11th World Congress on Computational Mechanics (WCCM XI)
5th European Conference on Computational Mechanics (ECCM V)
6th European Conference on Computational Fluid Dynamics (ECFD VI)
July 20 - 25, 2014, Barcelona, Spain

Structure optimization using PGD-based computational vademecum

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Key Words: *Model Order Reduction, Proper Generalized Decomposition, Computational Vademecum, structure optimization, parametric model*

In the computational optimization of structures such as trusses a large part of the computational effort is usually devoted to the evaluation of a numerical model in order to compute maximum stresses, strains and displacements and assess the satisfactions of physical and design constraints. Classical approaches rely, for efficiency, on the extensive use of simplified models such as those coming from the theory of plates and beams. Such models do however have their limitations and one must then rely on 3D Finite Element analysis to evaluate the design of a potential solution to the optimization being solved.
In this work, we propose a method based on the use of PGD-based [1] computational vademecums [2] to circumvent the use of a full 3D finite element analysis of the truss within the optimization procedure. The method is applied to the optimization of an airplane structure for which each truss element is computed with a full 3D Finite Element model.

The Proper Generalized Decomposition is a powerful model order reduction technique, which allows the solution of high fidelity models, high dimensional [1] and parametric models at a reduced computational cost through the use of a separated representation for the solution. For an arbitrary unknown **u**, the solution is searched in the following form:

$$u = \sum_{i=1}^{N} X_i \ \ (x,y,z) \cdot P_i^1(p^1) \cdot P_i^2(p^2) \cdots P_i^k(p^k)$$

where $x,y,z,p^1,\ldots, p^k$ are the coordinates of the model. The partition of the variables used above is arbitrary and other partition schemes are possible depending on the model being solved. In particular, the separation of space coordinates allows significant computational gains when the problem permits its use [3]. Moreover the possibility to consider additional coordinates allows the construction of parametric solutions. In this case, the parameters $p^1,\ldots, p^k$ can represent geometrical [4], material or loading parameters [5]. Such solutions can then be used to create a computational vademecum that encompasses all the possible solutions of the model.

In this work, during an off-line stage, we use the PGD to create a computational vademecum for the detailed 3D Finite Element analysis of a parametric beam element. In addition to the space coordinates, we consider the geometrical features (length, width, sole thickness,…) as additional coordinates. We also use an in-plane, out-of-plane decomposition of the space to further reduce the computational effort. In an on-line stage, we perform the optimization of the truss structure and of the different beam elements:

a) For each tentative choice of the optimization variables the computational vademecum is used to instantaneously generate the condensed matrices of the different beams of the truss and the global truss equations are solved.
b) From the global truss solution, the computational vademecum is then used to evaluate the different optimization constraints as well as the objective function.

This two stages approach where a vademecum is first computed offline and then used as a meta-solution to solve a global equilibrium problem extends the possible uses of PGD-based vademecums. Furthermore, it permits the use of computationally expensive high fidelity models in structural optimization problems.

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