Dynamic analysis of Composite Micro Air Vehicles

Shishir Kr. Sahu

Professor and Head, Civil Engineering, National Institute of Technology, Rourkela, India
E-mail: sksahu@nitrkl.ac.in

ABSTRACT

The present work deals with a combined experimental and numerical study of vibration of woven fiber Glass/Epoxy (G/E) composite plates with delamination used for aerospace vehicles including Micro air vehicles (MAV). The airframe and wings of a MAV are preferred to be of composite materials, which allows for wing flexibility without sacrificing durability. The resulting vehicle is durable but lighter than conventional counterparts. For numerical analysis, a finite element model was developed using first order shear deformation theory for an eight noded two dimensional quadratic isoparametric element having five degrees of freedom per node. In the experimental study, the influence of various parameters like delamination size, boundary conditions and fiber orientations on the natural frequencies of delaminated composite plates were investigated. Comparison of numerical results with experimental results showed a good agreement. Fundamental natural frequencies were found to be decreased with the increase of delamination size and fiber orientation of delaminated plate. Natural frequency of delaminated plate varied significantly for different boundary conditions.

INTRODUCTION

Micro air vehicles or MAVs are a class of aircraft with a maximum size of 150 mm and are capable of operating at maximum speeds of 25mph. These are used for surveillance, measurement missions in difficult situations, monitoring crops and wildlife distributions. Composite materials are widely used in a multitude of thin-walled light-weight load bearing structural parts i.e wings and fuselage panels for various modern aerospace including Micro air vehicles, marine, automotive and civil engineering structures. The usage of woven composites are increased over the recent years due to their lower production costs, light weight, higher fracture toughness and better control over the thermo mechanical properties. Failure analysis of laminate composite structure due to delamination is an essential issue in the evaluation of composite laminate for durability. The presence of delamination may affect some design parameters such as the vibration characteristics and stability of the structure. In many situations vibration testing is recognized as an effective and fast method for detecting various failures in structural elements. Detection of delaminations and the study of their dynamic behaviour of delaminated composite structures are important for the successful use of composites and improvement of stability of such structures.

REVIEW OF LITERATURE

The changes in dynamic characteristics of isotropic constructional elements with fatigue damage have been studied by many authors, but relatively few people have devoted their works to the changes in the dynamic characteristics of the composite constructional elements. Nikpour and Dimargonas [1] elaborated a method of calculating the local compliance matrix for unidirectional composite materials. Ju *et al.* [2] presented finite element formulation for the analysis of free vibration of composite plates with multiple delaminations. Krawezuk *et al.* [4] developed a finite element model to study the dynamics of cracked composite material structures. Chattopadhyay *et al.* [5] formulated a higher order theory for dynamic stability analysis of delaminated composite plates. Parhi *et al.* [6] carried out several parametric studies to investigate the dynamic behavior in the presence of single and multiple delaminations of laminated composite plates. Zak *et al.* [7] studied the influence of the delamination length and position on changes in natural frequencies and modes of vibration of the unidirectional laminated composite plates by using finite element method. Yam *et al.* [8] proposed finite element model to predict dynamic behavior of a multi-layer composite plate with internal delamination at arbitrary locations. Oh *et al.* [9] developed a four-noded finite element based on the efficient high-order zig-zag plate theory of laminated composite plates with multiple delaminations. Azouaoui *et al.* [10] made an experimental investigation to study the delamination behaviour of glass/polyester composite plates.

The investigations on modal analysis of delaminated woven roving fiber composite plates were found to scarce in literature. Therefore in the present study, the free vibration of industry driven woven roving glass-epoxy delaminated composite plates are investigated both numerically and experimentally. The influences of various parameters like effects of delamination area, boundary conditions and fiber orientation on the natural frequency of woven roving delaminated plates were studied.

MATHEMATICAL FORMULATION:

Fig. 1 showed a delaminated composite plate where the delaminations were presumed to be parallel to the mid-plane of the plate. The global coordinate system was located at the mid-plane of the plate with the z-axis perpendicular to it.

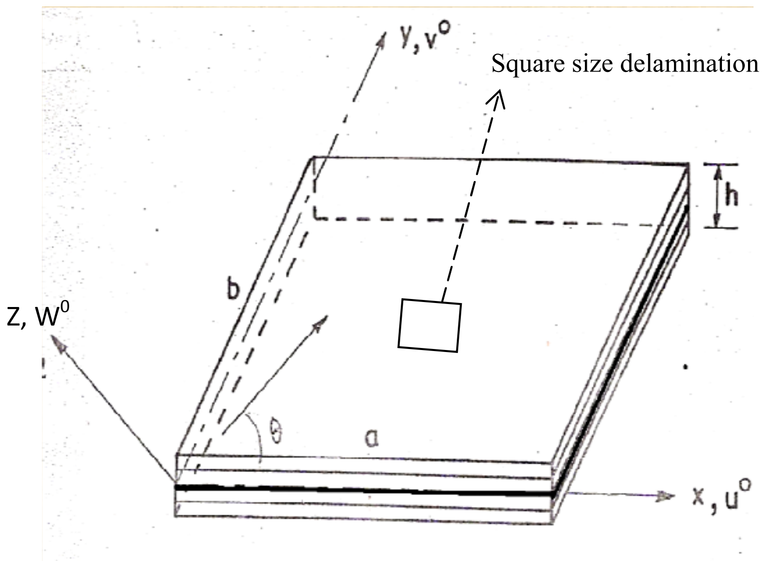

Fig. 1 Rectangular plate with delamination

The finite element used for dynamic behavior analysis of delaminated composite plate in the present investigation, was an eight noded two dimensional quadratic isoparametric element having five degrees of freedom (u^0, v^0, w^0, θ_x, θ_y) per each node. For analysis of free vibration of delaminated composite plate , a finite element model was developed using first order shear deformation theory.

Delamination Modelling:

A simple two dimensional single delamination model proposed by Gim [3] has been extended in the present analysis. It can be applicable to any general case of a laminated composite plate having multiple delaminations at any arbitrary location. Here the delaminated area is assumed as the interface of two separate sub laminates bonded together along the delamination surface. Typical composite plate of uniform thickness *h* with *n* number of layers and *p* number of arbitrarily located delaminations is considered for the analysis as shown in Fig. 2. The principal material axes of each layer is arbitrarily oriented with respect to the mid-plane of the plate. Let Z^0_s is the distance between the mid-plane of the original laminate and the mid-place of the arbitrary sth sub-laminate Fig. 3.

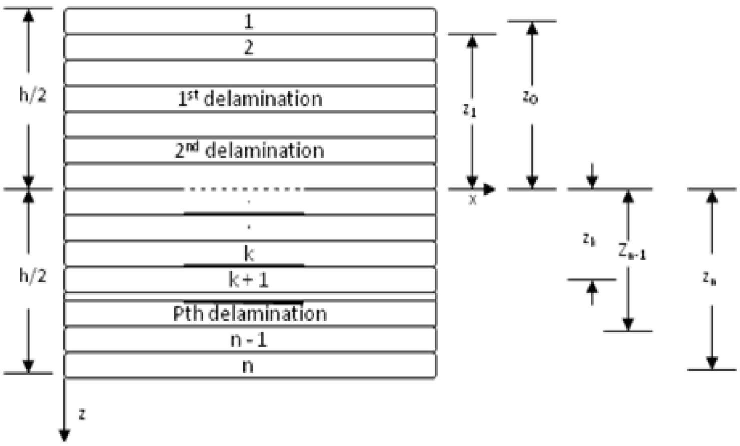

Fig. 2. Laminate Geometry with Multiple Delaminations

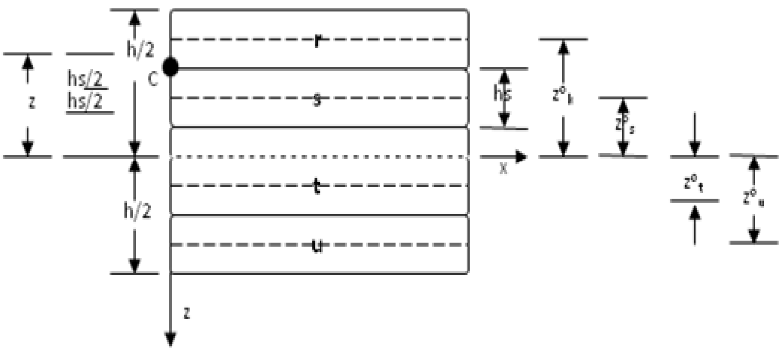

Fig. 3. Three arbitrary delaminations leading to four sub laminates r, s, t, and u

After finding the elastic stiffness matrices separately for different sub laminates along the thickness, the sum of all the sublaminate stiffnesses represents the resultant stiffness matrix.

EXPERIMENTAL PROGRAMME:

The composite plate specimens used in this research were made from (0/90) woven glass fiber with epoxy matrix. The percentage of fiber and matrix was 50:50 in weight. Specimens were fabricated by hand layup technique. Square size delaminations has been introduced in 6.25%, 25% and 56.25% area of composite plate by providing Teflon film centrally at midplane of the plate during fabrication . All the specimens were tested for free vibration. The natural frequencies of 8-layered woven fiber Glass/Epoxy composite plates without and with delaminations were determined experimentally using B&K FFT analyzers. Elastic parameters of the plate were determined experimentally by tensile testing of specimens in INSTRON machine as described in ASTM standard: D638-08 and D3039/ D3039M-2006 [11]. The geometrical dimensions and the material property of the woven roving glass/epoxy composite plates has been given in Table 1.

Table 1. Geometrical dimensions and Material properties of composite plates

Length a= 0. 24 m, Breadth b= 0.24 m,	Thickness h= 0.003 m
Young's modulus: $E_{11}= E_{22}$=7.7 Gpa	Shear Modulus: G12= G23= G31= 2.81 GPa
Density ρ=1661.25kg/m^3	Poisson ratio υ_{12} = 0.17

RESULTS AND DISCUSSION:

In the present investigation, the numerical calculations and experimental work were carried out for an eight-layer [$(0/90)_4$] woven roving glass/epoxy composite plate. In this research work, the effect of delamination area, boundary conditions and fiber orientations on the natural frequencies was investigated in details.

Effect of Delamination Area

The effect of delamination area on the fundamental natural frequencies of laminated and delaminated [$(0/90)_4]_s$ plates were depicted in Fig.4, 5, & 6 as a function of delamination area for cantilever, four side clamped and four side simply supported boundary conditions respectively. The numerical (FEM) results showed a good agreement with the experimental results for all the three boundary conditions and the discrepancy between numerical and experimental results may be aroused due to the idealization of the support condition. The fundamental frequencies of 6.25%, 25% and 56.25% delaminated plates were found to be decreased by 10%, 14% and 22 % respectively as compared to un -delaminated plates in case of cantilever boundary condition (Fig. 4). The fundamental frequencies of four sides clamped

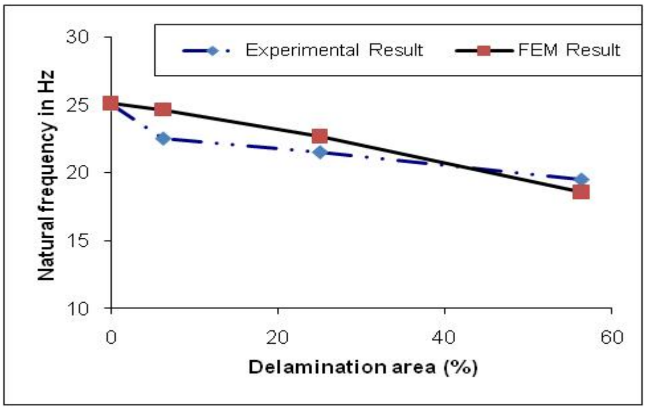

Fig. 4. Variation of frequency with delamination of woven fiber cantilever composite plate

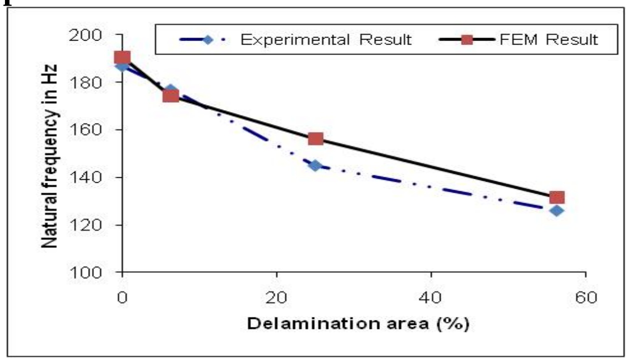

Fig. 5. Variation of frequency with delamination of four side clamped composite plate

condition (Fig.5) were found to be decreased by 5.23%, 22% and 32% for 6.25%, 25% and 56.25% delaminated plates respectively as compared to un- delaminated plates. In case of four sides simply supported boundary condition (Fig.6) the natural frequency decreased by 14%, 19.5% and 35 % for 6.25%, 25% and 56.25% delaminated plates respectively from undelaminated plates . From Figs. 4-6, it was noticed that the natural frequency decreases with the increase of delamination area invariably for all the boundary conditions and relatively large delamination area has considerable effect on the fundamental frequency.

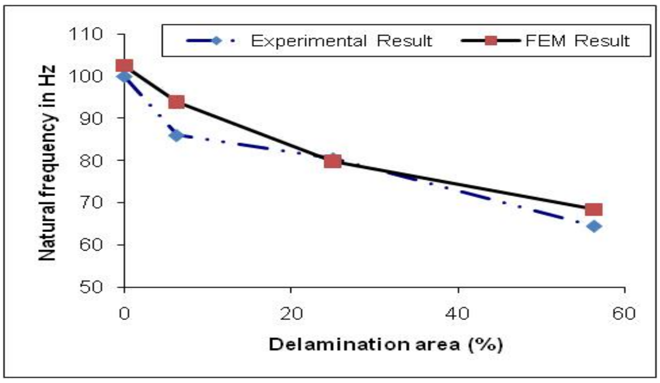

Fig. 6. Variation of frequency with delamination of four side simply supported composite plate

Effect of Boundary Condition

To investigate the influence of boundary conditions on natural frequencies of delaminated plates, three types of boundary conditions were considered, namely, S-S-S-S (four edges simply supported), C-C-C-C (four edges clamped) and C-F-F-F (cantilever). The specimen taken for the study was of eight layered composite plate having stacking sequence of $(0/90)_4$ with 25% of delamination area. Fig. 7 & 8 explained the effects of boundary conditions on the natural frequencies of delaminated composite plates for experimental and numerical results respectively. It was observed that the numerical (FEM) and experimental results were in good agreement for all the boundary conditions. The 1st, 2nd and 3rd mode natural frequencies obtained from experimental work (Fig. 7) were found to be the least for C-F-F-F (cantilever) condition and the highest for C-C-C-C (four side clamped) condition. This study implied that the effect of delamination on the natural frequencies was greatly dependent on the boundary conditions.

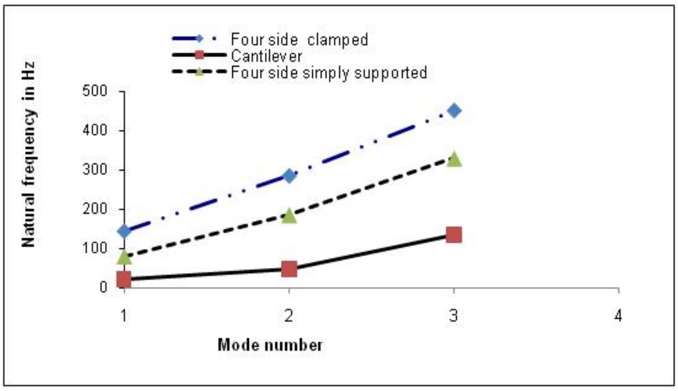

Fig. 7. Variation of frequency with different modes of experimental results of 25% delaminated composite plate for different boundary conditions

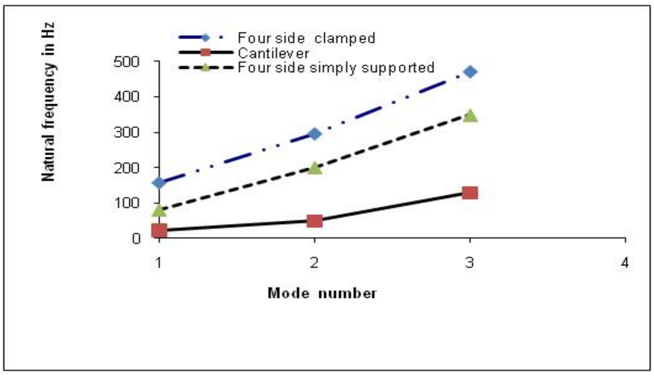

Fig. 8. Variation of frequency with different modes of FEM results of 25% delaminated composite plate for different boundary conditions

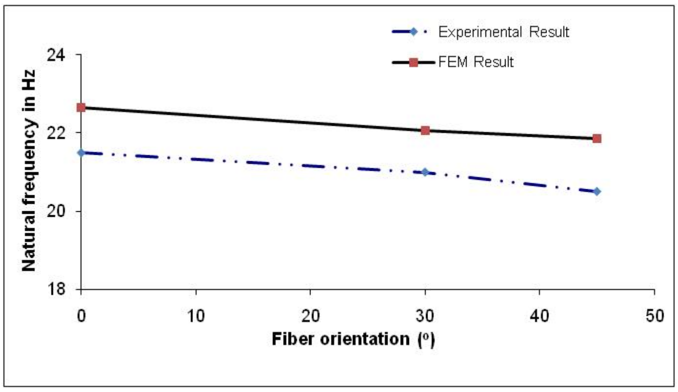

Fig. 9. Variation of frequency with fiber orientation for delaminated cantilever composite plate

Effect of Fiber Orientations

In order to know the effect of fiber orientations on natural frequencies of 25% delaminated plate (8-layers), three types of fiber orientations i.e. $(0/90)_4$, $(30/-30)_4$, $(45/-45)_4$ were considered. The change in the natural frequency as a function of fiber orientation was presented in Fig. 9 for cantilever boundary condition. The results obtained from free vibration of the plates of both experiment and present FEM were in good agreement. From the Fig.9, it was observed that the fundamental natural frequency of delaminated plate with 30° and 45° orientation was decreased by 2.32% and 9.3% respectively from 0° orientation. This implied that the fundamental natural frequency of woven fiber delaminated plates decreased with the increase in fiber orientation unlike the unidirectional composite plates.

CONCLUSIONS

Based on numerical and experimental results the following conclusions can be drawn:

- A formulation for dynamic behavior of composite Micro air vehicle is presented.
- There is a good agreement between the experimental and numerical results.
- The natural frequencies of vibration decrease with the increase in delamination area in woven fiber composite plates.
- Numerical and experimental results show that the natural frequencies of delaminated composite plates is dependent not only on the size but also on the boundary conditions.

- For cantilever boundary condition, there is a decrease in natural frequency with increase in the fiber orientation.

From the above studies, it can be concluded that the dynamic behavior of Micro air vehicles is significantly affected by the delamination, boundary condition and ply orientation. So, the designer has to be cautious while dealing with composite Micro air vehicles.

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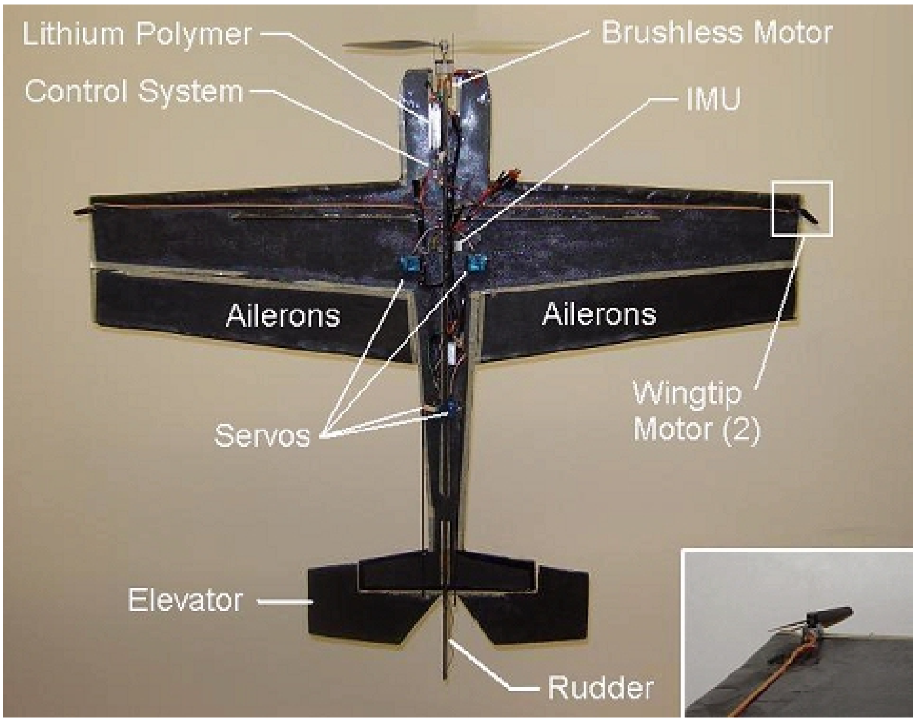
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