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Numerical Optimization of a Zero-Net-Mass-Flux Actuation for a High Lift Airfoil

V. Ciobaca
Institute of Aerodynamics and Flow Technology, German Aerospace Center (DLR), Lilienthalplatz 7, 38108 Braunschweig, Germany

INTRODUCTION

The laminarity on the wings in cruise flight is one technology retained to significantly reduce fuel burn of future transport aircraft (e.g. JTI CLEANSKY EU program [1]). This technology requires smooth surfaces with a maximum step height of tenth of millimetres. Thus, the existing high-lift devices are incompatible with laminarity on both sides of the wings and new technical solution has to found. The active flow control (AFC) is unanimously seen as one of the mean to tackle this issue. At low speed conditions, a smart active flow control could even replace the existing high-lift devices. The high mass-flux requirements and the need of a plumbing system were identified as drawbacks for typical continuous and/or pulsed blowing systems. The synthetic jet (SJ) is seen as an option to avoid the air feeding (plumbing system) and to use only an electrical feeding. A common research project (CRP) of ONERA and DLR, the CRP LEAFCO (2012-2015), tackles the application of zero-net-mass-flux (ZNMF) actuation on a laminar high-lift airfoil by means of wind tunnel experiments and simulations. Here only numerical results are discussed. The capability of modern numerical methods, unsteady Reynolds-averaged Navier-Stokes (uRANS), to predict the impact of the AFC application on the aerodynamic performance is here used to optimize the unsteady actuation parameters prior the manufacturing and testing of a high-lift airfoil DLR-F15LLE (Laminar Leading Edge). The main objective is to define geometrical parameters of the actuation slit, such as position, direction and width, which are to be considered for the extensive wind tunnel testing with ZNMF-actuators in large test facilities of ONERA and DLR.

NUMERICAL STUDY

The method of choice is a gradient-free optimization method, with the subPlex algorithm, in a framework known as Pyrahna [2]. A sketch of the optimization loop is depicted in figure 1. The objective is to maximize lift for a large angle of attack, $\alpha = 12°$, which is larger than α_{max} of the baseline flow. Therefore an increased overall maximum lift for the airfoil is expected, a coefficient that is crucial for the evaluation of the landing capabilities of a transport aircraft. The design variables are the actuation parameters: chordwise position x_{AFC}, actuator's width w_{AFC}, outflow direction α_{AFC}, and jet velocity U_{AFC}. The frequency is a moderate f=100Hz and by the definition of the ZNMF the dutc cycle DC=0.5. The aerodynamic behavior is computed with a well-established framework for AFC, based on uRANS simulations with the

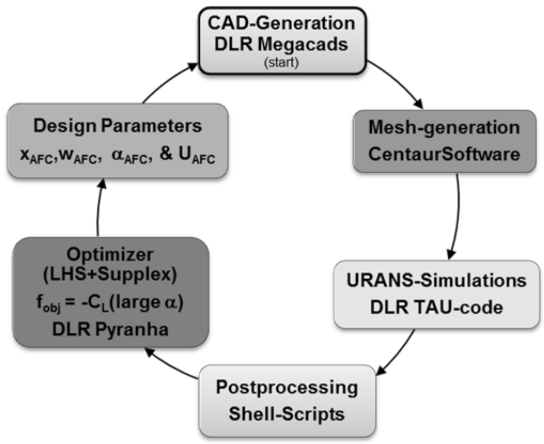

Figure 1: Optimization loop for ZNMF-actuation

DLR TAU-code [3], on hybrid meshes for a geometry that is accordingly updated with an in-house tool known as Megacads. The study is performed at inflow Mach number M=0.2 and Reynolds number $Re_c=3x10^6$, according to typical landing speedsof transport aircraft but for a Reynolds number specific for atmospheric wind tunnel testing.

The DLR-F15 [4] high-lift airfoil is a well-established platform for flow control research and the new geometry of the laminar leading edge was particularly designed within the

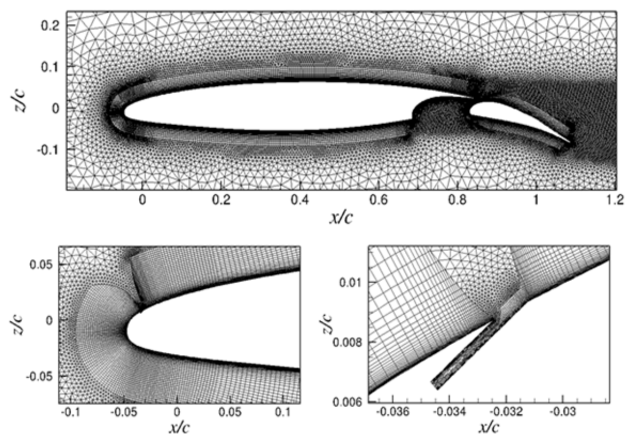

Figure 2: Mesh topology for the 2-elem. DLR-F15LLE including a modeled actuation slit at the leading edge of the laminar airfoil

JTI CLEANSKY EU program (by Dassault Aviation, France) and is used here accordingly. The typical mesh topology for a configuration with an upper side slit is depicted in figure 2. The geometry resolves a portion of the actuator modeled bellow the airfoil's surface. Approximatively 200 thousand points with 60 quasi-structured stacks for resolving the local boundary layer characterize a typical grid. With this discretization of the simulation domain the high-order unsteady simulations are conducted with a dual time stepping approach and a semi-implicit temporal discretization in the inner iterations of the uRANS computations.

The focus was on optimizing the geometrical parameters as sketched in figure 3. The blowing direction is varied between tangential upstream and tangential downstream, the width between 0,1mm and 0,9mm, the chordwise station from leading edge till 2%c and the jet velocity between a few m/s till the close to sonic speed, U_{max}= 300m/s. A sampling of the studying domain was initially investigated and the resulting objective function is shown in figure 4. Finally a gradient-free

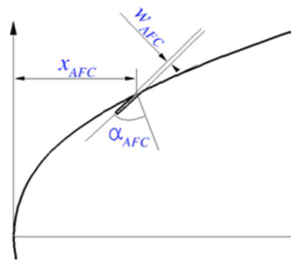

Figure 3 Geometrical optimization parameters of the slit

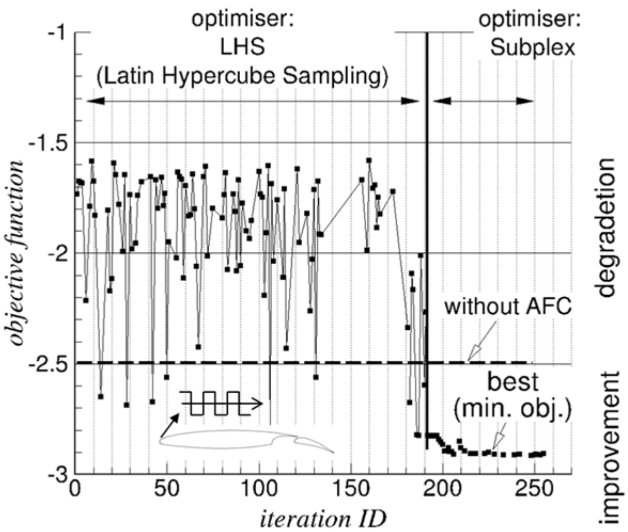

Figure 5: Optimization convergence for the upper side ZNMF

optimization was performed with a subPlex algorithm starting from the best solution of the sampling. Many setups with AFC had a lift coefficient lower than the corresponding baseline (without AFC). The optimized geometrical parameters where much in agreement with the previous experimental experience and are shown in figure 5. Tangential slits with a large width which allows for large mass-flows where the best for lower and upper side ZNMF-actuators. The actuation speed was selected to be large, close to the maximum selectable. The objective function was sensitive to the position x_{AFC} and was found to be optimal as $x_{AFC,lower}$=1.45%c and $x_{AFC,upper}$=1.65%c. The absolute value of maximum lift was slightly larger for the best computed setup with upper slit than the best configuration with lower side actuation.

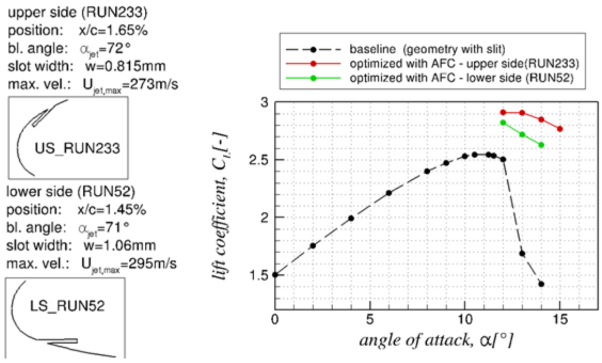

Figure 4: Results of optimized ZNMF for upper and lower side actuations on the DLR-F15LLE airfoil

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