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PROPOSITION DE SUJET DE THESE

Intitulé : Topology Optimization of Ultra-light Laminate Frames Immersed in 3-dimensional Design Regions

Référence : **SNA-DMAS-2024-31**
(à rappeler dans toute correspondance)

Début de la thèse : 01/10/2024	**Date limite de candidature :** 31/05/2024

Mots clés

Immersed finite element methods, enriched finite element analysis, feature-based topology optimization, geometry projection, laminated composites.

Profil et compétences recherchées

You should have the following qualifications:

- A strong background in computational mechanics, and in particular finite element analysis;
- Knowledge for optimization techniques (particularly gradient-based) is desired;
- Strong programming skills;
- MSc university degree in engineering (mechanical, aerospace, civil), or a related area;
- High motivation for teamwork and excellent communication skills.

Présentation du projet doctoral, contexte et objectif

The goal of this thesis is to formulate numerical techniques to determine the optimal layout of ultra-light structural assemblies made of fiber-reinforced laminate components within a 3-dimensional design region. By ultra-light, we refer to structures whose volume occupies a low fraction (e.g., less than 5%) of the volume of the available design region. This type of structures is common in airframe design. However, existing topology optimization techniques are inadequate for designing large laminate structures with very low volume fractions due to the computational cost associated with capturing the length scale of the components in the analysis while rendering designs that conform to prevalent manufacturing processes for laminate assemblies.

Numerical optimization methods are playing an increasingly important role in the design of mechanical structures and are gradually finding their way into engineering design workflows thanks to the continuing increase in computing power and the rapid improvement of software tools. In particular, topology optimization is a booming field that is driven by the concomitant development of additive manufacturing techniques. Nevertheless, taking design and manufacturing constraints into account, either for conventional processes or more innovative methods, is a fundamental challenge for the widespread acceptance and implementation of this type of method in design. Topology optimization based on the principle of geometry projection of components is an original method that attempts to meet this challenge [1], [2]. This component-based formulation is based on the use of geometric primitives, or predefined elementary shapes, to design the shape of the structure with a reduced number of parameters. The high-level parametric representation of the primitives is mapped in a differentiable manner onto a density field, which is subsequently discretized with a finite element mesh for analysis. Therefore, as in density-based and level-set methods, no re-meshing is necessary upon design changes. Component-based formulations are particularly well-suited to describe the structure as an assembly of manufacturable components. This differentiates it from conventional density and level-set methods, for which the geometric interpretation of the optimized design is less straightforward for structural assemblies. This method was recently adapted at ONERA as part of F. Savine's PhD thesis [3] for the optimization of stiffened laminated composite structures for launch vehicles. In particular, this work combines component-based topology optimization with composite laminates optimization.

Geometry projection techniques have recently been applied with success for the topology optimization of structures made of fiber-reinforced plates, where the optimization simultaneously determines the optimal spatial layout of the plates and the reinforcement layup in each plate [4], see Figure 1. However, this technique is limited to relatively large volume fractions and large ratios of the plate thickness to the dimensions of the design region. This is because the finite element size should be smaller than half the smallest plate thickness to adequately capture the mechanical behavior of the structural assembly. For ultra-light assemblies with low volume fractions, this would lead to a mesh with an excessively large number of elements (e.g., O(108)). A solution to this problem is to employ adaptive mesh refinement [5], which can significantly reduce the number of elements and consequently the computational cost to perform the optimization. Nevertheless, the adaptivity incurs in an additional cost, and these techniques still require high-performance computing resources to perform the optimization in a time that is practical for design workflows. In addition to the computational cost associated with the topology optimization of ultra-light structural assemblies, the quality and representativeness of the analysis can be questionable, particularly in the case of slender or thin structural components for which certain behaviors, such as bending, may be difficult to capture using a volumetric mesh. Low-order finite elements can exhibit locking on bending-dominated problems, so mixed-enhanced formulations or reduced integration should be used. To overcome these problems, formulations based on plate/shell theory are particularly appealing.

This thesis aims at developing novel computational techniques within the finite element framework, that enable the robust and high-performance implementation analysis and design of ultra-light structural assemblies made of fiber-reinforced laminates [6], [7]. The central idea of the proposed work is to model the laminate components using shell elements, which are subsequently immersed in a 3-D design region meshed with solid elements. As in geometry projection techniques, the individual shell meshes can freely 'move' within the 3-dimensional design region so that plate intersections are created, modified or removed during the optimization, thus changing the structure's shape and topology. This analysis discretization has the advantages of requiring a mesh with far fewer elements than existing techniques (as the background solid mesh can be coarse) and simultaneously providing an accurate prediction of the mechanical behavior of the laminates. The drastic decrease in the number of equations will enable the topology optimization of ultra-light assemblies in a single workstation, which can significantly hasten airframe design workflows. Moreover, the increased analysis accuracy can lead to faster convergence of the gradient-based optimization and better optima. The proposed work will exploit state-of-the-art advances in so-called immersed finite element methods (CutFem [8], DE-FEM [9]), which are particularly well suited to the computation of structures with moving boundaries, since they may not coincide with the mesh.

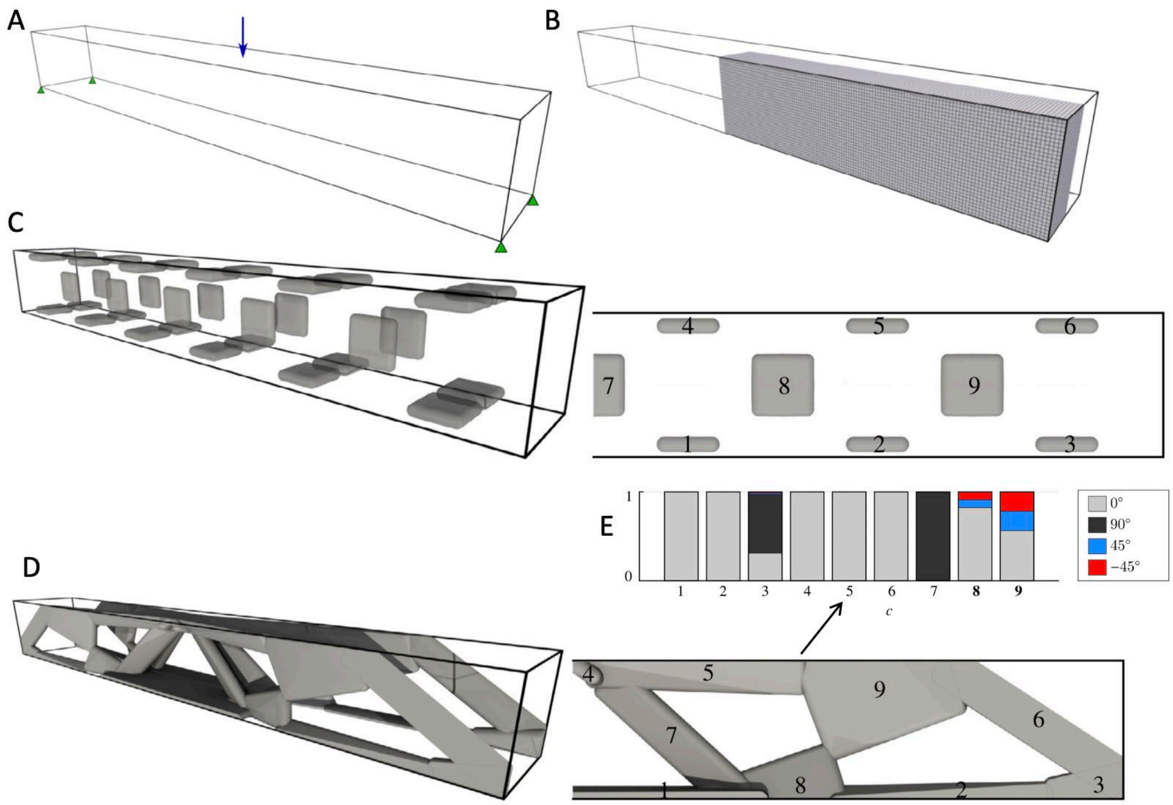

Figure 1. Simultaneous topology optimization (layout) and fiber reinforcement (layup) of laminate plates within a 3-d design region [4]. A : loading and boundary conditions; B: solid mesh; C: initial design; D: optimal layout; E: optimal layup for each plate.

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Collaborations envisagées

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