# A preliminary design method for optimizing composite forward-swept wings

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**In this work, we describe a preliminary design method for optimising composite forward-swept wings. The approach uses a simplified structural wing model based on the theory of thin walled anisotropic laminate cross-sections. This way, a cross-sectional stiffness matrix can be obtained which is used to couple the deformations with the aerodynamic forces. Bending-torsion coupling of the spar is used to avoid aeroelastic divergence, a typically encountered problem for forward swept wings. Optimisation was undertaken for different sweep angles, the weight of the wing spar being the objective function. A number of constraints were applied, including the avoidance of aero-elastic divergence.**

## I. Introduction

Aircraft wings have traditionally been swept backwards rather than forwards due to aeroelastic problems with the configuration, one of the most significant problems being divergence. However, if these problems can be addressed, Forward-Swept Wings (FSW) have a number of advantages, including better maneuverability and the potential to deliver a decrease in vortex drag due to weaker vortices at the wing tips.[5] The cabin layout can also be improved for smaller aircraft due to the more aft location of the wing root and therefore continuous spar, when compared to a rearward swept wing.

The work presented here demonstrates a fast means of obtaining an early estimate of possible weight savings by using composite tailoring for FSW aircraft.

## II. Aeroelastic and structural models

The wing is divided along the span into a discrete number of sections, with the lift about the quarter chord obtained from the sections' lift curve slopes. The wing spar was modelled as a thin-walled cantilever beam with rectangular cross sections. It was assumed to carry all the loads. In order to obtain the relationship between beam's deformations and the applied aerodynamic loads, a model is developed from the theory of anisotropic thin-walled closed sections presented in.[6] The resulting model relates the cross-sectional forces and moments to the respective curvatures via a global stiffness matrix. This eventually leads to two coupled differential equations describing the twisting and bending of the wing due to the aerodynamic loads. The Ritz method has been used to predict the occurrence of aeroelastic divergence, as a closed-form solution to these equations can only be obtained for specific wing properties.[2]

## III. Optimisation

Optimisation was undertaken on the composite stacking sequence, using a bi-level approach as presented by.[4] Lamination parameters (LP) are used as the first level design variables. A correspond-

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ing stacking sequence is matched to these parameters in a second step, using a permutation GA. The ply angles were restricted to the set of {0°,±45°,90°}, as is typical in many industrial applications. The minimum weight was sought, subject to the constraints below:

- No aeroelastic divergence
- No stalling: $\alpha < \alpha_{stall}$ at all wing span locations
- Twist angle $\bar{\theta}(\bar{y}) \leq 5°$ at all wing span locations
- Lift equal to lift required ±1%
- Ply percentage in each pre-defined direction $\geq 10\%$
- No structural failure as estimated by the Tsai-Hill criterion (first-ply-failure, FPF)
- Feasible LP region as described by[3]

## IV. Results

Typical results showed the variation in the stiffness along the length of the wing as shown in figure 1. It is interesting to note that the coupling coefficient, $\kappa$, leads to a nose down twist of the wing in response to aerodynamically applied bending moments. The reason for this coupling was the fraction of 45° plies in the top panel (and a corresponding number of −45° plies in the bottom panel, as observed from the exterior of the wing-box). This is illustrated in figure 2. Results also showed the bi-level optimisation strategy to be more efficient than a computationally expensive approach of directly optimising the stacking sequence of the composite spar. Compared to an optimised design achieved with quasi-isotropic layups and hence no bend-twist coupling, a weight saving of 13% was found for the wing spar, at a forward sweep angle of -25° and at Mach 0.7.

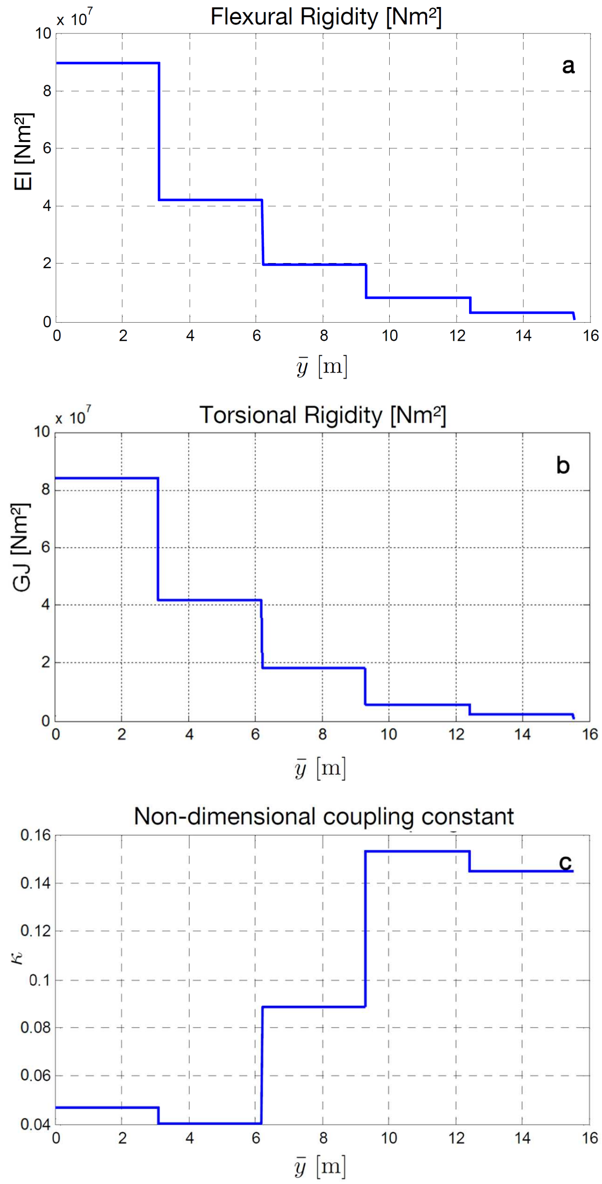


**Figure 1:** Optimum stiffnesses $EI$, $G$ and $\kappa$. Results obtained for $\Lambda = -15°$, $M_\infty = 0.8$

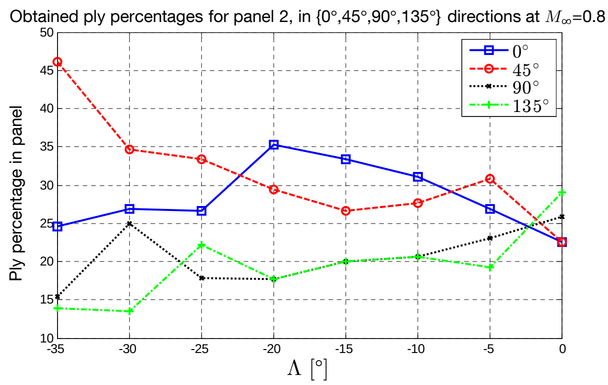


**Figure 2:** Ply percentages in top panel of wing discretization segment 2 vs. $\Lambda$, at $M_\infty = 0.8$.

## References

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