EXPERIMENTAL STUDY OF FLOW THROW STENOSIS

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Abstract: In this paper is presented experimental measurement of two stenosis models by using Particle Image Velocimetry (2D PIV). Two stenosis models (45 areal percents and 65 areal percents) were measured both in steady and unsteady flow. From measured data were assessed the flow characteristic in the both type of stenosis models. The effect of stenosis model shape was evaluated from the comparison of the flow characteristics of both stenosis model.

Introduction

Hemodynamics of stenosis has been widely studied in the least years both in experimental and numerical way.

The long-term project is solved in author's workplace and its objective is to optimize the shape of anastomosis (end-to-side), which is used for the bypass anastomosis, and thus to minimize the negative impact of the flow dynamics on the vascular walls and blood, thanks to which the bypass failure risk can be successfully reduced.

The flow behind the bypass junction is significantly impacted by the flow from host artery. The flow in host artery is affected by shape type of stenos, the development degree of stenos, distance the stenos from the junction etc.

The flow in two stenosis models was searched in first stadium of research flow in stenosis. First stenosis model was 45% narrowing and the second stenosis model was 65% narrowing. (It does mean - 100% stenos is closed)

Experiment

Both of stenosis models were measured and both of them were measured in steady and unsteady flow. The flow field was measured by using PIV-2D (Particle Image Velocimetry) method.

Steady Flow

Simple experimental equipment (Fig.1) was compiled for steady flow, which warranted steady flow on the inlet of stenosis model. For the occasion two stilling boxes were made. First stilling box is cubical shape, which space is divided by help two barriers into three parts. The working fluid was brought in the first

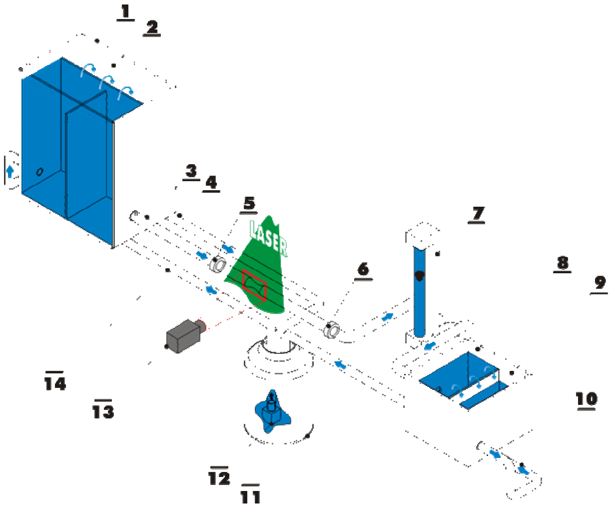

Figure 1: Schemeof experimental steady equipment:. 1-first stilling box, box, 2- spillway of first stilling box, 3-glass pipe, 4-spillway from first stilling box,5,6-preassure sensors, 7-rotametre, 8-second stilling, 9- spillway of first stilling box, 10- spillway from second stilling box, 11-reservoir, 12-pump, 13-CCD camera, 14-inlet pipe to the first stilling box

part of stilling box. The working fluid is calm down after following over barrier, the second barrier is used as spillway into spilling part of first stilling box. The second barrier is used for regulation of working fluid high in the first stilling box.

The stenosis model was placed between first and second stilling box, the rotametr with flow regulation was placed behind the stenosis model.

The second stilling box is divided by one barrier to two parts. The working fluid was brought in the first part of second stilling box and the second part of this box was used as spilling part of second box. Both of the stilling boxes were used as well as deaerating boxes.

Difference between barrier's height in the first box and barrier's height in the second box was determining for maximum hydraulic gradient. The working fluid from both of spilling part of box was removed to the reservoir. From reservoir the working fluid was took by pump into first part of the first stilling box.

The PIV system from Dantec Dynamics which comprises these components: camera Dantec HiSense, 1 024k x 1 280k pixel CCD, frequency 4.5 Hz for double frame mode and 9Hz for single frame mode; a pair of pulsed lasers Nd:YAG New Wave Geminy 15 Hz-120

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mJ, with optics; PIV processor Dantec FlowMap 1500, 2 x 1Gb buffer, PC DELL Precision 2 x P4 Xeon 2 800 MHz was used.

Laser was fixed on the construction over the model for illumine the model symmetry plane. The camera was placed perpendicularly to the laser sheet. For better resolution and higher sensitivity the area around (15x15)mm was scanned by CCD camera. Traversing system was used for scanning longer area behind the stenos model. This traversing system enabled axial displacement. The area of three or four inner diameter behind stenos model was measured by the help of this traversing system.

There are two pressure sensors (XTM-190M-0,7bar D, Kulite with measured card PCI-6024E National Instruments) in front of and behind the stenos model. Rotameter with flow regulation was placed between the second pressure sensor and the second stilling box.

Unsteady Flow

The experimental equipment and its placed for unsteady flow was similar as experimental equipment in article „Unsteady Flow Investigation Behind the End-to-Side Anastomosis“ by Matěcha Jan, Netřeská Hana, Tůma J. Schmirler M. and Adamec J, which is presented in this conference too.

The stenosis models were made of the glass pipes, which were warmed up over pilot flame. The glass pipes were deformed by tensile stress into stenotic shape. The big advantage of this manufacturing process is price availability and technical simplicity. Disadvantage of these models are the imperfect desired shapes, which depend on manual experiences of maker.

The water with 5 µm polyamid tracing particles was used as working fluid.

Processing of measuring data

The hundred pictures were measured for one position of CCD camera in steady flow. Ten pictures were measured for one position of CCD camera and one part of unsteady flow period.

Everyone set of picture was processed in Flow Manager these sequences:

- Mean Pixel Volume
- RMS Pixel Volume
    - Subtract Image
- Subtract Image
- Making Image Map
- Adaptive Correlation (16 50%)
- Making Image Map
- Peak Validation
- Moving Average
- Vector Statistic

The statistics (Tab. 1) was evaluated from the instant flow fields. The set of statistics was exported from Flow Manager to MATLAB with the help of command "Link to MATLAB" and saved. The matrixes of all statistics values are stored together with axis vectors X and Y which contain coordinate values.

A(i).	- structured variable of field type	
	alfa	- graft angle
	Q	- total flow rate
	Q1	- flow rate in graft
	X, Y	- coordinates in host artery
	U, V	- velocity in X, Y direction
	StdU, StdV	- standard deviation for U, V velocity
	K	- Correlation coefficient

***Tab.1:** Structured variable saved dates.*

The corresponding set of statistics (for one measured regime) was connected in one matrix in MATLAB for next evaluation. The Matrixes of evaluated data (Fig. 2 - I) have different size (different number of columns and rows) dependent on concrete setting of analysis sequence and overlap each other in the direction of host artery axis.

First, the final matrix was created (Fig. 2 - VI) with required number of columns and rows with corresponding final X and Y vectors. The values from statistics (Fig. 2 - I) (without overlap) were interpolated into the final matrix with the help of MATLAB command *interp2*. Whole sequence was carried out simultaneously for all matrixes (U,V, StdU, STdV, K).

The connected set of statistics was stored in one structured variable (Tab. 1) of field type where index of field is the order of the measured regime. The data storage in one structured variable enables easy evaluation and comparison of flow characteristics for different models and regimes.

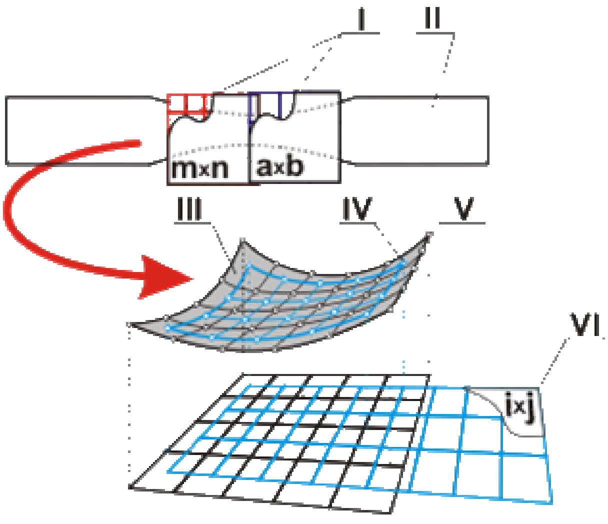

Figure 2: Scheme of data manipulation.

Results:

The results of flow characteristics are presented in graphs. The data were calculated in mathematical software, where the graphs of flow profiles were generated from data, which were sent from FlowManager.

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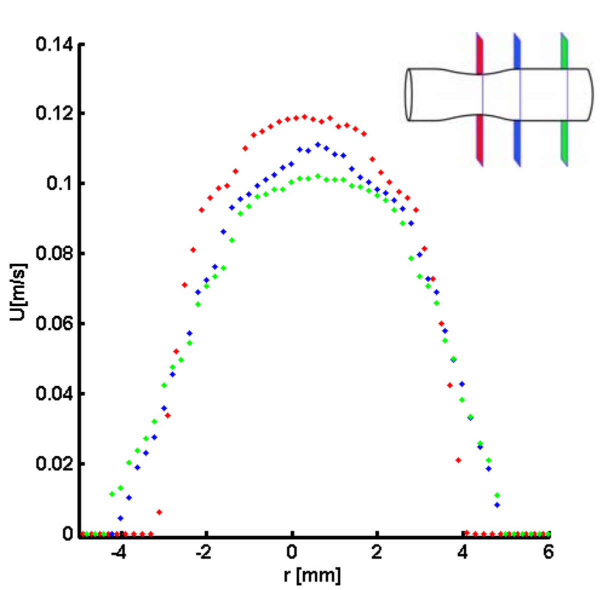

Figure 3: The development of steady flow field in 45% stenosis model (Re=367,5).

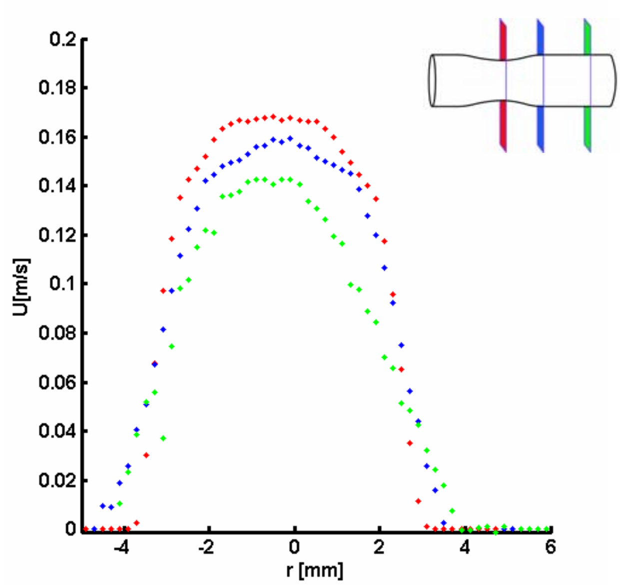

Figure 4: The development of steady flow field in 65% stenosis model (Re=367,5).

The results of flow characteristics are presented in graphs. The data were calculated in mathematical software, where the graphs of flow profiles were generated from data, which were sent from FlowManager.

Steady Flow The steady flow characteristics are presented in Fig. 3-12. The developments of velocity profiles in 45% and 65% stenosis model are presented in Fig. 3-6, where are illustrated the profiles from the place of narrowing, in one-diameter distance behind the narrowing place and in three-diameter distance behind the narrowing place.

The velocity profiles in different flow behavior from stenosis model narrowing are presented in Fig. 7-8, the velocity profiles from one-diameter distance behind the narrowing place are presented in Fig. 9-10 and the velocity profiles from three-diameter distance behind the narrowing place are presented in Fig. 10-12.

Unsteady Flow Inlet velocity profiles during the whole period in the both stenosis models were measured in four-diameter place before the narrowing for possibility of comparison with the flow characteristic behind the place of narrowing. (Fig. 13, 14 – 45% stenosis, Fig. 15, 16 – 65% stenosis)

The immediate flow field are demonstrated in Fig. 17, 18.The velocity profile development during one period in place of narrowing, one-diameter distance behind the narrowing place and two-diameter distance behind the narrowing place are presented in following figers (Fig 19-24).

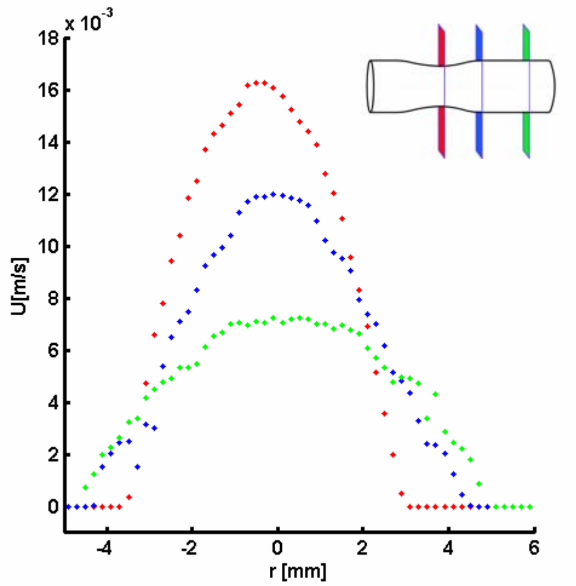

Figure 5: The development of steady flow field in 45% stenosis model (Re=24,5).

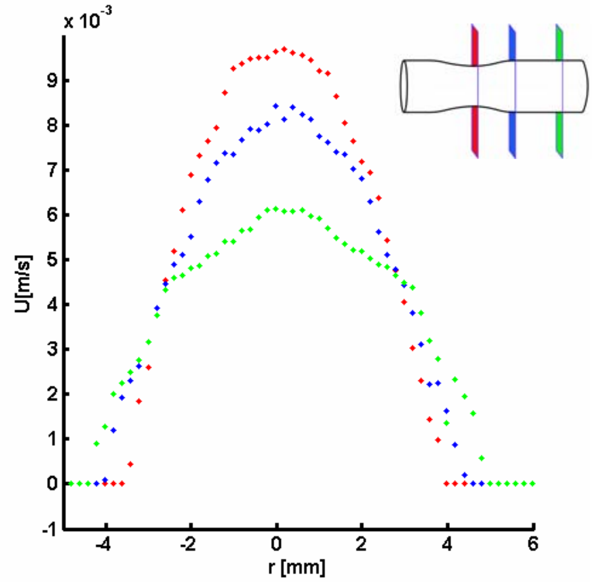

Figure 6: The development of steady flow field in 65% stenosis model (Re=24,5).

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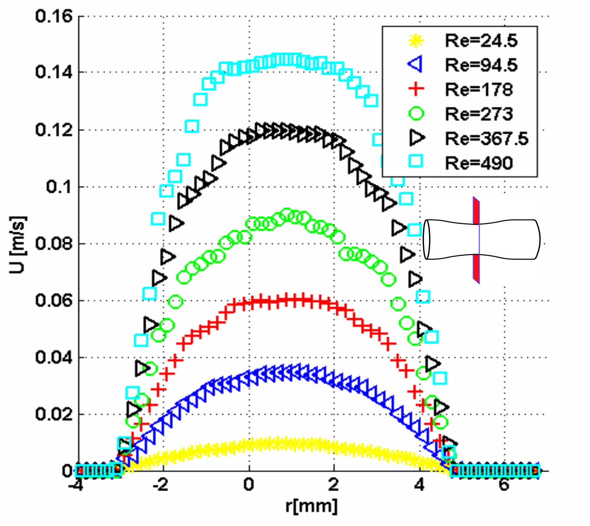

Figure 7: The velocity profiles in the narrowing place of 45% stenosis model

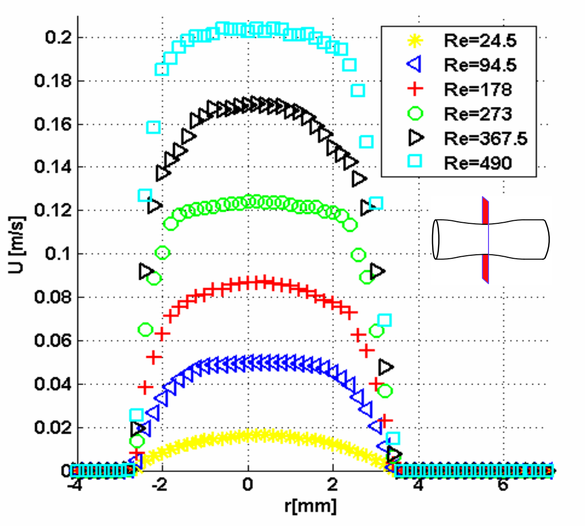

Figure 8: The velocity profiles in the narrowing place of 65% stenosis model

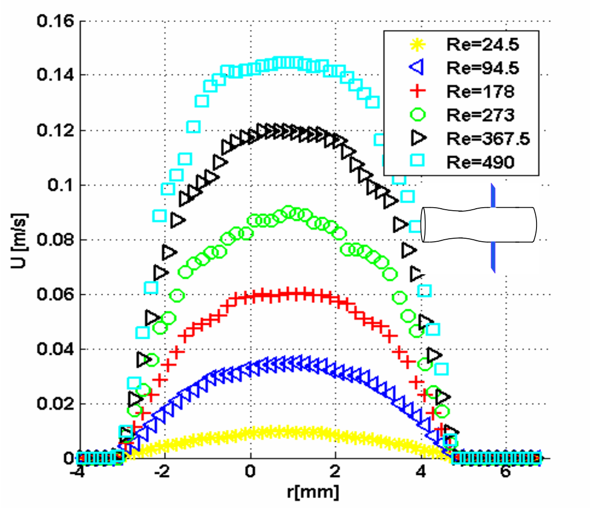

Figure 9: The velocity profiles in one-diameter distance behind the narrowing place of 45% stenosis

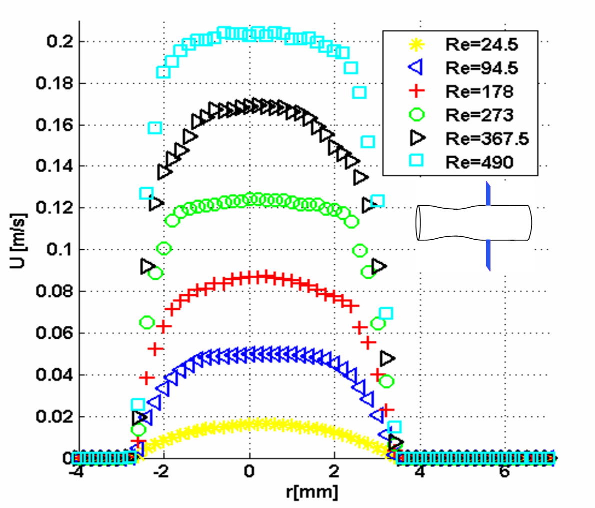

Figure 10: The velocity profiles in one-diameter distance behind the narrowing place of 65% stenosis

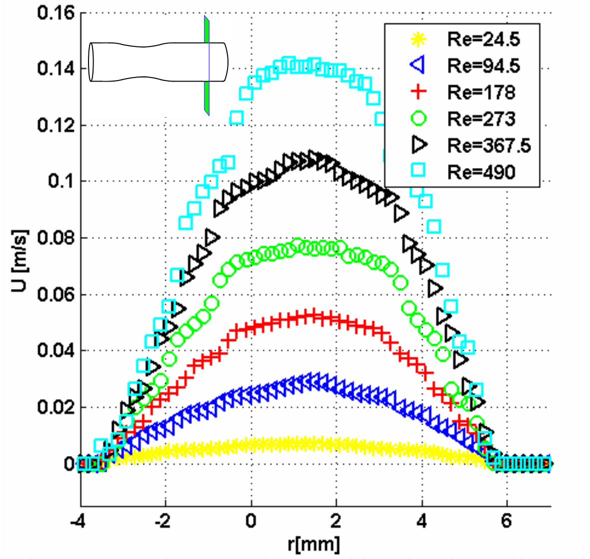

Figure 11: The velocity profiles in three-diameter distance behind the narrowing place of 45% stenosis

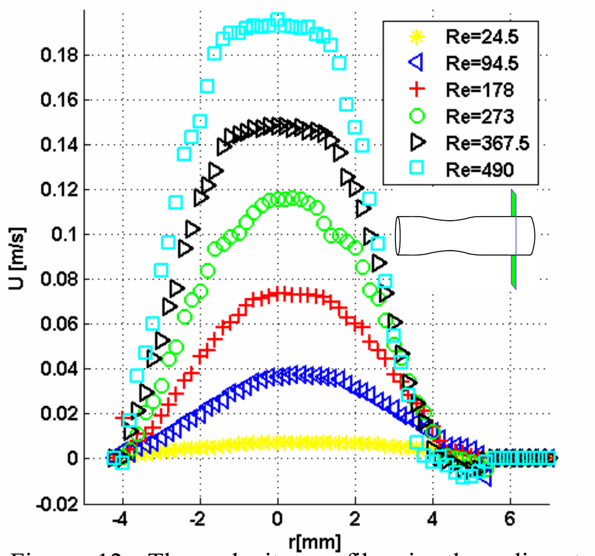

Figure 12: The velocity profiles in three-diameter distance behind the narrowing place of 65% stenosis

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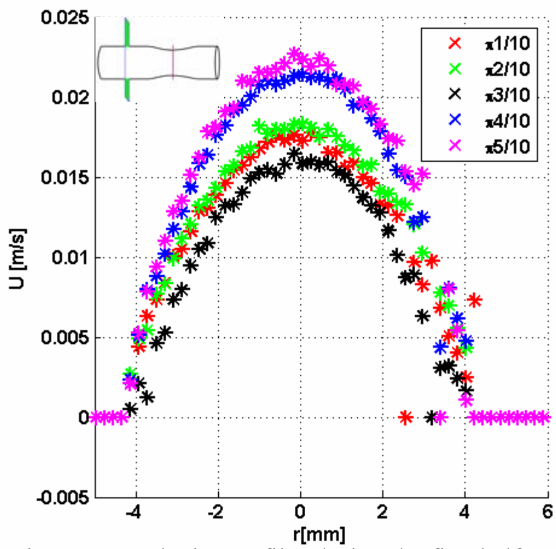

Figure 13: Velocity profiles during the first half period in the 45% model four-diameter before the narrowing

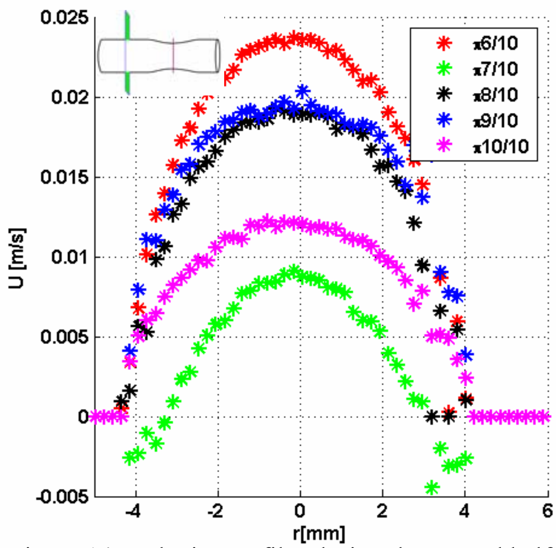

Figure 14: Velocity profiles during the second half period in the 45% model fo;ur-diameter before the narrowing

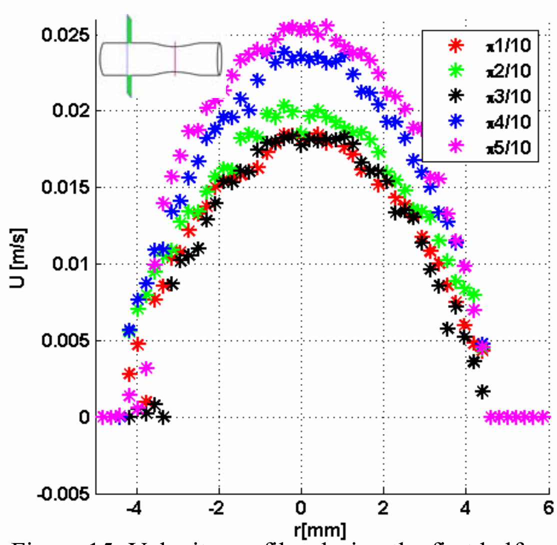

Figure 15: Velocity profiles during the first half period in the 65% model four-diameter before the narrowing

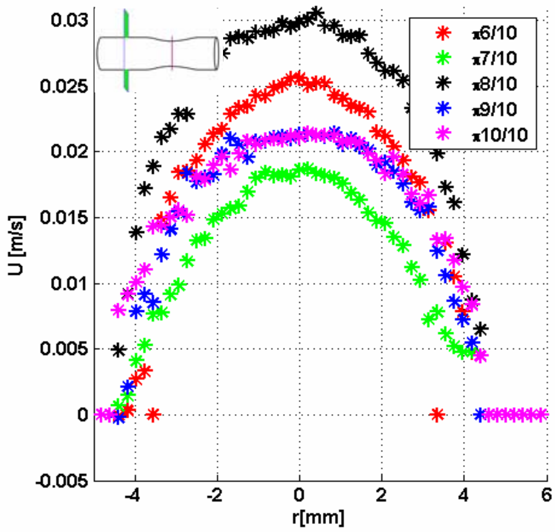

Figure 16: Velocity profiles during the second half period in the 65% model four-diameter before the narrowing

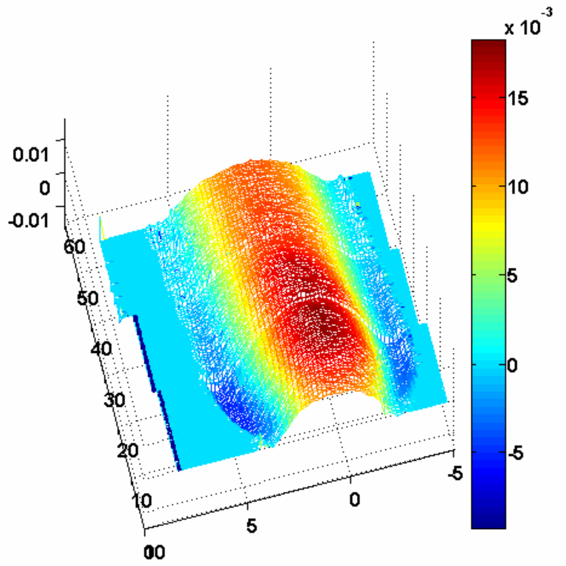

Figure 17: Unsteady flow field of 45% stenosis model and for period instant 7/10π

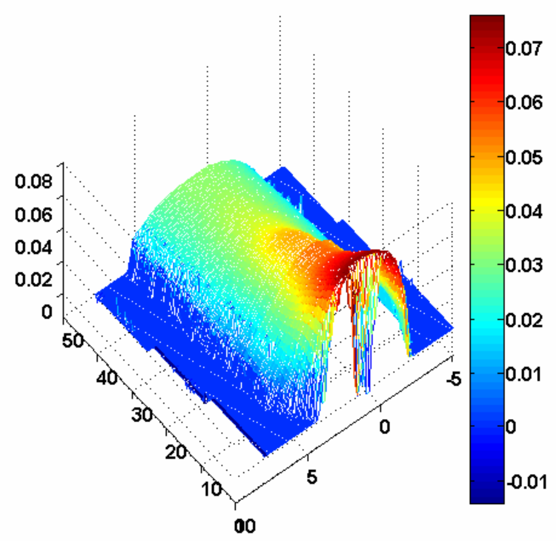

Figure 18: Unsteady flow field of 65% stenosis model and for period instant 7/10π

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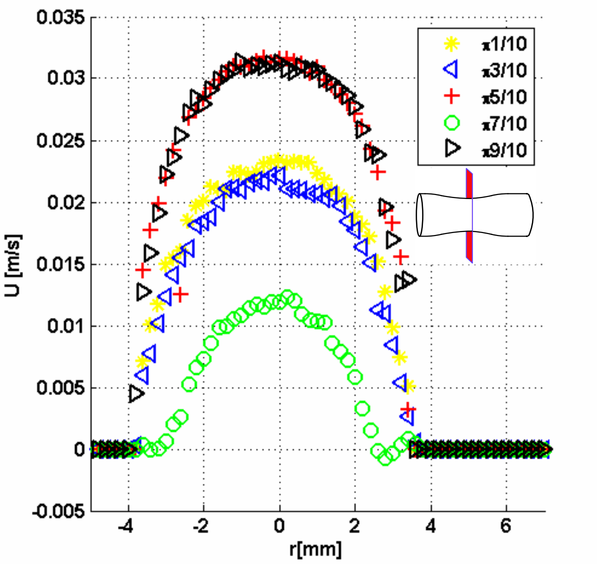

Figure 19: The velocity profile dutiny period in the narowing place of 45% stenosis model

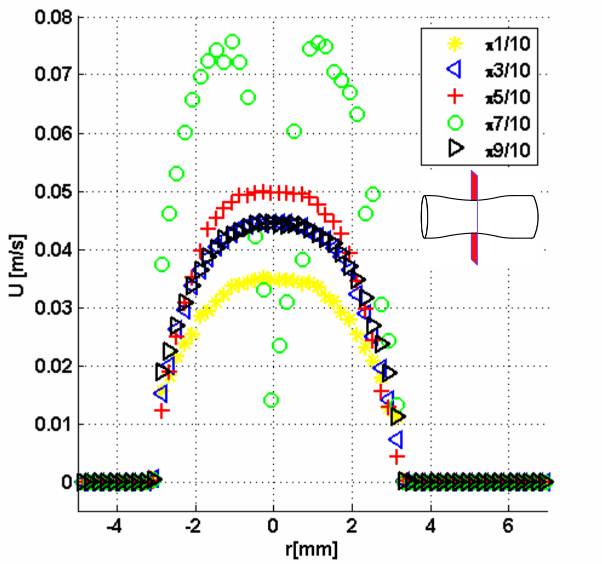

Figure 20: The velocity profile dutiny period in the narowing place of 65% stenosis model

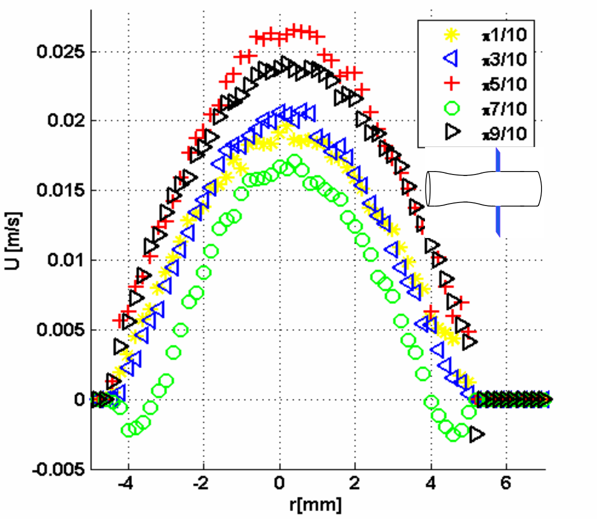

Figure 21: The velocity profiles during period in one-diameter distance behind the narrowing place of 45% stenosis mode.

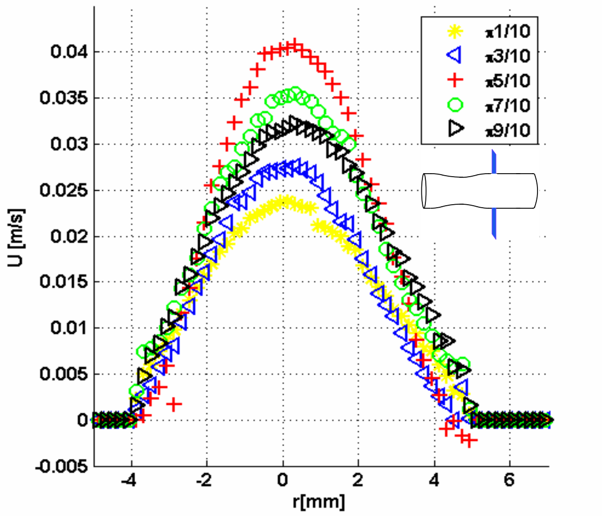

Figure 22: The velocity profiles during period in one-diameter distance behind the narrowing place of 65% stenosis model

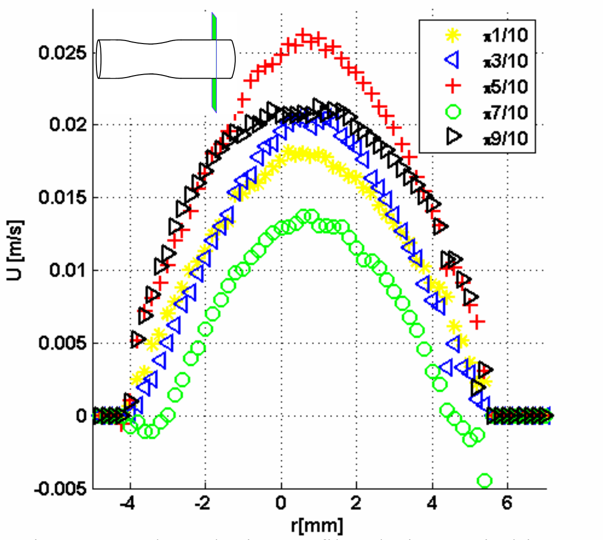

Figure 23: The velocity profiles during period in two-diameter distance behind the narrowing place of 45% stenosis model

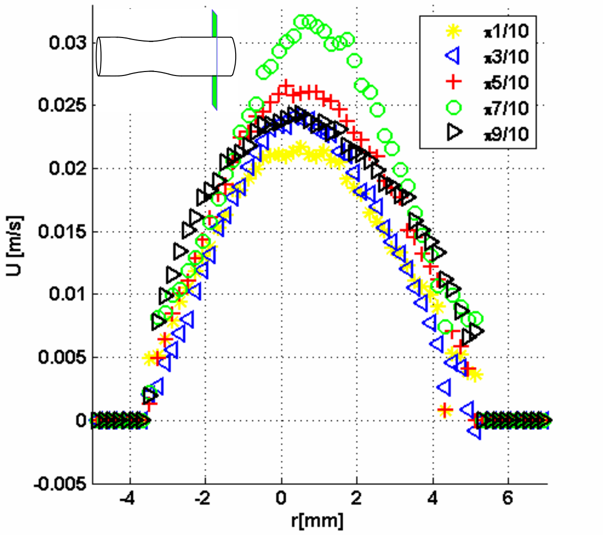

Figure 24: The velocity profiles during period in two-diameter distance behind the narrowing place of 65% stenosis model

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Conclusion:

The experimental equipments for steady and unsteady flow field in symmetry plane of glass stenosis models by using PIV method were created. Two stilling box for steady flow were proposed and created, which assured the inlet steady flow.

Two type of stenosis models were measured, first 45 areal percents and second 65 areal percents. Both of them was created from glass pipe.

The steady flow fields of both stenosis model types were measured in five-diameter area behind the narrowing place. For better distinction of CCD camera was monitored the area of one and half diameter. The corresponding set of statistics (for one measured regime) was connected in one matrix in MATLAB and estimated as global flow field.

The steady flow velocity profiles exhibits are presented in Fig. 3-12. The negative velocity values near the model wall are showed in the Fig. 12, which reflect to vortex structures.

The stronger vortex structures are created in unsteady flow, which are presented in Fig. 17-24.

Acknowledgements

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