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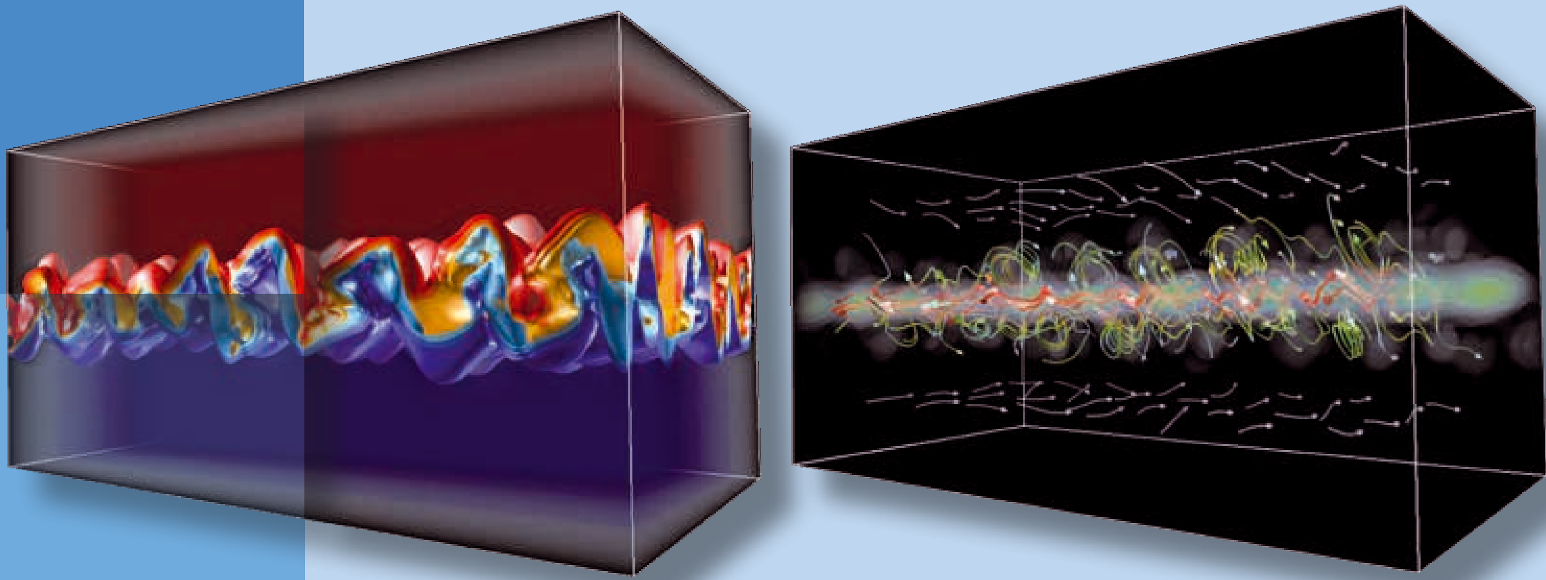

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Bilder des SuperMUC (Vorwort, Seite 8/9, sowie Umschlag-Rückseite) von Helmut Satzger.

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Wake Vortices of Landing Aircraft

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Introduction

As an unavoidable consequence of lift aircraft generate a pair of counter-rotating and long-lived wake vortices that pose a potential risk to following aircraft. The prescribed aircraft separations during landing to avoid wake vortex hazards contribute significantly to capacity restrictions of large airports. Severe encounters of wake vortices have also been reported during cruise. Wake vortex behavior is largely controlled by the prevailing meteorological conditions and the interaction with the ground. The most important meteorological parameters are ambient wind, wind shear, turbulence, and temperature stratification.

The Deutsches Zentrum für Luft- und Raumfahrt (DLR) develops wake vortex advisory systems for airports and en route which aim at optimizing the air traffic with respect to the measured and predicted wake vortex behavior. As part of such systems simple probabilistic wake vortex prediction models are required that predict wake vortex behavior accurately, robust, and fast. Highly resolving large eddy simulations (LES) conducted on the SuperMUC supercomputer provide valuable insights in the physics of wake vortex behavior under various atmospheric conditions. These LES contribute indispensable guidance for the development of the real-time/fast-time wake vortex models.

Results

A particular risk prevails during final approach, where the vortices cannot descend below the flight path, but tend to rebound due to the interaction with the ground. Moreover, the possibilities of the pilot to counteract the imposed rolling moment are restricted due to the low flight altitude of aircraft above ground. Numerical simulations and field measurements indicated that approaching aircraft frequently fly close to or even through not fully decayed wake vortices in ground proximity. We got several steps further in understanding the physics, leading to unexpectedly save landings, with the help of numerical simulations.

The wake vortex evolution depends not only on environmental conditions such as atmospheric turbulence, temperature stratification and wind shear, but also on

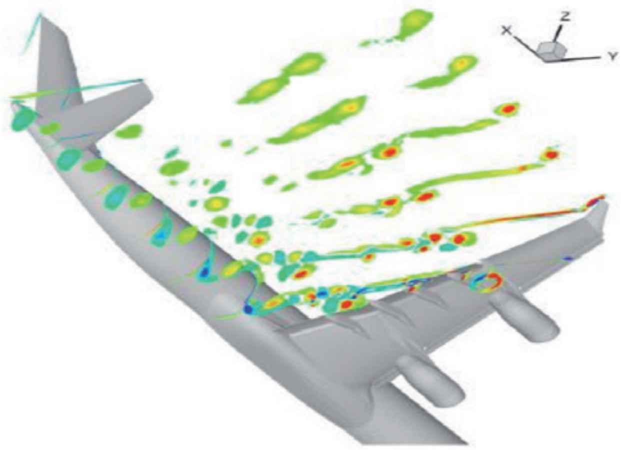

Figure 1: Near-field vorticity distribution around AWIATOR long range aircraft model obtained from RANS simulation.

the specific aircraft geometry and the configurations for cruise, take-off or landing. A novel wake initialization approach, where a realistic aircraft wake is generated in an LES domain by sweeping a high-fidelity Reynolds-Averaged Navier-Stokes (RANS) flow field through the domain, was applied to an A340 aircraft in high lift configuration. Using this approach a simulation was performed from the wake roll-up until the vortex decay.

Figure 1 shows near-field vorticity distributions obtained from the RANS simulation. The contours in blue and red represent axial vorticity in clockwise and counter-clockwise directions, respectively, viewed from the tail. The vorticity distribution is complex just after the main wing in high-lift configuration. Nevertheless, only a few vortices remain at the position of tail wings, i.e., wing- and flap-tip vortices as well as vortices from the wing-fuselage junction. Only the vortex from the wing-fuselage junction has opposite rotation direction among the vortices at the position of the tail wings.

With this novel method we simulated the complete landing phase including final approach, flare, touchdown, and vortex decay. Figure 2(a) shows the roll-up process of the aircraft wake. The tracer is initialized at certain vorticity levels, depicting the vortex structure behind the aircraft. Wing-tip and flap-tip vortices as well as a vortex from the engine pylon and from the wing fuselage junction remain at the tail wing position, as strong coherent structures. Wing-tip and flap-tip vortices merge in the mid-field constituting the so-called wake vortices.

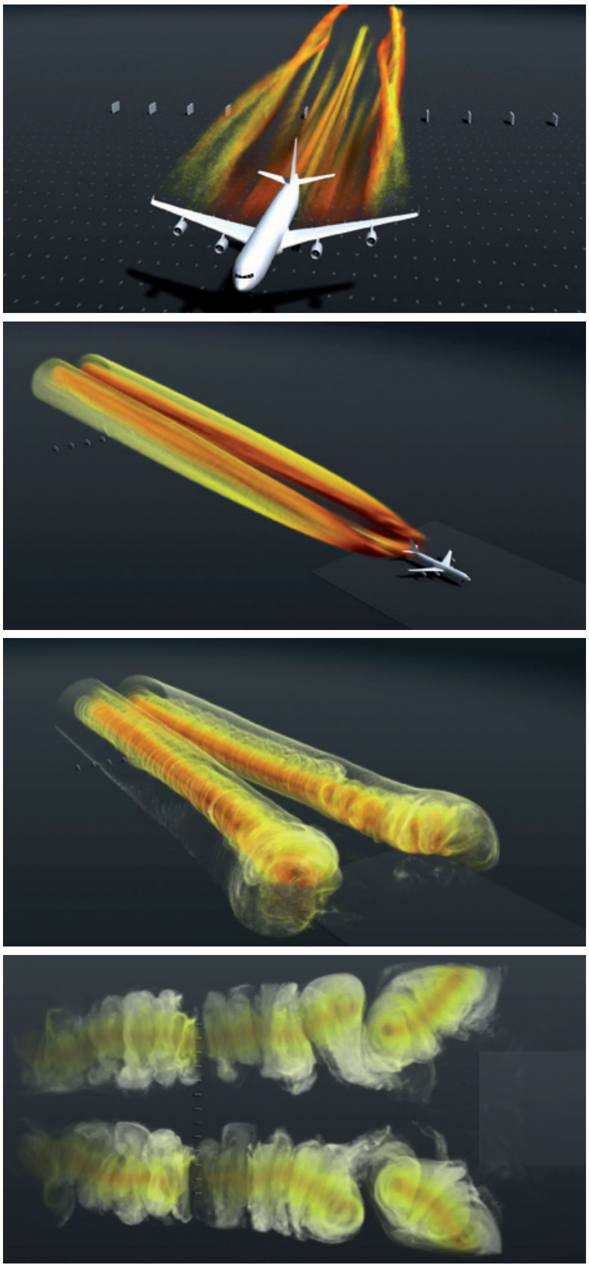

Figure 2: Spatial LES of landing with plate line (a) final approach, tracer initialized inside the wake vortex (b)-(d) touchdown and vortex decay, tracer initialized behind the aircraft wing, velocity of the tracer color coded.

Figure 2(b) depicts the instant of touchdown. The wake is initialized incorporating the approach and the lift reduction after touchdown. Regions of high velocities (red color), particularly dangerous for following aircraft, are around the vortex cores. After touchdown, Figure 2 (c), the vortices remain freely in space for a short time. At this instant so-called end effects appear from the touchdown zone, propagating against flight direction, weakening the wake vortex strength.

Figure 2(d) depicts the vortex decay phase of the wake vortices. Multiple ground linkings can be observed.

The introduction of a plate line at the ground surface substantially accelerates vortex decay [2] in the critical area close to the threshold where most vortex encounters occur, as shown in Figure 2(d). The reddish fraction of the vortices, indicating the potentially hazardous region, dissolves quickly. Figure 3 shows the reduction of vortex circulation along the final approach path. In flight experiments at the Airport Oberpfaffenhofen it was confirmed that the obstacles effectively accelerate vortex decay, see Figure 4 [3].

On-going Research / Outlook

The capabilities of SuperMUC enabled to reveal valuable insights into wake vortex physics in cruise and approach to airports. The results have been validated with flight measurement campaigns. Field experiments have shown that the number of plates should be sufficiently large to achieve a maximum efficiency of the plate line. In an ongoing study we aim to optimize the plate line design. For this purpose the flight tests have to be simulated as accurate as possible. In future aircraft landings will be investigated in even substantially increased computational domains.

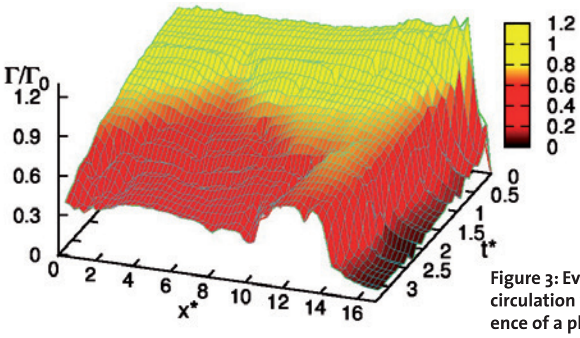

Figure 3: Evolution of vortex circulation with the influence of a plate line.

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[2] Stephan, A., Holzäpfel, F., Misaka, T., "Aircraft Wake Vortex Decay in Ground Proximity -Physical Mechanisms and Artificial Enhancement," Journal of Aircraft, 2013

[3] Holzäpfel, F., Stephan, A., Körner, S., Misaka, T. "Wake Vortex Evolution during Approach and Landing With and Without Plate Lines", AIAA Paper 2014-0925

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Figure 4: Flight experiments at Oberpfaffenhofen airport, confirming the efficiency of plate lines.