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Space Structures II Development and Verification (Orbital deployable and dimensionally stable structures, including mechanical and robotic systems and subsystems) (2)

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IMPLICIT VS EXPLICIT NONLINEAR DYNAMICS FOR THE UNFOLDING OF DEPLOYABLE SPACE STRUCTURES USING ADVANCED ONE-DIMENSIONAL FINITE ELEMETS

Abstract

In recent years, the push for smaller space systems has been facilitated by advancements in technology and lower launch costs for small satellites. Nonetheless, larger components like antennas and solar sails still necessitate large sizes, leading to the need for deployable structures such as tape-springs and TRAC booms. These structures rely on thin materials that unfold and expand, using the stored energy, to create rod-like shapes. However, issues arise with metallic structures due to thermal effects, prompting a shift towards composite materials. Despite their benefits, composites introduce challenges such as anisotropy and complex stress fields during deployment, complicating the design process.

To accurately design these deployable structures, robust numerical tools are essential, minimizing the reliance on extensive physical testing. Traditionally, 2D models have been preferred for their simplicity and compatibility with the slender profiles of thin-shell structures. However, these models struggle to accurately predict out-of-plane stresses, leading to potential inaccuracies in assessing failure. Adopting 3D finite element analysis offers a solution by providing a detailed view of stress and strain, though at a significant increase in computational demands, especially for nonlinear analysis. Addressing these computational challenges is crucial for developing efficient and reliable design processes for deployable space structures, aiming for a balance between accuracy and computational effort in modeling.

This work presents a solution using a mathematical model based on the Carrera Unified Formulation (CUF), enhancing one-dimensional models with advanced cross-sectional capabilities through higher-order functions. This enables detailed exploration of 3D and localized effects with models that require less degrees of freedom than traditional ones, overcoming typical aspect ratio limitations, especially in composites.

The efficiency of CUF in analyzing buckling and post-buckling behaviors in deployable booms has been well-demonstrated, showcasing its reliability in structural analysis. Previous studies have concentrated on simulating the folding of structures through quasi-static geometrically nonlinear analysis, employing a total Lagrangian approach, Newton-Raphson linearization, and the arc-length control method. This work shifts attention to the deployment phase, utilizing a dynamic analysis to simulate the deployment process. It employs both implicit and explicit computational schemes, with the implicit analysis utilizing a Newmark or HHT-α type method. This method demonstrates the capability of accurately assessing the dynamic responses of ultra-thin composite shells, showcasing the effectiveness of both approaches in capturing the complexities of their behavior, comparing the results with experiments and those obtained with the Abaqus commercial software.