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Improving the dynamic performance of launch vehicle structures

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Structural elements can account for up to 60% of a launch vehicle's dry mass, hence significant effort is being undertaken to develop **highly mass-efficient** structures. **Tow-steered composites**, those in which the reinforcement fibres follow curvilinear reference paths, give opportunities for structural tuning. The aim of this work is to design and optimise tow-steered structures that raise the dynamic performance of laminated **thin-walled cylindrical shells** for launch vehicle structures when compared to straight tow baseline designs.

1. Problem Specification

- Next-generation launch vehicles require lightweight structures to maximise payload to orbit.
- Tow-steered composites identified as avenue for significant structural performance benefits.
- Resonance represents structural instability and can lead to payload damage or vehicle loss.

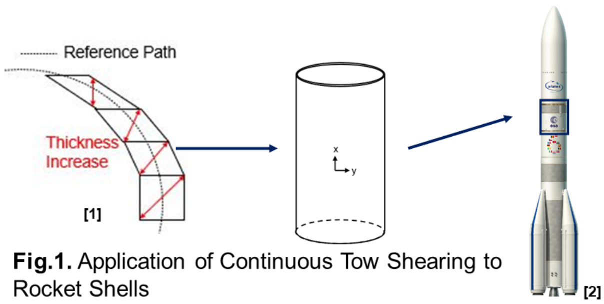

Fig.1. Application of Continuous Tow Shearing to Rocket Shells

3. Structural Analysis Methodology

- Eigenvalue extraction to calculate natural frequencies of Ariane 6 interstage demonstrator.
- Laminate stiffness components found by Classical Laminate Theory.
- Exhaustive search of potential reference paths with comparisons of frequency and stiffness results to straight tow designs.

4. Preliminary Results

- Structural deformation at resonance dominated by circumferential half-waves.
- Pseudo-hoops are most effective by raising crucial circumferential stiffness component ($\overline{D}_{22}$) through non-linear stiffness variations.
- Normalised-specific frequency increases of 102% and 22% with respect to Quasi-Isotropic and *optimum* straight tow designs respectively.

2. Tow-Steered Cylinder Design

- Tow steering achieved by Continuous Tow Shearing (CTS).
- Single CTS ply denoted as $\phi\langle T_0|T_1\rangle^n$. All considered laminates are balanced and symmetric.

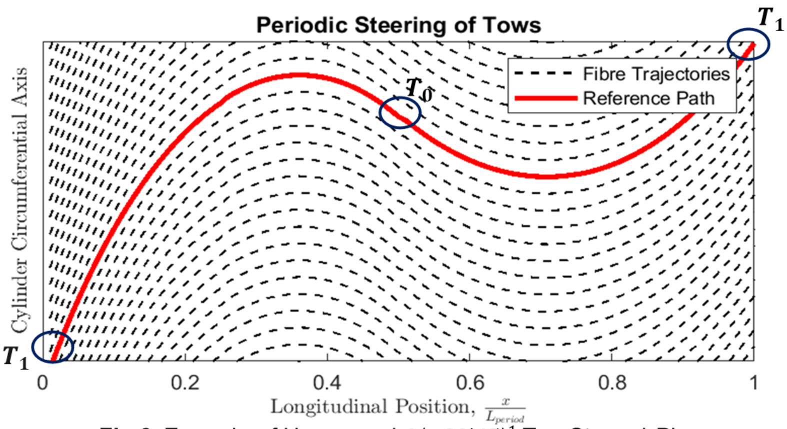

Fig.3. Example of Unwrapped $0\langle -30|45\rangle^1$ Tow-Steered Ply

- CTS process gives rise to an orientation-thickness coupling which can be exploited as pseudo-stiffening features.

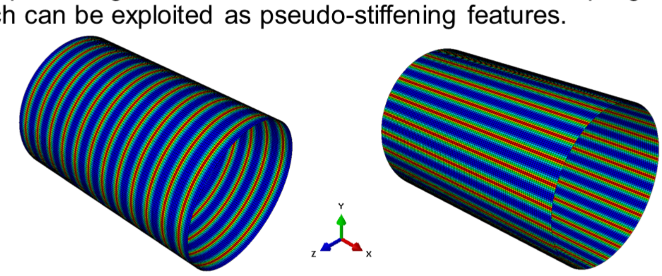

Fig.3. Circumferentially (L) and axially (R) thickness build-ups to give *pseudo-hoops* (L) and *pseudo-stringers* (R).

5. Future Work

- Detailed design space exploration.
- Formal optimisation studies for single and multiple loading conditions to maximise dynamic performance without impeding axial load-carrying capacity.
- Manufacture and test optimal structure demonstrator.

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[1] Kim, B. C., Potter, K., and Weaver, P. M., "Continuous tow shearing for manufacturing variable angle tow composites," Composites Part A: Applied Science and Manufacturing, Vol. 43, No. 8, 2012, pp. 1347–1356.

[2] J. Merino, A. Steinacher, M. Windisch, G. Heinrich, R. Forster and C. Bauer, "ARIANE 6 – TANKS & STRUCTURES FOR THE NEW EUROPEAN LAUNCHER," in German Aerospace Conference, Munich, 2017.