Mitteilung

Projektgruppe/Fachkreis: Turbulenz und Transition

Numerical analysis of boundary-layer transition on a high-aspect ratio backward-swept laminar wing considering different mass cases

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Motivation:
In the interest of sustainable and ecologically friendly aviation, the design process of future aircraft generations must incorporate a contribution to reduce global greenhouse gas emissions. One way of reducing the fuel consumption of aircraft is to increase their aerodynamic efficiency by modifying the shape of the wing. Using a laminar wing design, the transition location on the wing can be pushed further downstream increasing the amount of laminar boundary flow and therefore minimizing frictional drag. In addition, the use of a particular leading edge shape according to a crossflow attenuated laminar flow (CATNLF) design strategy [1-3] decreases the risk of crossflow instabilities even for large leading edge sweep angles compared to other design approaches.
The design robustness might be a major challenge in the structural optimization process. According to CS-25 regulations, many different load cases have to be considered for the structural sizing within the preliminary design process of the aircraft. Furthermore, different mass cases must be taken into account based on varying fuel mass and different payload during cruise flight, which eventually have a significant influence on the elastic behavior of the wing. At the moment, it is not known how robust this kind of laminar wing design is in specific flight scenarios with varying wing deflection under loading. To ensure aerodynamic performance of the laminar wing for each individual mass case, the impact of the wing deformation on the transition characteristics must be considered.

Objective:
This work assesses an aircraft wing with natural laminar flow design in consideration of different mass scenarios using transitional CFD simulations. Each mass case is defined by a distinct amount of payload and fuel mass, thus modifying the centre of gravity and the deformation of the wing structure. It should be identified to what extent the transition location of the boundary layer flow on the wings surface is preserved in relation to each individual mass case.

Methods:
The LuFo-VI-2 project ULTIMATE (**ul**tra high efficien**t** w**i**ng and **m**ove**a**bles for nex**t** g**e**neration aircraft) investigates new concepts and strategies for improving the aerodynamic performance of future generation aircraft. Based on a derivative of the DLR-F25 configuration, a short/medium-range aircraft developed within the LuFo-VI-2 project VirEnfREI [4], an aircraft model is designed with a high-aspect ratio and backward-swept wing. The aerodynamic design of the flight shape follows a CATNLF-design for the leading edge [5]. The final design shape of the wing is used as an input for a structural optimization process as part of the DLR in-house parametric model generator cpacs-MONA [6], in which different gust and maneuver load cases are considered together with four different mass cases regarding payload and fuel mass. A hybrid CFD-mesh is created for the flight shape of the wing. In order to consider different mass cases, the CFD-mesh of the flight shape is deformed according to the particular wing deformation obtained for a specific case using radial basis functions. RANS-simulations are performed using the TAU transition module with the e^N-method for transition prediction. Here, a combination of the boundary layer solver COCO and the linear stability solver LILO is used [7].

Results:

The maximum-take-off-weight (MTOW) mass case has the largest deformation of all the mass cases considered with a maximum structural deflection of roughly 6% with respect to the semi span of the wing. It is defined by 100% payload and 49% fuel. Figure 1 shows the deformation of the wing structure for this mass case compared to the flight shape. The influence on the laminar-turbulent transition is illustrated in Figure 2 which shows a contour plot of the distribution of the wall friction coefficient c_f on the upper surface of the wing at transonic flow conditions. Due to intellectual property rights, the surface data are projected onto a rectangular planform. Neglecting the region close to the fuselage at the wing root as well as at the wing tip, it can be seen that laminar flow (low c_f values) is present almost everywhere on the upper side of the wing for the flight shape. In the case of the MTOW configuration, almost no change of the transition location is detectable in spite the large deflection at the wing tip. In this region, laminar flow is even promoted for the MTOW configuration. It can be stated that the design of the presented laminar wing provides a robust behavior against wing deformation for the particular conditions considered.

In the full paper, further mass cases with different elastic structural deformations will be considered and the impact on the performance will be analyzed.

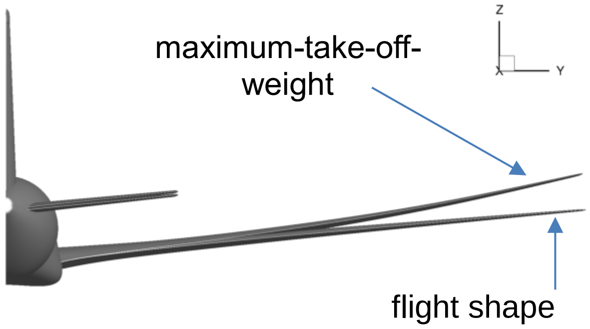

Figure 1: Deformed wing shape of mass case MTOW compared to the flight shape

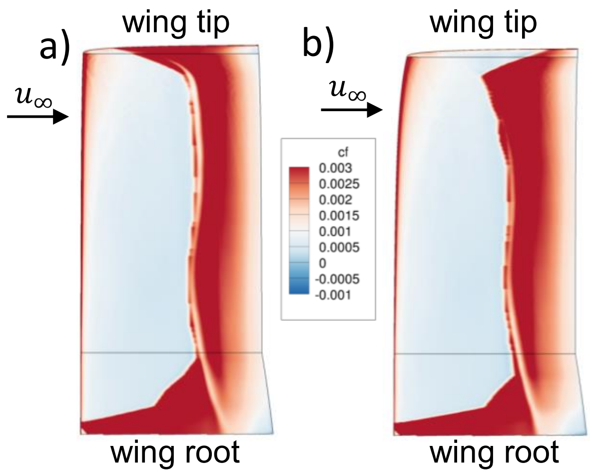

Figure 2: Distribution of the wall friction coefficient c_f on the upper surface of the wing at transonic flow conditions (rectangular wing projection): a) flight shape b) mass case MTOW

This work is supported by the Federal Ministry for Economic Affairs and Climate Action (BMWK) on the basis of a decision by the German Bundestag.

References

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