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Optimisation of variable-stiffness cylinders under axial compression with realistic imperfections

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Bristol Composites Institute Postgraduate Research and Training Showcase

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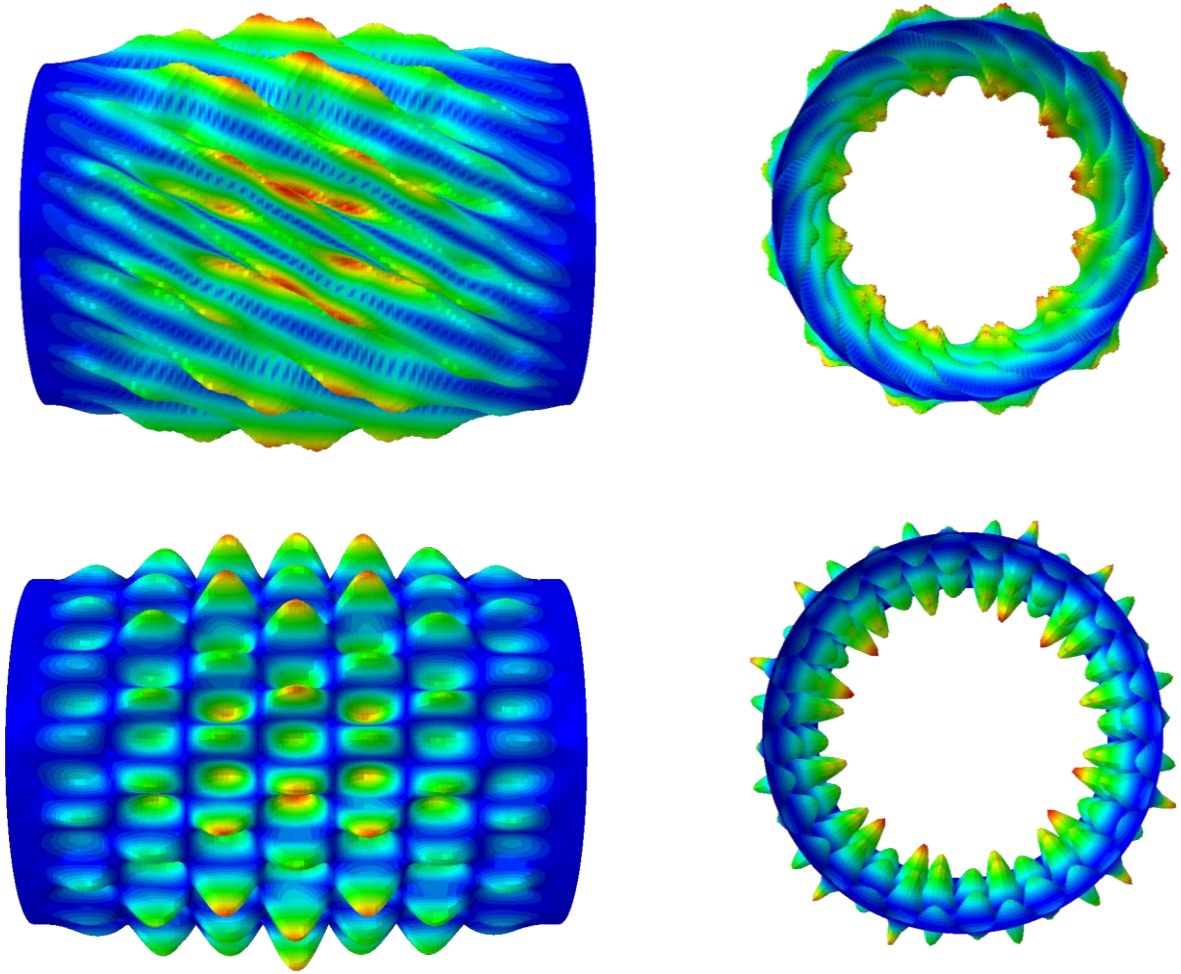
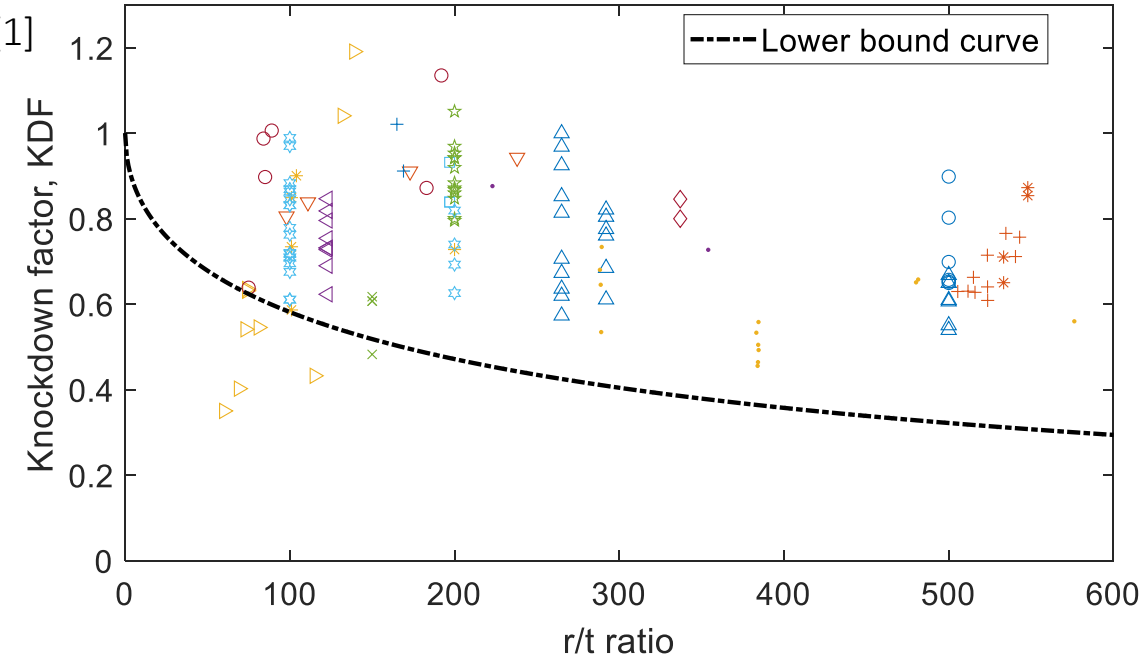


Context – Cylinders and tow shearing

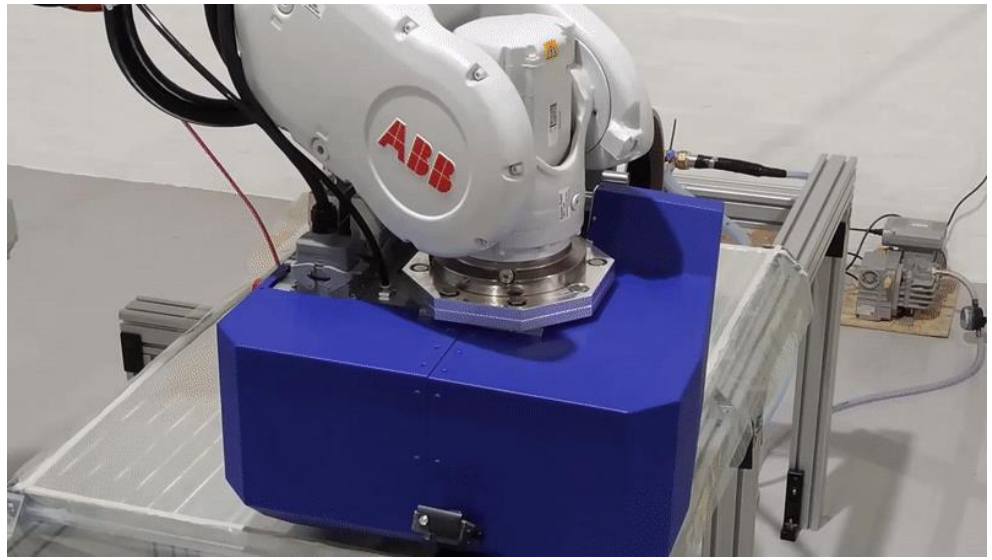
[1]



- Due to sensitivity to geometric imperfections [2]

$$\mathrm{KDF} = \frac{P^{\mathrm{ex}}}{P^{\mathrm{th}}}$$

- Steer fibres to tailor load paths
  - Reduced imperfection sensitivity due to symmetry-breaking effect of anisotropic stiffness [3]



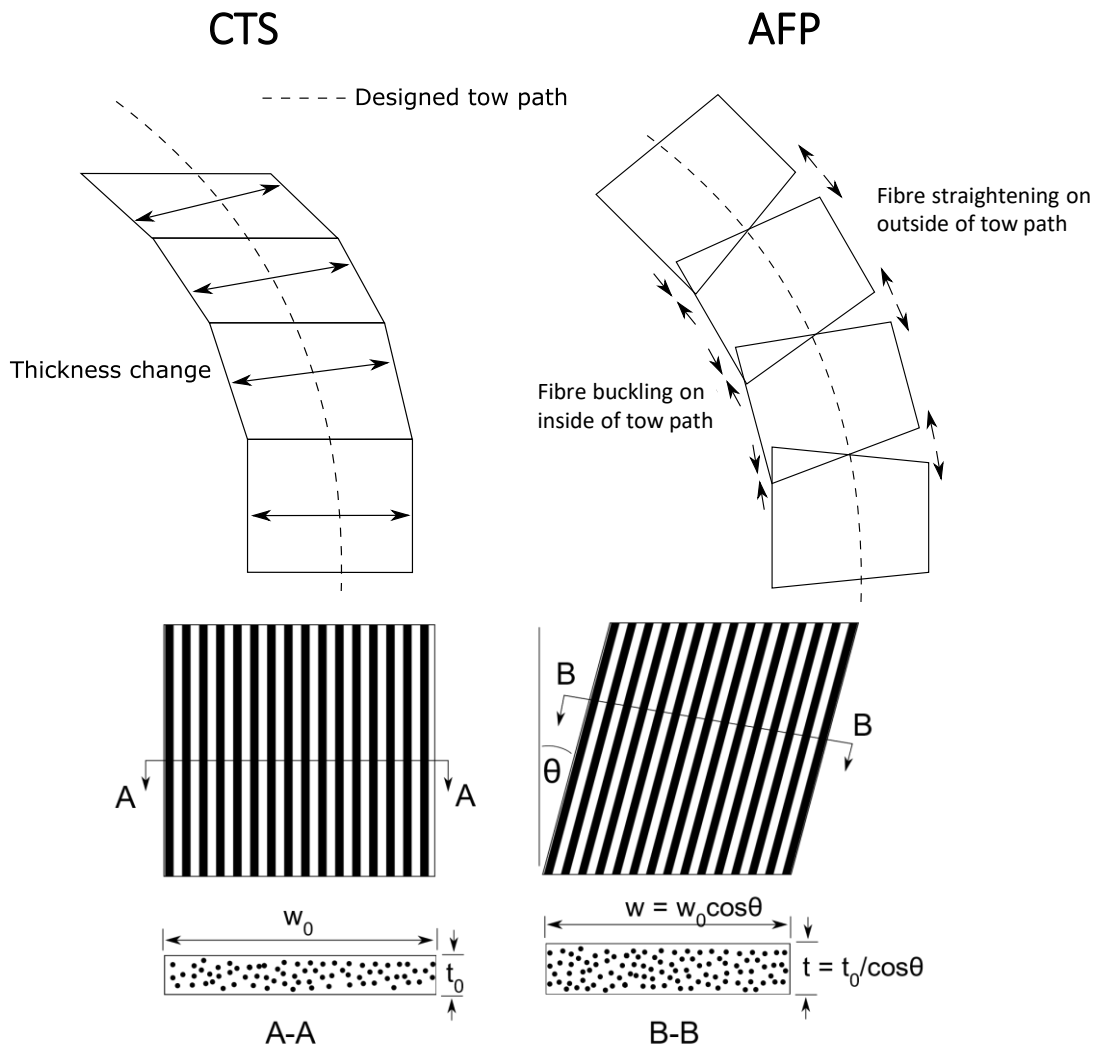
[4]

[1] Wagner, *Int. J. Mech. Sci.*, 2018
[2] Koiter, Tech. rep., NASA TT-F-10833, 1967
[3] Lincoln, *Compos. Struct.* 2019
[4] tinyurl.com/CTSLincolnApril2021

Context – Continuous Tow Shearing (CTS)

- Automated Fibre Placement (AFP) derived mechanism to place curvilinear tow paths [5]
  - Shears tows instead of in-plane bending of tows
  - Eliminates fibre buckling, fibre straightening, ply gaps, ply overlaps, has a smaller steering radii *and* perfect tessellation
- Additional design feature is a fibre-angle thickness coupling
  - Shearing by an angle θ results in a thickness build-up

$$t = t_0 / \cos(\theta)$$



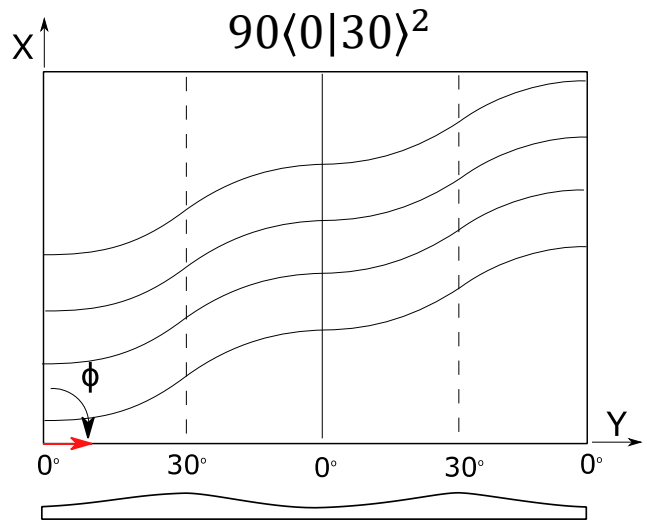
[5] Kim, *Compos. Part A – Appl. S.*, 2012

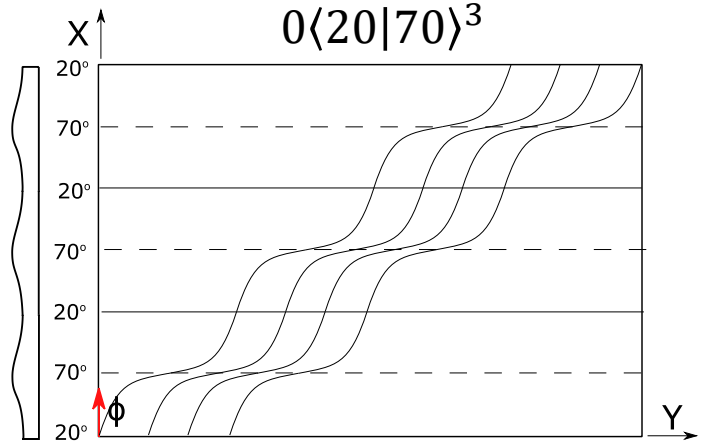
Context – Nomenclature

- Adaptation of Gürdal and Olmedo [6]

$$\phi\langle T_0|T_1\rangle^n$$

- Where:
  - $\phi = [0, 90]$
  - $n = [0, 1, \dots, 10]_{\phi=0}$
    $= [0, 1, \dots, 18]_{\phi=90}$
  - $T_0 = [0, 5, \dots, 70]$
  - $T_1 = [0, 5, \dots, 70]$





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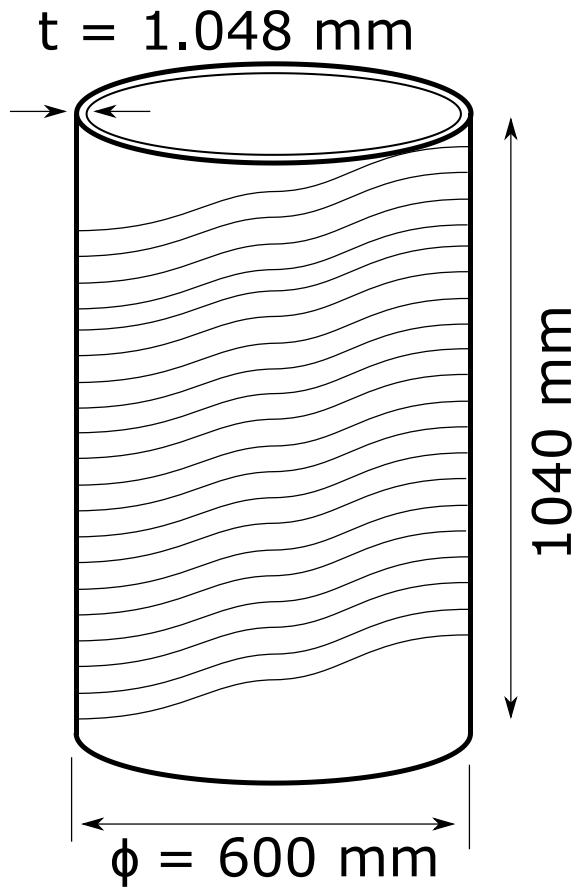
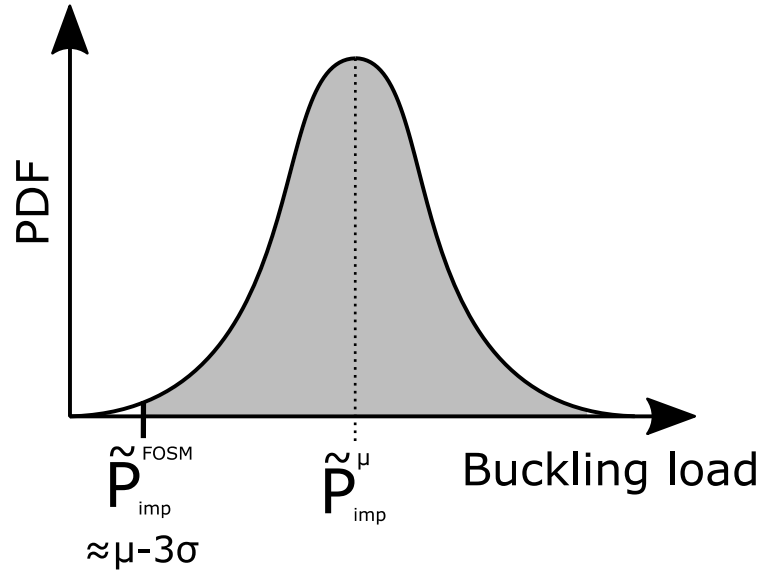
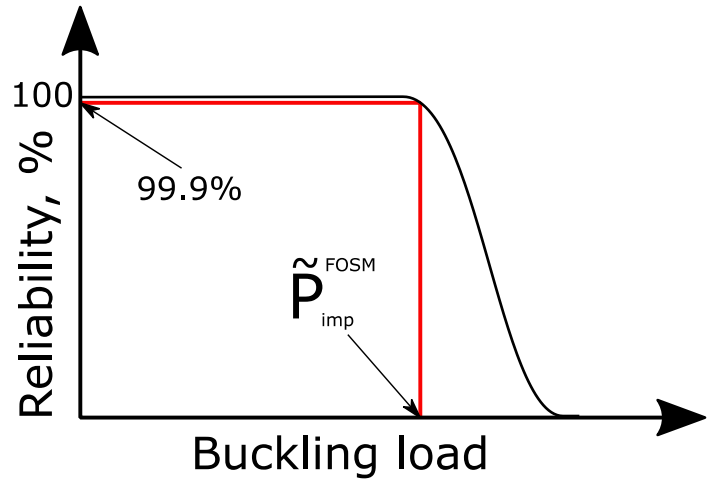


Optimisation

- Realistic imperfection signatures [7], 'reliability-based genetic algorithm' (GA)
- First-Order Second-Moment (FOSM) methodology [7] implemented into GA
- Maximize $\tilde{P}_{\mathrm{imp}}^{\mathrm{FOSM}}$ $(\tilde{P}_{\mathrm{imp}}^{\mathrm{FOSM}} = \tilde{P}_{\mathrm{imp}}^{\mu} - b \cdot \tilde{P}_{\mathrm{imp}}^{\sigma})$
  - $\tilde{P}_{\mathrm{imp}}^{\mu}$ is the specific, imperfect buckling of the mean imperfection signature
  - b is a reliability factor (assuming normal distribution and 99.9% of cases)
  - $\tilde{P}_{\mathrm{imp}}^{\sigma}$ is the standard deviation of buckling loads across the imperfection data set



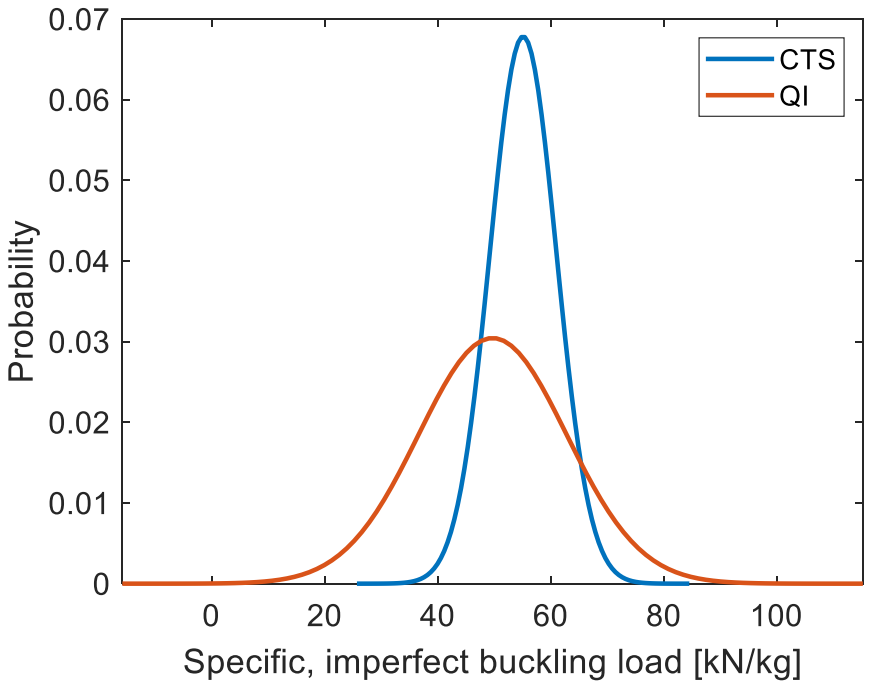


[7] Wagner, *Thin Wall. Struct*, 2020

Results

- GA-optimum has higher $\tilde{P}_{\mathrm{imp}}^{\mathrm{FOSM}}$ than QI

Layup	$\tilde{P}_{\mathrm{imp}}^{\mathrm{FOSM}}$ [kN / kg]	$\tilde{P}_{\mathrm{imp}}^{\mu}$ [kN / kg]	$\tilde{P}_{\mathrm{imp}}^{\sigma}$ [kN / kg]	$\mathrm{var}(\tilde{P}_{\mathrm{imp}})$	KDF
$[\pm 45, 0, 90]_s$	9.22	49.7	13.1	171	0.152
$[\pm 90\langle 65 \vert 60\rangle^2, 0\langle 0 \vert 20\rangle^9]_s$	36.9	55.1	5.88	34.6	0.574
Δ%	+120	+10.3	-76.1	-133	+166

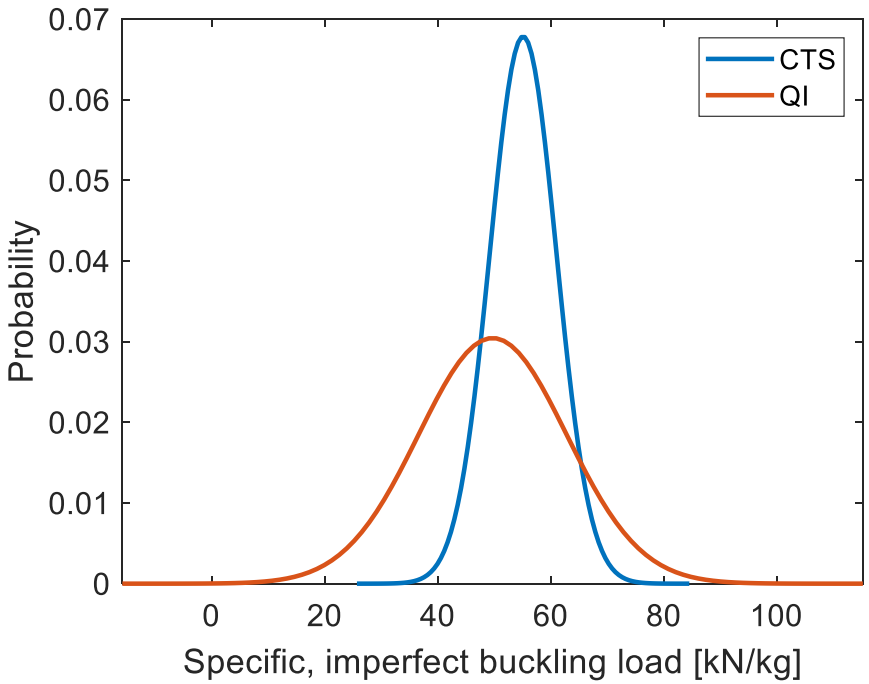


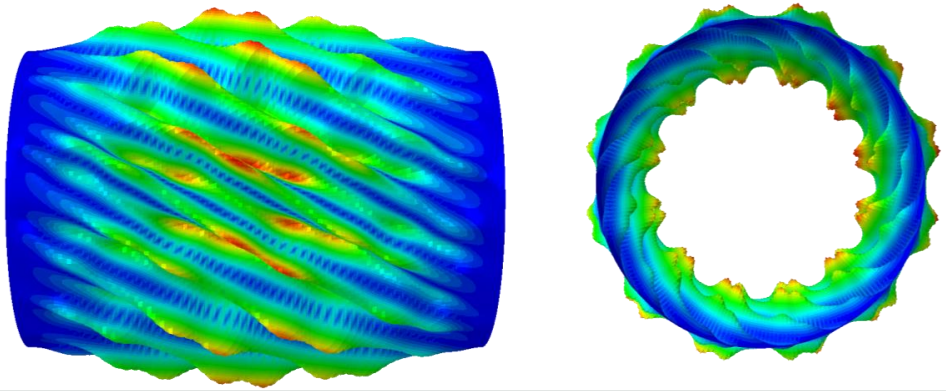
- 'Reliability-based' KDF calculated from

$$\mathrm{KDF} = \frac{\tilde{P}_{\mathrm{imp}}^{\mathrm{FOSM}}}{\tilde{P}_{\mathrm{perf}}}$$

Conclusions and future work

- Novel probabilistic ‘imperfect-geometry’ optimisation
- Realistic data bank of imperfections of composite cylinders
- Reliability has been increased through an increase in mean buckling load and decrease in std. and var





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Thank you for listening

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Poster: Optimisation of variable-stiffness cylinders under axial compression with realistic imperfections

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