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Multi-disciplinary analysis and optimisation of large composite structures in the early design phase: issues and challenges

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ABSTRACT

Recent trends in the field of design of composite structures involve global approaches in the early design phase. Engineers of the future shall have to meet specific demands of each particular application. First, they shall keep in mind the essential relationships between e.g. structure, material, manufacture, assembly process and damage if they want to achieve significant technological progress. Second, they shall handle composite materials and their vast array of design options: material's choice, volume fraction of constituents, ply orientation and thickness, stacking sequence, manufacturing process, ... usually coupled with a variable geometry - a standard in structural design. In this frame, automated virtual testing and optimization procedures are the subject of increasing research and development efforts, aiming at providing tomorrow's mechanical engineers with new efficient design tools.

In this contribution, the authors present a computational chain developed for the purpose of the optimization, both technical and economical, of advanced composite structures.

The optimization problem is described by objectives, constraints and by a design space (i.e. the set of design variables). Two types of objectives are considered: i) multi-disciplinary technical objectives including for instance, simple mechanical objectives such as minimum displacement and maximum stiffness in a given zone, or complex objectives bringing into play different types of analyses, ii) economical objectives such as minimum material's, manufacturing and maintenance costs, ... Common constraints include total mass, geometrical interfaces, damage criteria, maximum stress, resistance to buckling, absence of problematic vibration modes, ... The design space usually includes i) discrete and/or integer variables such as the material properties as imposed by the off-the-shelf composite materials that are available, the introduction or removal of a structural feature (e.g. a stiffener), the stacking sequence of the plies, ii) continuous variables such as the ply orientation, geometrical parameters (angles, lengths, ...).

The results of the optimization loop are summarised under the form of the so-called Pareto-Front, defined as the locus of the equivalent or non-dominated designs.

The current challenges in the development of such integrated approaches to the virtual design and optimization of composite structures are here discussed using different examples, with increasing levels of automation of the computational chain:

- FEM-model based optimization. In this case, the whole computational chain is based on a parameterised FEM model where dimensions, materials, can be changed. The mesh and boundary conditions are defined in the FE model. Limited geometrical variability is allowed in this case. Most of the pre and post-processing must be hardcoded, resulting in a loss of generality of the method.

- Discrete-model based optimization. In this case, the computational chain is based on the parameterised CAD model. This allows for a larger variability of the geometrical design. This computational chain is essentially based on the native access to the CatiaV5 model, using either Visual Basic functions or the CADNEXUS Capri gateway. Automatic meshing is then performed based on a triangulation of the CAD model, from which a new dicrete model is rebuilt. Boundary conditions are imposed after identification of the physical Ids of the geometrical entities. This approach is really efficient as long as topological changes can be avoided. When dealing with topological changes (even minor) as it is ourmain interest, the major drawback of this approach is the difficult handling of Physical identities attached to items of the CAD-model. Indeed, the programming of automated computational chains requires that the associativity between Ids of geometrical entities, mesh entities and boundary conditions be kept. Nevertheless, so-called persitent Ids of the CAD model could be lost even with minor topological changes. Workarounds exist to circumvent some of these difficulties, building for instance maps between parent and children entities.

Beside the challenge of getting an optimal CAD-CAE link, other problems are addressed or, at least, highlighted (the list is not exhaustive):

- the need for optimization algorithms that can handle discrete and continuous variables, while allowing to find rapidly the global optimum. In this contribution, the authors present a computational chain based on the use of genetic algorithms enhanced with meta-models, as implemented in the MAX software, developed by Cenaero

- the need for distributed computing and parallel optimization schemes that help reducing the computational cost

- the need for proper constitutive behaviors, damage models, failure criteria with a sound physical basis

- the need for dedicated skill tools, design rules, manufacturing constraints that keep the virtual design connected with structures that can indeed be manufactured

- ...

The applications presented in this contribution are: a generic stiffened panel, a composite door of an aircraft, a dispenser of micro-satellites.