HYBRID SIMULATION OF WAKE VORTICES OF LANDING AIRCRAFT IN A TURBULENT ENVIRONMENT

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Abstract Wake-vortex evolution during landing of a long range aircraft is investigated in a turbulent environment. The simulations cover final approach, touchdown on the tarmac, and the evolution of the wake after touchdown. An ambient turbulent crosswind and headwind field is generated in a pre-simulation. The wake is initialized using a RANS-LES coupling approach. The further development of the vortical wake is investigated by large-eddy simulation until final decay.

INTRODUCTION

As an unavoidable consequence of lift, aircraft generate a pair of counter-rotating and long-lived wake vortices, posing a potential risk to following aircraft, due to strong coherent flow structures [2]. Particularly during final approach wake vortices encounter may occur [1]. The transport and decay of the wake vortices in ground proximity is largely controlled by the prevailing meteorological conditions and the interaction with the ground. Aircraft landing and the evolution of the wake in its meteorological environment is an example of complex turbulent flows, composed of strong coherent flow structures that exhibit a range of length scales spanning several orders of magnitude all interacting with one another. The flow around an aircraft's main wing, fuselage, slat, flap, jet engine and tail plain, as well as the interaction with the approaching ground and the sudden lift reduction during touchdown substantially affect the generated wake vortices.

Previous investigations show that various structures appear in the wake after touchdown interacting with each other and finally leading to the decay [8]. Effects, well known from vortex dynamics, such as vortex bursting [5] and vortex linking appear. Additionally end effects appearing after touchdown as well as vortex disturbing effects generated by so-called plate lines [7] lead to a complex decay pattern. Understanding those structures serve to control and manipulate the wake vortex decay. The present work investigates the physical mechanism of end effect generation and its effect on wake vortex decay close to the touchdown zone as well as the installation of plate lines at the runway ends for artificial vortex decay enhancement [7] with so-called hybrid large-eddy simulations (LES), a RANS-LES coupling. This work continuous the investigation in [8] including the effect of turbulence - ambient turbulence as well as fuselage turbulence. We deduce the fully three-dimensional vortex characteristics in a turbulent environment. We study the turbulent interaction of so-called end effects, appearing after touchdown, with disturbances caused by plate lines - a method for artificial vortex decay enhancement [7].

NUMERICAL METHOD

We employ a wake initialization approach where a realistic aircraft wake is generated in a LES domain by sweeping a high-fidelity Reynolds-averaged Navier-Stokes (RANS) flow field through the domain, which enables to simulate the wake vortex evolution from generation until final decay [4]. The RANS flow field serves as a forcing term in the LES. The RANS solutions along the glide slope are obtained by the DLR TAU-code with an adaptive mesh refinement for wingtip and flap vortices as well as the fuselage wake. The incompressible Navier-Stokes code MGLET is employed for LES [3], together with a Lagrangian dynamic subgrid scale closure. The simulations are performed for a large transport aircraft model in high-lift configuration. Fuselage turbulence is modeled as white noise. The plate line is introduced as a drag force source to accelerate vortex decay. In order to provide a realistic environment we establish a turbulent wind in a separate simulation simulating a turbulent half-channel flow.

RESULTS

In contrast to a simplified constant wake initialization in flight direction, the flow field of a hybrid simulation reveals a highly complex three-dimensional flow. From the roll-up Fig. 1 a) until decay Fig. 1 d) we observe the interaction of strong vortices with one another and with the ground [6]. Before touchdown and ground interaction the wake is undisturbed, Fig. 1 b). After touchdown ground effects as well as end effects appear, vortices burst, Fig. 1 c). Finally horseshoe vortices as well as partly straight vortices remain, which are transported with the wind, Fig. 1 e). The plate lines introduce another disturbance to the vortices Fig. 1 c) and accelerate vortex decay Fig. 1 f). Additionally they create secondary vortex structures and trigger ground linking Fig. 1 d). The propagation speed of the disturbances is studied. The mentioned phenomena are strongly influenced by cross- and headwinds. Beside advection of the coherent

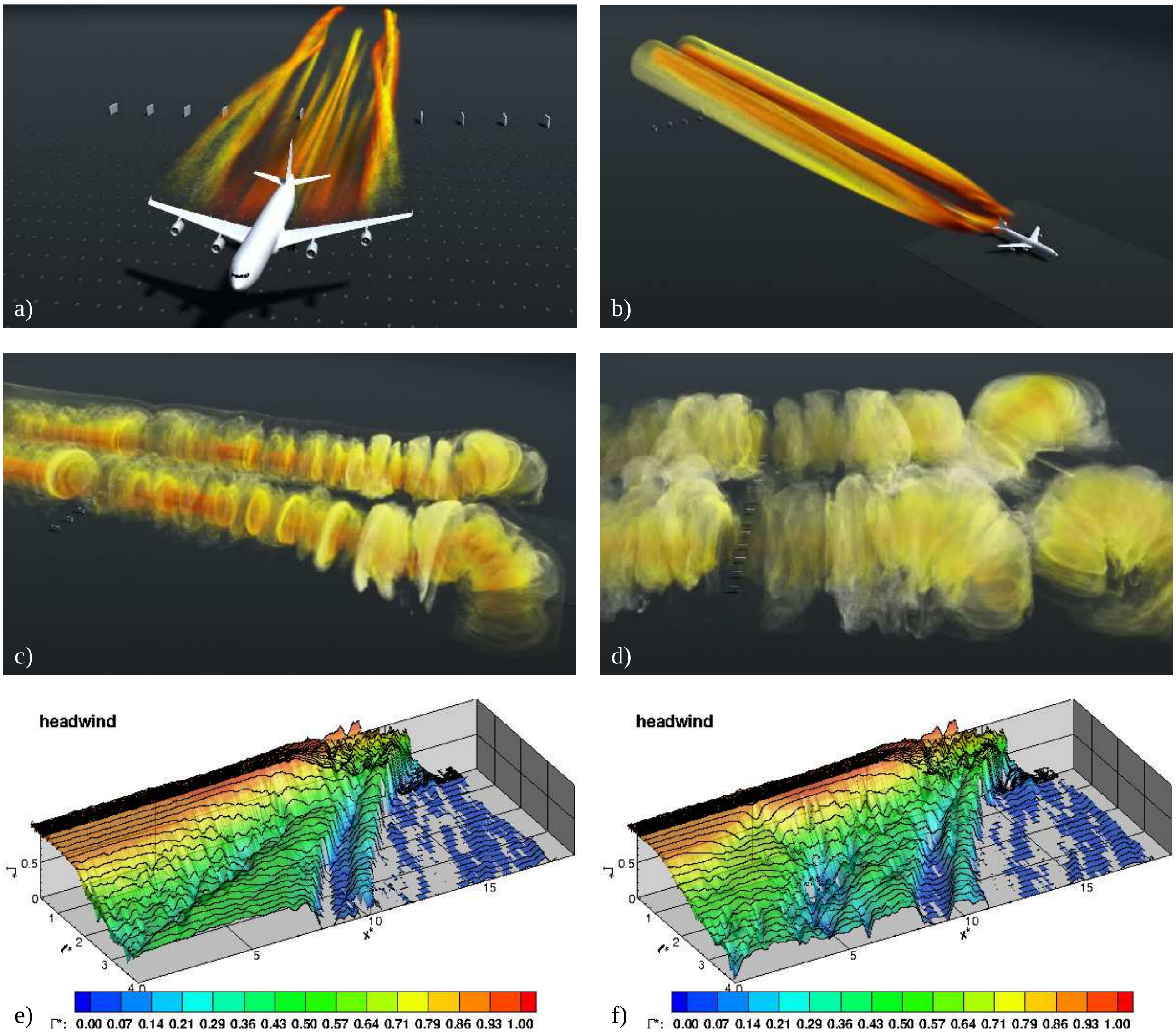

Figure 1. Hybrid LES of landing, a),b) initial wake, c) ground effect with vortex bursting, d) plate line effect aground linking. Normalized vortex circulation development for the entire upwind vortex, headwind case, without plate line e), plate line f).

structures, wind suppresses or intensifies the structure formation. The simulations show the effectivity of plate lines in the head- and crosswind situation. The findings serve to improve wake-vortex advisory models and help to interpret LIDAR measurements. However, the effect of those structures encountered by following aircraft is not fully clear.

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