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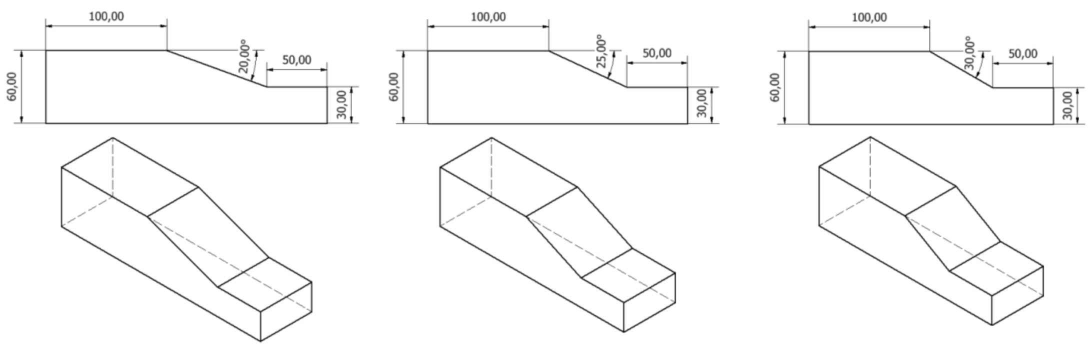
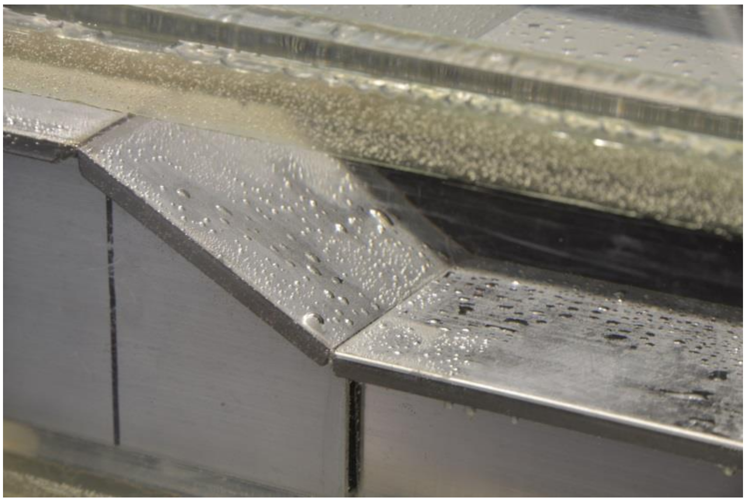
The design of the experimental device for the measurement of slip velocity near the wall depending on Coand effect

The aim of this task was the design and implementation of an experimental setup for study of Coanda effect. The experimental setup drew on previously designed water channel. This water channel of 4 meters total length is fitted with flow stabilizing elements to achieve stable flow. The flow is induced by gravity principle that is free from pulsations. The water source for the water channel is an open container placed in a height of 2 meters above the plane of the water line. The water channel was fitted by of extension of different degrees of the inclination (20 °, 25 °, and 30 °). As a basis for samples placement were used aluminum profiles. There were tested the samples of steel without modification (as measured CA dry surface of 83 °) and ultra-resistant hydrophobic finish (CA dry surface of 150 degrees) at each step of the inclination. The sloping transition part was made as fitting of precisely cut steel stripes. The leading part of the channel was filled with the same material to 2m distance before extension as well as the ending plane part.

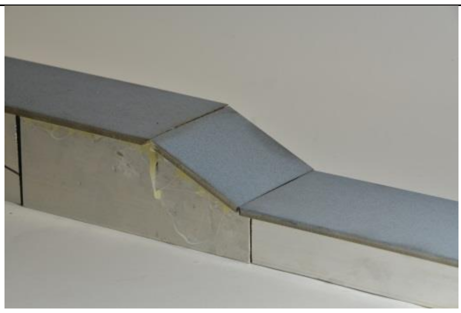


The drawing for the realization of the extension, the aluminium profiles prepared for mounting with steel stripes. The schema for various degree of inclination: 20, 25, a 30.

The characteristic extension of the inclined segment was chosen based on the knowledge of Coanda effect behaviour. There was the assumption that on the inclined segment the flow will adhere to the wall. This phenomenon is dependent on many parameters of the liquid flow and surface properties (roughness, contact angle).



The detailed photo of ultra-hydrophobic surface placed in the water channel. The interaction between ultra-hydrophobic surface and the water leads to creation of air film. This air film is well seen as a silver layer on the surface. In this case, the air film is ununiformed and more leads to bubble creation.

Inclination degree	*Steel, CA 83°*	*Ultra-hydrophobic surface, CA 150°*
20°		
25°		
30°		

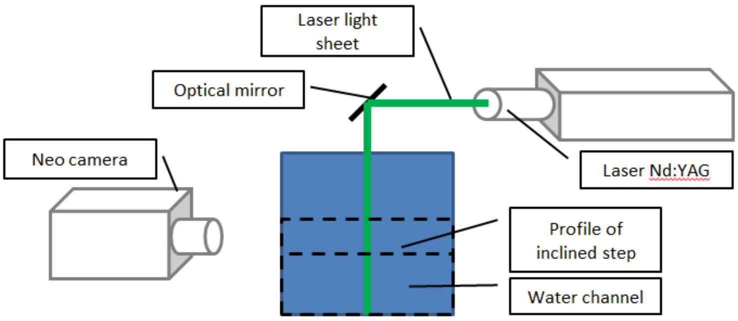
The set of segments fitted with steel stripes and ultra-hydrophobic segments, just prepared to be mounted in the water channel.

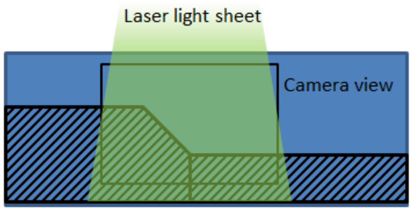
Study of the influence of adhesion coefficient on the formation of vortex structures depending on the Coand effect

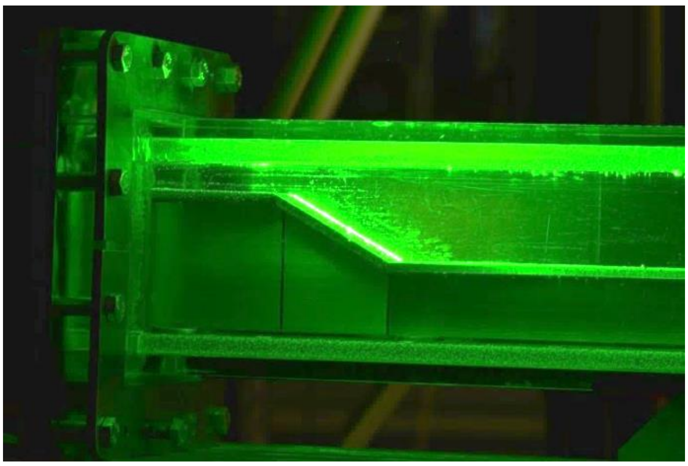
The experimental study was focused on the flow behaviour and the interaction with the ultra-hydrophobic surface. There was measured flow field in the extension and close to the inclined part. There were calculated characteristic quantities from the measured datasets. There was expected non – stationary flow in the water channel. Here we used the Particle Image Velocimetry (PIV). This optical method enables to record the velocity flow field across the whole recording area.

The PIV method is based on the pulse laser (Nd:YAG, 532nm wavelength) and is synchronized with the CCD camera recordings. We used the sensitive Neo HiSense camera with the full resolution of 5,5MPix, in this experimental study. The camera was fitted with Nikon 60mm lens system. The scene was captured with the frequency 12Hz. The diameters of the recorded area were (190x220) mm.

The laser beam was extended to the laser sheet and lead to the water channel through the optical mirror to form the plane illuminated with laser light. The vertical illuminating plane was placed axisymmetric to the water channel width. The illuminated area responds to the recorded area. This area begun at the entrance plane part, lead over the inclination and stopped at the extended plane, where the flow supposed to be steady.







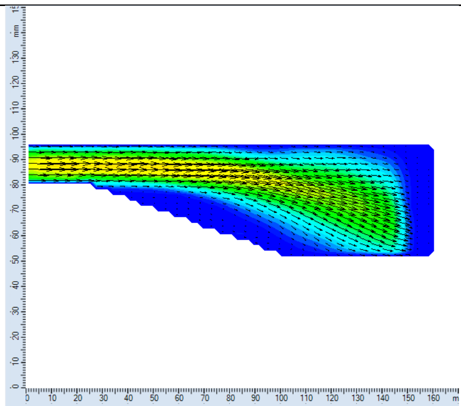
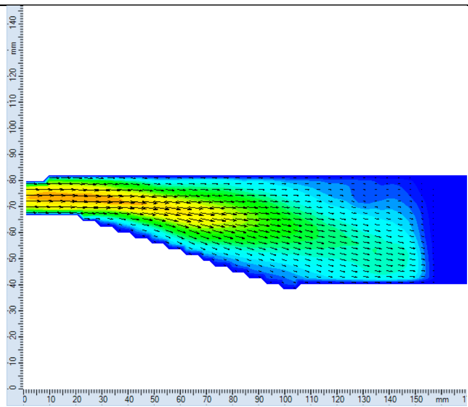
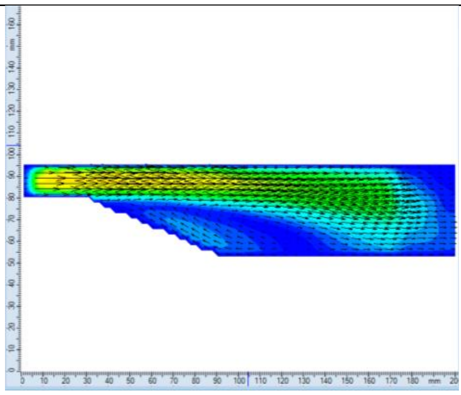
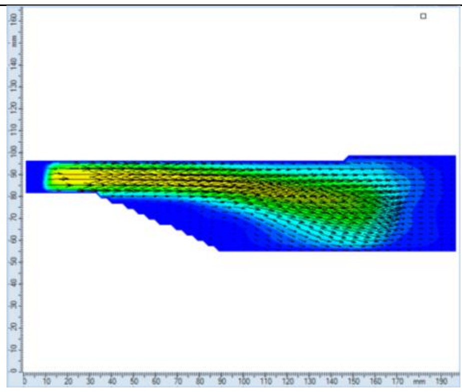
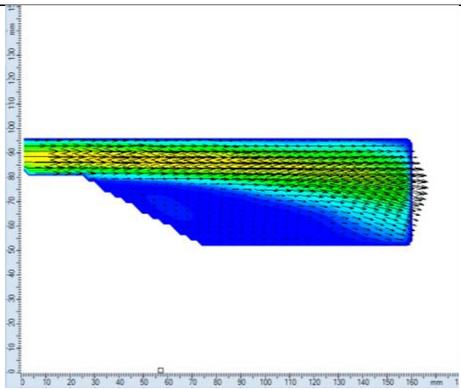
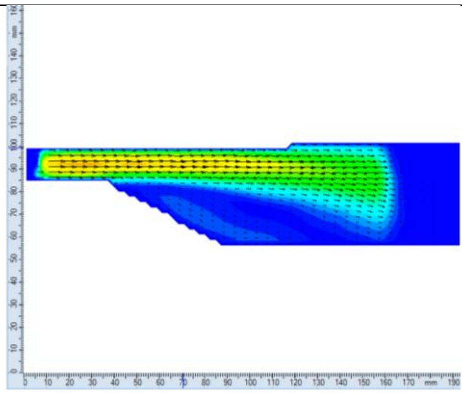
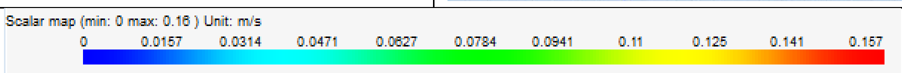
There is seen the laser and the camera setup. The figure of the laser sheet and the position of the illuminated area according the camera view.

There is simple visualization of the flow and the measurement with PIV method. The illuminated plane and its placement in the water channel.

Discussion / Interpretation of Results

The dataset measured with PIV method was analysed with Cross-correlation algorithm. It was further validated using Moving Average Validation and Average Filter methods. The analyses results were processed as separated results in each time step as well as the complex statistics.

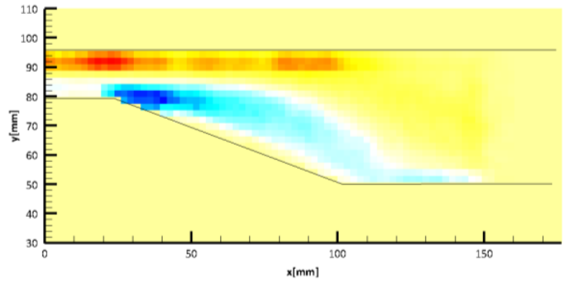
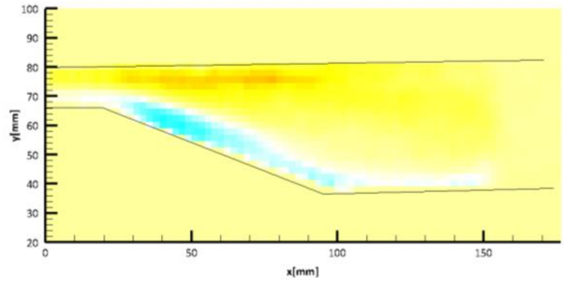
The measurement itself run in four flow regimes: 0, 25, 0, 5, 0, 75, and 1 L/s. This flow rates corresponds to the Reynolds number between 3000 and 13000.

Inclination degree	*Steel, CA 83°*	*Ultra-hydrophobic surface, CA 150°*
20°		
25°		
30°		
		

This table includes the vector statistics overview for the flow rate Q 0, 25 l/s.

The adherence of liquid flow can be observed above the 20 degree of inclination. The adherence is supposed to be caused by Coanda effect. This effect was observed over the entire flow range. In other modes, there was observed flow separation and the backflow. The flow adhesion was subsequent monitored in the stabilizing part of the channel. The flow was very unsteady. This cannot be characterized by one mean vector map.

The next step of data processing was the assessment and evaluation of dataset according to the occurring instability of the flow. We focused the analysis on the character of vortex structures. Individual vortex structures and their movements wiped statistical evaluation, i.e. averaging the values over 250 entries. The way to visualize the vortex structure is an expression Vorticity (z) and it’s averaging.

<table>
<tr><td></td><td colspan="2">20°of inclination</td></tr>
<tr><td>Q [l/s]</td><td>Steel, CA 83°</td><td>Ultra-hydrophobic surface, CA 150°</td></tr>
<tr><td>1</td><td>
</td><td>
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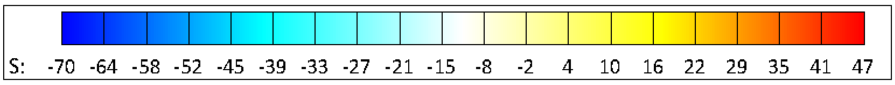
<tr><td></td><td colspan="2">
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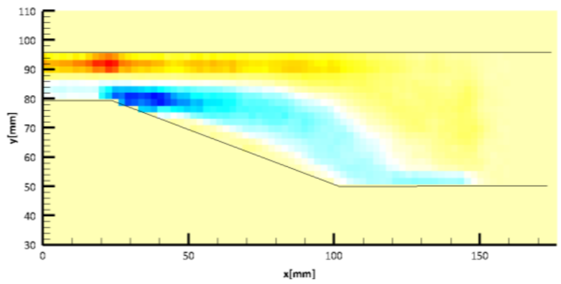
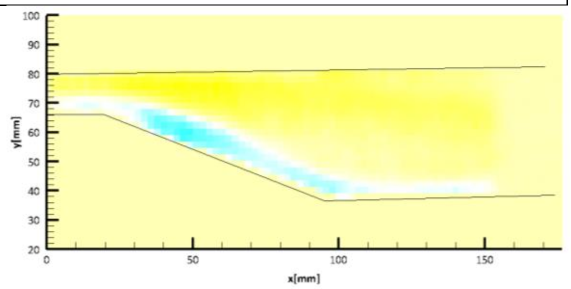
<tr><td>0.75</td><td>
</td><td>
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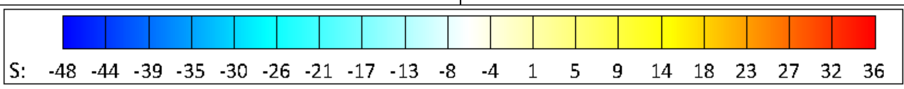
<tr><td></td><td colspan="2">
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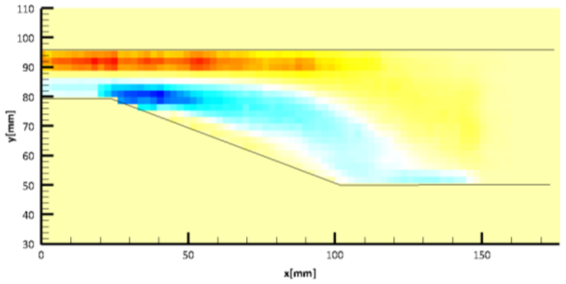

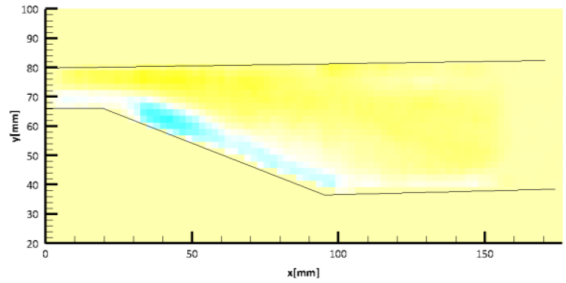

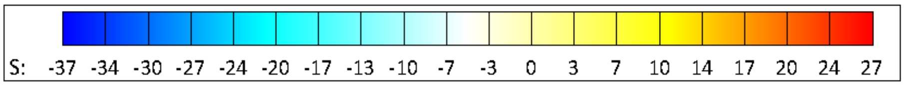

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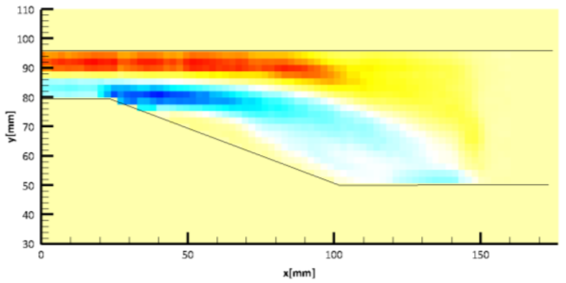
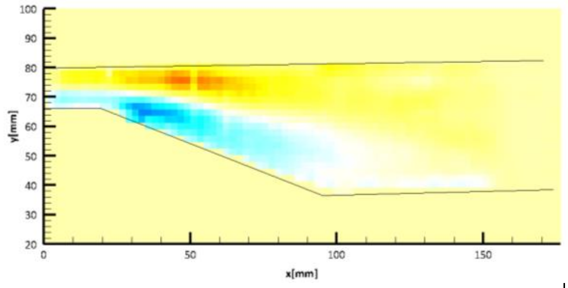
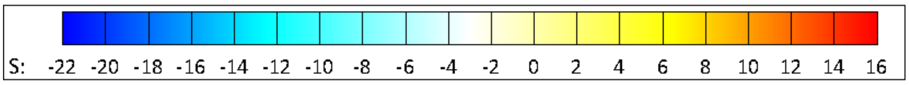




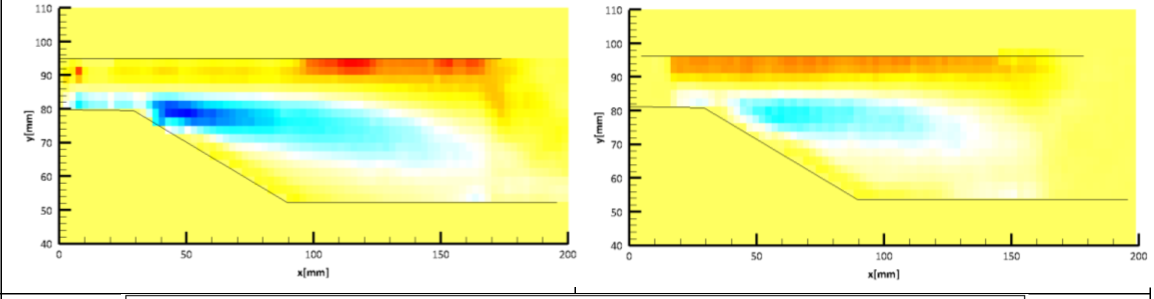


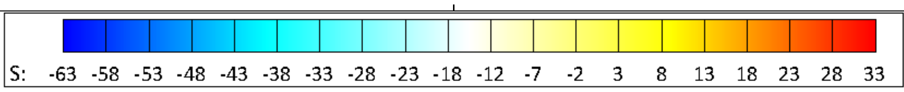
The scalar intensity maps of Vorticity (z) shows the noticeable effect of ultra-hydrophobic surface. There was recorded significantly lower value (Max and Min) above this surface, in all flow modes as it is shown in the table below. Values of Vorticity (z) for ultra-hydrophobic surfaces liquid interaction take on half average values than above the surface without modification.

Maximum and minimum value of Vorticity(z) for 20°of inclination		
Q [l/s]	Steel (Min; Max)	Ultra-hydrophobic surface (Min; Max)
1	-68.873; 46.345	-37.663; 25.569
0.75	-47.322; 35.917	-22.190; 14.666
0.5	-36.481; 26.257	-17.372; 8.877
0.25	-24.099; 15.675	-16.877; 11.779

	25°of inclination	
Q [l/s]	*Steel, CA 83°*	*Ultra-hydrophobic surface, CA 150°*

1





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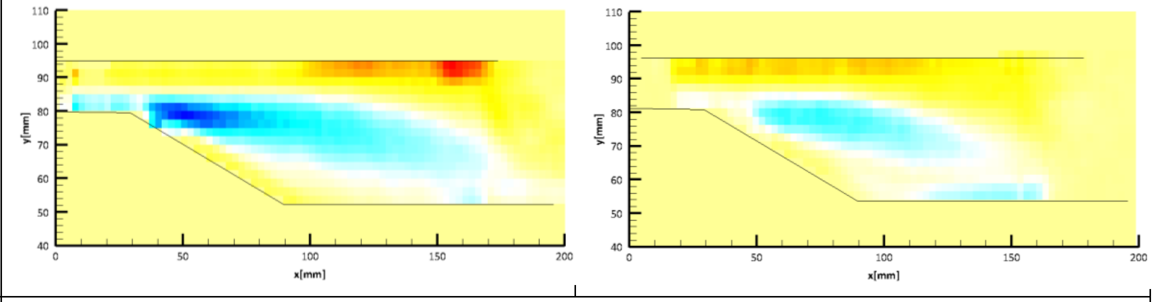

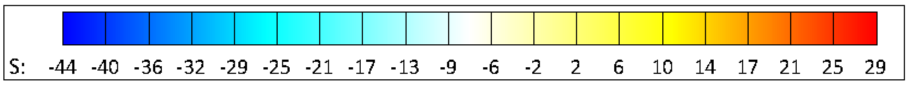

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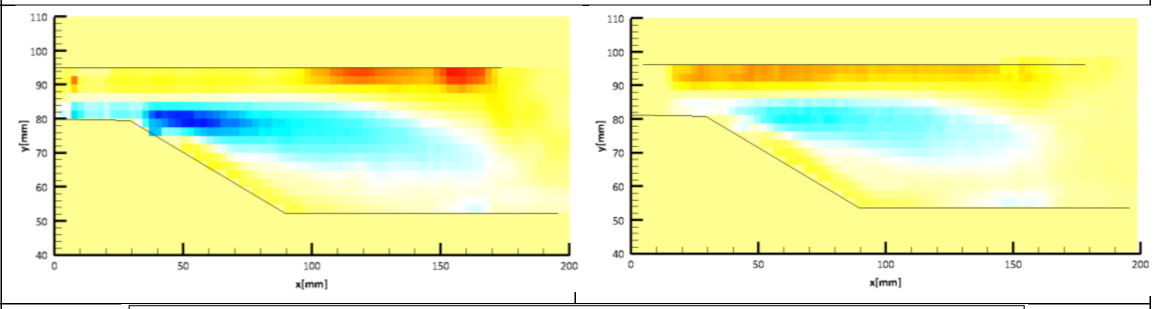

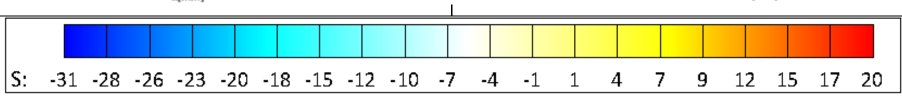

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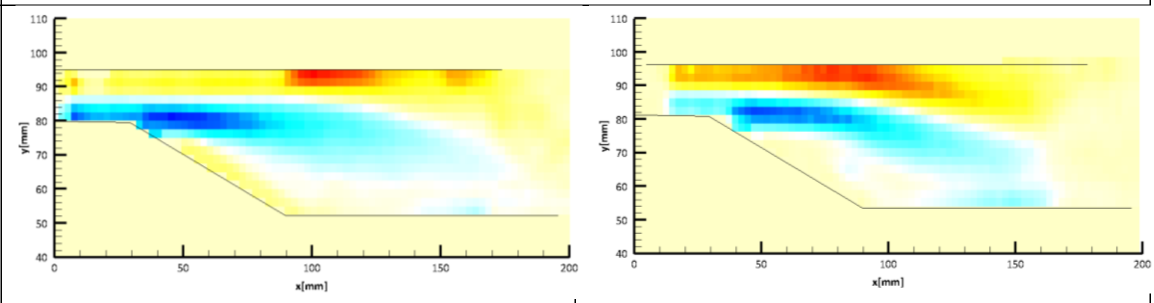
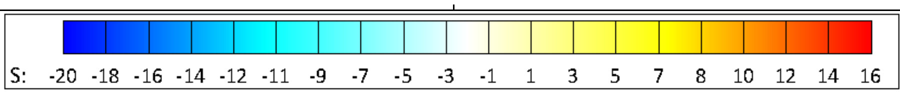
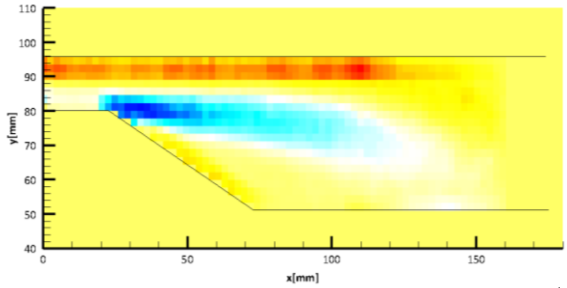
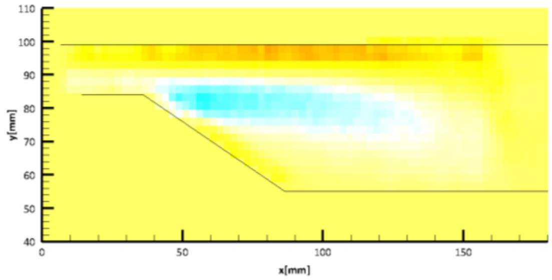
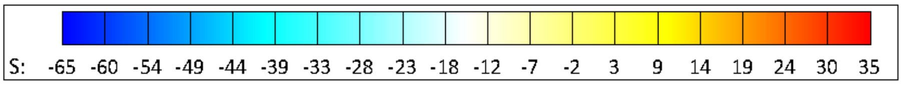
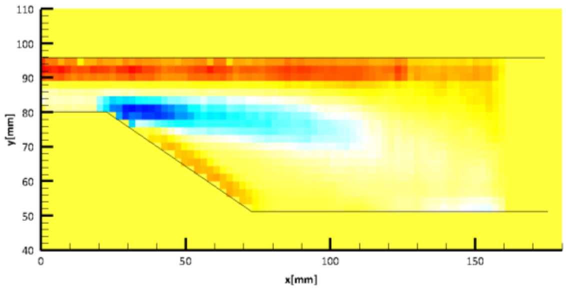
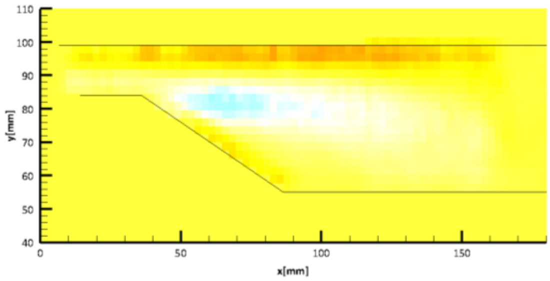
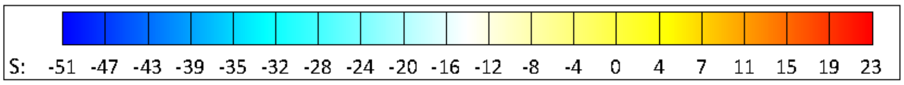
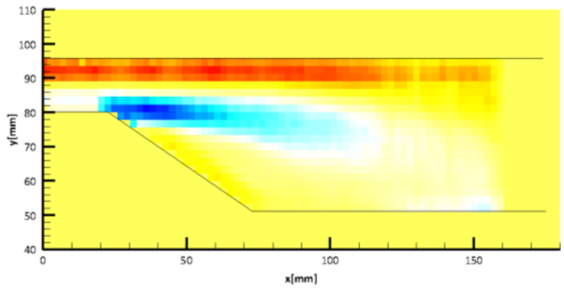
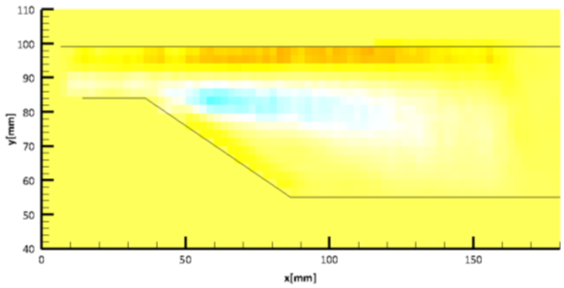
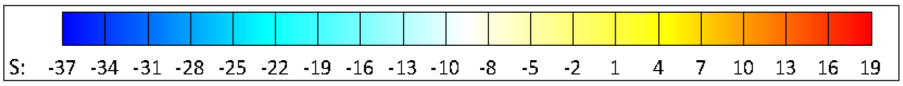




Maximum and minimum value of Vorticity(z) for 25°of inclination		
Q [l/s]	Steel (Min; Max)	Ultra-hydrophobic surface (Min; Max)

1	-62.827; 32.533	-36.830; 18.422
0.75	-43.492; -28.864	-20.319; 11.109
0.5	-30.038; 19.069	-17.489; 9.128
0.25	-19.440; 15.791	-15.260; 9.248

	30°of inclination	
Q [l/s]	*Steel, CA 83°*	*Ultra-hydrophobic surface, CA 150°*
1		
		
0.75		
		
0.5		
		

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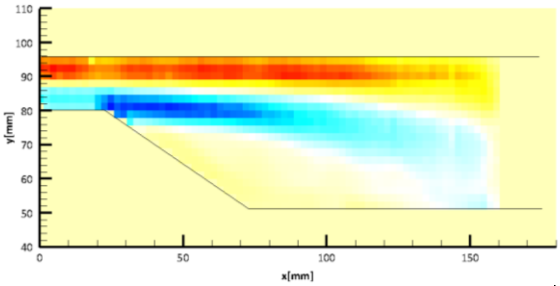
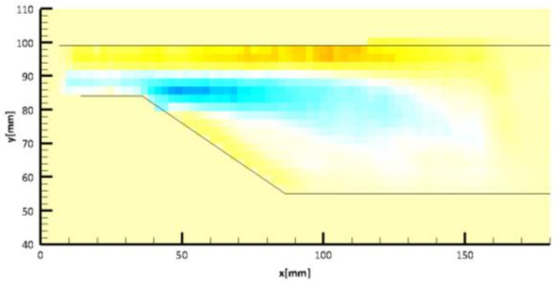
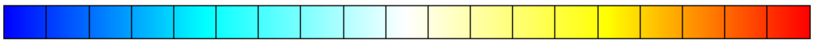




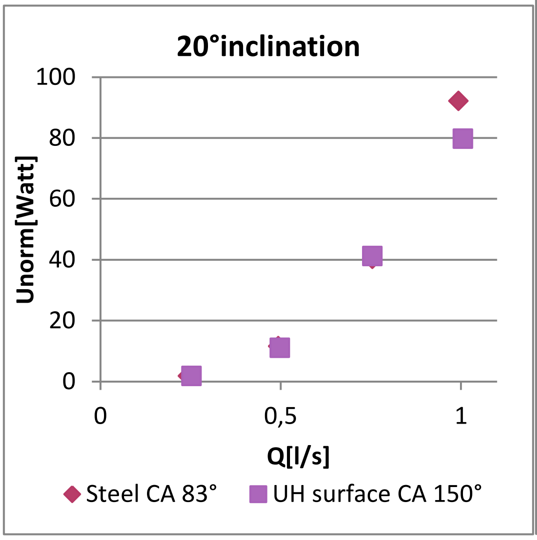


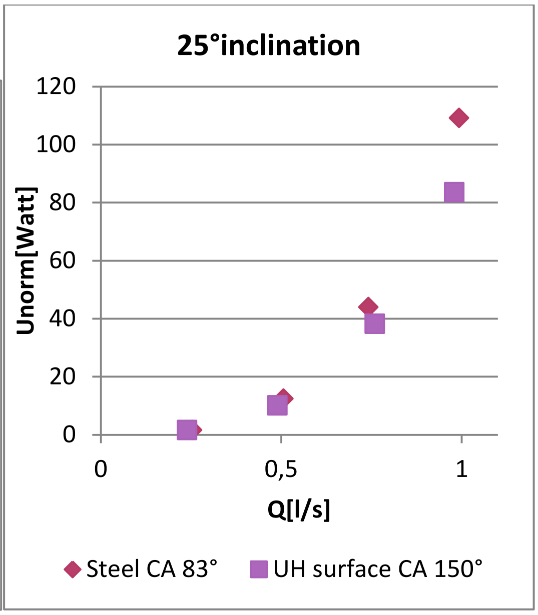
Maximum and minimum value of Vorticity(z) for 30°of inclination		
Q [l/s]	Steel (Min; Max)	Ultra-hydrophobic surface (Min; Max)
1	-64.060; 34.414	-36.830; 18.422
0.75	-50.241; 22.528	-20.319; 11.109
0.5	-36.554; 18.146	-17.489; 9.128
0.25	-20.134; 15.587	-15.260; 9.248

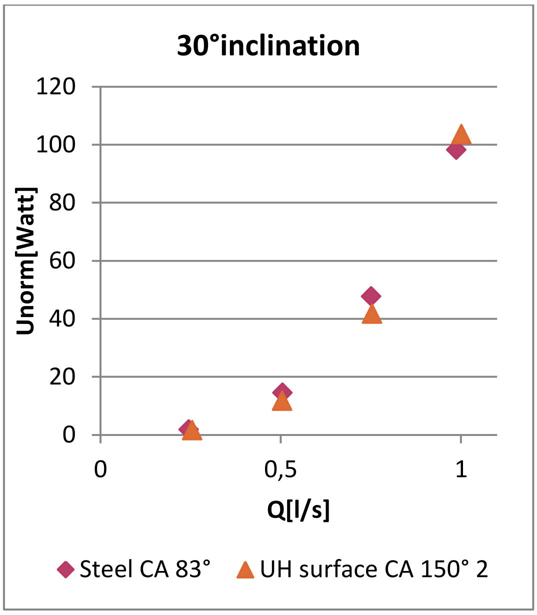
The calculation of the total power flow energy over defined area was another methodology for the quantification of non-stationarity of the flow. The area has been defined starting at the breaking point on the inlet and were compared with the same degree of inclination for the steel as well as the ultra-hydrophobic surface. We can compare mutually on the same inclinations because they differ on the length of the slope. Thus the area is not constant for all degree of inclination and this cannot be cross correlated.

The charts show that in most modes, the calculated output is 5-10% lower above the ultra-hydrophobic surface. The exceptions are for flows with Re 13,000 and the degree of inclination 30°.

There is another characteristic of flow and actual Coanda effect. This dependence can be quantified using the position of the stagnation point, re-adhesion of flow behind the extension. This is usually determined as statistically processed results of vector maps. These values are significantly influenced by the very instability flow, and emerging vortex structures. The vortex structures itself are changing the position and character. There was processed overview analysis that took into account the occurrence of vortex structures, and described the dispersal distances of the stagnation point during the 250 records.

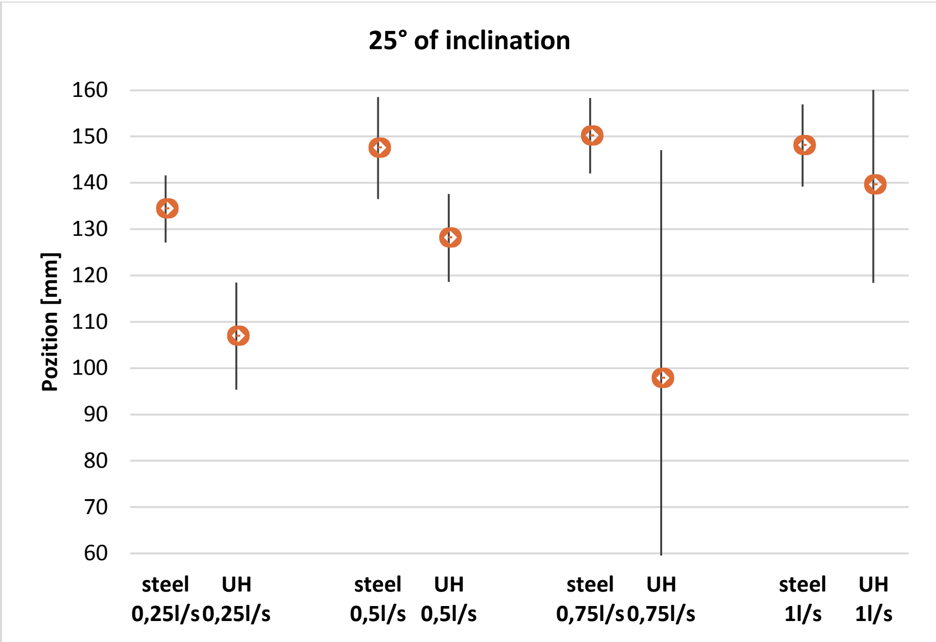


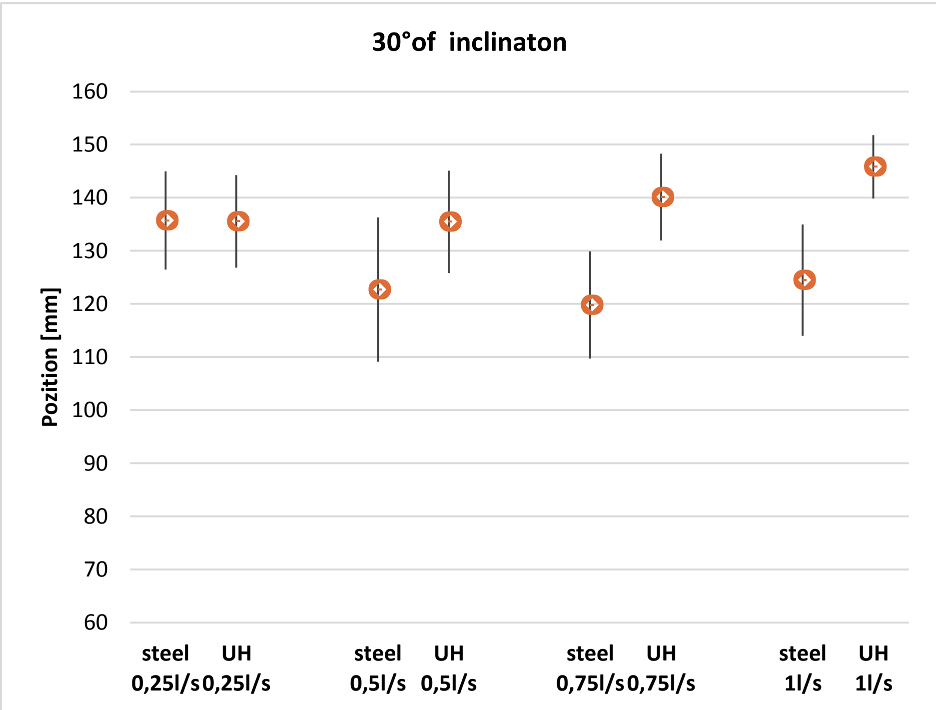




There was not found any of the stagnation point on the inclination of 20 ° above the ultra-hydrophobic surface. Liquid stream remained adhering directly to the extension. There was observed significant adhesion of the flow on the steel just on the inclined segment of the channel.

There occurred sticking straight up in a stabilizing part of the channel for angles 25 ° and 30 °. There is a trend of faster flow adherence to ultra-hydrophobic surface at the angle of 25 °. This phenomenon was not confirmed in the extension arrangement for 30 ° of inclination.





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T. W. Hansch, Handbook of Laser and Optics, Springer Science+Business Media, LLC New York, 2007.