Natural Frequencies and mode shapes of prestressed elastically foldable flat arrays

Keywords: Deployable structures; natural frequencies; prestress; connection modeling; scaling laws.

Abstract.

Large, lightweight deployable structures are central to next-generation space systems, yet predicting their natural frequencies remains challenging when ultra-thin components, geometric nonlinearity, and prestress interact at scale. Recent studies on ultra-thin composite deployables highlight both the promise of these systems and the modeling difficulties that arise from their extreme slenderness and complex connectivity. This work investigates a family of scalable, fully deployed structures of the Space Solar Power Project of Caltech [1-2]; they are composed of bending-stiff trapezoidal strips arranged as concentric squares and attached to prestressed tapes supported by deployable diagonal booms.

Two studies organize the work. **(1) Analyses across multiple scales:** how the modal content evolves with **array size** is assessed, performing a consistent scaling of concentric-square modules to emulate progressively larger systes. This reveals frequency-versus-size trends and identifies the size ranges that challenge pointing stability. **(2) Prestress sensitivity:** how the **magnitude of prestress** in the supporting tapes (and associated boom constraints) shifts the spectrum of natural frequencies is investigated. By sweeping the prestress level over a feasible deployment range, frequency gains are mapped, highlighting trade-offs between stiffness tuning and deployment compatibility.

Detailed models are developed within the **Carrera Unified Formulation (CUF)** [4]. CUF provides a hierarchical, physics-consistent way to represent ultra-thin laminated components with variable-order kinematics. Through-thickness expansions permit accurate capture of transverse shear, warping, and anisotropic coupling while avoiding common locking issues in very slender members. These features make CUF particularly effective for analyses across multiple scales and for systematic prestress sweeps at manageable computational cost.

The results will be compared to those from the literature [4], which include experimental tests and results obtained with commercial software Abaqus.

References

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