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Component-Wise Beam Modelling of Sandwich Panels with Arbitrary Core Topologies

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Abstract. This paper presents a Component-Wise (CW) 1D beam formulation within the Carrera Unified Formulation (CUF) [1] to model and simulate the mechanical behaviour of sandwich panels. The approach treats skins and cellular cores as distinct sub-domains in a single one-dimensional element. By representing the true cross-sectional geometry with high-order Lagrange polynomials, the model achieves high three-dimensional accuracy [2], including the capture of localized deformations and through-thickness stresses, while significantly reducing the degrees of freedom (DoFs) with respect to 3D FEM simulations. This paper provides evidence that this single refined 1D beam is easy to model, numerically efficient and mechanically accurate for any sandwich/metamaterial cores, from classic honeycomb to novel butterfly lattices, thereby enabling parametric studies and precise failure-onset assessment.

Sandwich and lattice-core metamaterials represent advanced and efficient lightweight structures for aerospace sector thanks to their high stiffness-to-mass ratio and multifunctionality [3]. Their architectural complexity, however, challenges traditional modelling processes. Homogenised Layer-Wise (LW) models are not able to detect the actual mechanical behaviour of the complex core geometry, whereas detailed 3D solids elements explode the number of DoFs and therefore the design-space exploration time. A modelling and simulation framework that is simultaneously efficient, accurate, and local-effect resolving is thus essential.

CUF allows to model complex sandwich structures with a single 1D beam element. The beam reference axis does not follow the panel length, as in the canonical beam descriptions, but aligns to the thickness direction, see Figure 1; the full cross-section is represented by arbitrary-order Lagrange polynomials describing independently skins and core. This CW discretisation preserves representation of actual structure geometry, including local variations, allowing to overcome core homogenisation while reaching 3D FEM accuracy. The polynomial order of Lagrange expansion is user-tunable, allowing trade-offs between level of resolution and number of degrees of freedom. Continuity across skin-core interfaces is guaranteed through shared Lagrangian nodes, producing reliable displacement and stress fields in critical interface regions.

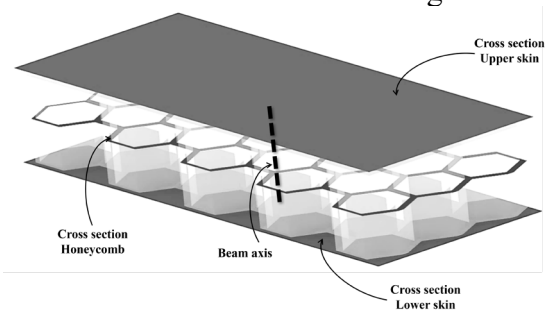


Figure 1. CW representation of the 1D beam model of a sandwich panel

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This approach is extremely flexible, as it allows the modelling of any core geometry for sandwich panels. To provide quantitative results, six different core topologies were simulated under several static load cases: butterfly, large and small unit cell hexagonal honeycomb, large and small unit cell square, and triangular lattice, see Figure 2.

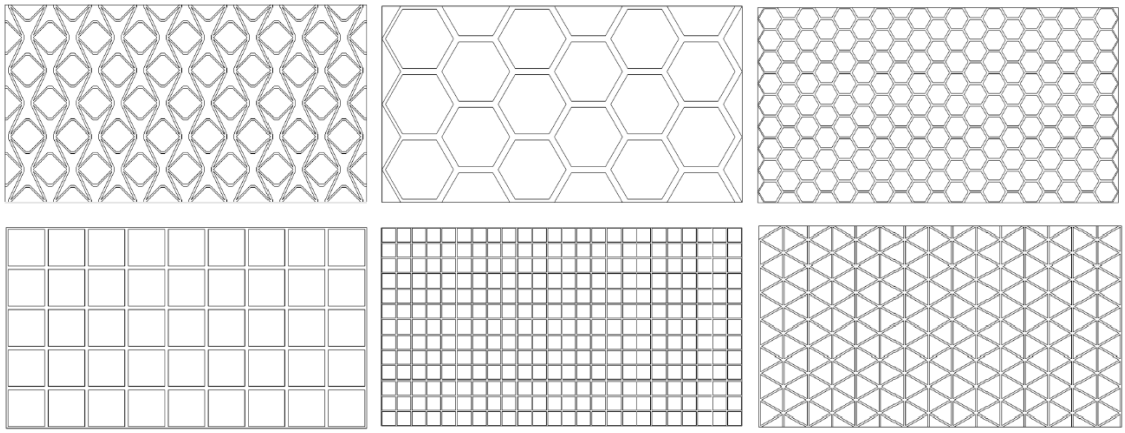


Figure 2. Cross sections of the different core geometries considered

Focusing on the large-cell honeycomb, several static load scenarios representative of service loads were applied: concentrated load on specific cells, uniform pressure, torsion, concentrated forces on skins edge, core inflection, and single-cell crushing. Each case was modelled and simulated with both CW and LW model whose core is homogenised [4].

Considering a case of sandwich panel clamped on both edges and with groups of concentrated forces on some selected cells, the potential of CW representation and the limitations of the LW model appear evident. Results in terms of deformed shape and Von Mises stress contour map comparisons are provided in Figure 3 and Figure 4, respectively. The CW model resolves the three distinct indentations in the upper skin, each corresponding to a loaded honeycomb cell. In contrast, the LW counterpart exhibits a smooth global inflection produced by bending; no local indentations appear because the core is represented as an equivalent continuum. This clearly anticipates major differences in the quantitative fields. Indeed, considering Von Mises stress distributions, in the CW model the stress field forms pronounced circular bands around each indented cell, with steep gradients that quickly decay into the surrounding webs, representing localised load transfer at skin-core interfaces. The LW displays an almost uniform distribution with only mild variations in the acting areas of the concentrated forces; the distinct zones evident in the CW analysis are entirely smoothed out. This proves that homogenised formulations prevents the identification of critical stress areas that the CW approach allows to detect, underscoring its superiority to capture failure-relevant local effects.

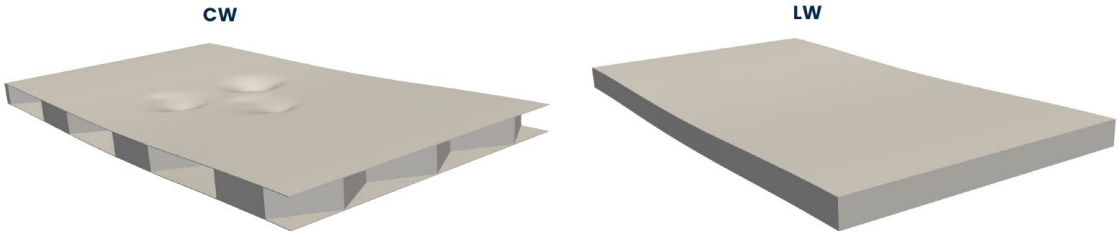


Figure 3. CW vs LW sandwich panel deformed shapes

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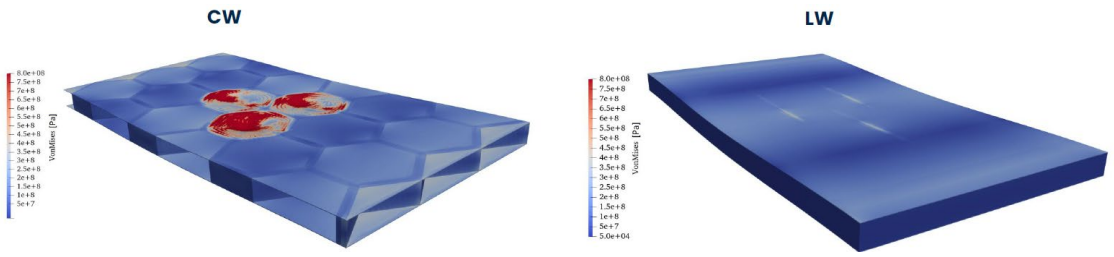


Figure 4. CW vs LW Von Mises stress distributions

The resolution of CW reveals how bending of individual hexagonal cell drives skin indentation; the homogenised LW model, lacking geometric detail, ignores these local kinematics and cannot identify the onset points for face-sheet wrinkling or local core stress peaks. These results highlight the indispensable role of CW kinematics when failure-critical local fields are required. Results provided in ref. [5] proved the accuracy of the approach, comparable to that of 3D FEM models, and its efficiency, as CW model reduces the number of DoFs up to six times compared to the 3D FEM counterpart.

The component-wise CUF beam element forms a unified and flexible tool for high-fidelity yet computationally efficient analysis of sandwich and metamaterial panels. By integrating exact geometrical and mechanical descriptions with high-order kinematics, it bridges the gap between oversimplified LW homogenized model and prohibitively heavy 3D solids FEM models. The framework not only provides an excellent framework for parametric design or structural optimization, but also provides a reliable tool for the local stress assessment indispensable for accurate failure-onset assessment, paving the way for accurate design of next-generation lightweight structures.

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