Bioinspired Aerofoils for Small Wind Turbines

18th International Conference on Renewable Energies and Power Quality (ICREPQ'20)

#488

R. Mulligan

Heriot-Watt University, Edinburgh, UK

rm96@hw.ac.uk

Background

7 AFFORDABLE AND CLEAN ENERGY

According to the UN, 1 in 10 people still do not have access to electricity [1] and most are in rural areas where small off-grid wind turbines could be the best solution.

This project aims to look at two bio-inspired methods for improving the performance of small wind turbines.

Small-Scale Turbine Issues

- Lacks the control mechanisms of larger turbines
- Simpler blade designs
- Typically have a higher cost per kW-h

Objectives:

1. A wind tunnel aerodynamic performance analysis was conducted on a set of corrugated aerofoils.
2. The effects of aeroelasticity on a flexible blade structure was explored using the QBlade[2] open source platform.

Biomimicry

What is biomimicry?

Biomimicry looks to nature for inspiration to solve human design challenges.

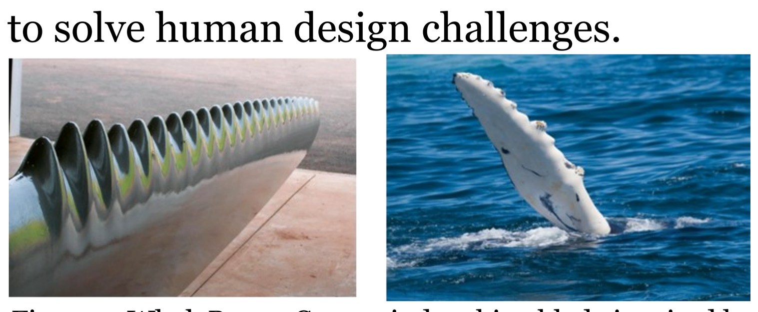


Figure 1: WhalePower Corp[3] wind turbine blade inspired by humpback whale tubercles

A company called Whale Power has adapted a wind turbine blade to have tubercle-like bumps on the leading edge which reduces drag and increased efficiency by up to 20%.[3]

Blade adaptations inspired by dragonflies?

Corrugated wing

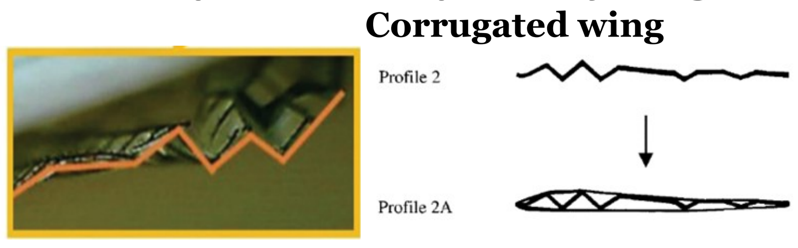


Figure 2: Dragonfly wing cross-section

Wind tunnel [4] and CFD [5] studies have shown an improvement of a dragonfly wing structure on the lift to drag ratio compared to a smooth aerofoil

Blade flexibility

Plants have flexible stems to tolerate high winds. In addition, an insect's flexible wing enable less thrust to be required to produce the same amount of lift .

Method

Part 1: Corrugated Aerofoil

Design

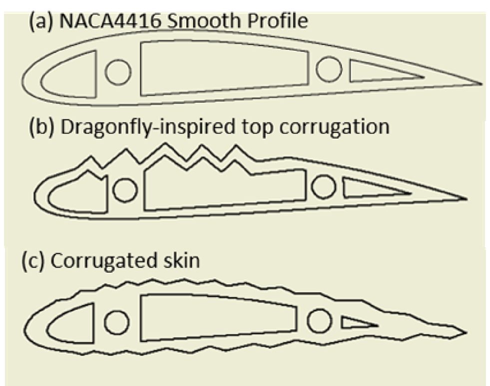


Figure 3: Aerofoil Designs

Testing

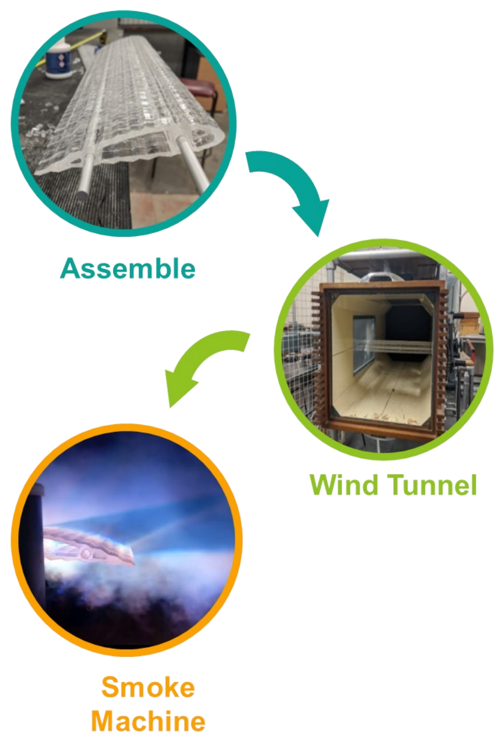


Figure 4: Corrugated aerofoils test procedure

Part 2: QBlade Aeroelastic Simulations

Design

E (GPa)	flexibility	Material
73	Rigid	CFRP
40	Semi-flexible	E-glass/ Epoxy
10	Fully flexible	Bamboo/ poplar

Table 1: Material properties of blades of varying flexibility

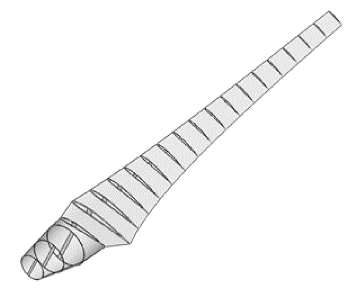


Figure 5: Blade Design

- 2-blade 5kw turbine with diameter 5m.
- NACA 4412 aerofoil
- Pitch and chamber optimised
- Spar and thickness

Testing

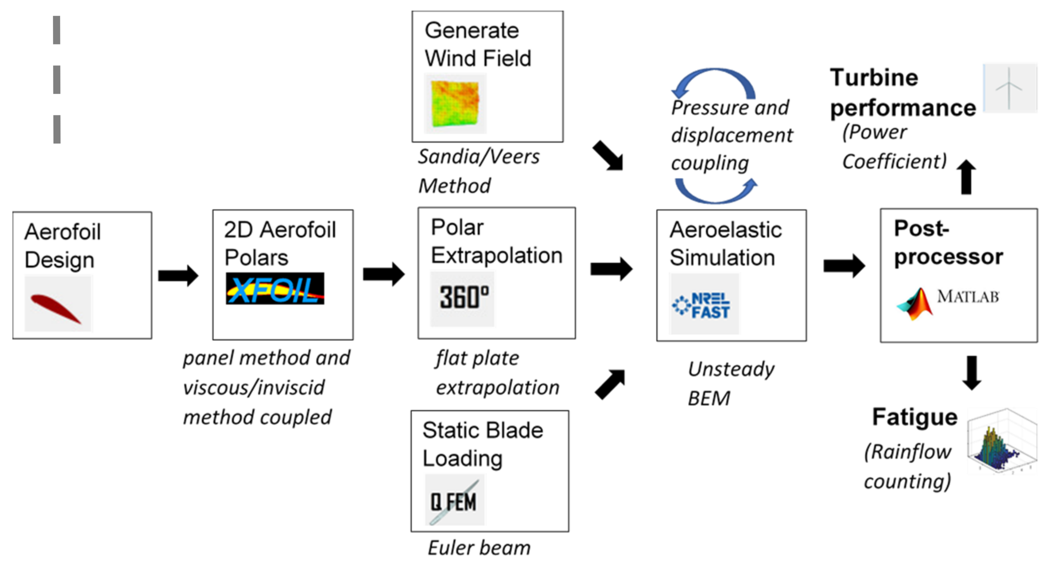
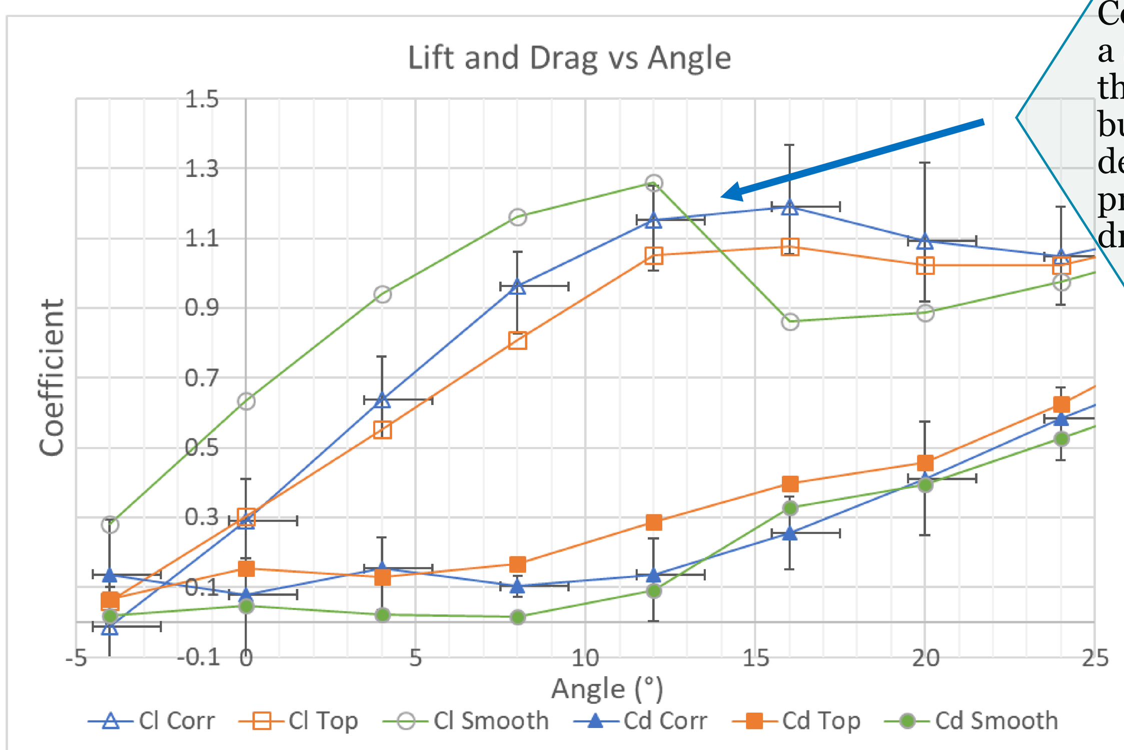


Figure 6: Flow diagram of QBlade method for aeroelastic simulations

Results

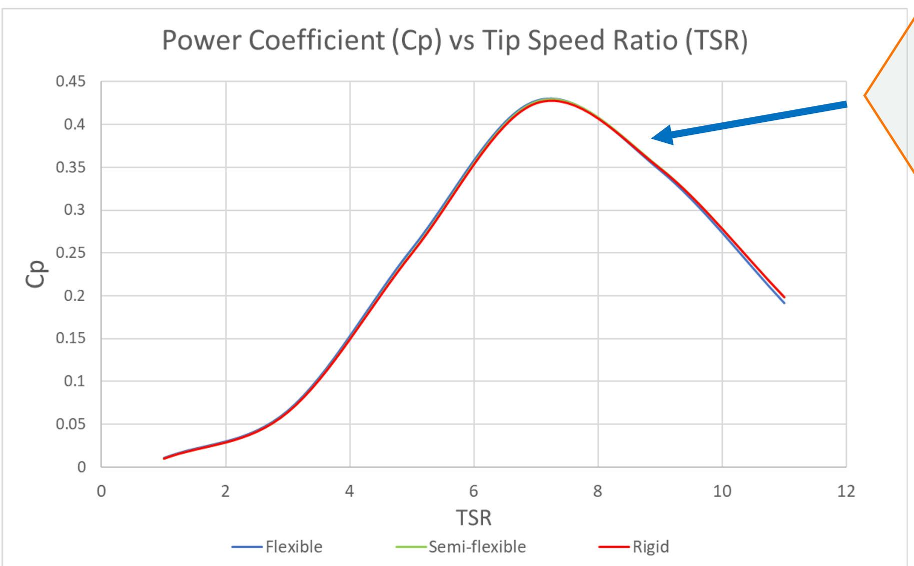
1. Corrugation on Performance



Corrugation gives a slight reduction in the lift to drag ratio but importantly delays stall and prevents this big drop in lift

Figure 7: Lift and Drag coefficient versus angle of attack for corrugated, top corrugated, and smooth aerofoils (*shown in figure 3*)

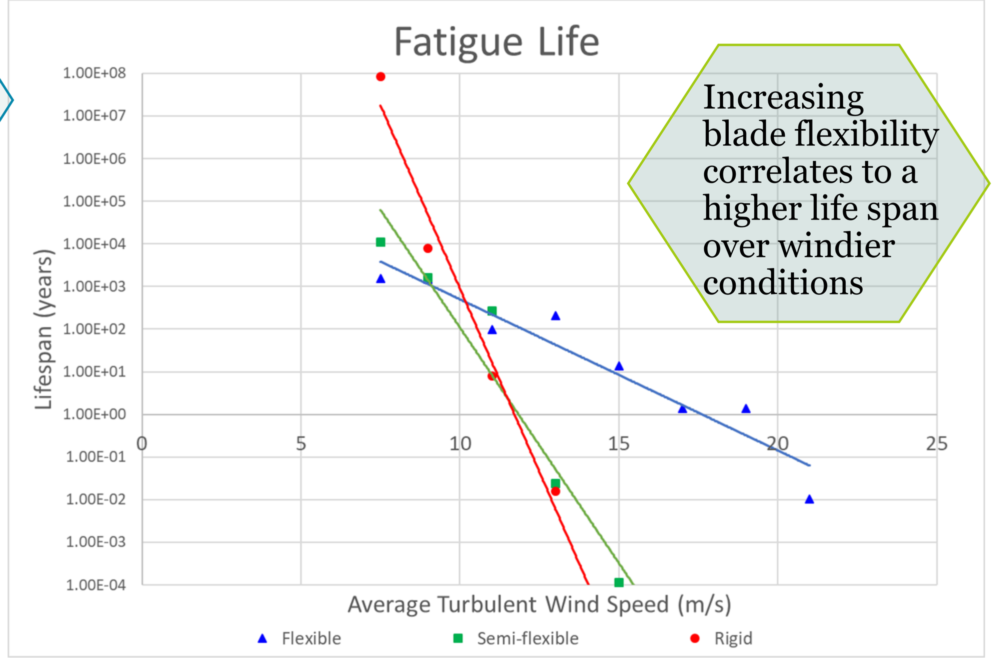
2. Flexibility on Performance



Despite the large deflections, the QBlade simulations showed very minimal difference in the power coefficient

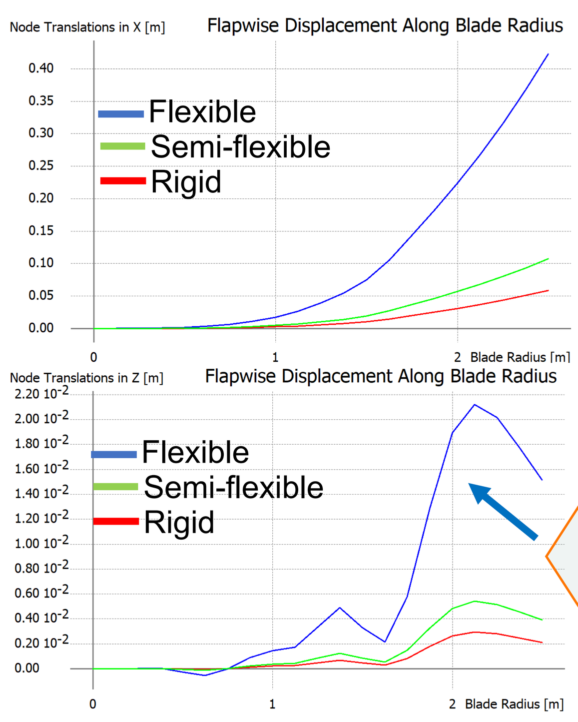
Figure 8: Power Coefficient versus Tip Speed Ratio for the fully flexible, semi-flexible, and rigid blade

3. Flexibility on Fatigue Life



Increasing blade flexibility correlates to a higher life span over windier conditions

Figure 9: Lifetime of wind turbine (effects of cyclic blade loading only) with an increasing average windspeed with a turbulent intensity of 18%



A high edgewise displacement should alter the chamber of the foil and affect the performance

Figure 10 *(top)* & Figure 11 *(bottom)*: Flapwise and Edgewise displacement along the blade radius under wind loading conditions

The flexible blade stress waves are more distributed in amplitude and mean stress is lower

Rigid blade has smaller stress waves but more frequent

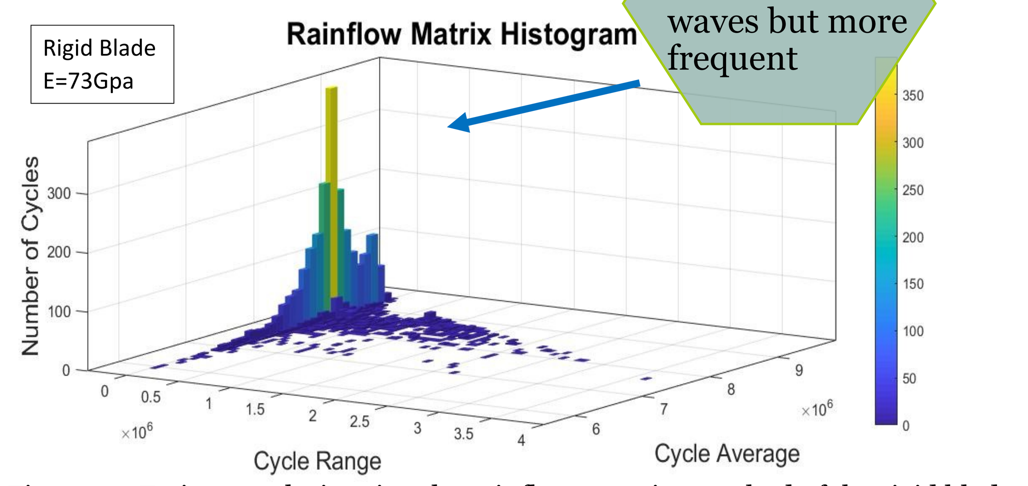


Figure 12: Fatigue analysis using the rainflow counting method of the rigid blade

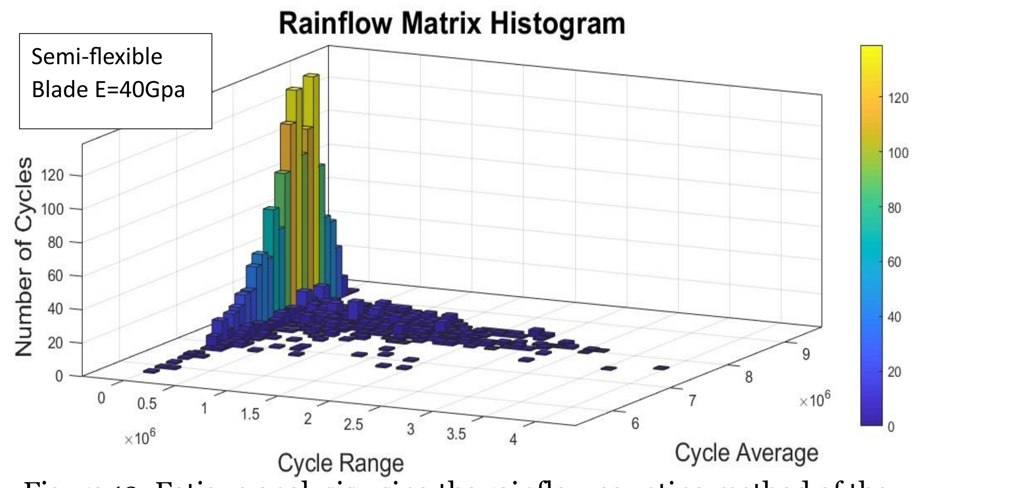


Figure 13: Fatigue analysis using the rainflow counting method of the semi-flexible blade

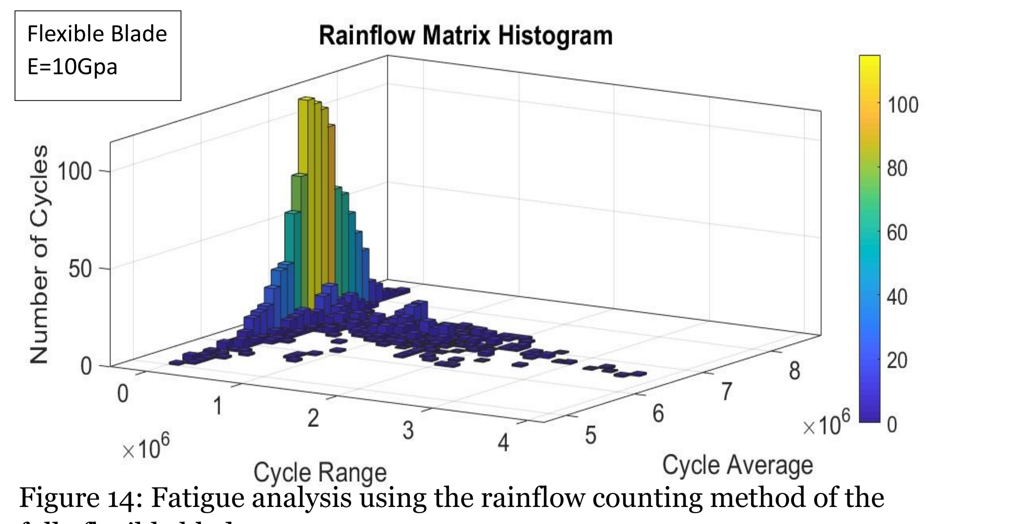


Figure 14: Fatigue analysis using the rainflow counting method of the fully flexible blade

Conclusion

Stall

Both corrugated structures delayed stall by 4° and minimised the post-stall effects. Thus, the wind turbine operates more efficiently over a larger range of windspeeds.

Lift and Drag

The corrugated skin displayed small a reduction of 7.3% in the lift to drag but has the steepest lift slope. The top corrugated aerofoil had higher drag due to an early separation of the boundary layer and increased vortices.

Power Coefficient

A large edgewise displacement in the flexible blade should increase chamber and improve lift however the Qblade results show no difference in the Cp with flexibility.

Fatigue

Increasing the flexibility of the blade resulted in a decrease in the root bending moment and an increase in the lifespan of the blade which is more tolerant to high wind regimes .

Future Research and Technologies

Limitations and Further Research:

In order to develop an industrial design combining these two technologies, further research identified in the following areas:

- A physical model to validate the performance of a flexible blade (Qblade may have some limitations).
- Rainflow fatigue analysis was highly sensitive, again could be validated with a test turbine.
- Corrugation size requires optimisation through CFD.

Sustainability:

Composite fibreglass blades are difficult to recycle. Sustainable alternatives such as bamboo has been shown here to:

- provide comparable performance
- increase the design lifetime of the blade.

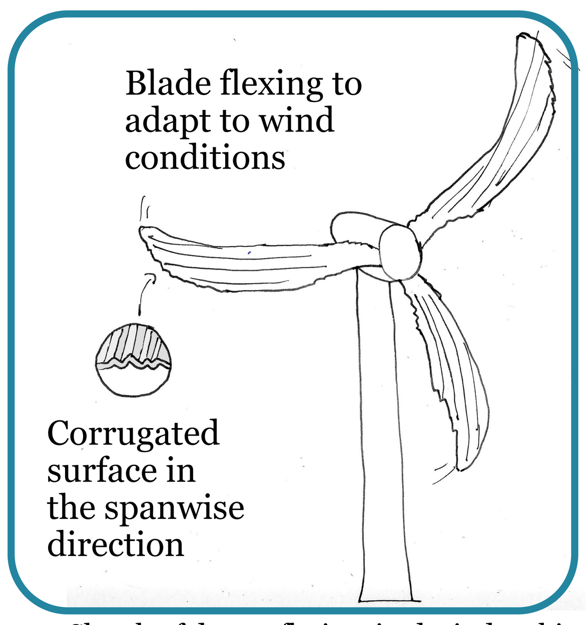


Figure 15: Sketch of dragonfly-inspired wind turbine combining blade flexibility and corrugation

References

1. UN, "Affordable and clean energy" The Sustainable Development Goals Report, UN, New York (2019).
2. D. Marten, "QBlade Guidelines v 0.6", TU , Berlin (2012).
3. F. Fish et al. "The tubercles on humpback whales' flippers: application of bio-inspired technology", Integr Comp Biol (2011). Vol. 51, pp. 203-213.
4. S. Zhang et al. "Influence of Microstructures on Aerodynamic Characteristics for Dragonfly Wing in Gliding Flight", Journal of Bionic Engineering (2019). Vol. 16, pp. 423-431.
5. A. B. Kesel, "Aerodynamic characteristics of dragonfly wing sections compared with technical aerofoils", Journal of Experimental Biology (2000). Vol. 203, no. 20, p. 3125.

Acknowledgements

I wish to extend my thanks to Wolf-Gerrit Fruh for his supervision and expertise across the whole project. This work was supported by the Institute of Mechanical, Process and Energy Engineering at Heriot-Watt University and made possible by the Incorporation of Hammermen of Edinburgh Award.

Contact

For more information please contact:

Rosie Mulligan

rm96@hw.ac.uk

HERIOT WATT UNIVERSITY