Challenges of Morphing Wings for Airborne Wind Energy Systems

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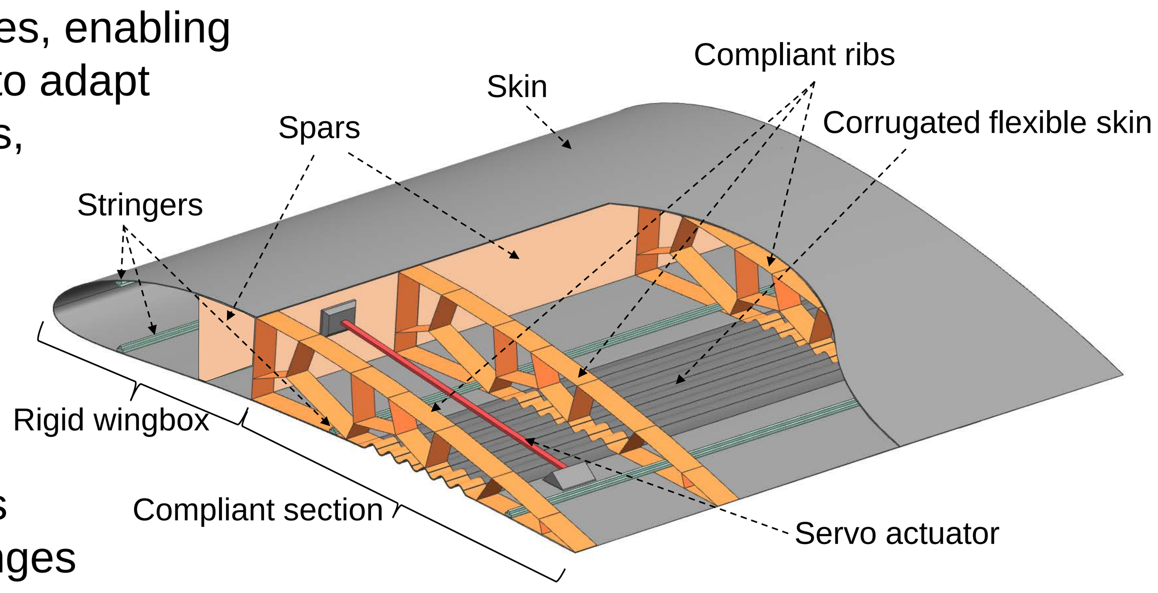
1 Morphing Wings

Conformal morphing of aerodynamic surfaces can be used to alter their properties, enabling to control the aircraft motion and to adapt to a wide range of flight conditions, in a similar fashion as birds deform their wings.



Wing structure and actuation

Advantages of Morphing
- Smooth deformations
- Component count reduction
- Gapless aerodynamic surfaces
- Elimination of bearings and hinges
- Optimal aerodynamics for various flight conditions

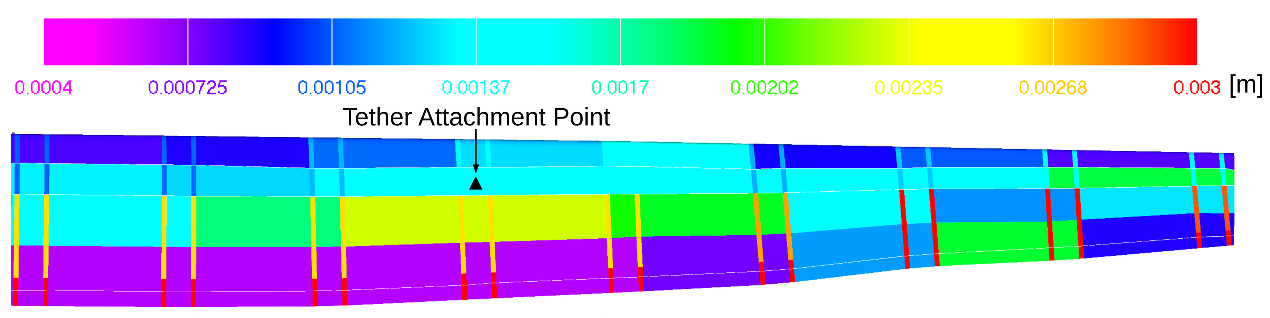
Potential of morphing for AWE applications
- Adaptation of lift distribution enabling optimal performance over a wide range of wind speeds
- Weight decrease through load carrying distributed compliance morphing structure
- Potential for gust load alleviation and load tailoring
- Parasitic drag reduction

Morphing wings appears to have conflicting requirements. The structure needs to be stiff to withstand the loads, while still being compliant to adapt its shape through aerodynamically favourable deformations.

3 Aircraft

The optimized system is based on the concept developed by ftero using a vertical take-off and landing system. The tether is attached at the fuselages. The optimized laminate decreased the weight by 12% with respect to the original design, while maintaining the load carrying capabilities, namely buckling factor and flutter speed.

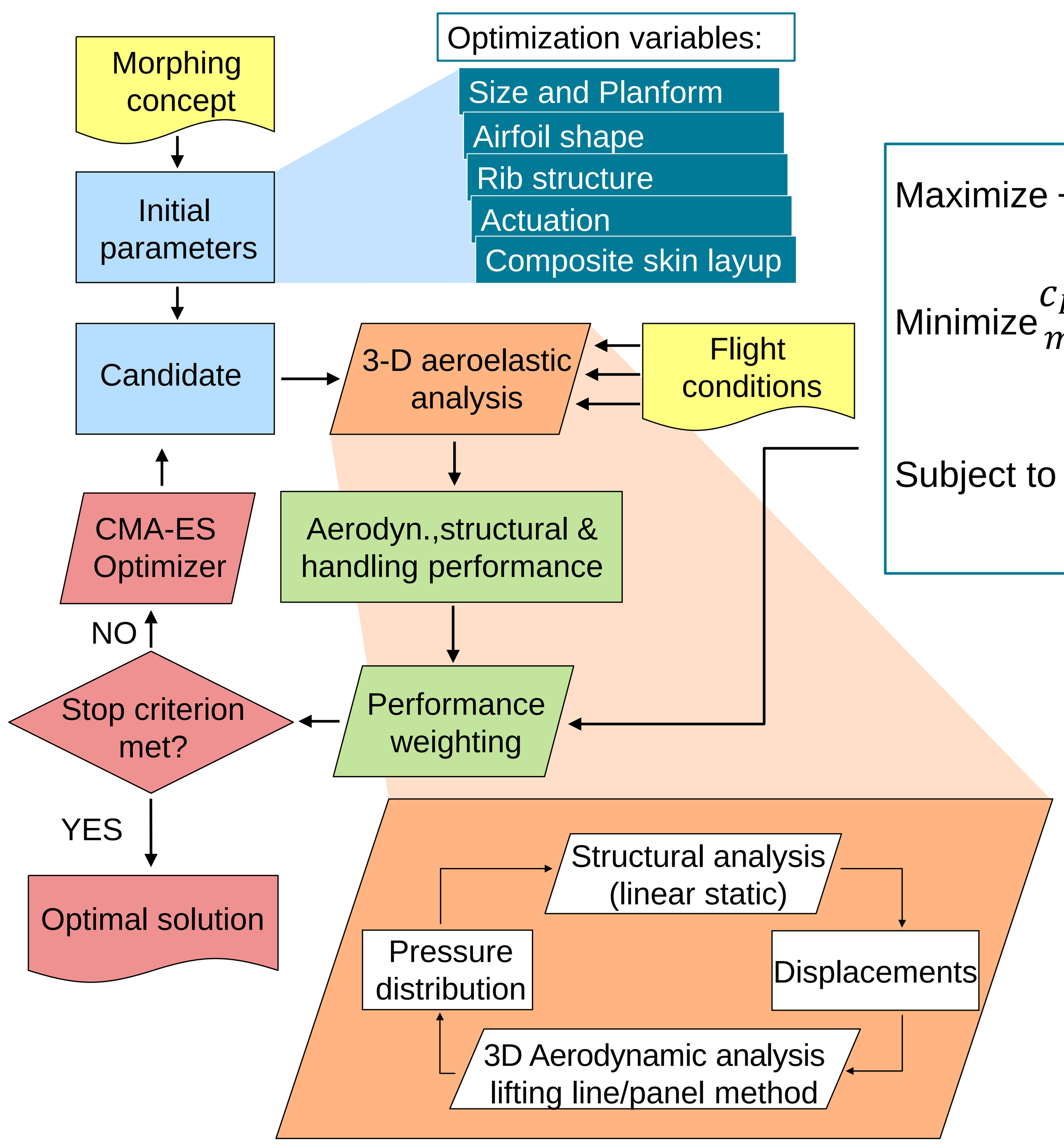

Morphing wing assembled for flight test



Optimized laminate thickness for the upper skin of the half-wing

2 Optimization

The ideal wing characteristics are determined by a multidisciplinary optimization, capable of assessing the wing behaviour considering aeroelastic interactions. The aerodynamic shape was optimized for maximal power output at different wind speeds. The wing structure, actuation position and skin layup were optimized to minimize the aircraft weight, while preventing flutter and buckling at the ultimate load.



Maximize $\frac{4\,C_L^3}{27\,C_D^2}$

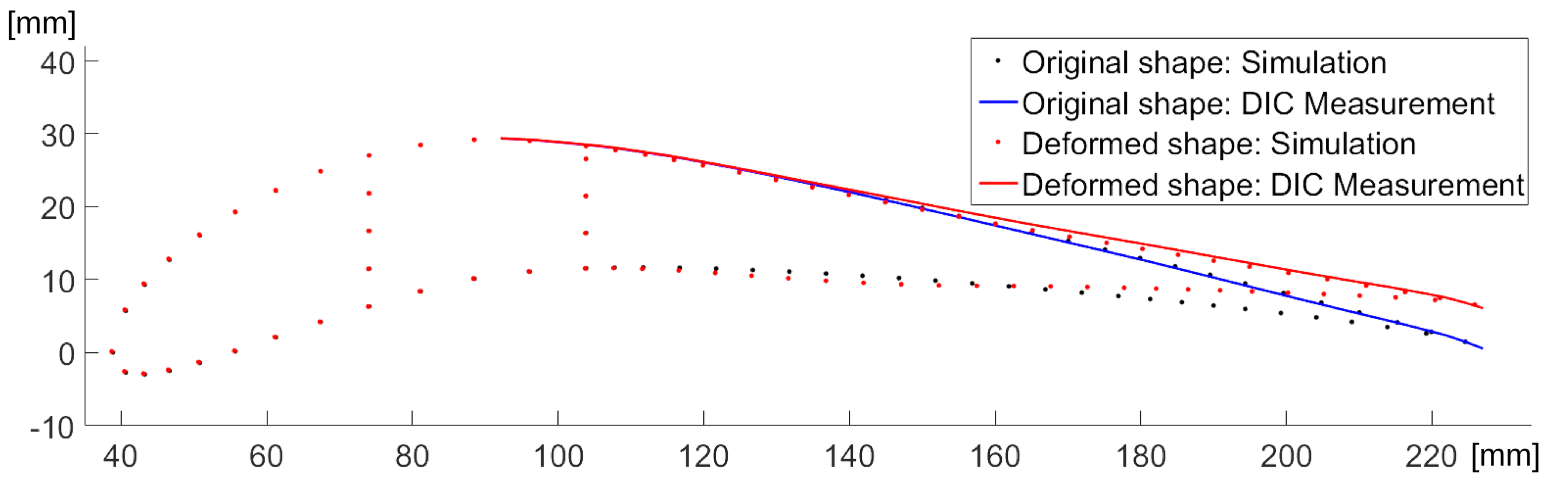
Minimize $\frac{c_{D,Roll}}{m_{wing}}$

Subject to $k_{Buckling} \geq 1.5$, $c_{Roll} \geq 0.02$, $SF_{flutter} = 1.5$

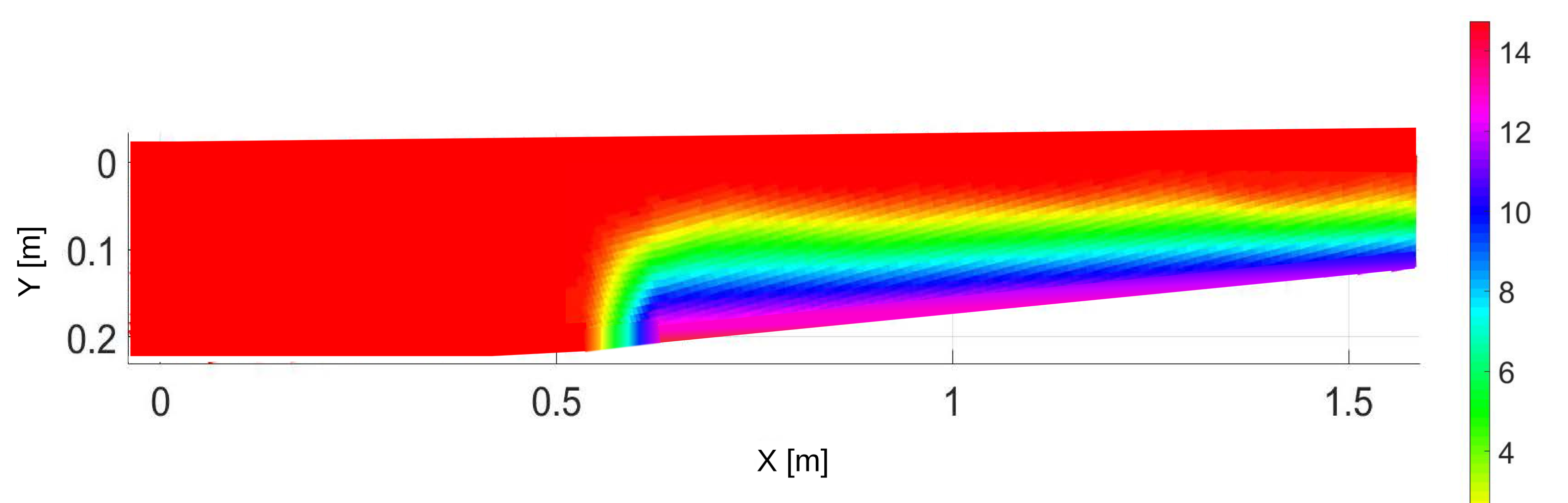
Analysis and Optimization routine

4 Results and Conclusion

The wing was manufactured, assembled and tested for its morphing performance. The out-of plane deformation was assessed using a digital image correlation (DIC) system, and compared to the results of the optimization, as shown below.



Trailing edge deflection; Comparison between simulation and experiment



Experimentally determined peak-to-peak active out-of-plane deflection

Conclusion:
- Proven manufacturability
- Optimized wing satisfies stiffness/compliance trade-off
- Wing can withstand a load factor of 20
- Sufficient actuation deflection resulting in $\Delta c_L = 0.11$ and $c_{Roll} = 0.023$, according to the aeroelastic analysis

References:
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