Mitteilung

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Optimization of an airfoil polar in transonic RANS flow using an adjoint gradient-based approach

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Preliminaries

Computational fluid dynamics (CFD) is today an established tool in the design of transonic aerodynamic vehicles, such as modern transport airplanes. The next logical step is automatizing parts of the design process, by coupling CFD simulations and formal optimization methods. Computationally the most efficient (when applicable) are gradient-based optimization methods; however, their efficiency hinges on the ability to quickly and accurately evaluate gradients of cost functions. The time to evaluate the gradient should not depend on the number of design parameters. This is achieved by adjoint methodology.

Within DLR, a mature industry-strength flow solver TAU is in continuous development. The discrete flow adjoint capability for RANS equations has been added to TAU by Dwight [1], including derivation of turbulence models. Its utility has been demonstrated on a variety of 2D and 3D cases, e.g. [2]. For gradient evaluation time to become truly independent of number of design parameters, flow adjoint can be supplanted by mesh adjoint. This was implemented in TAU by Widhalm [3].

Objectives

Application of gradient-based adjoint approach in DLR until recently has been limited to single-point design. Especially in transonic flow, single-point designs tend to be non-robust, with strong shocks reappearing when conditions (Mach number, lift coefficient) are slightly perturbed. One goal, therefore, was to employ the efficiency of adjoint gradient-based approach and examine how to obtain more robust designs. To this end, a multi-point optimization on (C_L, L/D) polar has been performed, using different shape parametrizations and point selections.

Results

An RAE 2822 airfoil at flow conditions M = 0.75, Re = 6.5 10^6, C_L = 0.76, was taken as the initial shape and design point (in case of single-point optimization). The flow was modeled with RANS equations, using Spalart-Allmaras turbulence model. Two shape parameterizations were used. Parametrization A consisted of two sets of bump functions to control the camber and the thickness distributions, and angle of attack. Parametrization B also consisted of two sets of bump functions, but to control the upper and lower surface distribution, and angle of attack. Both parametrizations had 31 parameters in total. The objective was to maximize lift over drag (L/D), with the constraints on lift and pitching moments, and the volume enclosed by the airfoil.

In this setup, the initial shape exhibited a strong shock on the upper surface, which was eliminated by single-point optimization. However, the resulting L/D polar was “peaky”, with inflection towards the lower lift coefficients, and the resulting airfoil shape was somewhat ungainly – the optimizer had over-exploited the flexibility of parametrization. Multi-point optimization fixed these problems, as shown on the figure 1. Two multi-point optimizations were performed, one with 4 equidistant equally-weighted points in range of C_L = [0.46, 0.76], and another with 8 points in range C_L = [0.41, 0.76]. The 4-point optimization yielded a smoother polar and shape than the single-point optimization, while sacrificing some L/D at the design C_L = 0.76. The 8-point optimization seemed to do a bit worse, because it tried too hard to improve on the lower part of C_L range. Parametrization B showed similar results (figure 2), but, although having same number of design parameters as parameterization A, more limited L/D polars were attained. Optimizations required 15 to 25 (multi-point) function evaluations, and 10 to 14 gradient evaluations. In terms of wall clock time, on a 2×4-core Intel Xeon E5540 computing node it took from 30-35 minutes for single-point optimizations to 160-180 minutes for 8-point optimizations.

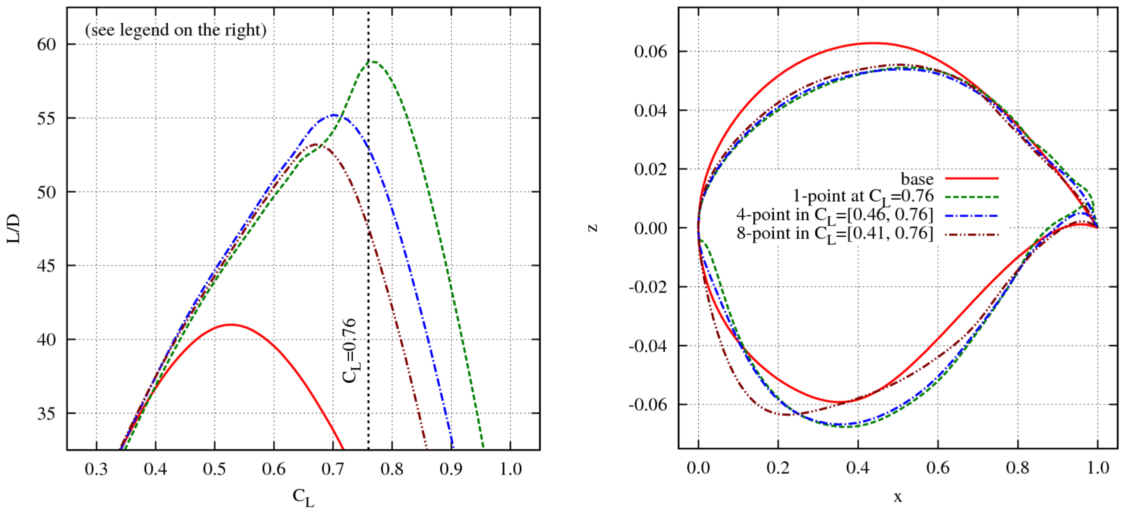

Fig. 1: Base and optimized L/D polars (left) and shapes (right), with parametrization A.

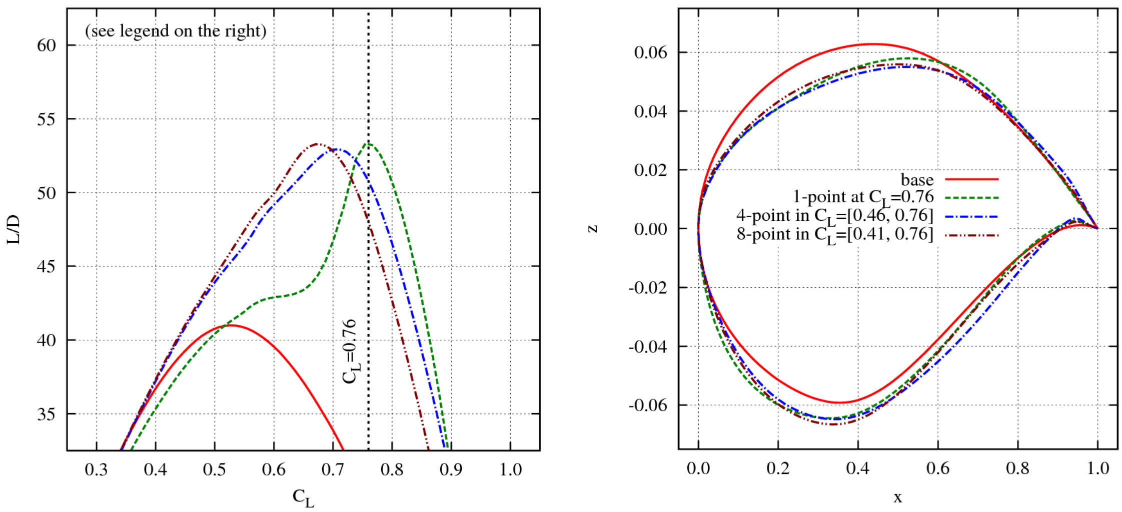

Fig. 2: Base and optimized L/D polars (left) and shapes (right), with parametrization B.

This examination shows that the adjoint gradient-based optimization approach can be used effectively to explore the effects of shape parametrizations and point selections in multi-point aerodynamic design of airfoils, resulting in more robust designs than those obtainable by single-point optimization.

References

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[3] M. Widhalm, J. Brezillon, C. Ilic, T. Leicht, "*Investigation on Adjoint Based Gradient Computations for Realistic 3D Aero-Optimization*", 13th AIAA/ISSMO Multidisciplinary Analysis Optimization Conference 13-15 Sep 2010, Fort Worth, Texas.