Mitteilung

Fachgruppe: Hochagile Konfigurationen

Experimental and numerical investigation of the vortical flow
on the transonic missile LK6E2

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Introduction

A key requirement for modern subsonic, transonic and supersonic interceptor missiles is high maneuverability. This requirement is associated with high angle of attack maneuvers, resulting in large flow separations and vortical flow. The vortices that form can have a crucial influence on the aerodynamic characteristics of the missile and lead to non-linear aerodynamic behaviour. Nevertheless, an exact numerical prediction of the flight performance in this non-linear range is a desired goal for future missile design. But it is precisely in this area that RANS methods sometimes still do not show sufficient accuracy. This study addresses a transonic test case for which standard RANS simulations do not correctly predict a vortex-induced break in the rolling moment coefficient with increasing total incidence σ. Figure 1 shows the corresponding rolling moment development for a Mach number of M = 0.85 and a fixed roll angle of λ = 45°. The break at σ > 16.0° is the result of a non-simultaneous transformation of leading edge vortices that form on two wings of the four wings of the missile. The geometry studied is the LK6E2 transonic missile (Fig. 1, left side). LK6E2 is the result of an internal design study of the DLR for high maneuverable transonic missiles. The LK6E2 and the associated test case was already investigated in the NATO STO Task Group AVT-316 [1], but the comparisons between CFD and experiment was based solely on aerodynamic coefficients. This study also includes data from pressure sensitive paint measurements [2] (PSP) and Oil film interferometry measurements [3] (OFI) which is compared with the results of numerical simulations.

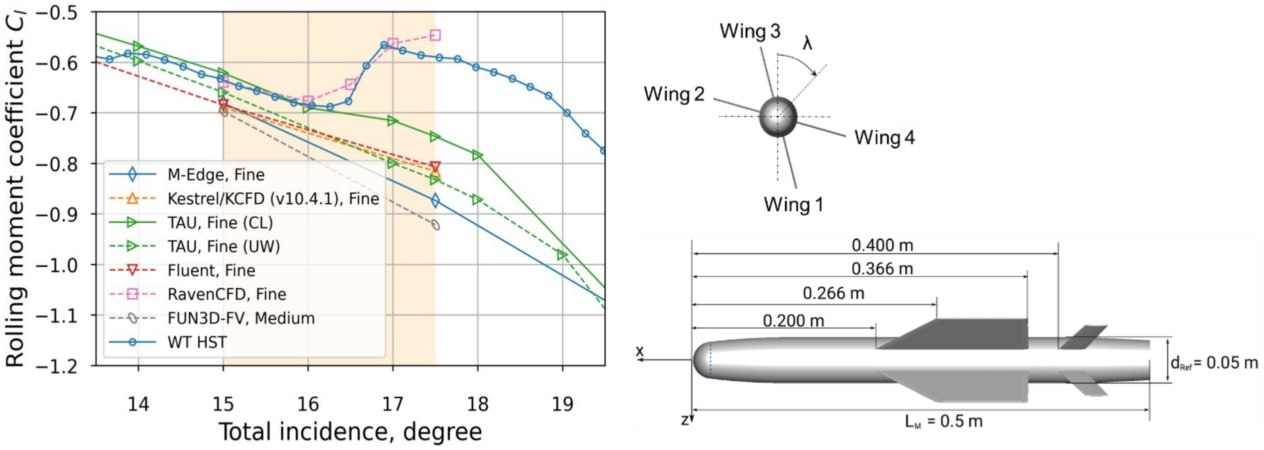

Figure 1 Comparison of numerical predicted data and wind tunnel data (WT HST) for the test case LK6E2 for a Mach number of M = 0.85 and a Reynolds number of 500,000 *Fehler! Verweisquelle konnte nicht gefunden werden.* **(left plot). Outer mould line of the LK6E2 (right plot).**

Tools and Method

The numerical simulations have been carried out with DLR's finite volume flow solver TAU. TAU solves the Reynolds-averaged Navier-Stokes equation on hybrid grids. In this study the standard Menter SST turbulence model was used to closure the system of equation. All the simulations have been conducted with the finest grid of the family of grids as defined in [1].

The optical flow measurements have been carried out in the Transonic Wind Tunnel Göttingen (DNW-TWG) for a Mach number of 0.85 and a roll angle of 45°.

Results

Figure 2 shows the visualization of the wall shear stress lines on wing 2 and wing 4 on the right-hand side and the corresponding pressure distribution on the left-hand side. Both results clearly indicate that the flow separation and the development of the vortical flow over the wings are different between both wings shown. On wing 2, the OFI data reveals that a leading edge vortex forms from the shear layer separating at the leading edge. Downstream of the reattachment line of this vortex, the flow continues in longitudinal direction of the wing. A second flow separation at the trailing edge is not observable. The aforementioned leading edge vortex is clearly reflected in the pressure distribution on the left side of Fig. 2. In contrast, the pressure distribution on wing 4 shows a kind of pressure plateau in the first half of the wing. A footprint of a leading edge vortex is not identifiable. Compared to wing 2, the pattern of the wall shear lines on wing 4 is also completely different. There is no sign of a vortex at the leading edge. Instead a kind of recirculation can be observed, which takes place in the plane of the wing. Combining the results of the two measurements methods provides clear evidence that the leading edge vortex on wing 4 disappears for $\sigma > 15.0°$. This agrees with the result of a RANS simulation with RavenCFD which is able to predict the break in the rolling moment [1].

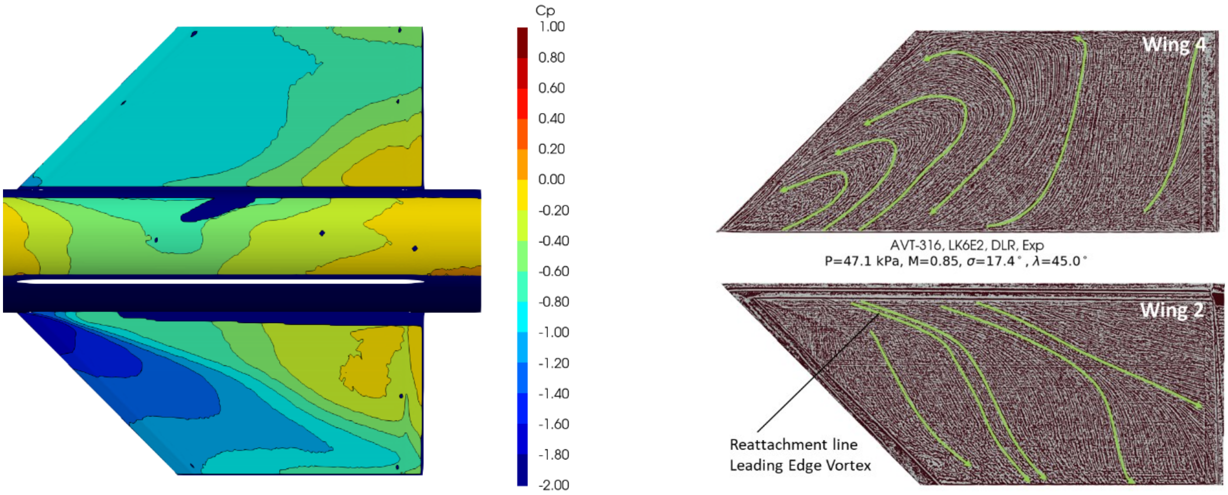

Figure 2 Pressure distribution (PSP) and visualization of the wall shear stress lines (OFI) for M = 0.85 and σ = 17.5°.

Outlook

In the final paper the development of the flow with increasing σ will be analyzed for a total incidence range of $14.0° < \sigma < 20.0°$ based on the data of the optical flow measurements. This data will be compared with data of numerical simulations and the differences that exist are highlighted. It is shown that in the range of $15.0° < \sigma < 20.0°$ the transformation of the leading edge vortex on wing 4 is not always correctly predicted by standard RANS simulations.

[1] NATO STO, "Vortex Interaction Effects Relevant to Military Air Vehicle Performance", STO-TR-AVT-316, 2024.
[2] Henne, U., Yorita, D., and Klein, C., “Application of Lifetime-Based Pressure-Sensitive Paint for Transonic Tests on a Generic Delta Wing Planform,” New Results in Numerical and Experimental Fluid Mechanics XII: Contributions to the 21st STAB/DGLR Symposium, Darmstadt, Germany, 2018, Springer, 2020, pp. 287–296
[3] Lunte, J., Schnepf, C., and Schülein, E., “Optical wall shear stress measurements on the leeward side of a delta wing,” 2018 Aerodynamic Measurement Technology and Ground Testing Conference, 2018, p. 3806.