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.

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 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, EP3 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) 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.

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).

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.