Multidisciplinary Gradient-Based Optimization of Turbomachinery Components using CAD Parameterization

Lasse Müller

Turbomachinery and Propulsion Department, von Karman Institute for Fluid Dynamics, Belgium, lasse.mueller@vki.ac.be

Supervisor: Tom Verstraete

Assistant Professor, Turbomachinery and Propulsion Department, von Karman Institute for Fluid Dynamics, Belgium, tom.verstraete@vki.ac.be.

Abstract

This PhD research aims to extend the VKI optimization system towards gradient-based algorithms to be utilized on turbomachinery components. Due to the industrial applicability, a CAD based parameterization will be used.

Keywords: Multidisciplinary Optimization, Gradient-Based Optimization, Turbomachinery Components, CAD

Over one decade of research has been conducted at the *von Karman Institute* (VKI) to develop a fully automatic multidisciplinary and multi-objective optimization system with focus on turbomachinery components (e.g. [1],[2],[3],[4],[5]). Evolutionary algorithms (EA), based on mechanisms found in nature according to the Darwinian theory such as mutation, crossover, and selection are used to find designs with minimal objective values ([6][7]). EA's have certain advantages [6] as they can handle non-differentiable, nonlinear, and multi-modal objective functions. These features make EA's particularly suitable to explore the complete design space without the risk of becoming trapped in a local minimum.

However, once the region of the global optimum within the design space is identified (see Fig. 1) gradient-based methods become attractive as they make directly use of the gradient of the objective function [8]. Moreover gradient-based methods provide the sensitivity of the gradients, i.e. the direction in which parameters need to be relocated to minimize the objective values. This is an important feed-back in the overall design process of turbomachinery components.

Regarding the terminology of CAD-based and CAD-free parameterization, a clear distinction is necessary. CAD-based parameterization refers to curves and surfaces defined by Bézier and B-Spline curves and surfaces [9], respectively. In CAD-free parameterization, surfaces are represented by the nodes of the surface mesh of the body. According to Fudge et al. [10] the CAD-free approach is intended for academic studies of relatively simple geometries, while the CAD-based system is suitable for geometries that are more complex and for industrial use. The CAD-based approach has certain advantages, e.g. it guarantees G2 continuity of the curves and surfaces and allows to use engineering parameters like lean, sweep, and stagger angle [11]. The main disadvantage is the inaccessibility of the source code of commercial CAD systems to compute the gradients. However, in recent years, great efforts were made to develop an in-house CAD system at VKI [12], hence being fully differentiable.

The main objective of this PhD research is to im-

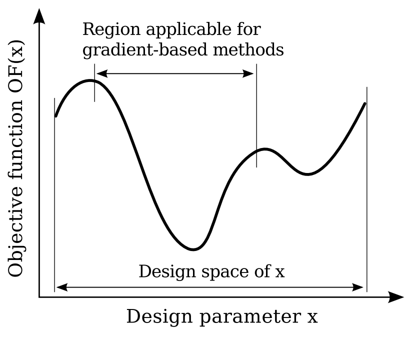

Figure 1: Feasible region of gradient-based methods for a single-objective function

plement gradient-based algorithms in the VKI optimization system based on CAD parameterization and to investigate the possible improvement as compared to evolutionary algorithms when applied to turbomachinery components. Computing the gradient of the objective function with respect to the design variables is an active field of research. Hence, many methods exist, e.g. the adjoint approach or automatic differentiation (AD). The feasibility of these methods will be assessed within the scope of this project and the most promising will be realized.

References

[1] S. Pierret, Designing Turbomachinery Blades by Means of the Function Approximation Concept Based on Artificial Neural Network, Genetic Algorithm and the Navier-Stokes Equations, Ph.D. thesis, von Karman Institute for Fluid Dynamics (1999).

[2] P. Rini, Z. Alsalihi, R. Van den Braembussche, Evaluation of a Design Method for Radial Impellers Based on Artificial Neural Network and Genetic Algorithm, in: Proceedings of the 5th ISAIF Conference, 2001, pp. 535–543.

[3] T. Verstraete, Z. Alsalihi, R. Van den Braembussche, Multidisciplinary Optimization of a Radial Compressor for Micro Gas Turbine Applications, in: ASME Turbo Expo 2007: Power for Land, Sea and Air, no. GT2007-27484, 2007.

[4] T. Verstraete, S. Amaral, R. A. Van den Braembussche, T. Arts, Design and Optimization of the Internal Cooling Channels of a HP Turbine Blade – Part II, Optimization, in: ASME Turbo Expo, Vol. GT2008-51080, 2008.

[5] T. Verstraete, Multidisciplinary Turbomachinery Component Optimization Considering Performance, Stress, and Internal Heat Transfer, Ph.D. thesis, Von Karman Institute for Fluid Dynamics - University of Gent (2008).

[6] R. Storn, K. Price, Differential Evolution - A Simple and Efficient Heuristic for Global Optimization over Continuous Spaces, Journal of Global Optimization 11 (1997) 341–359.

[7] G. Goldberg, Genetic Algorithms in Search, Optimization and Machine Learning, Addison-Wesley, 1989.

[8] A. Jameson, Gradient Based Optimization Methods, http://aero-comlab.stanford.edu/jameson/ (2005).

[9] G. Farin, Curves and Surfaces for Computer Aided Geometric Design, Academic Press. (1993).

[10] D. M. Fudge, D. W. Zingg, R. Haimes, A CAD-Free and a CAD-Based Geometry Control System for Aerodynamic Shape Optimization, American Institute of Aeronautics and Astronautics, 2005, 43.

[11] S. Shahpar, Challanges to Overcome for Routine Usage of Automatic Optimisation in Industry, in: VKI Lecture Series: Introduction to Optimization and Multidisciplinary Design in Aeronautics and Turbomachinery, 2011.

[12] T. Verstraete, CADO: a Computer Aided Design and Optimization Tool for Turbomachinery Applications, in: 2nd International Conference on Engineering Optimization, 2010.