Advanced Numerical Modeling of Buckling in Thin-Walled Structures Under Nonconservative Dynamic Loads

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Abstract

Dynamical buckling of immersed thin-walled structures subjected to complex loadings coupling surface follower pressure and shock waves is one of the most delicate instability problems in solids mechanics. The intricate fluid-structure interaction, the non-linear response of the thin-walled structure in the post-buckling regime and the accurate modeling of the loading are three scientific bottlenecks that need to be addressed to be able to uncover the behavior of the structure under such circumstances.
This study represents a significant advancement in the numerical modeling of structural instabilities by proposing an innovative method to simulate the buckling of thin elastic structures subjected to nonconservative dynamic loads. A particular focus is placed on structures immersed in a fluid, subjected to surface pressure of a nonconservative nature coupled with shock waves, which notably influence their structural inertia.

The approach is based on the Asymptotic Numerical Method (ANM), a high-order perturbation technique enabling the explicit integration of motion equations, using time as the perturbation parameter. Unlike conventional methods, which compute solutions at discrete points, ANM provides a continuous approximation of solutions through high-order polynomials. This feature enhances the robustness of computations, even in the presence of geometric nonlinearities and nonconservative loading conditions.

Spatial discretization employs shell elements, maintaining the three-dimensional formulation of constitutive laws. Numerical locking phenomena, frequently encountered in such discretizations, are avoided through the Enhanced Assumed Strain (EAS) concept, introduced by (Simo and Rifai, 1990).

Encouraging findings from previous research (Claude et al., 2023) have motivated this study. Earlier work focused on the buckling of a cylindrical panel subjected to a time-dependent localized load and demonstrated that ANM predicted earlier buckling onset compared to

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reference results (Kuhl and Ramm, 1999; Baguet and Cochelin, 2011). Validation through Abaqus simulations with increasingly refined meshes confirmed convergence toward ANM results, albeit at a significantly higher computational cost (506 elements for Abaqus versus only 16 for ANM).

The primary goal of this research is to extend the developed method in the case of non-conservative, time-dependent pressure loads. This development process, with validation at each step, aims to deepen the understanding of mechanisms influencing structural stability. In quasi-static analyses, ANM already identifies bifurcation points and stability limits. It is desired to extend its capabilities to dynamic analyses, exploring nonlinear stability under complex loading scenarios.

At the conference, results will be presented comparing our developments against benchmark cases and other numerical approaches. These findings highlight the strengths of ANM, particularly its precision and computational efficiency for thin-walled elastic shells subjected to nonconservative dynamic and quasi-static loads.

Keywords: Asymptotic Numerical Method (ANM), explicit time integration method, dynamic buckling.

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