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Aircraft wake vortices – prediction and mitigation

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The current abstract presents selected topics investigated within the wake-vortex research program of DLR. Two approaches are addressed that both aim at increasing airport capacity without compromising safety. One approach is to directly alleviate wake vortex strength and stability by constructive measures at the aircraft wings. The other approach utilizes the dominant influence of meteorological parameters like turbulence, wind shear, and temperature stratification on wake vortex fate.

1 Introduction

As an unavoidable consequence of lift, aircraft generate a pair of counter-rotating vortices, the so-called wake vortices. These vortices may exert a serious danger on following aircraft if the separation between leading and following aircraft is not sufficient. The incentive of today's wake vortex research still rests on the empirically motivated separation standards between consecutive aircraft introduced in the 1970s. These aircraft separations constrain the capacity of congested airports in a rapidly growing aeronautical environment.

The current abstract presents selected topics investigated within the wake-vortex research program of DLR. Two approaches are addressed that both aim at increasing airport capacity without compromising safety. One approach is to directly alleviate wake vortex strength and stability by constructive measures at the aircraft wings. The other approach utilizes the dominant influence of meteorological parameters like turbulence, wind shear, and temperature stratification on wake vortex fate. In the meantime, the physical mechanisms that control the interaction of wake vortices with their environment are largely understood. This knowledge constitutes the basis for predicting wake vortex behavior along the glide slope and dynamically adjusting vortex separations. First, large eddy simulations that are employed within both approaches are briefly described and, then, the Wake Vortex Prediction and Monitoring System (WSVBS), which has demonstrated its functionality at Frankfurt airport during winter 06/07, is introduced.

2 Wake-Vortex Alleviation

One possibility to mitigate wake vortices is to generate additional secondary vortex pairs by differential flap settings. The interaction of the vortex pairs leads to a fast initial decay which is then sustained at a slower rate. Figs. 1 and 2 depict the results of large eddy simulations of a conventional wake vortex pair and a four vortex system in weak ambient turbulence at

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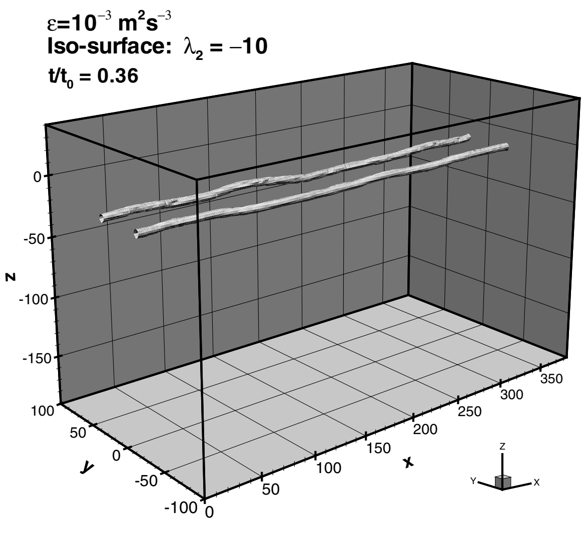

Fig. 1 Numerical simulation of a wake-vortex pair ...

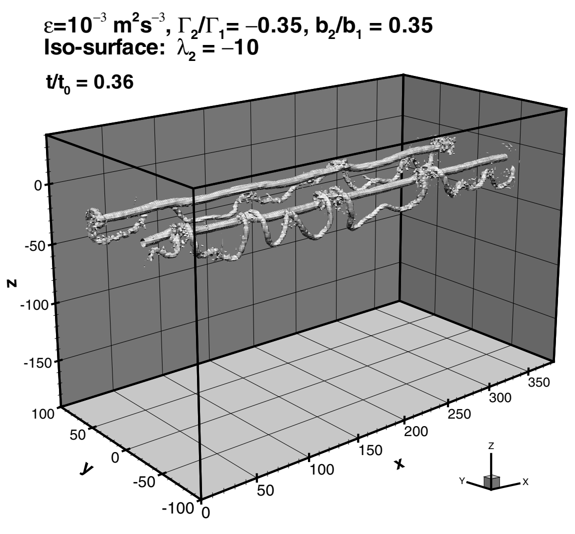

Fig. 2 ... and of two counter-rotating vortex pairs.

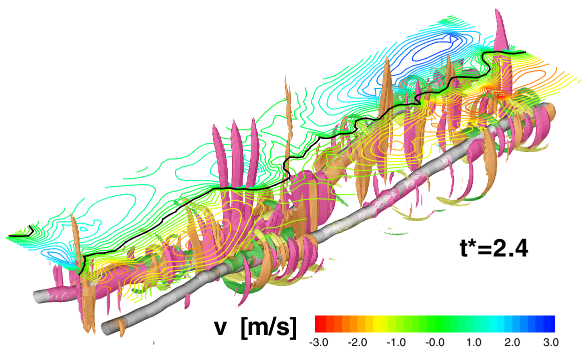

Fig. 3 Wake vortex topology in a turbulent atmosphere at a vortex age of about 60 s.

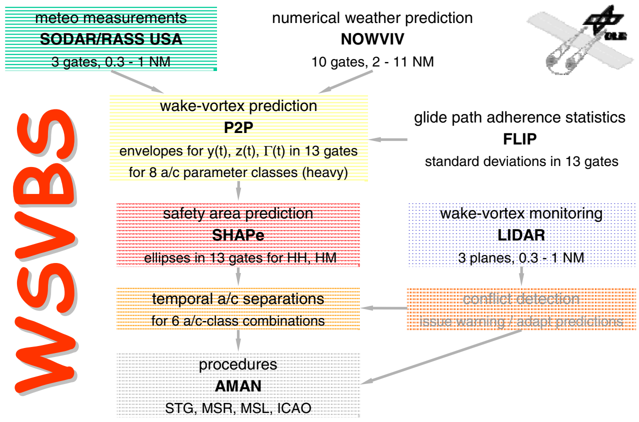

Fig. 4 WSVBS flowchart.

a vortex age of 12 s. For the four vortex system an initially wavy disturbance of the secondary vortices has already led to the formation of so-called omega loops. The secondary vortices wrap around the primary vortices and subsequently weaken the primary vortices by direct interaction. The developed instability is robust w.r.t. environmental flow, since it produces "its own" turbulence.

3 Wake-Vortex Behaviour in Atmospheric Boundary Layer

As an example for wake-vortex evolution in the atmospheric boundary layer, Fig. 3 shows the simulated wake vortex topology in a turbulent atmosphere at a vortex age of about 60 s. The two gray primary vortices are surrounded by coloured secondary vorticity structures that are generated by stretching and tilting of ambient turbulence [1]. These vorticity structures preferentially emerge at locations with strong axial gradients of the crossflow velocity v. The secondary vorticity structures promote exchange of fluid between the vortex pair and thus reduce wake vortex strength by direct compensation of vorticity. Similar mechanisms can be identified in environments with pronounced stable temperature stratification or wind shear.

4 Wake-Vortex Prediction and Monitoring System

The Wake Vortex Prediction and Monitoring System (WirbelSchleppen-Vorhersage- und -BeobachtungsSystem - WSVBS) has been developed to tactically increase airport capacity for approach and landing [2]. The WSVBS is thought to dynamically adjust aircraft separations dependent on weather conditions and the resulting wake vortex behaviour without compromising safety. For this purpose it predicts wake vortex transport and decay and the resulting safety areas along the glide slope from final approach fix to threshold.

Fig. 4 delineates the components of the WSVBS and their interplay. In ground proximity the best wake prediction skill is required which is achieved based on measurements of meteorological conditions with a SODAR/RASS system and an ultra sonic anemometer (USA). Along the glide slope the meteorological conditions are predicted with the developed numerical weather prediction system NOWVIV. Based on glide path adherence statistics (FLIP) the probabilistic wake vortex model P2P [3] predicts upper and lower bounds for position and strength of vortices generated by heavy aircraft. P2P considers all effects of the leading order impact parameters: aircraft configuration, crosswind, headwind, wind shear, turbulence, temperature stratification, and ground proximity. A training procedure has been developed which employs statistics of measured and predicted wake vortex behaviour and allows adjusting the predicted uncertainty allowances to defined probabilities. The P2P bounds are expanded by the safety area around a vortex that must be avoided by follower aircraft for safe and undisturbed flight (SHAPe). The instant when these safety areas do not overlap with the flight corridor define temporal aircraft separations that are translated into established procedures by the arrival manager (AMAN). As a safety net the Lidar monitors the correctness of WSVBS predictions in the most critical gates at low altitude.

The WSVBS has demonstrated its functionality at Frankfurt airport from 18/12/06 until 28/02/07. In 75% of the time capacity improving modes could have been used. This corresponds to significant reductions in delay and/or an increase in capacity of roughly 3% taking into account the real traffic mix and operational constraints.

References

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