ABSTRACT

Cost-Weight Trades for Modular Composite Structures

— Assessment of the modularity concept using dynamic programming optimization routines —

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The goal of our research was to investigate whether a middle course between manufacturing cost and structural weight can be adopted by designing structures using the concept of modularity. The term modularity here refers to the idea of replacing a collection of parts which all have a unique design by a collection of parts where the same design is used multiple times. Introducing higher levels of modularity in a structure will increase the weight of the structure since it is harder to design a weight efficient structure when the amount of different designs is limited, but this weight increase might be worth the associated decrease in manufacturing costs. Two trade study cases were set up to assess the cost-weight efficiency at different modularity levels: the first involved the design of stringers of a fuselage and the second case dealt with the design of frames along an aircraft fuselage, both structures are highly repetitive and therefore well suited to the modularity concept.

Three MATLAB routines were developed that, together, formed the building blocks of the trade study analyses. The first building block was aimed at efficiently creating designs with increasing levels of modularity using an optimization routine based on the principles of dynamic programming. The second building block consists of two structural optimization routines aimed at designing weight-efficient stringers and frame webs for the structures of the trade study cases. The first of these two optimization routines, the enumerative lay-up family optimizer (ELFO), combines smart lay-up building routines to create lay-ups that meet several rules on good design practices (10% rule, maximum ply stack, etc.) with a gradient-based optimization to determine the optimal width of the stringer's web and flanges. The second optimization routine, the additive lay-up generation optimizer (ALGO), combines smart lay-up building routines with an ad hoc flange design to reinforce a possible cut-out in the structure being designed. For the structural analysis in ALGO existing methods were complemented by conservative approaches for the design of panels with cut-outs and tuned with finite element analysis. Both ELFO and ALGO are able to quickly create reliable optimal designs. The third building block was an implementation of the cost estimation software SEER-MFG in MATLAB used to enable a parametric cost analysis of the different modular structures.

Cost-weight diagrams were created for the fuselage stringers and fuselage frames and they indicated that the modularity concept provides a useful methodology for designing more cost-weight efficient structures. In both study cases it was possible to replace a large amount of designs and increase the level of modularity of the structure, yielding significant reductions in recurring and non-recurring manufacturing costs while keeping the associated weight increase of the structure to a minimum. Our research showed that the modularity concept has much potential, however, future work must focus on the methodology in a more realistic case study on an existing aircraft structure.