New manufacturing techniques for optimised fibre architectures

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This approach will not be constrained to architectures that can be produced using existing manufacturing technologies such as weaving or braiding.

Objectives

• Establish computational framework for textile preform optimization not limited to existing processes
• Via a series of case studies, identify classes of materials with improved properties over existing forms
• Develop new or modified textile preform technologies to realize these material forms
• Validate predicted properties and demonstrate their utility to materials suppliers and end-users
What is an optimised fibre architecture?

Motivation, existing solutions
What is an optimised fibre architecture?

Conservative composite design – “black aluminium”

- “Black aluminium” – quasi-isotropic laminates without load-specific design
- Overdesign of components

What is an optimised fibre architecture?

“Classical” optimisation of composite design

- Optimisation of ply sequence (layup)
- Load-specific optimisation of ply orientation
- Interplay between orthotropic plies

What is an optimised fibre architecture?

“Modern” optimisation of composite design

• Variable angle tow laminates
• Local load-specific design
• Aeroelastic tailoring

AFP layup of variable-stiffness cylinder

What is an optimised fibre architecture?

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Fibre tailoring in lug joint using composite 3D printing

Courtesy of Peng Zhuo (University of Nottingham)
Optimised textile architectures?

3D weaves, 3D braids

- Resistance to delamination
- Near-net shapes for reduced manufacturing and materials costs
- Integral joints: T joints, PI joints, seamless tubular/box sections
- Possibility to incorporate multifunctional materials

3D woven composites offer better delamination resistance

Unidirectional non-crump fabric laminate

Angle interlock 3D woven composite
Optimisation framework for 3D woven textiles
Optimisation framework for 3D woven textiles

What binder architecture can provide the properties we need?
Optimisation framework for 3D woven textiles

CIMComp Fellowship – establishing the framework

- Impossible to run through all the possible architectures
- Genetic algorithm provides faster way

Manufacturable textiles only
Optimisation framework for 3D woven textiles

CIMComp feasibility studies – extending the framework

- Relaxing the manufacturing constraints
- Introducing off-axis yarns
- 20% increase of buckling load vs orthogonal 3D weave
Optimisation framework for 3D woven and braided textiles

• Relaxing the manufacturing constraints further
  – Significant modifications to state-of-the-art manufacturing technologies
  – Development of novel manufacturing concepts driven by optimisation

  – Programmable motions with the knowledge of textiles to create optimised fibre architectures

• Multi-objective optimisation: buckling, delamination, permeability...
New manufacturing technologies

3D weaving, 3D braiding and many more
Current toolbox of manufacturing technologies (CIMCOMP)

3d weaving using Jacquard

Robotic tow placement and stitching

Radial braiding

9-axis winding

3D winding
3D Weaving

Carbon fibre weaving on a rapier loom (2014)

3D Weaving on a 4 x 4 shuttle loom (1990s)

Multi-insertion 3D weaving (2015)
Relaxing manufacturing constraints in 3D weaving

- Ability to change ‘weave topology’ at any location
  different locations
- Variable warp, weft and binder densities and tow counts
- Ply drops in warp and weft directions
- Ability to ‘lock-and-trim’ tows at any location
- Ability to change local tow tensions
Robotic fibre placement with stitching and tufting

- Multi-axial tow placement
- Variable density
- Contoured plies
- Off-axis plies
- Local tow steering!
Robotic multi-axial 3D weaving

Off-axis tows
Tow-steering
Plydrops
Integral joints
3D braiding

Triaxial or quadraxial layup

Steering of +/- tows in each layer

Through-thickness binders
Discussion

Potential routes for manufacturing optimised preforms

- 3D printing with continuous tows
- AFP technologies with prepregs and dry tape
- Textile preforming with ‘commercial tows’
  3D weaving and braiding technologies with optimized fibre layups, containing through-thickness reinforcement
  Low-cost, high volume manufacturing
  Compatibility with liquid infusion tech
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