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Correlation-based Transition Modeling for Three-dimensional Aerodynamic Configurations

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The prediction of boundary-layer transition is an important element of airfoil and wing design as the correct prediction of transition locations influences the resulting lift and drag forces and, thus, the overall performance. Boundary-layer transition is characterized by boundary-layer quantities like the velocity profiles in the boundary layer along a streamline or the momentum thickness computed from these profiles. In Computational Fluid Dynamics (CFD), many codes are based on the finite-volume discretization of the Reynolds Averaged Navier-Stokes (RANS) equations. Computations with these codes yield no information about streamlines in the flow, which means the characterizing quantities for boundary-layer transition are not directly available. To deal with this, two different approaches were introduced into the DLR TAU code, the unstructured CFD solver of DLR for aircraft analysis and design.

The first transition-prediction approach is streamline-based and applies the e^N-method [1,2]. The second is the γ-$Re_{\theta t}$ model, a correlation-based and completely local transport equation approach [3]. This means, the γ-$Re_{\theta t}$ model can be directly implemented into a finite-volume based CFD-solver. The γ-$Re_{\theta t}$ model was mainly developed for turbo machinery applications where bypass-transition is the most important transition mechanism. In addition, the γ-$Re_{\theta t}$ model is able to capture transition due to TS-instabilities and laminar boundary-layer separation, which makes the model interesting for application to configurations of external aerodynamics like airfoils and wings. The model has been implemented into the TAU code and successfully applied to various two- and three-dimensional test cases [4].

For the application to external aerodynamics, the most severe constraint of the γ-$Re_{\theta t}$ model is that prediction of any three-dimensional transition mechanism is not included. Therefore, the authors extended the model to predict transition due to crossflow transition [5-7] on wing-like geometries. Resulting transition locations of the application of the extended γ-$Re_{\theta t}$-CF model were shown for two infinite swept wing test cases as well as for a three-dimensional clean wing test case. The predicted transition locations were in good agreement with measured transition locations and transition locations that were obtained using the e^N-method.

The work presented here deals with the application of the extended γ-$Re_{\theta t}$-CF model to a general three-dimensional test case which is the 6:1 inclined prolate spheroid and to an industrially relevant wing-body configuration.

The 6:1 inclined prolate spheroid was selected as test case, because it is a fuselage-like three-dimensional and not a wing-like geometry. This becomes important for the application of the

extended γ-$Re_{\theta t}$-CF model to other aerodynamically relevant but non-wing-like geometries like, e.g., fuselages or helicopter bodies. The extended γ-$Re_{\theta t}$-CF model was designed for wing-like geometries, which means, that some modifications have been necessary for its application to the spheroid. These modifications and the results of the application of the γ-$Re_{\theta t}$-CF model are shown, compared to experimental results and discussed in detail.
A wing-body configuration is a typical industrially relevant three-dimensional aerodynamic configuration and the application of both, the γ-$Re_{\theta t}$ model and the extended γ-$Re_{\theta t}$-CF model must yield correct transition locations depending on the dominating transition mechanism. The influence of the Reynolds number for the γ-$Re_{\theta t}$ model is discussed for this test case and a modification of the model approach is presented to account for these Reynolds-number effects. The results for the application of both, the γ-$Re_{\theta t}$ model and the extended γ-$Re_{\theta t}$-CF model, are shown and compared to experimental data.

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