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Assessment of surrogate models for the global optimization of turbomachinery flows

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ABSTRACT

This study addresses the issue of selecting surrogate models suitable for the global optimization of turbomachinery flows. Most of the publications dealing with neighboring subjects validate several types of surrogate models for the approximation of mathematical functions - [1] [2]...-, or assess the use of one or two types of metamodels for an actual aerodynamic shape optimization problem - [3] [4]... A rather detailed review of both types of articles will be given in the introduction of this contribution.
As a first step towards the goal of casting a metamodel for the global optimization of turbomachinery flows, the analysis of a family of 2D flows on a two-parameter design space is presented. The considered test case is derived from the stator blade of VEGA2 configuration, which is a classical stator rotor turbine configuration. Due to the high cost of global optimization, only a 2D geometry deduced from an appropriate projection of the 3D geometry at the hub is studied. The Reynolds averaged Navier-Stokes equations are considered. The turbulent viscosity is computed by Smith $k-l$ model. A view of the iso-Mach number lines for the nominal geometry is presented.
The geometric deformation of the blade consists in moving the trailing edge along both x and y axis. The leading edge is fixed. The deformed shape of the blade is defined by a smooth algebraic function of the curvilinear coordinate. The main output of the computation is the total pressure at the exit, computed by integration on the exit surface. A large regular sampling of the design space with 21×21 points is considered for reference. The plot of the function of interest on the design space is presented. Its non dimensional value (actual value divided by inlet value) varies from 0.918 to .924 on the design space (such low values are due to the strong shocks). This variation is large enough to define an optimization problem.
Four types of surrogate models are considered : least square polynomials, artificial neural networks (multi-layer perceptron and radial basis function) and Kriging. All classical variants of Kriging are studied : simple Kriging, ordinary Kriging, universal Kriging with degree one and degree two polynomial regression. A sampling strategy is defined for all meta-model : starting from enough points to define the surrogate function, added points are location of extrema of the metamodel and furthest points

Sur. Mod.	C1	IT	C2	IT	C3	IT	E(100)
Pol. 6	OK	47	KO	-	KO	-	$1.2e^{-3}$
Pol. 8	OK	53	OK	65	OK	-	$4.9e^{-4}$
Mu.Pe.	OK	300	KO	-	KO	-	$2.5e^{-3}$
RBF	OK	37	OK	38	OK	46	$1.6e^{-3}$
Sim. Kri.	OK	25	OK	69	OK	165	$3.7e^{-4}$
Ord. Kri.	OK	25	OK	69	OK	165	$3.7e^{-4}$
Uni. Kri.$^{deg\ 1}$	OK	28	OK	72	OK	72	$3.6e^{-4}$
Sim. Kri.$^{deg^2}$	OK	28	OK	72	OK	72	$3.6e^{-4}$
Uni.Kri.$^{deg\ 1}$ MSE	OK	28	OK	57	OK	57	$4.1e^{-4}$

Table 1: Summary of surrogate model performances

to the sampling. The mean square error estimator of Kriging is also used specifically for this model. Discussed is the ability of these surrogate functions to give a satisfactory description of the exact function of interest on the design space, during a global optimization. Several criteria are defined based on the L_2 norm of the difference between the exact and approximate function (C1), and the ability of the meta-models to locate approximately (C2) or accurетly (C3) the two maxima of the function of interest. The number of CFD evaluations needed to satisfy this criteria is detailed for all types of surrogate functions - see table. Kriging and RBF neural network exhibit the best performances with respect to the chosen criteria.

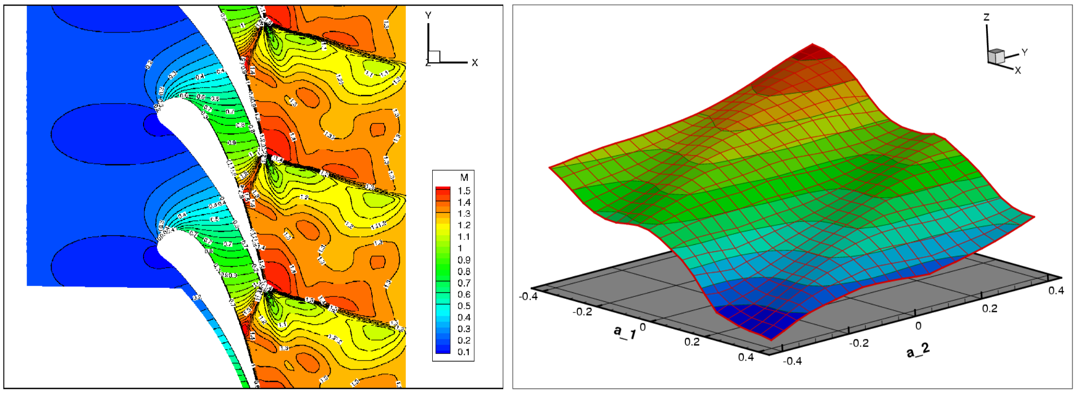

Figure 1: nominal iso-Mach / exit-total pressure on design space

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