Mitteilung

Projektgruppe / Fachkreis:
Numerische Verfahren / Aerodynamik

Drag reduction of a 2D airfoil with constraints on lift and pressure distribution using adjoint approach.

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Ausgangssituation:

For the design of laminar profile, specific pressure distribution - such as a smooth continuous pressure decrease at the suction side - is desired to delay as far as possible the Tollmien-Schlichting laminar-turbulent transition point. An efficient inverse design tool based on the adjoint approach has been therefore developed to provide the airfoil geometry that satisfies a given target pressure distribution [1]. Such tool is based on a gradient-based optimization strategy to minimize the L2-norm of the target pressure residual - measured as the difference between the current and target pressure - over the body surface.

Ziel:

The inverse design tool developed so far requires the definition of the target pressure distribution over the complete airfoil. Such target pressure is however complex to find since it has to be physically feasible and match some specific aerodynamic performance, in terms of lift and pitching moment coefficients. An alternative is to minimize the target pressure residual over parts where laminar flow should occur - typically some percent of the upper and lower front parts – and to perform a classical drag minimization at target lift and pitching moment at the same time. This approach allows 1) to ensure that the final geometry satisfies the target aerodynamic performance 2) to design a laminar profile with a low wave drag, without the use of laminar transition criteria in the optimization process. The transition criteria are in fact used to define the target pressure prior to the optimization. The objective of the current study is focused on demonstrating the feasibility of the approach using the adjoint framework.

Lösungsweg:

The goal of the optimization is to minimize the cost function I, which is defined as:

$$I = \int_{S1}^{S2} (Cp - Cp^*)^2 ds + w_1 (Cl - Cl^*)^2 + w_2 Cd$$

where Cp^* is the target pressure defined between S1 and S2 on the profile, Cl^* is the target lift and w_1 and w_2 represent constant weighting factors. By choosing proper weighting factors, the optimization is expected to reduce the drag while matching target lift and target pressure distribution.
The shape parameterization method used for optimization is mesh point parameterization. The gradients at the trailing edge are usually extremely high because the cost function is very sensitive to the deformation at trailing edge. In order to avoid the high deformations at trailing edge, the gradients at trailing edge are scaled to 1% of their actual value before they are passed to the optimizer.

Ergebnis:

In this optimization, the NACA2412 airfoil is selected as the initial airfoil with $Cl|_{initial} = 0.413$ and $Cd|_{initial} = 0.0229$. The pressure distribution up to 60% of the upper surface of the laminar DLR-LV2 airfoil is set as the partial target pressure, and the lift coefficient of DLR-LV2 airfoil is set as the target lift $Cl^{*} = Cl|_{LV2} = 0.590$, where $Cd|_{LV2} = 0.0144$. The weighting factors w_1 and w_2 are set as: $w_1 = 100.0, w_2 = 10.0$.

Fig.1 shows the convergence of the aerodynamic coefficients Cl, Cd and the cost function versus the design iterations. The optimization converged after 895 iterations. The cost function decreases quickly at the beginning of the optimization, and the convergence rate of the optimization slows down after 150 design iterations. The lift of the optimized shape matches the target value with a difference of about $\Delta = 0.5\%$. The drag coefficient of the optimized shape is $Cd|_{optimised} = 0.0119$. Compared to the DLR-LV2 profile, the drag is reduced by 17.4%. Fig.2 shows the comparison of shape and pressure distribution between the optimized shape and the NACA2412 airfoil: the partial pressure on the upper surface of optimized shape matches the target pressure distribution very well.

Abschluss:

The drag minimization at target lift and pressure distribution based on the adjoint approach is a promising way to design laminar profile, without the need of transition criteria during the optimization run. First encouraging results have been achieved and the methods will be further improved by including the pitching moment and by defining a target pressure at the pressure side.

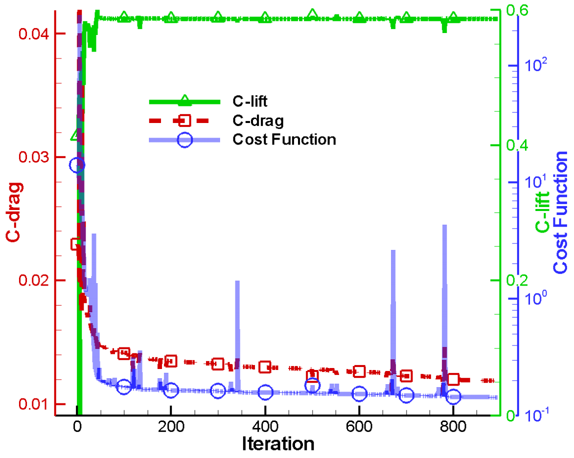

Fig.1 : Convergence of Cl, Cd and Cost function

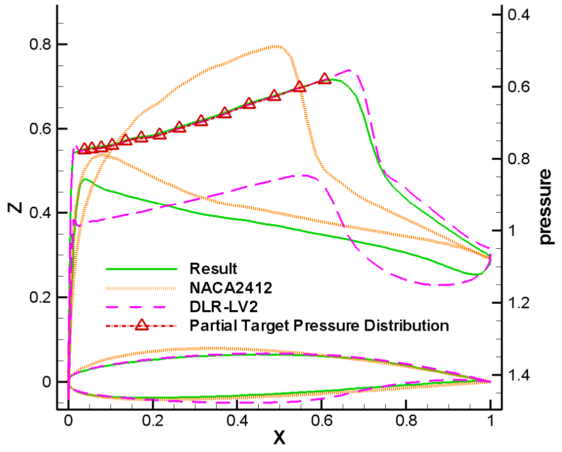

Fig.2 : Comparison of pressure and shape

Literatur :

1. Brezillon, Joël and Abu-Zurayk, Mohammad (2010) *Aerodynamic Inverse Design Framework using Discrete Adjoint Method.* 17. DGLR-Fach-Symposium der STAB, Berlin, Deutschland.

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