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QUANTIFICATION OF NON-LINEAR AERODYNAMIC EFFECTS ON THE LIMITING GUST LOAD CASES

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1 ABSTRACT

Modern transport aircraft configurations tend to higher aspect ratios to minimize the induced drag. An increase of the aspect ratio is achieved either by a higher wingspan, a smaller wing area or a combination of both. These two parameters also have an influence on the quasi steady and unsteady loads of the aircraft. If the lift distribution is the same, the increasing span of the wing results in a higher wing root bending moment. This means, the overall structural mass of the wing also increases. The reduced wing area plays a decisive role, too. It leads to a higher aerodynamic loading of the airfoils at the outer wing, with high local lift coefficient in horizontal trimmed flight. This lead to higher potential of aerodynamic non-linearities. Different types of aerodynamic non-linear effects, like flow separation and changing shock configuration were seen in the past [1–5]. Typical state-of-the-art methods, like DLM or linearized frequency domain (LFD) Computational fluid dynamics (CFD) are not capable to compute these non-linear effects. The influence of these non-linearities on the limiting loads and the structural design is not known yet. In this paper, CFD will be used in time domain to compute the non-linear unsteady gust loads for the DLR-F25, a high aspect ratio wing configuration. These loads will be compared to a linear reference to show the difference in the limiting load cases and classify different regions in the flight envelope. To get a full loads envelope, the maneuver loads such as pull-up, push-down and accelerated rolling maneuvers are also computed. The results show that non-linear loads exceed the limits of the linear ones. Compared to the linear reference, the number of limiting load cases and the critical region inside the flight envelope is narrowed down to a smaller altitude range for the non-linear simulations.

1.1 Preliminary results

In order to find the most critical gust, a set of approximately 600 different discrete gusts were simulated for the maximum take-off weight mass case according to the CS-25 [6]. No gust load alleviation is used. The major part of the gusts were simulated at the design cruising speed (VC) for altitudes between 0 m and 12000 m. These gusts were obtained to be the most critical, because of the combination of high dynamic pressure, Mach number and gust velocity. In addition to the gusts, different quasi steady maneuver, such as pull-up, push-down and accelerated rolling maneuvers, were simulated. The overall loads are plotted in figure 1, with the non-linear gust loads in blue and the linear ones in green. The maneuver loads are plotted in red. Two major findings can be identified. At first, steady load cases results in much lower maneuver loads compared to the gust loads. The fuselage shows a significant influence on the overall lift, with

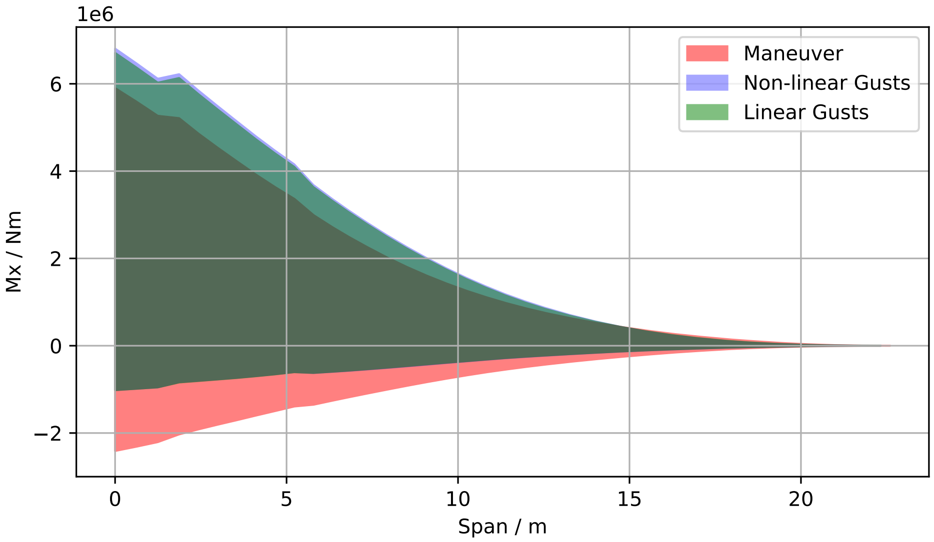

Figure 1: Maximum wing root bending moment along the wing for maneuvers, non-linear and linear gusts

a share of up to 17 % of the overall lifting forces for the pull-up maneuvers. This leads to this offset between the steady maneuver loads and the dynamic gust loads. Second, the non-linear loads exceed the maximum of the linear loads. For better comparison, the maximum wing root bending moments at VC versus the altitude are plotted in figure 2. The accompanying Mach number is shown as a red dash-dotted line, the linear loads are shown as dashed lines and the non-linear ones as solid lines. The colors of these lines are mapped to the different gust gradients. The loads shown in this plot can be classified into three major regions. Inside the first region for 0m to 4000m, the loads are linear, and no transonic effects can be spotted in the flow flied. The second spans between 4000m and 6000m. In this region the Mach number for the trimmed conditions is still below the critical Mach number. Due to the additional gust velocity

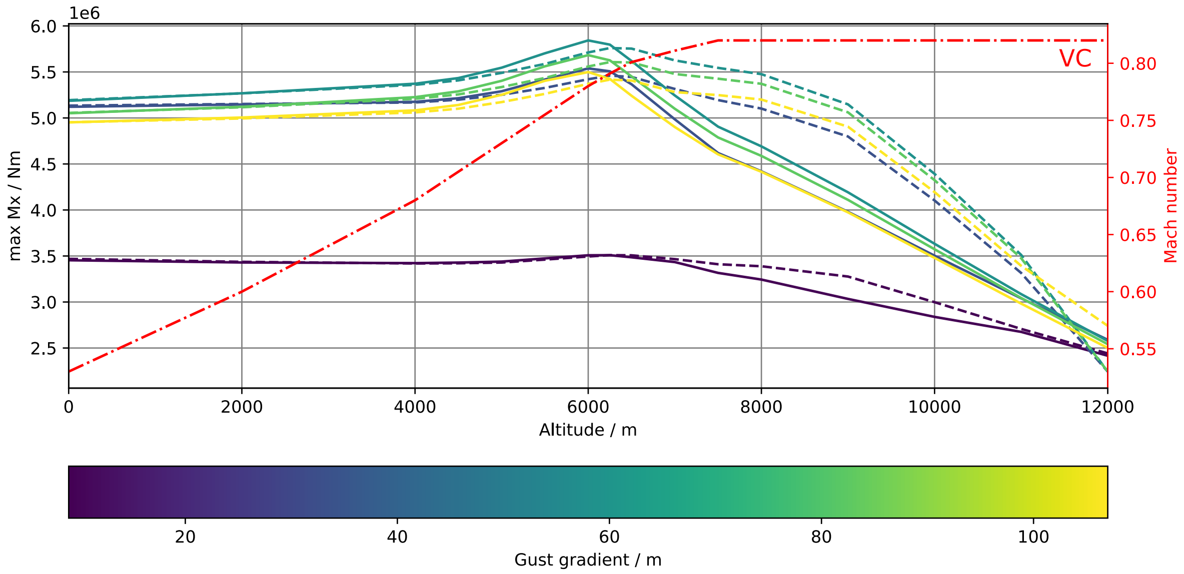

Figure 2: Maximum bending moment for different gusts and altitudes at VC for the linear (dashed lines) and nonlinear (solid lines) simulations

the local velocity exceeds the speed of sound and a shock is formed. This emerging shock leads to additional lift, which results in higher loads for a non-linear computation. The third region, above 6500m, the unsteady flow is dominated by shock induced flow separation. This leads to a lower maximum lift and a reduced bending moment. As a result of the non-linearities, a sharp peak in the loads can be seen at 6000m.

1.2 Outlook to the full paper

In the full paper, the presented preliminary results will be discussed in more detail. For the steady maneuver, the MLA settings will be analyzed. For the dynamic gusts, the unsteady transonic aerodynamics will be investigated for the three different regions. In addition to the analyses of the aerodynamics and the inertial forces, all forces of the linear and non-linear load set will be applied to the full finite element model of the wing. Finally, the limiting load cases and their resulting strain will be evaluated on the level of the upper and lower skin of the wing.

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DISCLAIMER

CLEAN AVIATION

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