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Optimal Design of Fighter Aircraft Wing Panels Laminates under Multi-Load Case Environment by Ply-Drop and Ply-Migrations ☆

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Abstract

The ply-drop (PD) is termination of specific plies at rib-axis for getting tapered laminates. The present optimization study aims to achieve minimum weight tapered wing panels laminates by PD followed by ply-migrations (PM). The PM are required for ply-continuity (blending) and achieving smooth external aerodynamic surface. A genetic-algorithm mutation operator and fitness based search algorithm is developed in the present study for the optimization. The laminate weight minimization has been achieved as goal of multi-objective optimization (MOO), by utilizing excess design margins of Tsai-Wu first ply failure-index (FI) and wing tip lateral deflection. The finite-element (FE) model of laminate is a set of discrete laminates (chromosomes) between ribs with continuity by virtue of ply-orientations. To select best fit laminate, ply orientations were randomly selected and perturbed for thickness during optimization. The fitness function for evaluating chromosomes is a composite function of multi-objective design requirements and design constraints. The algorithm submits orientation/thickness combinations to ABAQUS/CAE by python-script for function evaluation. The application of algorithm over an initially assumed quasi-isotropic laminate of uniform thickness showed 57% weight reduction for a fighter aircraft's wing panel. The optimization process is automated making PD practically viable in the design process itself.

Keywords: Ply-Drop, Ply Migration, Composite Wing Box Design, Laminate Blending, Multi-objective optimization, Python-Scripting

1. Introduction

The aerospace structures like wing, fuselage are now coming up with high strength light weight fibrous composites with prepreg construction. Often such structures have tapering thickness laminates by virtue of experienced loads. The tapering of laminates have potential for significant weight reductions in engineering structures. Unlike metals, continuous tapering of laminates is not possible, therefore, plies are dropped at different locations to achieve tapering. The termination of plies at the rib-axis is termed as ply drop (PD). In the present study, an attempt has been made to design tapering wing panel laminates by optimally terminating uni-directional carbon fibre composite plies near the ribs as shown in Fig. 1. The PD is governed by a genetic-algorithm mutation operator and fitness based search algorithm followed by ply migrations (PM) for achieving blended and smooth external surface laminates. The smoothness of laminate top surface is an aerodynamic requirement to avoid separation of air-flow.

The literature review on weight minimization studies shows that many researchers have attempted re-orientation and deletion of plies in laminate by governing laminates through evolutionary algorithms. It is very well discussed that the re-orientation and deletion of plies in a laminate provide ample scope for laminate optimization [1, 2, 3, 4, 5]. However, very few researchers have worked on PD design aspect, which can further refine the optimization procedure to get significant amount of weight savings for the structure under design. Weigang et al. [6] attempted such an optimization for wing-box by proposing group of laminates with same ply-orientations, considering thickness and length of lamina groups as design variables for the design of blended laminates. Irisarri et al. [7] introduced stacking sequence (SS) tables to obtain optimal tapered laminates. They have optimized a 18-panel benchmark problem under buckling criterion with a set of guidelines, which were important from the aspect of de-lamination and manufacturing. Some of the guidelines like symmetry, balanced, covering and continuity from [7], [8] were part of the present study. Liu et al. [9] minimized material volume of laminate for 18-panel benchmark problem for buckling and strain, by local level stack shuffling to satisfy blending [10] for manufacturability and proposed lamination parameter

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