A Comparison of the Vibrational Responses of Four Different Uniform and Tapered Composite Beams

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ABSTRACT
A combined experimental and finite element approach was used to compare the vibrational response of the composite beams with different configurations of internal taper and uniform cross sections. Composite beams were made using the hand lay-up process. Glass fibre was used as reinforcement in the form of a bidirectional fabric and a general-purpose epoxy resin as the matrix for the composite material. Experimental dynamic tests were carried out on FFT analyzer using specimens with different taper configurations. From the results, the effect of different taper configurations on the flexural natural frequencies and mode shapes was investigated. Finite element analysis of the same problem was carried out on software package ANSYS and the results were validated using the experimental results. From the results, a thorough comparison was made between the natural frequencies, loss factors, displacements and mode shapes of the specimens with different taper configurations and uniform cross sections considered. The aerospace implications are provided.

KEYWORDS
Cantilever Beam, FFT Analyser, Finite Element Method, Flexural Vibrations, Glass Fabric/Epoxy, Mode Shapes, Natural Frequencies, Ply-Drop Off

1. INTRODUCTION
Composite structures are extensively used in aerospace, automotive, marine and civil engineering applications due to their very high-stiffness-to-weight ratio and the ability to yield different strengths in different directions. The behaviour of these composite structures can be tailored effectively to satisfy the strength and stiffness requirements in practical engineering designs by changing their lay-up properties. In some specific applications, the composite structure needs to be stiff at one location and flexible at another location. It is desirable to modify the material and structural arrangements to match the requirements of the localized strength and stiffness by dropping the plies over a length. Such a laminate is referred to as a tapered laminate. Tapered laminated structures have received much more attention from researchers for creating significant weight savings in engineering applications. Complex structures like rotor blades, shovels, gun barrels and other taper-walled structures are frequently used.

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and the loading conditions of these structures are complex in nature. Some interesting investigations have been carried out on tapered composite structures.

Vizzini and Lee (1995) conducted a combined finite element and experimental approach to investigate the structural integrity of tapered composite beams. The location of the damage initiation, the interaction between the free edge and the taper discontinuities, the effect of realistic geometries, the extent and mode of damage growth and the ability of simple physical models to explain the occurrence of the interlaminar stress state of tapered composite beams were determined. Cairns et al. (1999) have explored various factors for the design of composite structures with ply drops and evaluated the threshold loadings under which the delamination growth could be identified. He et al. (2000) have performed and presented a thorough review of many investigations that have been carried out on tapered composite structures. Analysis of such composite structures with an emphasis on interlaminar stress analysis, delamination analysis and parametric study was presented. Mukherjee and Varughese (2001) have studied the effect of different design and geometric parameters on the strength of the ply drop-off laminates. It was concluded that the laminate strength could not be increased effectively when the plies are combined with various orientations during the drop-off locations. Vidyashankar and Murty (2001) carried out a study on the effects of ply drops and resin pockets on the tensile behaviour of tapered laminates considering certain important parameters such as taper angle, the number of plies dropped, and the fiber orientation. Steeves and Fleck (2005) have conducted experiments on tapered laminates loaded in axial compression and failures by micro-buckling or delamination were observed to nucleate near the dropped plies. The new model given in this work for delamination provides satisfactory predictions of strength for more severe defects. Ganesan and Zabihollah (2007) formulated a higher order finite element with two nodes and four degrees of freedom per node for tapered composite beams to investigate the dynamic characteristics of various configurations of a tapered composite beam. Using their formulation, Ganesan and Zabihollah (2007a) performed various parametric studies to investigate the effect of taper angle, laminated taper configuration, boundary conditions, ply orientation and various geometric parameters on the un-damped natural frequencies. Calm (2008) developed the governing differential equation of motion for the free and forced vibrations of non-uniform composite beams in Laplace domain including the effects of shear deformation, rotary inertia and non-uniformity of the cross-section. Ghaffari et al. (2009) studied the vibration based structural health monitoring to detect the delamination in the tapered laminated composite beam. Allegri et al. (2009) have presented an optimization tool, based on fracture mechanics, for the preliminary design of tapered composite laminates. Validation of the presented optimization procedure is demonstrated by comparing the results obtained using finite element analysis. Sudhakar et al. (2017) have investigated the rotational effects on a tapered laminated structure. Other than an experimental investigation by Manchit Kumar et al. (2013) on the dynamic characteristics of a tapered composite cantilever beam, it is observed that there is a considerable dearth of detailed experimental investigations on the comparison of dynamic characteristics and vibrational response of tapered laminated composite beams of various configurations and architectures.

Hence, in this investigation the dynamic characteristics of two different tapered composite laminated architectures (different from that investigated by Manchit Kumar et al., 2013) were studied and comparisons with uniformly thick and thin counterparts were made. This investigation also includes a comparison of the numerically obtained dynamic characteristics with those obtained experimentally. Such a comparison has been found to be technologically important as the tapered composite architectures are increasingly being used in the study of vibrational characteristics of aeronautics, rotorcraft and wind energy blades, to name a few. There is also an impending need to replace physical dynamic testing of tapered composite structures with reliable finite element analysis as modelling and analysing the same pose challenges.

In this study dynamic characteristics of the tapered beams with different taper configurations are investigated experimentally and numerically. Two taper configurations that have been considered are continuous plies interspersed type and staircase type configuration as shown in Figure 1 and
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