Mitteilung

Projektgruppe/Fachkreis: Turbulenz und Transition

Assessment and Adaptation of Transition Criteria for Non-Self-Similar Flows

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Background

With the establishment of transport equation approaches for transition prediction a revival of simple transition criteria is accompanied. Some of the transition criteria used in transport equation approaches are derived based on linear stability theory (LST) results for self-similar flows. In this regard, one transition prediction method available in the DLR TAU code is the DLR-γ transition transport model that utilizes a simplified form of the AHD criterion [1].

Objective

Ideally, the LST based transition criteria emulate the behavior of LST computations not only for self-similar flows but also for non-self-similar flows. Generally, flows around general aerodynamic configurations deviate from having a self-similar character. This deviation is especially pronounced if the considered flow undergoes more or less strong local variations, e.g. the flow is subject to (strong) pressure gradients or to (local) suction/blowing. The objective of the work is to assess transition criteria based on reference LST computations and, if necessary, to adapt and/or reformulate these criteria to improve their prediction capability for non-self-similar flows, especially with focus on flows with suction.

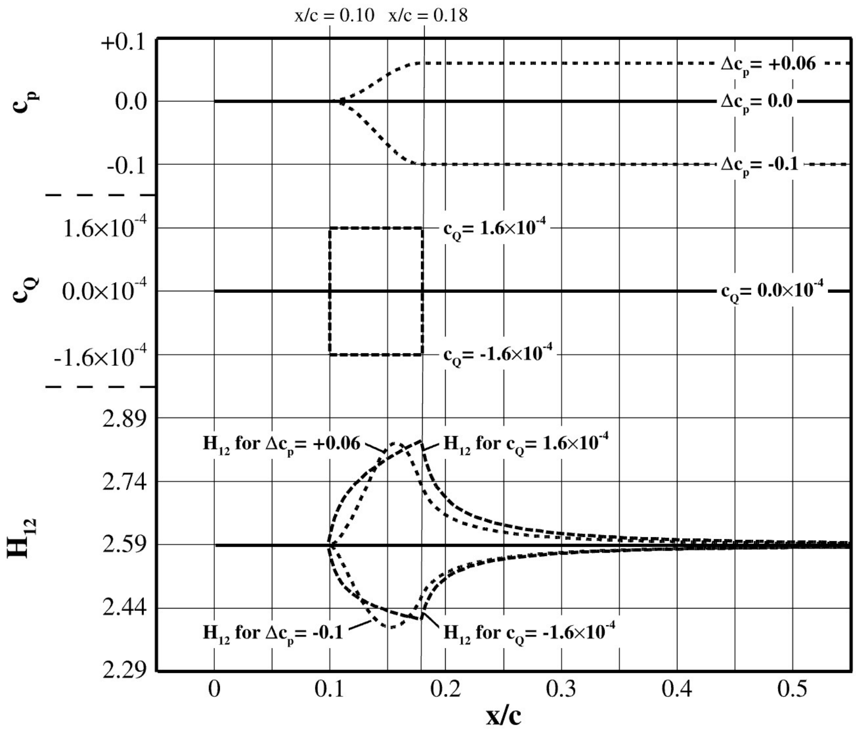

Fig.1: Flow conditions and boundary layer development

Approach

For Falkner/Skan flows the envelope of computed N-factors can be approximated as a straight line if the envelope is considered to be a function of the momentum loss Reynolds number Re_θ [2]. Based on different specific external velocity distributions different Falkner/Skan solutions can be obtained, each characterized by having a constant shape factor H_{12} and a constant pressure gradient parameter Λ_θ.

The AHD criterion [2] has been derived based on these characteristics and the parameters to determine the N-factor envelope are then based on Re_θ and Λ_θ. A general distinction of the original AHD criterion to the simplified version used in the DLR-γ model is that the original criterion utilizes Λ_θ, averaged in streamwise direction, whereas the simplified version just uses a local Λ_θ. To consider also blowing and suction, for the present work an effective pressure gradient parameter $\Lambda_{\theta,eff}$ has been established, that makes use of a certain equivalence of pressure gradient and blowing/suction for Falkner/Skan flows [3].

Results

Based on a Blasius flow at a velocity of u = 40m/s and a unit Reynolds number of $2.6x10^6$ 1/m, non-self-similar solutions have been established by locally imposing cosine-shaped positive and negative pressure gradients (Δc_p = +0.06 and Δc_p = -0.1) and locally introducing constant blowing/suction ($c_Q = v_{wall}/u = +/-1.6x10^{-4}$), see figure 1. Computations for the different flow conditions have been performed using a laminar boundary layer code. The different developments of the laminar boundary layer, expressed by the shape factor H_{12}, are shown in figure 1. LST analyses have then been undertaken to compute reference N-factor envelopes. For the simplified AHD criterion with $\Lambda_{\theta,eff}$ in its original local formulation (i.e. usage of the non-averaged $\Lambda_{\theta,eff}$) the computed N-factor envelopes more or less resemble the LST results for the Blasius flow upstream and also immediately downstream of the region with pressure gradient respectively with suction/blowing (not shown here). Additionally, an exceptionally large deviation to the LST results exists in the region with pressure gradient respectively suction/blowing (not shown here). However, using an averaged $\Lambda_{\theta,eff}$ for the simplified version of the AHD criterion significantly improves the predicted N-factor envelopes and gives results in good agreement with LST for the considered flow conditions (Fig. 2).

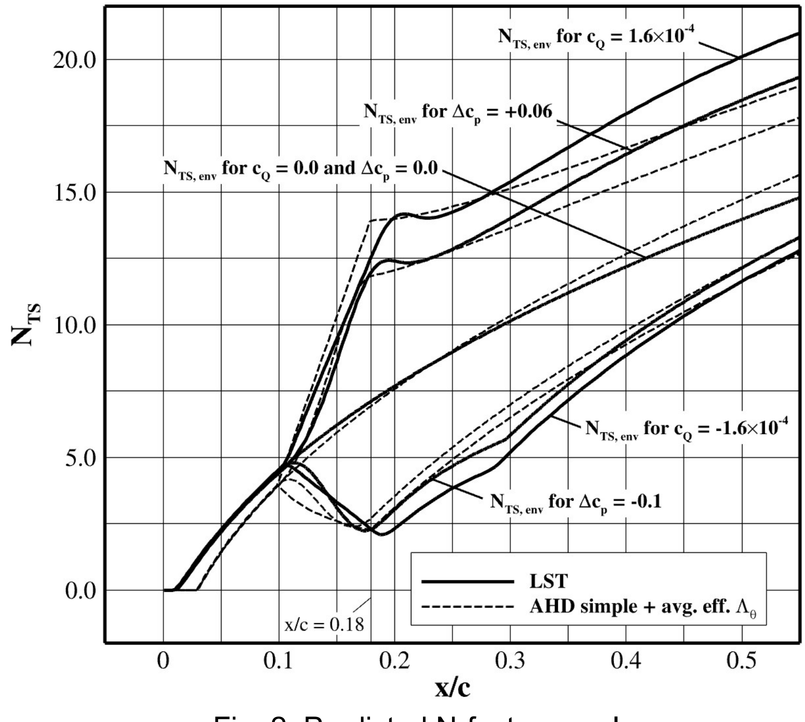

Fig. 2: Predicted N-factor envelopes

Literature

[1] François, D. G., Krumbein, A., Krimmelbein, N., and Grabe, C., “Simplified Stability-Based Transition Transport Modeling for Unstructured Computational Fluid Dynamics,” Journal of Aircraft, 2023, pp. 1–12.

[2] Habiballah, M., Analyse de l’instabilité des couches limites laminaires et prévision de la transition de régime laminaire au régime turbulent, Ph.D. thesis, École nationale supérieure de l’aéronautique et de l’espace, 1981.

[3] Stock, H. W., “On Laminar Boundary Layers with Blowing and Suction,” Zeitschrift für Flugwissenschaften und Weltraumforschung, Vol. 4, No. 2, 1980, pp. 93–100.