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3D Transition Prediction in Navier-Stokes Computations using Linear Stability Theory

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ABSTRACT

For automatic transition prediction in Navier-Stokes computations for flows around general three-dimensional, complex configurations a transition prediction module has been developed [2,3]. The transition prediction module is attached to the DLR Navier-Stokes solver Tau [5] and uses a stability solver [4] to apply the linear stability theory in form of the e^N-method. A suitable integration path to calculate the N-factors from the amplification rates in three-dimensional flows is the group velocity trajectory [4] that is approximated for the presented method by an edge (or external) streamline.

During the solution process of the solver, the iteration process is interrupted in certain intervals, and the transition prediction is executed (Fig. 1). From the boundary layer edge velocities, projected onto the geomtries surface, a certain number of edge streamlines for the application of the transition criterion is calculated. For all edge streamline of the problem individual transition points are found which form a transition line. This transition line is used to generate new laminar and turbulent regions in the RANS solver. The procedure is repeated, until the transition lines are converged, i.e. the transition points on the transition detection lines stay constant.

To account for the computational effort for the three-dimensional flow calculation around general three-dimensional components and configurations, the transition module is developed to be used in fully parallel Navier-Stokes computations.

The result of a feasibility study displays the calculated edge streamlines and the predicted transition lines for a generic, complex three-dimensional aircraft configuration (Fig. 2). It is demonstrated that the approach using edge streamlines from the Navier-Stokes is suitable for transition prediction for different components (fuselage, wing) in one and the same computation.

First validation investigations have been undertaken in predicting the transition for the fully three-dimensional flow around a 6:1 prolate spheroid. From local wall shear stress measurements [1] the transition locations have been experimentally determined. For this test configuration, transition is characterized to change from pure Tollmien-Schlichting transition to cross flow transition for certain flow conditions. The numerically determined transition lines are in very good agreement with the experiment, exemplarily shown for two distinct cases with transition dominated by TS-instabilities (Fig. 3) and CF-instabilities (Fig. 4).

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FIGURES

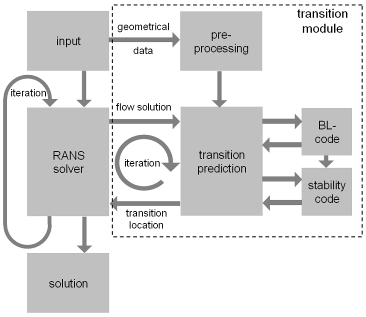

Figure 1: Coupled program system. Navier-Stokes solver with transition module

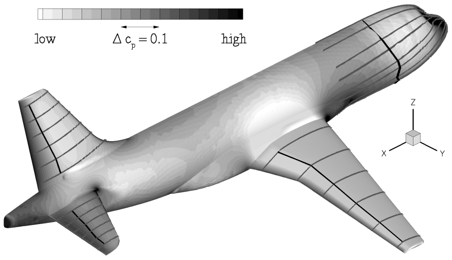

Figure 2: c_p distribution, edge streamlines and predicted transition lines. Transport aircraft. $\alpha = -4.0°$, $Ma = 0.2$, $Re = 2.3 \times 10^6$, $i_H = 4.0°$

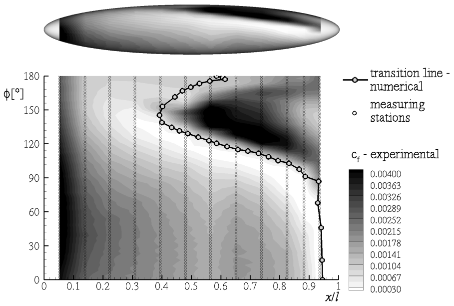

Figure 3: Comparison of computed and measured transition location. 6:1 Prolate spheroid, $\alpha = 10.0°$, $Re = 1.5 \times 10^6$, $Ma = 0.03$

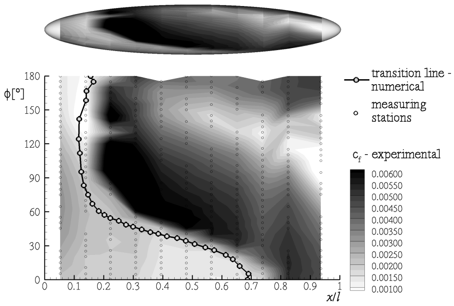

Figure 4: Comparison of computed and measured transition location. 6:1 Prolate spheroid, $\alpha = 15.0°$, $Re = 6.5 \times 10^6$, $Ma = 0.13$