Elastic Tailoring of Composite Structures by Fibre Steering

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

Doctoral Research Symposium 2023

4th April 2023

bristol.ac.uk/composites
Motivation: Lightweight Aerospace Structures

- Increasing use of advanced composites in aerospace structures
- **Mass efficiency is a key design driver**
  - Larger payload capacity
  - Lower fuel burn
  - Enable new economic opportunities

### Increasing Use of Advanced Composites in Aerospace

[Graph showing percent of composite in airframe from 1940 to 2020]

### Boeing 7E7 Dreamliner Material Use

[Diagram showing material distribution: Composites 50%, Titanium 15%, Aluminum 20%, Steel 10%, Other 5%]
Context: Fibre-Steered Composites

- Steering of composite material tapes produces non-constant fibre angle across a ply to redirect load paths and tailor performance.
- In-plane shearing of material tows by Continuous Tow Shearing (CTS) process along curvilinear reference eliminates potential defects and allows tessellation.
- CTS process exhibits nonlinear orientation-thickness coupling and allows periodic fibre steering.
Methodology: Structural Problem

• Application
  • Common aerospace problem of **simply supported panel under uniaxial compression**

• Hypothesis
  • Can a novel fibre-steered panel have a **greater load carrying** capacity than a conventional straight fibre panel?

• Constraints
  • Enforce ‘design’ load

**Problem Setup**

![Diagram of Problem Setup with labels: $u_x = 0$, $u_y = 0$, $u_z = 0$, $\Delta u_x < 0$, $\Delta u_x > 0$, and applied loading as uniform end-shortening.]

**Structural Targets**

- Applied loading as uniform end-shortening
- Design Load = 3600 N
- Force (N) vs. End-Shortening Displacement (m)

---

Elastic Tailoring of Composite Structures by Fibre Steering

4th April 2023
Results: Design for Load-Carrying Capacity

- Considering only balanced and symmetric layups
- No ‘bucklephobic’ design constraints

- Tailoring conducted on;
  - **Constant stiffness (CS)**, angle ply laminate
    - \([\pm \theta_1 / \pm \theta_2]_s, [t_0]_s\)
  - **Variable stiffness (VS)**, fibre-steered laminate
    - \([\pm \theta_1 (x,y) / \pm \theta_2 (x,y)]_s, [(t_0 \sec \theta(x,y))_2 / (t_0 \sec \theta(x,y))_2]_s\)

- Fibre-steered panels
  1. Increase and delay buckling load
  2. Improve postbuckling stability
  3. Increase mass-efficient load-carrying capacity
Conclusions & Future Work

• Significant scope for performance tailoring
• Increased design space allows for novel design
• Fibre-steered structures can achieve greater mass-specific performance

• Meta-heuristic optimisation to identify true solution space minima
• Addition of geometric features (cutouts)
Questions?

calum.mcinnes@bristol.ac.uk

References
