Efficient Global Optimization of a Transonic Wing with Geometric Data Reduction

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I. Introduction

In the framework of aerodynamic design, the shape is usually parameterized by acting on the design variables which generate the design space and are handled by the optimizer. However, when increasing the geometry complexity of the problem at hand, the number of design variables may grow up significantly, giving rise to the well-known 'curse of dimensionality'.[1] This may hamper the success of the optimization process, as the enlargement of the design space may result in multi-modal and noisy landscapes, thus making the search problem harder to be solved. This behavior is independent of the search method employed, i.e. deterministic or stochastic or heuristic.

In surrogate-based optimization, the meta-model that mimics the behavior of the objective function is made explicitly dependent on the design variables. From literature, it is known that, whatever the meta-model, a drop in prediction performance is associated to an increase of dimensionality.[2] On the other hand, sensitivity analysis often shows that not all the design variables have the same influence on the objective function behavior. As a matter of fact, a reduction of the design space is envisaged to preserve the main features of the target function landscape while avoiding the high-dimensional noisiness.

The aim of the paper is to introduce a sort of geometric filter on the design variables set by performing a variance analysis based on Proper Orthogonal Decomposition (POD). By exploiting the intrinsic properties of POD, the effects of each design variable are ranked according to their importance and a new geometric parameterization is derived in a transformed space. The beneficial aspect of this transformation is twofold and it introduces both a quantitative and qualitative filtering at the same time: first, as a result of POD ranking and truncation, the new design space is shrunk, thus reducing the effective dimensionality of the problem at hand (quantitative filtering); second, the new geometric modes are orthogonal and, hence, independent:[3] this removes all possible spurious coupling between original design variables (qualitative filtering). The beneficial aspects of such a linear technique facing with data reduction was investigated in literature in recent years, showing good performances compared to other non-linear techniques.[4,5]

A first investigation has been carried out on a two-dimensional problem, i.e. the optimization of an airfoil in transonic viscous flow.[6] In the present work, instead, the shape optimization problem of a three-dimensional wing in viscous transonic flow and multi-point conditions is addressed by using POD-based geometric filtration and surrogate-based optimization. Results will be compared with more classical optimization approaches, like plain evolutionary optimization or Efficient Global Optimization (EGO).

II. Surrogate-Based Optimization with Geometric Data Reduction by POD

Given m the dimension of the design space and a set of n design vectors $\{\mathbf{w_1}, \mathbf{w_2}, \ldots, \mathbf{w_n}\}$, the geometry parameterization can be seen as a correspondence $\mathbf{s}$ that converts a generic design vector in a set of $1 \times p$ (z) geometric coordinates (snapshots) :

$$\mathbf{s} : \mathbf{w} \in \mathbb{R}^m \rightarrow \mathbf{s} \in \mathbb{R}^{1p}$$

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