About the influence of the windward edge structure on the flow characteristics at forest edges

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Abstract

Experimental investigations in an atmospheric boundary layer wind tunnel were carried out in order to study the influence of the windward edge structure on the flow characteristics at the canopy top. Two different types of forest edges were used. The inclination angle was varied three times for both edge types and all inclined edges were combined with both dense and sparse forest stands. In addition, a configuration was investigated where the airflow in the trunk space of the dense forest was blocked completely by the windward arrangement of an impermeable wall.

1. Introduction

The amount of storm damage in forest stands depends on numerous parameters such as topography, stand density, canopy roughness, tree species, forest edge structure and soil parameters. A detailed knowledge of the relations between these various influencing parameters and the flow field is necessary to work out silvicultural strategies for the reduction of the storm damage risk and to assess the storm damage vulnerability of forest stands.

2. Methods

The experimental study has been carried out in the closed, 29 m long atmospheric boundary layer wind tunnel of the Laboratory of Building- and Environmental Aerodynamics at the Institute for Hydromechanics at the University of Karlsruhe. The characteristics of the simulated neutrally stratified atmospheric boundary layer, generated in the wind tunnel by means of vortex generators and roughness elements, are already described in Frank and Ruck (2007). The boundary layer is typical for suburban terrain and forest areas respectively.

The velocity measurements were accomplished by means of a two-component laser Doppler anemometer (2D-LDA) system. At every measuring point, about 26 600 data points were sampled in coincidence mode with a sampling frequency of 500 Hz. Hence, one point measurement took 53 s.

Canopy model

Forest arrangements with inclined windward stand edges of different structure were investigated in the scale 1:200. Two different types of edges were used: single tree edges (Figs. 1b-d) and abstracted edges, made of highly porous foam (Figs. 1e-g). Fig. 1a shows the dense forest with vertical edge and open trunk space. The inclination angle TW was varied three times for both edge types and all inclined edges were combined with both the dense stand (BD100) and the sparse stand (BD25), where every 2nd to 4th row was removed (see also Frank and Ruck, 2009). The used foam material is characterised by a very uniform, open-celled structure and is specified by 10 p.p.i (i.e. 10 pores per inch, cell size = ca. 2.5 mm) and a pore volume fraction of 97 %. The pressure loss coefficient of this foam amounts to $k_{r,M} \approx 300\ m^{-1}$ in model scale (corresponding to $k_{r,N} = 1.5\ m^{-1}$ in full scale). The height of the foam edges amounts to 11 cm at the windward stand edge, thus, the edge is slightly lower than the mean stand height H = 11.5 cm. The single tree edges consist of individual trees arranged at distances of 2 cm x 2 cm (what corresponds to the tree distance of the dense stand (BD 100)). The structure of the single tree edges is less uniform, but more natural and slightly sparser than that of the foam edges. In addition, a configuration was investigated where the airflow in the trunk space of the dense forest was blocked completely by the windward arrangement of an impermeable wall (Fig. 1h).

The approach flow takes place perpendicular to the stand edge. The origin of the used x,z-coordinate system is located on the wind tunnel floor at the windward side of the actual stand (i.e. at the leeward side of the upstream forest edges) with the x-axis in horizontal streamwise direction and the z-axis in upward oriented vertical direction (Fig. 1h).

In order to detect the flow phenomena near the canopy top, measurements were carried out at a height z/H = 1.13 with a high spatial resolution between 1 cm = 0.087·H (2 m in nature) near the windward edge and 5 cm = 0.435·H (10 m) near the leeward edge.

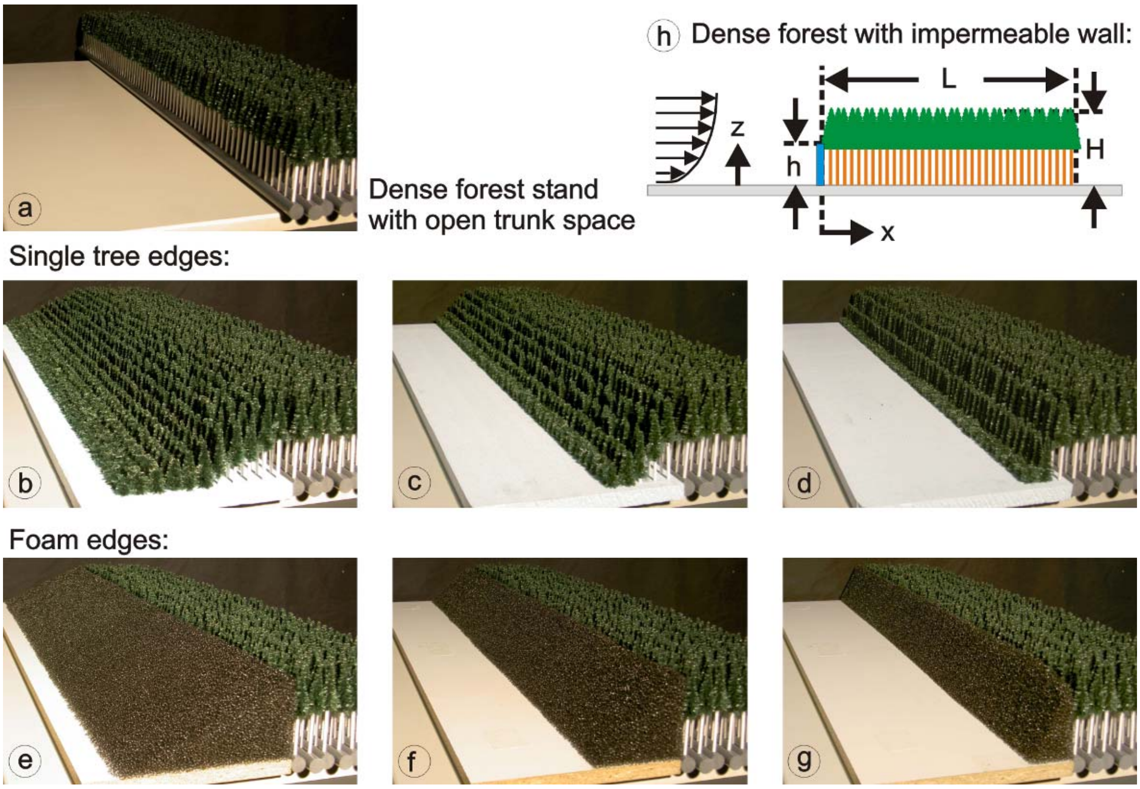

Fig. 1: Photos of the investigated forest edges: dense stand (BD100 = 600 trees/ha) a) with open trunk space (TW = 90°), b-d) with single tree edges [b) TW = 27°, c) TW = 45°, d) TW = 63°], e-f) with foam edges [e) TW = 27°, f) TW = 45°, g) TW = 63°]. h) sketch of the dense forest with impermeable wall and nomenclature used

3. Results

In this chapter, the streamwise variability of the wind loads near the canopy top (z/H = 1.13) is described. The mean wind load is proportional to the square of the mean horizontal velocity; the maximum wind load is proportional to the square of the sum of the mean horizontal velocity and the product of a gust weighting factor and the standard deviation of the mean horizontal velocity. The gust weighting factor was assumed to be 3.5. The wind loads are normalised by the wind load in the undisturbed approach flow at the same height. Furthermore, the ratio of maximum to mean wind load at z/H = 1.13 is also shown.

3.1 Edge structure impact for sparse forest stands

For the sparse forest stands, no clear dependency of the mean and maximum wind loads on the inclination angle was observed, neither for the foam nor the single tree edges, see Fig. 2. The differences between the curves are all in all quite small and, thus, lie probably in the range of the measuring accuracy.

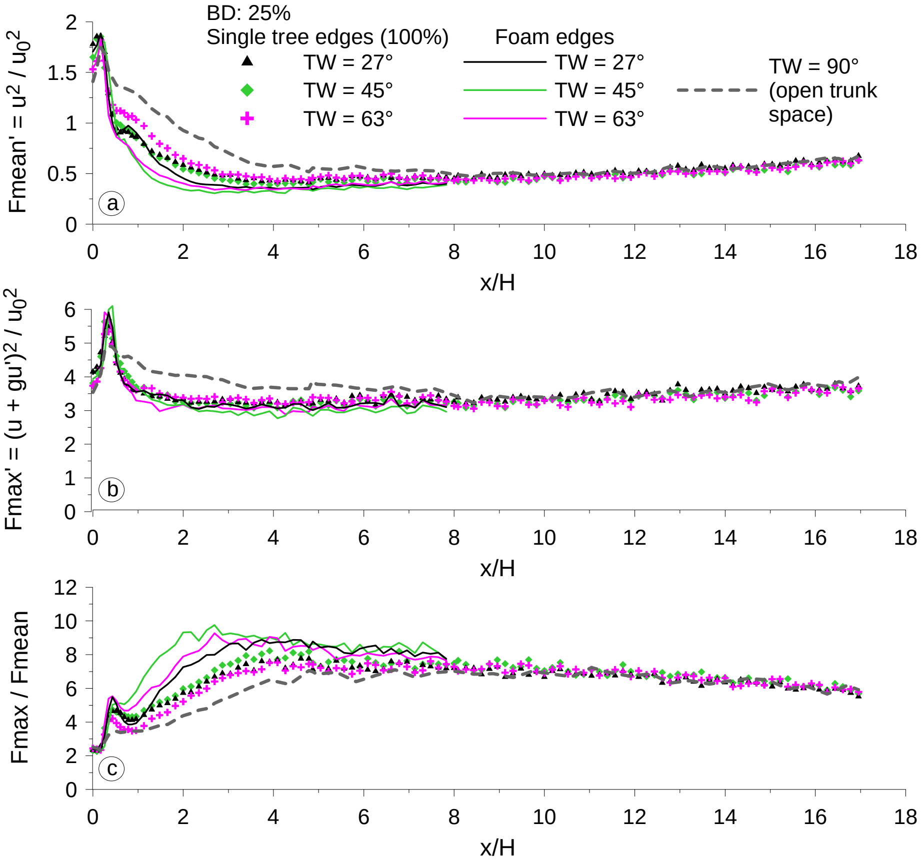

Fig. 2: Streamwise variability of wind loads near the canopy top (z/H = 1.13) above sparse forest stands (BD25) with different edges: a) normalised mean wind loads Fmean', b) normalised maximum wind loads Fmax', c) ratio of maximum to mean wind loads Fmax/Fmean; the variability above the sparse stand with open trunk space is also depicted (u_0 = 5.4 m/s)

For 1 < x/H < 4, the mean wind loads are smaller for the foam edges than for the single tree edges, whereas no significant differences were observed for the maximum wind loads. Consequently, the Fmax/Fmean-ratio is higher in this area for the stands with foam edges. The latter agrees by trend with the observations above dense forest stands.

A comparison of the sparse stand with open trunk space and the arrangements with inclined edges shows, that for 0.5 < x/H < 8 the wind loads above the forests with inclined edges are clearly smaller. The lowest Fmax/Fmean-ratios occur above the sparse forest with open trunk space.

3.2 Edge structure impact for dense forest stands

Dense forest with inclined edges

With increasing inclination angle both the mean and the maximum wind loads near the canopy top above dense stands with single tree edges decrease slightly and the Fmax/Fmean-ratio increases slightly, see Fig. 3. (For the foam edges, such clear trends were observed only between the shallow and the two steeper edges).

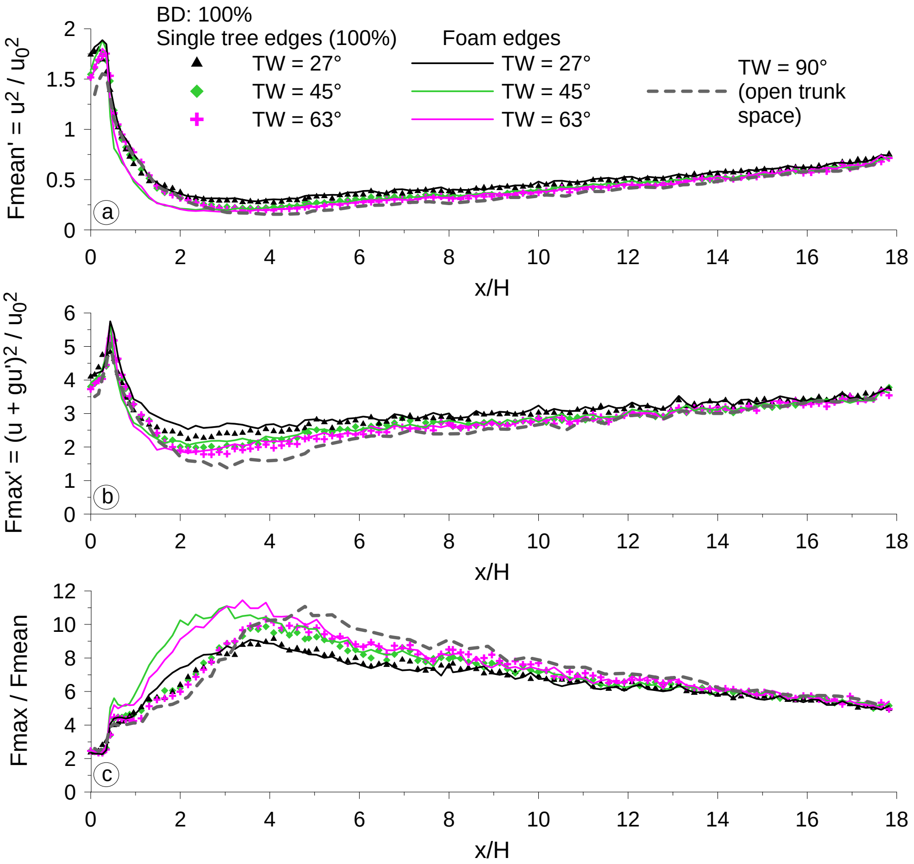

Fig. 3: Streamwise variability of wind loads near the canopy top ($z/H = 1.13$) above dense forest stands (BD100) with different inclined edges: a) mean wind loads, b) maximum wind loads, c) ratio of maximum to mean wind loads; the variability above the dense stand with open trunk space is also depicted ($u_0 = 5.4$ m/s)

The lowest wind loads occur for x/H > 2 above the dense forest with open trunk space. In comparison to the single tree edges, the maximum Fmax/Fmean-ratio moves towards the edge for the foam edges. The maximum Fmax/Fmean-ratio above the stands with the two steep foam edges is comparable to that observed above the dense stand with open trunk space and it is slightly higher than that above the stands with steep single tree edges. Near the windward stand edge (x/H < 4) the highest Fmax/Fmean-ratios occur above the forests with steep foam edges and further downstream above the dense forest with open trunk space. The lowest Fmax/Fmean-ratios appear above the dense stand with shallow single tree edge (TW = 27°).

Dense forest with impermeable wall

The impacts of an impermeable wall, being arranged windward of the dense stand and impeding the inflow of air in the trunk space, on the wind loads are shown in Fig. 4. In comparison to the dense stand with open trunk space, both mean and maximum wind loads increase. The Fmax/Fmean-ratio increases near the windward edge (x/H < 4) and decreases slightly further downstream. The impacts of the wall are comparable by trend to the implications of the foam edges, being characterized by a high density.

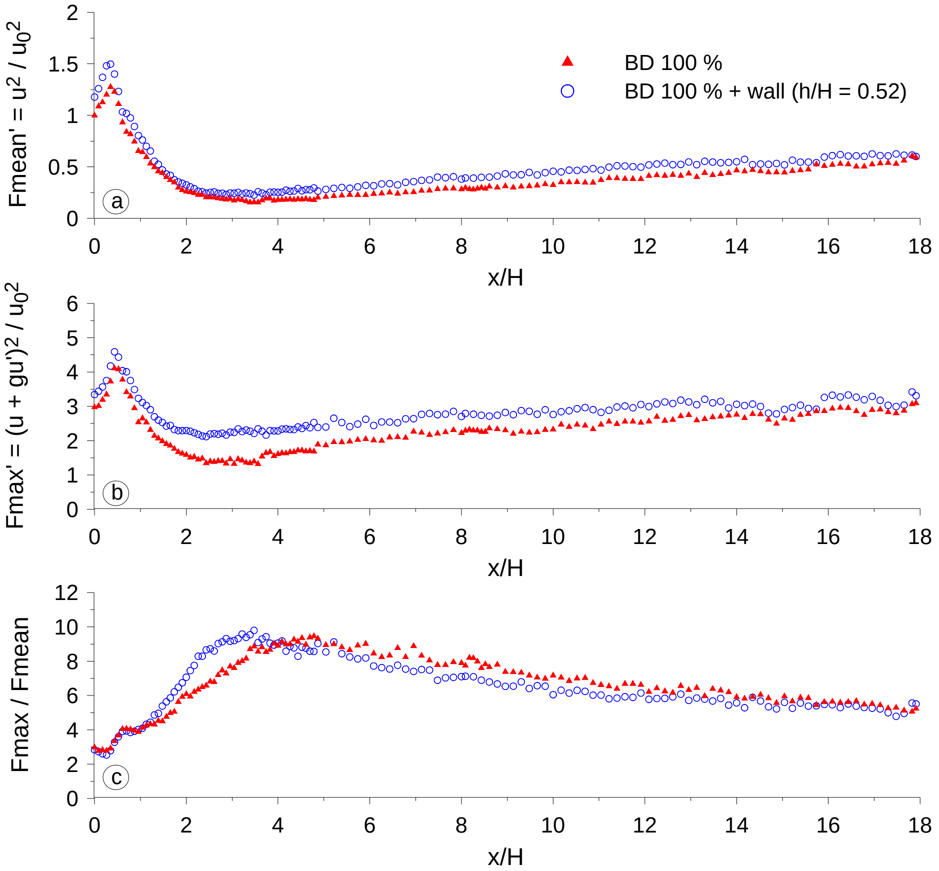

Fig. 4: Streamwise variability of wind loads near the canopy top (z/H = 1.13) above the dense forest stand (BD100) with windward arranged, impermeable wall (at x/H = 0): a) mean wind loads, b) maximum wind loads, c) ratio of maximum to mean wind loads; the variability above the dense stand without wall is also depicted (u_0 = 5.4 m/s)

3.3 Comparison of edge structure impact for sparse and dense forest stands

The arrangement of identical edges windward of sparse and dense forests results in an assimilation of the wind load curves (Figs. 2 and 3). The quite strong dependency of the mean and maximum wind loads on the stand density observed above the windward stand half for the forests with open trunk space diminishes due to the presence of the inclined edges. In general, the inclination angle seems to have a slightly higher influence for the dense stands than for the sparse stands as the curves of both edge types scatter stronger above the dense stands. Leeward of the denser foam edges, the differences between the curves of the sparse and dense forests are slightly smaller than leeward of the sparser single tree edges.

4. Conclusions

The results show that the windward edge structure affects the flow phenomena near the canopy top predominantly above the windward stand half, thus, its impact is locally restricted. This observation agrees with those of Dupont and Brunet (2008) and Gardiner and Stacey (1996). The similar trends observed above dense forests with impermeable wall and inclined edges suggest that the (total) density of the edge (and thus the amount of volume flux through the edge) is primarily responsible for the curve progression near the canopy top.

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