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Coupled Field Formulation – A Unified Method for Formulating Structural Mechanics Problems

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Abstract : Engineers create inventions and put their ideas in concrete terms to design new products. Design drivers must be established, which requires, among other things, a complete understanding of the product design, load paths, etc. For Aerospace Vehicles, weight/strength ratio, strength, stiffness and stability are the important design drivers. A complex built-up structure is made up of an assemblage of primitive structural forms of arbitrary shape, which include 1D structures like beams and frames, 2D structures like membranes, plate and shell structures, and 3D solid structures. Justification through simulation involves a check for all the quantities of interest, namely stresses, deformation, frequencies, and buckling loads and is normally achieved through the finite element (FE) method. Over the past few decades, Fiber-reinforced composites are fast replacing the traditional metallic structures in the weight-sensitive aerospace and aircraft industries due to their high specific strength, high specific stiffness, anisotropic properties, design freedom for tailoring etc. Composite panel constructions are used in aircraft to design primary structure components like wings, empennage, ailerons, etc., while thin-walled composite beams (TWCB) are used to model slender structures like stiffened panels, helicopter, and wind turbine rotor blades, etc. The TWCB demonstrates many non-classical effects like torsional and constrained warping, transverse shear, coupling effects, heterogeneity, etc., which makes the analysis of composite structures far more complex. Conventional FE formulations to model 1D structures suffer from many limitations like shear locking, particularly in slender beams, lower convergence rates due to material coupling in composites, inability to satisfy, equilibrium in the domain and natural boundary conditions (NBC) etc. For 2D structures, the limitations of conventional displacement-based FE formulations include the inability to satisfy NBC explicitly and many pathological problems such as shear and membrane locking, spurious modes, stress oscillations, lower convergence due to mesh distortion etc. This mandates frequent re-meshing to even achieve an acceptable mesh (satisfy stringent quality metrics) for analysis leading to significant cycle time. Besides, currently, there is a need for separate formulations (u/p) to model incompressible materials, and a single unified formulation is missing in the literature. Hence coupled field formulation (CFF) is a unified formulation proposed by the author for the solution of complex 1D and 2D structures addressing the gaps in the literature mentioned above. The salient features of CFF and its many advantages over other conventional methods shall be presented in this paper.

Keywords : coupled field formulation, kinematic and material coupling, natural boundary condition, locking free formulation
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