On the Coupling of Laminarity and Shock Wave Intensity in Drag Reduction CFD Problems at Transonic Flow Regimes using MOGA Software and Game Strategies

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ABSTRACT

In order to improve the flight performance (e.g. increasing the flight time of cruise) of an aircraft, it is necessary to investigate viscous drag reduction (mainly turbulent friction drag) which represents about 40% of the total drag. Laminar flow technology can offer the greatest potential for reducing turbulent friction drag at high Reynolds numbers. In a conflicting behavior of the flow, the existence of a wide range of favorable pressure gradient on laminar airfoil surface contributes to the increased intensity of shock wave on the neighborhood of the trailing edge. Concurrently, an additional wave drag occurs during the skin friction drag reduction. The laminar turbulent transition prediction module which consists of a boundary layer method with the well known e^N based method for the Tollmien-Schlichting instabilities is coupled to a flow solver in order to predict automatically the transition location.

In this paper, the RAE2822 airfoil is selected as the baseline airfoil shape. A Multi-Objective Genetic Algorithm (MOGA) is used to optimize both airfoil and bump shape configurations. Using Pareto or Nash-game strategies provide a *larger laminar flow range and a weaker shock wave near the trailing edge.* Non dominated solutions of the Pareto Front of the two-objective optimization problem are computed with the MOGA software, as well as Nash game solutions of this two-objective optimization problem. Pareto and Nash results of airfoil shapes equipped with bumps are compared in terms of drag performance to those obtained with the baseline configuration (without bump). Numerical experiments obtained from the shape design optimization of an airfoils/bump configuration operating at flow conditions, Reynolds = 1.5×10^7 and angle of attack = 2.31^0 M=0.729 are discussed.

In order to solve the natural laminar airfoil optimization with bumps, the following two optimization problem are performed simultaneously using cooperative games (Pareto) or conflicting games (Nash).

$$\begin{cases} \max\limits_{X} J_1 = X_{tr\_upper} + X_{tr\_lower} \\ \min\limits_{X} J_2 = C_{D_P} \\ Subject\ \ to: \ C_L \geq C_{L_0} \\ X = Airfoil + Bump \end{cases}$$

The computation is performed on a LENOVO T260 workstation, with six (6) 2.13 G Hz CPU used for the two objective optimization problem (Figures 1 to 5).

A detailed analysis of numerical experiments shows that the shock wave intensity affects significantly the delay of the transition location. Results demonstrate clearly that aerodynamic performances of MOGA optimized airfoils and bumps shape configurations computed with Pareto or Nash games significantly reduce the drag when compared to the drag value of the RAE2822 airfoil baseline. This paper illustrates the potential of design optimization tools using game strategies in industrial environments.