ACTIVE CONTROL OF SHOCK/BOUNDARY LAYER INTERACTION IN TRANSONIC FLOW OVER AIRFOILS

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Summary The objective of this paper is to show, via numerical simulation, the feasibility of weakening the shock wave(s) and reducing the pockets of supersonic and separated flow regions on an airfoil (NACA 0012) in transonic flow at small angles of attack using an active flow control device such as a synthetic jet actuator. The weakening of shock and control of shock/boundary-layer (SBL) interaction can result in both reduced drag and lift, which may be beneficial in achieving rapid altitude change in descent flight.

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Recently it has been shown experimentally by Amitay et al [1] and computationally by the authors of this paper [2] that the pressure drag of an airfoil at low speeds and small angles of attack can be significantly reduced with a minimum change in lift by modification of the apparent aerodynamic shape of the airfoil. In [1], a small stationary flow interaction domain adjacent to the upper surface of the airfoil was created deliberately by employing a passive small surface mounted obstruction which of course increased the drag appreciably. A synthetic jet actuator was then placed immediately downstream of the obstruction to see its effect on lift and drag of the airfoil; the frequency and momentum coefficient of the synthetic jet were varied in the experiment. It was shown that it was possible to reduce drag with minimal change in lift at higher momentum coefficient and frequencies of the jet. These results have been very encouraging. However, although some computational and experimental work has been done in the application of active control for virtual aeroshaping of an airfoil to reduce drag in subsonic flow, hardly any work has been reported in the literature to date for active control of the strength of shock waves and their unsteadiness, the supersonic regions and shock-induced separation due to shock/boundary layer interaction. This problem is of great relevance for reducing the transonic cruise drag of a transport aircraft and high speed impulsive noise of a rotorcraft.

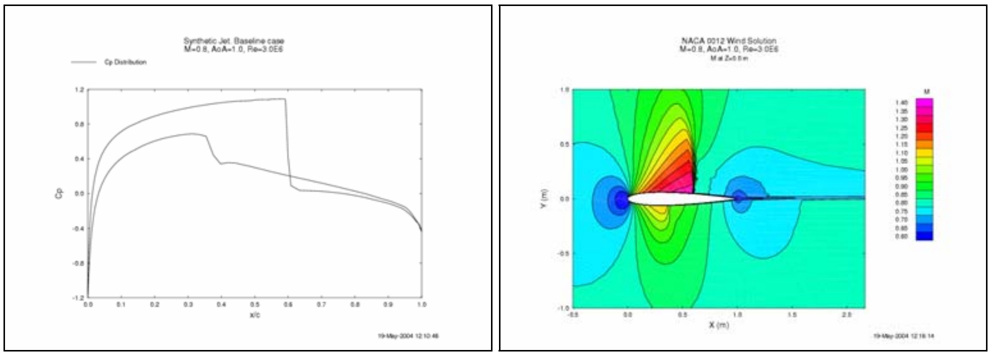
In this paper, CFD simulations are performed by employing an extensively validated well known multi-zone hybrid RANS/LES flow solver WIND. Detached Eddy Simulation (DES) modification of Menter's two-equation Shear Stress Transport (SST) model was employed in the computations. The grid refinement study was performed to ensure that the computed solutions were grid-independent. The uncertainty in the computed solutions due to the numerics (size of computational domain, grid, numerical algorithm and boundary conditions) was minimized. The actual geometry of the control device was included in the simulations. It has been shown by many investigators that the geometry of the control device (e.g. cavity of the synthetic jet) should be included in the computations for accurate simulation of the flowfield; the simplified boundary conditions implemented on the airfoil surface can introduce significant errors.

A large number of numerical simulations were performed for transonic turbulent flow past a NACA 0012 airfoil at small angles of attack by varying various parameters of the synthetic jet such as amplitude of the jet velocity, jet width, momentum coefficient, frequency and jet location on the airfoil surface. Here due to lack of space, we show the results of a typical computation for flow past a NACA 0012 airfoil in transonic flow at Mach 0.8, angle of attack = 1°, chord Reynolds number Re = 3×10^6, with and without a synthetic jet. Figure 1 shows the pressure distribution and Mach contours on the airfoil in the absence of synthetic jet. A synthetic jet of width 0.003c (c = chord of the airfoil), frequency = 1550 Hz, and jet Mach number M_j = 0.3 (maximum amplitude) is applied at the foot of the shock. Figure 2 shows the Mach contours and pressure distributions at three normalized time intervals during one cycle of the synthetic jet. These calculations show reduction in both lift and drag during one cycle of the synthetic jet for this free stream flow condition and the synthetic jet parameters employed. Additional computations will be presented in the complete paper for this case for different amplitudes, frequencies and locations of the synthetic jet. It is concluded that the active control of shock/boundary layer interaction on an airfoil in transonic flow can be achieved, resulting in both reduced drag and lift, for suitably selected parameters of the synthetic jet.

References

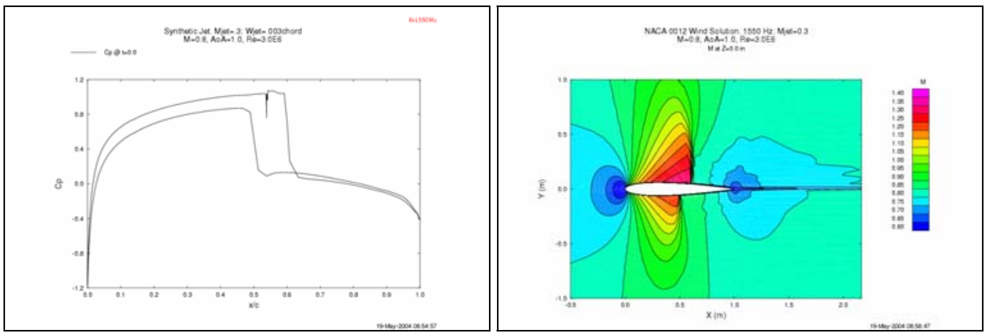
[1] Amitay, M., Horvath, M., Michaux, M., and Glezer, A.: Virtual Aerodynamic Shape Modification at Low Angles of Attack Using Synthetic Jet Actuators. AIAA Paper 2001-2975, 2001,

[2] Vadillo, J.L., Agarwal, R.K., Cary, A.W., and Bower, W.W.: Numerical Study of Virtual Aerodynamic Shape Modification of an Airfoil Using a Synthetic Jet Actuator. AIAA Paper 2003-4158, AIAA 33rd Fluid Dynamics Conference, 23-26 June 2003.



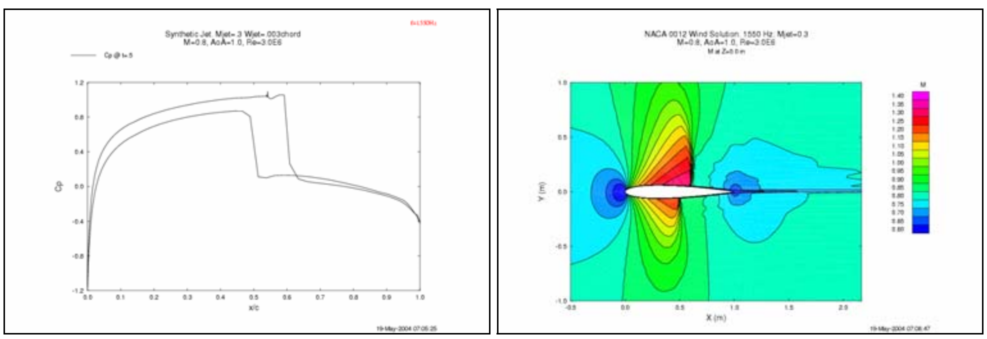
(C_L = 2.64567E-01; C_D = 1.68244E-02; M_{Max} = 1.3510143)

Figure 1: Computed Pressure Distribution and Mach Contours for Flow Past a NACA 0012 Airfoil at M=0.8, Re = 3.0×10^6, α=1.0° without Synthetic Jet.



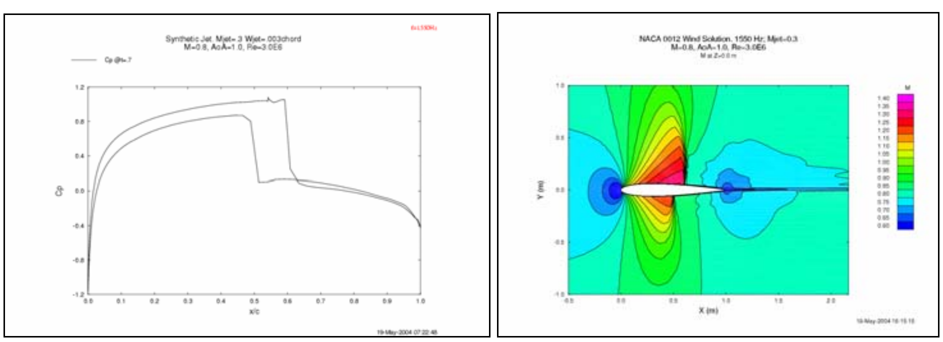
(a) blowing stroke

(C_L = 1.56638E-01; C_D = 1.60760E-02; M_{Max} = 1.3408358)



(c) suction stroke

(C_L = 1.55913E-01; C_D = 1.57559E-02; M_{Max} = 1.3548344)



(d) end of suction stroke/ beginning of blowing stroke

(C_L = 1.56292E-01; C_D = 1.57468E-02; M_{Max} = 1.3583143)

Figure 2: Computed Pressure Distribution and Mach Contours for Flow Past a NACA 0012 Airfoil at M=0.8, Re = 3.0×10^6, α=1.0° with Synthetic Jet, Jet Width = 0.003c, M_j = 0.3, f = 1550 Hz.