Mitteilung

Fachgruppe: Turbulenz und Transition

Modeling Approaches for Boundary-Layer Suction in Transition Transport Models

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Background

Laminarity is an important component of research for future sustainable and energy-efficient aviation and boundary-layer suction is a well-known active means of laminar flow control. As the design of laminar aircraft relies on CFD simulation the relevant physics of laminar-turbulent transition has to be included in the numerical model. In recent years transition transport models, such as the γ-$Re_{\theta t}$ model [1] or the DLR γ model [2], have been employed more frequently in aerodynamic shape optimization and also for the investigation of unsteady aerodynamic forces on laminar wings. However, to the authors' knowledge none of these models have been developed to capture the effect of boundary-layer suction.

Objective

The objective of this work is to derive and assess modeling approaches to capture the effect of boundary-layer suction in transition transport models. The focus of this work is on the DLR γ model.

Approach

The DLR TAU-Code is used for Reynolds-Averaged Navier Stokes (RANS) simulations. A mass flux boundary condition is applied to model boundary-layer suction [3]. Different models are considered to predict laminar-turbulent transition:

- The linear stability theory (LST) and e^N method are applied to generate reference solutions. This model framework has been validated for cases with boundary-layer suction [3].
- The γ-$Re_{\theta t}$ model is a widely-used model which founded the class of transition transport models [1]. It contains a transport equation for the transition criterion ($Re_{\theta t}$), which might be exploited to model the downstream effect of boundary-layer suction. However, unsatisfactory predictions were observed compared to wind-tunnel measurements of laminar-turbulent transition over a flat plate with boundary-layer suction [4].
- The DLR γ model was developed based on the γ-$Re_{\theta t}$ model with adaptations made for transport aircraft conditions [2]. It is currently our preferred transition transport model to predict laminar-turbulent transition in this particular context.

Results

For the ideal flat plate with homogeneous suction, a consistent delay of the transition location is observed for all transition prediction criteria (both for direct evaluation with boundary-layer data and as part of the transport equation approach) when the suction rate c_Q is increased (Fig. 1). However, the suction effect is significantly underestimated in comparison to the reference (LST). This discrepancy can be attributed to the fact that the stabilizing effect of suction on the boundary-layer profile is not considered by the transition criteria (LM2009 for the γ-$Re_{\theta t}$ model [1] and AHD simple for the DLR γ model [2]). The relatively small downstream displacement of the predicted transition location is caused by the reduction of momentum thickness when the rate of suction is increased. To address the current limitation of transition transport models the present work considers different approaches to correctly account for boundary-layer suction. This includes a correlation-based modification of transition criteria [5], the concept of equivalent pressure gradient [6] and different concepts to integrate the criteria into the transport model framework.

The different approaches are evaluated and assessed based on computations for the ideal flat plate with homogeneous and inhomogeneous suction. Furthermore, the measurement data of a real flat plate with finite thickness and blunt leading edge [4] are used for the validation of the modeling approaches.

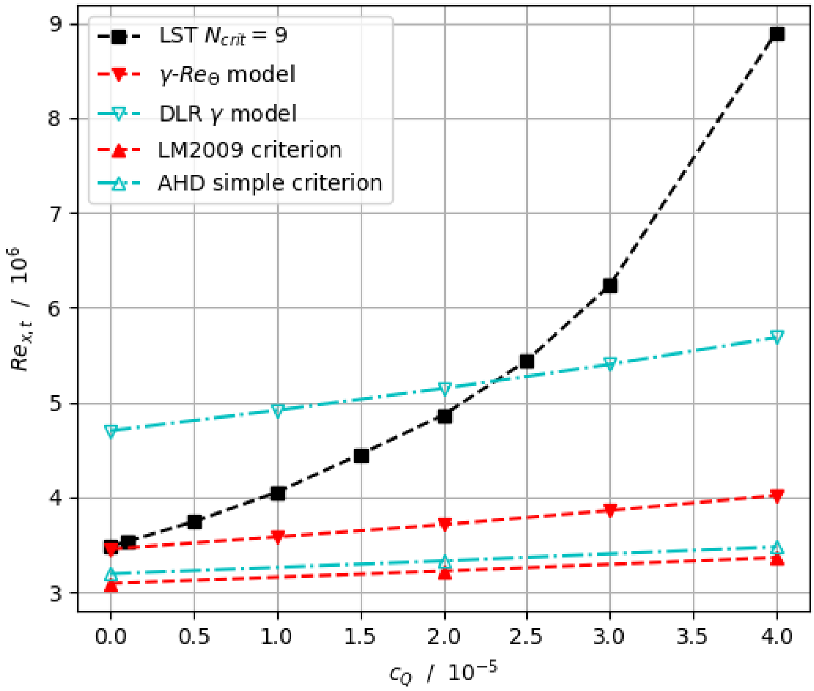

Fig. 1: Effect of homogeneous boundary-layer suction on the predicted transition location ($Re_{x,t}$) over an ideal flat plate at Mach number M=0.2 and turbulence intensity Tu=0.07% corresponding to N_{crit}=9

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