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Numerical and Experimental Vibration Studies of a Compact Vehicle Shell

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Abstract
Laminated composite shells are widely used in aerospace and automotive applications due to their excellent strength-to-weight ratio. However, delamination during fabrication or service reduces their structural performance and alters vibration characteristics. This paper presents numerical and experimental studies on the free vibration behavior of a delaminated composite cylindrical shell. The Finite Element Method (FEM) was implemented in MATLAB to compute natural frequencies, and experimental validation was conducted using an accelerometer and FFT analyzer. Results indicate a significant dependency of natural frequency on shell curvature, delamination area, aspect ratio, and boundary conditions. This study provides insights into optimizing composite shell structures for enhanced performance.

Keywords: Composite Shells, Delamination, Finite Element Analysis (FEA), MATLAB, Experimental Vibration Testing

1. Introduction
Composite materials are increasingly utilized in engineering applications due to their high specific strength, stiffness, and lightweight properties. However, **delamination**—a separation between layers—can significantly reduce the mechanical properties and alter vibration behavior. Understanding the free vibration response of delaminated composite structures is crucial for designing efficient and reliable structural components. This research focuses on analyzing the vibration characteristics of a delaminated composite cylindrical shell using both numerical and experimental approaches.

2. Literature Review
2.1 Overview of Laminated Shells
Composite shells have been extensively studied for their vibration characteristics. Bert and Kumar (1982) analyzed the effects of ply orientation on natural frequencies, while Ju et al. (1995) used the Finite Element Method (FEM) to analyze composite shell behavior. Librescu et al. (1989) introduced shear deformable theories for laminated composite shells.
2.2 Shells with Delamination
Limited studies exist on the free vibration behavior of delaminated composite shells. Parhi et al. (2001) examined the effects of delamination size and location on natural frequencies. Kim and Cho (2003) developed higher-order shell theories for delaminated structures. This study extends existing research by comparing numerical FEM simulations with experimental findings.

Schematic of Delaminated Composite Shell

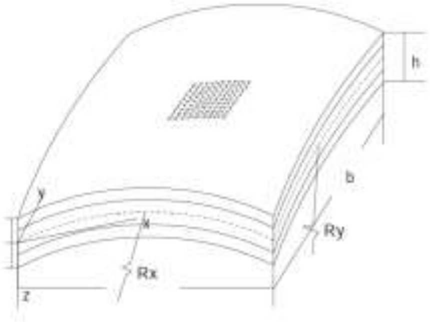

Fig: Doubly curved panel with delamination

3. Mathematical Formulation & Methodology

3.1 Finite Element Analysis

The free vibration behavior of the delaminated shell is modeled using **First-Order Shear Deformation Theory (FSDT)**:

$$[K] - \omega^2[M] = 0$$

where

- $[K]$ = Global stiffness matrix
- $[M]$ = Global mass matrix
- ω = Natural frequency

A MATLAB-based **FEM simulation** was used to compute eigenvalues, and results were compared with experimental findings.

3.2 Experimental Setup

To validate the FEM model, vibration experiments were conducted using:

- **Modal Hammer (2302-5)** for excitation
- **Accelerometer (4507)** for response measurement
- **FFT Analyzer (Bruel & Kjaer 3560)** for frequency analysis

Three boundary conditions were tested:

1. F-F-F-F (Free-Free-Free-Free)
2. S-F-S-F (Simply Supported-Free-Supported-Free)
3. C-C-C-C (Clamped-Clamped-Clamped-Clamped)

Experimental Setup Diagram (FFT Analyzer, Modal Hammer, Accelerometer)

Fig: Experimental Testing Setup

4. Results and Discussion

4.1 Numerical vs. Experimental Results

The numerical and experimental results demonstrated good agreement, validating the MATLAB FEM model. The natural frequencies obtained for different delamination sizes are presented below:

Delamination (%)	Numerical Frequency (Hz)	Experimental Frequency (Hz)
0	103.02	103.01
6.25	88.16	88.15
25	69.59	69.60
56.25	59.92	59.92

4.2 Influence of Key Parameters

4.2.1 Effect of Curvature

A higher curvature increases natural frequency due to higher stiffness.

Graph Showing Natural Frequency vs. Curvature

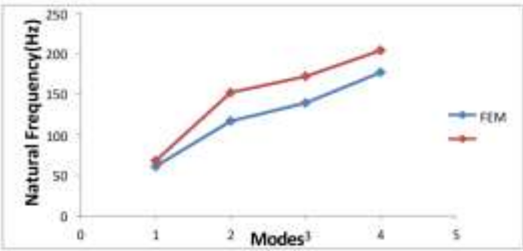

Fig: Variation of natural frequencies of laminated composite plate with mode

4.2.2 Effect of Delamination Area

Larger delamination areas reduce stiffness, leading to lower natural frequency.

Graph Showing Natural Frequency vs. Delamination Area

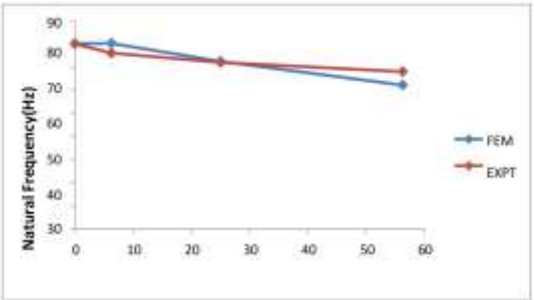

Fig: Variation of fundamental natural frequency with delamination area of cylindrical shell at F-F-F-F boundary condition.

4.2.3 Effect of Aspect Ratio

Increasing the length-to-width ratio increases vibrational response.

Graph Showing Natural Frequency vs. Aspect Ratio

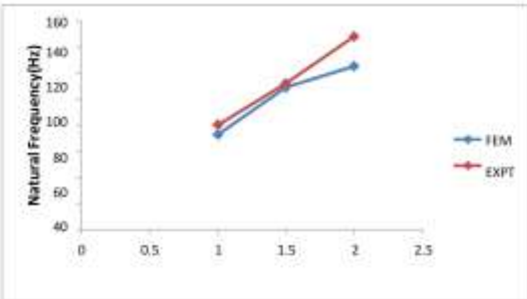

Fig: Variety of major characteristic recurrence with angle proportion for round and hollow shell with 25% delamination

4.2.4 Effect of Boundary Conditions

C-C-C-C boundary conditions yield the highest fundamental frequency, while F-F-F-F exhibits the lowest.

Comparative Graph of Different Boundary Conditions

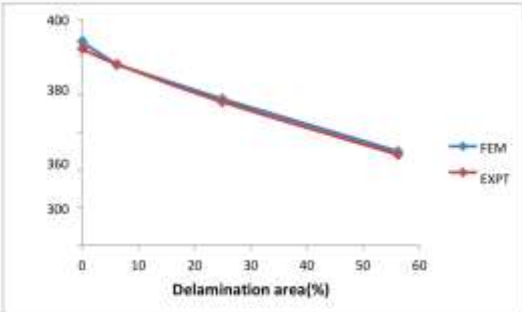

Fig: Variation of fundamental natural frequency with delamination area of cylindrical shell at C-C-C-C boundary condition.

5. Conclusion

This study highlights the effects of delamination on the vibration response of laminated composite shells. The key findings include:

- **Delamination reduces stiffness, lowering natural frequency.**
- **The FEM model provides accurate predictions for free vibration behavior.**
- **Boundary conditions significantly impact vibration response.**

5.1 Future Work

- Investigating dynamic response under impact loads.
- Developing hybrid composite materials with enhanced properties.
- AI-based delamination detection in composite structures.

6. References

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