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PIV Measurements of Flow immediately above Woven Fabrics

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May 4, 2011

May 1-4 PaperCon 2011
Northern Kentucky Convention Center

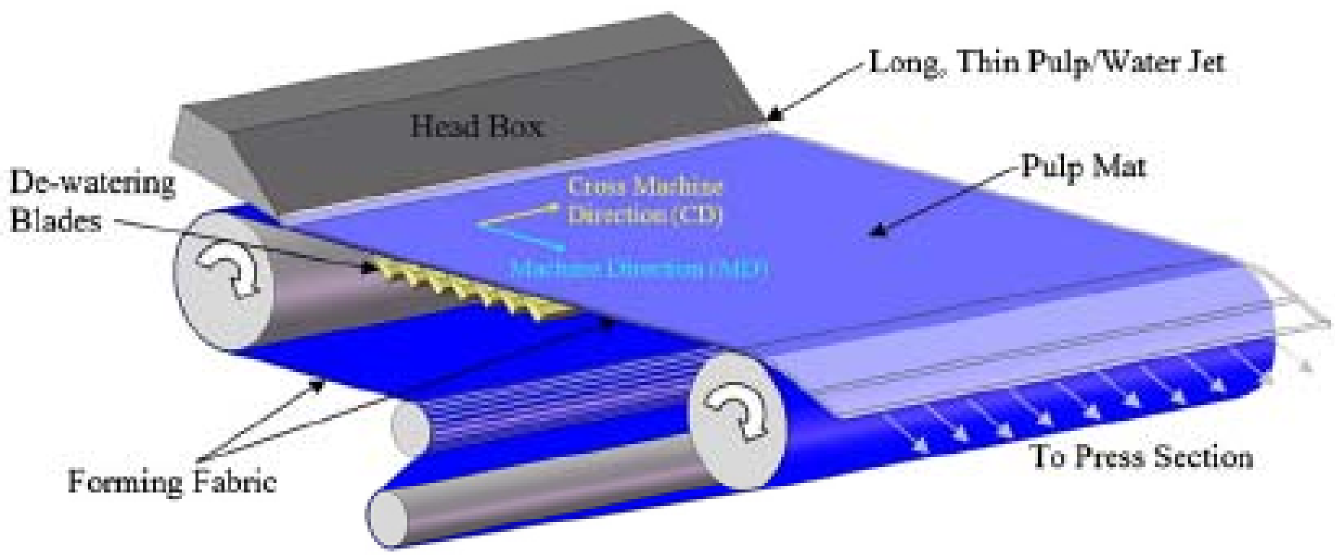
RETHINK PAPER: Lean and Green

Introduction

•Paper making contains three basic processes: forming, pressing and drying.

•In the forming section, a dilute suspension of pulp(0.7%) is forced through a woven forming fabric to create a fibrous pulp mat.

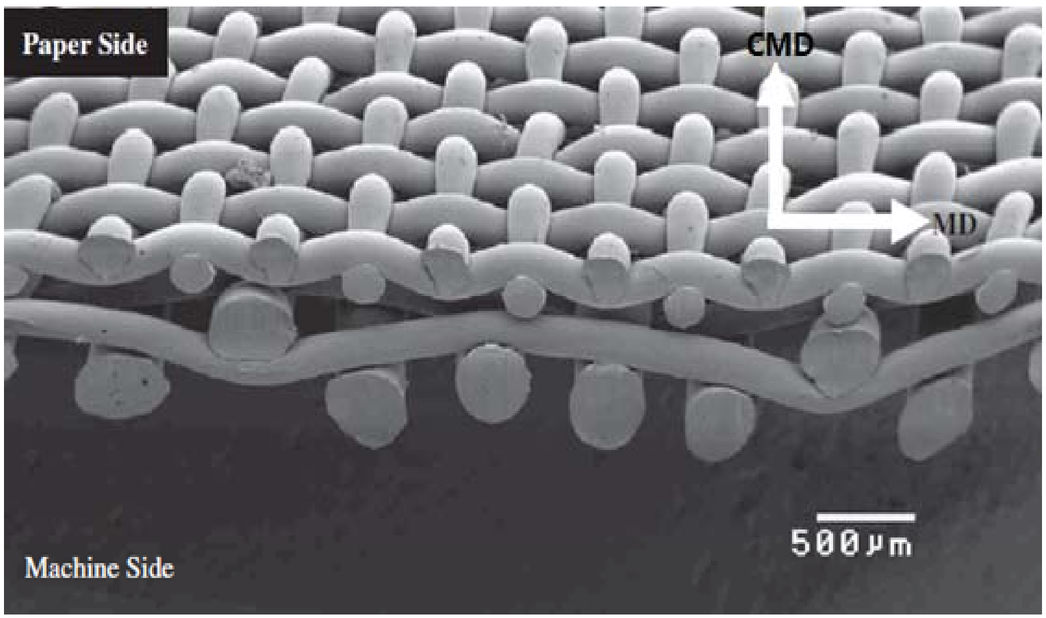
•High quality paper ⟶ Uniform fiber distribution ⟶ Uniform velocity profile on the upstream side of fabric layer on which the pulp mat is formed.

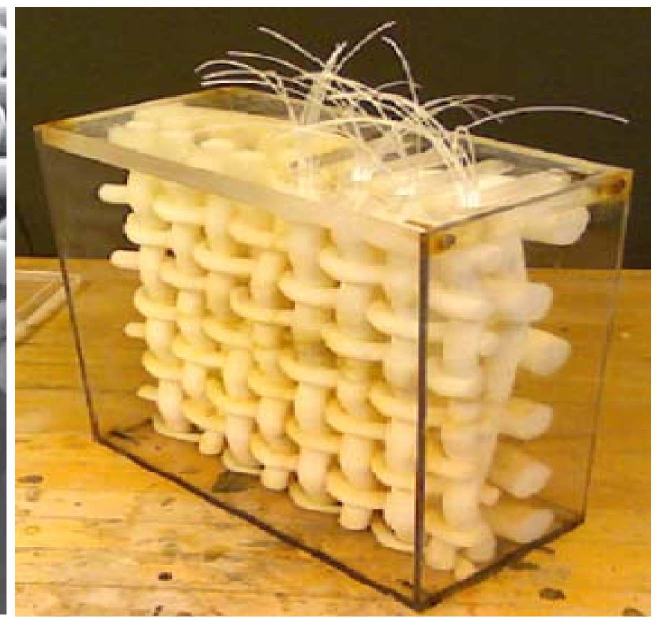


Introduction

- Forming fabric structure: complex 3d woven matrix, which consists of machine direction (MD) and orthogonal cross machine direction (CMD) filaments in two or more layers.

- A scaled model is used for the experiments to investigate flow property based on the same Re of real papermaking process. (Re is defined by paper side filament diameter, 6.5~65)





Objective

- To measure 3d velocity fields in the approach flow to a multiple layer forming fabric by Particle Image Velocimetry (PIV).
- To investigate the flow non-uniformity and its probable effect on paper.

Assumption:

- The pulp at the beginning of the forming section has a very low concentration of fibers in water (0.7%), and therefore single phased glycerin solution was used in the experiments.

Literature Review

1. Numerical and experimental investigation were done of the flow through two rows of cylinders.

[1]. Huang, Z., 2003. Numerical simulation of flow through model paper machine forming fabrics. *Master's Thesis, The University of British Columbia*

[2]. *Huang, Z., Olson, J., Kerekes, R., Green, S., 2006. Numerical simulation of the flow around rows of cylinders*. Computers & Fluids 35,485-491.

[3]. Gilchrist, S., Green, S., 2009. Experimental investigation of flow through bank of cylinders of varying geometry. Journal of Fluids and Structures 25, 506-518.

2. Single layer fabric was used to represent the fabric model.

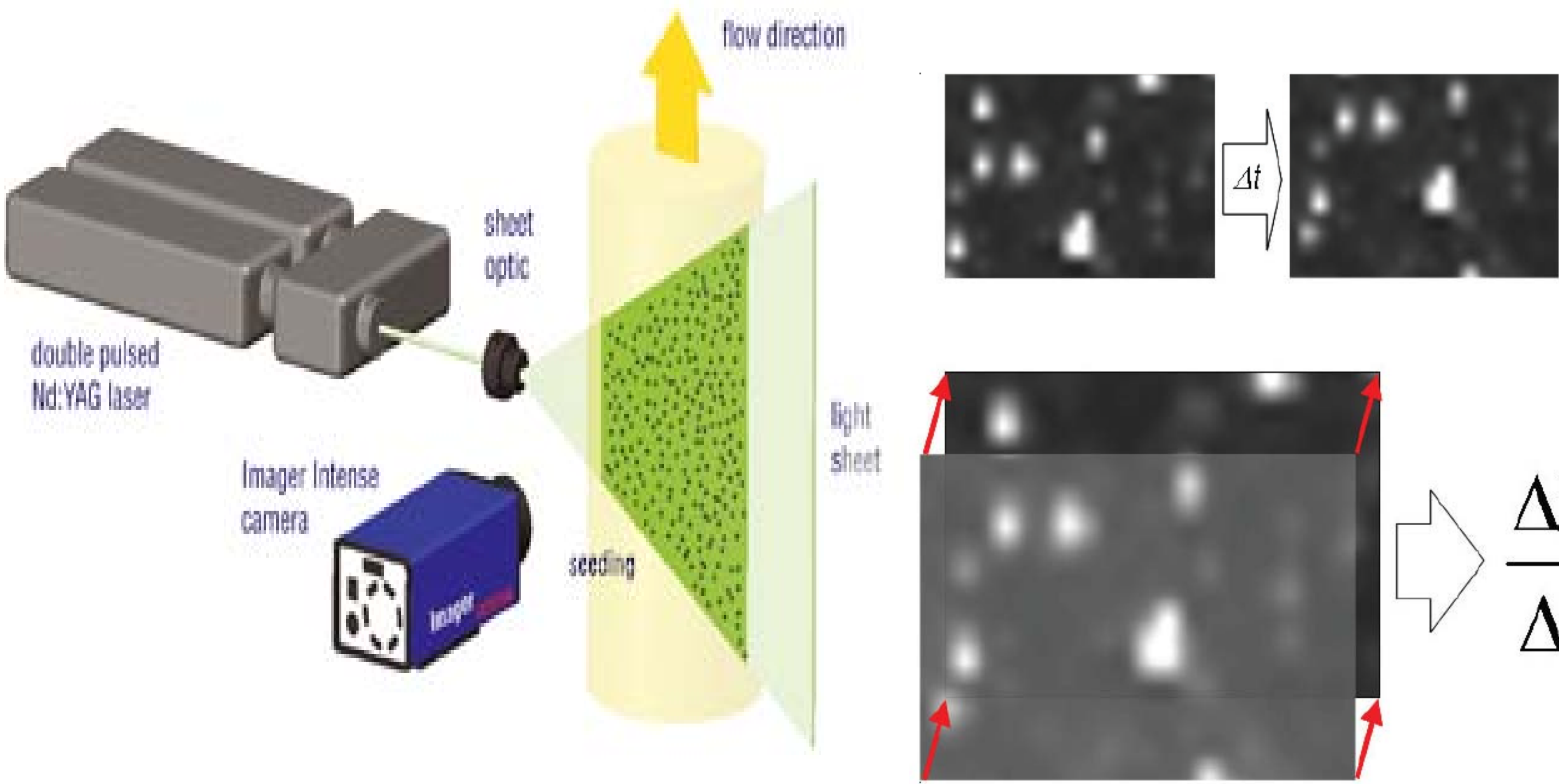
[4]. Green, S., Wang, Z., Waung, T., Vakil, A., 2008. Simulation of the flow through woven fabrics. Computer & Fluids 37, 1148-1156.

3. A novel method, CT scan, was found to create an accurate 3d cad model of forming fabric by a rapid prototype machine.

[5]. Vakil, A., Olyaei, A., Green, S., 2009. Three-Dimensional Geometry and Flow Field Modeling of Forming Fabrics. Nordic Pulp and Paper Research Journal.

Experimental Methods: PIV

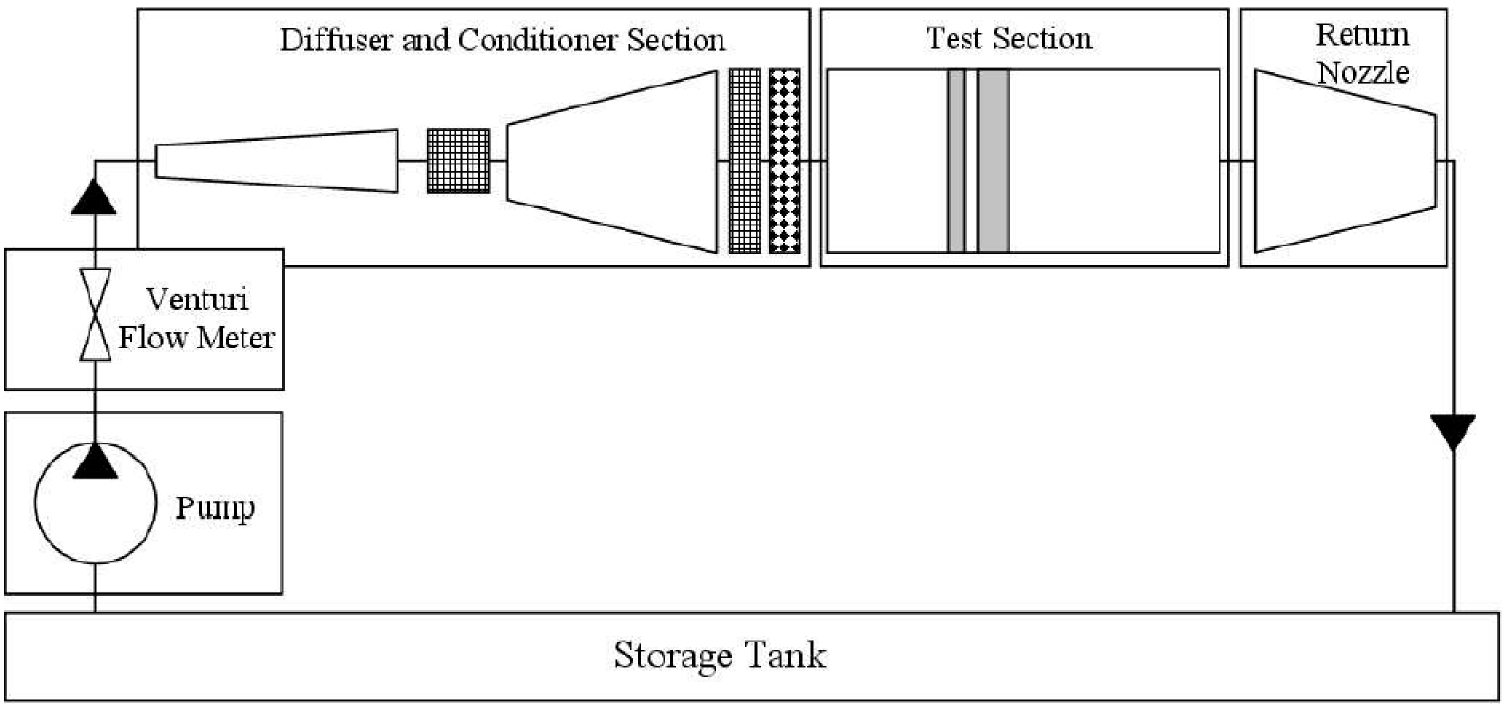
- Principle of Particle Image Velocimetry



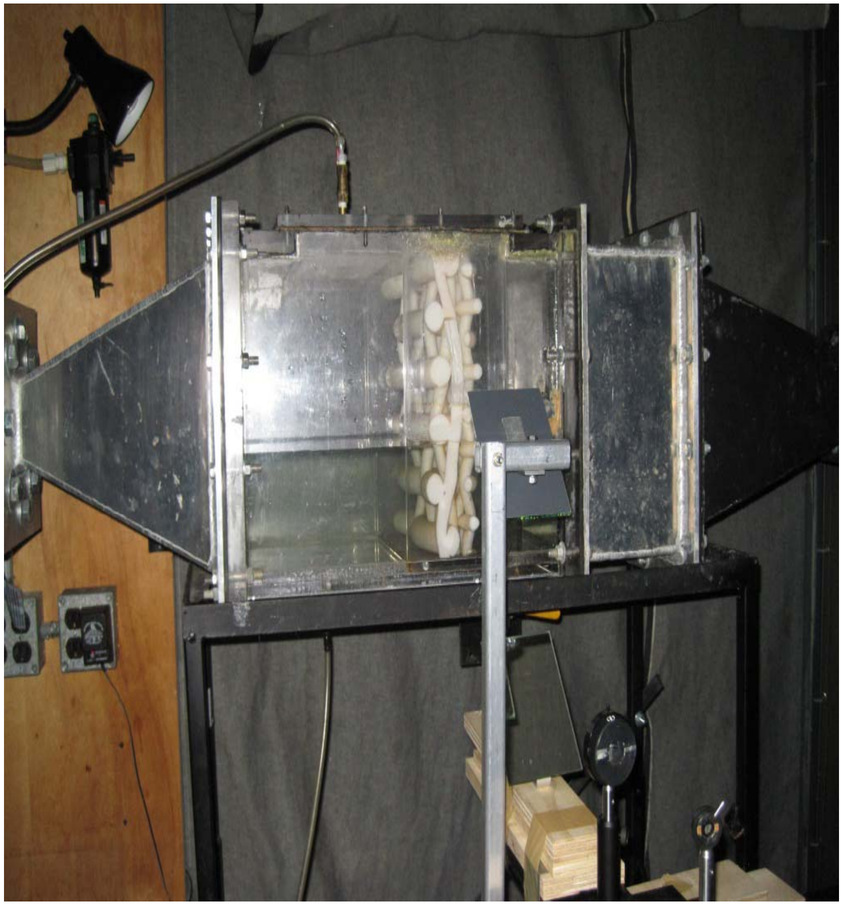
$$\frac{\Delta \bar{x}}{\Delta t} \approx \bar{v}$$

Experimental Methods: Flow loop

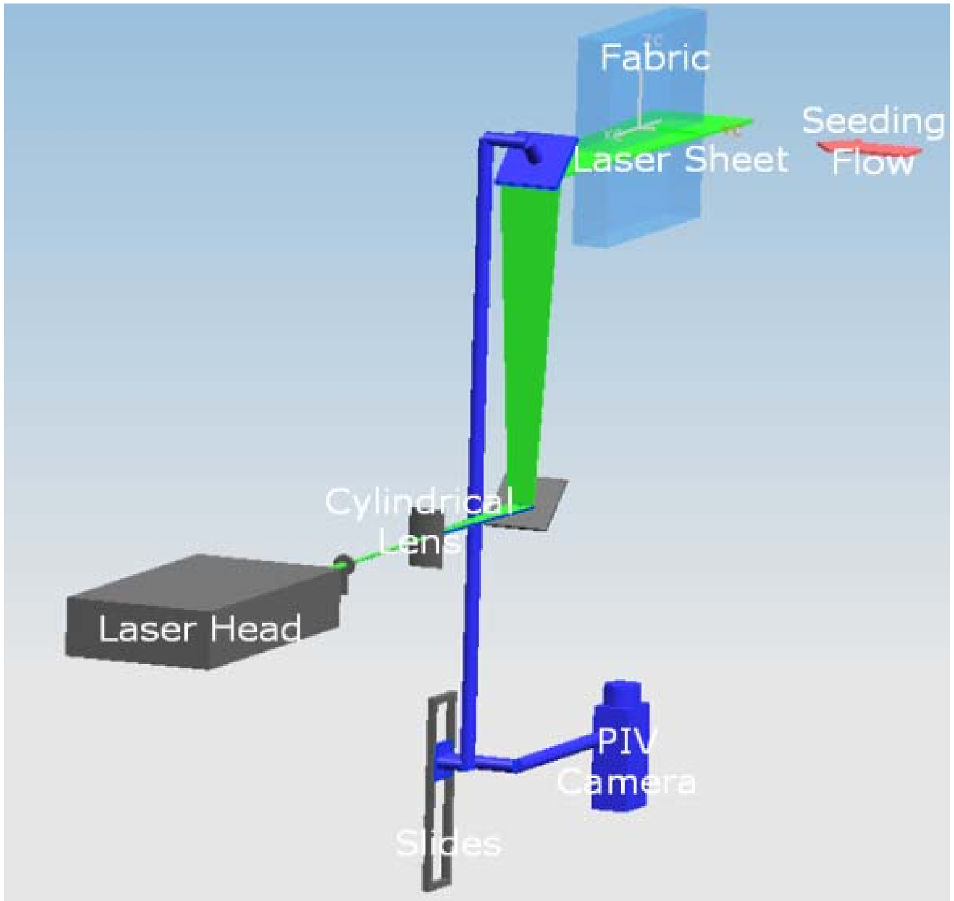
- Velocity: 1.5 to 8 cm/s in the 30cm × 30cm test-section
- Dynamic Viscosity: 10 to 25 cP by using a glycerin solution
- Fabric Model: 80 times-scaled fabric model
- Reynolds Number:10-65



Experimental Methods



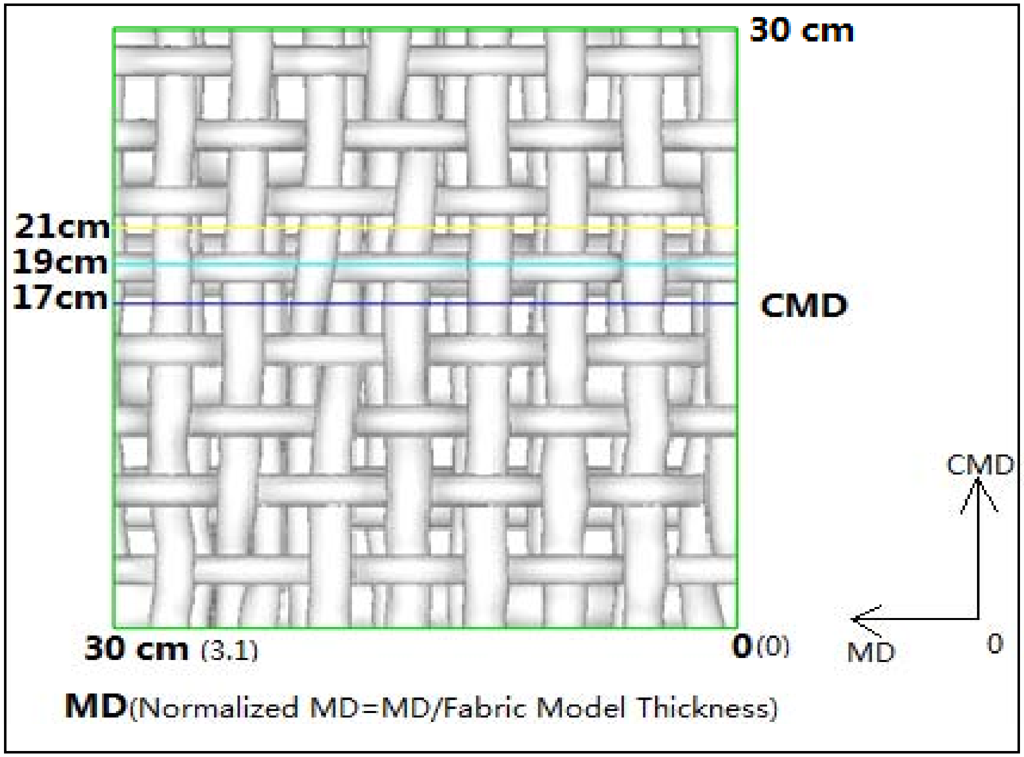
∆ 30cm×30cm test section



∆ Optical setup of the PIV experiment

Experimental Methods

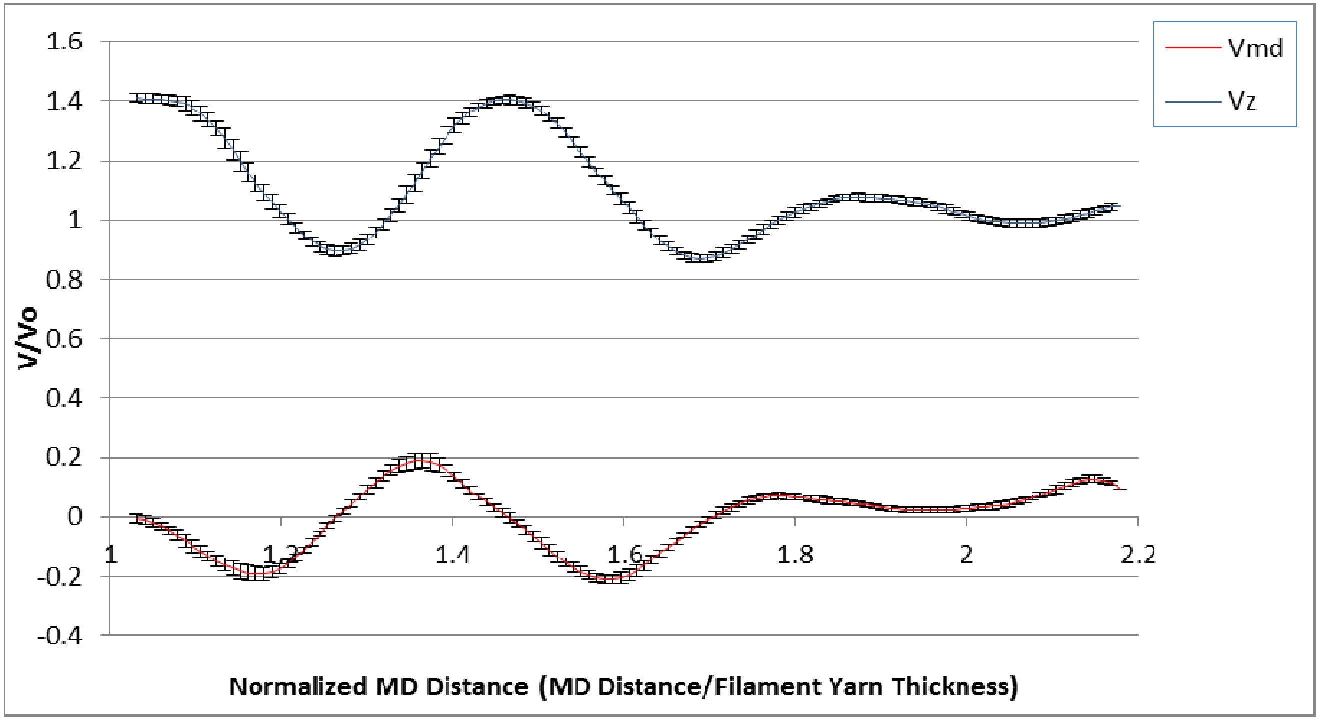
- The fabric model using in the flow loop is a portion smaller than one fabric repeat;
- Only the portion of the fabric away from the test section wall was studied;
- Measurements were taken at different CMD plane for different Re. (15 to 65);
- CMD=17cm (the plane with multiple open areas);
- CMD =19cm (the plane with multiple filament knuckles).



∆ MD-CMD view of the scaled fabric model

PIV Results and Discussions

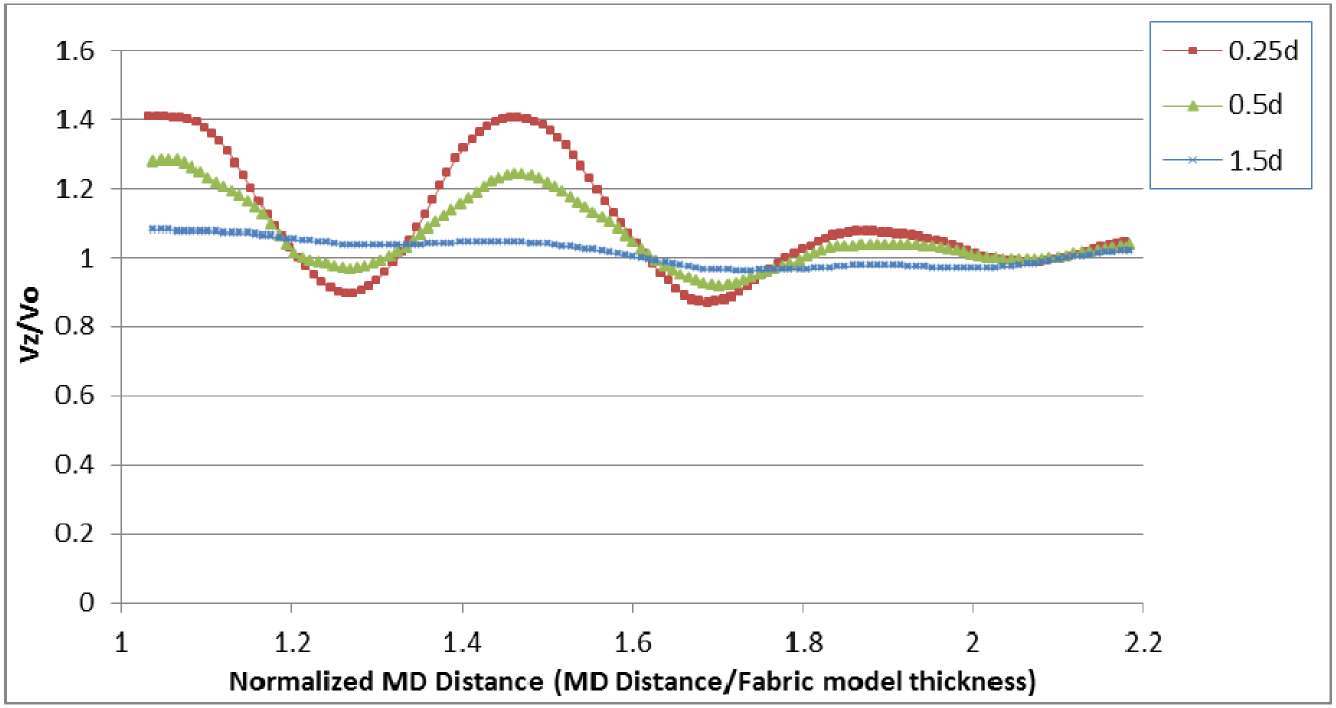
- Velocity vs. MD, @ CMD=17cm, 0.25d upstream, Re=35.
- 95% confidence interval based on 60 PIV image pairs. Highest uncertainty for Vz is ±2.8%.
- $(V_{MD})_{RMS} \approx 0.1 * (V_Z\ @0.25d)_{average}$



PIV Results and Discussions

- $(V_Z@0.25d)_{std}$= 15.1% $decrease\ to$ $(V_Z@1.5d)_{std}$= 3.8%.

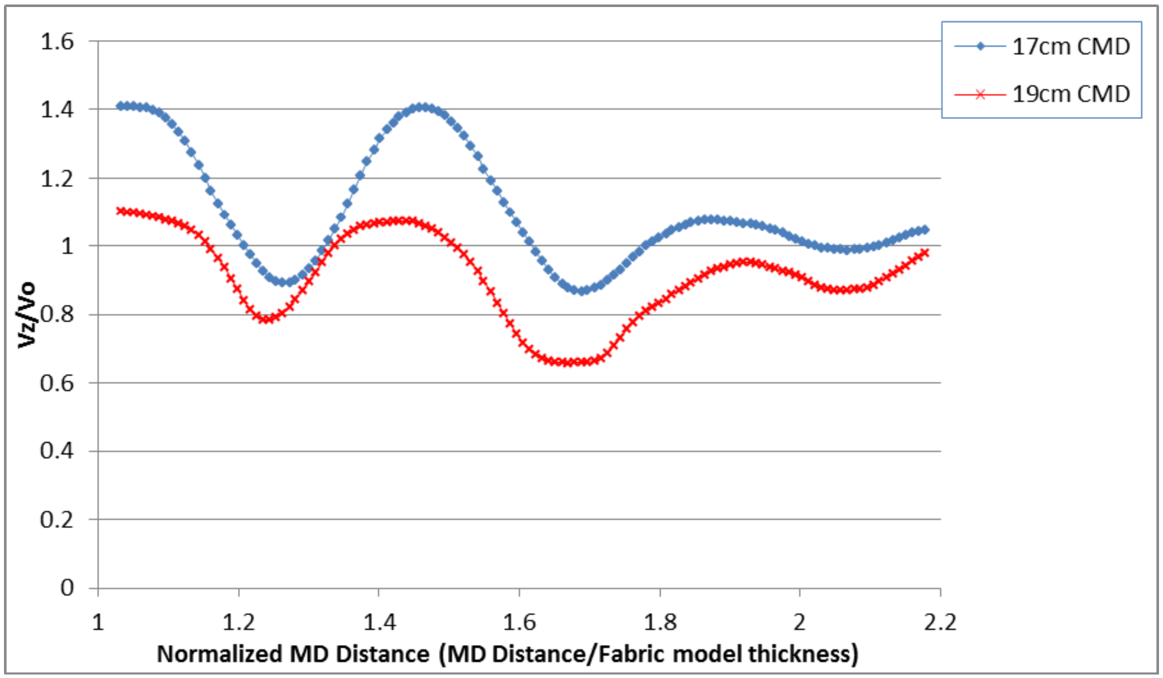
The flow non-uniformity caused by the fabric is only significant within about 1.5 paper side filament diameters (300μm) upstream the fabric.



∆ Vz profile for different distances upstream the fabric; CMD=17cm, Re=35

PIV Results and Discussions

- $(V_Z@0.25d)_{max} = 2.2 * (V_Z@0.25d)_{min}$, the initial accumulation of fines and/or filler content would be 2.2 times higher than in adjacent areas if 100% retention.
- Once fines and fillers start to accumulate on the fabric, the “healing effect” will reduce the magnitude of this variation.



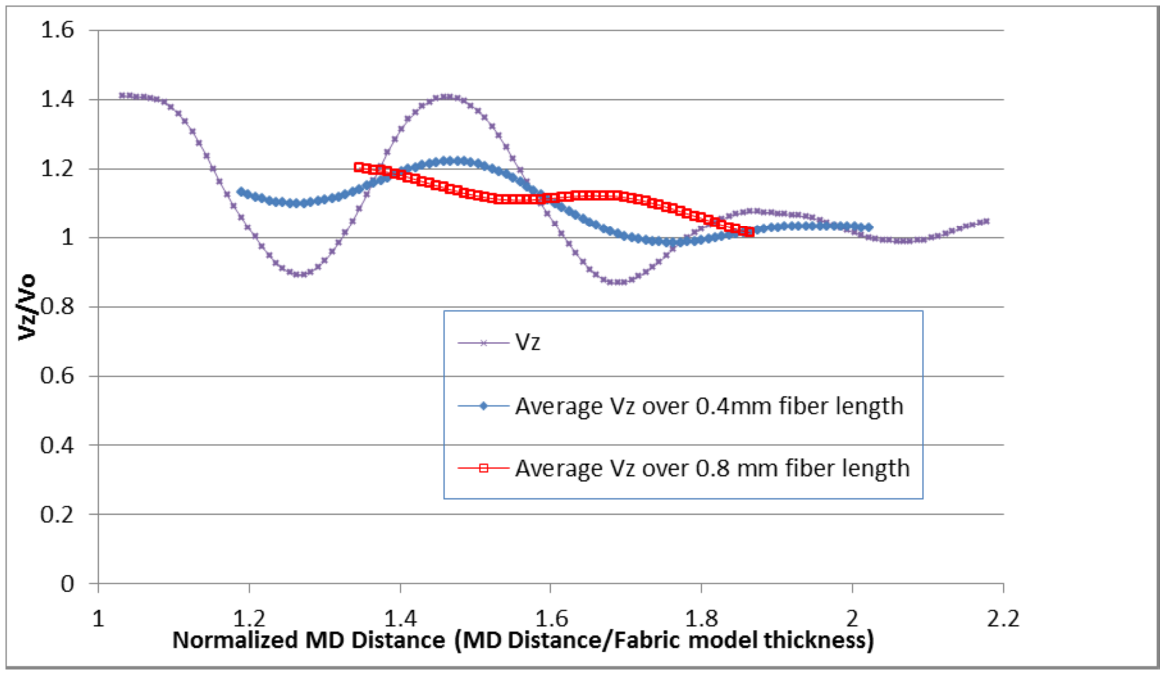
Δ Vz profile on different CMD plane, 0.25d upstream, Re=35

PIV Results and Discussions

- Pulp fiber exposed to flow field forcing related to the average velocity along fiber.

- $(V_z)_{std}$ decrease from 15.1% to 4.2% when averaged over a 0.8mm fiber(shorter than most wood fiber) oriented in MD.

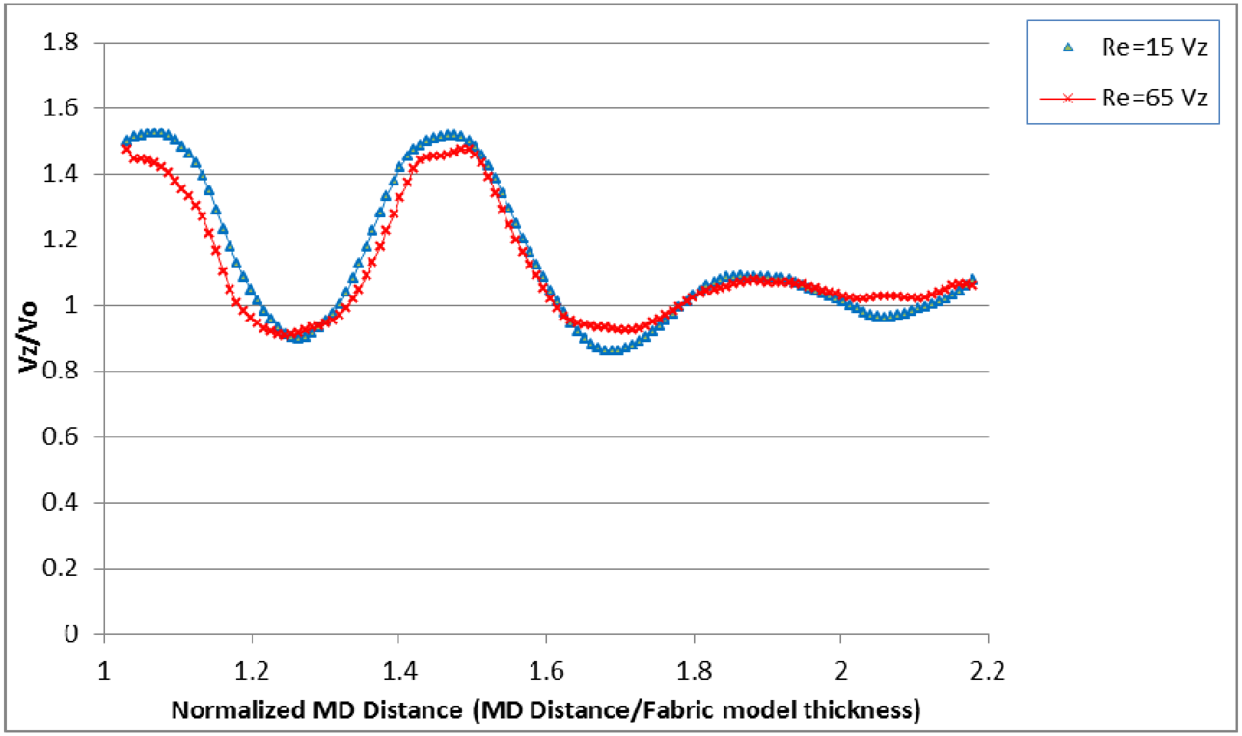
- If fibers were uniformly distributed in the approach flow, they would remain so during interaction with this forming fabric.



Δ Vz averaged over different fiber length in MD

PIV Results and Discussions

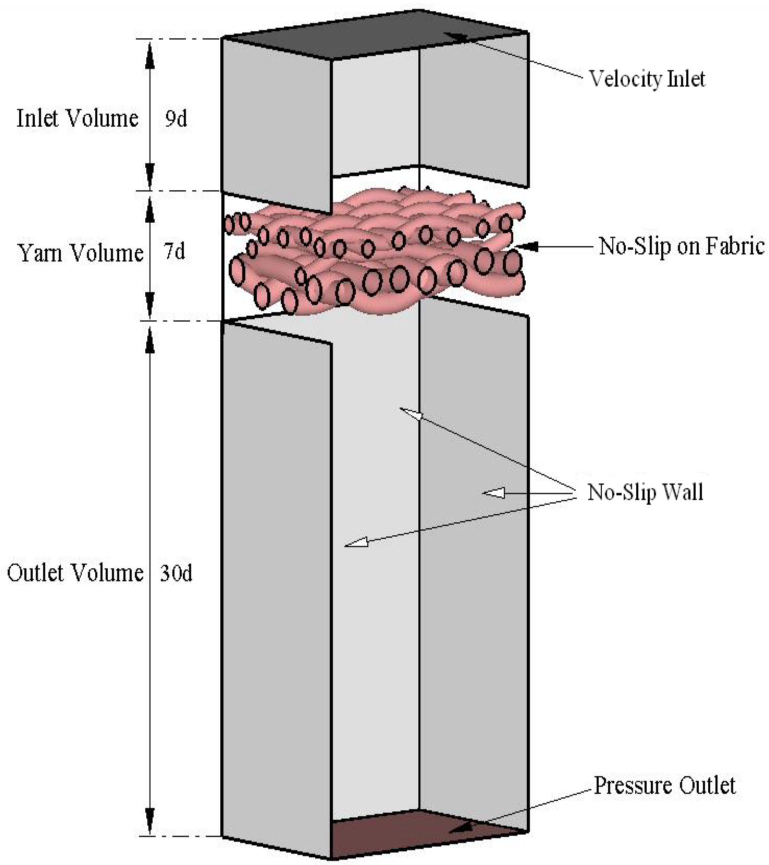
- The standard deviation for a Re of 65 is 16% lower than the deviation for Re 15.
- The reduced standard deviation is consistent with the fact that the distance over which objects affect flow is smaller at higher Re.

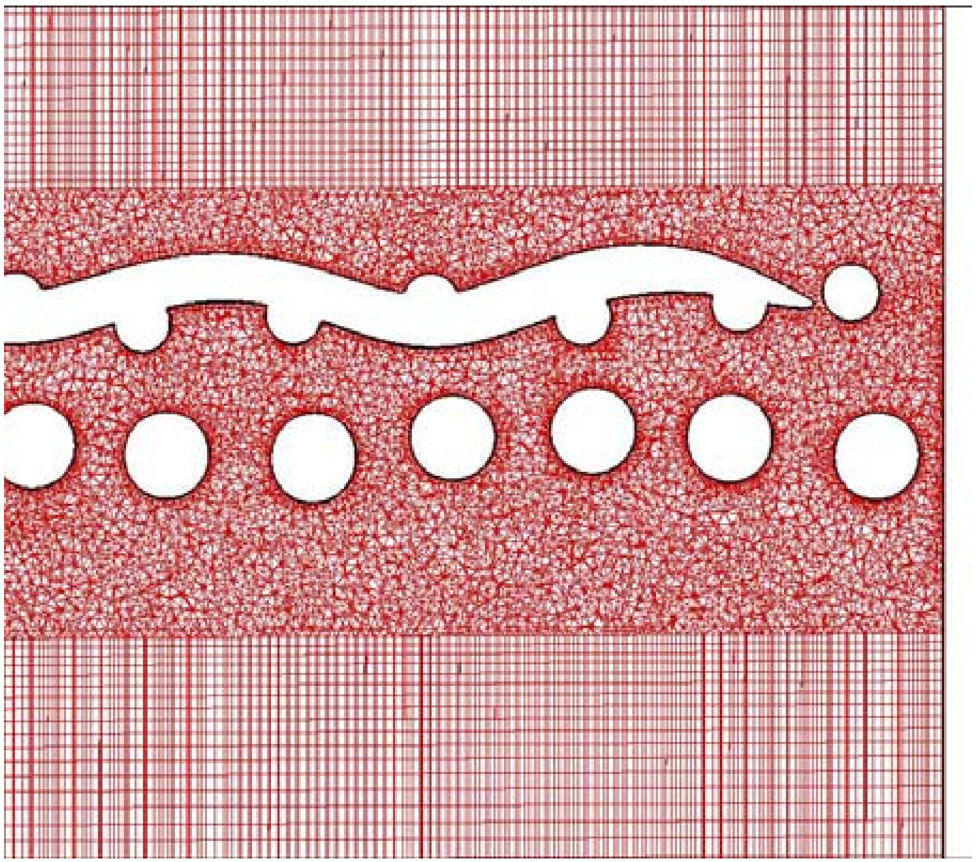


Δ Vz comparison at different Reynolds number

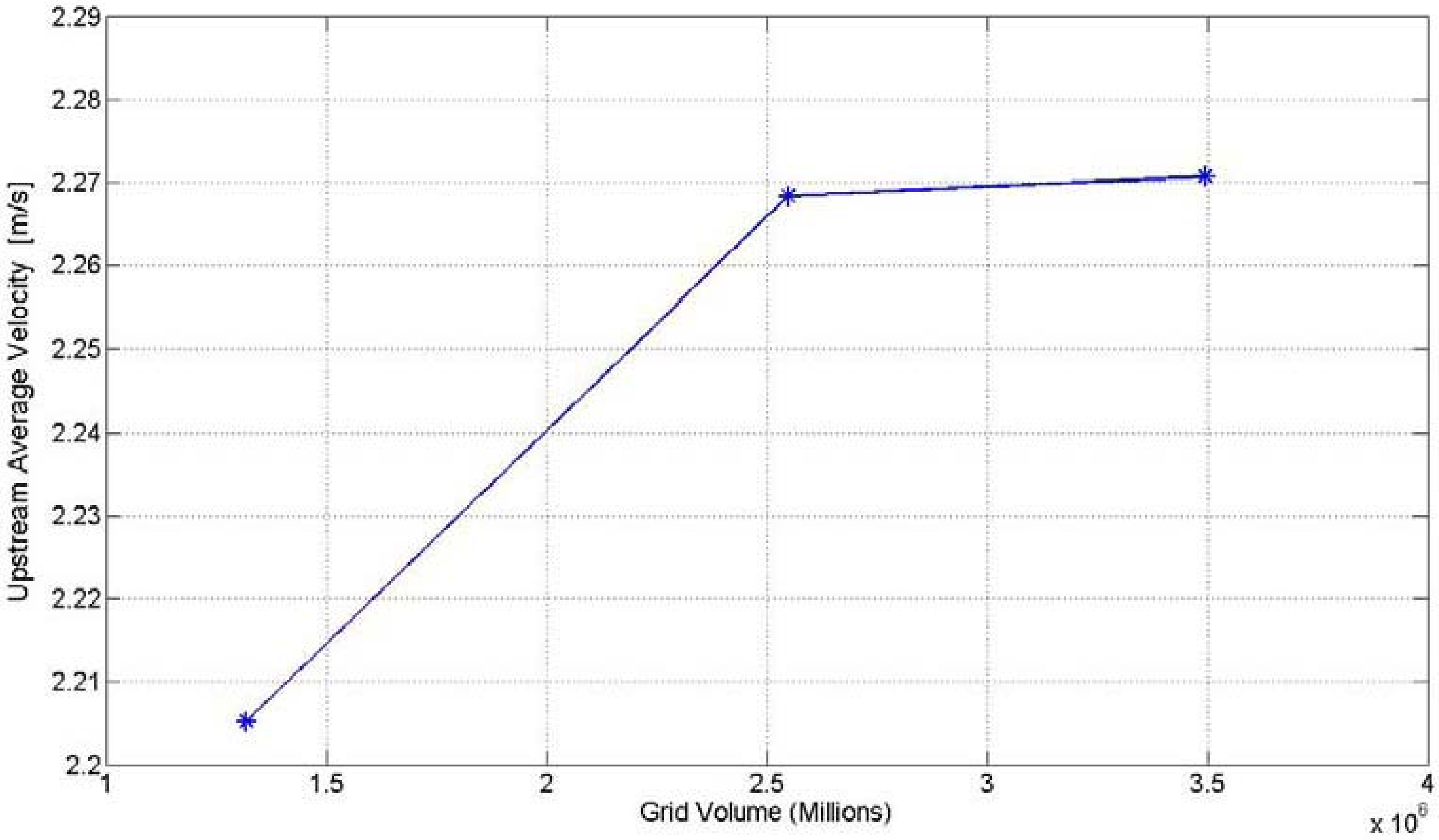
Preliminary Simulation Result

- Solution Method: 3d laminar in Fluent.
- Boundary Condition: Velocity Inlet, Pressure Outlet, No-Slip Wall





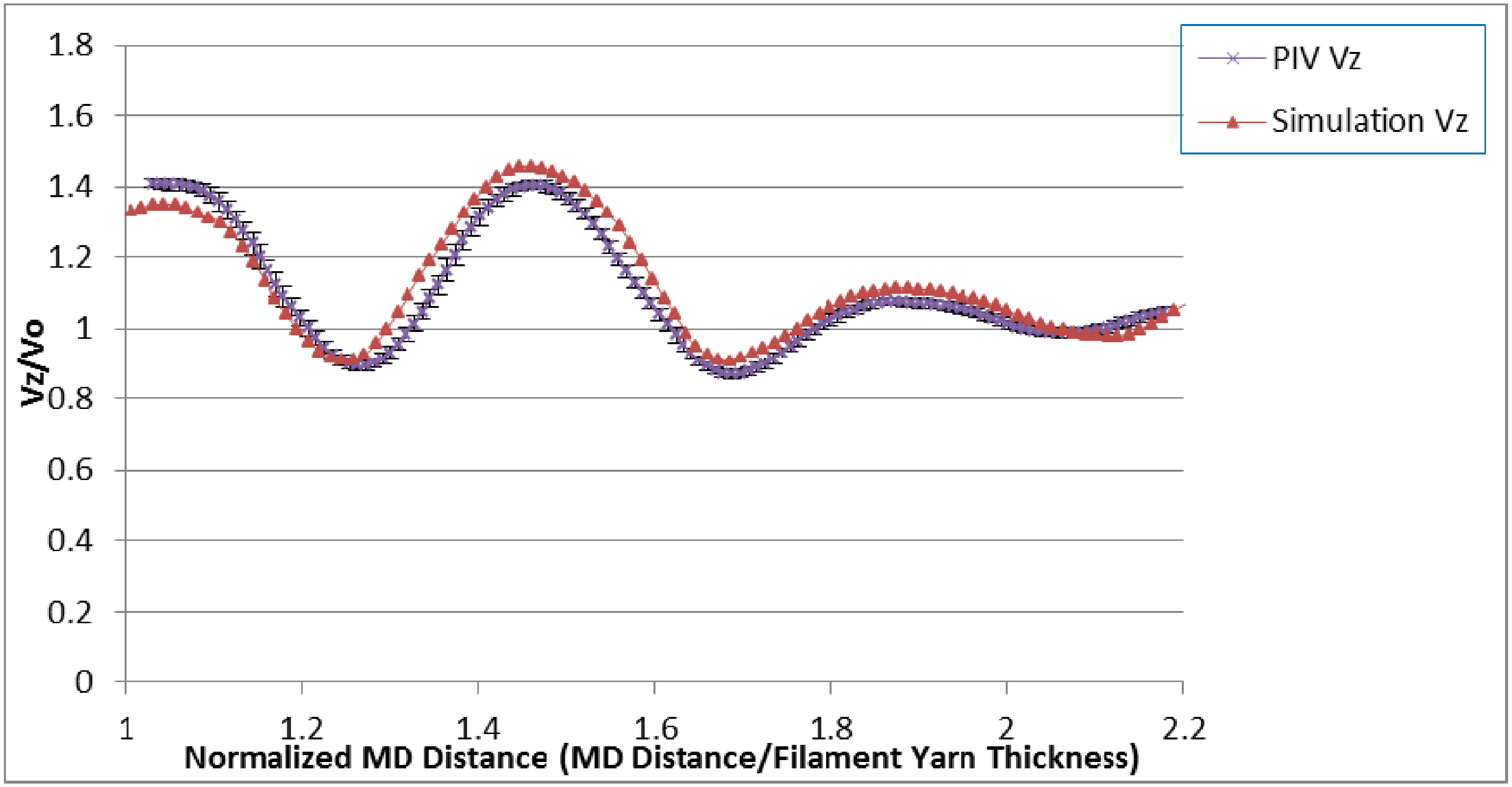
Preliminary Simulation Result: Mesh Independence



Δ Upstream average velocity against mesh density for a pressure drop of 125 Pa

PIV vs. Simulation

- Simulations were consistent with PIV measurements within 9%.
- Simulations conducted at higher and lower Reynolds numbers were also in fairly good agreement with the experimental measurements.



Δ 0.25d upstream, CMD=17cm, Re=35

Conclusions

- $(V_{MD})_{RMS} \approx 0.1 * (V_Z\ @0.25d)_{average}$

- $(V_Z@0.25d)_{std}$= 15.1% $decrease\ to$ $(V_Z@1.5d)_{std}$= 3.8%. The flow non-uniformity caused by the fabric weave is constrained to a short distance above the fabric.

- $(V_Z@0.25d)_{max}$= $2.2 * (V_Z@0.25d)_{min}$,the initial accumulation of fines and/or filler content would be 2.2 times higher than in adjacent areas if 100% retention.

- However, this non-uniformity is not particularly felt by fibers, whose length scale results in averaging of the local velocity field.

- The Z direction velocity variation decreases by 15.5% when the Reynolds number is increased from 15 to 65.

- CFD simulations of the same flow were consistent with the PIV measurements within 9%.

Future Work

- Conduct multiple measurements at enough CMD plane to create a full Z direction velocity distribution in certain Z plane, e.g. 0.25d upstream fabric, then we can predict the movement of fiber that not oriented in MD.
- Rotate the whole experimental set up with 90 degrees to measure the CMD velocity distribution.
- Test different fabric model for the comparison between different design of forming fabric.

Industry Application

- Different fabrics will have different velocity distributions and therefore different effects on the fines and filler distribution in the finished paper.

- By better understanding the velocity distributions of fabrics we may then design fabrics that produce a superior (more uniform) distribution of fines and fillers in the finished paper.

Acknowledgements

- I would like to thank AstenJohnson Inc. and NSERC for their financial support.

Questions

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