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# A MULTI-FIDELITY FORMULATION FOR MULTIDISCIPLINARY DESIGN OPTIMIZATION OF AIRCRAFT CONFIGURATIONS

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## ABSTRACT

The paper shows preliminary results of a formulation for multidisciplinary design optimization (MDO) for conceptual design of civil transportation aircraft. The attention is focused on the use of multi-fidelity models for the description of all the relevant disciplines involved in the design process. Specifically, the formulation will be applied to the optimal design of an aircraft characterized by a low environmental impact.

The motivation of a multi-fidelity formulation may be found in the high demand of computational resources needed by a traditional multidisciplinary optimization process. During the optimization task, each analysis module may be called hundreds of times with a high cost in terms of time and computational resources. The use of multi-fidelity (and "multi-cost") models can drastically lower the resources and the time required for the design process, coupling the high accuracy of the high-fidelity models with the low computational cost of the low-fidelity methods.

Specifically, a first order approximation of the high-fidelity model is build on the basis of the low-fidelity model, by imposing the congruency of functions values and derivatives in the current design point [1]. The resulting model is assumed as a good approximation for the high-fidelity functions within a thrust region in which the minimization is performed. The approximation/minimization procedure is iterated until convergence [1,2].

In our application, a suitable set of high- and low-fidelity models is chosen for all the relevant disciplines involved in the evaluation of the objectives (e.g. structural weight, fuel burn, noise emissions) and the design constraints (e.g. normal and tangential stress in the structure elements, flutter and divergence speed). The (high-fidelity) models are, whenever possible, prime-principle based (see, e.g. Refs. [5]), so that the whole analysis may be applied on innovative configurations for which the designer can not rely on past experience. According to this, the structural problem is solved using a finite element model (FEM) with a fine mesh for the high-fidelity model, whereas a coarse mesh is adopted for the low-fidelity model. The high-fidelity aerodynamics is evaluated using a quasi-potential formulation for compressible flows, and solved by a boundary element method (BEM), whereas the low-fidelity model is based on a simplified formulation for

incompressible flows. The high-fidelity aeroelasticity is based on an aeroelastic reduced-order model (ROM) achieved by coupling a high-fidelity aerodynamic model with an accurate structural model. The first is obtained via linearization of the non-linear BEM operator about a transonic steady-state equilibrium configuration [6]; the second is solved by the high-fidelity FEM. The corresponding low-fidelity model consists on the coupling of the simplified aerodynamic model and the coarse computational grid FEM.

The objective function and the constraints are evaluated during the optimization process using the proposed approximation. Within each iteration, the constrained minimization problem is solved using a sequential quadratic programming (SQP) algorithm [7]. The results are compared with those obtained by a traditional (high-fidelity) optimization process, showing an excellent agreement in terms of final solution, and resulting in a relevant abatement of computational costs [Fig.1, Tab.1].

### Comparison between High-Fidelity and Multi-Fidelity model applied to the optimization of a civil transportation aircraft wing

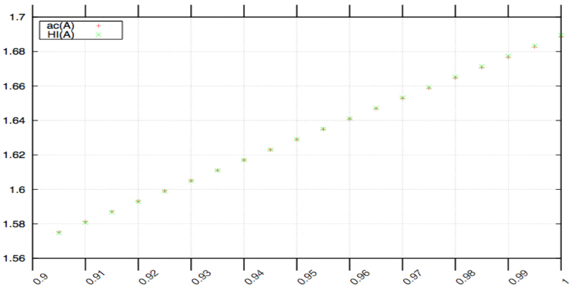

Fig.1 Examination of consistency of the approximated model (wing span).

| $FEM_{HI}$ n=20 ; $FEM_{LO}$ n=6 - $BEM_{HI}$ (8,4,4) ; $BEM_{LO}$ (2,2,2) | | |
|---|---|---|
| | HIGH - FIDELITY | MULTI - FIDELITY |
| Wing span | 0.824 | 0.824 |
| Root chord | 0.304 | 0.299 |
| Tip chord | 0.400 | 0.400 |
| Root spar thickness | 0.182 | 0.182 |
| Tip spar thickness | 0.182 | 0.182 |
| $f_{HI}(x_{OPT})$ | 1.070 | 1.068 |
| $\sigma$ | 0.978 | 0.999 |
| $\tau$ | 0.613 | 0.656 |
| Number of $f_{HI}$ calls | 47 | 28 |
| % reduction in $f_{HI}$ calls ≈ 40 % | | |

Tab.1 Comparison between the two models (design variables).

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