A FAST OPTIMIZATION TECHNIQUE FOR PRELIMINARY SIZING OF ANISOTROPIC COMPOSITE STIFFENED PANELS

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Keywords Lamination Parameters, Anisotropy, Stiffened panel, Closed Form Solutions, Genetic Algorithm

Abstract
A fast optimization technique is presented for preliminary sizing of anisotropic composite stiffened panels. The optimization consists of two steps. At the first step, a representative skin-stiffener assembly (superstiffener) of the composite stiffened panel is optimized using continuous optimization of lamination parameters under strength, local and global buckling and practical design constraints. For computational efficiency, buckling constraints are provided in terms of closed form solutions and conservatism is partially removed by considering the skin-stiffener interaction. At the second step, a genetic algorithm is used to identify the actual superstiffener’s laminates. The fitness function in the genetic algorithm is formed by the first step constraints, instead of the traditional lamination parameter distance. Studies will be conducted for certain loading conditions and geometries to examine the optimisation process as well as the effect of the constraints on the skin and stiffener geometry and final lay-up.

1 Introduction
Nowadays, aerospace structures such as wings, fuselages or empennages are tended to be designed using composite stiffened panels due to their load bearing capabilities, specific strength and stiffness ratios and capacity to be elastically tailored. Composite stiffened panels are formed by a series of skin-stiffener assemblies, which have plates as basic structural elements. The shape of the composite stiffener is commonly selected based on the cost-weight ratio. T-shaped stiffeners are usually the preferred choice as they present an economic alternative without sacrificing structural performance. Due to practical, yet often limiting, manufacture considerations, composite panels have been restricted to symmetric or mid-plane symmetric laminates with 0, 90, 45 and -45 degree, ply angles. The manufacture of the T-shaped stiffeners increases design complexity since it allows thickness variation of the stiffener web and flange by adding extra and capping plies, respectively. Several optimisation techniques have been developed to assist engineers on composite design. The full paper will give an in-depth review.

The authors’ previous work based upon two-step optimization approach coupling a gradient based technique with a GA showed that composite anisotropy could be used to improve structural performance of anisotropic composite panels with T-shaped stiffeners. Design constraints such as strength, buckling and practical design rules were considered. Recently, Herencia et al. showed that using a fitness function based on constraint satisfaction in the second step within the GA, produced designs with equal or lighter mass and with less constraints violation that those obtained with a fitness function based on the lamination parameter distance. This paper extends that work and provides a two-step optimization technique for preliminary sizing of anisotropic composite stiffness panels. The approach couples a gradient based technique with a GA. For computational efficiency, buckling constraints are provided in terms of closed form solutions and conservatism is partially removed by considering the skin-stiffener interaction. The fitness function within the GA is formed with the actual constraints plus penalty terms associated with lay-up constraints to determine the laminate stacking sequence.

2 Stiffened Panel Geometry and Loading
As in Ref. 2 the composite stiffened panel is assumed to be long, wide and composed of several skin-stiffener assemblies or superstiffeners under combined loading. Each super stiffener element consists of three flat plates (skin, stiffener flange and stiffener web) that are assumed to be rigidly connected along their longitudinal edges. The super stiffener element is assumed to model the panel’s behaviour. Figure 1 defines the superstiffener element geometry, the material axis as well as the positive sign convention for the loading.
Due to the stiffener’s manufacture, four different stiffener configurations are considered. The stiffener is manufactured as a back to back angle (Fig. 2a), adding capping plies in the stiffener flange (Fig. 2b), or extra plies in the stiffener web (Fig. 2c), and finally the combination of the previous configurations (Fig. 2d).

3 Laminate Constitutive Equations
The classical laminate theory is applied to the skin, stiffener flange and stiffener web respectively, assuming laminates are symmetric or mid-plane symmetric. Thus,
\[
\begin{bmatrix}
    N \\
    M
\end{bmatrix} = \begin{bmatrix}
    A & 0 \\
    0 & D
\end{bmatrix} \begin{bmatrix}
    \varepsilon^0 \\
    \kappa
\end{bmatrix}
\]

(1)

4 Formulation of the Optimization Problem

The mathematical formulation of the optimization problem is defined as follows:

Minimize \( M(\mathbf{X}) \) \hspace{1cm} \text{(Objective function)}

Subject to \( G_j(\mathbf{X}) \leq 0 \hspace{1cm} j = 1, \ldots, n_c \) \hspace{1cm} \text{(Design constraints)}

\[
X_i^l \leq X_i \leq X_i^u \hspace{1cm} i = 1, \ldots, n_v \hspace{1cm} \text{(Upper and lower design variable bounds)}
\]

(2)

4.1 Objective function

The objective function is the mass of the superstiffener element. The mass as a function of the design variables, materials properties and geometry is given by,

\[
M(\mathbf{X}) = \alpha \rho_{\text{skin}} d_{\text{skin}}(\mathbf{X}) + \rho_{\text{stg}} d_{\text{stg}}(\mathbf{X})
\]

(3)

4.2 Design variables

The design variables are the superstiffener cross-sectional dimensions and the lamination parameters \( \xi \) for the basic superstiffener’s laminates. The vector of design variables for each of the basic superstiffener’s laminates (skin(1), stiffener flange(2) and web(3)) is given by,

\[
x(i) = (h, t_i, t_{st}, t_{fl}) \hspace{1cm} i = 1, 2, 3
\]

(4)

The vector of the design variables for stiffener types a-b and c-d is given respectively by,

\[
\mathbf{X} = (x(i), x^{(2)}, h_{st}, b_{st})^T \hspace{1cm} \text{and} \hspace{1cm} \mathbf{X} = (x(i), x^{(2)}, x^{(3)}, h_{st}, b_{st})^T
\]

(5)

4.3 Design constraints

The design constraints used in the optimization are similar to those reported in Ref. 2 and are listed below:

a) Lamination parameters-feasible region constraints (e.g. Ref. 5).

b) Strength constraints at laminate level (e.g. Ref. 2)

c) Buckling constraints via closed form solutions considering the local and global skin-stiffener interaction (e.g. Refs. 6-7).

d) Practical design rules such as the minimum percentages of the ply angles, skin-stiffener flange Poisson’s ratio mismatch, and minimum skin gauge (e.g. Ref. 8).

5 Optimization Strategy

The optimization strategy is shown in Fig. 3 and consists of two steps coupling a gradient based technique with a GA. At the first step, the super stiffener is optimized using continuous optimization of lamination parameters under strength, buckling and practical design constraints subjected to combined loading. The optimum continuous super stiffener’s cross-sectional dimensions and lamination parameters are identified. At the second step, a GA is used to identify simultaneously the actual super stiffener’s laminates. The fitness function to be minimized is given by the maximum value obtained from the actual design constraints plus penalty terms to account for ply contiguity. Thus,

\[
f(\mathbf{Y}) = \max \left\{ 0, G_j(\mathbf{Y}) \right\} + \sum_i \Theta_i \hspace{1cm} j = 1, \ldots, n_c \hspace{1cm} i = 1, \ldots, 4
\]

(6)
where $\Theta_i$ is the $i$th penalty term and $Y$ is the gene representing the combined (skin and stiffener) laminate stacking sequence.

**Fig. 3. Optimization flow chart**

6 **Numerical examples**
Several studies will be conducted for certain loading conditions and geometries to examine the optimisation process as well as the effect of the constraints on the skin and stiffener geometry and final lay-up.

The full paper will give details of these studies.

**References**
Please note that only a few references are included due to space limitations.