Adaptive Spacetime Discontinuous Galerkin Model for Wave Propagation in Layered Composite Plates with Defects

1.2 Algorithms for Wave Propagation: A Symposium in Honor of the 60th Birthday of Professor Leszek Demkowicz

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High-resolution simulations of wave propagation in multilayer composite plate structures are required to support next-generation systems for structural health monitoring for civilian and military airframes. The requirement to capture response changes due to the emergence of minute flaws, such as nucleating cracks and delaminations, gives the problem a multiscale character that tests the limits of existing computational technology. In addition to scale, suitable models must be available to describe the particular physics of different failure and damage mechanisms. We describe recent advances in developing spacetime discontinuous Galerkin (SDG) finite element models to address these challenges. Our focus is on forward simulation capabilities. However, these must eventually be integrated with signal processing or inverse solution methods to implement a complete structural health monitoring system. We extend our multi-field, elastodynamic SDG model to accommodate the three-dimensional layered-plate geometries and the kinematic constraints that define various plate theories. We use a new SDG code in which finite elements in up to 3d x time can be distinct from quadrature cells and in which nonsimplicial cells are supported. We begin the spacetime mesh construction by generating a spacetime mesh of tetrahedral base cells that covers the trajectory of a reference surface, such as the plate's bottom surface. The base mesh satisfies a causality constraint that enables the scalable and parallel properties of our patch-by-patch SDG solver. A second step extrudes each base cell in the thickness direction to generate a cell stack that represents the complete spacetime plate geometry. Each cell is a tetrahedral hypercylinder in spacetime supported by special four-dimensional quadrature methods. Typically, we use equal-order polynomials in space and time in SDG models for elastodynamics. Here we use lower-order models in the thickness direction to implement specific plate models. For a first-order shear-deformation theory we use higher-order models parallel to the reference surface for all solution components. A single linear polynomial through the entire plate thickness completes the tensor-product basis for the in-plane components of displacement, velocity and strain, while a uniform distribution across the thickness suffices for out-of-plane components. Kinematic continuity across element boundaries is only weakly enforced, so the necessary degrees of freedom are available to model delaminations and through-thickness fractures with cohesive, damage and contact models. Numerical examples demonstrate powerful adaptive/parallel solution methods that capture fine-scale solution details.