Development of a multiaxial test for a wind blade substructure

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Abstract

Large composite structures that are manufactured in bulk are often certified using a “testing pyramid” or “building block” approach, which is a methodology for evaluating design allowables for components at various length scales, starting at the coupon level for material characterisation to full-scale for full structural evaluation. Wind turbine blades (WTBs) are certified according to such an approach, although currently the only standardised means of collecting design allowables is at the coupon scale, whilst any tests between coupon and full scale is to be defined by the manufacturer [1]. The increase in blade size over recent years makes full-scale testing prohibitively time and cost intensive, and standardised substructure testing would help to provide structural behaviour data that can be used to inform full-scale design. To allow substructural testing to become a useful design tool, high-fidelity (HF) and multi-scale models are required to design the tests and to simulate the structural response accurately so that operational conditions can be simulated. It may not fully replace full-scale testing but will reduce the number of tests required for design development and certification, for example if the design of a detail or component internally to a large composite structure is altered. The validation of such models, and the test conditions they represent, is therefore essential for improving development, and therefore, robust validation methodologies must be implemented.

A testing rig has been designed to apply multiaxial load conditions to a WTB substructure using a kit of configurable structural frames in the Large Structures Testing Laboratory (LSTL) at the University of Southampton and custom clamps (Figure 1). The region of the WTB where the sparcap joins to the internal web was selected (referred to as the “T-joint”) as it is a region of structural importance, is relatively complex, open to design changes, and as of yet not included in WTB test standards. The specimen is an idealised version of the operational T-joint, with straight edges to ease manufacture and reproductivity. The composition is a combination of unidirectional (UD) and biaxial (biax) glass fibre reinforced polymer (GFRP) composites, epoxy resin, and wooden core materials. Key design stress components in representative combined load cases are applied to the T-joint using three servo-hydraulic actuators. The substructure test outcomes comprise the following increasing complex steps:

1. Elastic response identification and numerical modal validation
2. Decoupled and coupled load component analysis and comparison
3. Substructure strength and failure characterisation

Full-field imaging techniques are used to obtain measurements of the strain and stress fields on the surface of the T-joint specimens. Digital Image Correlation (DIC) obtains a discrete vector field of displacements by tracking subregions of white light images, from which strain is derived [2]. Thermoelastic Stress Analysis (TSA) evaluates principal stress state from temperature change for elastic bodies with known material characteristics for a measured temperature field [3]. The imaging equipment, as well as LVDTs, is attached to a frame that surrounds the T-joint specimens.

The captured and simulated data is compared and fused using a full-field data fusion (FFDF) methodology [4], which enables a holistic and quantitative HF analysis. The principles of this were demonstrated for a simpler 2D case, where a similar T-joint structure was tested under a three point bend configuration, and the numerical and experimental data was fused and compared [5]. For the significantly more complex 3D representative WTB T-joint substructure test presented here, the methodology is further developed to include three-dimensional surface mapping, to inform model validation and experimental condition monitoring.

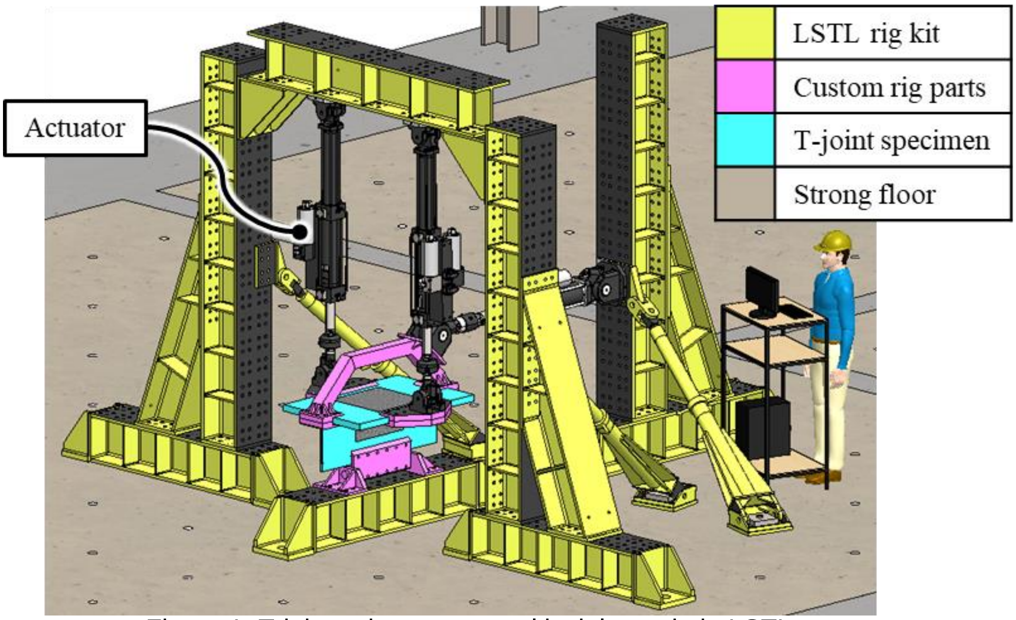

Figure 1: T-joint substructure multiaxial test rig in LSTL

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References

[1] DNV-GL, "DNVGL-ST-0376 Rotor blades for wind turbines," no. December, p. 107, 2015, [Online]. Available: http://www.dnvgl.com.

[2] T. C. Chu, W. F. Ranson, and M. A. Sutton, "Applications of digital-image-correlation techniques to experimental mechanics," *Exp. Mech.*, vol. 25, no. 3, pp. 232–244, 1985, doi: 10.1007/BF02325092.

[3] P. Stanley and W. K. Chan, "Quantitative stress analysis by means of the thermoelastic effect," *J. Strain Anal. Eng. Des.*, vol. 20, no. 3, pp. 129–137, 1985, doi: 10.1243/03093247V203129.

[4] J. S. Callaghan, O. T. Thomsen, J. M. Dulieu-Barton, and D. A. Crump, "A methodology for quantitative full-field comparison and fusion of multi-modal numerical and experimental data for complex composite substructures," *Submitted*, 2021.

[5] J. S. Callaghan, O. T. Thomsen, J. M. Dulieu-Barton, and S. Laustsen, "An integrated methodology for comparing and fusing full-field experimental and numerical data for complex composite substructures," 2019.