Design-Oriented Assessment of Composite Aircraft Panels under Multiple Loading Conditions

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INTRODUCTION & AIM

Composite laminates exhibit highly anisotropic behavior, resulting in significantly **different** responses under mechanical and thermal loading. In aerospace structures, components are typically subjected to combined loading environments rather than isolated load cases.

However, early-stage design lacks efficient tools for simultaneously evaluating laminate performance across multiple loading scenarios. Most approaches rely on single-load optimization, potentially leading to suboptimal structural configurations.

The objective of this study is to develop a multi-load laminate selection framework based on normalized stiffness metrics, enabling systematic comparison and design-oriented decision-making.

METHOD

Structural Model

- Simply Supported composite panel
- 16 plies, total thickness = 2 mm

Laminate Configurations

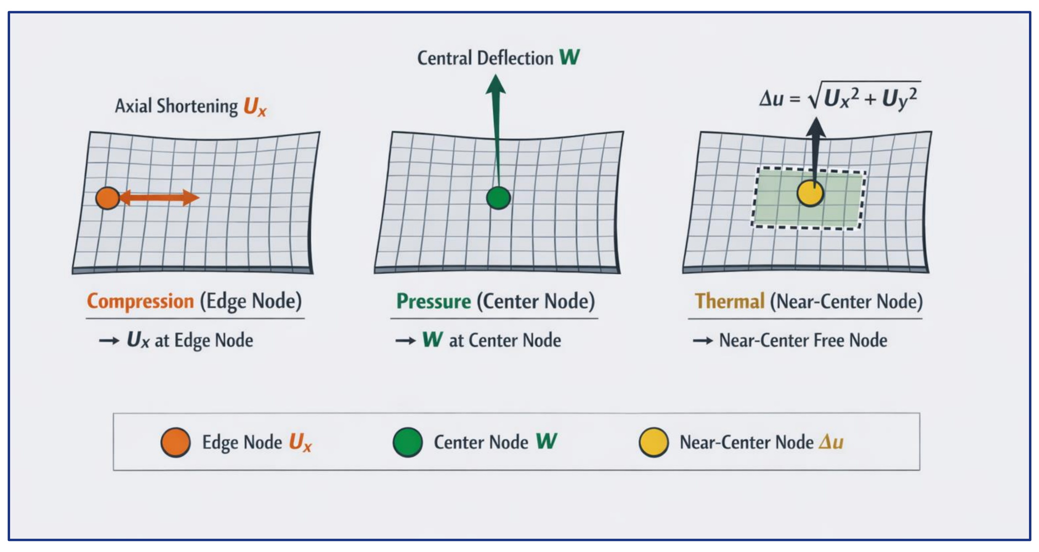
- $[0]_s$, $[90]_s$, $[\pm45]_s$, Hybrid configurations ($[0/90]_s$, $[0/\pm45]_s$, $[90/\pm45]_s$)
- Quasi-isotropic: reference laminates

Loading Cases

- In-plane compression (membrane-dominated response)
- Out-of-plane pressure (bending-dominated response)
- Uniform thermal loading (thermo-mechanical coupling)

Data Processing Workflow

Finite Element Analysis → Displacement Extraction



Stiffness evaluation: $K_{C,P,T} = \frac{Load}{Displacement}$

Normalization of stiffness indices (K) → **Construction of Pareto fronts**

Additional Metrics

- **Stiffness Anisotropy Index (SAI):** Directional Stiffness Imbalance

$$SAI_A = \frac{A_{11}+A_{22}}{A_{11}-A_{22}} \qquad SAI_D = \frac{D_{11}+D_{22}}{D_{11}-D_{22}}$$

- **Robustness Index (R):** Multiload Performance Concistency

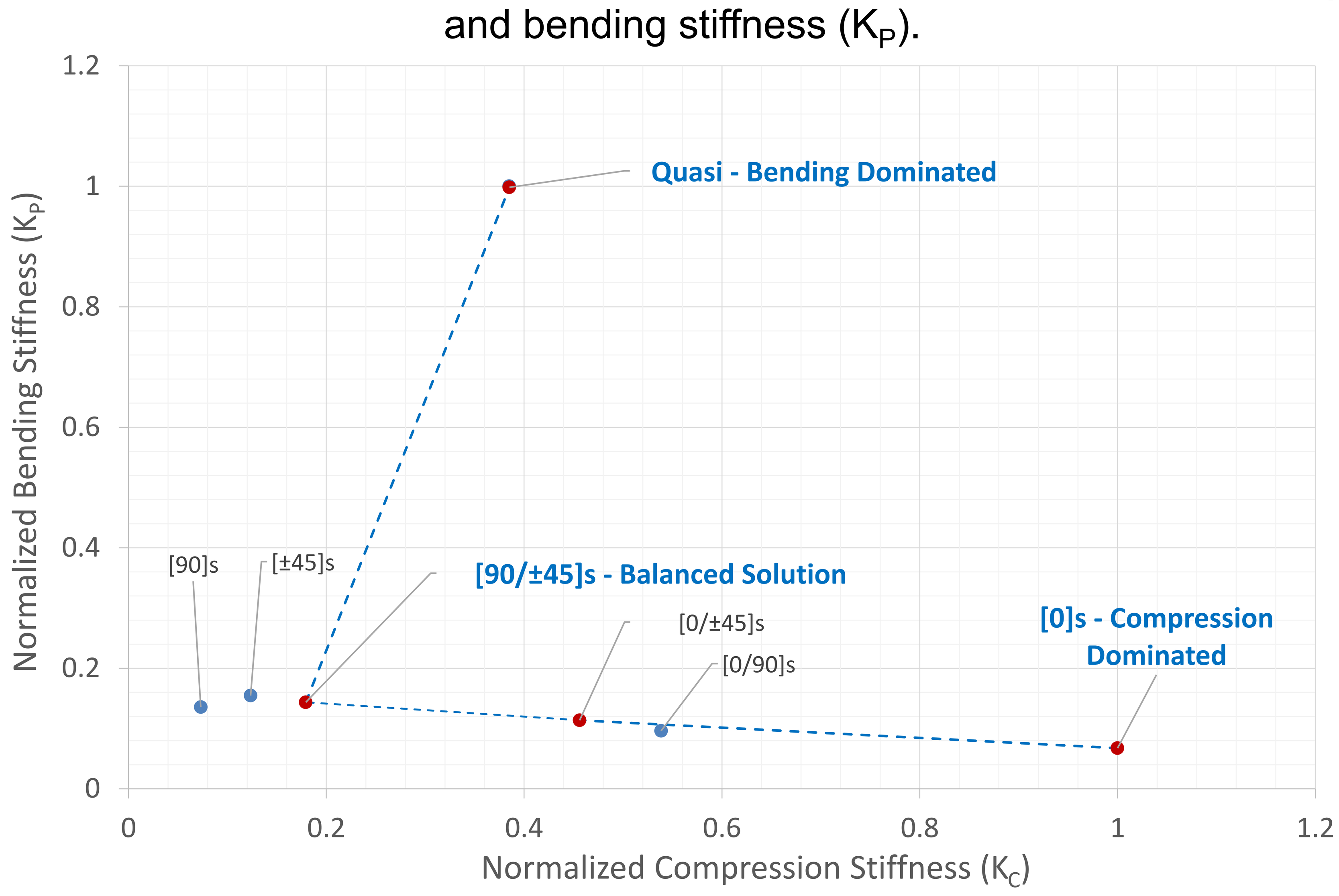
$$R = \frac{Max(K_C, K_P, K_T)}{Min(K_C, K_P, K_T)}$$

CONCLUSIONS

- Conflicting performance across loading conditions is inherent in composite laminates.
- The proposed framework supports systematic laminate selection
- Hybrid configurations improve multi-load robustness.
- Stiffness anisotropy governs structural response.
- No single laminate is optimal for all load cases.

Results & Discussions

The Pareto front reveals a clear trade-off between membrane stiffness (K_C) and bending stiffness (K_P).

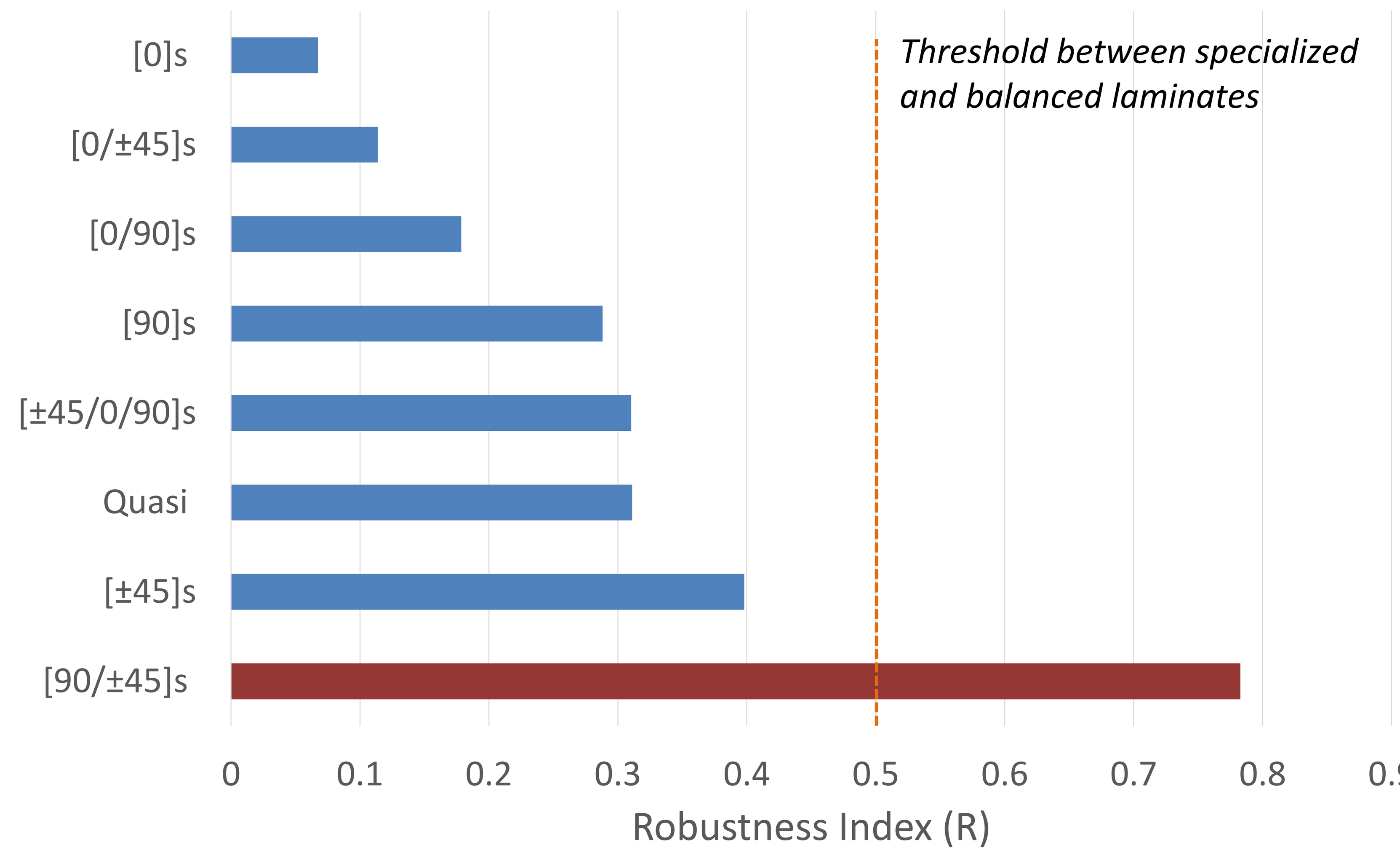


- **Compression-dominated:** $[0]_s$ — high K_c, low K_P
- **Balanced response:** Quasi-isotropic — uniform performance
- **Trade-off solutions:** Hybrids — intermediate behavior

- SAI are used to interpret laminate behavior, linking stiffness directionality to observed performance trade-offs
- Thermal effects are incorporated within the Robustness index (R), enabling unified multi-load evaluation without increasing visual complexity.

ROBUSTNESS INDEX

Robustness Index (R) comparison across laminate configurations.



- Hybrid laminates exhibit **improved** multi-load performance balance, with $[90/\pm45]_s$ achieving the highest Robustness Index.

FUTURE WORK

- Extension of the framework to additional laminate configurations
- Extension to weight-driven optimization
- Explore the cases of stiffened panels
- Integration with buckling constraints