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LOW REYNOLDS UAV AIRFOIL ADJOINT-BASED OPTIMIZATION WITH SA-BCM TRANSITION MODEL

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Abstract. *High-fidelity optimization frameworks have significantly advanced aerodynamic design by enabling systematic performance improvement across complex geometries and multiple operating regimes. These frameworks leverage Computational Fluid Dynamics (CFD) solvers to explore extended design spaces, thereby approaching theoretical performance limits. However, the computational cost associated with high-fidelity simulations demands efficient optimization algorithms. Gradient-based algorithms employing adjoint methods offer the necessary scalability for handling large numbers of design variables. For low Reynolds number regimes ($Re < 10^6$), such as small unmanned aerial vehicles (UAVs) applications, laminar flow may dominate a substantial portion of the wing chord, making the accurate prediction of laminar to turbulent flow transition critical. Conventional turbulence models, such as the Spalart–Allmaras (SA), which assume fully turbulent flow, can lead to misleading design outcomes by either underestimating or overestimating aerodynamic performance. Preliminary studies show that designs optimized under fully turbulent assumptions often fail to maintain their advantages when re-evaluated using laminar-turbulent transition models, and in some cases, exhibit degraded performance. To address this limitation, an algebraic transition model, known as SA-BCM, triggered by a critical empirical momentum-thickness Reynolds number, was integrated into an aerodynamic adjoint-based solver, ADflow in the MACH-Aero framework. This approach enables efficient and robust transition prediction and was implemented to remain compatible with adjoint-based optimization. Validation against experimental data, including cases such as the NACA 0012 airfoil, demonstrated satisfactory agreement. Initial optimization studies incorporating transition modeling yielded improved low-Reynolds-number airfoil designs, with notable gains in aerodynamic efficiency. Beyond enhancing predictive accuracy, the inclusion of transition effects facilitates the design of geometries that favorably manipulate boundary-layer behavior, potentially delaying separation and improving flow control. Ongoing work focuses on extending this capability to three-dimensional configurations, capturing transition phenomena in regions such as wing-fuselage junctions, winglets and propulsion integration. This effort aims to enable a higher fidelity level in aerodynamic shape optimization at low Reynolds number regimes.*