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Optimal design of composite lateral wing upper covers. Part I: Linear buckling analysis

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ABSTRACT

The present investigation is devoted to a development of new optimal design concepts of aircraft lateral wing upper covers made of advanced composite materials. In the first part three rib bays laminated composite panels with T, I and HAT-stiffeners were modeled with ANSYS and NASTRAN finite element codes to investigate their buckling behavior as a function of skin and stiffener lay-ups, stiffener height, stiffener top and root width. Due to the large dimension of numerical problems and large number of optimization tasks to be solved, an optimization methodology was developed employing the method of experimental design, response surface technique and linear buckling analysis. Weight optimization problems were solved for the laminated composite panels with three types of stiffeners, two stiffener pitches and four load levels taking into account manufacturing, repairability and damage tolerance requirements. The composite panel with the best stiffener type was identified for the subsequent nonlinear buckling analysis and optimization presented in the Part II. Optimal results were verified successfully using ANSYS shared-node and NASTRAN rigid-linked models.

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1. Introduction

The European Aeronautics Industry's Strategic Research Agenda addresses the reduction in operating costs of relevant European aerospace products by 15% through the cost effective application of carbon fibre composites to aircraft primary structure and taking into account systems integration. This can be achieved by realizing the weight saving potential of advanced composite materials, by reducing the manufacturing costs of composite components and by reducing subsequent product maintenance costs. Due to increasing application of advanced composites in aircraft structures, significant progress was achieved recently in the optimization of stiffened laminated composite panels with different type of stiffeners [18,15,5,21,19,7,8,13,10,11,22].

A study of minimum-weight panel designs that satisfy buckling and strength constraints for different wing rib panels configurations (tailored corrugated panel, corrugated panel with a constant-thickness continuous laminate, hat-stiffened panel and blade stiffened panel) subjected to a wide range of combined in-plane (axial compression and shear) and out-of-plane (pressure) load conditions was performed in paper [18] where thicknesses of different plies with preselected ply orientations in the different sections of the panels and detailed cross-sectional dimensions were used as sizing variables. The optimization methodology based on genetic algorithms was developed in paper [15] for the design of blade stiffened panels with stability and strain constraints. To minimize the weight of stiffened panels, the optimization problem was formulated as finding the stacking sequences of skin, stiffener blade and flange laminates, as well as the stiffener height.

Minimum weight design of T-stiffened and HAT-stiffened panels made of laminated composites was performed in paper [5] with the PANDA2 program. The panels were subjected to axial compression, in-plane shear and normal pressure loads, and designed for service in their locally post-buckled states. PANDA2 program was used also to obtain an initial optimum structural design for an HAT-stiffened laminated composite panel used for the airplane upper covers in paper [21]. A refined optimum structural design was obtained then by an optimization using response surface technique. HAT-stiffened panel was subjected in this study to internal pressure load and to combined internal pressure and in-plane loads. The structural optimization problem was formulated using the panel weight as the objective function with stress and buckling constraints. As the design variables, the spacing of HAT-stiffeners, and thickness of skin and components of HAT-stiffener were taken into consideration. At the same time the stacking sequence of the preforms used in the skin and in all of the components of HAT-stiffeners was examined in this paper as a constant value. The

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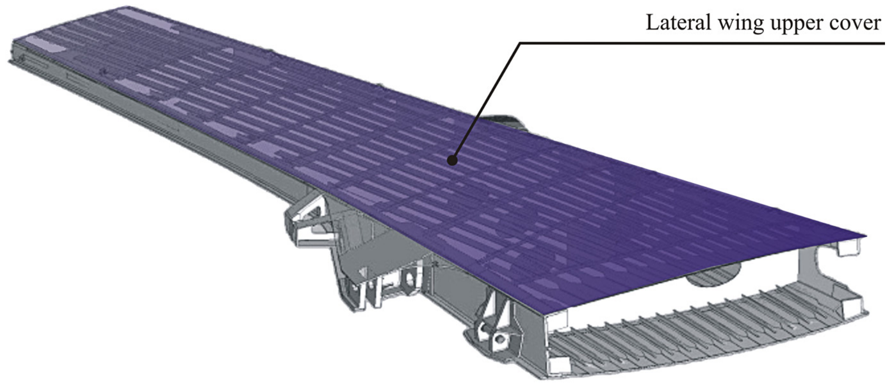

Fig. 1. Lateral wing of aircraft.

response surface methodology was applied also in paper [19] to optimize the dimensions of HAT-stiffened composite panels and stacking sequences under buckling constraints. In this case the optimization method was based on modified efficient global optimization with the multi-objective genetic algorithm and kriging response surface. As an advantage of the present methodology, a feasible optimal structure at a low computational cost could be examined.

A method to optimize long anisotropic laminated fibre composite panels with T-shaped stiffeners was developed in paper [7], where the optimization problem is solved in two steps. At the first step, continuous optimization of lamination parameters with gradient-based techniques is used to get near the optimum discrete design. In this step the cross-sectional dimensions and values of the lamination parameters for an optimum superstiffener design are obtained, and strength, buckling and practical design rules are taken as the design constraints. At the second step, a genetic algorithm is used to identify the lay-ups for the superstiffener's laminates, which are the closest in the lamination parameter space to the continuous optima (minimum-distance approach) and satisfy the discrete design constraints. However, sometimes the optimum discrete designs were not the closest in the lamination parameter space to the continuous optima. On this reason a new second-step optimization that uses a genetic algorithm to find the safest design based on a linear approximation of the design constraints, instead of searching for the closest design in the lamination parameter space to the continuous optimum, was successfully developed in paper [8].

An optimized design of laminated composite panels with other types of stiffeners, namely Z, L, C, J-stiffeners and squared tubes was examined in papers [13,10,11,22]. A bilevel optimization strategy for a fast design of composite stiffened panels, using VICONOPT and embracing practical composite design rules, was developed and applied for the design of highly strained Z-stiffened composite panels in paper [13], where the stacking sequences satisfying laminate design rules were found using an optimization at the laminate level. The effect of different stiffeners for combined compression and shear load stiffened panels both from a weight and cost perspective was studied including their buckling and post-buckling behavior in papers [10] and [11] respectively. The design that simultaneously minimizes cost and weight in these papers is found from among the points in the Pareto set. The objective of the design problem in paper [22] was to maximize the buckling loads of panels with squared tubes used as stiffeners by optimally oriented fibre plies.

Two-level composite wing structural optimization methodology using response surfaces was applied for the design of a simple wing box structure subjected to strength and buckling constraints in paper [12]. The procedure is based on continuous optimization at the wing level using a finite element model and genetic optimization at the panel level. A response surface of optimal panel buckling load was used for communication between the two levels. Unfortunately the wing in this paper is assumed to consist of unstiffened composite panels. In paper [20] a system for classifying complexity in optimization problems based on model size, analysis procedure, and optimization size and methodology was described for the composite stiffened shells and plates. It is necessary to note that most investigations were devoted to the optimal design of laminated composite panels with one type of stiffeners and focused on their application in the primary fibre composite fuselage structures. When the optimal results for the composite panels with different type of stiffeners are compared, these solutions were obtained in most cases with not the same constraints and operational-engineering requirements, and by using different optimization methodologies and techniques that cannot be used properly for the comparison study. At present time investigations on the optimal design of stiffened laminated composite panels continue taking into account more new design rules obtained from the airspace industry.

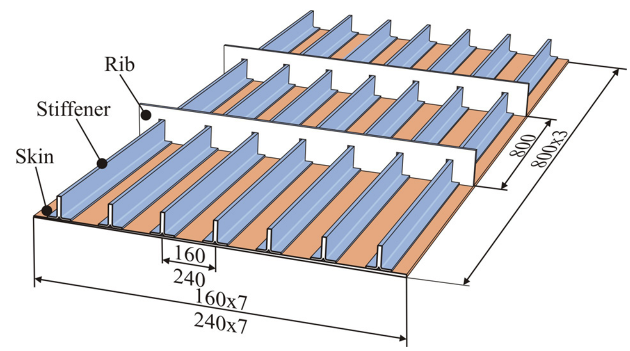

Fig. 2. Composite panel with T-stiffeners.

The present investigations are devoted to the methodology development based on the planning of experiments and response surface technique for optimal design of stiffened laminated composite panels with special emphasis on more close conformity of the developed finite element analysis and operational requirements for aircraft lateral wing upper covers. This study gives the possibility to compare properly optimal solutions obtained for the laminated composite panels with different type of stiffeners and to choose a panel with the best weight/design performance for the further development.

2. Construction of stiffened composite panels

An aircraft lateral wing upper cover (Fig. 1) in the present study is examined as a plane stiffened panel (Fig. 2) consisting of skin, ribs and stiffeners made from unidirectional Intermediate Modu-

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