

Advanced 1D Finite Elements for the Nonlinear Thermoelastic Analysis of Thin-Walled Beams and Space Booms

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Thin-walled structures are key components in modern aerospace systems due to their high stiffness-to-weight ratio and deployability. In particular, composite deployable booms for space applications are increasingly used in satellite and deep-space missions, where thermoelastic effects induced by extreme and cyclic thermal environments can significantly influence structural behavior. It is imperative that the structural analysis guarantees a high level of accuracy in the prediction of displacement and stresses. The requirement for high-fidelity results necessitates the combination of geometrically nonlinear analysis and high-order kinematic theories.

This work presents an advanced one-dimensional finite element (FE) formulation for the nonlinear thermoelastic analysis of thin-walled metallic and composite beams and deployable booms. The proposed approach is based on the Carrera Unified Formulation (CUF), which enables the development of refined, theory-independent beam models capable of capturing three-dimensional effects within a 1D framework.

The formulation presents a comprehensive consideration of the geometrical nonlinearities by incorporating the complete Green-Lagrange strain tensor, in contrast to the more simplified von Karman nonlinearities. Furthermore, the nonlinear problem is solved using a combination of the Newton-Raphson method and the arc-length constraint. The numerical studies are performed to investigate nonlinear buckling and post-buckling responses under thermal loads.

Results demonstrate that the proposed CUF-based FE model achieves excellent accuracy in terms of displacement and stresses compared to high-fidelity 3D analyses while maintaining computational efficiency. The presented methodology offers a robust and versatile tool for the design and optimization of thin-walled, thermally loaded space structures.