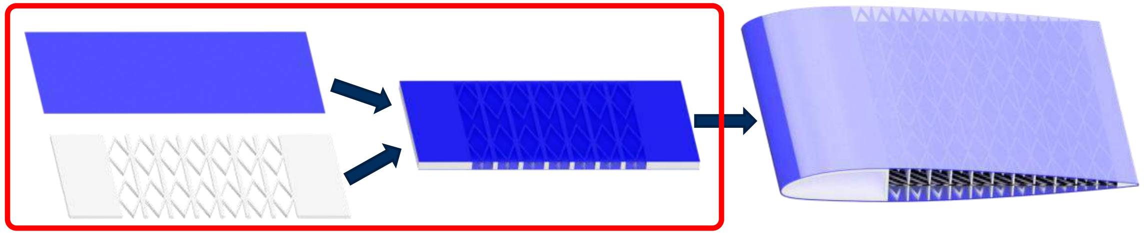
Geometrically **A**nisotropic **T**herm**O**plastic **R**ubber morphing skin design principles

Thermoplastic Elastomers

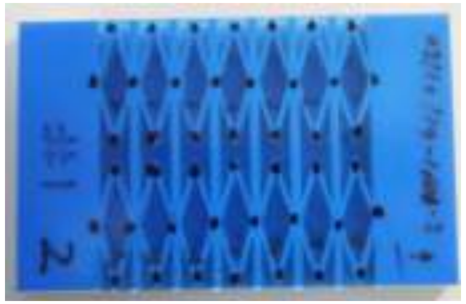
Multi-Material 3D Printing

Exploiting Geometric and Structural Scaling Laws

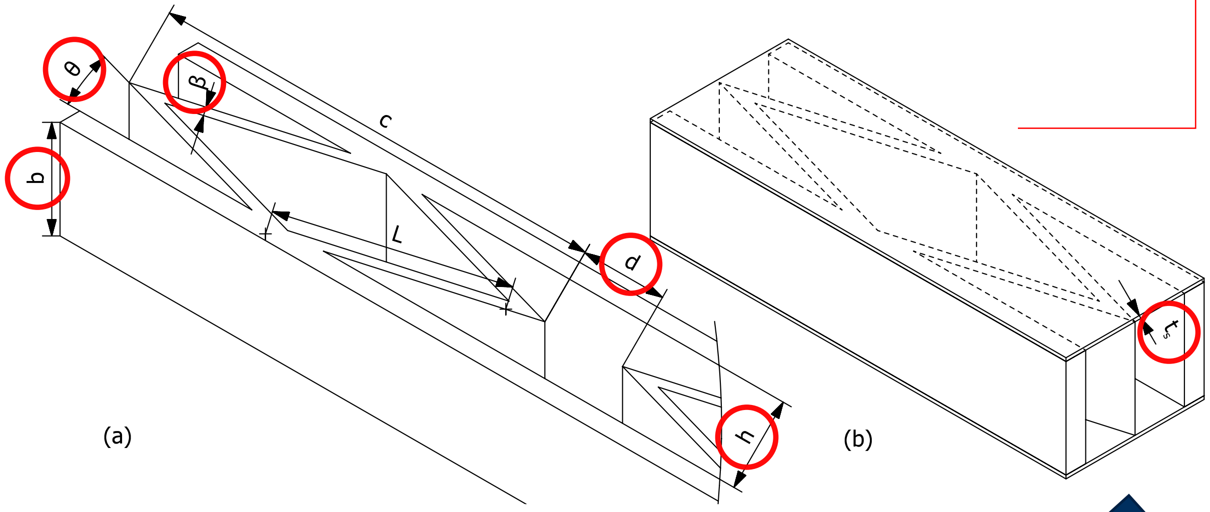




Proof of concept



Modelling of GATOR skins

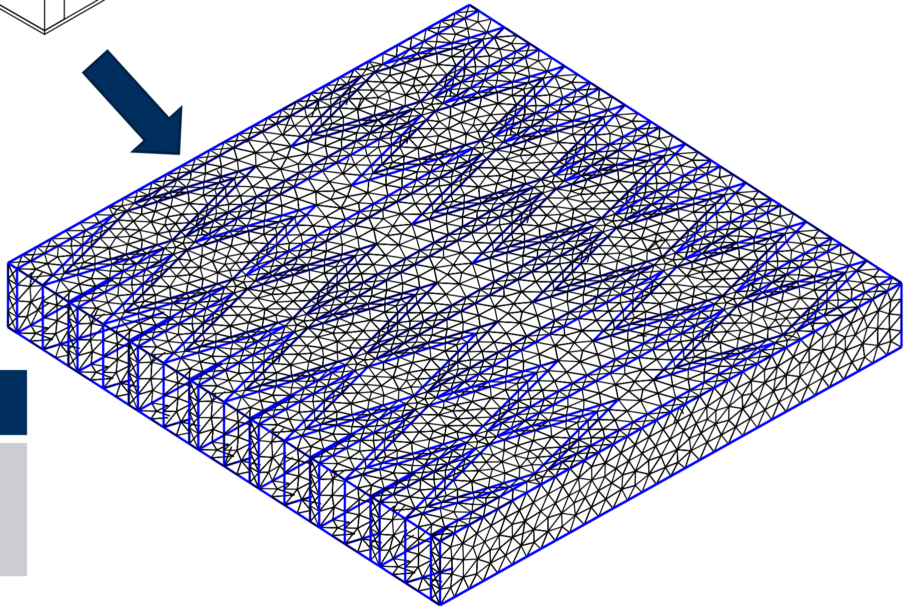


MATLAB Input variables and model setup parameters

GMSH to generate 2D and 3D shape and mesh

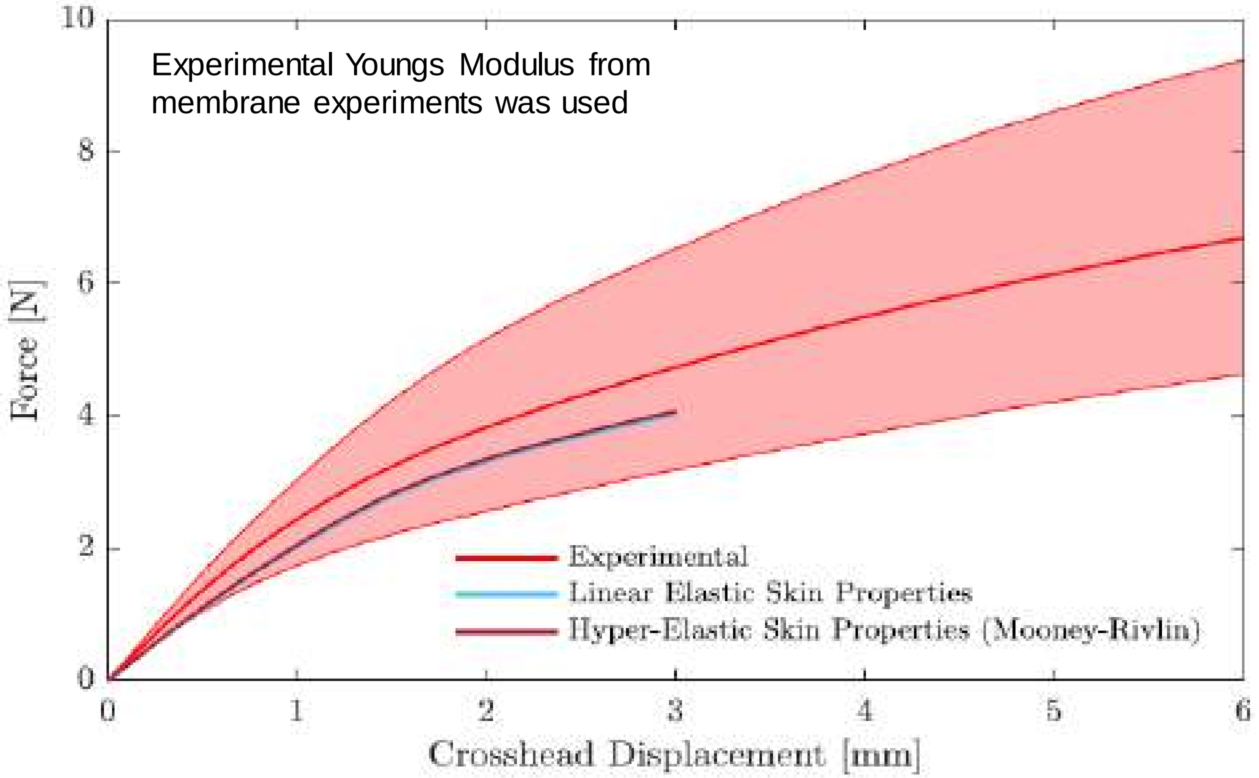
ABAQUS to solve FEA model

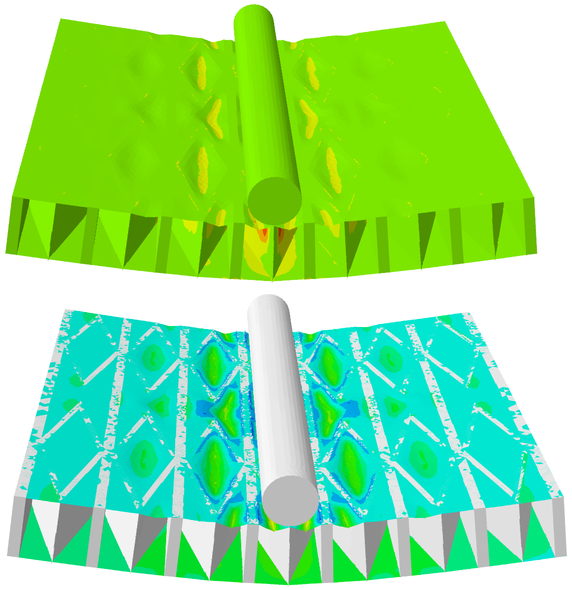
MATLAB to post-process data

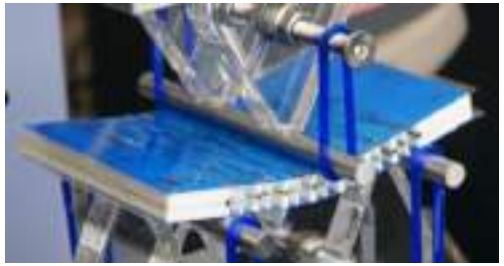


	3D Elements	2D Elements
Type	2^{nd} order 10 noded Tetrahedron	1^{st} order Triangular shell element

Model validation: Out-of-plane response


Experimental Youngs Modulus from membrane experiments was used





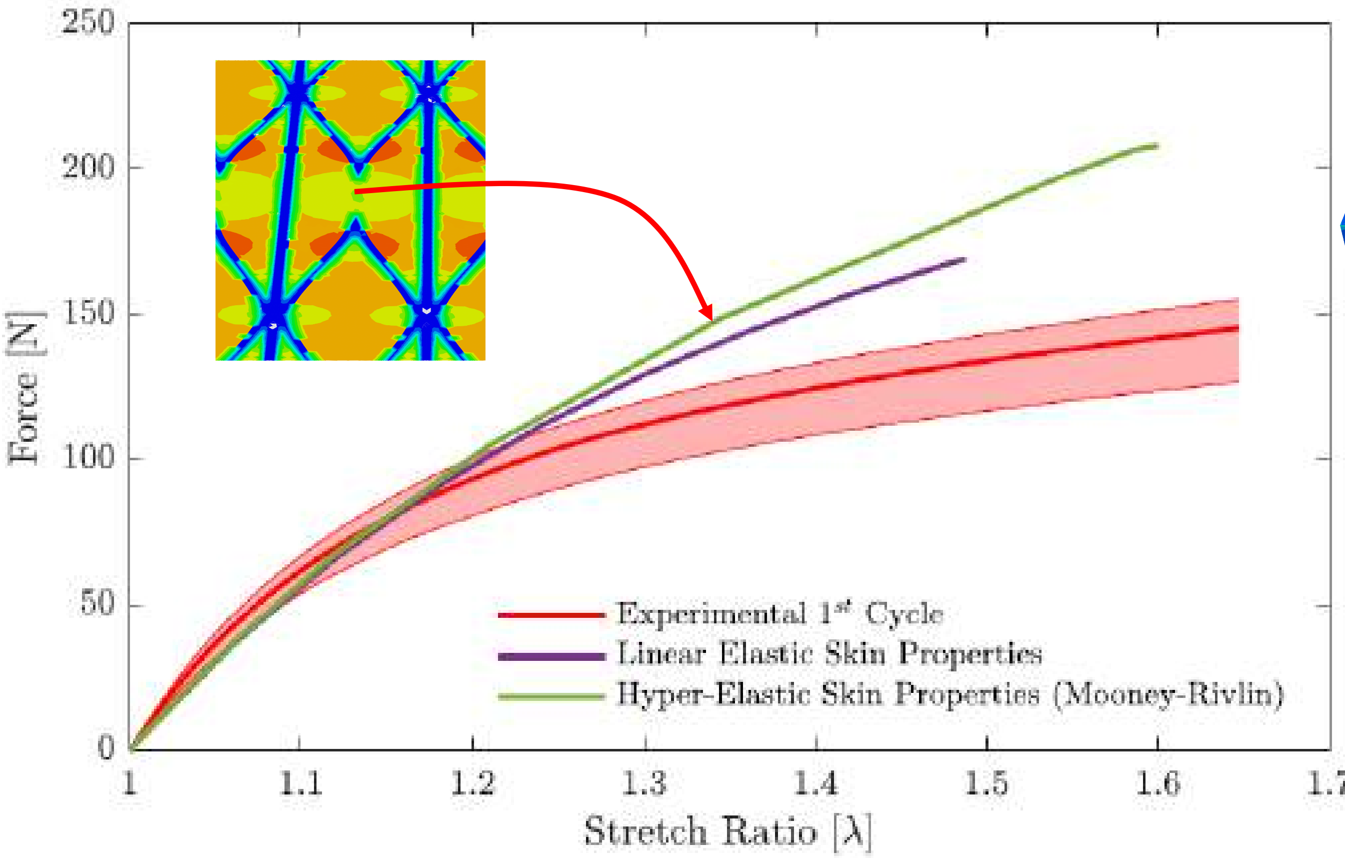
Mooney-Rivlin constants

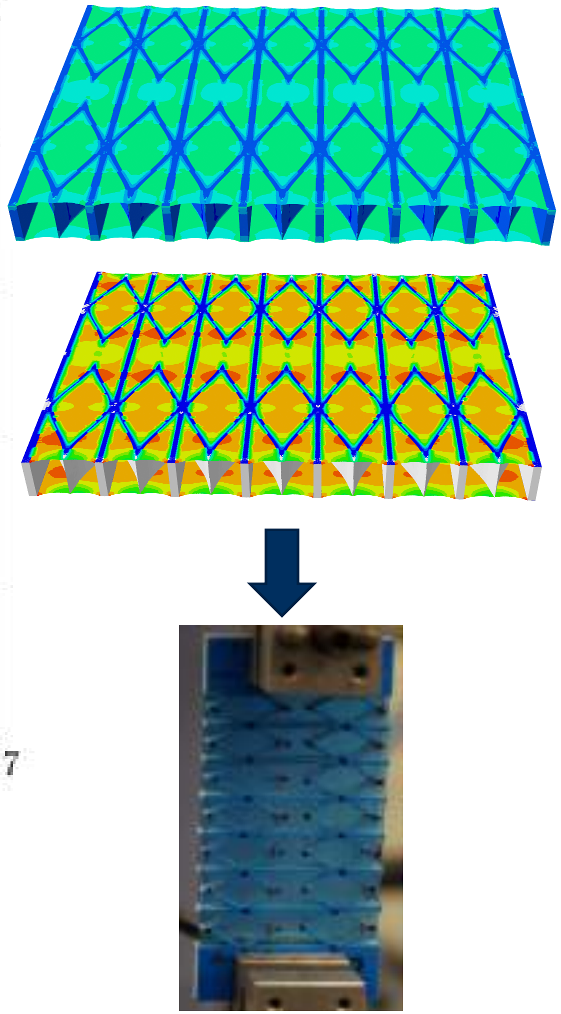
$\mu 1$ [Mpa]	$\mu 2$ [Mpa]
0.5034	3.1410

Linear elastic material properties

E (Experimental, Membrane)	ν
22.9 MPa	0.46

Model validation: In-plane response





Mooney-Rivlin constants

$\mu1$ [Mpa]	$\mu2$ [Mpa]
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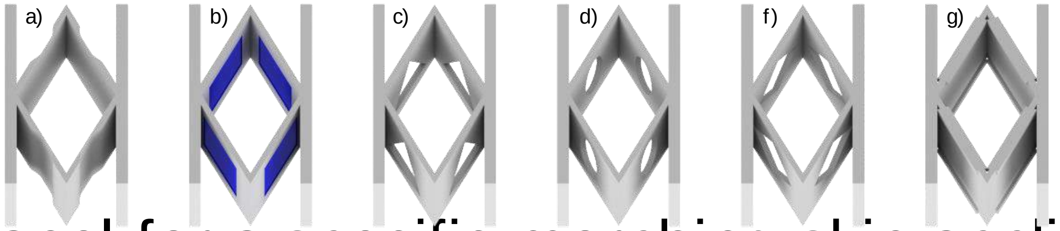
Linear elastic material properties

E (Experimental, Membrane)	ν
22.9 MPa	0.46

Future work

- Detailed design space analysis of a sandwich panel using standard MorphCore
- Implement proposed permutations



- Optimise panel for a specific morphing skin application

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Thanks for your attention

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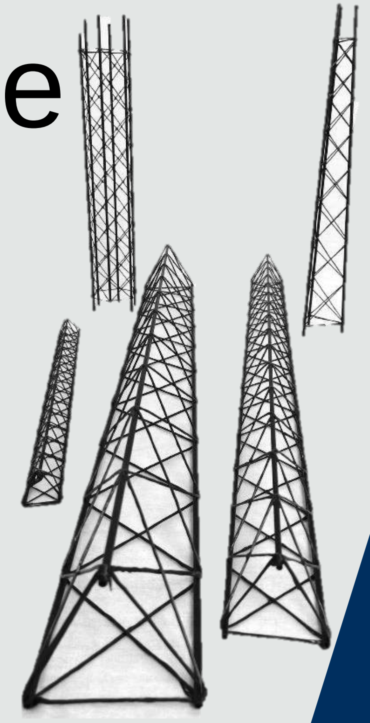
WrapToR Truss Stiffened Skin Panels for Aerospace Vehicles



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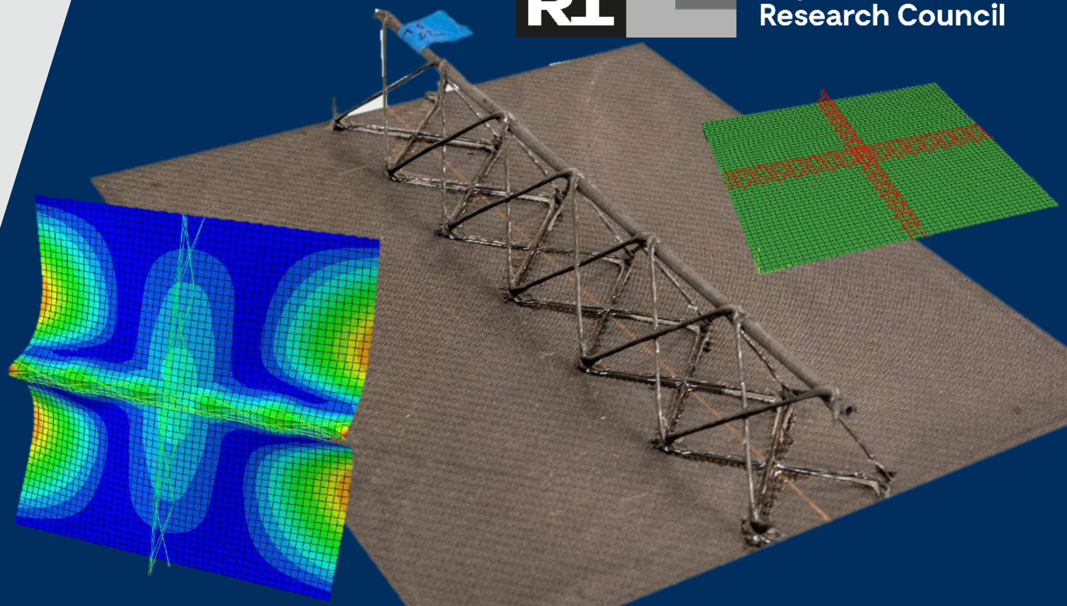

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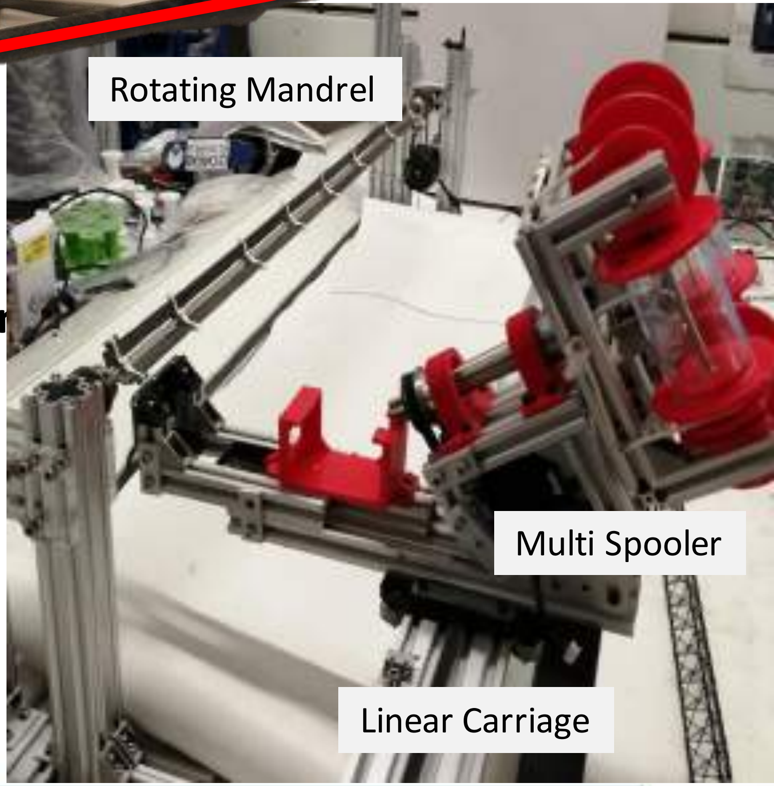
What is WrapToR Truss?

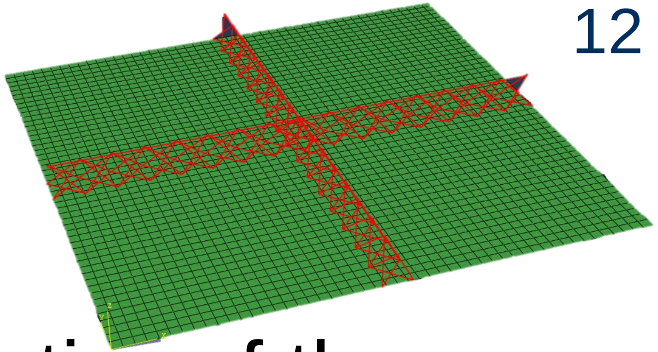
- **Wrapped Tow Reinforced Truss**
- 3 longitudinal/chord members –
  - Pultruded Composite tubes
- Shear members –
  - Continuous Resin Wetted Fibre
  - Adapted filament winding technique

- **3-point bend test comparison against pultruded composite tubes (7 & 8 mm carbo**
  1. 7% greater mass, 1006% stiffness increase, 181% greater load carrying
  2. 9% smaller mass, 537% stiffness increase, 133% greater load carrying

- **Tow Twisting Improvements in large profile truss**
  1. 51% increase in load carrying
  2. 10% increase in stiffness

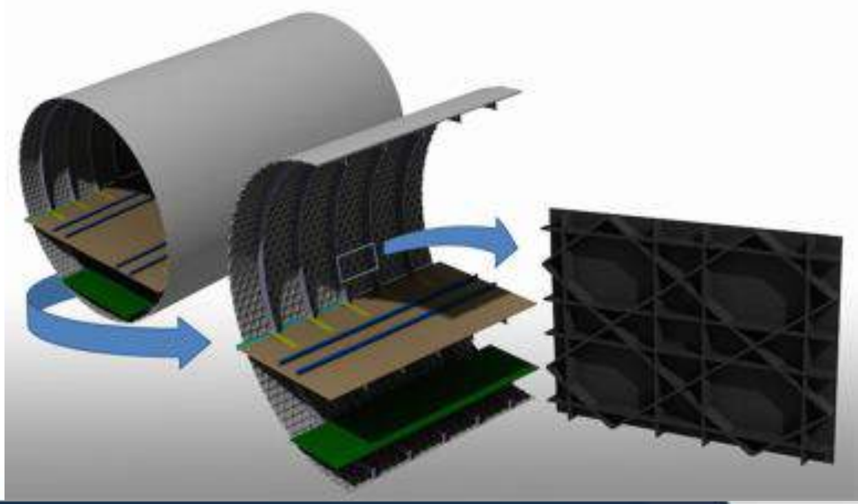


WrapToR Truss Stiffened Skin Panels



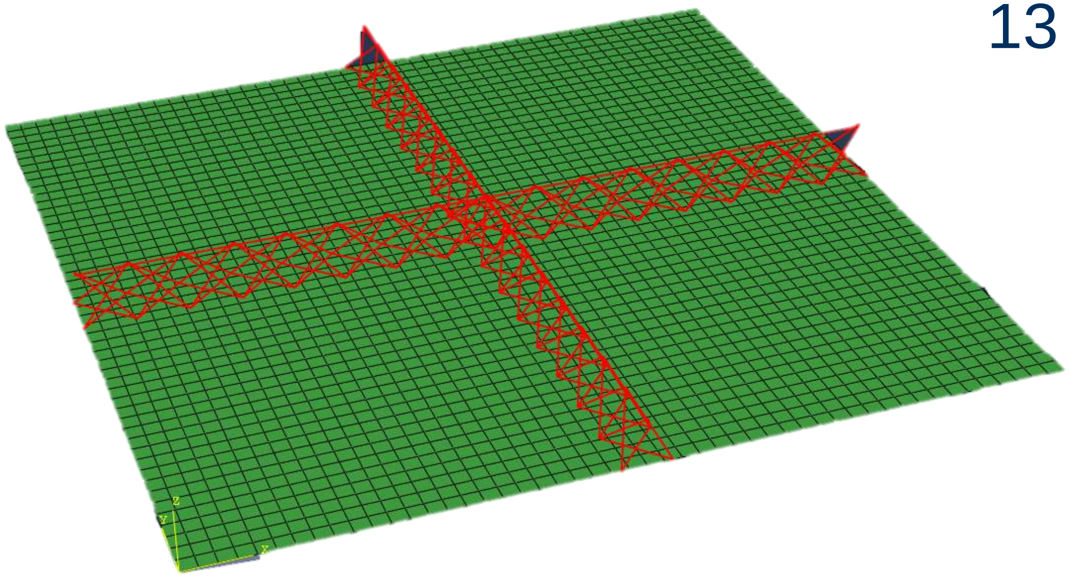
Objective: Characterise and optimise the application of the WrapToR truss concept as a reinforcement member for structural panels

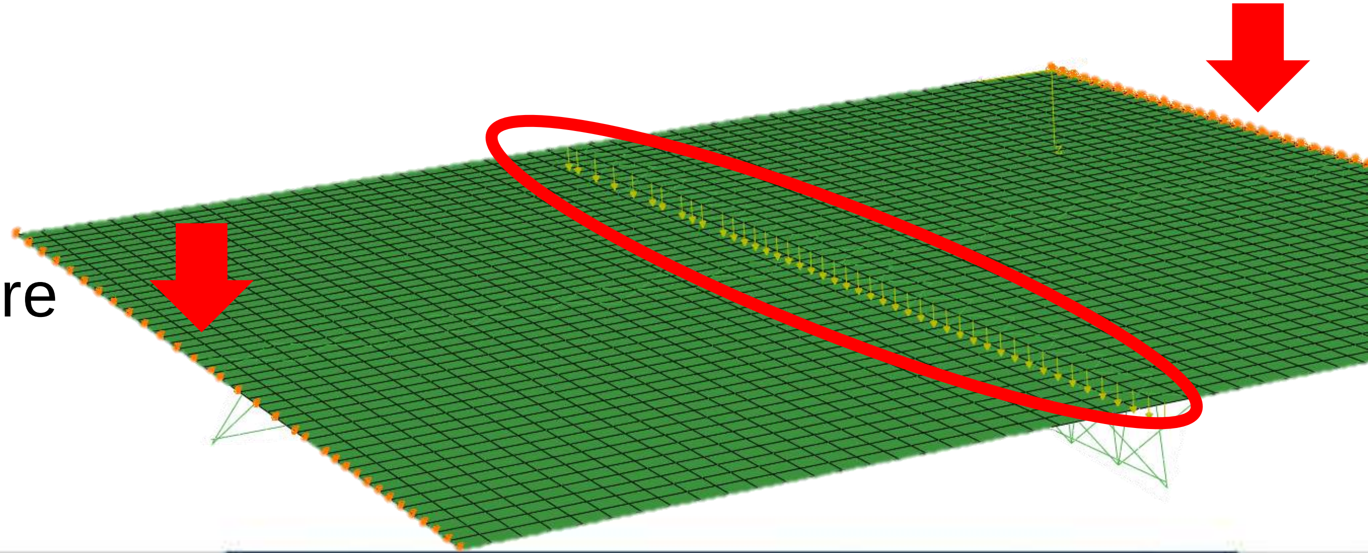
- Combination of composites with mass efficient structures
- Utilise continuous carbon fibre construction
- Potential applications in range of scales

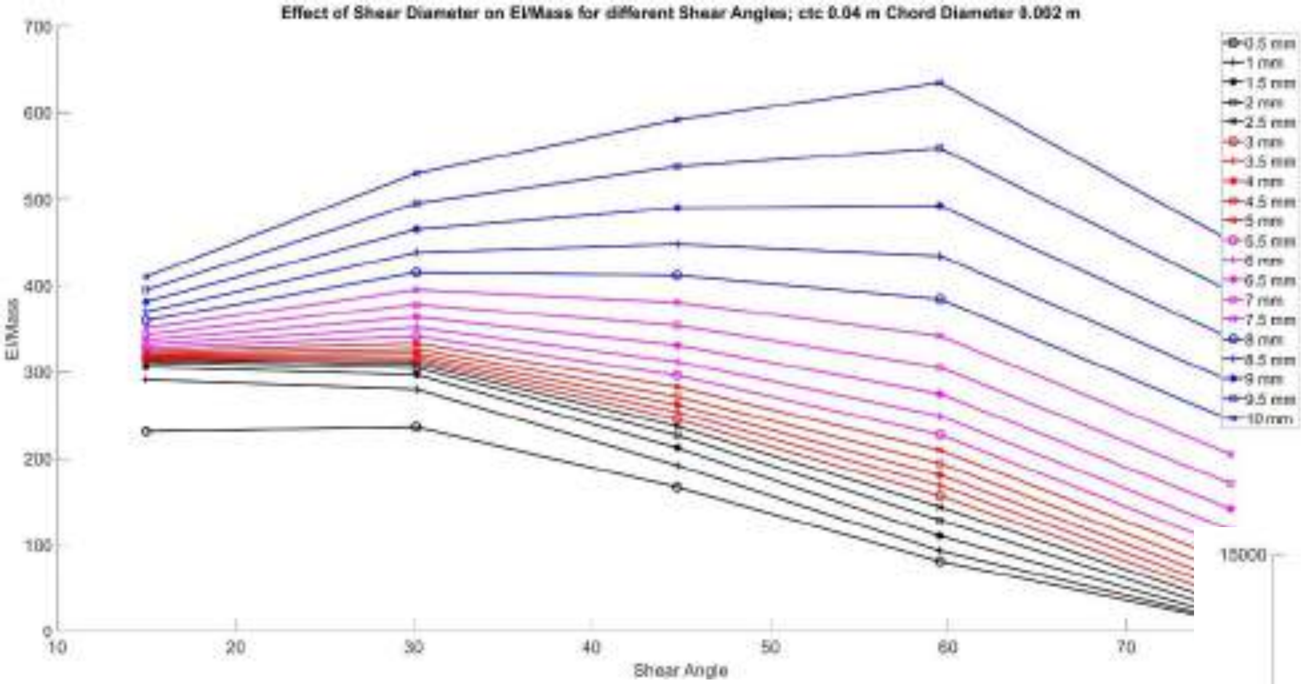


Modelling and Analysis

- Square composite panel
- 2 trusses in cruciform
- 2 chord members removed
- Line load along centre
- Simply supported BC on two edges
- Performance Metrics:
  - Low Mass
  - High Stiffness
- Record Displacement along centre
  - $\delta = \frac{Fl^3}{48EI} >>> EI = \frac{Fl^3}{48\delta}$

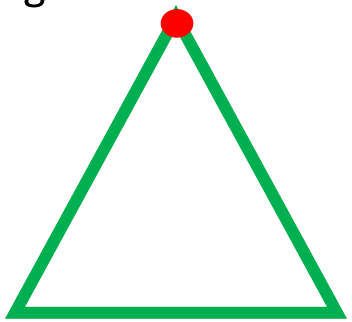






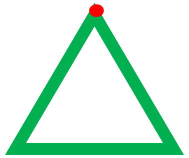
Large ctc

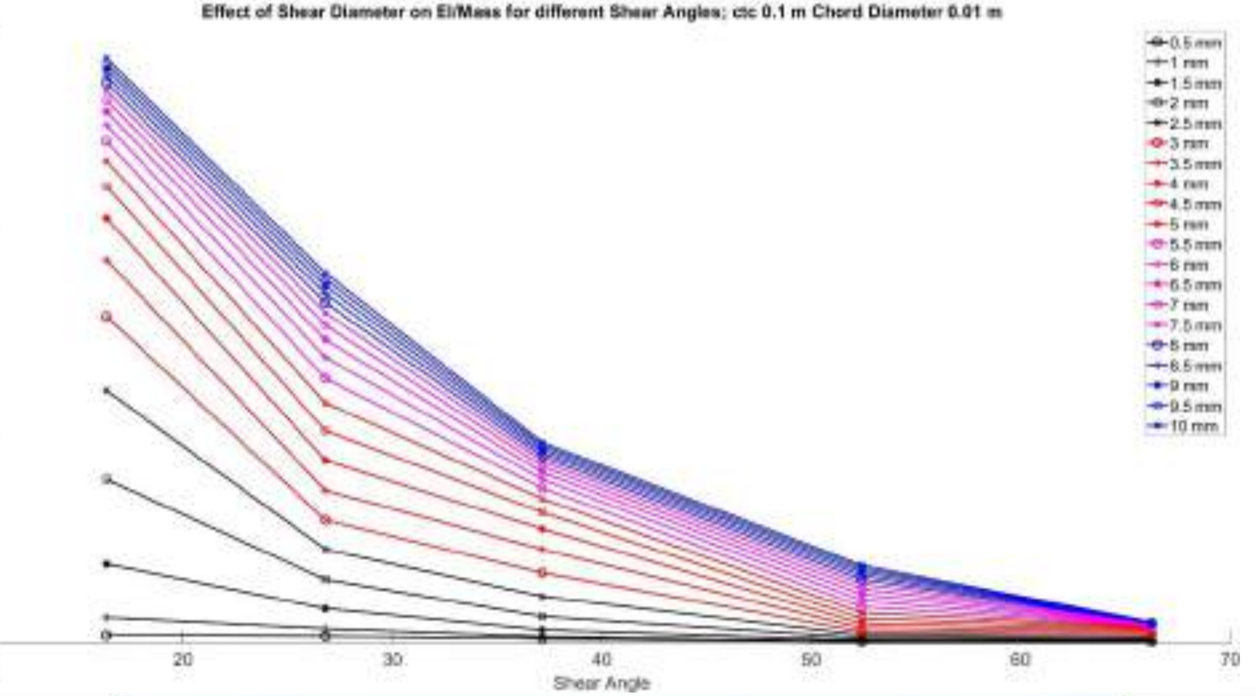
Large Chord Diameter

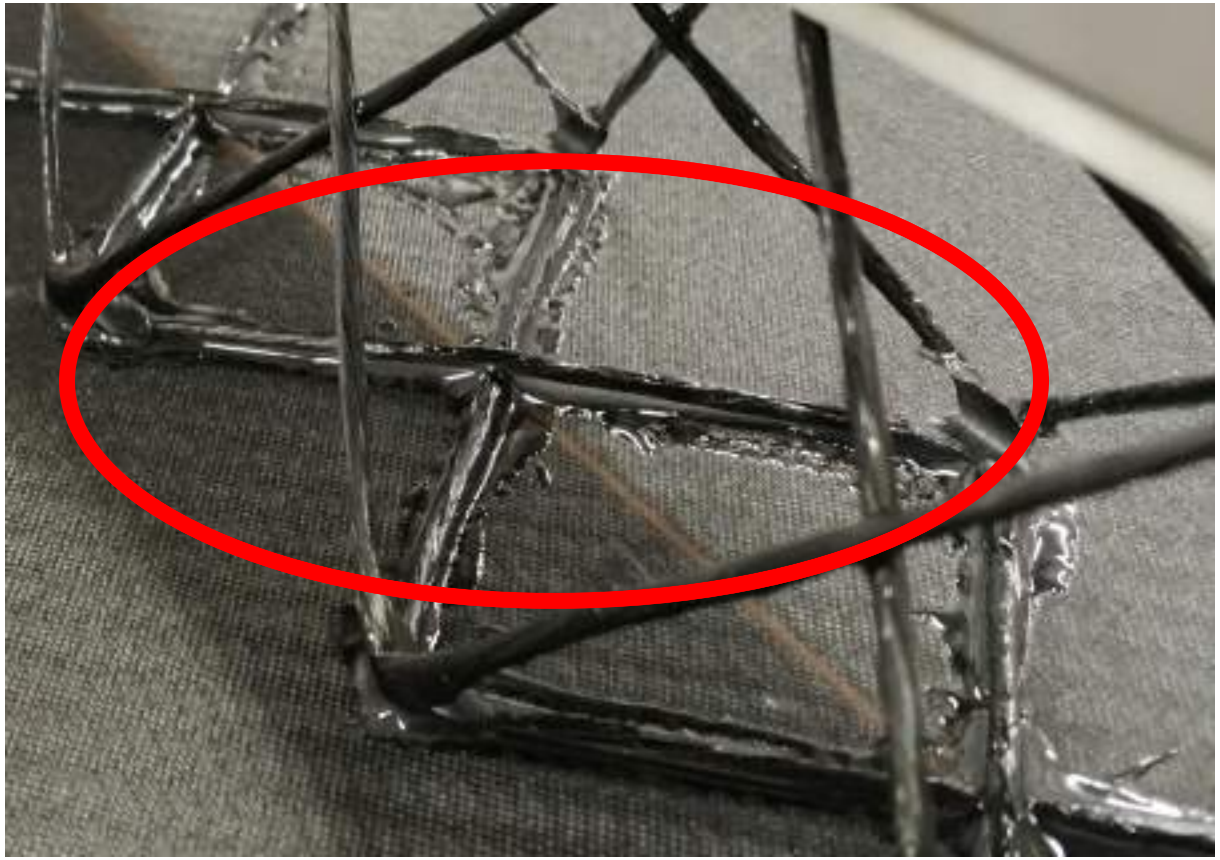


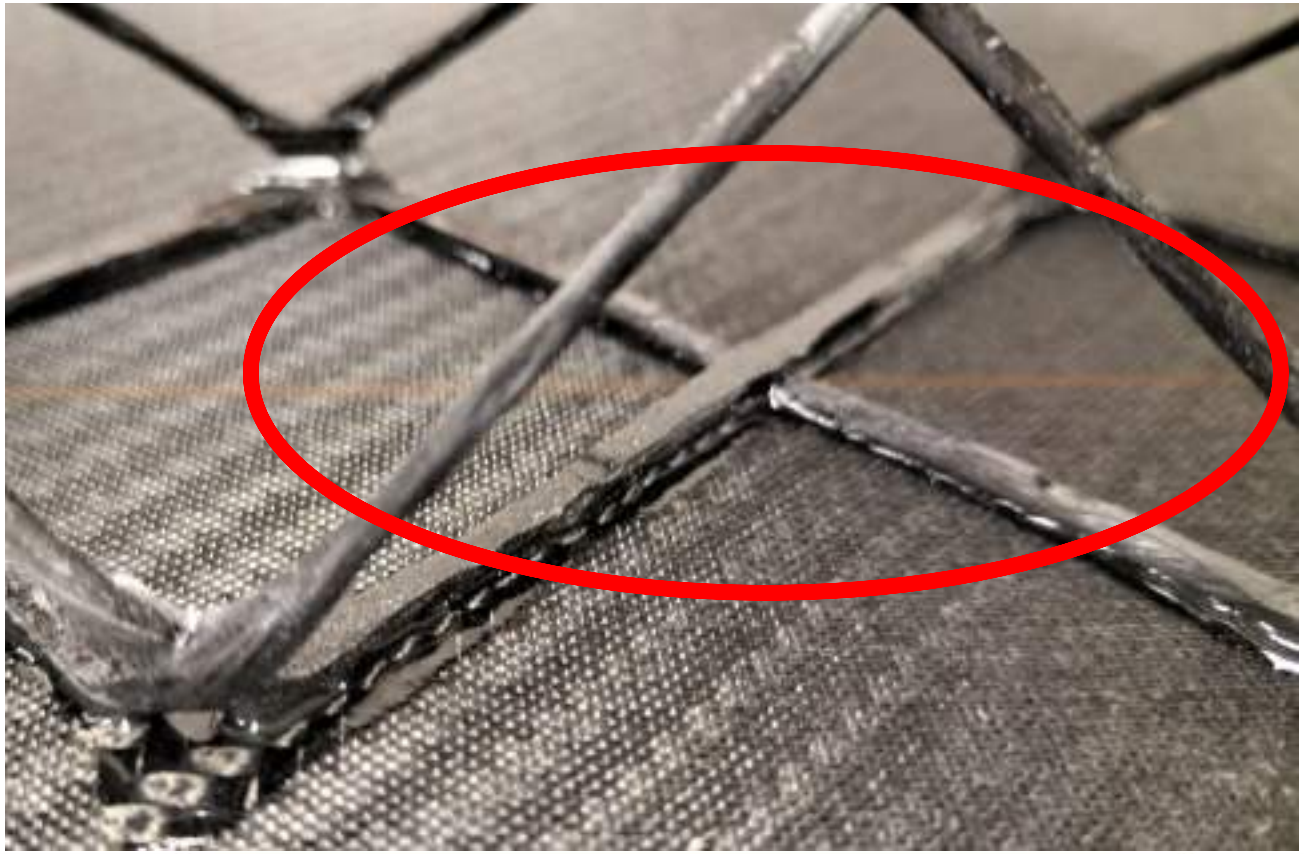
Small ctc

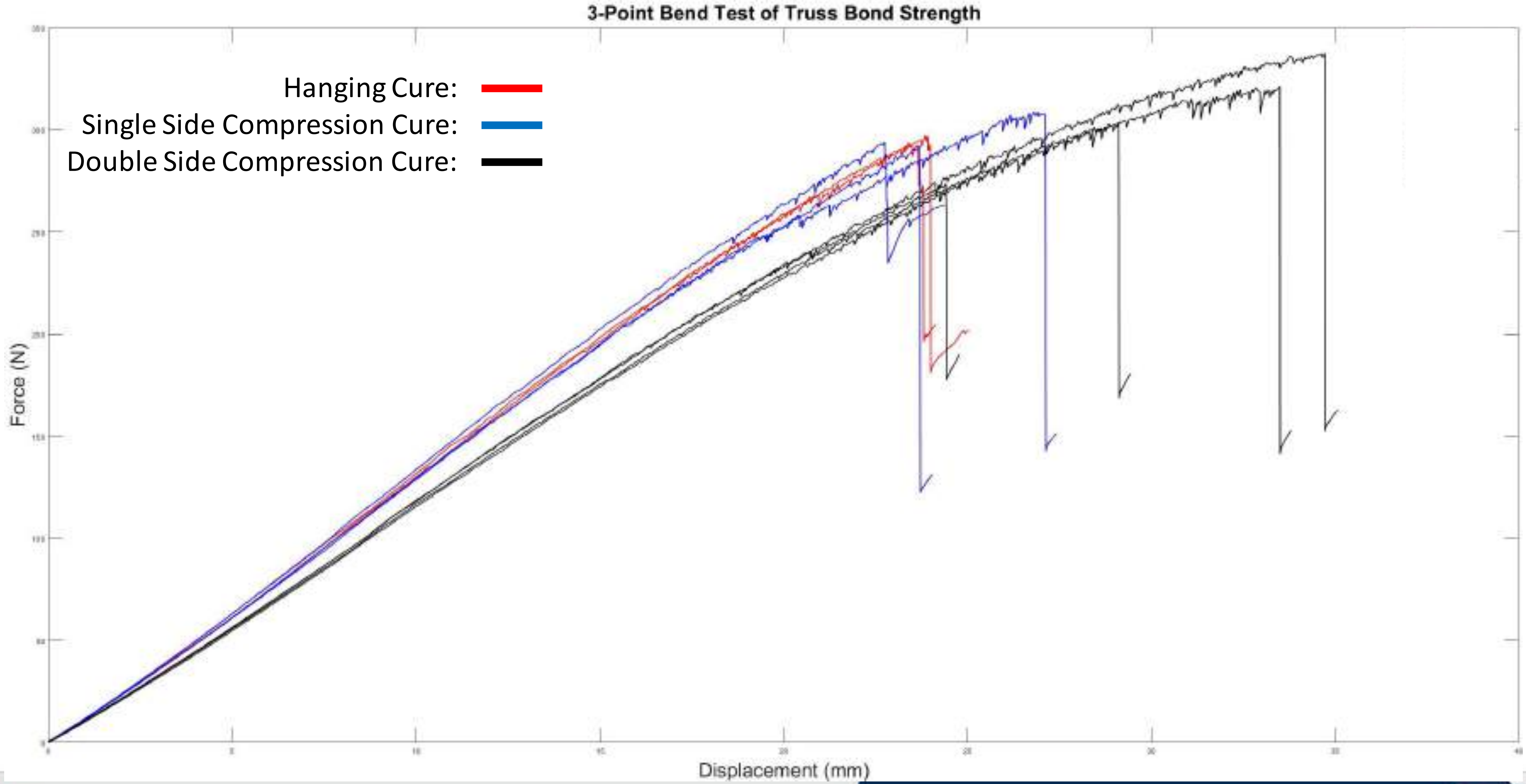
Small Chord Diameter










3-Point Bend Test of Truss Bond Strength
Hanging Cure: 🟥
Single Side Compression Cure: 🟦
Double Side Compression Cure: ⬛
Force (N)
Displacement (mm)
350
300
250
200
150
100
50
0
0
5
10
15
20
25
30
35
40

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Thank you for listening

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Embedded Stiffening Grids in Laminated Plates and Shells

Calum J. McInnes, Alberto Pirrera, Byung Chul Kim,
Rainer M.J. Groh

Doctoral Research Symposium 2022

12th April 2022

University of BRISTOL
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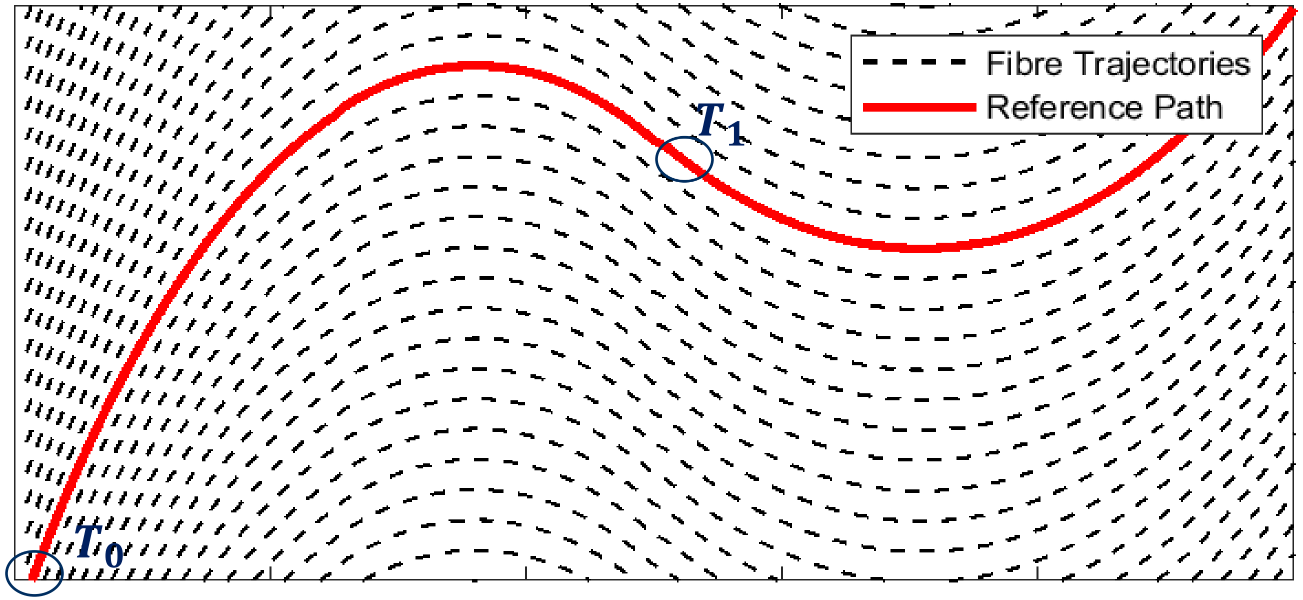
Motivation: Tow-Steered Composites

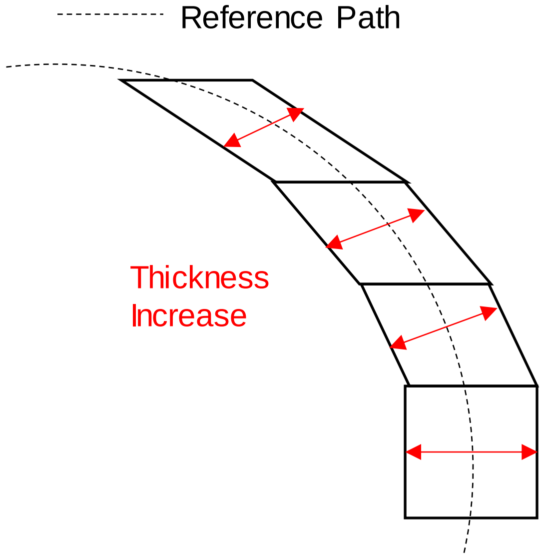
- Steering of composite material tows produces non-constant fibre angle across a ply
- Variation in fibre angle allows for variable stiffness structures to redirect load paths and tailor mechanical response
- Proven benefits for stress redistribution and buckling performance
- Represents a **step change in design potential**



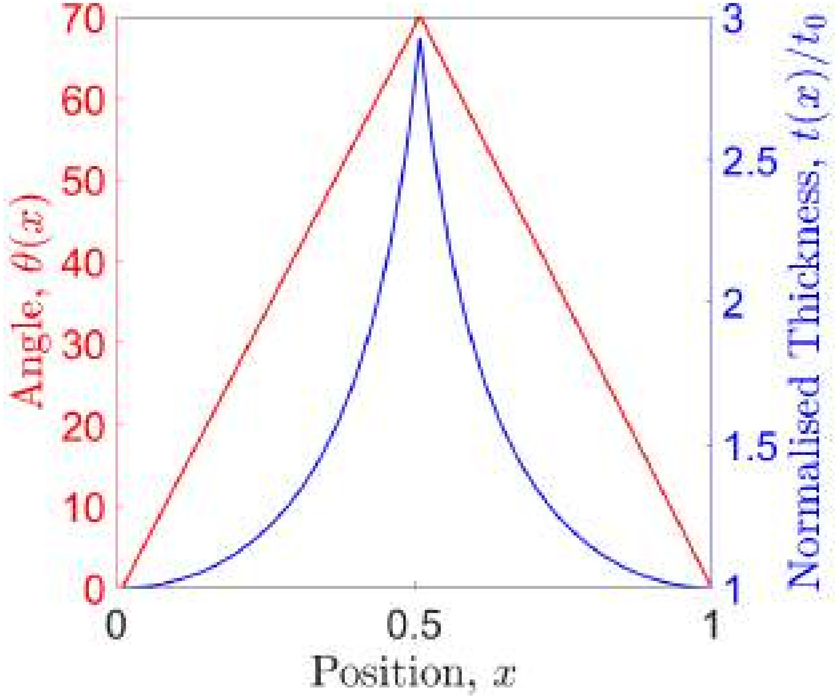
Tow-Steered Ply

Context: Continuous Tow Shearing

- **In-plane shearing of material tows by Continuous Tow Shearing (CTS)** along curvilinear reference eliminates potential defects of Automated Fibre Placement (AFP) steering and allows perfect tessellation
- CTS process exhibits **nonlinear orientation-thickness coupling** of sheared tows due to material volume conservation

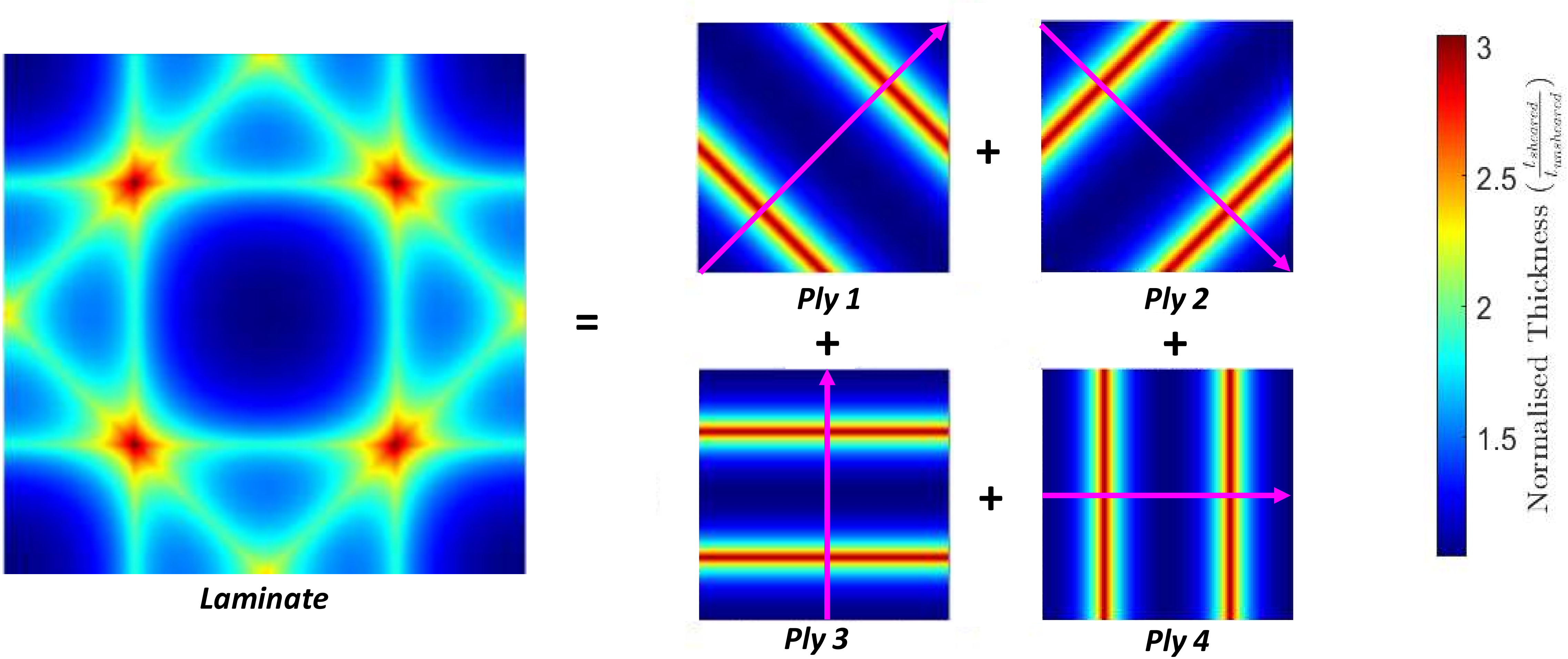


[1]



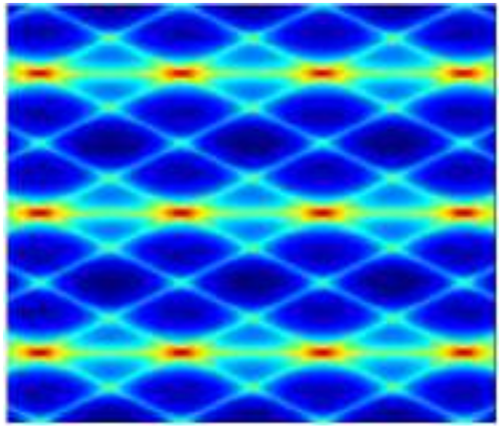
Results: Design Methodology

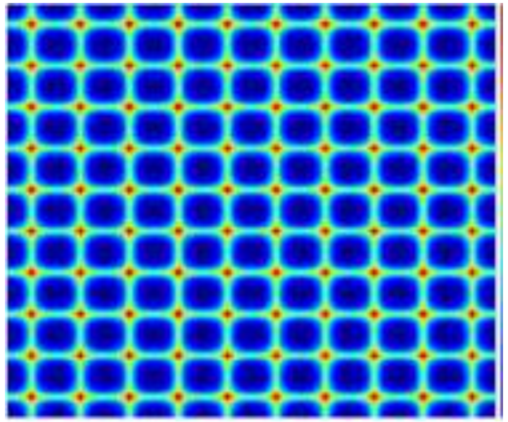
- **Steer plies at differing directions to produce structural-level thickness build-up pattern**

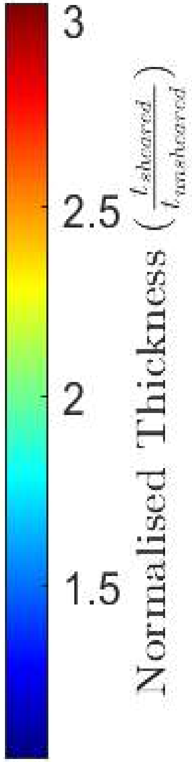


Results: Laminated Plate Design

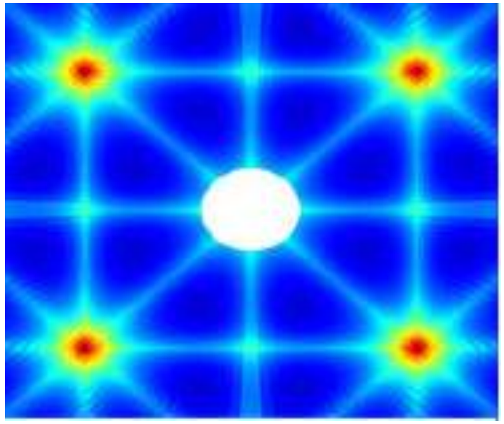
- Periodic ply-level thickness build-ups are laminated, where differential steering directions produce grids



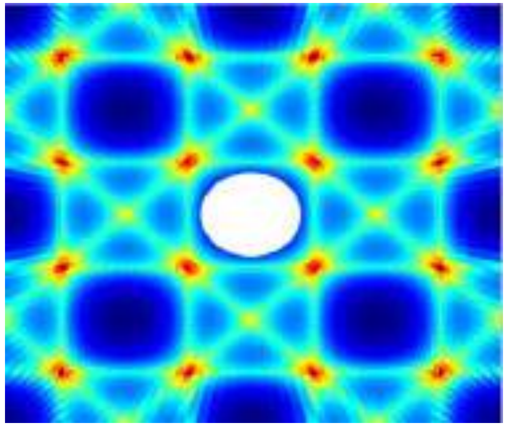




- Geometric features can be included in design to mitigate detrimental effects



Hole Intersection

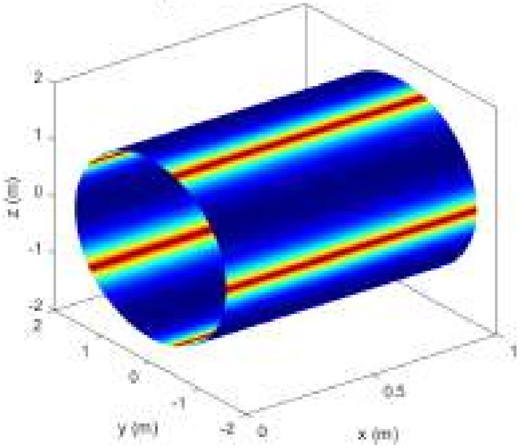


Hole Containment

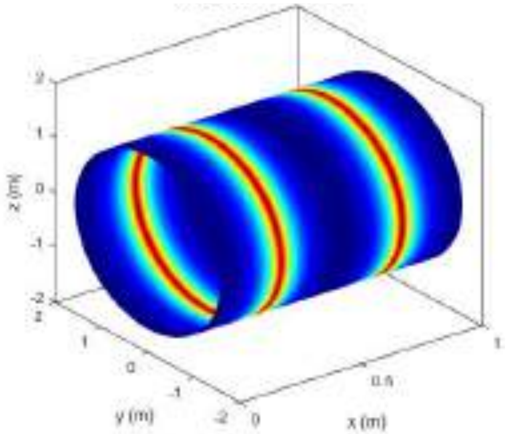
Results: Laminated Shell Design

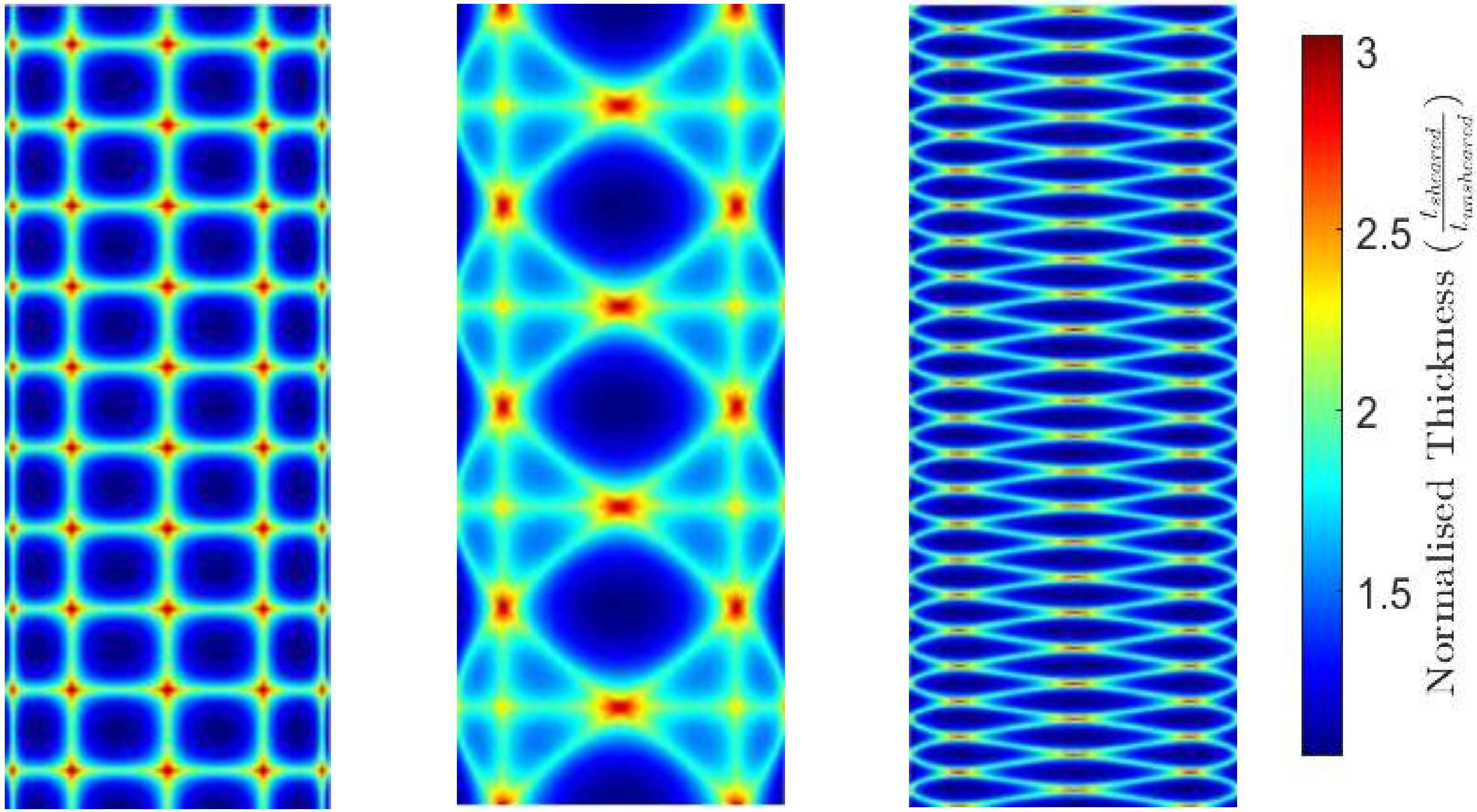
- Conventional aerospace stiffening schemes can be embedded into monocoque structures

Stringers



Hoops

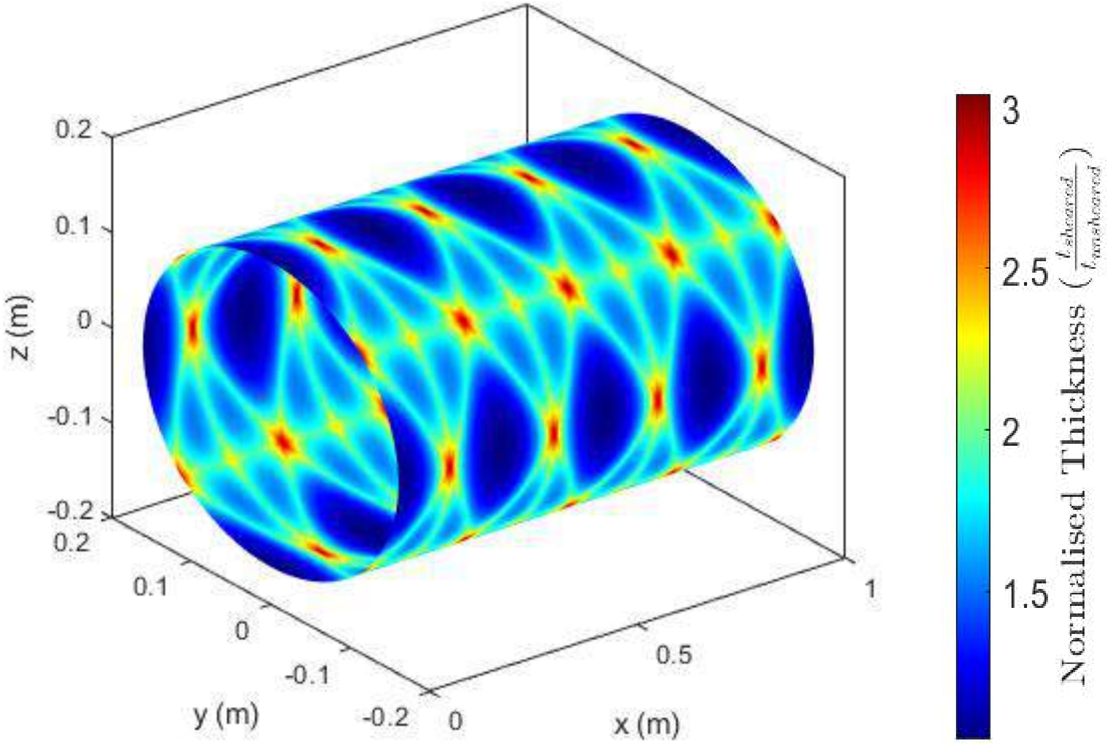




Orthogrid **Isogrid** **Anisogrid**

Conclusions & Future Work

- Manufacturing influenced design methodology derived
- Significant structural design potential
- Rich solution space to explore
- Fast computational tools required for enabling iterative design
- Meta-heuristics optimsiation will enable optimum design solution



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Questions? Come find me at my poster!

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References

[1] B. C. Kim, K. Potter and P. M. Weaver, "Continuous tow shearing for manufacturing variable angle tow composites," Composites: Part A, vol. 43, pp. 1347-1356, 2012.

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Design of 3D Printed Wind Turbine Blades using Topology Optimisation

Alex Moss

BCI Doctoral Research Symposium

12th April 2022

University of BRISTOL
EPSRC Centre for Doctoral
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Supported by: CATAPULT Offshore Renewable Energy

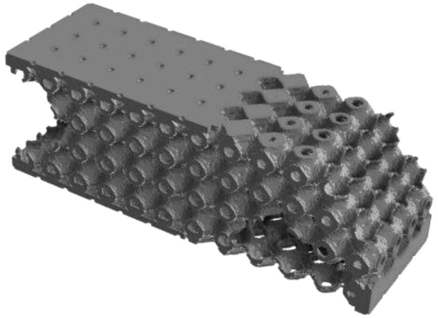
Motivations

3D Printed Internal Structure

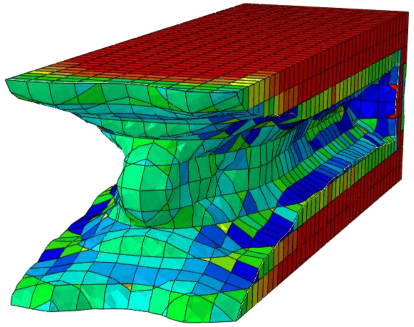
Removal of Female Mould
Faster Blade Production
Additional Design Freedom

Designed by Topology Optimisation

Innovative Design to Reduce Weight
Reduced Gravitational and Inertial Loads
Longer Lifespan



Larger Installed Capacity of Wind Energy
Lower Levelized Cost of Energy



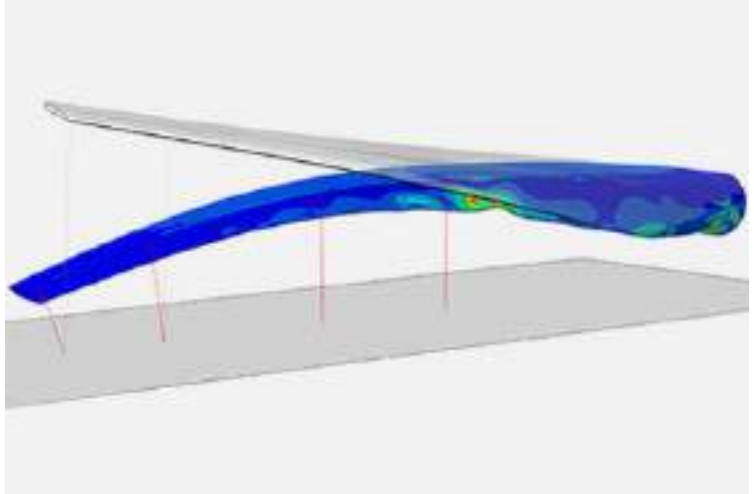
Design Methodology: Challenges

Aeroelastic Design Requirements

- Aero-servo-elastic optimisation is key to improving the structural efficiency of wind turbine blades
- Topology optimisation is difficult to use in combination with other design methods

Multi-Material Topology Optimisation

- A combination of composite laminates and printed structure is required for optimal design
- A single stage optimisation using off-the-shelf solvers cannot provide the detailed design which is necessary for manufacturing



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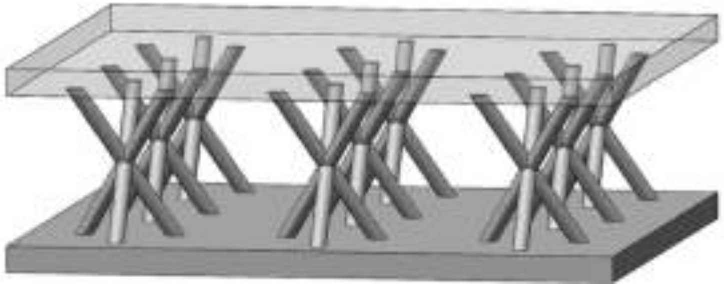
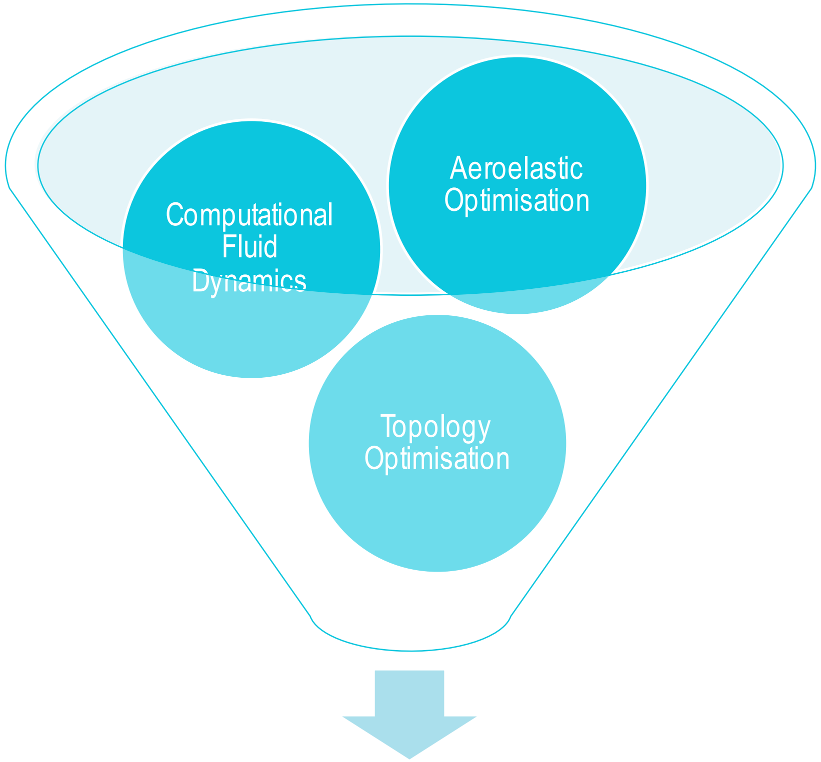


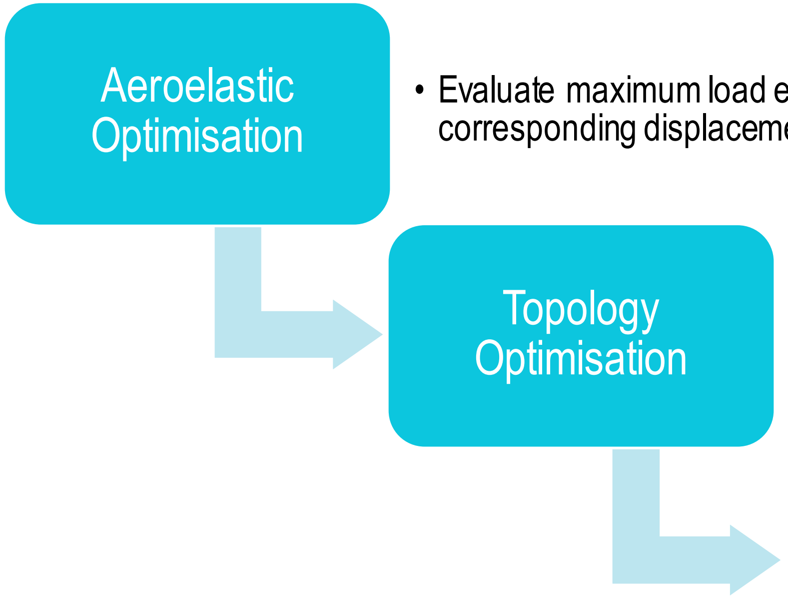
https://doi.org/10.1038/s41598-018-27963-4

Design Methodology: Aeroelastic Design



Accurate Result

Impractical Computational Expense



Aeroelastic Optimisation

- Evaluate maximum load envelopes and corresponding displacement distributions

Topology Optimisation

- Apply load envelopes and displacement constraints

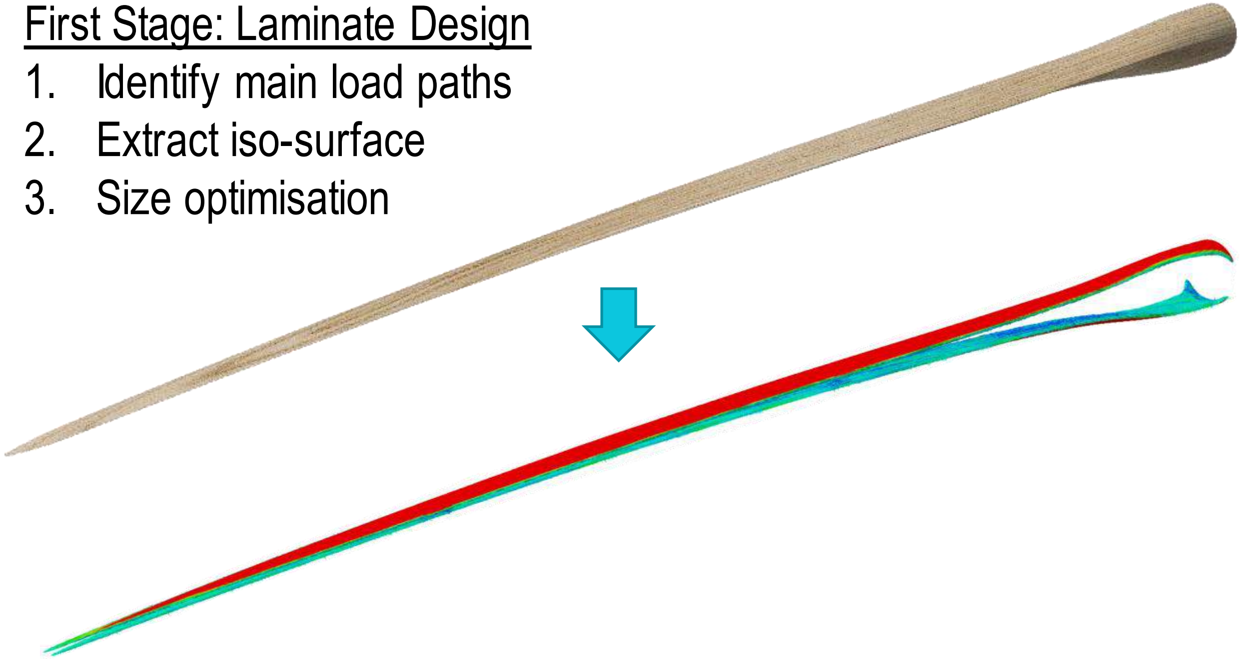
Approximate Result

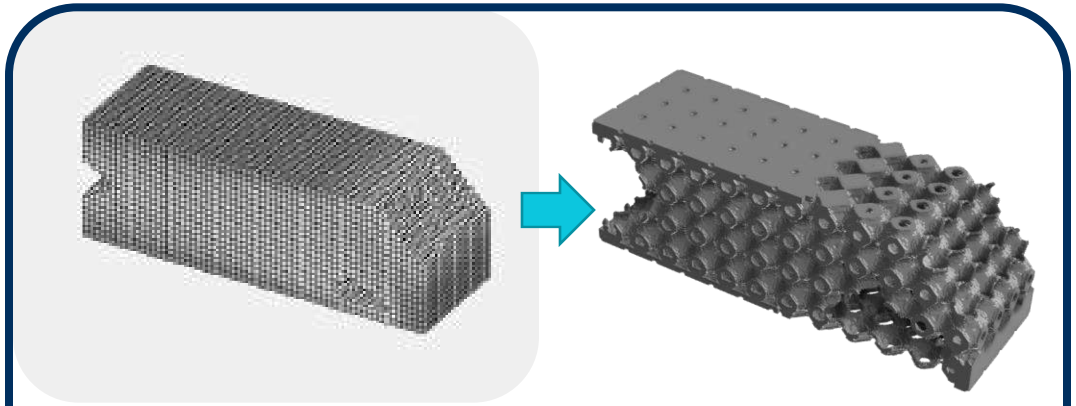
Feasible Computational Expense

Design Methodology: Multiple Materials

First Stage: Laminate Design

1. Identify main load paths
2. Extract iso-surface
3. Size optimisation





Second Stage: Lattice Design

1. Freeze laminate region
2. Find optimal lattice configuration
3. Convert density field values

Acknowledgements

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- Dr Ajit Panesar & IDEA Lab, Imperial College London
- Dr Mark Forrest & Dr Peter Greaves, Offshore Renewable Energy Catapult

This work is supported by: CATAPULT Offshore Renewable Energy

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