PhD position @ ISAE-SUPAERO

Towards a fully uncoupled Multidisciplinary Optimization formulation based on surrogate modelling and uncertainty propagation: application to conceptual aircraft design

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Summary: Multidisciplinary Design and Optimization (MDO) is an efficient approach to take into account the interactions between the various disciplines involved in conceptual aircraft design [1], [2] (aerodynamic, structural mechanics, propulsion etc.). Formally these interactions lead to an optimization problem whose objective function and/or constraints involve the resolution of a non linear system of equations (e.g. aero-elasticity). During the conceptual phase, this non linear system of equations is solved by a partitioned approach. This means that disciplinary solvers are called as black boxes by a non linear solver until convergence is reached. Typically a finite element (FEM) solver, handling the structural mechanics resolution, is coupled with a computational fluid dynamics (CFD) solver, handling the aerodynamic resolution, by a fixed point algorithm. Once the aero elastic equilibrium is reached, the solution i.e. the displacement and the pressure fields, are used to compute the objective function (and/or constraints) of the optimization problem (range, drag over lift ratio etc.).

Several formulations have been proposed in the literature [3] to solve this optimization problem. Among them, the Multidisciplinary Feasible approach (MDF) is the most simple to implement and one of the most efficient. It consists in coupling an optimization algorithm (gradient based [4] or gradient free [5]) handling the design variables, with a non linear solver (fixed point, Newton etc.) ensuring the resolution of the non linear system in which the coupling variables are considered. Hence, for each set of design variables proposed by the optimizer, the "costly" non linear system (aero-elasticity by partitioned approach) is solved and the objective function is evaluated. Consequently the MDF approach allows to use standard optimization algorithms but requires strong modifications of the disciplinary solvers (e.g. make them able to efficiently compute gradient with respect to the design variables [6]) and involves a huge numerical cost as the non linear system is solved, at each iteration of the optimizer, by the actual disciplinary solvers (e.g. fixed point over FEM and CFD solutions). These difficulties make the MDF approach very difficult to implement with standard disciplinary solvers and thus limits its industrial use.

The objective of the Ph.D. project is to develop a new uncoupled MDO approach inspired by the MDF method and the Efficient Global Optimization (EGO) algorithm [7], and to apply it in the context of middle and high fidelity disciplinary solvers (FEM and CFD). Starting point of this new approach is the construction of surrogate models (or meta-models) of each disciplinary solver. The basic idea is then to use these surrogate models, instead of the actual solvers, in a MDF approach. Hence, the disciplinary solvers are used independently to construct the surrogate models by sampling them as black boxes. In a first place aero-elastic optimization problem involving a reduced number of design parameters will be study. The issue of dealing with a large number of design parameters might be studied according to the advancement of the project.

The challenge lies in the construction of these surrogate models. With respect to this issue, the EGO algorithm proposes to iteratively construct Kriging surrogate models (Gaussian process interpolation) based on an enrichment criterion such as the Expected Improvement (EI). In practice this criterion is used to decide at which point of the design space the surrogate model must be improved. Contrarily to the EGO method, in the approach we propose, it is not the objective function which is replaced by a surrogate model but each disciplinary solver. Hence, the first challenge is to quantify the uncertainty affecting the objective function due to the use of surrogate models to solve the non linear system of equations. This question has been partially solved in the literature (see [8] [9] for examples) in some slightly different contexts. In particular the handling of a non-scalar coupling through a high dimensional vector field (e.g. pressure field) is still problematic and no satisfactory approaches exit today. The first objective of the Ph. D. project is thus to propose an efficient method for uncertainty propagation in a non linear system involving vector coupling variables (discretized displacement and pressure fields). To achieve this goal, various model order reduction methods ([10], [11], [12], [13]) will be studied and experimented. It should be noted that the control of the error and uncertainty induced by the used of model order reduction and surrogate modelling is a keystone of the approach and will be particularly studied ([14], [15]).

After this first step, the second objective of the Ph. D. project is to derive an optimization strategy allowing to iteratively improve the accuracy of the disciplinary surrogate models in the area of the design space where the minimum is likely to be. Finally, this new strategy will be tested and validated on academic test cases and on industrial test problems involving aero-structure interactions (e.g. wing design).

It should be noted that this project will benefit from a previous study done at ONERA in the context of the AGILE H2020 European project, in which a similar approach has been developed for MDO problems involving scalar coupling variables (see [8] [16] [17]).

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