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

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Context – Cylinders and tow shearing

- Due to sensitivity to geometric imperfections [2]

\[
KDF = \frac{p_{\text{ex}}}{p_{\text{th}}}
\]

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

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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 $\theta$ results in a thickness build-up
    $$ t = t_0 / \cos(\theta) $$


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Context – Nomenclature

- Adaptation of Gürdal and Olmedo [6]

\[ \phi(T_0 | T_1)^n \]

- Where:
  - \( \phi = [0, 90] \)
  - \( n = [0, 1, \ldots, 10]_{\phi=0} \)
    \[ = [0, 1, \ldots, 18]_{\phi=90} \]
  - \( T_0 = [0, 5, \ldots, 70] \)
  - \( T_1 = [0, 5, \ldots, 70] \)
Optimisation

• Realistic imperfection signatures [7], ‘reliability-based genetic algorithm’ (GA)

• First-Order Second-Moment (FOSM) methodology [7] implemented into GA

• Maximize $\bar{P}_{\text{imp}}^{\text{FOSM}}$ ($\bar{P}_{\text{imp}}^{\text{FOSM}} = \bar{P}_{\text{imp}}^\mu - b \cdot \bar{P}_{\text{imp}}^\sigma$)
  
  • $\bar{P}_{\text{imp}}^\mu$ is the specific, imperfect buckling of the mean imperfection signature
  
  • $b$ is a reliability factor (assuming normal distribution and 99.9% of cases)
  
  • $\bar{P}_{\text{imp}}^\sigma$ is the standard deviation of buckling loads across the imperfection data set

Results

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

<table>
<thead>
<tr>
<th>Layup</th>
<th>$\tilde{P}_{\text{imp}}^{\text{FOSM}}$ [kN / kg]</th>
<th>$\tilde{P}_{\text{imp}}^{\mu}$ [kN / kg]</th>
<th>$\tilde{P}_{\text{imp}}^{\sigma}$ [kN / kg]</th>
<th>var($\tilde{P}_{\text{imp}}$)</th>
<th>KDF</th>
</tr>
</thead>
<tbody>
<tr>
<td>$[\pm 45, 0, 90]_s$</td>
<td>9.22</td>
<td>49.7</td>
<td>13.1</td>
<td>171</td>
<td>0.152</td>
</tr>
<tr>
<td>$[\pm 90(65</td>
<td>60)^2, 0(0</td>
<td>20)^9]_s$</td>
<td>36.9</td>
<td>55.1</td>
<td>5.88</td>
</tr>
<tr>
<td>$\Delta%$</td>
<td>+120</td>
<td>+10.3</td>
<td>-76.1</td>
<td>-133</td>
<td>+166</td>
</tr>
</tbody>
</table>

• ‘Reliability-based’ KDF calculated from

\[
\text{KDF} = \frac{\tilde{P}_{\text{imp}}^{\text{FOSM}}}{\tilde{P}_{\text{perf}}}
\]
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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