Simulations of the vortex development for a steady and unsteady Lambda –wing wind tunnel model

Stefan Wiggen, Guido Voß
Deutsches Zentrum fuer Luft- und Raumfahrt e.V.
Bunsenstrasse 10
37073 Göttingen
stefan.wiggen@dlr.de, guido.voss@dlr.de

Abstract

For wings with high sweep angles, vortex development is a major aerodynamic phenomenon. Depending mainly on the sweep angle, the airfoil nose radius and the Mach number, it usually occurs at high angles of attack (AOA). This is connected with high loads. Therefore, dynamic wind tunnel experiments exist mainly for very low Mach and Reynolds numbers.

In the DLR (German Aerospace Center) project FaUSST (Advanced aerodynamic UCAV stability and control technologies) a generic lambda wing configuration of a UCAV (Unmanned combat aerial vehicle) is used to study stability concerns that are related to those kind of aircrafts. The model IWEX (Instationäres Wirbel Experiment – Unsteady Vortex Experiment) is designed for experiments in a transonic wind tunnel performing angle of attack oscillations with up to 25Hz at a mean AOA of up to 20° and Mach 0.7. A half wing model is attached to a hydraulic actuation system outside of the test section. The opening in the wall is sealed by a turnable disk. Hereby a nearly closed wind tunnel section and a continuous intersection of the wall and the model is achieved to facilitate the simulation and reduce the influence of possible gaps that otherwise exist.

In the experiment, the behavior of the vortex development at a round leading edge forming a thickness vortex is tested (Figure 1). During the design process, static and coupled dynamic simulations with the Navier - Stokes solver TAU and a modal representation of a Finite Element model were performed which included the wind tunnel walls. Their results will be presented.
The static behavior is mainly influenced by the heavily changing load and moment distributions when the main vortex moves inboard and detaches from the surface (Figure 2, Figure 3).

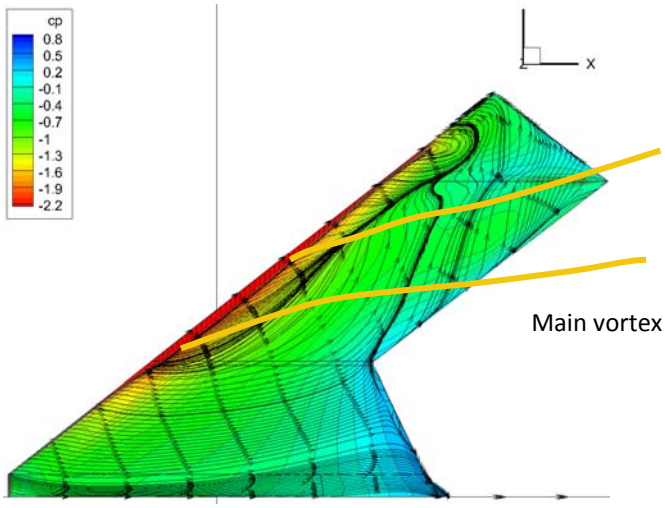

Figure 1: Pressure distirbution with beginning vortex development at AOA = 15deg

At the outer sections, the lift is already decreasing whereas the lift slope at the inner part is still positive. This results in a more triangular lift distribution. The moment distribution is also affected by the vortex running from the leading edge of the inner part over the trailing edge of the outer part. Thereby the moment (Figure 3) distribution changes more heavily. Because next to the loss of lift at the leading edge, that effect it is augmented by the increased lift at the trailing edge.

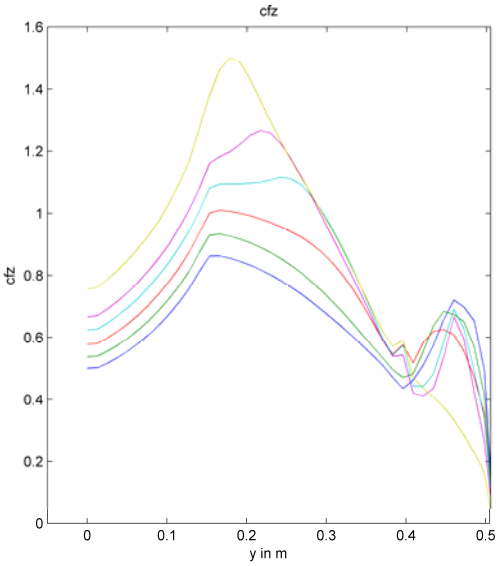

Figure 2: Lift force distribution AOA [14:20] deg, Mach 0.5, Re – Number 2.65 Mil.

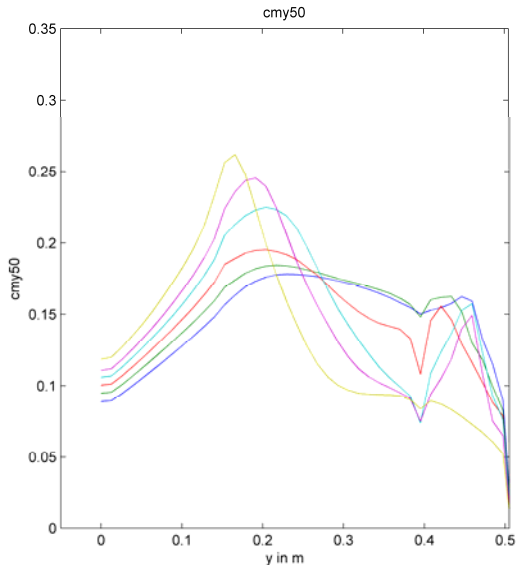

Figure 3: Moment force distribution AOA [14:20] deg, Mach 0.5, Re - Number 2.65 Mil.

Furthermore, beginning transonic effects change the vortex development. Shocks let the vortex detach from the surface and change their direction due to the changed velocity normal to the shock front. Furthermore, the vortex-shock interaction leads to an earlier development of the vortex character peculiar for this configuration than for the subsonic cases.

The results of the simulations with pitch oscillations of the model showed that the influence of the high sweep angle and hereby the strong plunge - like movement of the outer part of the wing is much stronger than the change of the angle of attack. The same results can be seen when especially the bending mode is excited. Additionally, the decreasing lift slope of the “quasi-steady” load reduces the effect of the change of the angle of attack. The coupled simulations showed a damping of the structural vibration after an initial excitation. Nevertheless, a stronger pressure change than for the static cases could be seen.
Furthermore, a phase shift exists between the main vortex described above and the tip vortex developing at the outer triangle of the wing (Figure 4) that is also fed by a narrow co-rotating vortex along the leading edge. In the simulations this system of vortices seemed to be stable and was not changing significantly after the second or third simulated period of motion.

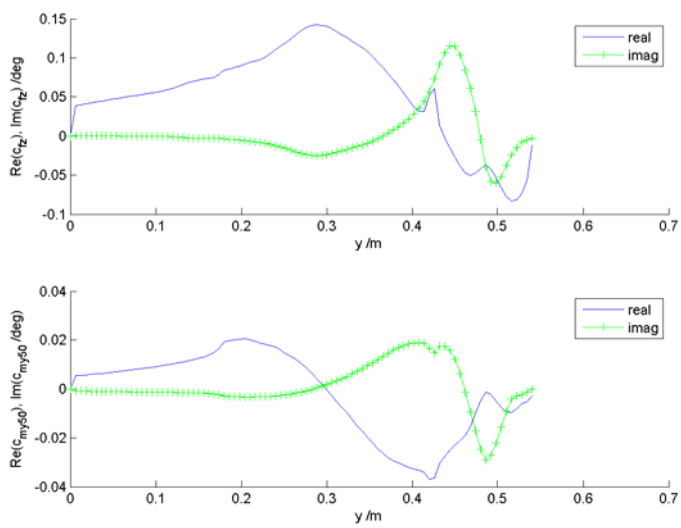

Figure 4: 1st harmonic frequency response, 20Hz, of lift and moment, AOA 14.5deg±1deg, Mach 0.5