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PROPOSITION DE SUJET DE THESE

Intitulé : Active Subspaces for Dimension Reduction Applied to Aerodynamic Shape Optimisation

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(à rappeler dans toute correspondance)

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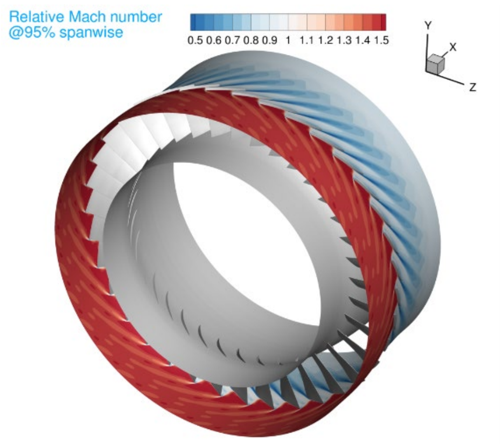
Mots clés

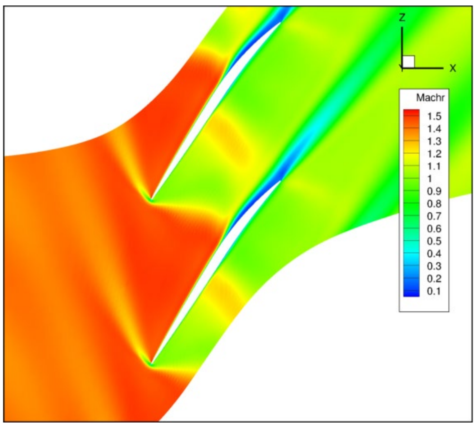
Shape Optimisation, Dimension reduction, Surrogate model, Computational Fluid Dynamics, Turbomachinery

Profil et compétences recherchées

Computational Fluid Dynamics, Applied Mathematics, Machine learning

Aerodynamic shape optimisation plays a fundamental role in aircraft design. Typically we seek to minimize/maximize a scalar quantity of interest (QoI) like drag or lift-to-drag ratio for winged-typed surfaces under lift and/or moment constraints or, for engine components (fan blades, compressors, turbines) isentropic efficiency under pressure ratio and mass flow requirements. This thesis will focus on the optimisation of the geometry of the compressor blade of the well-referenced ROTOR 37 configuration [1].





An example of relative Mach number distribution at 95% blade height for the ROTOR 37 configuration.

For this kind of realistic application useful parameterisations of shapes often result in high-dimensional design spaces (several tens to several hundreds of design variables) which can create challenges for both local and global optimisers.

Local optimisation typically relies on gradient-based algorithms which require efficient computation of derivatives. This is possible thanks to the adjoint solver developed in the ONERA elsA CFD software during the past decade [2, 3]. On the other hand global optimisation strategies are meant to explore a larger design space which may exhibit several local optima [4]. However current formulations based on surrogate models find their limit in terms of building complexity and prediction accuracy even for modest size design parameter sets.

As far as we know, none of these approaches properly addresses the optimisation of a multimodal function of interest defined on a high-dimensional design space. To overcome these limitations, this thesis will develop a hybrid approach based on promising dimension reduction techniques coupled to efficient adjoint-based derivative computations.

A recent technique for reducing the dimension of the parameter space has been proposed by P. Constantine [5]. The idea consists in revealing a low-dimensional subspace that captures the global trends in the QoIs and then exploits these directions to efficiently find an optimal design in the appropriate areas of the design space. This subspace is called the Active Subspace (AS). The method can find a justification in that many engineering quantities of interest exhibit a monotonic behaviour with respect to input parameters.

Once the AS has been discovered, a common practice is to build a global surrogate model in the reduced subspace and perform an optimisation with respect to the components of the active vectors. Exploiting the dominant directions usually accelerates the convergence of the optimisation process since, by construction, the QoIs are very respondent to changes in the active variables.

However, the Active Subspace being a global feature of the function of interest, its ability to identify a global optimum in the parameter space is questionable, especially in high dimension. More specifically this research will extend the current strategy by building local Active Subspaces in sub-regions of the parameter space and appropriately recombine them to cover the entire design space.

One important aspect when considering high-fidelity simulations is the cost associated to function and gradient computations. To mitigate this issue, a multifidelity strategy to discover the active subspace using low fidelity modeling and then exploit active directions at high fidelity level will be considered.

The work plan will be as follows:

- Literature review of usual dimension reduction techniques like Proper Orthogonal Decomposition, Partial Least Squares and Active Subspaces will be carried out. Fundamentals of standard response surface models like Kriging will be also reviewed.
- Set up and apply the AS method to well-known academic multimodal test functions representative of typical optimisation problems. This step will answer relevant questions such as the number of function and associated gradient evaluations required for an accurate active subspace discovery for an increasing number of dimensions.
- Address more advanced topics like building local Active Subspaces in sub-regions of the parameter space. The proposed extension of the original method anticipates that for complex design landscapes, the trends discovered by the AS method might not be constant over the entire design space. As a consequence, local response surface models will also be built in each sub-region with obviously less underlying complexity. These sub-models will then be recombined appropriately.
- Extension of the previous formulation by considering different levels of simulation fidelity.
- Application to the shape optimisation of the compressor blade of the ROTOR 37 configuration.
- Analysis of the added value of the proposed algorithm compared to state-of-the-art gradient-based optimisation processes already available at ONERA.

References

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Collaborations envisagées **Université Bordeaux (chaire PROVE)**	
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