AEROELASTIC STABILITY CALCULATIONS OF A LAMINAR WING USING VISCOUS-INVISCID INTERACTION

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ABSTRACT

Laminar wing technology has drawn interest over the past decades because of the potential reduction in drag and fuel consumption it can provide. Despite numerous studies carried out on this topic, multiple challenges remain to be solved before this technology can be integrated into the aircraft design process. In particular, the prediction of transition from laminar to turbulent flow and its effect on the aeroelastic behaviour of the aircraft are still active areas of research. Within this context, the present work proposes a novel approach for calculating the aeroelastic stability of laminar wings. A steady flow solution is first calculated by means of a viscous-inviscid interaction (VII) methodology, which is then used to correct an unsteady compressible source and doublet panel method. Finally, the flutter solution is calculated using a non-iterative *p*-*k* method. The VII method used in this work is implemented in the code BLASTER [1, 2][1]. It relies on the coupling of the full potential solver DART [3, 4][2] with a pseudo-unsteady integral boundary layer solution method by means of a quasi-simultaneous coupling algorithm. The transition from laminar to turbulent flow is predicted using the e^N method. Resorting to VII is computationally less costly than solving the Reynolds-Averaged Navier Stokes (RANS) equations and offers a natural way of predicting the transition. The generalized aerodynamic forces are calculated using the source and doublet panel method implemented in SDPM [5][3] and are corrected to account for transonic and viscous effects using the correction technique recently developed by Dimitriadis [6]. Finally, the flutter solution is calculated using a non-iterative version of the standard *p*-*k* method implemented in PyPk [7][4]. The interest of using a panel method combined to the *p*-*k* method lies in the fact that this approach is similar to industrial standard and can be integrated easily in the aircraft design process.

The methodology developed within the context of the present work is used to calculate the flow over the CAST-10-2/DOA 2 aerofoil and to predict its flutter behaviour at transonic speed. The CAST-10 aerofoil is a supercritical aerofoil featuring laminar flow designed and extensively studied by the NASA and DLR since the eighties [8]. Recently, a rectangular wing using this aerofoil was mounted on a pitch and plunge mechanism and tested in the Transonic Wind Tunnel Goettingen [9-11]. Figure 1a shows the pressure coefficient along the chord of the CAST 10-2 aerofoil at a Mach number $M_\infty = 0.75$, a Reynolds number $\mathrm{Re} = 2 \times 10^6$ and an angle of attack $\alpha = 0°$ calculated using BLASTER and compared to that obtained experimentally by Hebler et al. [9-11]. Figures 1b to 1d show the location of the transition on the suction side of the aerofoil, the lift, and the moment coefficients as a function of the angle of attack, respectively. The results obtained using BLASTER have been computed using three

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[1] https://gitlab.uliege.be/am-dept/blaster
[2] https://gitlab.uliege.be/am-dept/darflo
[3] https://gitlab.uliege.be/am-dept/sdpm
[4] https://gitlab.uliege.be/am-dept/pypk

different approaches: A) by fixing the location of the transition to the leading edge, hence producing a fully turbulent boundary layer, B) by fixing the location of the transition to the value obtained experimentally, and C) by letting the transition develop freely. Overall, the numerical results are in good agreement with the experimental data. BLASTER is able to capture the change in location of the transition and the associated loss of lift and decrease in moment coefficient, which is of paramount importance for flutter prediction. Moreover, the solver is faster than traditional RANS-based solvers and requires only 30 seconds per angle of attack on a laptop in this challenging case. However, the software currently lacks robustness, which can lead to spurious oscillations in the results or even failure to converge (e.g. red and green curves in figures 1b to 1c).

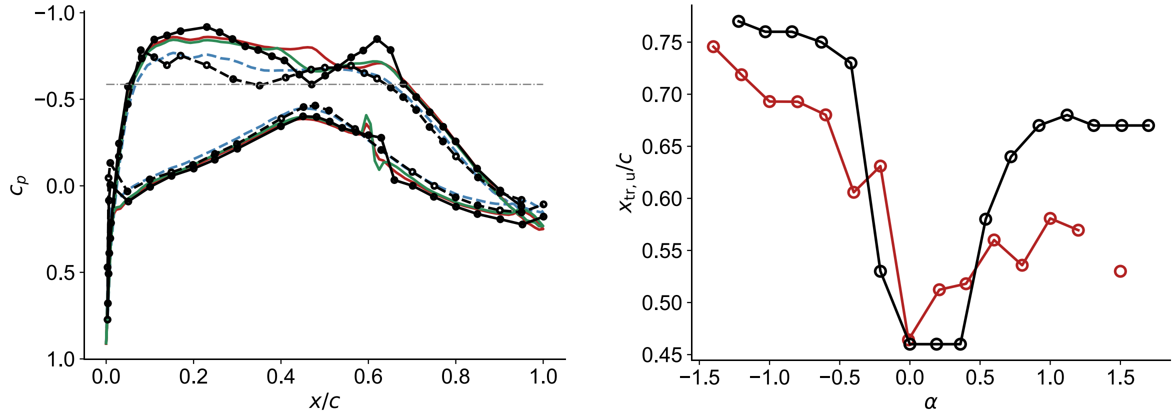

Figure 1a: Pressure coefficient at $\alpha = 0°$.

Figure 1b: Transition location (suction side).

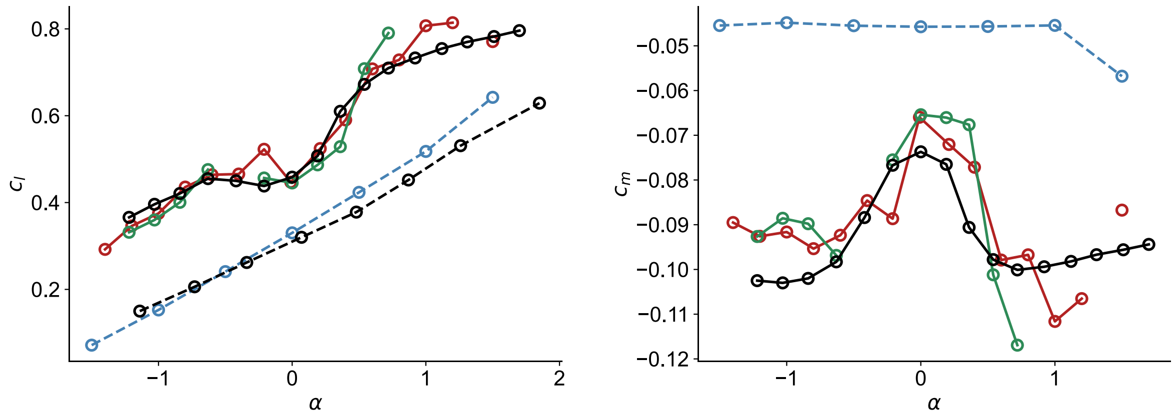

Figure 1c: Lift coefficient.

Figure 1d: Moment coefficient.

Figure 1: Results obtained using BLASTER on the CAST 10-2 airfoil at a freestream Mach number $M_\infty = 0.75$ compared to experimental data. Dashed blue: BLASTER (fully turbulent), solid red: BLASTER (free transition), solid green: BLASTER (transition fixed at experimental value), solid black: experimental (free transition), dashed black: experimental (fully turbulent), horizontal dash-dotted grey line: critical pressure coefficient.

The full conference article will describe the methodology and the various codes in details. BLASTER will be improved and compared to the VII method developed by Le Balleur at ONERA [12], and to RANS solutions. The article will also feature flutter calculation results, illustrating the benefits of the proposed approach within an aeroelasticity context.

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