About the influence of the stand density on the flow characteristics at forest edges

Cornelia Frank, Bodo Ruck

Institute for Hydromechanics, University of Karlsruhe, Germany

Abstract

The paper presents experimental wind tunnel investigations in order to demonstrate the influence of the stand density on the flow characteristics at the canopy top near forest edges. The density of homogeneous forest stands was varied three times by removing whole rows of the originally dense model forest. In addition, staggered forest configurations were studied, consisting of sparse and dense forest areas of varied length.

1. Introduction

Aerodynamically, forest edges are highly permeable steps (length of inner and outer forest edges in Germany: 700.000 km), which interact with the atmospheric boundary layer flow. It is known, that 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. However, it is not clear, how the stand density alters the flow field situation at the canopy near forest edges in detail. It is believed that the stand density has an impact on the storm damage risk. Thus, to contribute to the assessment of the storm damage vulnerability of forest stands, detailed flow field investigations at the canopy near forest edges are needed.

2. Methods

The experimental set-up is the same as in Frank et al. (2009).

The density of the homogeneous forest stands was varied three times by removing whole rows of the originally dense model forest (see Fig. 1 and Table 1). In addition, staggered forest arrangements were investigated, consisting of sparse and dense forest areas of varied length, see Fig. 2. According to their spatial composition in stream-wise direction, these arrangements can be further sub-divided into two types: “Sparse - Dense” and “Dense - Sparse”. For each type, four different length ratios L/H were studied, where H = 23 m is the stand height in full scale. All forests are characterised by vertical edges (inclination angle TW = 90°) and an open trunk space.

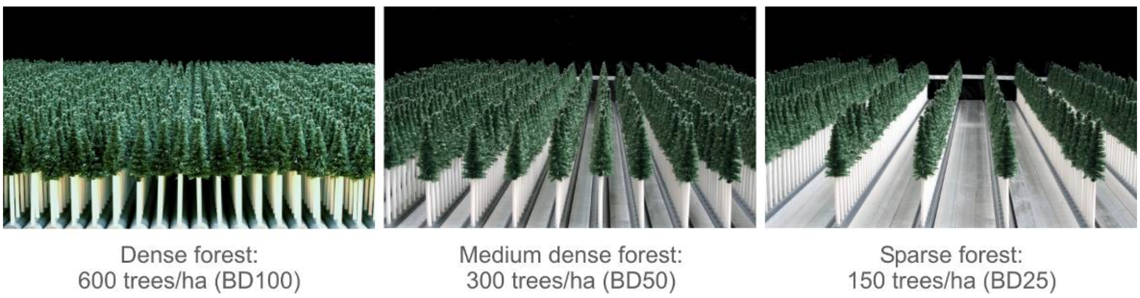

Fig. 1: Photos of the investigated homogeneous forest stands of varied stand density

Table 1: Homogeneous forest stands: outline of tests (ax = spacing between the trees in stream-wise direction, ay = spacing between the trees in lateral direction (perpendicular to the approach flow), Lw = length of the forest = distance between first and last tree row, H = mean stand height = 23 m, *stand density based on the ground area of the reference configuration)

	Stand density BD*			ax/H	ay/H	Lw/H
	[%]	Model	Nature			
		[trees/m²]	[trees/ha]	[-]	[-]	[-]
Reference	100	2400	600	0.18	0.17	17.9
Every 2nd row removed	50	1200	300	0.35		17.3
Every 2nd to 4th row removed	25	600	150	0.70		17.0

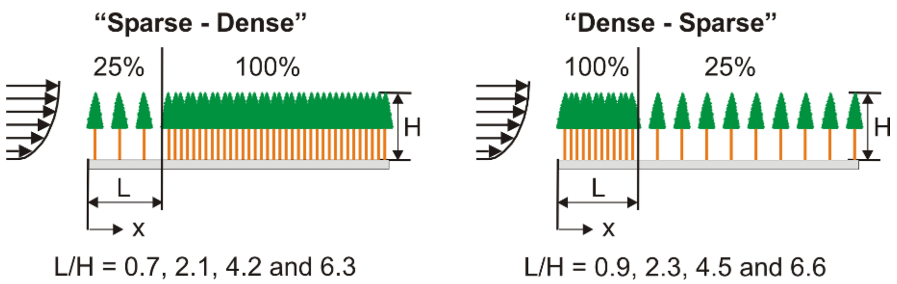

Fig. 2: Sketch of the staggered forest arrangements of varied length L (100% = 600 trees/ha, 25% = 150 trees/ha, H = 23 m)

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 Homogeneous forest stands

Fig. 3 shows the streamwise variability of the wind loads above homogeneous forest stands of varied stand density at a height z/H = 1.13. Above the windward stand half both the mean and the maximum wind loads clearly increase with decreasing stand density, whereas the Fmax/Fmean-ratio decreases. Above the leeward stand half the maximum wind load increases slightly due to an increase of the turbulent kinetic energy, whereas the differences at the mean wind loads are relatively small in this area. The highest values of mean and maximum wind loads are observed near the windward stand edge, the highest Fmax/Fmean-ratios occur at x/H ≈ 5.

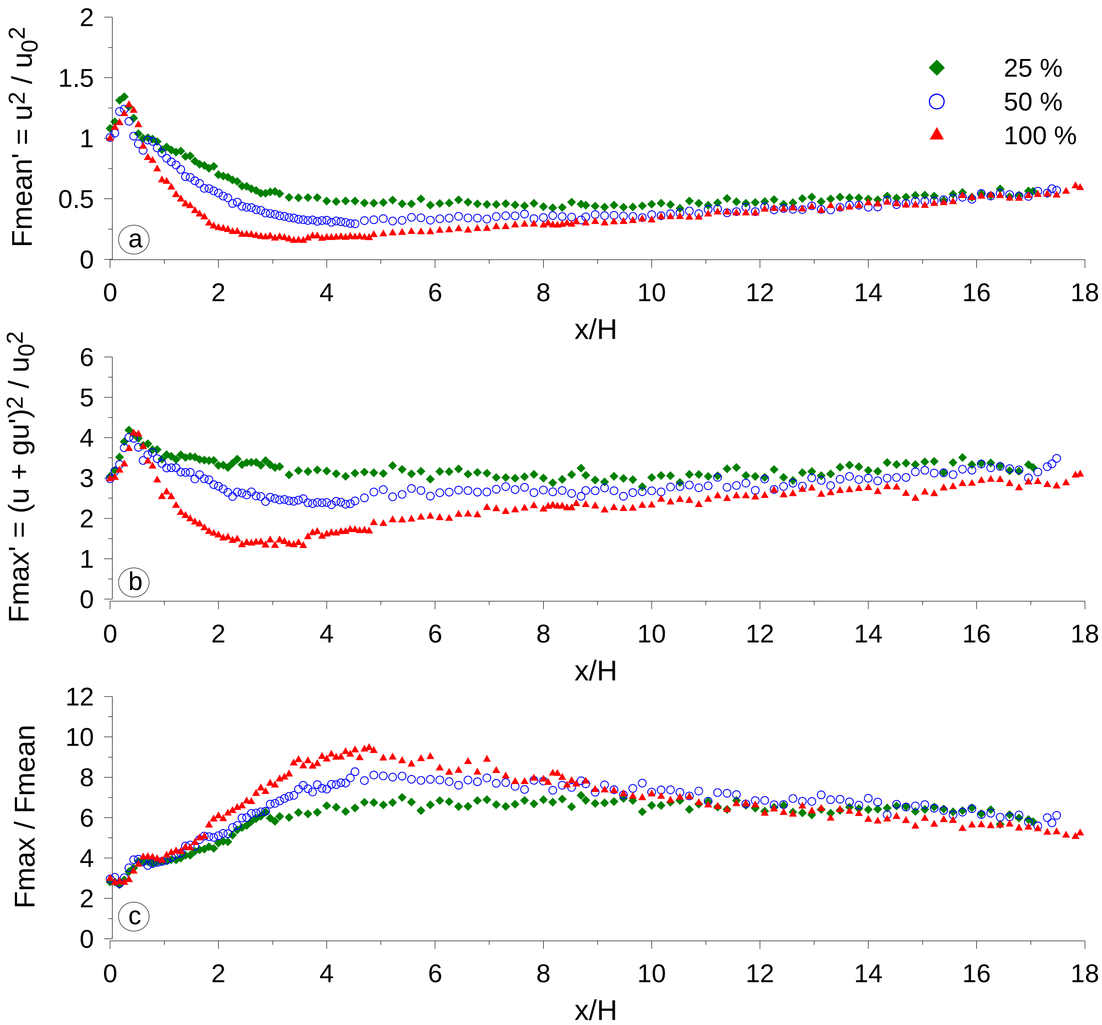

Fig. 3: Streamwise variability of wind loads near the canopy top (z/H = 1.13) above homogeneous forest stands of varied stand density: a) normalised mean wind loads Fmean', b) normalised maximum wind loads Fmax', c) ratio of maximum to mean wind loads Fmax/Fmean (u_0 = 5.4 m/s)

3.2 Staggered forest arrangements

Type "Sparse - Dense"

In Fig. 4 the streamwise variability of the wind loads above staggered forest arrangements of the type „Sparse - Dense" (with stand densities BD = 25/100 %) and additionally above the homogeneous forest stands of comparable stand densities is depicted. The vertical lines mark the transitions from sparse to dense forest area, that is, the position of the inner stand edges. The curves of the staggered arrangements are embedded by the curves of the homogeneous forest stands. If the windward arranged sparse forest area is short (L = 0.7H) the curves resemble yet those above the homogeneous dense stand, however, in the near-edge area up to x/H ≈ 4 the wind loads are slightly higher. For the configurations with longer sparse forest areas (L ≥ 2.1H), the curves of the staggered arrangements are nearly identical near the windward forest edge to the curves of the homogeneous sparse stand and they are comparable from a certain distance downstream of the inner stand edge to the curves of the homogeneous dense stand. The wind loads adjust to the varied stand density in an area between about 1-2H upstream and 4-5H downstream of the inner stand edges. With increasing length of the windward arranged sparse forest area, the minima of both the mean and the maximum wind loads increase and the maximum of the Fmax/Fmean-ratio decreases.

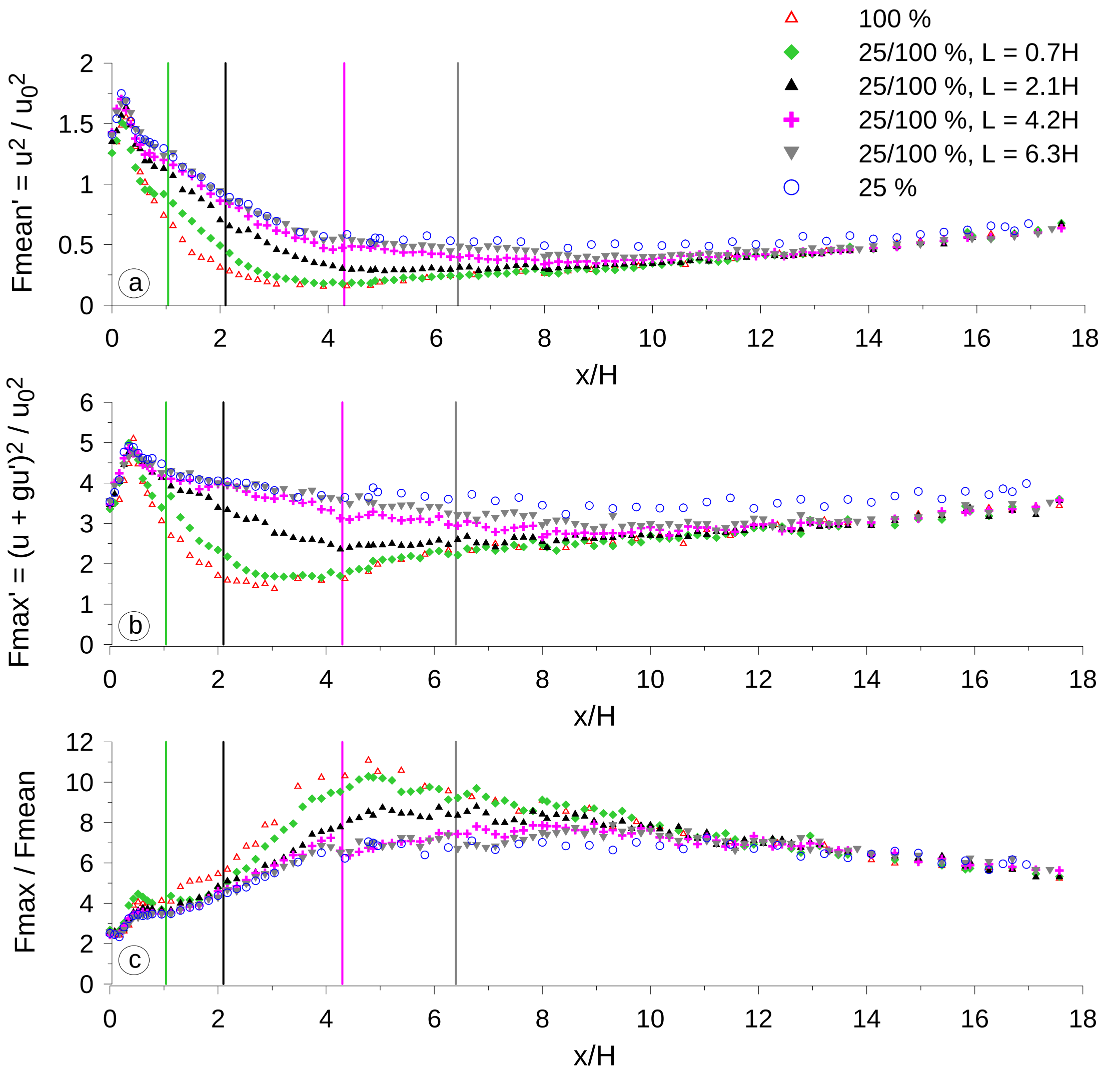

Fig. 4: Streamwise variability of wind loads near the canopy top (z/H = 1.13) above staggered forest stands (BD25 – BD100) of varied length: a) normalised mean wind loads Fmean', b) normalised maximum wind loads Fmax', c) ratio of maximum to mean wind loads Fmax/Fmean; the variability above the homogeneous stands of corresponding stand densities is also depicted (u_0=5.4 m/s)

Type "Dense - Sparse"

Fig. 5 shows that the curves of the staggered arrangements of the type "Dense - Sparse" are likewise embedded by those of the both homogeneous stands. The curves of the staggered arrangements are close to the windward forest edge nearly identical to those of the homogeneous dense stand. When the windward arranged dense forest area is short (L/H = 0.9) a clear increase of the wind loads is observed downstream of the inner stand edge in comparison to the homogeneous dense stand; for L/H = 2.3 only a slight increase occurs. For longer dense forest areas (L/H = 4.5 and 6.6) the wind load distributions along the whole forest length are similar to those of the homogeneous dense forest. The area in which the wind loads adjust to the varied stand density is all in all longer for the staggered arrangements of the type "Dense – Sparse" than for the "Sparse – Dense"-configurations.

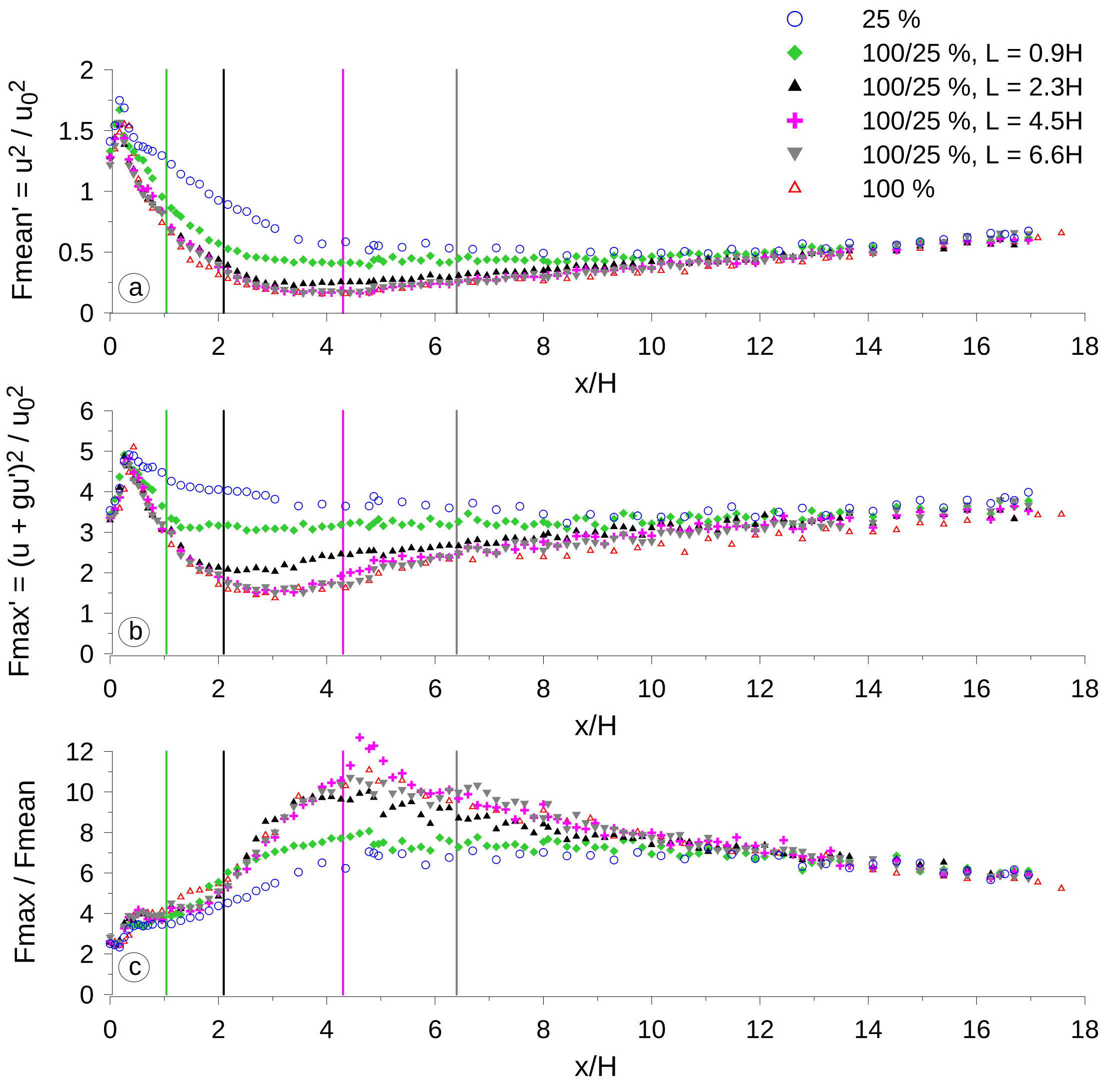

Fig. 5: Streamwise variability of wind loads near the canopy top (z/H = 1.13) above staggered forest stands (BD100 – BD25) of varied length: a) normalised mean wind loads Fmean', b) normalised maximum wind loads Fmax', c) ratio of maximum to mean wind loads Fmax/Fmean; The variability above the homogeneous stands of corresponding stand densities is also shown (u_0=5.4 m/s)

4. Discussion

Gardiner and Stacey (1996) measured mean and extreme stem bending moments along 15 m high Sitka model forests of varied stand density and also determined a gust factor describing the ratio of extreme to mean stem bending moment. Even if their model forests are denser and smaller than ours, a comparison of the different quantities shows a good agreement by trend. Only near the windward forest edge ($x/H < 1$) the behaviour of the wind load curves near the canopy top is contrary, what can be attributed to the fact that bending moments are integral quantities describing the change of wind loads over the whole stand height and that in the near-edge area the wind loads at $z < H$ still contribute significantly to the resultant bending moment.

Gardiner and Stacey (1996) as well as Dupont and Brunet (2008) carried out studies about the influence of forest edge structure on the amount of the applying bending moments and found out that upstream sparse forest areas being 2H long result in a bending moment reduction in the near-edge area of the dense stand. Our measurements confirm their results by trend, see Fig. 6, however, our results also show that further downstream (at a higher distance to the inner stand edge) the wind loads will increase.

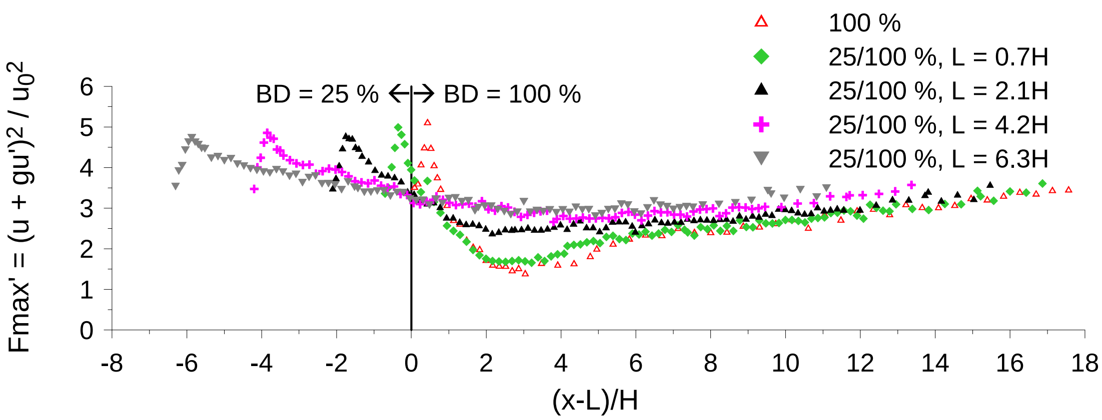

Fig. 6: Streamwise variability of the maximum wind load near the canopy top ($z/H = 1.13$) above staggered forest stands (BD25 – BD100) of varied length

Acknowledgement

These investigations were performed within the project ‘Improving the storm stability of forest stands’ which is part of the RESTER-network (‘Strategies for the reduction of the storm damage risk for forests’) within the research program ‘Challenge climate change’. The authors would like to thank the Ministry for the Environment of the German federal state Baden-Württemberg for the financial support of this project.

References

Frank, C., Ruck, B., Tischmacher, M., 2009: About the influence of the windward edge structure on the flow characteristics at forest edges. Ber. Meteor. Inst. Univ. Freiburg No. 19, 9-14.

Dupont, S., Brunet, Y., 2008: Impact of forest edge shape on tree stability: a large-eddy simulation study. Forestry 81, 299-316.

Gardiner, B., Stacey, G., 1996: Designing forest edges to improve wind stability. Forestry Commission, Technical Paper 16. 8 p.

Authors' address:

Dr. Cornelia Frank (frank@ifh.uni-karlsruhe.de)
Prof. Dr. Bodo Ruck (ruck@uka.de)
Laboratory of Building- and Environmental Aerodynamics, Institute for Hydromechanics
University of Karlsruhe
Kaiserstr. 12, D-76128 Karlsruhe, Germany