A Wind Tunnel Study of Windbreak Flow Dynamics Using Particle Imaging Velocimetry

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Abstract

Windbreaks play an important role in agriculture through reducing erosion and providing shelter from wind and snow. Additionally, they provide protection for roadways from snow and mitigate dust emissions from un-paved roads. Understanding the motion of air born particles, as well as the behavior of air as it passes over and through these windbreaks can help optimize performance and identify further benefits to plant growth, road protection, and road impact remediation. Here, near windbreak physics are studied using two dimensional particle image velocimetry (PIV). A range of overall windbreak porosities are studied with constant square hole geometries. Our initial analysis focuses on the basic behavior of the mean velocity field behind the windbreak and how it changes with porosity. In addition to mean flow patterns, here sample instantaneous flow realizations are examined to illustrate variability of the flow field. Particular emphasis is placed on the effects of porosity on the quiescent region directly downwind of the windbreak, the reattachment point where wall shear begins to dominate, and the shear layer emanating from top of the wind break. When applicable, comparisons are made to past experimental studies of windbreak flow dynamics.

Objectives

- Visualize effects of varying porosities on windbreak flow regions (Fig. 2).
- Observe mean and instantaneous reattachment zones.
- Determine the limits of operation for current PIV equipment and setup.

PIV

- 2x TSI PowerView 29MP cameras.
- 6592x4400, 12-Bit grayscale image, 1.6Hz.
- 800mm horizontal field of view.
- 71.4 μm per pixel resolution.
- 2x 250 mJ pulsed laser sheet.
- 1000 image pairs captured.
- 85-99k Vectors per image per camera.
- 96-99% Good vectors.

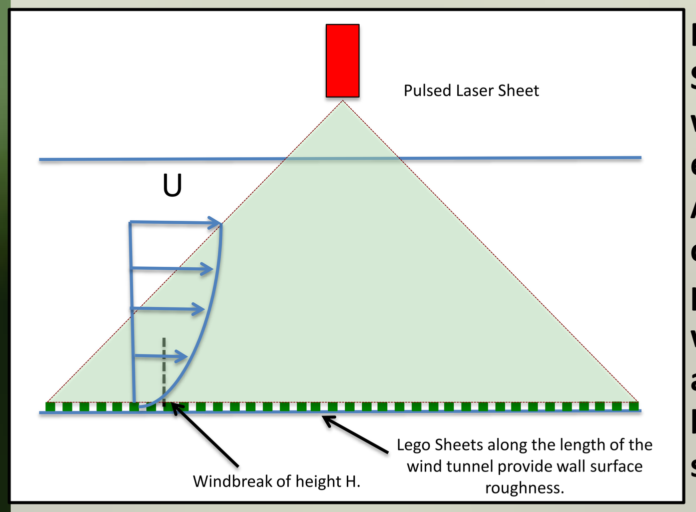

Figure 1: Schematic of windbreak PIV experiment. Atomized olive oil particles are pulled into the wind tunnel and illuminated by the laser sheet.

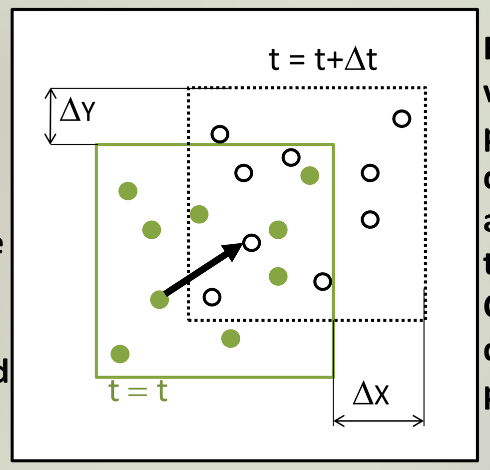

Fig. 2 To produce velocity vectors, particle displacements are measured at t=t and t+Δt. Cross correlations determine most probable vector

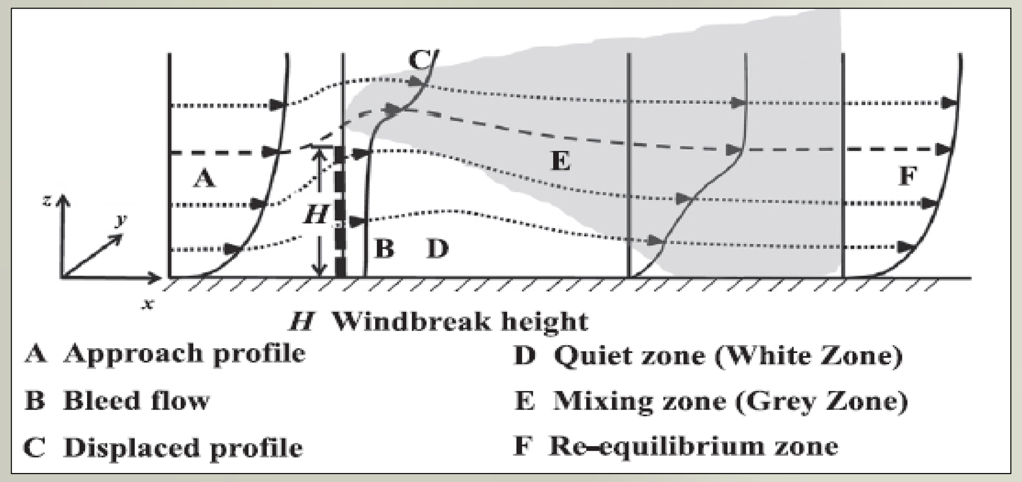

Figure 3: Schematic of windbreak flow regions and characteristics (Speckart and Pardyjak, 2014). This experiment analyzed the change in each of these regions across varying porosity windbreaks.

Experimental Setup

- 2D PIV with two cameras were used to increase downwind field of view and maintain high resolution. Camera images were stitched together in post processing using a common origin defined during calibration.
- Wind Tunnel free stream velocity was held constant across each run at 5.5 m·s^{-1}.
- Windbreaks are 200 x 70 mm, the boundary layer is 22cm, resulting in δ/h of ~3.

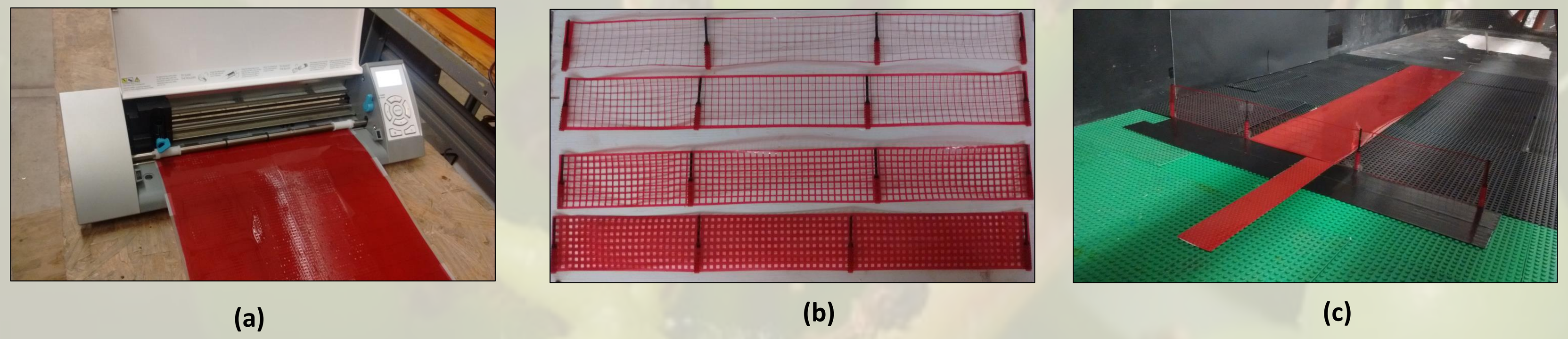

***Figure 4:** (a) Windbreaks are cut from red vinyl and a yellow filter is used on the camera lenses to reduce effects from reflections off the windbreak. (b)From top to bottom - 90, 75, 50 and 25% porosity windbreaks. (c) 90% porosity windbreak installed in wind tunnel.*

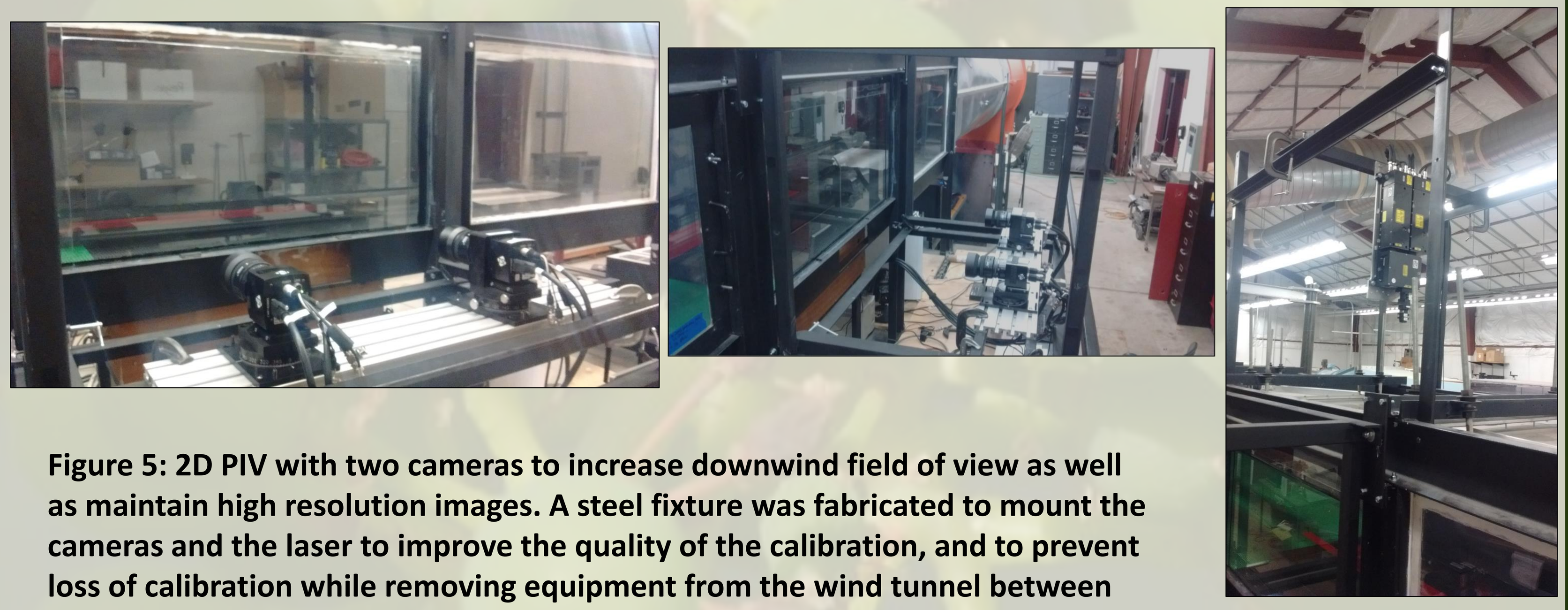

Figure 5: 2D PIV with two cameras to increase downwind field of view as well as maintain high resolution images. A steel fixture was fabricated to mount the cameras and the laser to improve the quality of the calibration, and to prevent loss of calibration while removing equipment from the wind tunnel between runs.

Ū Velocity profiles for varying porosities

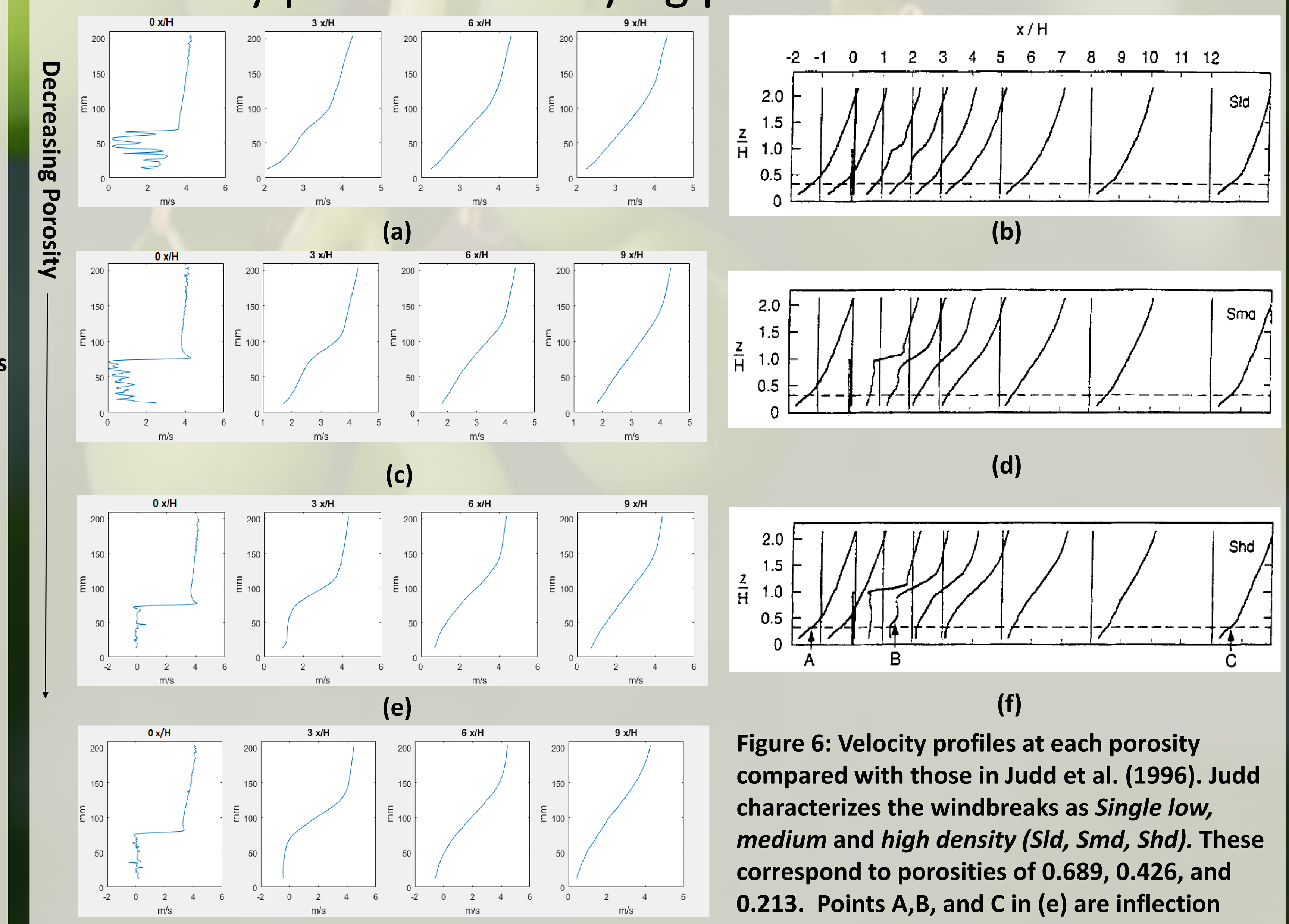

Figure 6: Velocity profiles at each porosity compared with those in Judd et al. (1996). Judd characterizes the windbreaks as *Single low, medium* and *high density (Sld, Smd, Shd).* These correspond to porosities of 0.689, 0.426, and 0.213. Points A,B, and C in (e) are inflection points as described in the published work.

Flow visualizations for 25, 50, 75, and 90% porosity

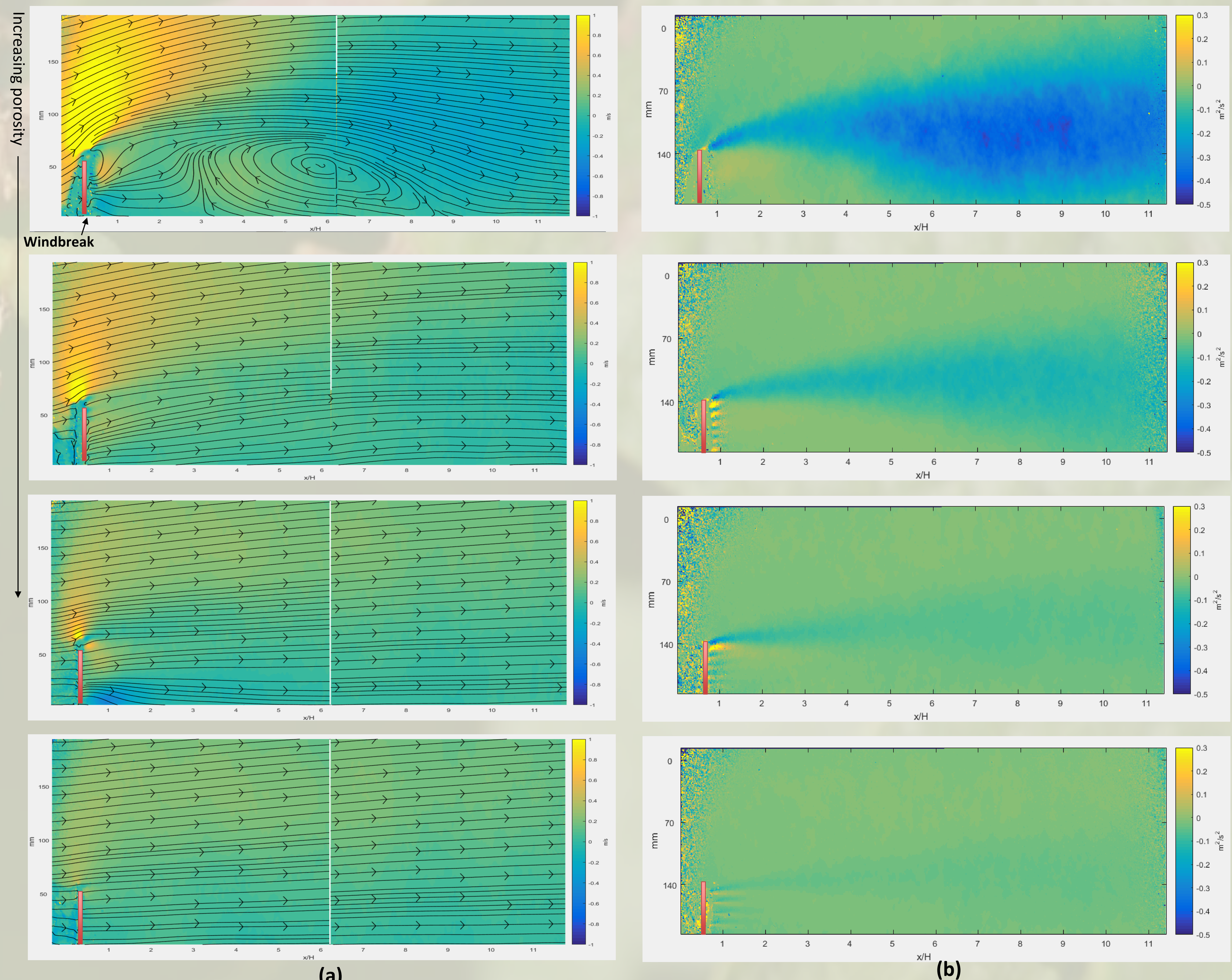

Figure 7: (a) $\overline{W}$ with super imposed stream lines and (b) Vertical stress U'W'. From top to bottom – 25, 50, 75, and 90% porosity.

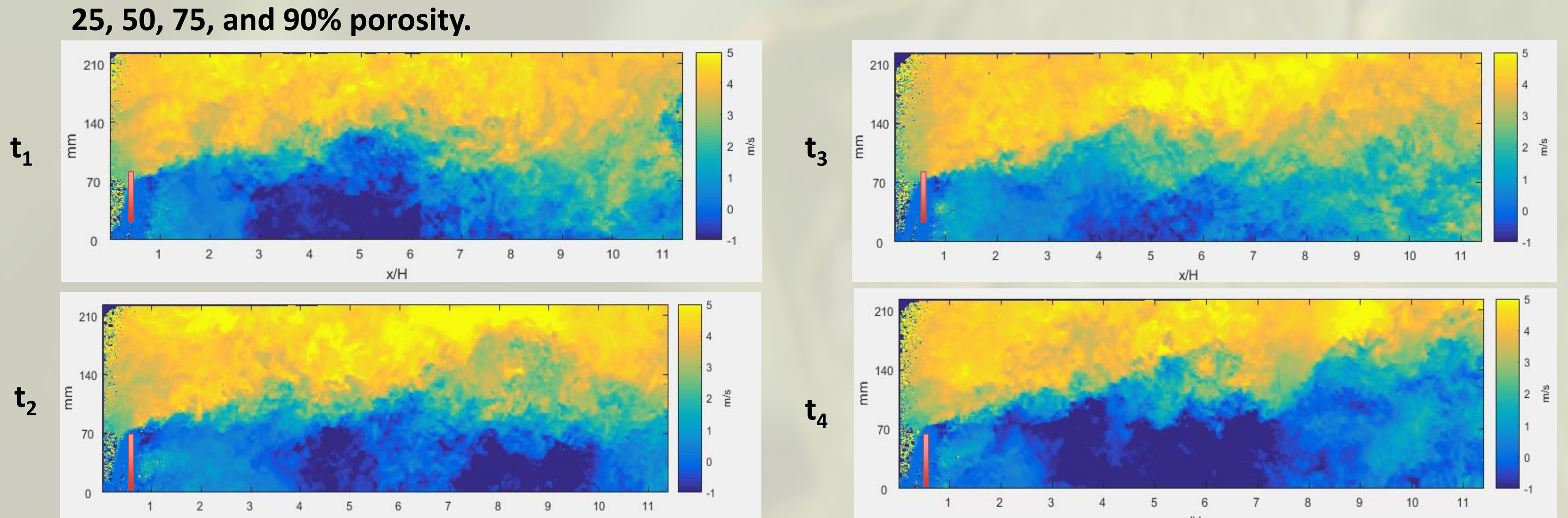

Figure 8: Instantaneous U velocity in four sequential frames (t_1-t_4) of the 25% porosity windbreak. Note the large changes in the shape of the characteristic flow regions depicted in figure 3.

Summary and Future Work

- The 50, 75 and 90% porosity windbreaks had significant bleed flow, reducing recirculation and decreasing the size of the quiet zone.
- A way to define reattachment in the case of a windbreak is needed in order to robustly characterize windbreak flow regions.
- Future work will focus on conditional averaging and instantaneous analysis of the flow fields in order to then characterize the variability of the windbreak flow regions.

References

1. M. J. Judd, M. R. Raupach, and J. J. Finnigan, "A wind tunnel study of turbulent flow around single and multiple windbreaks, Part 1: Velocity fields", *Boundary-Layer Meteorology,* 1996.
2. S.O Speckart, E.R. Pardyjak, "A Method for Rapidly Computing Windbreak Flow Field Variables", *Journal of Wind Engineering and Industrial Aerodynamics*, 2014.

Acknowledgements

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