Buckling analysis and vibrations of pre-stressed reinforced-shell structures by Component-Wise models

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Buckling analysis is of fundamental importance for the design and sizing of aerospace structures. These structures, which are essentially reinforced-shells, are commonly modelled by combining, via fictitious links, one-dimensional (1D/beam) and two-dimensional (2D/shell) finite elements that are implemented in commercial codes. This approach, however, introduces various physical and geometrical inconsistencies. For example, the out-of-plane warping of the stringers and the transverse normal stress in the panel are not considered. In the present paper, a geometrically exact higher-order beam model able to correctly characterize the three-dimensional strain/stress field is proposed for the accurate buckling analysis of reinforced aerospace structures. The proposed theory is based on the Carrera Unified Formulation (CUF), which, by employing a recursive index notation, allows to write the governing equations and the related finite element arrays of arbitrarily refined beam models in a very compact and unified manner. In fact, according to CUF, the three-dimensional displacement field is expressed as a generic expansion of the primary mechanical variables by arbitrary functions of the cross-section coordinates. Namely, in this work, higher-order Lagrange polynomials are employed to formulate advanced beam theories in a hierarchical manner. The proposed models are referred to as Component-Wise (CW) because Lagrange polynomials are used to model the displacement variables in each structural component (i.e., stringers, panels, ribs, etc.) at the cross-sectional level. In a finite element framework, this means that different components are modelled using the same 1D finite element. By using the principle of virtual displacements and by considering the complete 3D stress field in formulating the geometrical stiffness, linearized buckling analysis of metallic, composite and reinforced panels as well as complex aerospace structures assemblies are investigated by CW models. Critical loads are also find as zero-frequency modes from vibration analysis of pre-stressed structures. Various boundary conditions and loadings are considered, including compression, combined traction/compression, and bending loads. The results, which are compared to those from the literature and commercial FEM tools, provide good confidence and widely demonstrate the high accuracy and numerical efficiency of the CW models when applied to buckling.