Pseudo-unsteady quasi-simultaneous two-dimensional interactive boundary layer methodology for preliminary aircraft design

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Driven by increasingly stringent efficiency requirements, aerodynamic optimization is nowadays integrated early in the design process of new aircraft. Because many optimization variables are involved in the preliminary design stage, the aerodynamic model must allow a rapid assessment of design changes. This requirement is usually met by relying on methods with a low computational cost rather than on higher-fidelity Reynolds-Averaged Navier-Stokes simulations which quickly become impractical when a large number of cases must be considered. A more efficient alternative is the viscous-inviscid interaction method, popularized by Drela with his tool XFOIL (Drela, M. (1989). XFOIL: An analysis and design system for low Reynolds number airfoils. In Low Reynolds number aerodynamics (pp. 1-12). Springer, Berlin, Heidelberg.), whereby an inviscid flow calculation is corrected by including the viscous effects relevant in the boundary layer.

In the present work, the pseudo-unsteady integral boundary layer equations together with laminar and turbulent closure relations are coupled to a non-linear potential method to solve transonic flows with embedded weak shocks (Crovato, A. (2020). Steady Transonic Aerodynamic and Aeroelastic Modeling for Preliminary Aircraft Design. Doctoral dissertation, Université de Liège, Belgique). The boundary layer region is coupled with the inviscid flow through a quasi-simultaneous interaction scheme allowing for the computation of mildly separated flows. The e^N method is used to capture laminar to turbulent transition. A robust time-marching procedure with time advancement control and sporadic Jacobian evaluation is used to solve the pseudo-unsteady integral boundary layer equations. The inviscid and viscous equations are solved on dedicated meshes and the interpolation from one mesh to another is performed using radial basis functions and Bézier curves driven by local flow topology. Coupled solutions are presented for two-dimensional cases in the subsonic and transonic regimes for transitional and fully-turbulent flows. Good agreement with state-of-the-art and higher fidelity methods is demonstrated for attached and mildly separated flows. The associated computational time is typically a hundred times lower than the traditional RANS approach.