ADVANCED NUMERICAL METHODS FOR FAILURE ANALYSYS OF METALLIC AND COMPOSITE AEROSPACE STRUCTURES

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ABSTRACT

The MUL^2 (MULtifield analyses of MULtilayered structures) project aims at providing a reliable computational platform able to cover the broadest possible range of structural problems at macro-, meso-, and microscale. All mathematical models are being generated using the Carrera Unified Formulation (CUF), regardless of which characteristic dimension of the problem is considered. The CUF formalism enables one to straightforwardly manage the three-dimensional equations that govern the mechanical responses of the structural system by including all potential coupling phenomena due to the geometry and material anisotropy. Furthermore, the unified formulation makes it possible to generate an infinite number of refined theories that can overcome the intrinsic limitations of the one- and two-dimensional classical models.

It is possible to distinguish two main approaches for the development of the CUF-based kinematics theories. In the first method, the mechanical properties (stiffness and inertia) of the components that compose the cross-section are being homogenized in order to obtain equivalent quantities. As far as laminated structures are considered, this technique is known as Equivalent-Single-Layer (ESL) approach. The second methodology models each cross-section component with an arbitrary level of accuracy, and it is known as Component-Wise (CW) approach. Such a technique yields accurate results in the study of reinforced structures that consist of multiple components with different mechanical properties, for example, ribs, stringers, and panels. For the laminated structures, the CW technique represents the improvement of the Layer-Wise (LW) methodology since it allows the modeling up to the micro-scale of the matrix and fibers, and not only at lamina level (see Figure [1]).

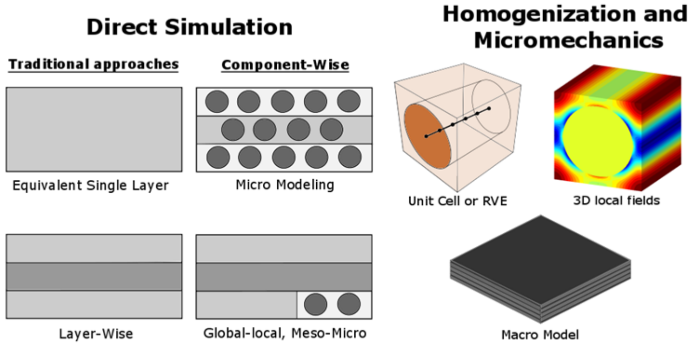

Figure [1]: CUF approaches for multi-component structures.

The outlined CUF models can provide precise 3D displacements, strain and stress fields with low computational cost. Such features are of particular interest for the damage and failure analysis of metallic and composite structures. In fact, the accurate prediction of the damage state and failure occurrence requires accurate 3D stress fields and local effects.
The CW approach, for example, has been used to compare the integral and the point-wise failure indexes of layered structures and to perform micromechanical analyses of periodically heterogeneous composite materials (see Figure [2]). These simulations have been carried out using the Mechanics of Structure Genome (MSG) based on the Variational Asymptotic Approach (VAM) [1].

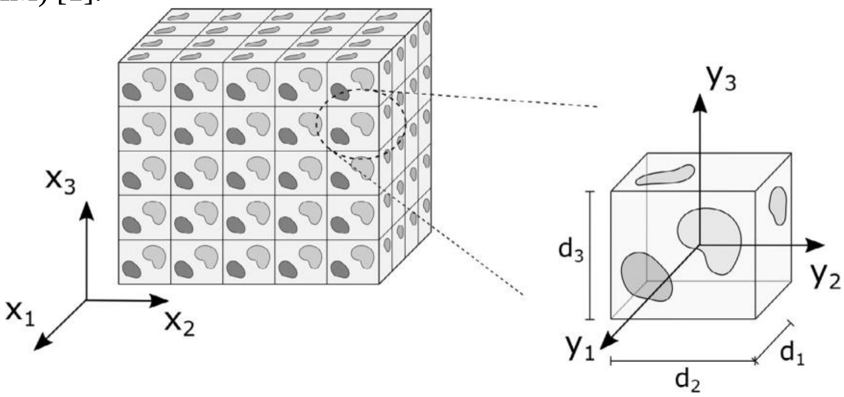

Figure [2]: a periodic heterogeneous material and its repetitive unite cell.

The comparisons with other existing codes demonstrated the effectiveness of the 1D-CUF solutions (see Figure [3]), especially in term of the computing time required.

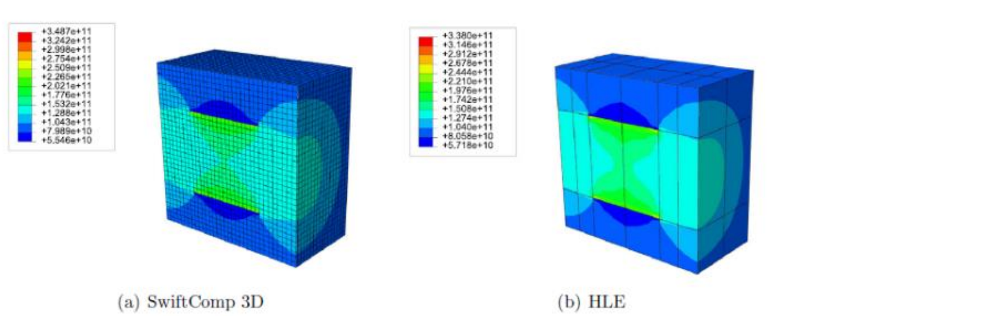

Fig. 13. σ_{11} under ε_{11}.

Computing time (s) for the particle inclusion RUC.

Model	SC refined	SC mid	SC coarse	HL4	HL8
Homogenization	138.65	18.23	3.21	1.17	10.78
Dehomogenization	120.02	41.08	14.62	3.96	6.71
Total	258.67	59.31	17.82	5.13	17.49

Figure [3]: CUF solutions (referred as to HLE models) and the SwiftComp 3D results.

Moreover, the progressive failure of fiber reinforced composites has been predicted combining the crack band theory and the CW approach [2, 3]. The 1D-CUF elements have been used to model the representative volume element (RVE) of the material, and for the computation of the principal stresses. The advantages of the current approach with respect to 3D solutions have also been proved in this case (see Figure [4]).

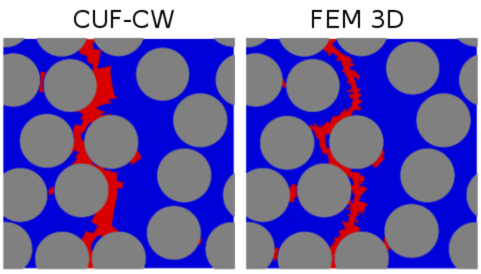

Table 2: Numerical results for randomly distributed fiber composite under transverse tension

	DOF	Ultimate global transverse stress (MPa)	Strain at ultimate global transverse stress (-)	Strain at complete failure (-)	Total CPU time (min)
CUF-CW	19,080	46.15	0.0031	0.0037	36
FEM 3D	91,305	51.11	0.0029	0.0040	108

Figure [4]: Damage in the randomly distributed fiber composite and comparison w.r.t. a solid FEM solution.

Other applications that have been satisfactorily resolved with the unified formulation are the delamination/de-bonding problem, and the placement of curvilinear fibers. (see Figure [5]).

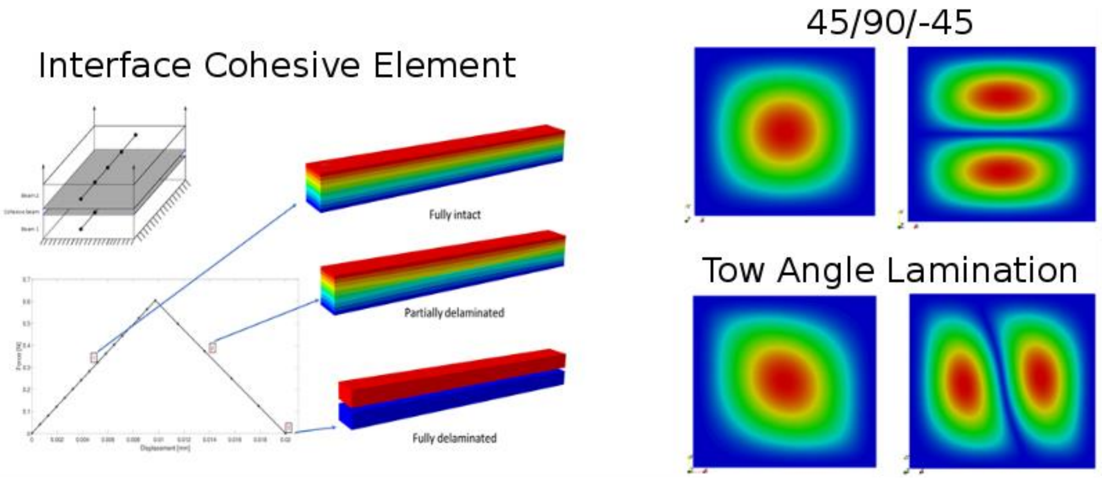

Figure [5]: interface elements for delamination problem and the tow angle placement.

Within the CUF framework, geometrical as well as physical nonlinearities can be taken into account in order to carry out large-deflection, stability, elastoplastic, and impact analyses. The higher-order 1D, 2D, and 3D CUF-based elements can be developed according to a node-dependent kinematics (NDK) approach. The NDK method represents a valuable global/local technique since it permits one to locally refine the solution by defining the kinematics of each node independently.

Over the last 20 years, more than 300 papers devoted to the Carrera Unified Formulation have been published in international peer-reviewed journals and four scientific books. The MUL^2 research group is involved in several national and international collaborations within European projects (FULLCOMP, ICONIC, ESA Future Launcher Preparatory Program - VTI), industrial partnerships (Embraer – LoHCW and DySAAB), and research joint ventures (Joint Project for internationalization of Research – Polito MUL^2 and Purdue University).

For further details, please visit the website http://www.mul2.polito.it/

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