FLUTTER AND DIVERGENCE BEHAVIOUR OF COMPOSITE WINGS AT SUBSONIC SPEEDS

F.A. Fazzolari, M. Boscolo and J.R. Banerjee

School of Engineering and Mathematical Sciences
City University London
Northampton square, EC1V 0HB, London
e-mail: Fiorenzo.Fazzolari.1@city.ac.uk

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Summary. Flutter and divergence behaviour of laminated composite wings is investigated by using generalized coordinates through the application of normal modes and strip theory based on Theodorsen type unsteady aerodynamics. The investigation is carried out in three steps. First, stiffness properties of the composite wing are established using classical lamination theory. Next, natural frequencies and mode shapes are computed by using the dynamic stiffness method which accounts for the bending-torsion coupling effect arising from the anisotropic nature of fibrous composites. Finally, flutter and divergence speeds are calculated by using a number of carefully chosen normal modes and strip theory based on Theodorsen type unsteady aerodynamics. A detailed parametric study is carried out to examine the effects of ply orientation, stacking sequence and sweep angle on the flutter and divergence behaviour of composite wings. The results are discussed and some conclusions are drawn.

1. INTRODUCTION

The advent of advanced composite materials has provided design engineers with ideas and opportunities to manipulate design configuration with various possibilities, particularly in the aerospace industry where weight-saving is a major consideration. Fibre reinforced composite materials, are light and strong and as a consequence, they provide high specific strength. In addition to the weight-saving benefit, there is however, another very important benefit of using such materials which is due to their directional properties, making it possible to distribute their strengths and stiffness in a desired manner. From an aeroelastic point of view, this is extremely significant because undesirable aeroelastic phenomena like flutter and divergence can be avoided or even eliminated by a suitable choice of stacking sequence. The essential purpose of this paper is to investigate the flutter and divergence behavior of composite wings at low speeds for a wide range of ply orientations, stacking sequences and sweep angles. The flutter problem is formulated by using the normal mode method linking unsteady aerodynamics of Theodorsen type in terms of the generalised coordinates. For structural idealisation, the dynamic stiffness method is used to idealise the wing as a collection of bending-torsion coupled
beams. The flutter matrix is formed by algebraically summing the generalised mass, stiffness and aerodynamic matrices. The formulation essentially becomes a double eigenvalue problem with airspeed and frequency being the two unknowns. The flutter problem is then solved by computing the zeroes of the flutter determinant yielding the flutter speed and the flutter frequency. Divergence analysis is carried out by considering only the torsional mode of the wing and divergence being a static phenomenon, the investigation in some (heuristic) way can be described as flutter analysis at zero frequency, i.e. without the contribution from inertia forces.

This work is partly motivated by the recent developments in the research of forward-swept wings using composite materials. The use of forward-swept wings has many aerodynamic benefits, particularly at high angles of attack and at supersonic speeds. Some of these benefits are related to the reduction in wave and profile drags and improved handling qualities at high angles of attack. Despite these benefits, the forward-swept wing design lost its appeal in the past because of its unacceptably low divergence speed due to the wash-in effect. Evidently, the problem could not be overcome using isotropic materials, but now with the advent of advanced composite materials, the situation has changed and research in "aeroelastic tailoring" has made the forward-swept wing a possible design solution fulfilling the aeroelastic requirements for the airworthiness. This paper investigates the aeroelasticity of composite wings and provide a wide range of results for both flutter and divergence speeds by varying significant design parameters such as ply angle, stacking sequence and angle of sweep.

2. THEORETICAL FORMULATION

The static aeroelastic analysis leads to the determination of the critical divergence dynamic pressure, which mathematically can be represented with the following eigenvalue problem:

$$\| K + \lambda_D K_{Aer} \| = 0$$

where the matrix $K$ is the structural stiffness matrix and $K_{Aer}$ is the aerodynamics stiffness matrix. The eigenvalue can be identified with the dynamic pressure $\lambda_D = \frac{1}{2} \rho V_B^2$. The dynamic aeroelastic analysis takes into account the classical flutter problem which leads to the following quadratic eigenvalue problem:

$$\| (K + K_{Aer}) + \lambda_F D_{Aer} + \lambda_F^2 M \| = 0$$

where $D_{Aer}$ is the damping aerodynamics matrices and $M$ the mass structural matrices. The quadratic eigenvalue problem can be reduced to a complex linear one by substitution leading to:

$$\| R + \Omega_F T \| = 0$$

where $R$ and $T$ are two matrices depending on structural and aerodynamics characteristics and $\Omega_F = \delta_F + i \omega_F$ being $\omega_F$ the flutter frequency and $\delta_F$ the damping which individuate the critical flutter airspeed when becomes zero.