Composite structures can lower the weight of an airliner significantly. The increased production cost, however, requires the application of cost-effective design strategies. Traditionally, the structural design and the manufacturing planning are done sequentially. This may work for metallic structures; for composites, however, the design is strongly influenced by the choice of the material, the manufacturing processes and the structural requirements. The design is then based on attributes like material properties, manufacturability, series size and stressing guidelines, while cost and potentials to save cost play a minor role.

Nevertheless, the manufacturing cost should be included in the early design phase of the component design of primary composite structures. Therefore, this work has been initiated. Within the scope of the European funded project ALCAS, a cost/weight optimization framework was developed; the aim is the optimization of structures with the direct operating cost or the life-cycle cost on a component level as the objective function. In the presented approach, the objective function is formed by the manufacturing cost of the component, in-production and in-service inspection cost and a specific fuel burn cost.

The optimization framework is shown in the following figure, where cost and weight contribute to the objective function by means of a weight penalty (EUR/kg). The prediction of the structural calculation is performed by finite element analysis.

The aim of a first milestone was the development of a structural optimization scheme for the minimum weight design of a generic composite skin/stringer element, thus performing a feasibility study on the optimization of discrete variables (i.e. prepreg layers), the optimization of algebraic buckling/failure equations and the implementation of the problem in ABAQUS (http://www.simulia.com) and Xopt (http://www.alfgam.se).

In a second step, the same generic skin/stringer panel was modeled in the cost estimation package SEER-DFM (see www.galorath.com). By combining the structural analysis done in ABAQUS/CAE and the cost estimation done in SEER, an integrated cost/weight optimization was performed.

It was noticed that the constant process parameters in SEER did not always match the knowledge of the experts during manufacturing. Hence, these parameters should be adjusted during the optimization of the component in order to provide the solver with the lowest possible manufacturing cost given a geometrical design.
The sub-optimization of process parameters was therefore introduced; this was done for a machined element first. The methodology, however, would be applicable for parameters of the manufacturing of composites as well.

So far, the design of composite structures has not been influenced by NDT aspects. In order to capture the full life cycle of a composite component, NDT should play a role in an early design phase. Therefore, the methodology was extended in order to include the parameters of the in-production and in-service testing into the design process. Hence, the scan distance of the ultrasonic C-scan was introduced as a variable. In a feature-based model, the NDT cost was calculated according to this scan distance (the scan pitch). Further, the design allowables of the laminate were adapted, as the scan pitch had a direct influence on the detectable flaw size. The effect of the quality management in an optimization framework was shown by a cost/weight optimization of a skin/stringer panel, thus showing the tradeoff between the testing cost and the guaranteed laminate quality.

In a fifth step, a detailed draping simulation (see http://www.simulayt.com) was implemented in the optimization framework in order to model the fiber directions of a curved C-spar closer to reality. This draping tool was used to (1) generate a draping knowledge database which contained a series of possible seed points for the draping of each prepreg layer and (2) select the appropriate combination of seed point and reference angle according to [minimum material consumption] or [minimum fiber angle deviation] rules.

Finally, the overall methodology will be applied to the integrated cost/weight optimization of a C-spar. Three material will be examined: an aluminum alloy, an RTM6 system and a M21/T800 prepreg system.

The work will be completed and summarized in a PhD Thesis at the end of 2009.
SELECTED PUBLICATIONS INCLUDE

Kaufmann M, Zenkert D and Wennhage P, “Integrated cost/weight optimization of aircraft structures”, accepted for publication in Structural and Multidisciplinary Optimization, online version http://dx.doi.org/10.1007/s00158-009-0413-1


Kaufmann M, Zenkert D and Mattei C, “Cost optimization of composite aircraft structures including variable laminate qualities”, Composites Science and Technology, 68 (2008) 2748-2754, online version http://dx.doi.org/10.1016/j.compscitech.2008.05.024


CONTACT

Markus Kaufmann

Department of Aeronautical and Vehicle Engineering
Kungliga Tekniska Högskolan (KTH)
SE-100 44 Stockholm, Sweden

Phone: +46-70-282 85 88
Fax: +46-8-20 78 65
E-mail: kaufmann@kth.se