Transition Prediction and Modeling in External Flows Using RANS-based CFD Codes

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Besides wind tunnel testing and flight tests, CFD simulation based on RANS solvers has become a standard design approach in industry for the design of aircraft. For the design point of aircraft a positive assessment of the numerical results was achieved for many validation and application tests and the prediction capabilities of the software tools could be positively evaluated. As a consequence, high confidence in numerical simulations could be achieved in industry and will eventually allow more simulation and less physical testing. However, and despite of the progress that has been made in the development and application of RANS-based CFD codes, there is still the need for improvement, for example, with regard to the capability of a proper capturing of all relevant physical phenomena. This can only be achieved if capable and accurate physical models are available in the codes. On the one hand, the combined use of turbulence and transition models is indispensable for flows exhibiting separation, because otherwise the close interaction between the laminar-turbulent transition and its impact on flow separation is not reproduced. On the other hand, it is not possible to fully exploit the high potential of todays advanced turbulence models if transition is not taken into account. Thus, in modern high-fidelity CFD codes a robust transition prediction and modeling must be established together with reliable and effective turbulence models.

At DLR, the RANS codes for external flows, [1]-[2], have been provided with transition prediction and modeling functionalities which can be applied to three-dimensional aircraft configurations. Two different basic approaches are currently at hand: the streamline based and the transport equation approach.

The streamline based approach uses information from the current flow solution along defined integration paths in order to compute the laminar boundary layers, either using a laminar boundary-layer method or by direct extraction from the RANS solution. A fully automated, local linear stability code analyses the laminar boundary layers and detects transition due to Tollmien-Schlichting or cross flow instabilities. The stability code, which applies the e^N-method, [3]-[4], and the two N factor approach, [5], for the determination of the transition points, uses a frequency estimator for the detection of the relevant regions of amplified disturbances for Tollmien-Schlichting instabilities and a wave length estimator for cross flow instabilities. Also separation induced transition is covered. Alternatively, different empirical transition criteria for streamwise and crossflow transition are available and, in addition, criteria for attachment-line and by-pass transition. Using this approach transition is predicted either along spanwise line-in-flight cuts through a wing or along the boundary-layer edge streamline. The latter is the only possible way in the case of fully three-dimensional flow about fuselages or nacelles. The streamline approach has been validated by numerous test cases and is the standard transition prediction approach currently used in production simulation. Here, it is usually applied in parallel mode on large compute cluster systems, [6].

The transport equation approach, [7], is relatively new and based exclusively on local variables so that it is inherently parallelizable and, thus, very well suited for unstructured CFD codes and large applications which can only be tackled by massively parallel computations. The boundary-layer quantities are resolved by the RANS computational grid and approximated by the modeling approach reflected by two transport equations. The prediction of the locations of transition onset is based on empirical criteria which can and must be evaluated locally. While the original model formulation was restricted to the prediction of streamwise transition mechanisms the model is currently extended in order to predict crossflow transition, [8].

The two different approaches and methods will be presented and explained, their applicability ranges are discussed and numerical results are compared to a number of validation test cases demonstrating the prediction accuracy of the different methods. The results from the application of the methods to large and partially very complex, industrial configurations are presented and discussed. Eventually, an outlook is given to the challenges placed by complex aircraft configurations and to the way forward to tackle the still open issues.

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