Navier-Stokes High-Lift Airfoil Computations with Automatic Transition Prediction Using the DLR TAU Code

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Summary

A Reynolds-averaged Navier-Stokes solver, a laminar boundary-layer code and different transition prediction methods for the prediction of Tollmien-Schlichting and cross flow instabilities were coupled for the automatic prediction of laminar-turbulent transition on general 3-dimensional aircraft configurations during the ongoing flow computation. The procedure is applied to a two-dimensional three-element high-lift airfoil configuration which is characterized by the existence of laminar separation bubbles using different operation modes of the procedure.

1 Introduction

The modelling of laminar-turbulent transition in Reynolds-averaged Navier-Stokes (RANS) solvers is a crucial issue when high quality simulation results for aircraft shall be produced. Especially the simulation of flows around high-lift systems of aircraft may result in significant errors when the transition points are of insufficient accuracy or are not taken into account at all. High-lift systems very often involve multi-component wings (e.g. slat, main wing, and flaps) and may have very high levels of total circulation. Because all components of the high-lift system are in close interaction with one another the total circulation and the complete flow field is affected by the transition line on any of the components.

Although the overall lift value may be predicted with satisfactory accuracy slight deviations between the real and the computed pressures can lead to large errors in the computed overall drag value. It could be shown that the overall pressure drag of a high-lift configuration, which dominates the drag value of the configuration as a whole as well as the drag of every single element, is composed of a balance of very large positive and negative contributions, such as the suction forces at the noses or the resistance forces in the coves and the trailing edge regions. The contribution of one single element may be one order of magnitude larger than the resulting overall drag of the complete configuration. Thus, a relative error of 5% of the computed drag on the slat upper side may result in a change of 50% for the overall drag value [1].
Another aspect of taking into account transition is that in many cases the high potential of higher order turbulence models can be made use of only when the areas of laminar-turbulent transition are known and deployed in the computational procedures with sufficiently high accuracy. Thus, in modern computational fluid dynamics (CFD) tools a robust transition modelling must be established together with reliable and effective turbulence models. Only if the transition locations are taken into account with sufficient accuracy all physical characteristics of the flow field can be reproduced in such a way that the demanding quality requirements are satisfied.

For the design process of wings, there exists the demand for a RANS-based CFD tool that is able to handle flows automatically and autonomously with laminar-turbulent transition. Existing transition prediction methods vary from empirical transition criteria via the local, linear stability equations based on small disturbance theory or non-local, linear and non-local, non-linear stability methods using the parabolized stability equations over large eddy simulations to direct numerical simulations of the Navier-Stokes equations. Empirical transition criteria and the eN-method [2],[3] based on local, linear stability theory and the parallel flow assumption represent state-of-the-art methods for the prediction of transition onset in many industrial applications. Although they do not account for a number of fundamental aspects in the transition process eN-methods are used in aircraft industry most frequently for design purposes covering transition due to Tollmien-Schlichting (TS) and cross flow (CF) instabilities. Because there are no other practical methods presently available for industrial applications eN-methods together with the two-N-factor method and empirical criteria for transition mechanisms which are not covered by the eN approach (e.g. bypass and attachment line transition) are going to be used further on for the design of aircraft wings and wing systems even for a future laminar wing of transport type aircraft.

Recently the unstructured/hybrid RANS solver TAU [4] of the Deutsches Zentrum für Luft- und Raumfahrt, German Aerospace Center (DLR) has been provided with a general transition prediction functionality which can be applied to general 3-dimensional aircraft configurations. The developments and first technical validation steps have been carried out at the Institute of Fluid Mechanics (ISM) of the Technical University of Braunschweig (TU-BS), [5],[6]. The TAU code is used together with the laminar boundary-layer method in [7] and the local linear stability code in [8]. These two codes and an infrastructure part of the TAU code are components of a so called ‘transition prediction module’ that is coupled to the RANS solver and that interacts with the RANS solver during the computation in a very similar way as it is documented in [9].

For a long time it was necessary to use transition database methods in order to apply the eN-method for transition prediction in a fully automatic way so that the transition location iteration could be executed without intervention (automatic) by the user of the RANS code and without a priori knowledge of the transition characteristics of the specific flow problem (autonomous). Now the fully automated local, linear stability solver in [8] is available using a frequency estimator for the detection of the relevant regions of amplified disturbances for TS instabilities and a wave length estimator for CF instabilities.

In this paper the coupling structure between the TAU code and the transition prediction module is outlined and the transition prediction strategy is described together with the different operation modes of the transition prediction module which can be selected by the user. The main objective is to demonstrate the different