University of BRISTOL
Bristol Composites Institute

Tow-steered composites for robust space structures

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Royal Academy of Engineering

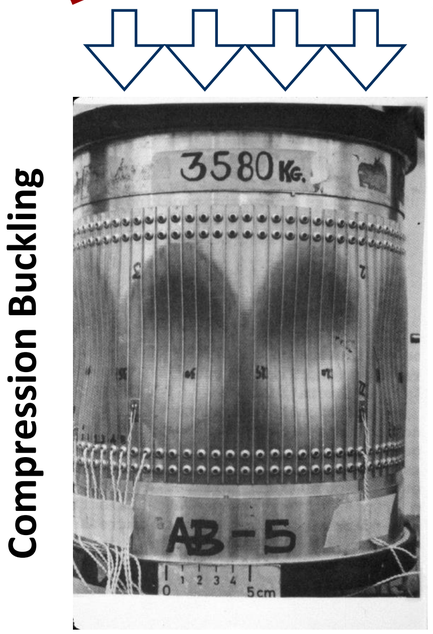
esa

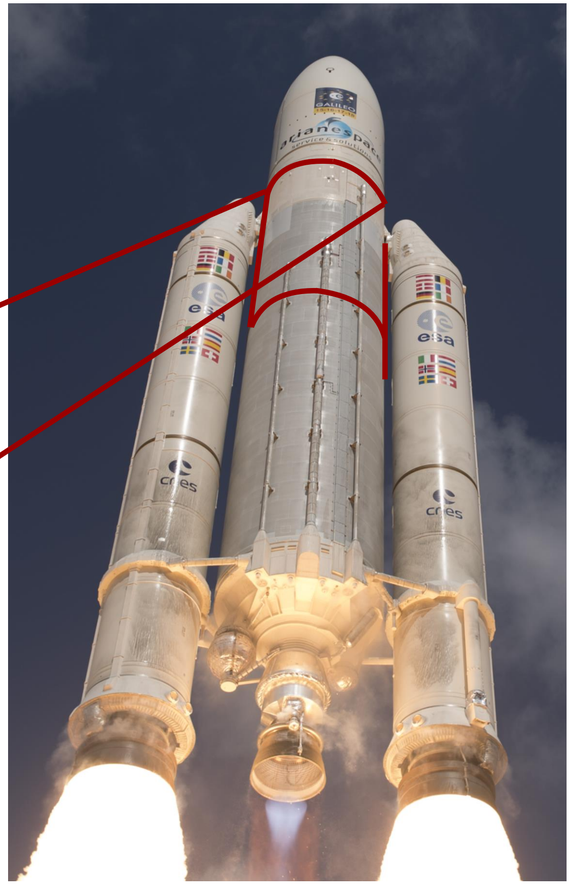
Background

- Renewed interest in launch vehicle design:
  - Launch mass comes at a premium
  - Minimise wall thickness
  - Design driven by stability due to compression

- Very sensitive to geometric & loading imperfections

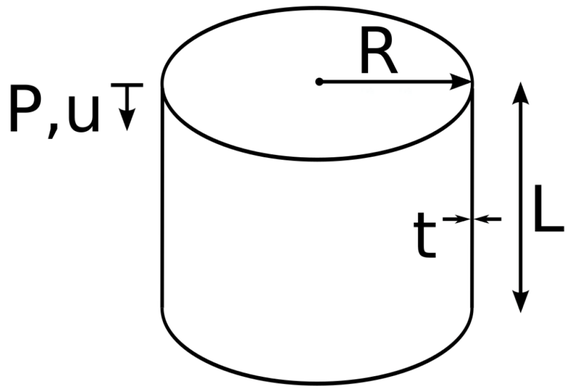
- Goal: reduce sensitivity to imperfections



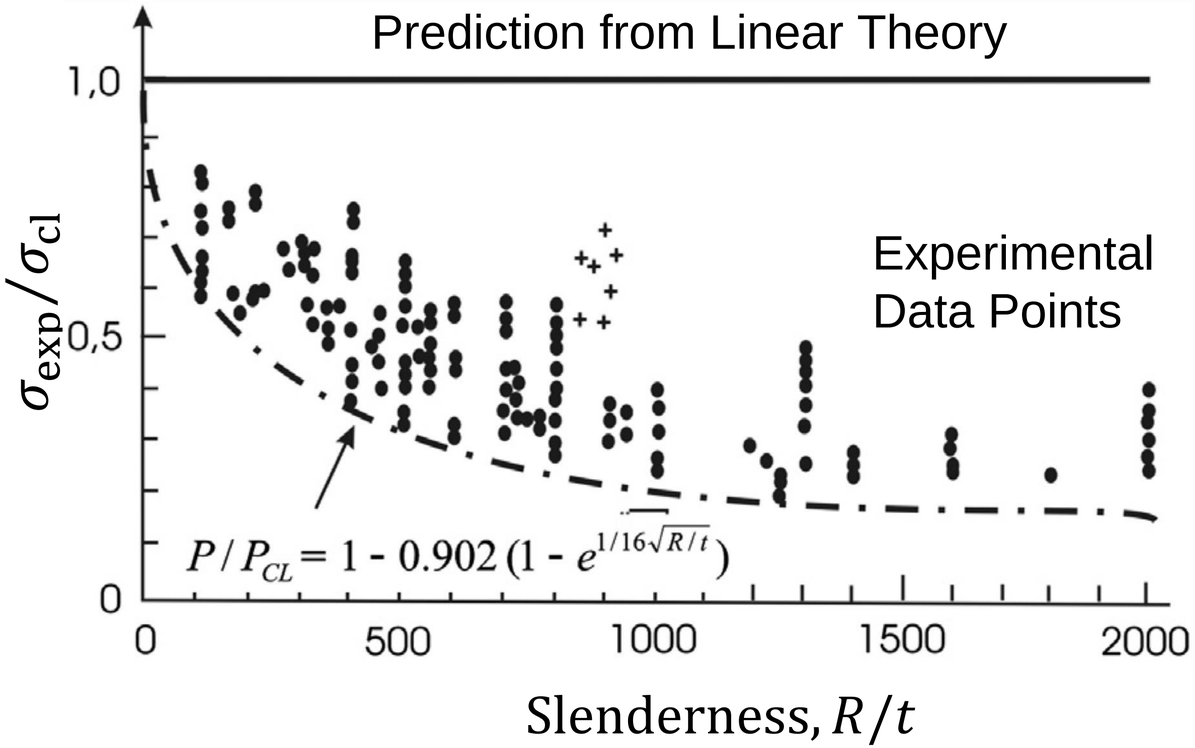


Ariane 5 launcher

Classic Buckling Analysis



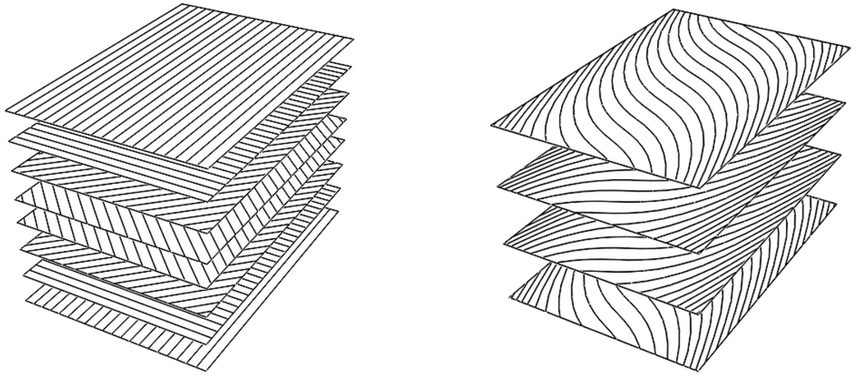
Large discrepancy between linear theory and experimental measurements



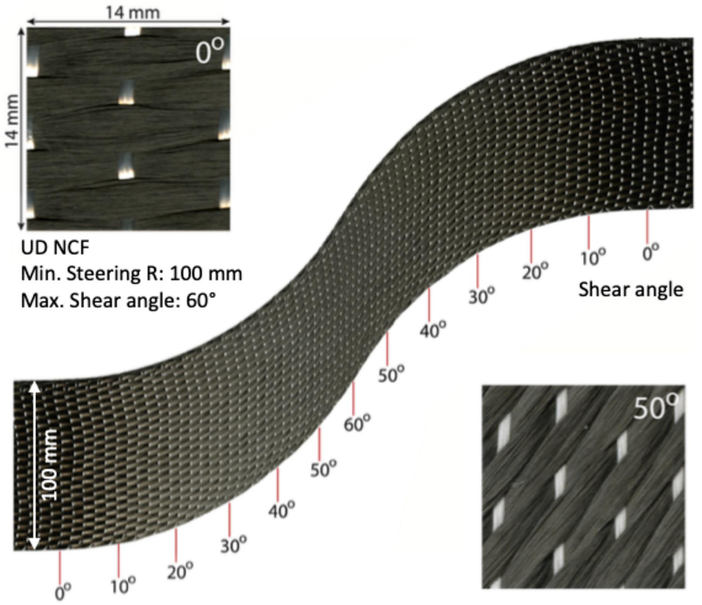
NASA SP-8007 Knockdown Factor from 1960s: very conservative design

Tow-Steered Composites

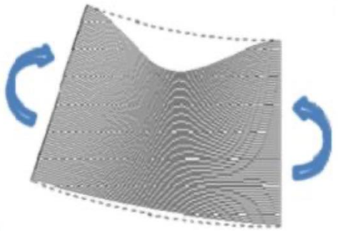
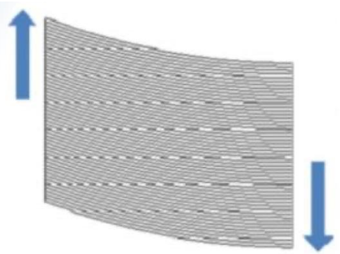
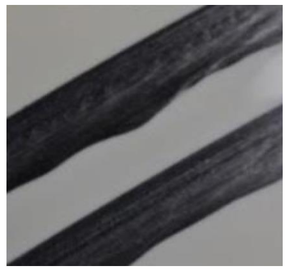
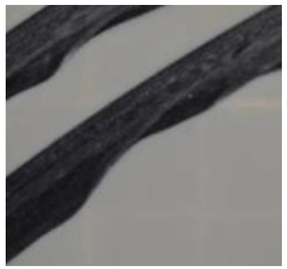
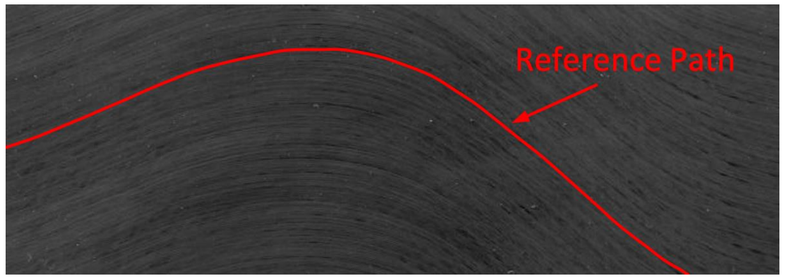
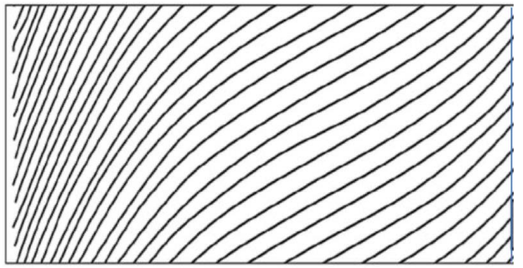
- Curvilinear rather than straight fibre paths
- Manufactured using robotic fibre placement head



- Steering creates:
  - Greater design freedom
  - Ability to steer around features (e.g. cutouts)
  - Ability to transition between different layups
  - Redistribution of load paths

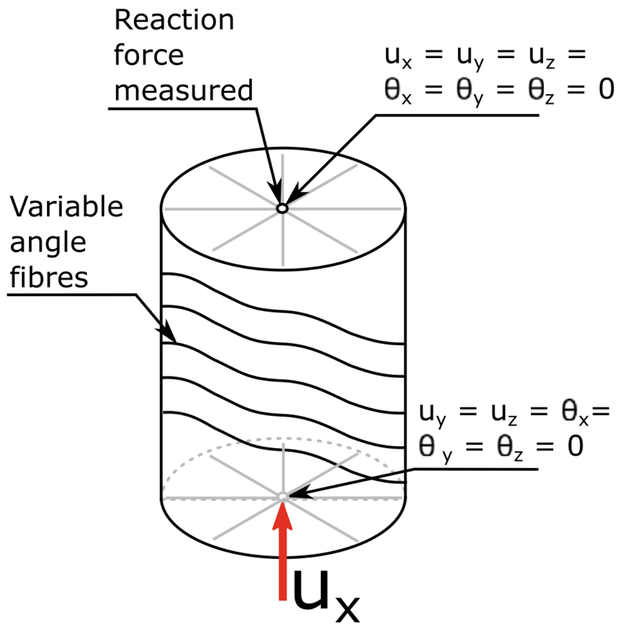


AFP vs CTS

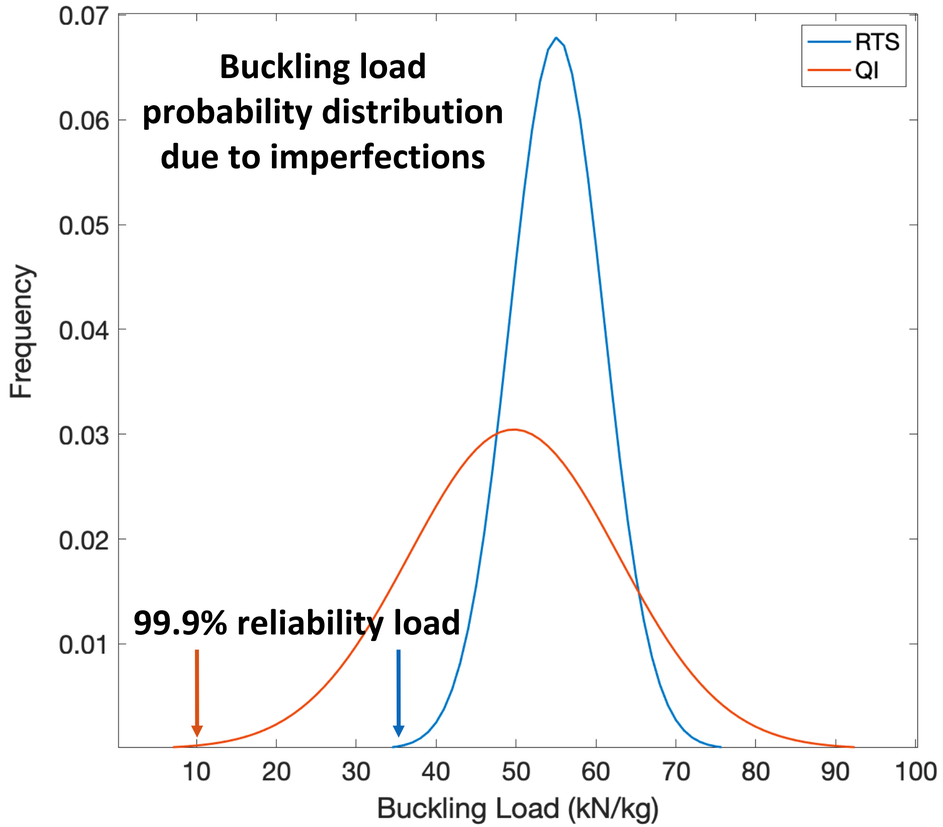
Automated Fibre Placement	Rapid Tow Shearing
Bending 	Shearing 
Defects  	Defect Free 
Gaps/ Overlaps 	Tesselate 

Imperfection-Insensitive Cylinder

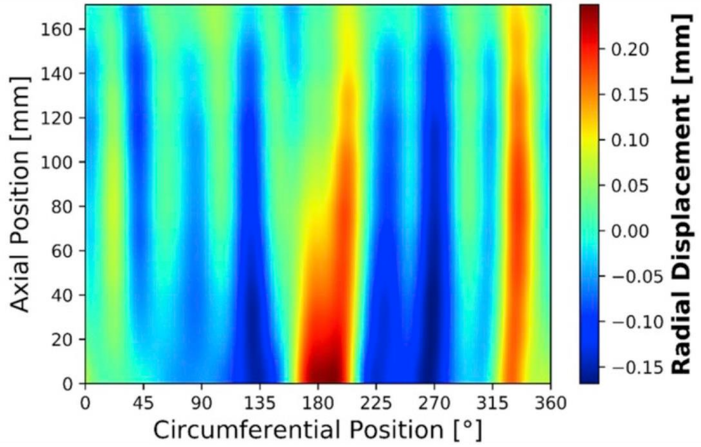
- Robust optimisation under uncertainty:
  - Maximise specific buckling load (load/mass) with manufacturing imperfections



R = 600 mm
L = 1040 mm
8 plies



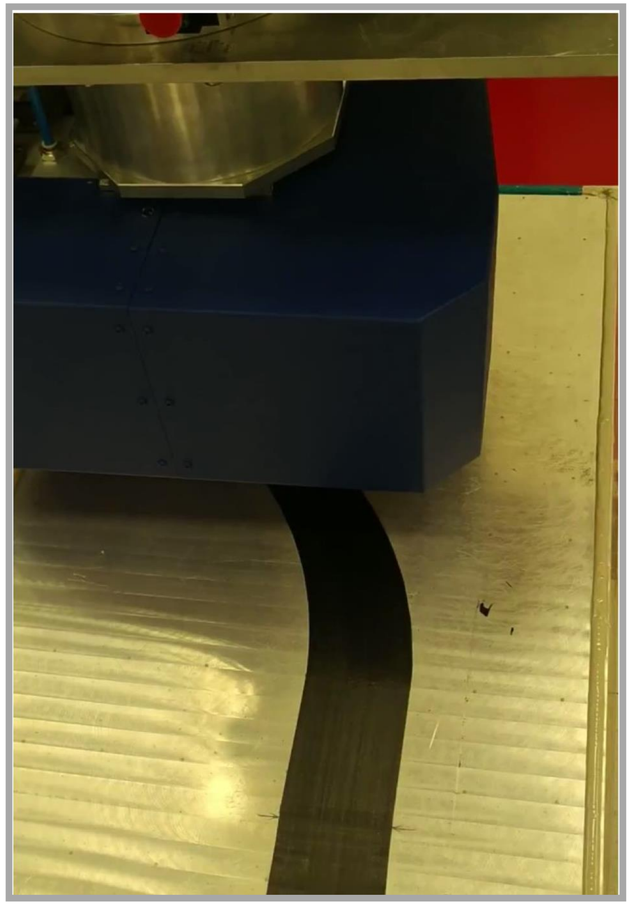
Measured Imperfection



Tow-steered outperforms quasi-isotropic straight-fibre

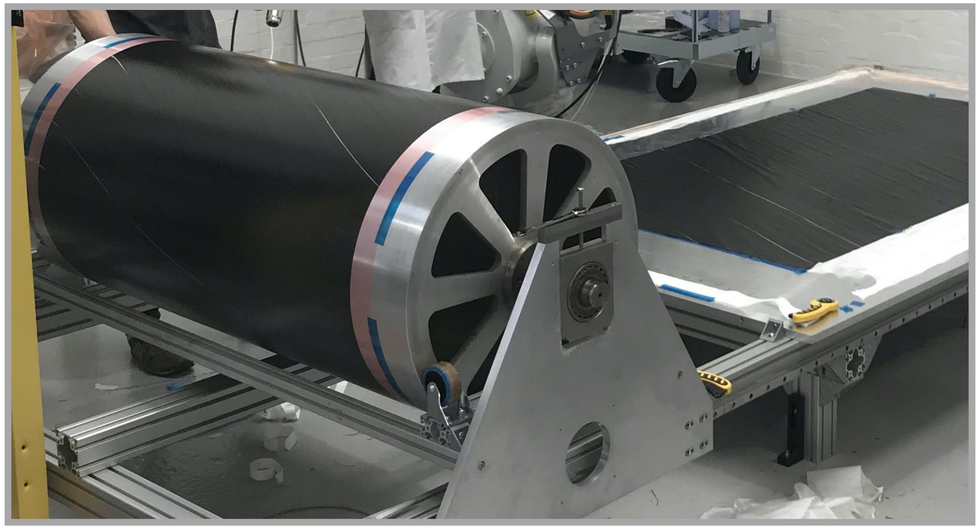
- higher mean buckling load (+11%)
- smaller variance (-80%),
- higher buckling load at 99.9% reliability level (+300%)

Manufacturing @ iCOMAT



Flat deposition

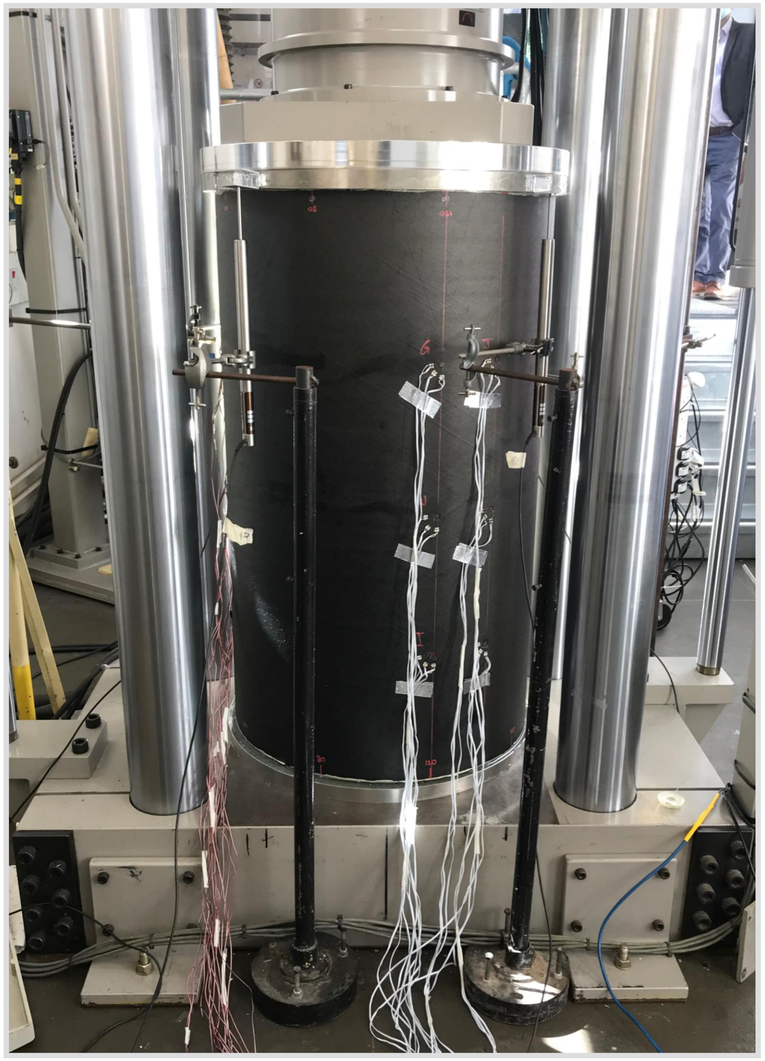
Manufacturing of one QI $[\pm 45,0,90]_s$
and one tow-steered cylinder



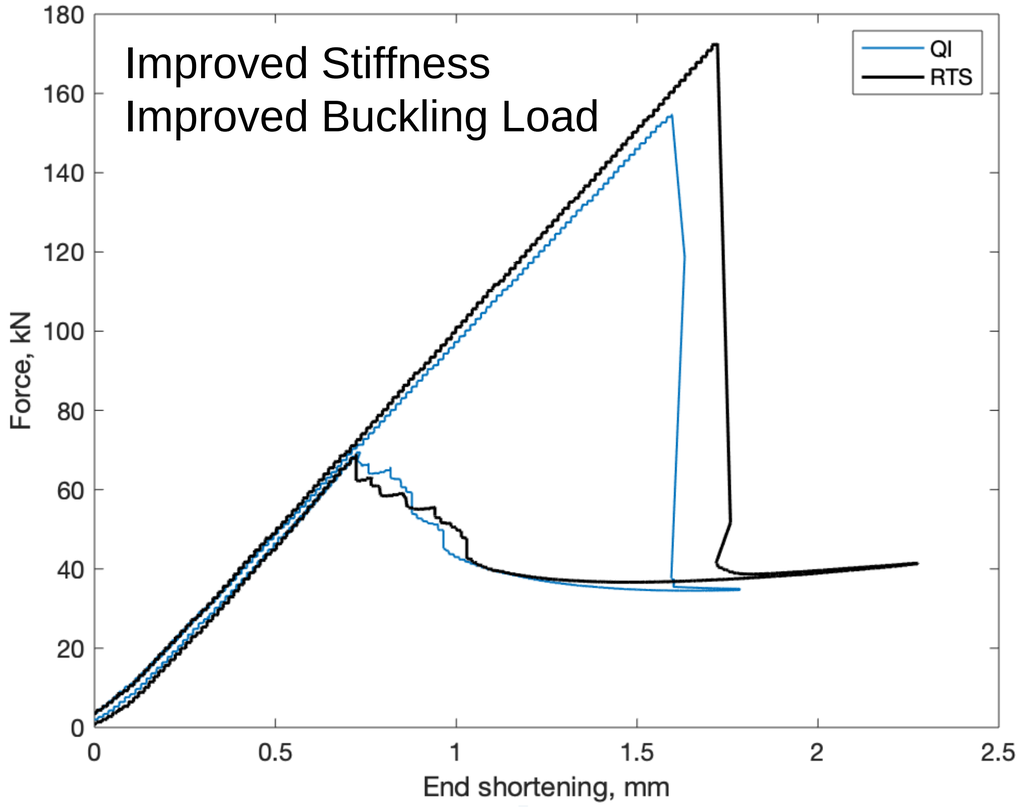
Wrap rolling onto mandrel

Cure and pot both ends

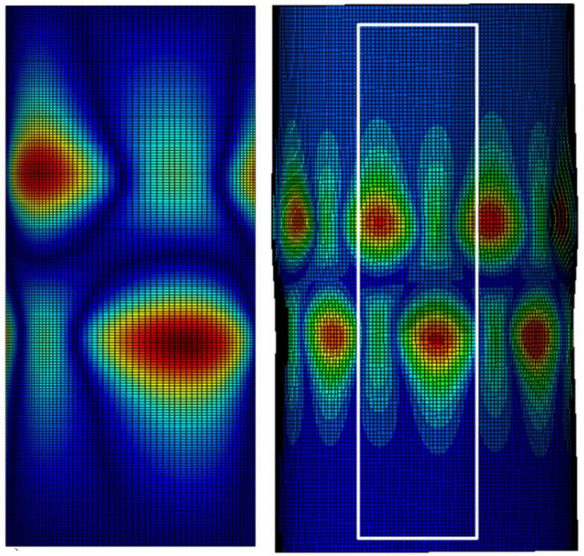
Testing @ UoB



Buckling Load (kN)	RTS	QI
Predicted	177.5	160.7
Experiment	172.9	154.6

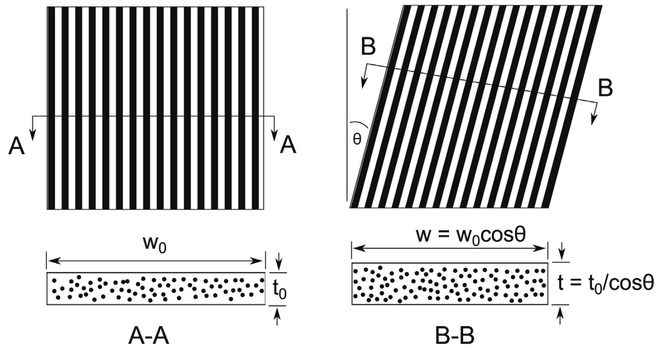


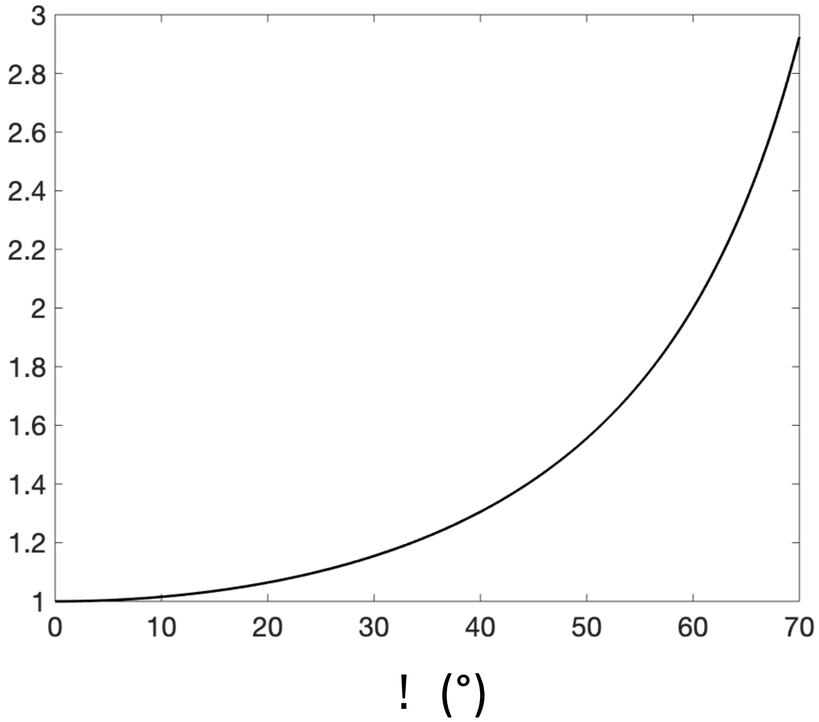
DIC FEM

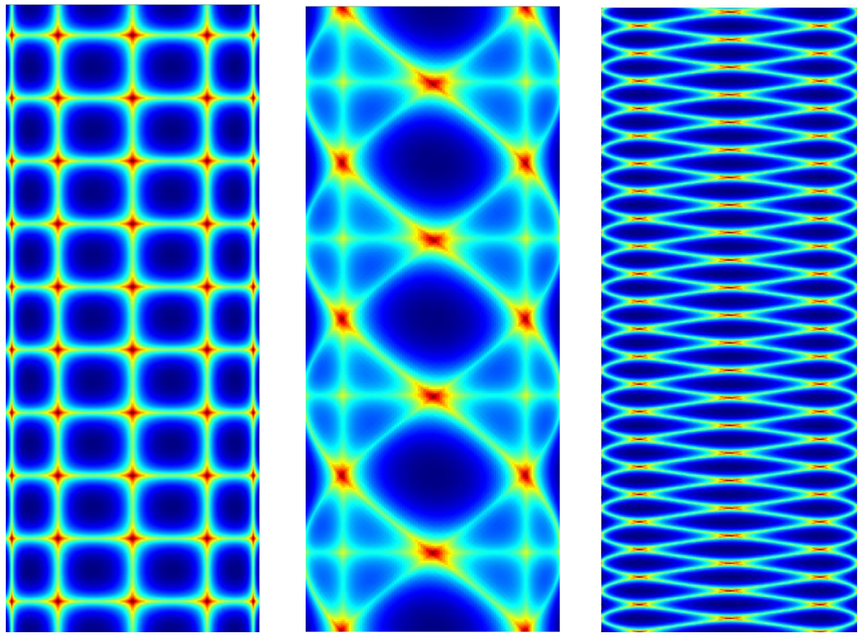


Local Steering

- Keep global straight fibre paths & steer locally
  - Only possible due to small steering radii of RTS
  - Embed stiffeners through local thickness increase







Orthogrid **Isogrid** **Anisogrid**

Conclusions

- Tow-steering provides additional design freedom
  - Better tradeoff between:
    1. Stiffness and
    2. Buckling load/imperfection sensitivity
- Possibility for embedded stiffeners

- Future work through follow-on ESA project:
  - Deposition onto 3D tool
  - Permeability
  - Real satellite central tube
  - In collaboration with prime contractor

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Questions?

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ESA Project

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