Large-eddy simulation on the influence of buildings on aircraft during take off and landing

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ABSTRACT

Building induced airflow disturbances may have a significant effect on landing and starting aircraft. The aim of this study is to analyze the turbulent wake of on idealized block-shaped obstacle representing an airport terminal or hangar using large-eddy simulation (LES). Both mean and instantaneous crosswind speeds along a virtual flight path of a landing aircraft are calculated to illustrate the influence of the obstacle induced wind disturbances. Two different distances of the hypothetical runway from the obstacle in the downwind region are considered. The results show that the mean wind deficit of the crosswind can reach more than 7 m/s over a distance of approximately 100 m along the flight path. The crosswind fluctuations exceed more than 15 m/s. Under this wind conditions, a landing or starting aircraft could experience strong and abrupt wind changes or gusts which may lead to hazardous situations during flight.

1 INTRODUCTION

A steady increase of air traffic leads to an expansion of airports and hence an increased number of airport buildings like terminals and hangars. Additionally, more buildings are constructed in the airport environment due to the rapid growths of urban areas. These changes at airports and their surroundings modify the meteorological conditions on and near the airfield. Building induced airflow disturbances may reach the runway or the flight path, which may significantly affect aircraft during take off or landing. Examples of buildings which demonstrably affect aircraft are located on the Amsterdam Airport Schiphol (e.g. Krüs et al., 2003; Nieuwpoort et al., 2006) and on the Hong Kong International Airport (e.g. Chan et al., 2010).

For construction regulations of buildings at and around airports as well as to promise a high level of flight safety, it is of utmost importance to develop guidelines and criteria which describe the influence of buildings on the airflow and hence the flight behavior of aircraft. Based on numerical simulations and piloted experiments the so called 7 knots criterion was developed by Nieuwpoort et al. (2006). It describes the maximum allowed mean wind deficit perpendicular to the aircraft over a short spatial interval. In practice, an exceeding of the mean wind speed deficit of 7 knots (3.6 m/s) over a distance of approximately 100 m may affect the maneuverability of the aircraft significantly. However, the 7 knot criterion takes only the mean wind speed under account. A clear definition of a criterion which considers turbulent fluctuations or gusts (like an additional wind speed magnitude) is not provided.

In this study, we want to compare both mean and instantaneous crosswind speeds along a virtual flight path through the wake of an obstacle. The possible impact on an aircraft is discussed by considering the 7 knots criterion.

As the next step, the presented wind fields will be used as initial wind data for a numerical simulation of the flow around an aircraft using the CFD model TAU of the DLR (German Aerospace Center). This allows to estimate the influence on a real aircraft.

2 METHODS

2.1 Model

To consider the building induces turbulence directly, we used large-eddy simulation to simulate the flow around an obstacle. The model used is the large-eddy simulation model PALM (**PA**rallelized **L**ES **M**odel). It was developed at the Institute of Meteorology and Climatology at the Leibniz Universität Hannover (Raasch and Schröter, 2001) and enables high resolution, turbulence resolving simulation of the atmospheric boundary layer.

In the present study, PALM (revision 1421) was used to simulate the dry atmosphere, where it solves the filtered non-hydrostatic, incompressible Boussinesq equations, the first law of the thermodynamics and the equation for turbulent kinetic energy (TKE). It scales very well on parallel computers and hence it can be used for high resolution simulations of the atmospheric boundary layer. In order to resolve small turbulent structures (or gusts) which may affect aircraft and aircraft wings, the grid resolution was chosen with one order of magnitude lower than these structures. With a minimum wing-span of some decameters (assuming a wing-span and a length of approx. 30 m of an Airbus A320), and a certain level of insurance, a model resolution of 2 m was chosen for this study. The simulation was carried out using cyclic lateral boundary conditions.

2.2 Meteorological conditions and setup

A rather simple setup was chosen in order to focus the investigation on the turbulent wake behind the obstacle and its influence on a hypothetical runway in the downstream direction. The shape of the obstacle was guided by the simulations of Nieuwpoort et al. (2006) who used a block shaped building. Its dimensions are 24 x 250 x 40 m^3 (length x width x height). The large width of the obstacle leads to a relatively large magnitude of the wake area which generally increases with an increasing obstacle width (see Blocken and Carmeliet, 2004; Nieuwpoort et al., 2006). A schematic view of the building, the runway, and the wind conditions can be seen in Figure 1. The undisturbed upstream flow was purely shear driven. The neutrally stratified boundary layer reached a height of 700 m, where a geostrophic wind u_g of 20 m/s was predefined. The corner streams with high wind speed values as well as the low wind speeds downstream of the building are indicated by red and blue arrows in Figure 1. The touchdown zone of the runway lies outside the building wake, so that a landing aircraft is affected by the building induced turbulence at a height of several decameters during the final approach.

The total model domain size was 4000 m in direction of the mean flow (x-direction) and 2000 m in the lateral direction (y-direction). The long distance in x-direction allows the dissipation of the artificial flow disturbances before reentering at the opposed side.

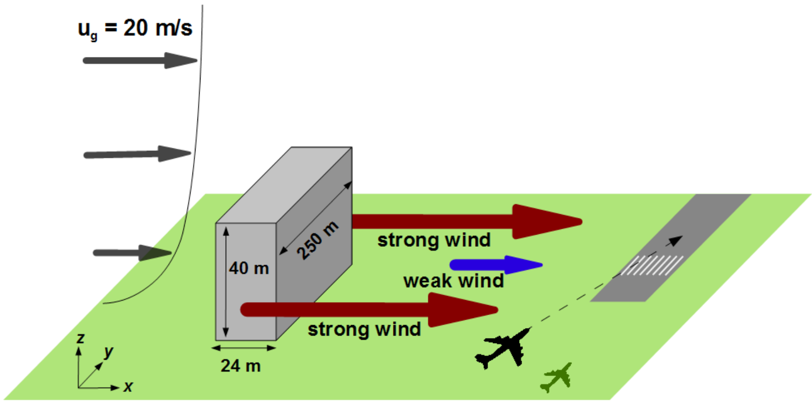

Figure 1: Schematic view of the simulated flight path through the wake of the building.

3 RESULTS

To get a brief overview of the flow around the building, a vertical and horizontal cross-section of the mean airstream is shown in Figure 2. The mean crosswind (colored) was calculated by averaging the wind speed component *u* over a time period of 30 min. Additionally, streamlines with arrows indicate the direction of the flow in each of the cross-sections. The typical recirculation zone behind the obstacle is marked by the large vertical vortex (Fig. 2, left) and the two horizontal vortices (Fig. 2, right). At the right end of the recirculation zone, the stagnation point occurs approximately 200 m behind the trailing edge of the building. Most of the smaller scaled turbulent eddies (not visible in Fig. 2) are generated between the large vortices mentioned and the corner streams (flow around the corners of the obstacle) where high velocity gradients occur (see e.g. Blocken and Carmeliet, 2004 for more details). The slight asymmetry of the flow, which is visible in the horizontal cross-section of Figure 2 (right), is a result of the slight rotation of mean wind direction in the boundary layer due to the Coriolis force.

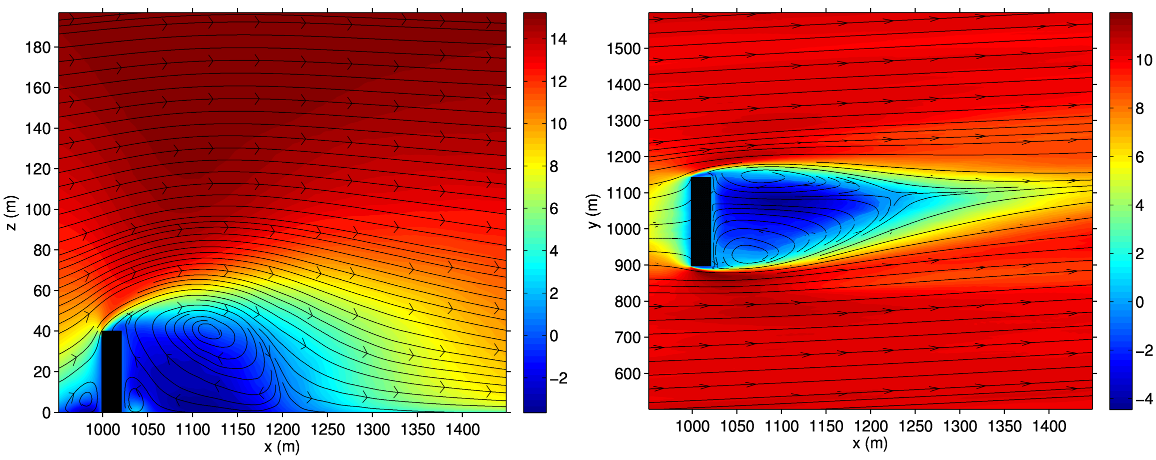

Figure 2: Mean flow around the building (black rectangle): Vertical cross-section in the middle of the building width at y = 1000 m (left). Horizontal cross-section in the middle of the building height at z= 20 m (right). The mean u-component (crosswind) in m/s is colored. Streamlines with arrows indicate the direction of the mean flow.

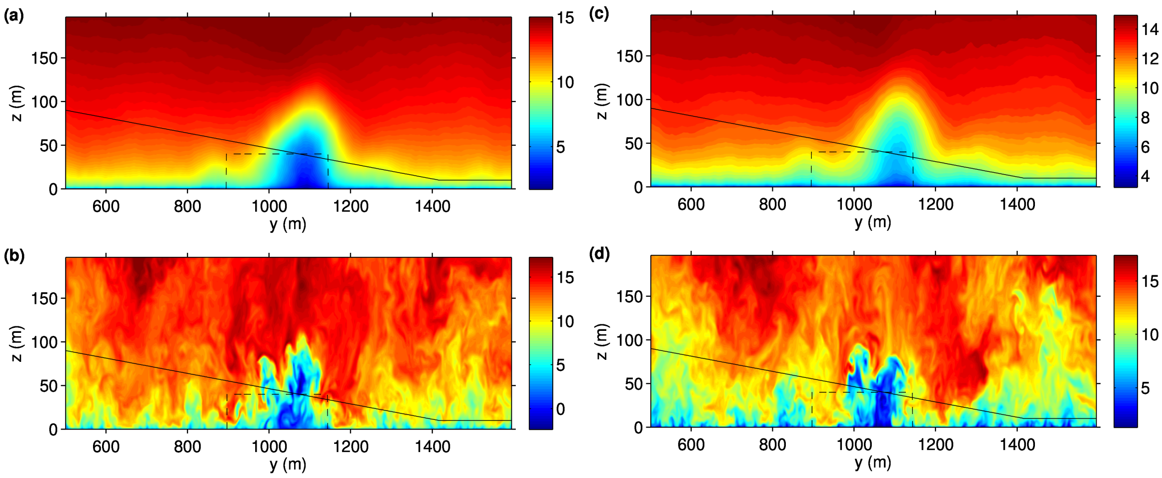

Figure 3: Vertical cross-sections of the mean (a and c) and instantaneous (b and d) crosswind in m/s downstream the obstacle (different color scales are used). The distance between the obstacle and the cross-sections is 300 m (a and b) and 430 m (c and d). The virtual flight paths are indicated by the black lines. For a better orientation the location of the building is shown by the dashed black lines.

Two different distances (300 m and 430 m) between the obstacle and the runway (flight path) were analyzed. The lower of the two values corresponds to the smallest distance considered in the study of Nieuwpoort et al. (2006). The flight path is parallel to the *y*-axis and has an angle of 5°. Along the runway, starting from the touch down point, a height of 10 m above ground was used to extract the wind speed data. The virtual flight paths are indicated as black lines in the vertical cross-sections of Figure 3, which show the mean and instantaneous crosswind fields in the plane of the two virtual runways. The differences between the mean and instantaneous flows can clearly be seen for both flight path distances. Furthermore, the higher wind speeds in the wake area further away from the obstacle are visible (Fig. 3, c, d, different color scales are used). In the cross-sections of the turbulent fields of Figure 3 (b) and (d), the building induced wind speed deficits are significantly more strongly than the surrounding turbulent disturbances (generated by wind shear due to surface friction) and reach heights of approximately 100 m.

The virtual measurements of the crosswind along the two flight paths indicated in Figure 3 are shown in Figure 4. Virtual flights were performed in both mean and instantaneous flow conditions. In the later case, the temporal development of the turbulence was considered by assuming an airspeed of 70 m/s. Thus, the complete flight duration is about 16 s along the 1100-meters-long glide path. The flight measurements in Figure 4 can be divided into three different periods which differ considerably from each other: Firstly, the region before reaching the wake (glide path = 500 m – 900 m) with mean wind speeds of more than 13 m/s and turbulent fluctuations of about 1-3 m/s. Secondly, the region of the wake (900 m – 1250 m) with strong perturbations and a reduction of the mean wind of more than 5 m/s. And thirdly, the region behind the wake (1250 m – 1600 m) where the aircraft reaches the ground (at z = 10 m). In this third region, the close ground surface causes lower mean wind speeds of approximately 10 m/s but stronger fluctuations up to 5 m/s than in the first region occur. In contrast to the rather typical turbulent fluctuations of an atmospheric boundary layer in the first and third region, the building induced fluctuations reach more than 10 m/s. In the first case

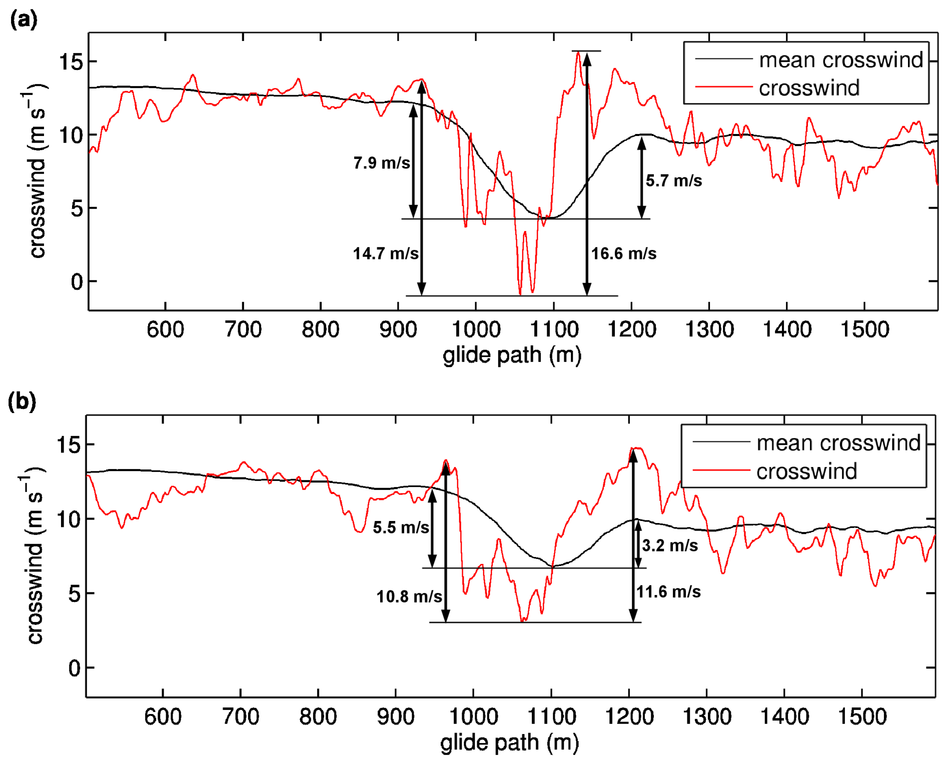

Figure 4: Virtual crosswind measurements along the glide path. The distances between the trailing edge of the obstacle and the glide path are 300 m (a) and 425 m (b).

of Figure 4 (300 m distance to the obstacle), the differences between the crosswind speeds along the flight path exceed 15 m/s over a distance of about 100 m. On the glide path 130 m further downstream (Fig. 4, b) the magnitudes of the fluctuations are smaller. However, nearly all the differences marked in Figure 4 meet the 7 knots criterion (both in mean and instantaneous flight measurements). Hence, the perturbed area could have a significant influence on the maneuverability of an aircraft.

4 CONCLUSIONS

High resolution LES were performed to analyze the turbulent wake of an idealized obstacle. The influence of the building induced flow perturbations on a landing aircraft was investigated by means of virtual crosswind measurements along the flight path. The measured wind deficit of the mean wind reach values of more than 5 m/s over a distance of about 100 m – 150 m and thus fulfill the 7 knots criterion. Instantaneous fluctuations partially exceed 15 m/s which is four times the threshold of the 7 knots criterion. This shows that it is important to consider the turbulent wind speed fluctuations in such a criterion.

Although the presented results show strong fluctuations in the turbulent measurements, it is very likely that variations of some important parameters would lead to larger wind speed differences along the flight path. These parameters are the distance between the obstacle and the runway as well as the position of the touch down point on the y-axis. The later has not been changed yet. Another very important parameter is the starting time of the virtual flight. In this study, we chose it by visible inspection of the turbulent structures in the wake of the building. During the time period of both virtual flights through the instantaneous wind filed, relatively strong disturbances occurred. However, a more detailed analysis of the temporal development of the turbulent wake may provide points in time, where stronger disturbances or gusts can be expected. As last parameter which could be changed to modify the turbulent building wake, the shape of the obstacle can be mentioned. More complex buildings like a Y-shaped terminal or an arrangement of several buildings would lead to more complex flow patterns and thus to a modification of the crosswind along the flight path.

To improve and develop criteria of flight safety which consider the turbulence better than the existing criteria, it is important to quantify the influence of the obstacle induced wind disturbances on aircraft. Therefore, a new method using the presented turbulent LES data to initialize a CFD model containing an aircraft is currently developed. The method of coupling the two models (PALM and the TAU code of the DLR) allows the calculation of the turbulence induced forces on aircraft during take off or landing under realistic atmospheric conditions. The results of these investigations will be presented in future.

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