UNIVERSITY OF Southampton

Engineering and the Environment

Aeronautics, Astronautics and Computational Engineering

Topology Optimisation for Design Trade Studies

(Funding Source: SILOET – **S**trategic **I**nvestment in **LO**w-carbon **E**ngine **T**echnology)

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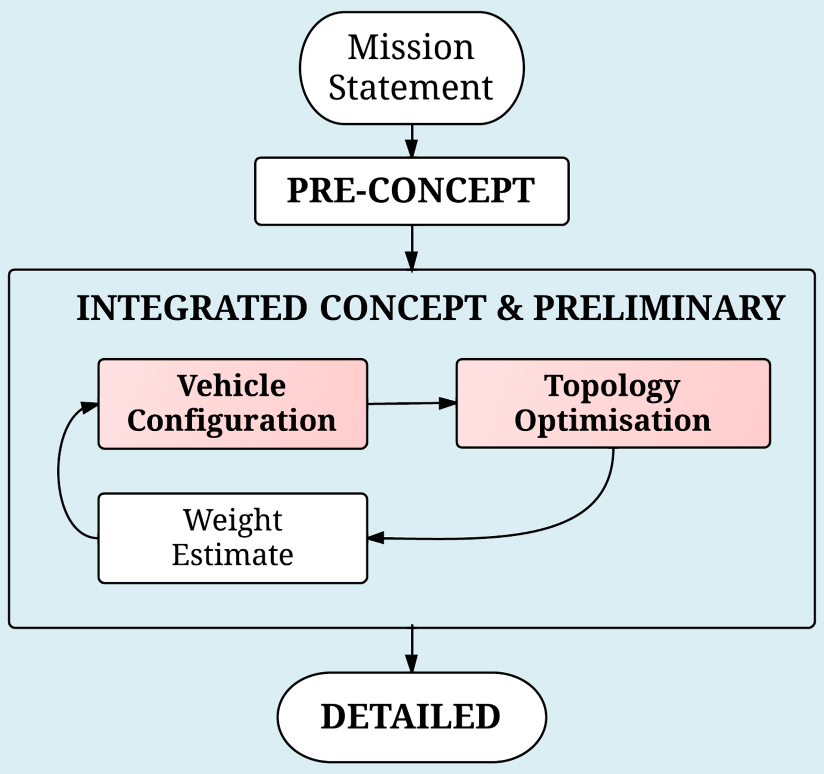
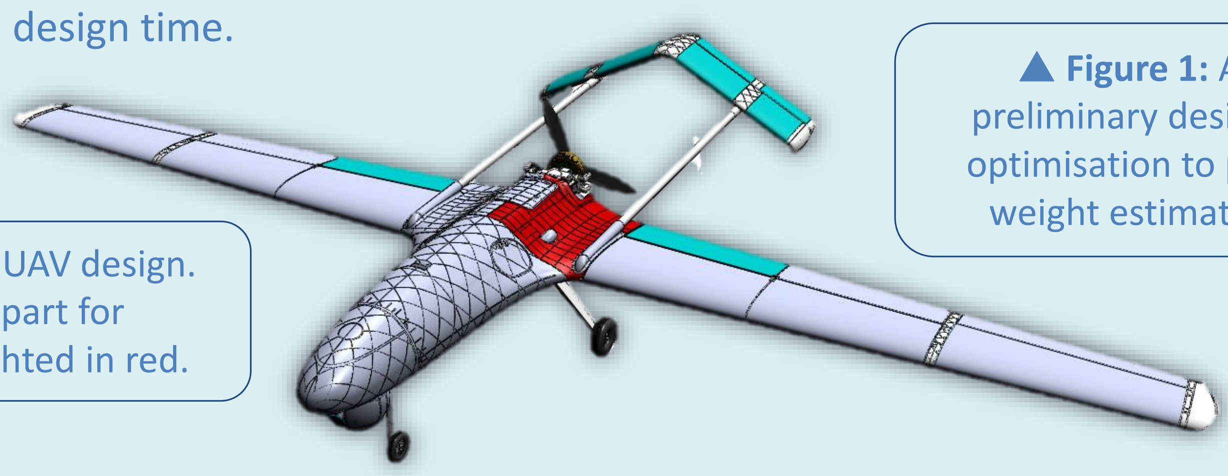
Introduction

Aircraft design requires a number of multidisciplinary design decisions. In a traditional design process, the vehicle configuration is selected during concept design using aerodynamic considerations and weight estimation techniques. Structural design is then considered during preliminary design.

Here, an integrated approach is suggested whereby topology optimisation is used to automatically generate structural designs and subsequently an estimate of weight which can be used to inform vehicle configuration decisions (**Figure 1**). The potential benefits of such an approach are: improved structural design, more accurate aerostructural design decisions and increased design autonomy leading to a reduction in design time.



▲ **Figure 1:** An integrated concept and preliminary design process utilising topology optimisation to provide structural design and weight estimations to design trade studies



▶ **Figure 2:** Complete UAV design. The rear fuselage part for optimization is highlighted in red.

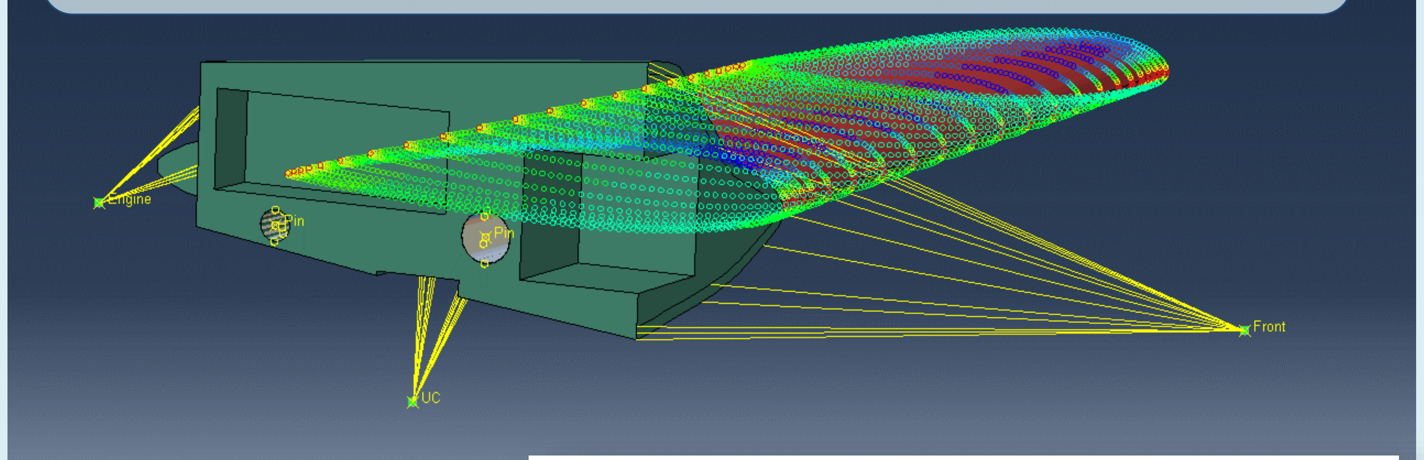
Method

An integrated design approach with topology optimisation is demonstrated here in the re-design of a UAV (Unmanned Aerial Vehicle) designed and built as part of the University of Southampton DECODE (Decision Environments for COmplex DEsigns) project, shown in **Figure 2**. A design trade study is carried out to select the best wing configuration by consideration of aerodynamic efficiency and aircraft mass.

A bi-level optimisation strategy is used to conduct the design trade study. At the top level, OPTIMAT v2[1] is used to construct a Kriging response surface model through an initial DOE (Design Of Experiments) of wing geometry parameters, before interrogating the model using an NSGA-2 search to find efficient design updates. The objectives of this optimisation are to minimise aircraft mass while maximising the lift-to-drag ratio. The parameters for optimisation are span, taper and twist as shown in **Figure 4**. The geometry selection is constrained by the ability to generate sufficient lift at landing speed.

At the second level, FP[2] is used to generate a pressure profile for the given wing geometry. This pressure profile is then mapped to the structural model, shown in **Figure 3**, before topology optimisation is carried out using a Bi-directional Evolutionary Structural Optimisation (BESO[3]) algorithm coded in MATLAB as part of this project. The objective is to minimise the mass of the fuselage part to satisfy a pre-selected mean von Mises stress constraint. For comparison, a shell model built to replicate the original fuselage design is subject to shell thickness optimisation.

Figure 3: The design domain assembly for the rear fuselage part. Point masses are used to represent components and wing loading is mapped from aerodynamic analysis for each wing configuration



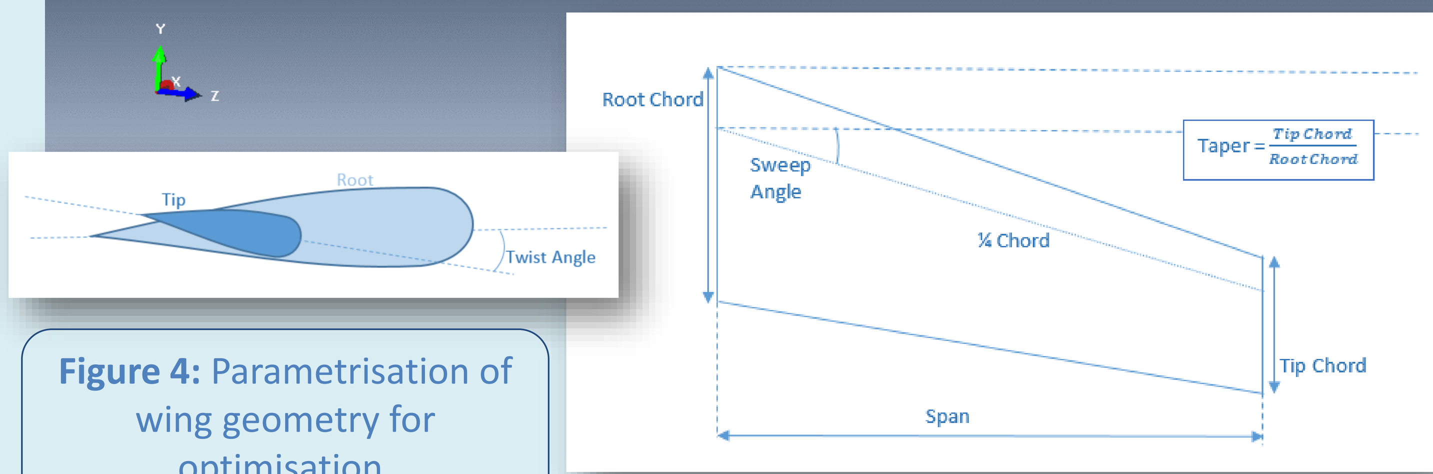


Figure 4: Parametrisation of wing geometry for optimisation.

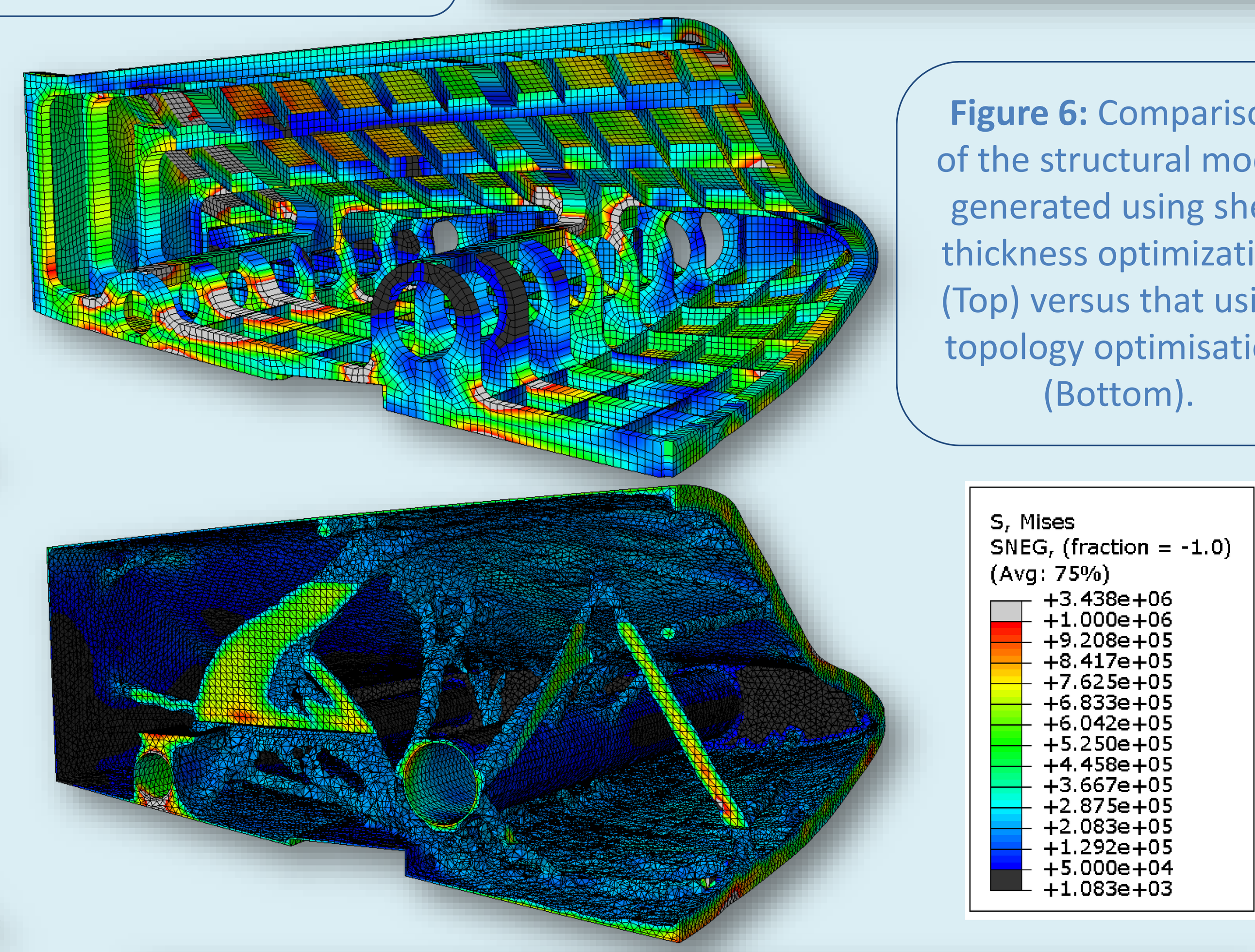
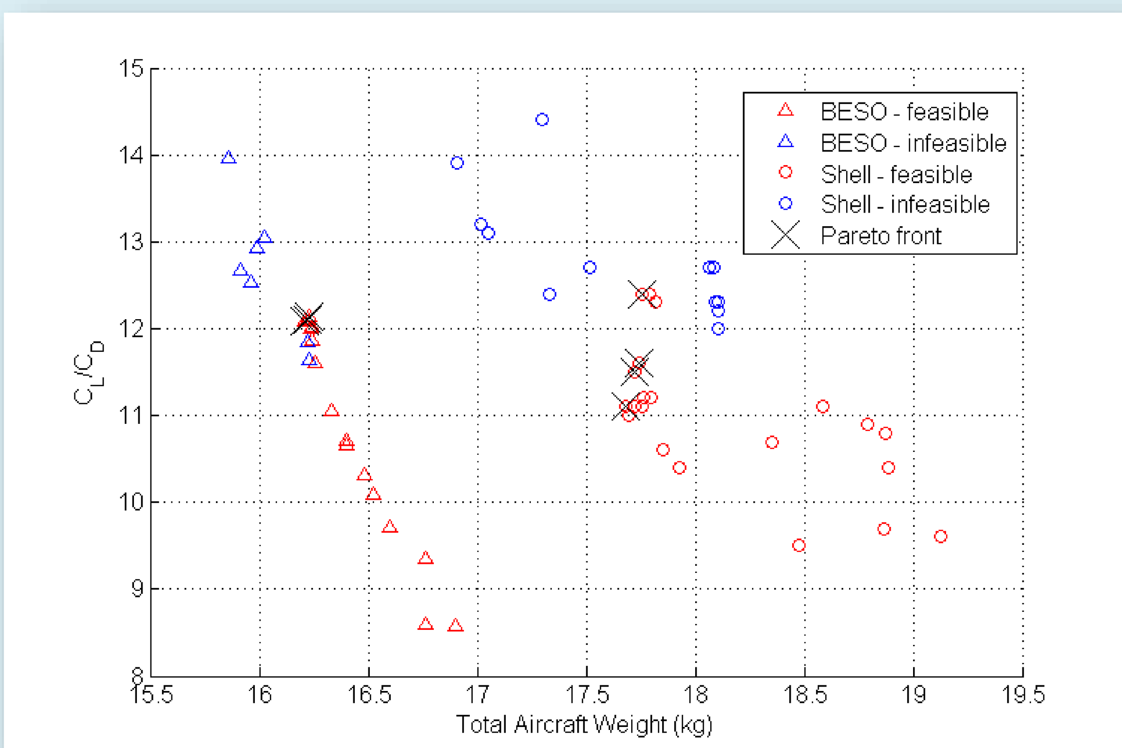


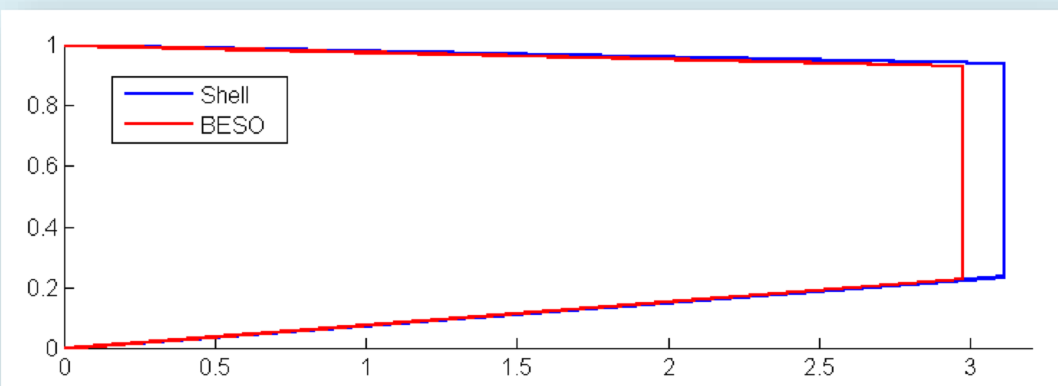
Figure 6: Comparison of the structural model generated using shell thickness optimization (Top) versus that using topology optimisation (Bottom).

Results

The results of the topology optimisation based and shell optimisation based trade studies are shown in **Figure 5**. For each method, a set of designs which satisfy the optimisation parameters are generated. It can be seen that for the same structural and aerodynamic performance, topology optimisation generates a much lighter structure – approximately 1.5kg. This mass is a combination of the heavier fuselage structure required (shown in **Figures 6** & **7**) and the larger wings required to generate sufficient lift (shown in **Figure 8**).

▼ **Figure 5:** Aerodynamic efficiency versus structural weight for both topology optimisation and shell optimisation method. Infeasible designs are rendered infeasible due to inability to generate sufficient lift at landing speed.





▲ **Figure 8:** Wing geometry comparison for topology optimised aircraft (Red) versus shell optimised aircraft (Green). Aircraft dimensions are normalized by the root chord (0.45m). Both designs have a taper ratio of 0.7 and positive twist. The main difference is the approx. 5% increase in span in the shell model.

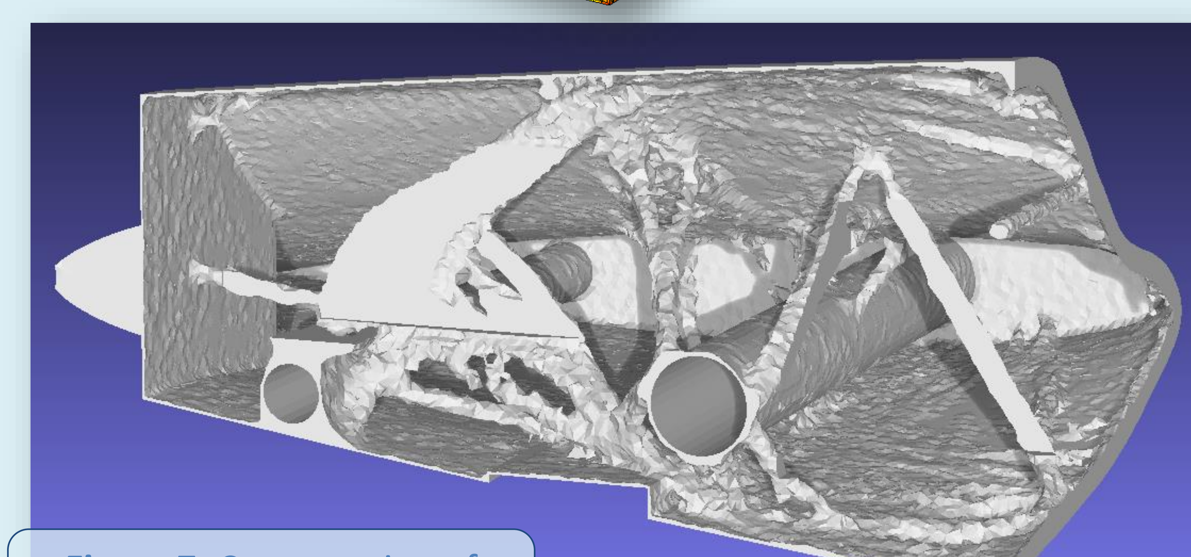


Figure 7: Cross-section of topology optimised design.

Conclusion

In conclusion, integrated design trades using topology optimisation have been used to improve the design of a UAV. This method has been shown to autonomously generate a set of designs which meet given optimisation objective and constraints. It is also shown that topology optimisation generates higher stiffness models versus traditional semi-monocoque stiffening configurations and subsequently lighter weight aircrafts. The complex stiffening structures generated here can be readily manufactured using additive manufacturing techniques.

[1]OPTIMAT v2 is Rolls-Royce multidisciplinary optimisation package developed and maintained at the University of Southampton
[2]ESDU (2002) *Full-Potential (FP) Method for Three-Dimensional Wings and Wing-Body Combinations – Inviscid Flow Part 1: Principles and Results*. London: ESDU-02013.
[3]HUANG, X. D., XIE, Y. M. & BURRY, M. C. (2006) A new algorithm for bi-directional evolutionary structural optimization. *Jsme International Journal Series C-Mechanical Systems Machine Elements and Manufacturing*, 49, 1091-1099.

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