Mitteilung

Fachgruppe: Turbulenz und Transition

Validation of CFD-based transition transport models to predict laminar-turbulent transition of swept transport aircraft wings

S. Helm[1,2], D. G. François[2], A. Krumbein[2]
[1] Cluster of Excellence SE²A – Sustainable and Energy-Efficient Aviation, TU Braunschweig, Deutschland
[2] Deutsches Zentrum für Luft- und Raumfahrt (DLR), Institut für Aerodynamik und Strömungstechnik, C²A²S²E,
Bunsenstraße 10, 37073 Göttingen, sebastian.helm@dlr.de

Background

Reducing the viscous drag of future commercial aircraft by means of laminar flow plays a key role in the transformation to climate-neutral aviation. To mitigate financial risks and to accelerate the design process of laminar aircraft, increasing use is being made of numerical methods, such as CFD. The applicability of CFD methods for the design process depends on a high degree of automation of the individual components and on the accuracy and reliability of the simulation results. In this respect, the design of laminar aircraft is particularly demanding for the CFD process.

Streamline-based methods, based on linear local stability theory (LST) and the e^N method [1] or, more rarely, based on the non-local Parabolized Stability Equations (PSE) [2] offer a high degree of maturity and are therefore considered state-of-the-art. Although, these models have shown to be accurate and reliable, they require expert knowledge and automation is limited.

At the same time, a new class of models for predicting laminar-turbulent transition is gaining attention. Transport equation transition models are based on information available locally (at the CFD node level), making them particularly well suited for automation and parallelization of 3D simulations with modern unstructured CFD codes. Despite the advantages these correlation-based transition models, the accuracy, robustness, and reliability of the models need to be ensured and demonstrated more extensively.

Objective

This work contributed to the continuous development and validation of transition transport models, in particular the DLR γ-CAS model. The presentation will demonstrate the capabilities of the model to predict three-dimensional and transonic cases at high Reynolds number, compared to wind tunnel data. Furthermore, the inclusion of the effect of surface roughness into the model is discussed.

Approach

The DLR TAU-Code is used for RANS simulations. On the one hand, transition prediction is based on the linear stability code LILO and the e^N method [1], as a reference. On the other hand, the DLR γ-CAS model [3] is used. The latter consists of a transport equation for the intermittency-like variable γ, an auxiliary field variable taking values between 0 (laminar) and 1 (turbulent) and acting as a switch for the turbulence model. The model has similarities with the γ-$Re_{\Theta t}$ model and includes advancements for the application of transport aircraft, e.g. the improved accounting of pressure gradient and compressibility on transition. This is achieved by means of a simplified version of the AHD transition criterion. In addition, the model offers extensions to account for crossflow transition [4], one based-on the helicity criterion and the other using the C1 criterion.

The NLF-ECOWING-FSW [5] and the CRM-NLF [6] are swept wing configurations designed for natural laminar flow (NLF). The former exploits the advantages of a forward swept wing to alleviate crossflow, whereas the latter is based on the CATNLF (Crossflow Attenuated NLF) concept, restricting flow acceleration to the vicinity of the leading edge. Both test cases are considered for validation in this work.

Results

Near the design condition of the NLF-ECOWING-FSW model both approaches for transition prediction yield good agreement with the experimental transition detection by means of temperature sensitive paint (TSP). A validation including the more challenging off-design conditions will be presented at the workshop. The baseline version of the DLR γ-CAS model was successfully applied to the CRM-NLF configuration before [7]. The present work extends the validation of the crossflow extension to this test case.

The effect of compressibility on Tollmien-Schlichting transition as well as the effect of surface roughness of crossflow transition is investigated based on both test cases.

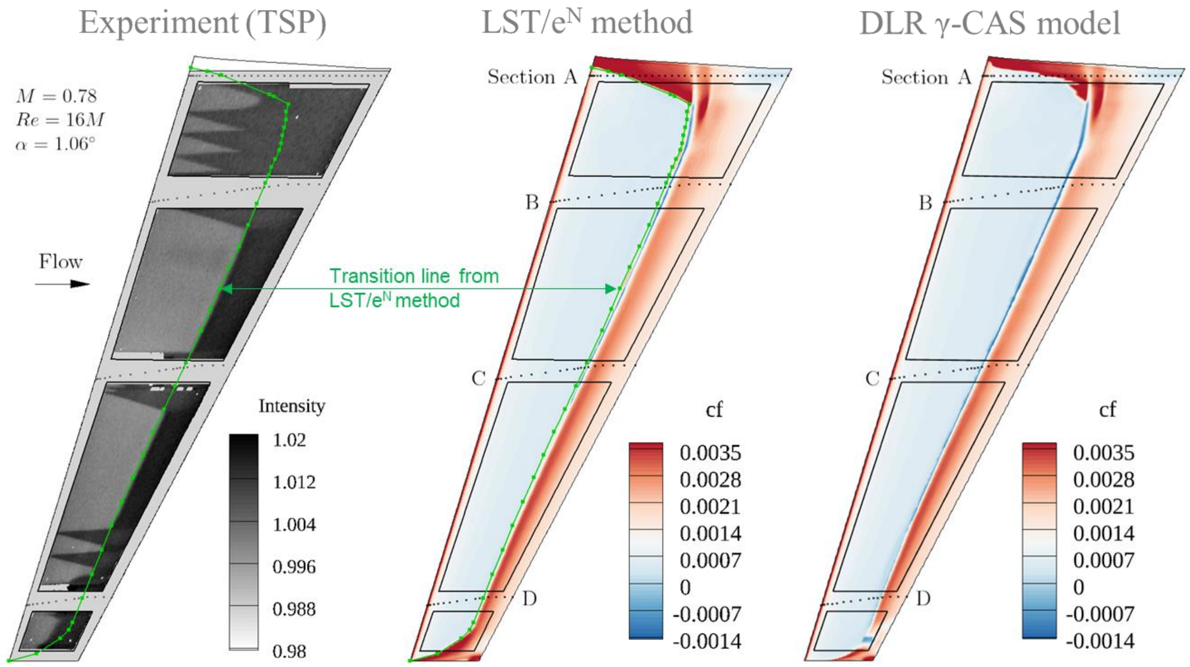

Fig. 1 : Experimental and numerical surface characteristics of the NLF-ECOWING-FSW model near the design condition. Laminar flow manifests itself as lighter area of low heat transfer in the TSP image (left) and light blue area of low skin friction c_f in the numerical solution (middle, right).

Literature

[1] Krumbein, A., Krimmelbein, N., Schrauf, G.: Automatic transition prediction in hybrid flow solver, part 1: Methodology and sensitivities. Journal of Aircraft, 46, pp. 1176-1190 (2009)

[2] Hein, S., “Nonlinear Nonlocal Transition Analysis - Code Development and Results” Recent Results in Laminar-Turbulent Transition, p. 123–134 (2004)

[3] François, D. G., Krumbein, A., Krimmelbein, N., Grabe, C.: Simplified stability-based transition transport modeling for unstructured computational fluid dynamics. J. of Aircraft (2023)

[4] François, D. G., Krumbein, A., Krimmelbein, N., „Crossflow Extension of a Simplified Transition Transport Model for Three-Dimensional Aerodynamic Configurations”, AIAA AVIATION Forum (2022)

[5] Seitz, A., Hübner, A., Risse, K.: The DLR TuLam project: design of a short and medium range transport aircraft with forward swept NLF wing. CEAS Aeronautical Journal (2019)

[6] Lynde, M. N., Campbell, R. L.: Computational Design and Analysis of a Transonic Natural Laminar Flow Wing for a Wind Tunnel Model. 35th AIAA Applied Aerodynamics Conference. (2017)

[7] Krumbein, A., François, D. G., Krimmelbein, N.: Transport-based Transition Prediction for the Common Research Model Natural Laminar Flow Configuration. Journal of Aircraft, Vol. 59, No. 6, p. 1562-1573 (2022)