Sheffield Hallam University | Arts, Computing, Engineering and Sciences

Experimental Validation of the Structural Integrity of Modular Horizontal Axis Wind Turbine Blades

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Hallam Energy

Sustainable Places 2017

28th-30th June

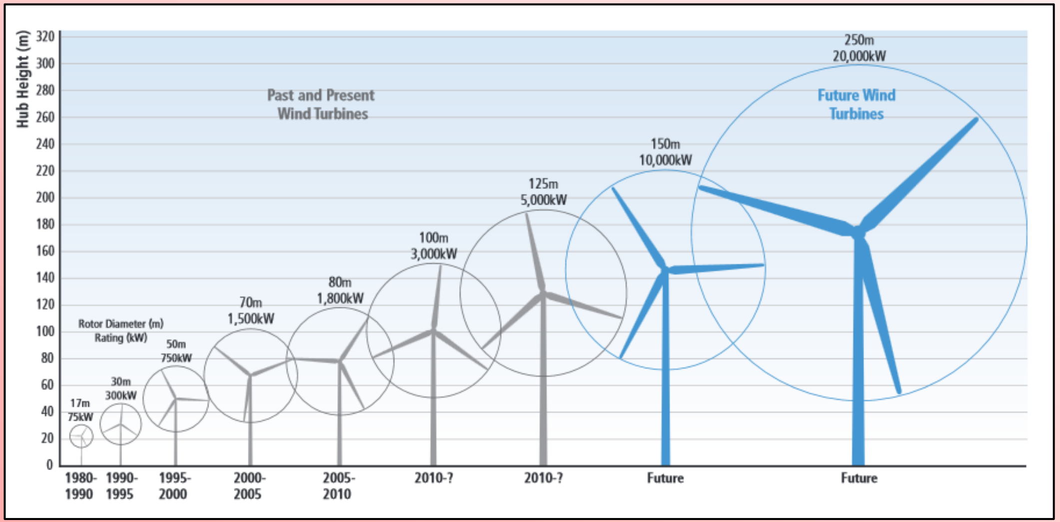
Middlesbrough UK

Teesside University

Teesside University

Sheffield Hallam University

Background



- Large wind turbine blades length > 85 m
- Larger sizes in future
- Blade Cost ~ £100,000
- Transportation Cost up to £50,000/blade

- Manufacturing
- Transport
- Repair

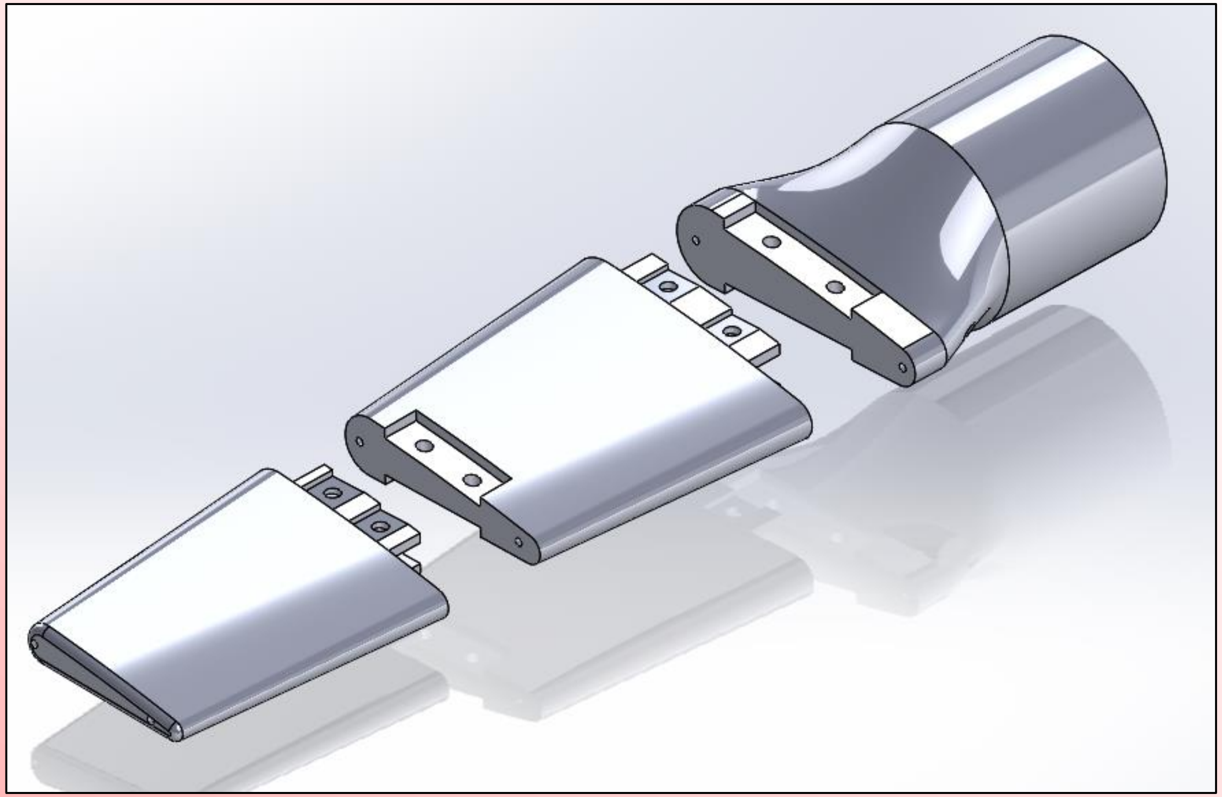
Expensive

- Transportation is the largest cause of wind turbine related public fatalities with 152 incidents recorded since 2002.
- These are generally caused by turbine components falling from transporters.

Modular Wind Turbine Blades

- Easy to manufacture in segments
- Lower transportation cost
- Easy repair or replacement

- Inherently weak due to joints



Project Aim and Objectives

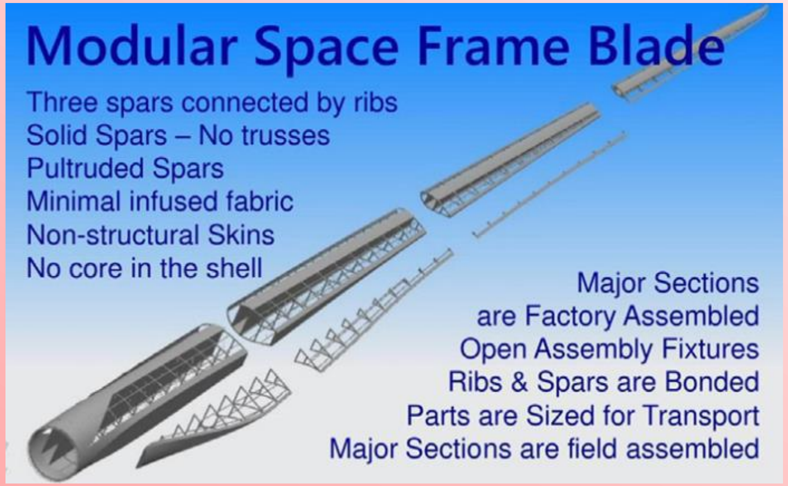
Aim:

Find if modular wind turbine design is structurally viable, so turbine blades can be transported in sections at a reduced cost, assembled onsite and modules can be replaced if damaged.

Objectives:

- **Create a modular design in CAD.**
- **Fabricate scaled final design prototypes using rapid prototyping (3D printing).**
- **Test and evaluate the prototypes performance against a conventional design in terms of stiffness and tensile integrity.**
- **Discover the suitability of a modular wind turbine blade design in horizontal axis applications.**

Current Modular Blade Designs



Wetzel Engineering

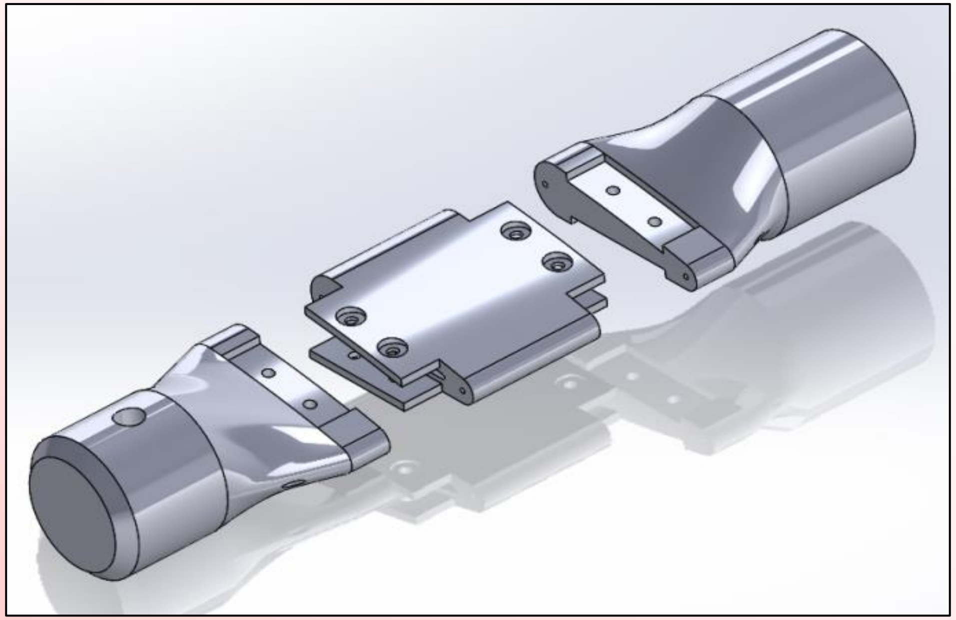
Blade Dynamics – D 78

Gamesa's G128 wind turbine blade

CAD Design and Prototypes

CAD Design in SolidWorks

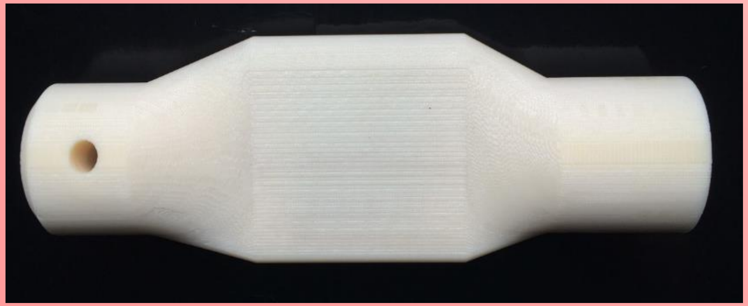
- 240-250mm in length



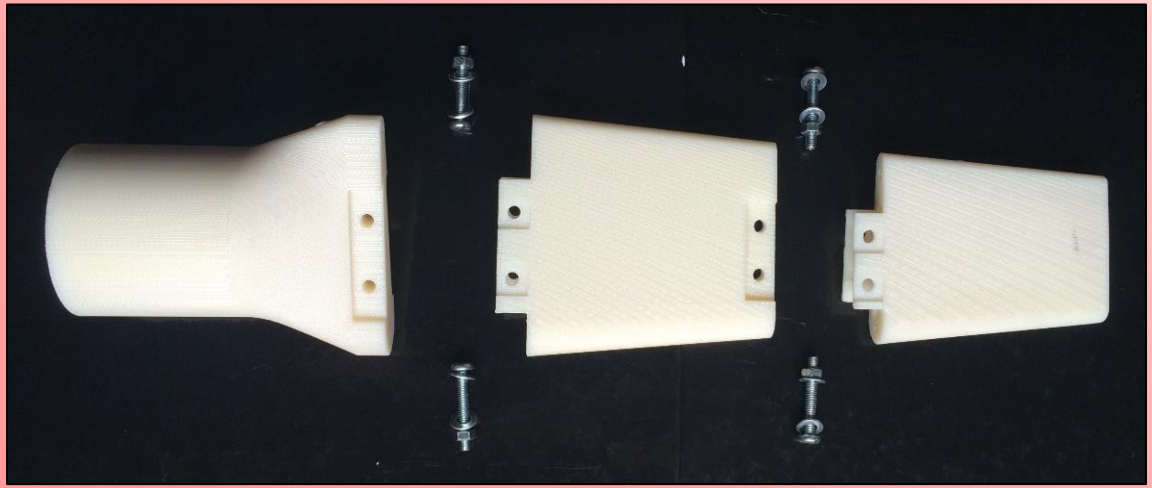
Material for Prototyping

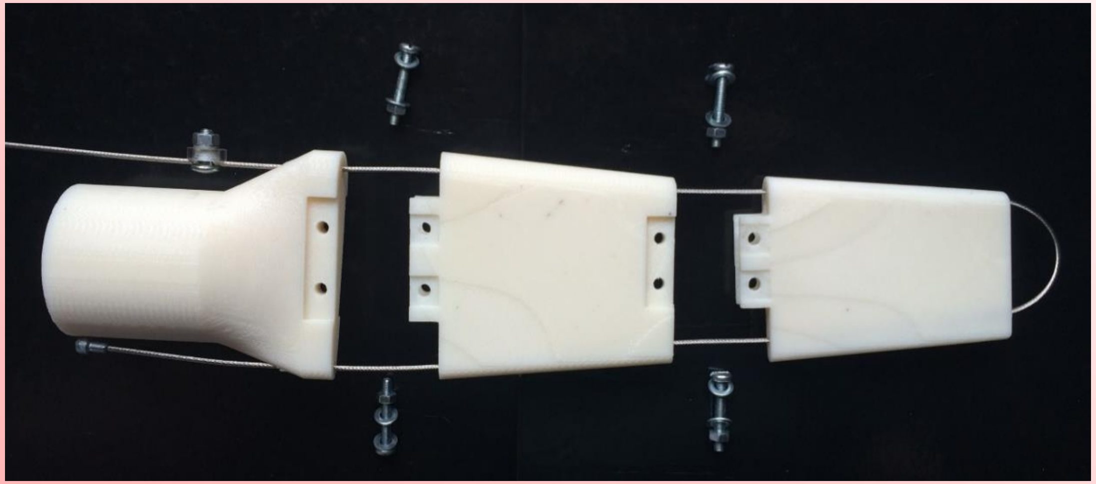
- Acrylonitrile-Butadiene-Styrene (ABS)
- Thermoplastic Polymer Material

3D printed blades : Layers of 0.245mm, perpendicular to leading edge

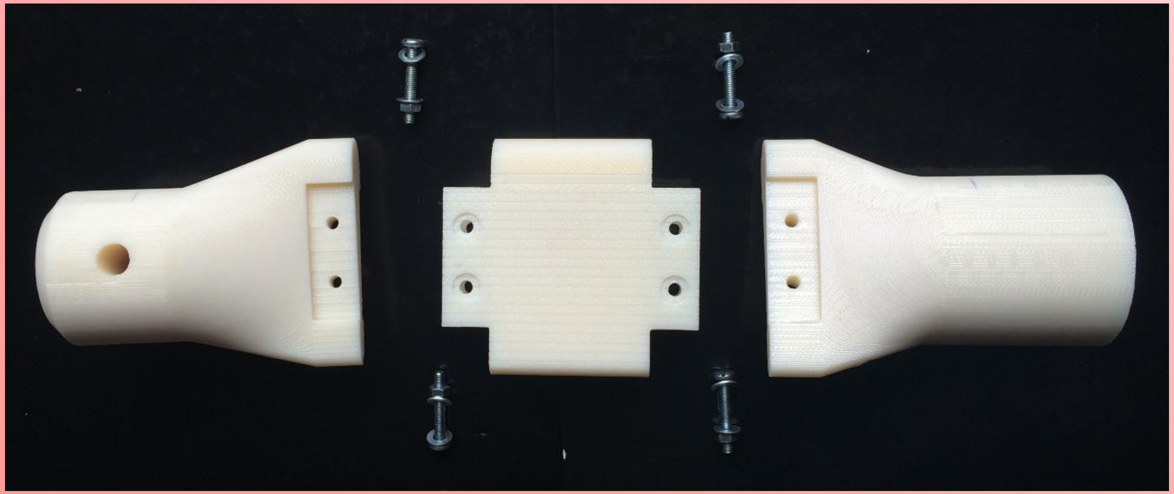


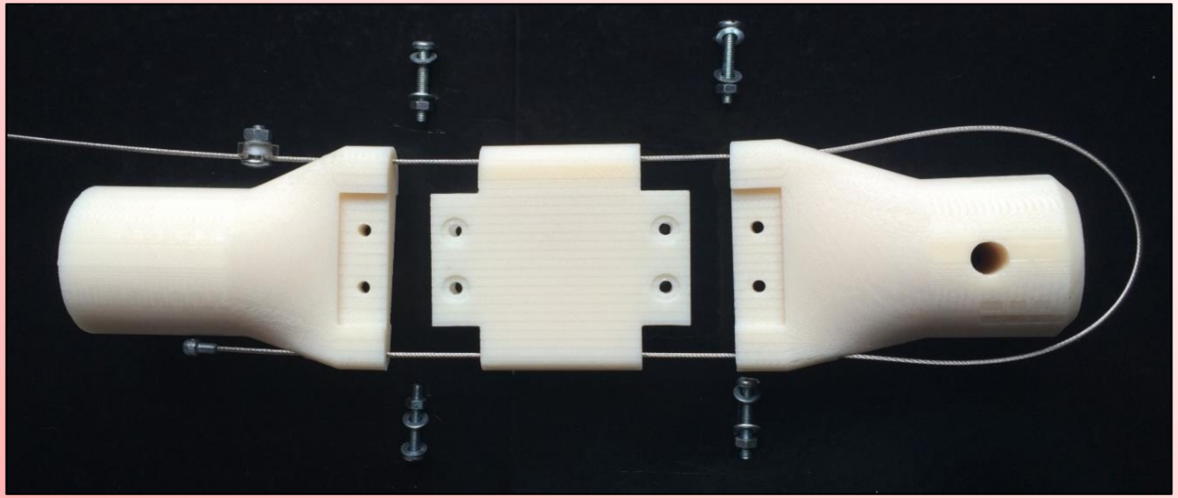
Cantilever Test Prototypes





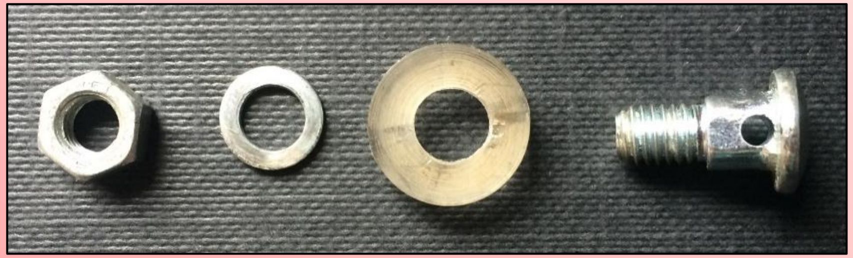
Tensile Test Prototypes





Metallic Components

1.6mm Shimano stainless steel bicycle brake cable, with welded anchor, used as post-tensioned tendons.

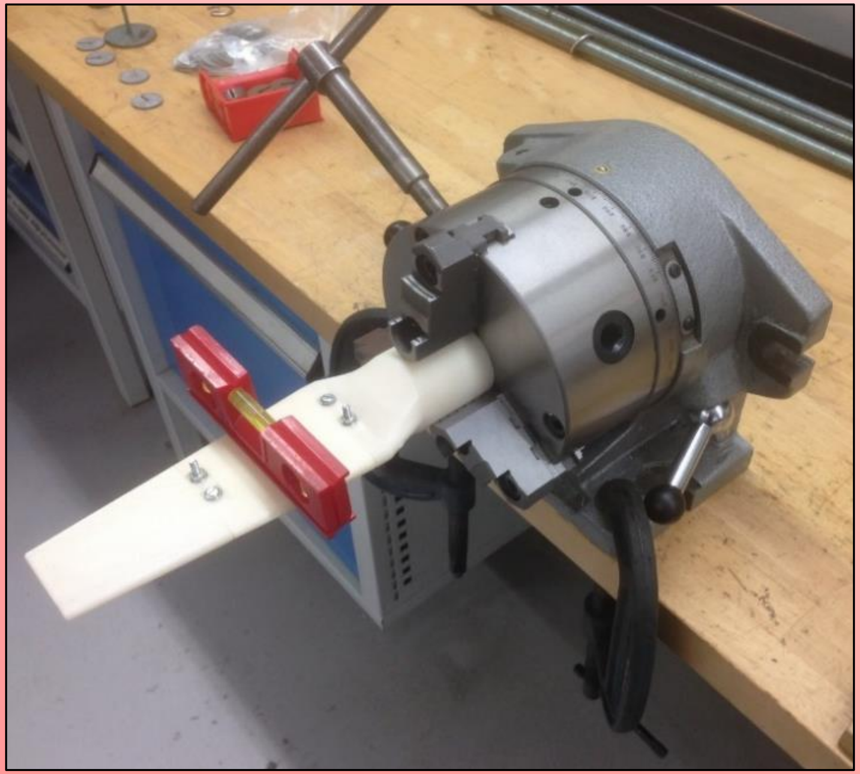


Cable clamp assembly, comprising a bolt with 1.6mm drilled hole, nylon washer, steel washer and nut. The cable is passed through the bolt hole and then clamped between the nylon washer and bolt head.

M4 Nut used to join the blade segments

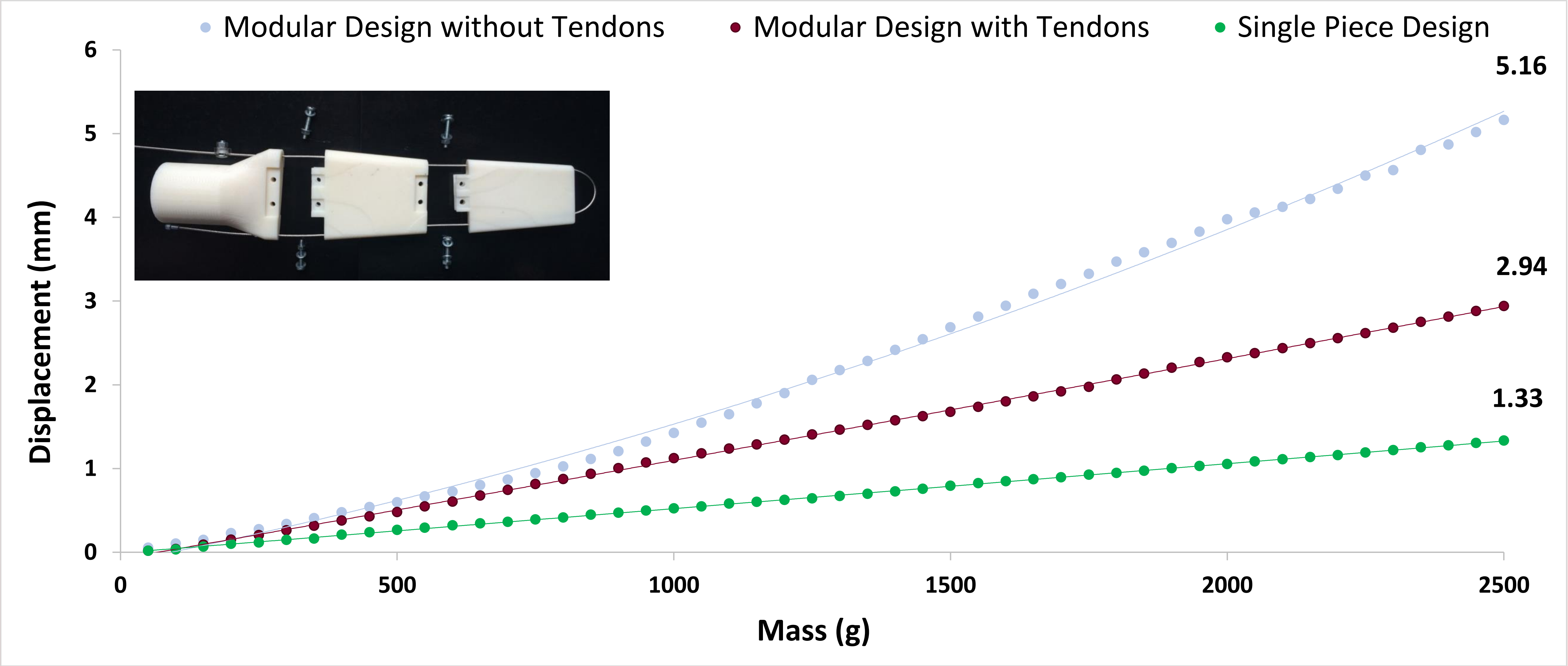
Cantilever Test Set Up

- Simulate the aerodynamic load applied to a wind turbine blade during service, as the blades root is fixed (replicating a hub attachment), and the load is applied at the end of the blade.
- Loaded cyclically to closer replicate changes in wind force, caused by wind shear.



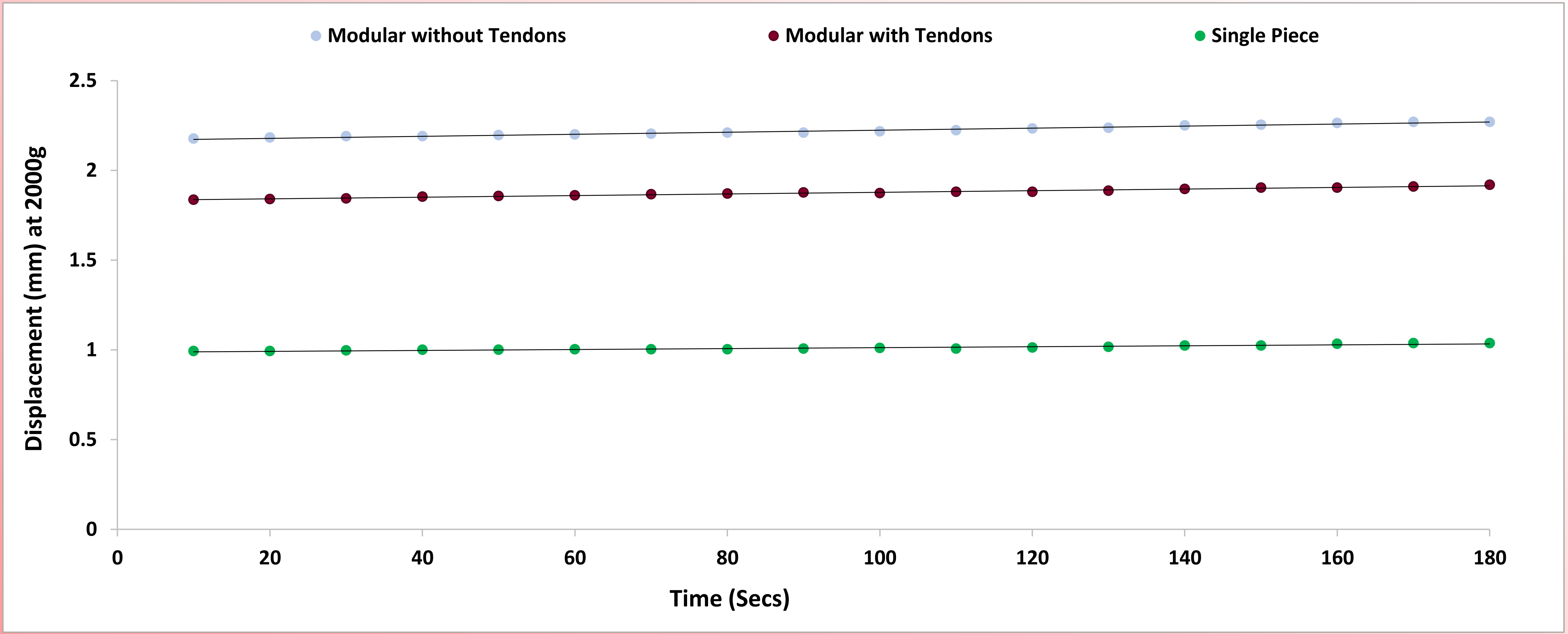
Deflection measured using a Mitutoyo 543-782 Absolute Digimatic Indicator

Cantilever Test with Incremental Loading



Tendons decreased incremental displacement by 43% in modular design. Could be improved further by properly tightening the tendons.

Cantilever Test with Cyclic Loading



Tendons reduced displacement by 15.4% for cyclic test

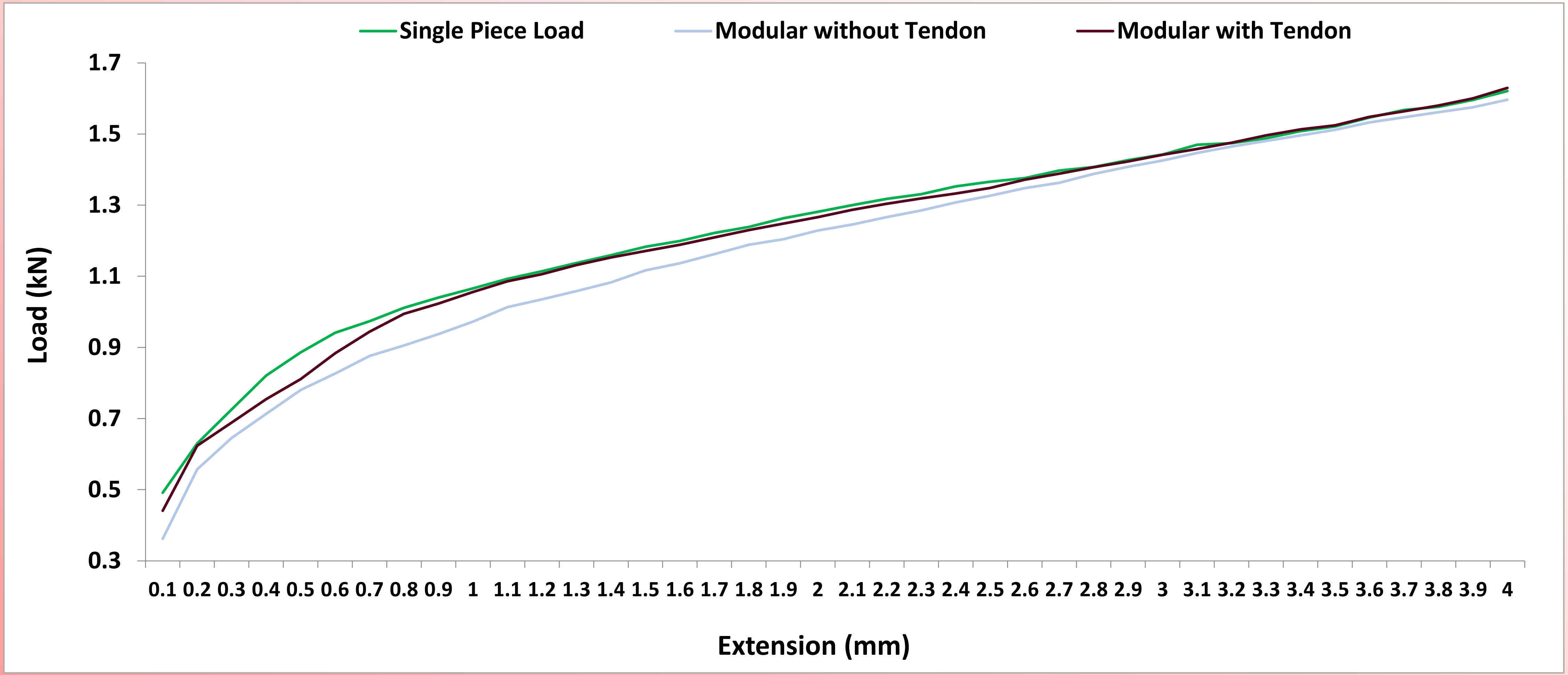
Tensile Test Set Up

- Prototypes positioned in dividing heads clamped to a DMG servo-hydraulic 50 kN mechanical testing machine during the tensile testing.

- The Rubicon Control Interface software extended each prototype in 0.1 mm increments whilst recording the peak load (kN) for each extension.

- The peak load was recorded for each 0.1 mm of extension until 4 mm.

Tensile Test Set Up

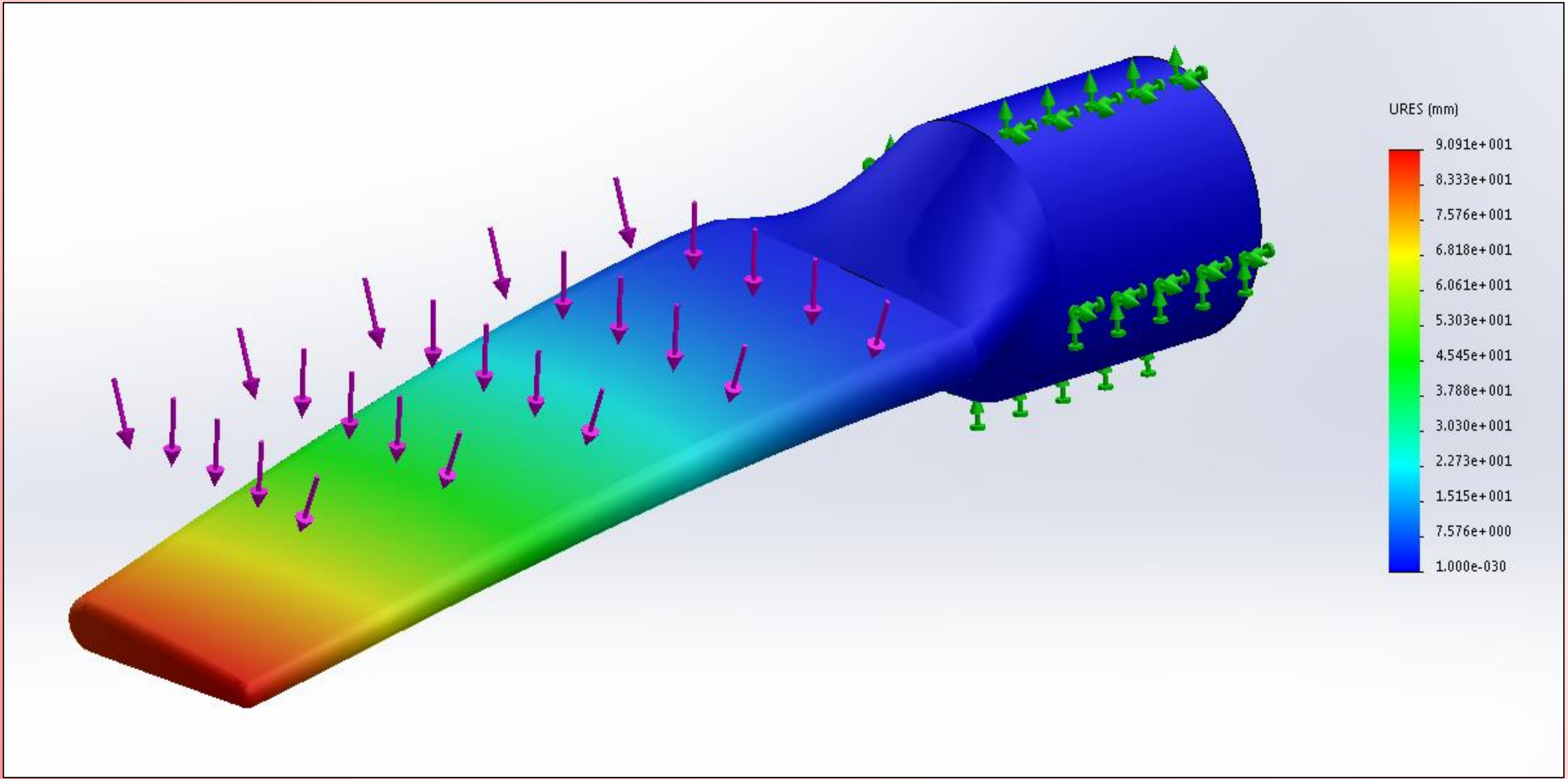


The tensile tests showed 1.45% difference between the standard single piece blade design and modular design with tendon.

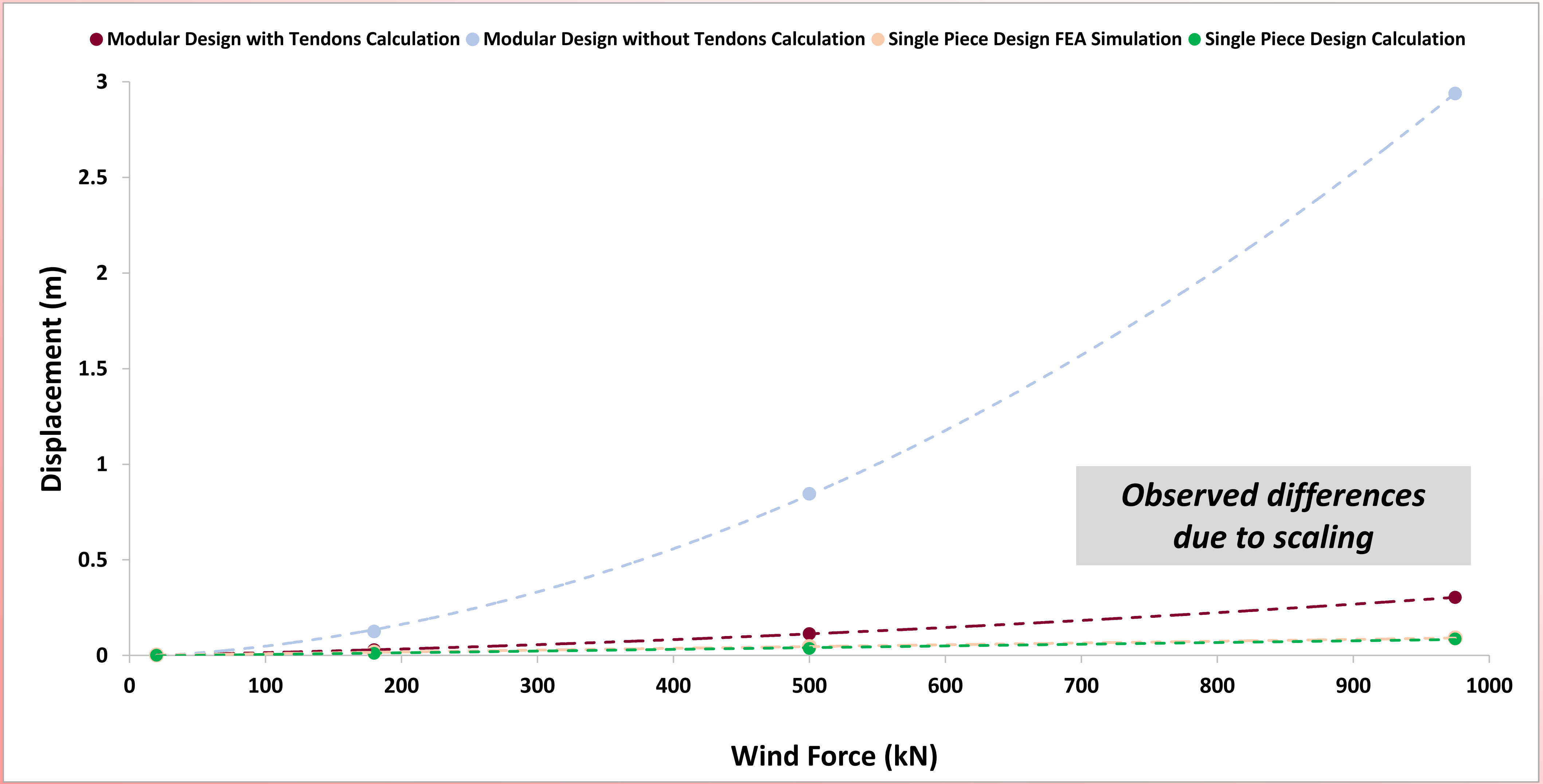
Tensile Test

- 1 to 2 mm movement allowed at joints in the scaled model.
- Better joint possible on larger blade.
- Tendons could tightened further on larger blades.

Upscaling to 50 m - Cantilever FEA Simulation



Experimental Validation on Scaled Prototypes



Conclusions

- **Modular blade design with tendons were only 5.71% heavier than the standard single piece blade design.**
- **Tendons decreased incremental displacement by 43% as compared to modular design without tendons in incremental test.**
- **The cyclic tests showed 15.4 % reduction in displacement for the modular design with tendons compared to modular blades without tendons design.**
- **5.8% difference between cantilever test and FEA simulation was observed for a 50m single piece design. Differences observed due to scaling.**
- **The tensile tests showed 1.45% difference between the standard blade design and modular design with tendon.**
- **The modular design without tendons performed consistently inferior throughout – unsuitable**
- **Modular design with tendons has potential but requires further testing and refinement.**
- **The performance of the modular design with tendons will be significantly improved by upscaling.**

Patents/Patent Applications

- GB2477847: Rotor blade with a segmented supporting structure and method for manufacturing the rotor blade for large wind turbines

- WO2011098785: Method of forming an aerodynamic arrangement by joining of segments for large wind turbines

Thank you

Any questions ?

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A full reference list can be provided on request.