# EFFECT OF ROOT FLEXIBILITY ON THE AEROELASTIC ANALYSIS OF A COMPOSITE WING BOX

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*Summary* This paper discusses the effect of fibre orientations, composite skin lay-up, bending-torsion material coupling, and the root flexibility or stiffness of a composite rectangular wing box model for different fibre orientations on the dynamic and aeroelastic analysis (flutter and divergence speeds) for the Circumferentially Uniform Stiffness (CUS) and Circumferentially Asymmetric Stiffness (CAS) configurations.

## INTRODUCTION

The main objective of this research is to establish the aeroelastic effects of variation of composite fibre orientations, bending-torsion coupling, root flexibility, and stacking sequence of the upper and lower skins for a rectangular closed thin-walled wing box. Although many of these features are already analyzed, usually they are treated individually and not considered collectively. A sensitivity analysis is carried out for the fibre orientation, stacking sequence and root flexibility in order to visualize their influence on the modal behaviour, flutter and divergence speeds. For flutter analysis, it is necessary to study and find the dynamic characteristics of the composite wing box, which are in the form of eigenvalues and associated eigenvectors. The finite element codes used are FEMAP version 8 and MSC/NASTRAN version 70.5 as pre-processor, post-processor and analyzer respectively. The ply-stacking and fibre orientation are studied systematically in the past [1-4] without considering the CAS and CUS configurations in a more realistic manner. The effects of bending-torsion material coupling stiffness on the dynamic and aeroelastic behaviors of both configurations using one laminate for all walls of the wing box is considered by [5-6]. The objective of this research not only entailed these three characteristics but also including root flexibility to determine the response and flutter and divergence speeds of a composite wing box. The first two variables, fibre orientation and ply stacking sequence, are modelled with finite elements. The last variable, the root flexibility, is not usually modelled. Therefore an innovative way is found to quickly and efficiently model the root flexibility. The boundary condition of the composite wing box is modelled with two springs to simulate translation and rotation degree of freedom which is very important to the static and dynamic aeroelastic analysis of aircraft wing structures. The eigenvalues versus root stiffness of the first laminate for different fibre orientations are compared with the change in physical properties, which for composite are essentially the effective bending stiffness, EI, effective torsional stiffness, GJ, and bending-torsion material coupling, K.

## FINITE ELEMENT MODELS

### Stiffness of the composite wing box

The equations for calculation of the effective bending stiffness, EI, torsional stiffness, GJ, and bending-torsion material coupling stiffness, K are derived using the mathematical equations presented in [7]. The structural stiffness is then calculated for different fibre angles, stacking sequence of both composite wing box configurations.

### Wing box description and models

A simple wing box is employed instead of a beam or plate to give a great semblance to a real wing structure. The reason of retaining a simplified structure is to yield workable results without the adding complication of a complex finite element model. The dimensions of the wing box are 762 mm, 24.21 mm and 13.46 mm length, width and depth respectively. The composite wing box is modelled using a structural idealization program FEMAP v8 and analyzed using MSC/NASTRAN v70.5 based on the finite element approach. All sides of the wing box are modelled with QUAD4 plate element with four grids. The root stiffness is modelled using rigid beam elements (REB2) and degree of freedom springs. The grid points at the root of the wing box are all attached to one grid point located at the centre of the wing box root using RBE2 element. This element made the displacements of all the root grids dependent on the displacement of the centre grid. The centre grid is attached to two springs whose translation and rotation stiffness properties could be changed. One end of the springs is attached to the centre grid with the independent degree of freedom. The other end of the springs is attached to a ground point. The additional structure, which the rigid element, RBE2 and springs, (CELAS2 element) are did not interfere with the results. This is checked by making the springs very stiff and comparing the results to the cantilevered boundary condition. The natural frequencies and associated mode shapes are exactly similar to the case where the wing root is fully clamped. Two wing model configurations are selected in the modeling of the composite wing box, namely, uniform or balanced (CUS) and asymmetric or unbalanced (CAS). In the CAS configuration, the ply lay-ups on the opposite sides are mirror with respect to the mid axis, where as in the case of CUS, the opposite sides are in opposite sign of fibre angle. Bending-twist material coupling stiffness is produced in the case of CAS, where as extension-twist coupling in the case of CUS.

**Laminates considered**

Symmetric and anti-symmetric laminates are used in the modeling of the composite wing box throughout the research. Symmetric laminate is used for the upper and lower skin and anti-symmetric laminate for the spar webs (side walls). This is done to investigate the effect bending-twist coupling generated only by the upper and lower skin on the eigenvalues and associated eigenvectors of the wing model. Laminate for the spar webs is $[\pm 45]_3$ and unchanged for both configurations throughout the research. The first symmetric laminate for the upper and lower skin is in the form of $[\theta_2/0]_s$ ply stacking sequence, where as the second laminate is in the form of $[0/\theta_2]_s$.

## RESULTS

The composite wing box model is validated with [8] for both configurations with a ply stacking sequence of the $[\theta_6]$ for all sides at fibre angle of 30 degree simulating cantilevered case. This is done by using three methods; the first method is with clamping the grids at the root section. The second and third methods are by fixing the centre grid which is attached to the root grids, and with using both REB2 and springs at higher stiffness of $10^9$ respectively. Normal mode and aeroelastic analysis are then carried out on the CAS and CUS configuration for both laminates of the composite wing box using Lanczos and PK methods respectively. The variation of the natural frequencies versus the root stiffness is shown in figure 1 of the first laminate at fibre angle of $0^o$ for illustration. The rest of the figures of both dynamic and aeroelastic analysis will be shown in the full paper. The research showed that the root stiffness has a significant influence on the natural frequencies and associated mode shapes and on the flutter and divergence speeds of the composite wing models especially at root stiffness lower than $10^3$.

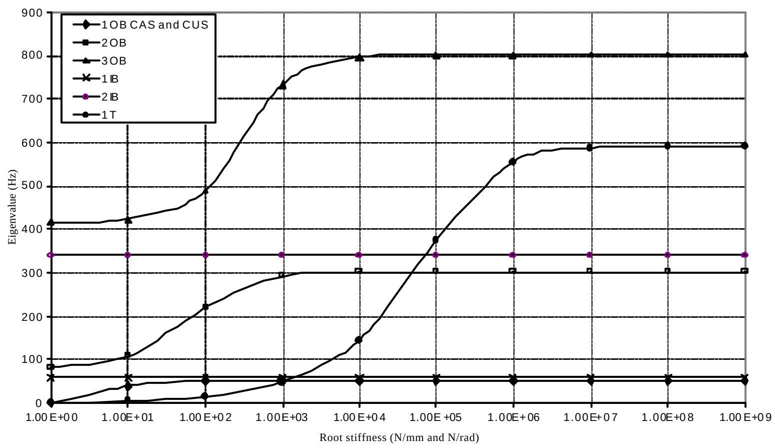


Figure 1. Eigenvalues versus root stiffness for the first laminate at $0^o$ fibre orientation.

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