A ps-FEM approach for the analysis of laminated shells

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Abstract

Modern aircraft structures are designed with increasing amounts of composite materials in load bearing regions. Therefore, the availability of computational tools that can accurately detect internal load paths and stress distributions is of paramount importance to assist the design phase.

In the context of finite element methods, the p-version Finite Element Method (p-FEM) [1] has been successfully used in many works, see e.g. [2-3]. In this case, the order of interpolation is increased hierarchically with Legendre-based shape functions. This enables the quality of the solution to be improved, without changing the element size or the number of nodes. In general, high-order approximations offer an excellent tradeoff between cpu cost and accuracy of the solution but can be better replaced by low-order piecewise representations in the presence of discontinuities or for nonlinear formulations.

For this reason, h-refinement is often considered, which generally requires the generation of time-consuming transition meshes. The mesh superposition technique, or s-version Finite Element Method (s-FEM) [4], has been proposed as a viable mean for overcoming this latter aspect. It is based on the definition of two incompatible meshes, a local and more refined mesh, which is overlaid on the global and coarser mesh, thus allowing for h-refinement to be performed straightforwardly in selective areas.

In this work, an advanced numerical tool is presented, which combines the possibility of refining the solution both via p- and s-refinement (ps-FEM), thus avoiding the need to generate transitions between the coarser and finer meshes. Local effects in regions of interest – e.g., free edges, cutouts, sharp corners – can be investigated with relative ease by applying locally p- or s-refinement, or both simultaneously. This is achieved without the need of regenerating the global mesh, but by adding progressively higher-order terms in the polynomial expansion of the elements (p-refinement) and through hierarchical augmentation of the global stiffness matrix with the contribution of the local mesh (s-refinement).

A finite element code based on a ps-FEM formulation which implements hierarchical shell elements is presented for the analysis of laminated composite structures. The hierarchical feature of the method allows for global/local analysis to be performed with reduced modeling effort, as well as cpu cost. Exemplary numerical tests are presented to demonstrate the potential of the approach in capturing very localized effects. Composite laminates with straight- and curvilinear-fiber configurations, see [5], are considered for this scope and results are compared with Abaqus finite element computations.

References:

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