DTU

Optimization of water flume and PIV-setup

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Abstract

This project concerns the improvement of an existing water flume in 414 at DTU Lyngby, and the PIV setup on this. During the project an elongation of both the setteling chamber and the outlet is performed. Furthermore more resistance is placed in the diffuser with the purpose of making the velocity profile more uniform. Discoveries about the effects of bobbles and dirt for the quality of the flow has been made and described. It has not been possible to obtain quality measurements of the effects of these, due to the lack of a fully functioning PIV- system. Experiences about the sensitivity of scheimpflug optics where made. The same level of sensitivity is part of the reasons why the equipment has not been sufficient for conduction quality measurements. The state of the specific system is described and proposals for further improvements is presented, especially in relation to the PIV system.

Contents

Chapter 1

The system

1.1 Introduction

This project is based on two earlier projects, both only partly successful. The first project was on the building of the water flume and the second was on measurements and use of the water flume. The first project succeeded in building a functioning water flume, though it had several issues considering the quality of the flow. The flume was designed to be quite small and portable so that it could be used in education, but still have a flow quality suited for experimental use. To obtain both compromises were made and unfortunately the flow did not reach a turbulence level of 1% as targeted, but 4-5%. This is expected to be as a result of a too high level of turbulence before the contraction. In the test section, a standing wave accrues, due to backflow. This is thought to be as a result of a too abrupt outlet. The second project was with using the water flume to test vortex generators. The first obvious problem with this, was that the water flume did not have a flow quality to perform valid experiments, according to the first project [1]. Based on their own analysis, this was though found not to be a problem. Secondly they did not create a working scheimpflug system enabling the cameras to create sharp images of the image plane. Nor did they did not have a computers that where able to handle the amount of data, it was stated. Along with this several other issues with the setup was not optimal.

In this project, the goal was to create a flume with a flow of a quality that is good enough for conduction valid experiments, and set up measuring equipment with the accuracy to conduct the same experiments. The scope of the turbulent intensity is 1%. The project also had ambitions of setting up 3 component PIV and using this to do experiments with vortex generators, this though was not done in this project. The project plan including Gant schemes is found in appendix A.

Firstly a description of the existing system is found, followed by a theoretical part about the measuring system and PIV. Afterwards the improvements done in this project is found, before the results and experimental findings.

1.2 Waterflume

Transferred from earlier project is a working water flume, looking like figure 1.1

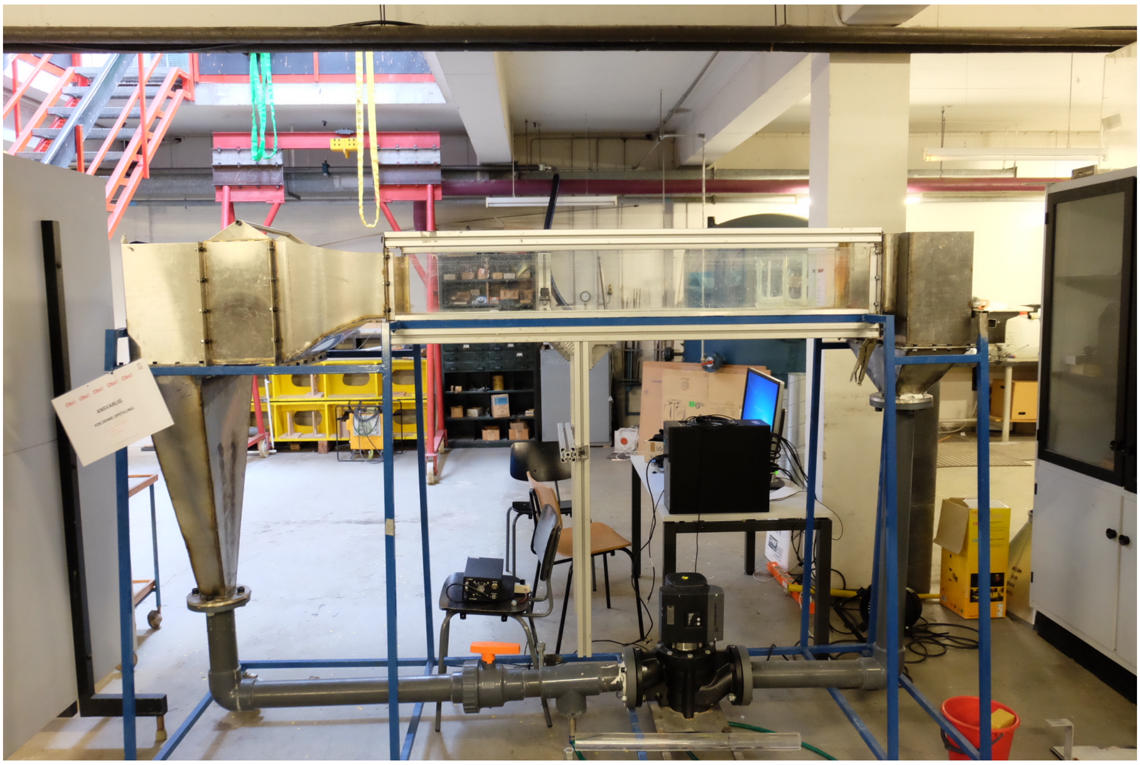


FIGURE 1.1: The water flume as it looked at the start of the project

The system is driven by a pump, witch pumps water through the pipes, into the diffuser with guide vanes placed on top to guide the flow in the perpendicular direction. From there into a set of screens and into a contraction just before the actual test section. The test section is the part where the quality of the flow is important. After this, an outlet is placed and the flow is let back into pipes and onto the pump.

1.2.1 Pump

The pump, Grundfoss TPE 80-30/4 AI-F-A-BUBE, is quite powerful compared to the size of the flume and the power losses in the system. If there was no pressure losses, there would not be any need for a pump, as soon as the process was started. Under current conditions, the pump is usually at level 1 or 2, to obtain the wanted flow. This allows greater pressure losses in the system, if it is found needed for the optimization.

1.2.2 Diffuser

In the diffuser the flow is accelerated down to a lower speed slowly to avoid separation of the flow. As the cross sectional area is increased, the velocity is reduced and the energy converted into pressure instead of velocity. This can be expressed by the Bernoulli equation, for an inviscid and incompressible flow:

$$\frac{p_1}{\rho} + \frac{V^2}{2} + gz = constant[2] \tag{1.1}$$

This is under the assumption that the flow is; Steady, frictionless, incompressible and along a streamline. In the diffuser two splitters is placed to avoid separation of the flow.

1.2.3 Guide vanes

On top of the diffuser the water is forced in the perpendicular direction. The guide vanes is mounted at a 5 angel of attack and follow 90°angle. The guide vanes serve the purpose of preventing large eddy structures and separation of the flow.

1.2.4 Screens

After the corner a set of screens is located to break eddys and lower the intensity of turbulence. The level of turbulence is defined as:

$$I_u = \frac{u_{rms}}{U}[3] \tag{1.2}$$

Currently there is screens of a fine structure with a spacing between of 40mm. There is 4 screens. By using screens larger structures is obliterated, but smaller is induced. These smaller though breaks up faster by the internal viscous forces.

1.2.5 Settling chamber

After the screens a settling chamber is usually placed with the purpose of allowing the smaller eddies induced by the screens to decay. There before this project there was no actual settling chamber, but a small distance between the screens and the contraction acting like a settling chamber.

1.2.6 Contraction

In the contraction the cross sectional area is reduced with a ratio c=3. As a consequence the speed of the flow is increased.
It is desired that the flow is at rest at this point, in terms of turbulence. The contraction is made of a fifth order polynomial and is well rounded.

1.2.7 Test section

The test section is 1500mm long, 300mm wide and 200mm high, made of glass so that it is easy to conduct experiments. Around the test section, Bosch profiles is mounted making it easy to mount measuring equipment.

1.2.8 Flow quality

The water flume has before this project not been changed since its creation. However the creator found the flow of an insufficient quality[1] and the project which takes use of it finds it sufficient[4]. The second of these investigations is limited to being of only two measurements and as the first investigation is deeper, it is believed that the flow is not sufficiently laminar. The first characterization is made in 2-component PIV and the second in stereo.
It is also possible to see flow disturbances with the naked eye. Therefore the analysis made by the second project is not trusted[4]. It would be appropriate to start the project of by testing the flow throughout, but with a lack of measuring equipment and setup, this is not done. More about measuring systems is found in next section. What was found though in the first analysis by [1] was problems with disturbances traveling up streams and a too high level of turbulence. Therefore modifications of the water flume was made to fix this, without further investigation.

1.3 Measuring system

1.3.1 State of previous setup

As the problems with the water flume itself was in focus, only too late was the state of the measuring system discovered. Earlier both one component PIV and stereo PIV systems had been used for measuring the system, latest the stereo PIV. This was also the system which was intended to use for measuring.
Before sending the water flume to the workshop, it was intended to do an analysis of the flow. At this point it was discovered what the system was no longer complete.
After not having been used in several years, the trigger box was gone, the amplifier for the signal as well and the software only known to former employees at DTU. Though the way of using the software was quite well described, the way of setting up the system was not, properly as under the assumption that it would not be needed to do again.
As this was discovered, the project got a lot behind schedule. A big thanks to Benny Edelsten for helping with the reetablation of the system.
Also there where a lot of confusion about the software, as several versions were available, which was nowhere described and the source code for the LabVIEW program not available.
At the start of the project, the water flume was assembled but there was no measuring equipment on it, and reassembling the project became a bigger task than expected.

1.4 Theory of the measuring system

1.4.1 Overview

The measuring system is made for SPIV, but can also be used for one component PIV. The overall setup is as this:

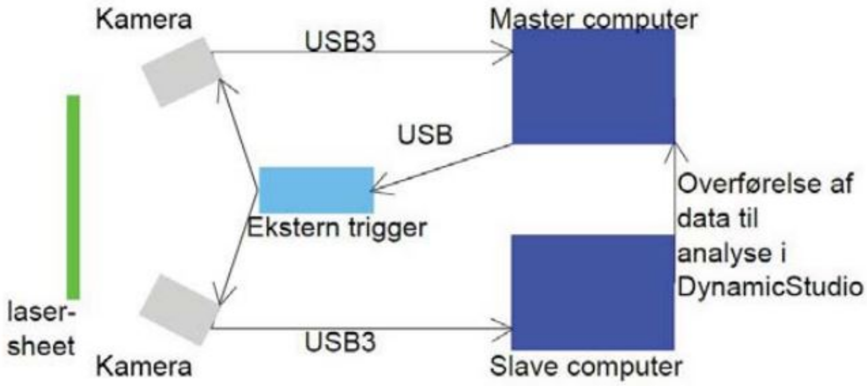


FIGURE 1.2: From [4]

The slave computer and the master computer collects the data from each of their camera. The trigger box is connected to each of them. The trigger box sends a signal to each of the cameras, when they have to take a picture which ensures that the pictures is taken at the exact same time.
The cameras is then connected to each of their computers, witch stores the data.

1.4.2 Collection of the data

The data is collected with the program "Mini PIV" created by Instrument Gruppen, for the second project. This program controls the trigger box, receives the images, converts and stores them. The program is in two editions, one for the slave computer and one for the master computer. Most of the control is on the master. A more detailed description of the use of the program is found in [4], both theory and user guide. The data connection is USB3 and the external trigger signals is via BNC. For this project, a trigger box for temporary use was constructed, it was made temporary as new cameras might be purchased soon. With new cameras, a new trigger box might be needed anyway. Therefor only a temporary was made. Along with the trigger box, a new piece of software might also be needed.

1.4.3 Processing of the data

The particles lighted up, is converted to vector plots in Dynamic Studio 3.4, and exported to txt files and processed in Matlab, the matlab scripts is based on the scripts made and used by [4].

Chapter 2

PIV

2.1 PIV

2.1.1 2-component PIV

PIV, Particle Image Velocimetry is a measuring technic that tracks particles and uses the change in position to analyses the flow. The technique is used in all kinds of flow and in many varieties. The basic concept is as shown in figure 2.1
It is seen here how the particles is spotted a t and afterwards at t'. From the change in position and the time, the velocity can be calculated. This though, only allows 2-D representation of the flow. The movement of the particles in the zy-plane.
In this system the camera is mounted on the side and the laser on the bottom.

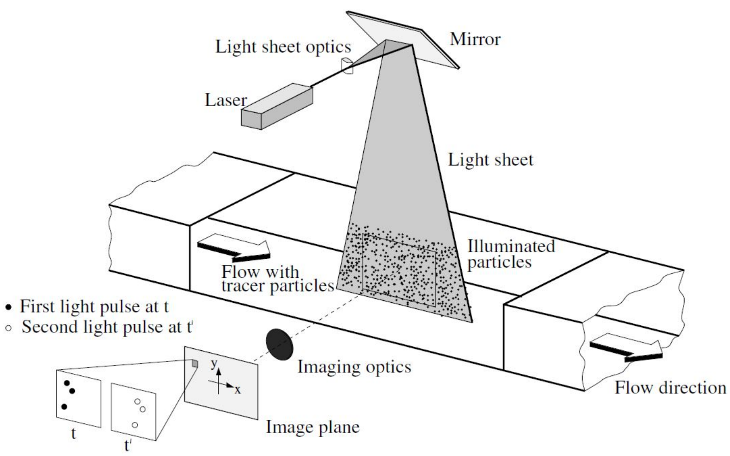


FIGURE 2.1: From [5]

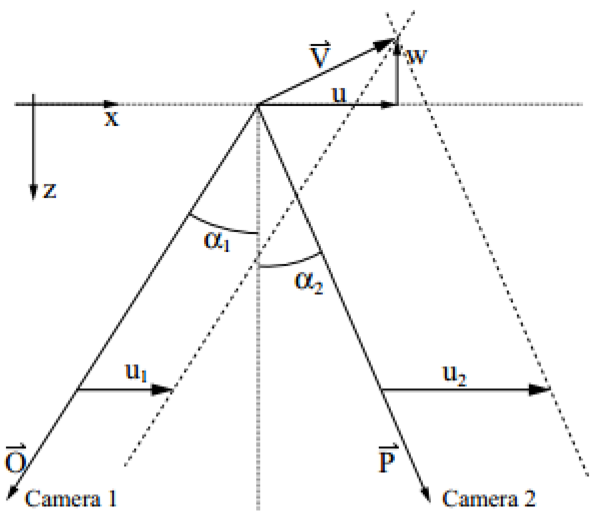


FIGURE 2.2: Figure from [5]

2.1.2 Stereo- PIV

With 2-component PIV it is possible to capture any movement in 2-D, while it is possible with stereo-PIV possible to capture movement in 3-D. With two cameras, the human sight can imitated. With two component vision, it is possible to capture the movement away/towards the cameras. This is done by having an angle between the cameras.
In 2.2, it is shown how the movement away from the two cameras in the component w. By using three component PIV, it is possible to get the full overview of the flow around the vortex generators, or any other obstacle.
This is described by:

$$W = \frac{U_1 - U_2}{tan\alpha_1 - \alpha_2} \tag{2.1}$$

Where U_1 and U_2 is the displacement received on each of the cameras and the α is the angle between the z-axis and ray from the particle to the lens. [5], page 214.

2.2 Scheimpflug

In stereo PIV, the two cameras have to be on each their side of the flow, and investigate in a plane perpendicular to the z-axis. As the cameras naturally have their focus parallel with the lens, the whole plane of investigation is not in focus. Therefore a customization of the cameras to have focus in the plane of investigation is needed. The usual way of doing this, is by the Scheimpflug principle.

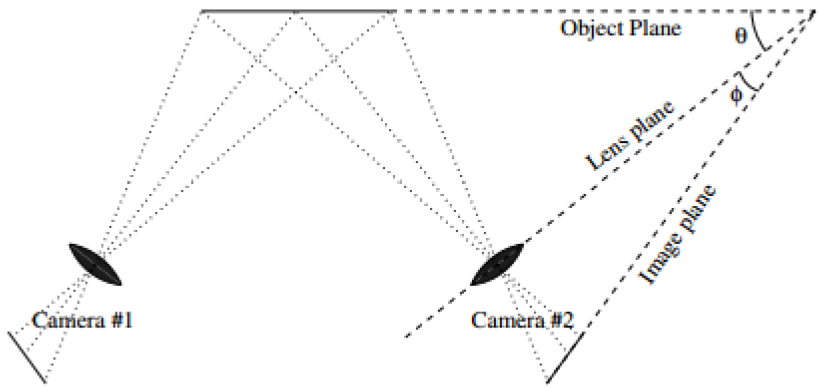


FIGURE 2.3: figure from[5] page 212

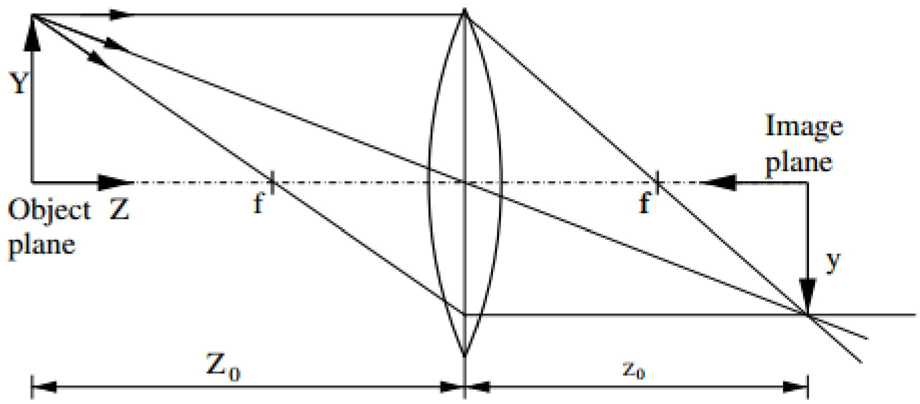


FIGURE 2.4: Figure from [5] page 50

As shown on 2.3 the lens is at an angle compared to the image-plan, the camera chip. By doing this, the focus is moved to the object plane, as desired. On the figure, it is obvious how the three planes are related, and coincident in one point.

2.3 Optics

To obtain good PIV measurements and using scheimpflug systems, requires the understanding of basic optics. The scheimpflug principle is all about creating focus. The basic focus comes as figure 2.4 shows.

For the object plane to be clear on the image plane, it needs to be in focus. The f-number

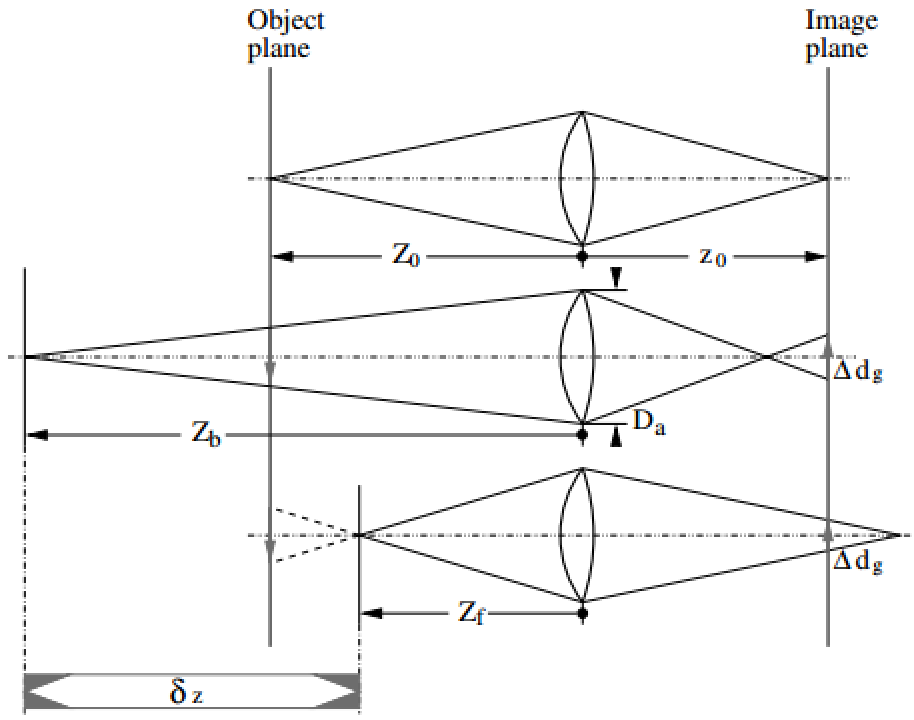


FIGURE 2.5: Figure from [5] page 50

has to be constant. If the lens is moves further away from the lens or closer towards it, it becomes out of focus, and the images become blurry and unfit for PIV measurements.

On Figure 2.5 it is shown how the image is out of focus. Creating a scheimpflug system from a normal camera involves dismounting the lens and therefrom placing it in a mount that enables the camera and lens to get the desired angel between. While doing this, it is important to leave the focal number constant, to get focus.

2.4 Illumination

The particles is lighted up by a laser, which provides strong monochromatic light that illuminates the particles. When the particles is illuminated by the light, is scatters around the particles. For practical reasons, it is often wanted to record the particles at a 90°angle, compared to the light source. This however, requires a quite powerful laser, as the light scatted from the particles only in very little extend scatters in a 90°angle. As 2.6 shows, depending on the size of the particles, only a little of the light would actually reach a camera, placed at a 90°angle. Therefore a powerful laser is needed. In this project a $1.5w523nm$ green light laser is used.

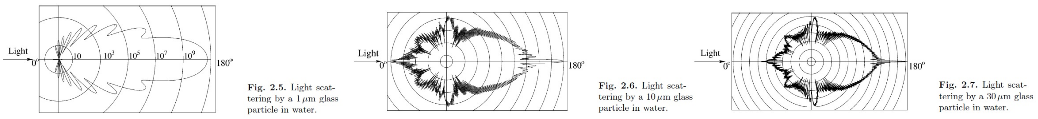


FIGURE 2.6: Light scattering for different sizes of particles in water, picture from [5]

2.5 Data processing

The data is processed in Dynamic Studio 3.4, where the movement of the particles is turned into a vector map which can be exported and analyzed in matlab. Then the data is processed in Dynamic studios, and the picture divided into interrogation areas, where the the particle movement is traced. For smaller interrogation areas, a high density seeding is needed, to capture the movement of the particles inside the same interrogation area. If a sufficiently high seeding is obtained smaller interrogation areas offers a higher resolution of the pictures, where more details is seen and the gradient over each interrogation area is smaller.

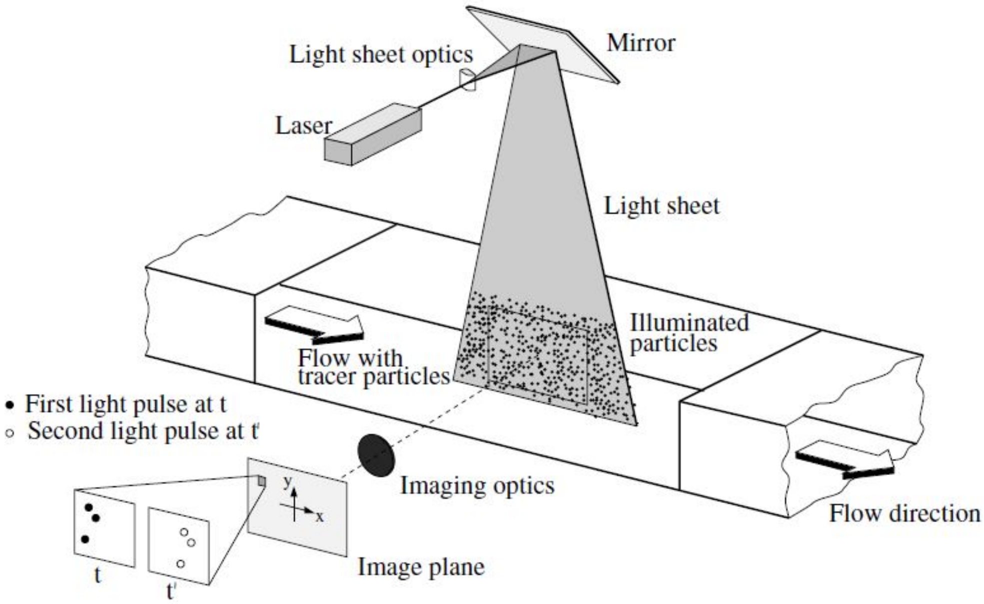


FIGURE 2.7: An overview of a typical PIV setup where the interrogation areas can be seen at to the left at the bottom picture from [5]

Chapter 3

Improvements

3.1 Scheimpflug

The Scheimpflug system design in earlier projects, did not reach completion, due to the lack of focus. As the system was designed to be a cheap option, it was made from small webcams with in a special holder enabling the lens to be at an angle relative to the CCD and object plane. The webcams was fitted with a lens with external thread, while the camera has opposite fitted. In the design of the holder, the lens should be unscrewed and mounted in the holder. Herby the lens is moved further away from the CCD than it was designed to. Therefore, no focus could be obtained at all. If the system should be modified to work the tread on the camera must be cut of, allowing the camera to be closer to the lens, even though it is at an angle.
In this project though, the tread on the camera is cut off, to allow the CCD and lens to have a constant distance. With this extra and small modification, the scheimpflug principle can be applied successfully.

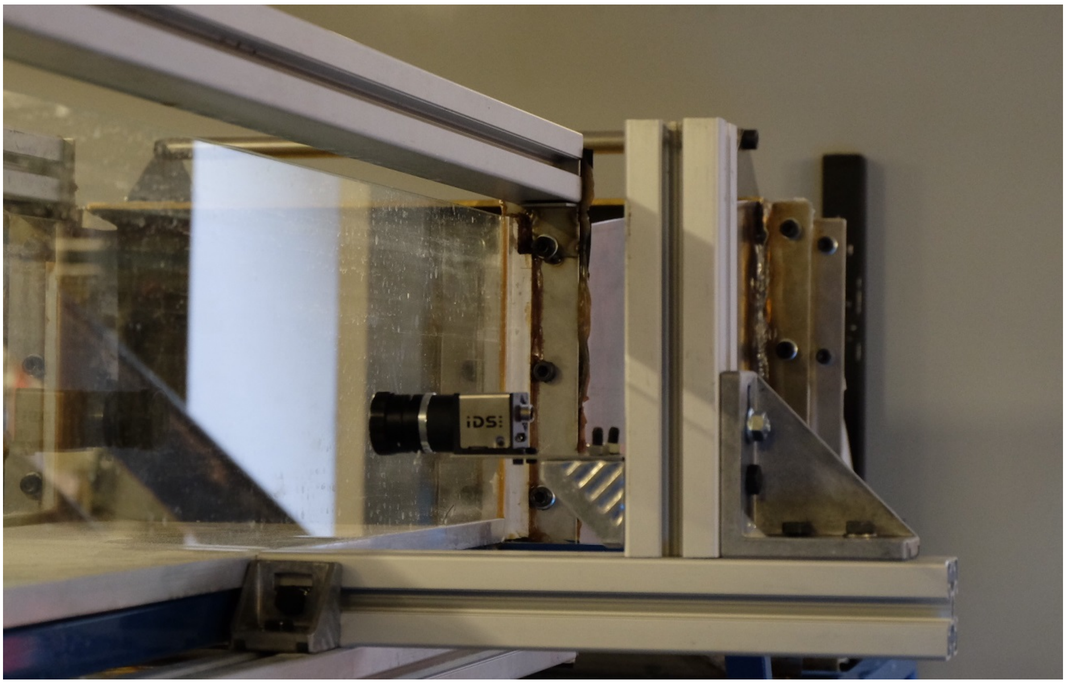


FIGURE 3.1: Camera before cutting of the lens socket

With this modification, it has then been possible to mount the camera in the mount created by [4].

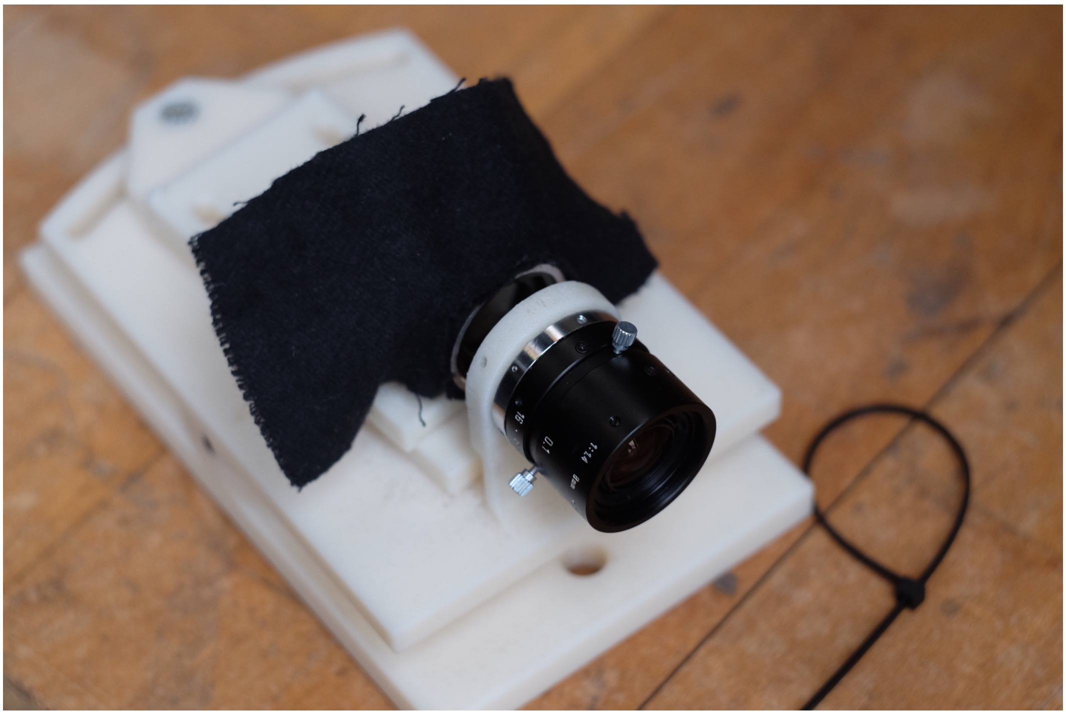


FIGURE 3.2: The camera mounted in the scheimpflug mount

Before the tread was cut off, the camera was tried mounted anyway, and as a result the focus was very close to the lens, following the theory in 2.5, at the bottom.
After modification the camera, the effects of the Scheimpflug principle was obvious.

Figure 3.3: Lens- and imageplane alligned, with differt focus.

Figure 3.4: Schimpflug principle implementet correctly

All three pictures is taken at the same position of lens and ruler. As with the current design of the Scheimpflug mount, there is no built in function to measure the angle so this is not measured for these images, as they would be very imprecise anyway. A build

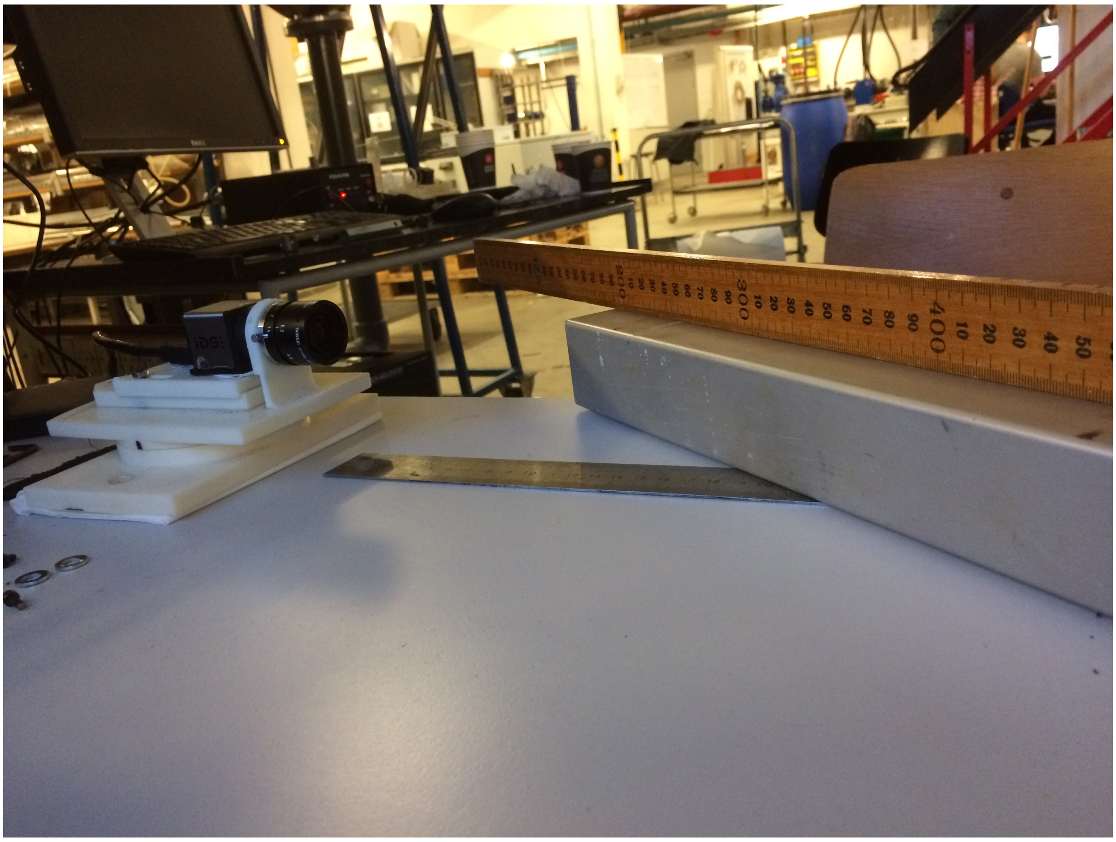


Figure 3.5: Setup in which the pictures was taken, lens to ruler distance is around 20cm

in measuring system for the distance between the lens and the camera would also be likeable. Furthermore the current system is very fragile, and the lens is fitted by friction. The lens is quite unstable and can easily fall off or be mounted wrong. The mount is also quite hard to adjust precisely, as the angle is adjusted by screwing and unscrewing a not with is hard to reach. Should a new mount be made, this would be of consideration for improvements.

FIGURE 3.6: Scheimpflug principle implementet oppisite towards the ruler. Note that the person in the upper left corner is in focus.

3.2 Setteling chamber

On the old system the design objective of 1 % turbulence was not reached, as the turbulence intensity was around 4%. One of the main reasons is the absence of a real settling chamber, as the current is too small.

The settling chamber is of the same width and height as the inlet to the contraction, so that the only free parameter is the length. The length is determent of how much turbulence is induced by the net, and how low a turbulence intensity that is desired in the test section, for this section, 1% is desired, though there is currently around 5%.

In the contraction, the turbulence in the longitudinal direction will fall[6]. Though the contraction will amplify the transverse turbulence, therefore this must be as low as possible.

In these considerations, it is assumed the theory of contractions for wind tunnels is overall applicable for water flumes as well. This assumption is not likely to be perfectly accurate. In the design of wind tunnels, there is no free surface, as in the water flume, furthermore gravity actually has an effect as water is heavier than air. Lastly the viscosity is lower than air.

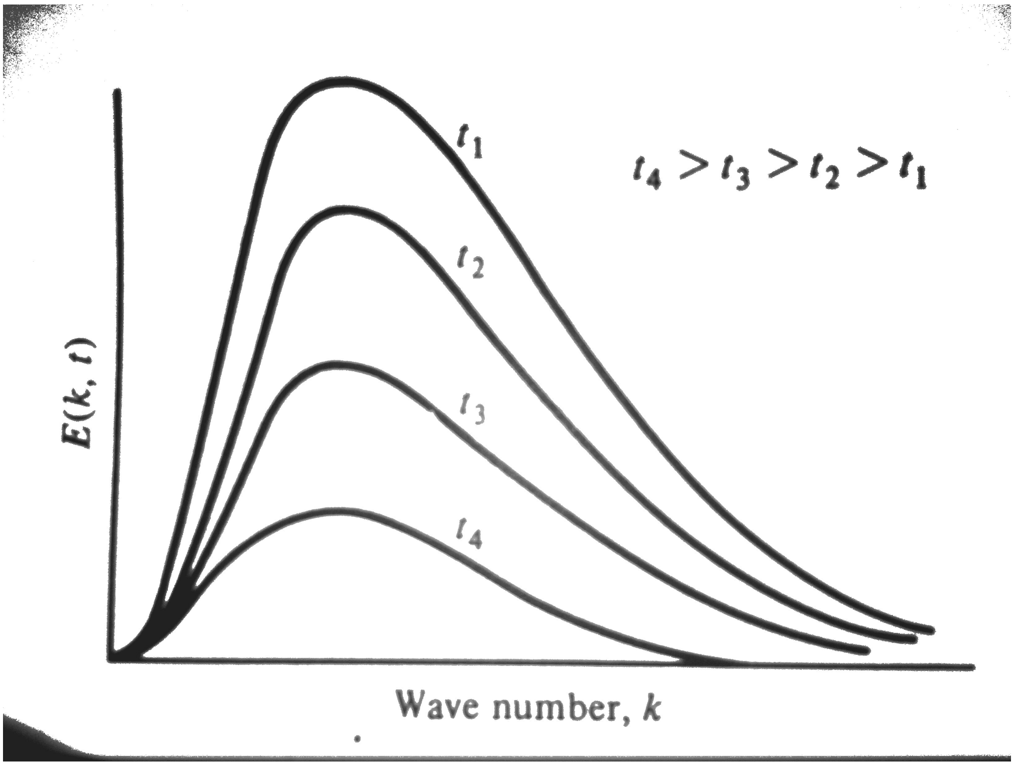


Figure 3.7: Decay of turbulence

Though this is known, it is difficult to account for during the design, as most knowledge on design of wind tunnels is based on experience and the nature of turbulence is generally hard to predict.
The energy of the turbulence decays exponentially over the wave number[7].

Furthermore it is known that the root mean square velocity decays exponentially over time.

$$u_{rms} = \sqrt{\frac{3RT}{M_m}} \tag{3.1}$$

The root mean square to the power of 2 follows the decay law:

$$u'^2 = const. * t^{-5/2}[7] \tag{3.2}$$

As the turbulence intensity is known in the test section, it would might be possible to calculate the turbulence intensity before the contraction, and at last how long a settling chamber needed to lower this level sufficiently to achieve a turbulence intensity of 1%. This, however would require a lot of weak assumptions and not deliver a very accurate answer.

Another option, is to estimate the turbulence induced by the net, and afterwards calculate how long a settling chamber that is needed for this to decay. However, this is a very sensitive calculation. Due to wire type and net density and the incoming flow, several different models for this is obtained[7]. These however, does not agree fully. A further study of this would be quite extensive and is not likely to give an exact answer anyway. Therefore, the length of the water flume is determined by scaling existing water flumes on DTU.
In the existing water flumes, the relation between width and length is around 0,55. With this, and a width of $535mm$ before the contraction, the chosen length for the settling chamber is $290mm$.

When the turbulent velocity is calculated from test results, following equations is used[8]:

$$\bar{u} = \frac{1}{N} \sum_{N}^{1} u_i \tag{3.3}$$

$$u_i' = u_i - \bar{u} \tag{3.4}$$

$$u_{rms} = \sqrt{\frac{1}{N} \sum_{N}^{i=1} (u_i')^2} \tag{3.5}$$

And finally the turbulence intensity:

$$I_u = \frac{u_{rms}}{\bar{u}} \tag{3.6}$$

These equations is used for data processing in matlab later on.

3.3 Outlet

A flow in an open channel can be categorized as either slow or fast, described by the Frode number. With a Frode number below 1, disturbances can travel upstream while this is not possible with numbers above. From earlier measurements of the flow, it is known that the flow is of a velocity around $0,11m/s$. The Frode number is calculated from this:

$$Fr = \frac{V}{\sqrt{gy}} = \frac{0,11m/s}{9,82m/s^2 * 0,2m} = 0,078 \tag{3.7}$$

In practices, this means that disturbances upstream can travel down streams and cause disturbances. Upstream from the outlet there is a small but quite clear hydraulic jump, which is assumed caused by water flowing back from the outlet. As in the inlet, the water has to change direction whilst the energy of the flow is kept constant. In the outlet the horizontal velocity has to be eliminated into pressure, which at last turns into velocity in the vertical direction.
In the current setup, the flow reaches the back end of the outlet with a velocity so great that it turns back and travels upstream, this is what is thought to be the reason of the hydraulic jump.
In the outlet, the kinetic energy has to be removed from the flow. As for now this is happening to fast, and the disturbance then travels quite far upstream. To account for this, a larger outlet is put in, inspired from already existing water flumes at DTU. By doing this the kinetic energy has more space to convert into turbulence, and not turn upstream. Should this happen anyway, there is now a longer way, from the end of the flume, to the test section.

3.4 Diffuser

Then turning on the flume without the guide vanes in the inlet, it was observed that the diffuser did not spread out the flow properly, and a significant larger flow where observed in the middle of the inlet, as it is seen on 3.8. It is clearly observed that there is a bigger flow in the middle. Similar is seen then the screens is placed in the flume.

FIGURE 3.8: The inlet without guidevanes.

As [1] also described how it had been found that the flow was crooked and it might be caused by separation in the diffuser, it is found very likely that this will cause the flow to have a non-uniform velocity profile, and might even raise the turbulent intensity. Therefore several plates with holes or squares where cut and placed just in above the vanes in the diffuser to even out the velocity in the diffuser, as it was clearly higher in the middle. 4 plates where cut, two just over the vanes in the diffuser, as seen in figure 3.10, and two at the top of the diffuser as seen in figure 3.9.

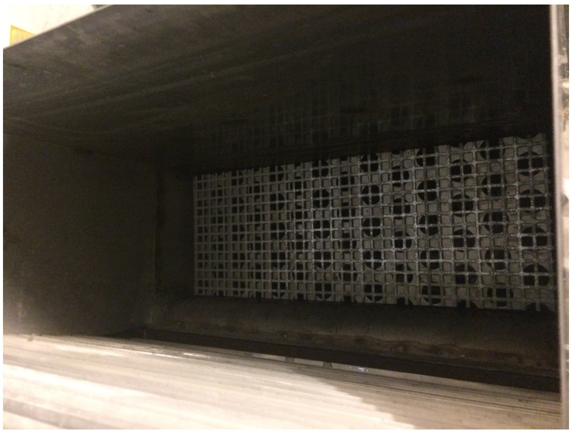


FIGURE 3.9: plates in the top of the diffuser

Figure 3.10: plates in the lower part of the diffuser

3.5 Mount for calibration target

In earlier projects, it had been described that it could difficult to mount the calibration target, and therefore a mount for the target used when doing stereo PIV was constructed. The mount is like seen in figure 3.11. On the micrometer screw a calibration target have to be mounted, and is then in a 90 °angle on the z-axis.

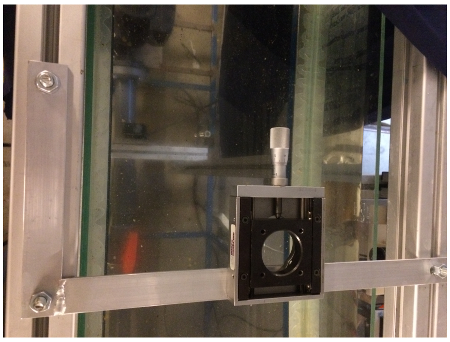


Figure 3.11: Mount for calibration

Chapter 4

Experimental investigation

4.1 Experimental Problems

4.1.1 Camera Mount

As both cameras was modified to fit the scheimpflug mount, the scheimpflug mounts had to be used even though no scheimpflug angel was wanted, to do 2D PIV. When using the mounts, several problem was discovered considering the quality of the mounts. Only one of the mounts could be used, as the lens could not be proper mounted in the second, and would simply fall of. In the mount where the lens could actuarially be attached, it was a bit loose and could be found different positions. Though it was still possible to get proper pictures, the camera and lens should be handled very carefully and checked before every measurement.

FIGURE 4.1: It is seen here that the camera is a bit lower than the lens

Then the camera was first mounted, the lens and camera was not in the same height, as seen in figure 4.1. Therefore small pieces of paper was stacked under the camera to get it to align the camera and the lens.
Before stacking the paper under the camera, the image from the camera was way higher than straight in front of the camera, as in the principle of figure 2.4. As the effects of the misalignment would amplify as distance from the lens to the object is raised, this could be used to calibrate the camera. Therefore two rulers was used for adjusting the camera correctly.

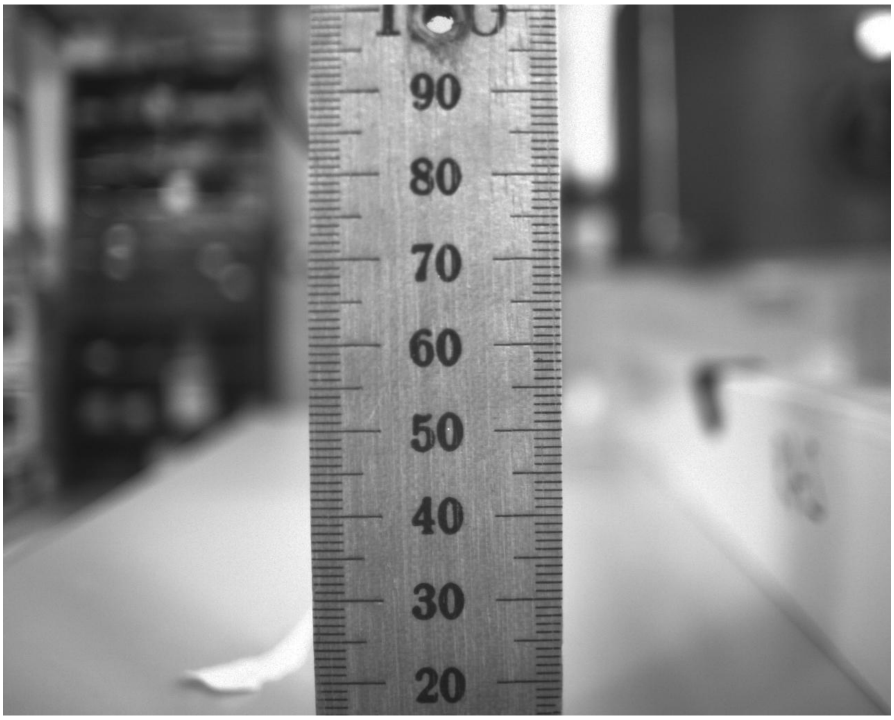


Figure 4.2: Ruler 11 cm from lens

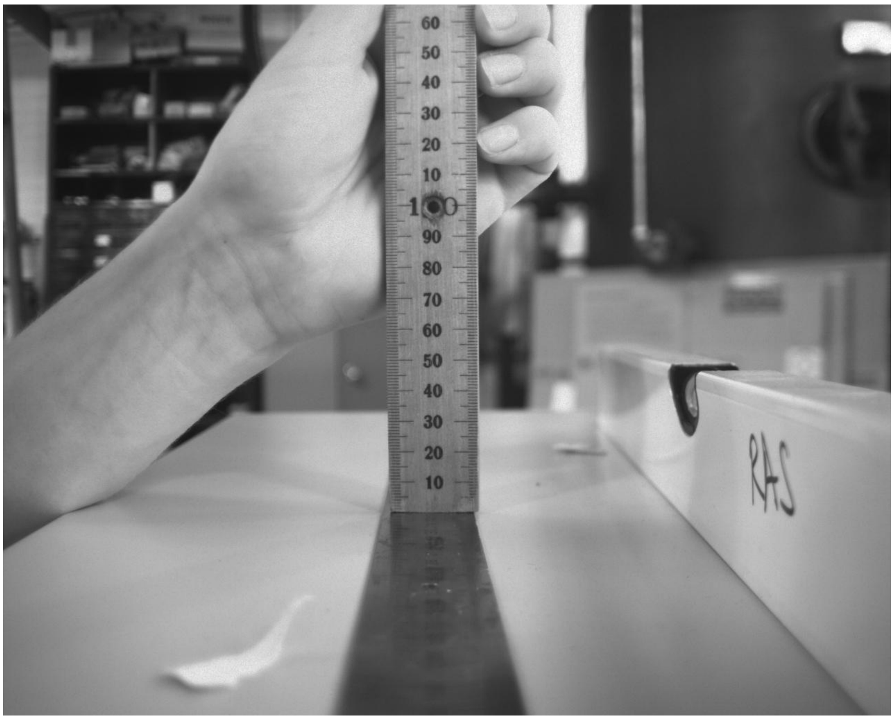


Figure 4.3: Ruler 33cm from lens

It is seen in 4.2 and figure 4.3 that approximately 60cm is in the middle of the picture, and it is therefore concluded that the lens and camera is approximately aligned. In the actual investigation, software was used to measure the pixels until a curtain point on the ruler.

4.1.2 Flow configurations

As the flume arrived back after construction, the flow was found to be of quite bad quality, just by observations with the naked eye. After trying several different configurations, it was found that an amount of bubbles in the screens was preventing the screens from breaking down the turbulence, instead it is thought to have been block some places and open at other parts, and therefore not lowering the level of turbulence and might even raising it. This though was simply solved by hitting the screens with bare hands or a rubber hammer. Then this is done, bubbles is clearly seen rising from the screens and the flow quality is seen clearly improved. The screens was also cleaned at the same time, as they were clearly filled with rubbish. This might be there the particles go after several hours of running with the flume.

Figure 4.4: The screens before cleaning

It was also quite quickly discovered that the flow in the bottom of the flume closest to the contraction was quite turbulent, which is thought to be caused by a rough edge between the contraction and the test section after the new setteling chamber. This edge was evened out afterward, by might still be of consideration, as the silicone fugue is not as smooth as desired.

4.1.3 Particles

The particles in the water from tap is found sufficient to conduct PIV experiments, though it is seen that over time they disappear from the flow. The particles is found in a great amount when the flume is just filled, but after a couple of hours the amount has fallen a lot. If the flume is left to run for many hours, there is almost no particles left in the flow. The particles is thought to be captured in the screens or accumulated in the bottom of the flume. It is important to be aware of the level of particles in the flow when measurements is conducted.

When the measurements is conducted, the laser/camera positions is also crucial as good measurements will only be conducted if there is an evenly intensity of the light sheet. This is primarily obtained by moving the laser lower, so that the whole field is better illuminated. Hereby the intensity of the whole field is of course lowered, but this is not found to be a course of errors in this investigation.

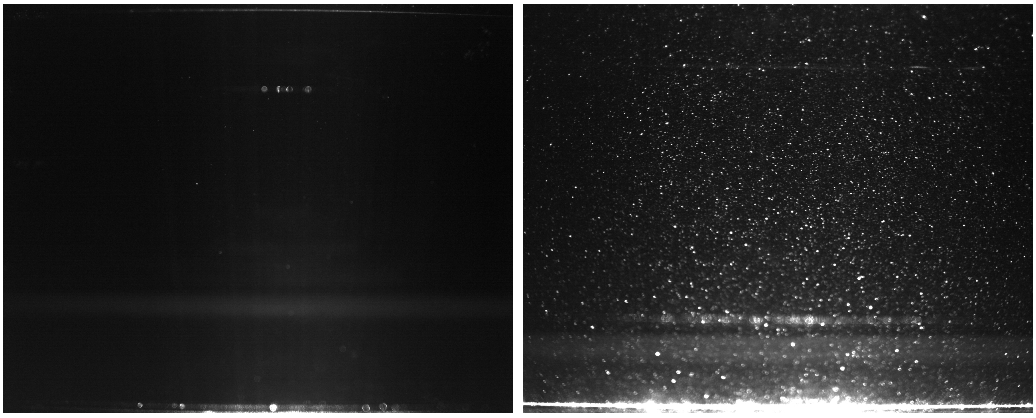


FIGURE 4.5: view with a lot of particles and with almost none.

4.2 Software

The cameras in the setup is USB 3.0 cameras, with a maximum resolution of 1280x1024. In the earlier project, [4] it was stated that a higher resolution than $800x600$ was not practical possible, as it would be a problem to transfer the data fast enough. This however was done by changing an .ini file, and the data was transferred without any problems. The software though was obviously not made for this though, as it only showed $800x600$ pictures in view mode. Therefore Ueye software was used when calibrating the camera.

Chapter 5

Test results

5.1 Parametric study

The flume have several different devices for flow management, with the function of keeping the flow as uniform and laminar as possible. 13 different configurations of all these devices was tested to find the best performing configuration. As described in the improvements section, 4 plates were cut to even out the velocity profile in the diffuser. From earlier projects, screens with course and fine net was cut, and guide vanes was manufactured.

The experiments were all conducted in on the same day following the experimental procedure found in appendix D. All the experiments was conducted in the same position, $z = 45cm, x = 15cm$. For each experiment, a contour plot of the turbulent intensity and the velocity profile was created for the plane of measuring. For a more precise presentation of the measuring, a graph of the same was also plotted for the mean values. Based on the study, it was found that the best configuration tested was with 2 plates, guide vanes and fine net.

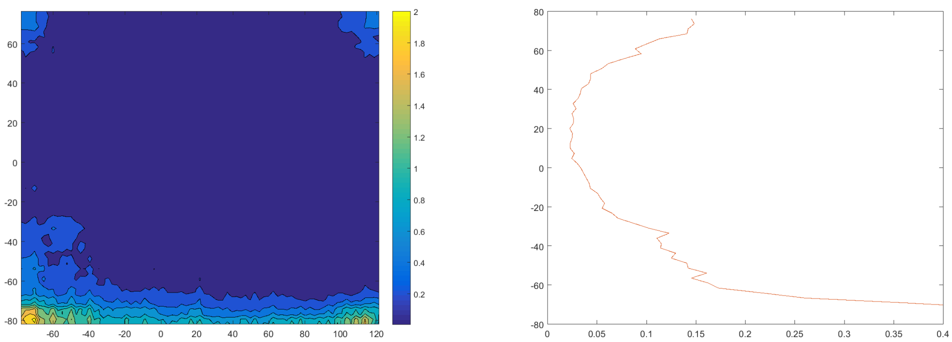


FIGURE 5.1: Turbulent intensity z=45cm,x=15cm

It is seen here that the turbulent intensity is about the same in most of the field, except the bottom around the boundary layer at the left side. On the right side it is seen how the mean intensity is lowest around the middle of the flume and high at the bottom and top

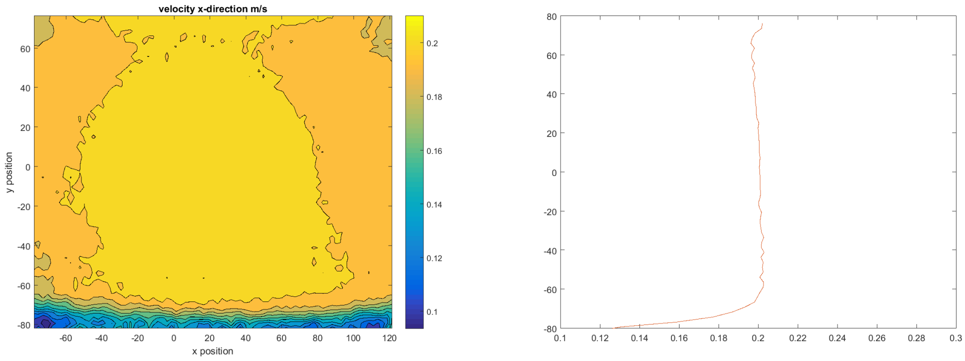


FIGURE 5.2: Velocity z=45cm, x=15cm

In this plot the mean velocity is seen, as a countourplot on the left and a curve at the right. It is noted how the mean velocity seems to be higher in the middle than in the sides. On the right it is noted how the boundary layer looks reasonable and the men velocity is quite constant

The rest of the results can be found in appendix D. At figure 5.2 the turbulent intensity at the right is found at the mean over the plane. If the same curve is plotted for just a single z value, a curve as figure 5.3. It is noted that this plot is made for the middle of the view of the camera.

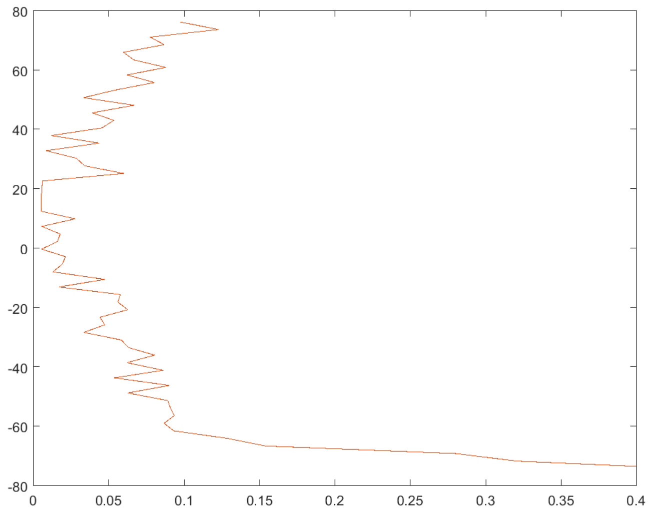


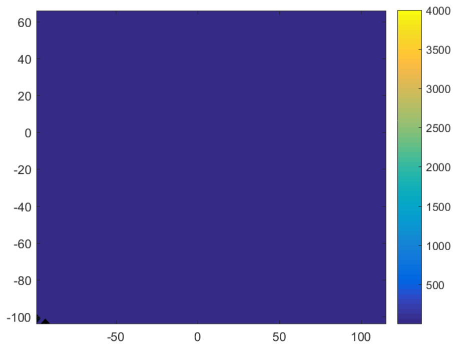
FIGURE 5.3: Turbulent intensity at z=45cm

In the contour plots, it is seen that the velocity is higher in the middle and the turbulent intensity is lower. This seems unreasonable, as the same pattern is showing in every measurement. Furthermore, is dos not add up, that the velocity is higher in the middle than in the sides. It seems that there is some sort of problem with the measuring equipment or setup of this.

5.2 Characterization of the flow

After finding the best configuration, a full characterization of the flume was conducted to determine if the flume meet the requirements for conducting actuarial experiments in. For this, three positions along the z axis was chosen. On each position, three different x-positions was tested too, making it 9 measurements in total. The z positions tested was:$z = 15cm, z = 55cm, z = 100cm$ and the x-positions tested was $x = 5cm, x = 15cm, x = 25cm$.
In the results it is seen that there is very different turbulent intensities over the profiles and the velocities is very changing too. In the following the three dataset for $x = 15$ is presented, datasets for $x = 5$ and $x = 25$ is found in appendix XXX.

z=15,x=15



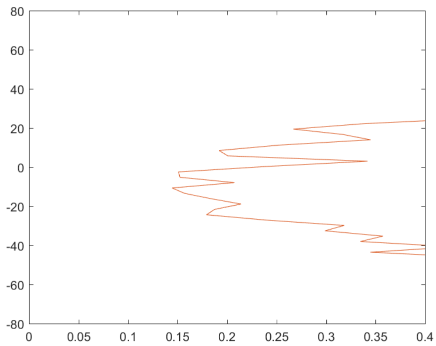


FIGURE 5.4: Turbulent intensity for the plane at z=15 and x=15 along the flow direction

The turbulent intensity is found to be quite high, but lowest in the middle of the flume. It is seen significantly higher than the turbulent intensities found in the parametric study.

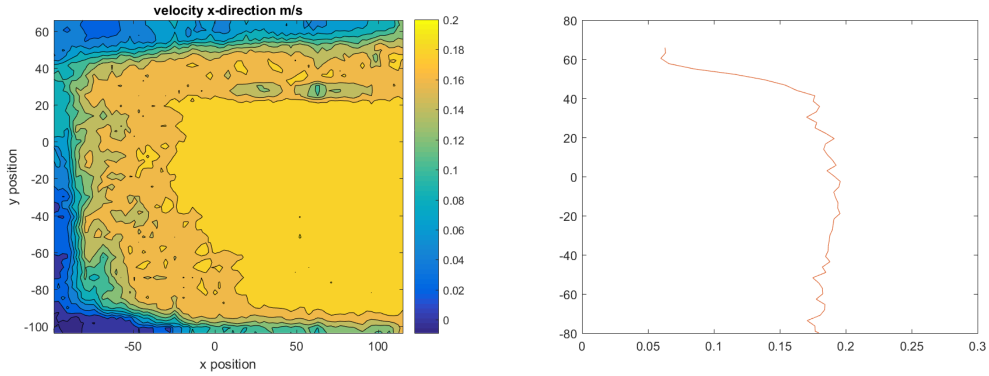


FIGURE 5.5: Velocity for the plane at z=15 and x=15 along the flow direction

The velocity is found to be of the same magnitude found in the parametric studio, but of very different distribution. On the curve it is especially noted how the velocity is much lower at the top of the flume.

z=55 x=15

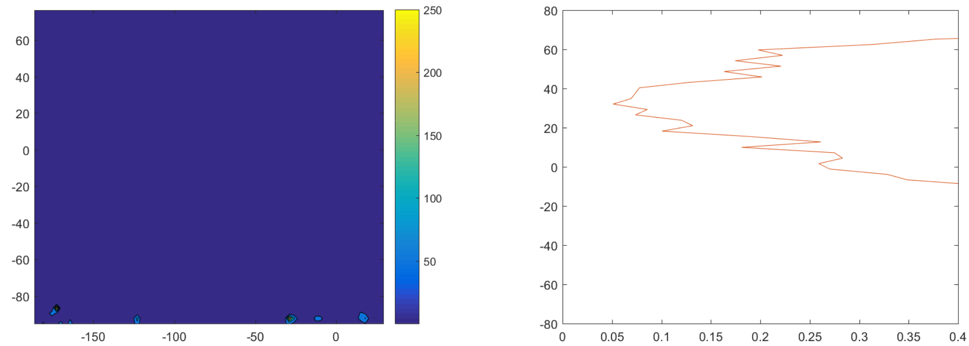


FIGURE 5.6: Turbulent intensity for the plane at z=55 and x=15 along the flow direction

It is seen here how the turbulent intensity seems to be distributed quite evenly over the plane, on this scale. However on the curve it is seen that the turbulent intensity is very high all over, but at around 30mm is close to 5%.

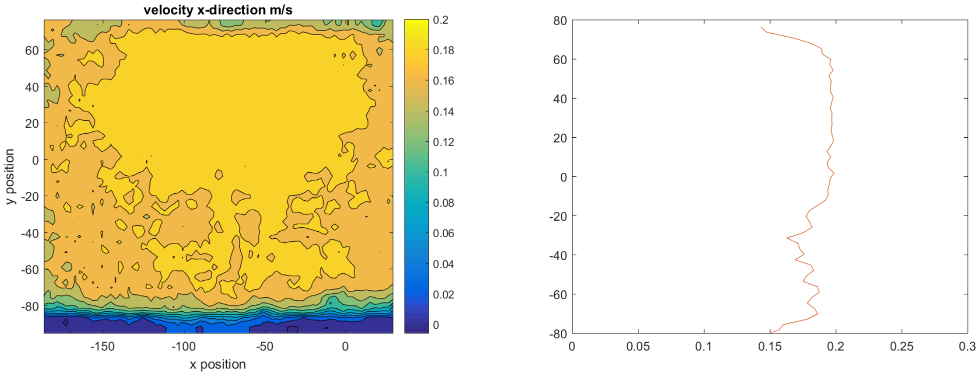


FIGURE 5.7: Velocity for the plane at z=55 and x=15 along the flow direction

It is seen here that the velocity profile is quite uneven compared to most of the other curves obtained. The contour plot is quite uneven too, and the velocity, especially in the sides are a lot slower than the middle.

z=100 x=15

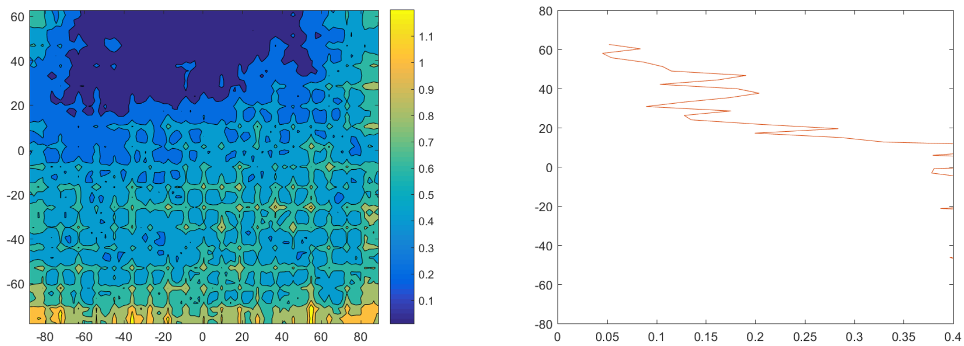


FIGURE 5.8: Turbulent intensity for the plane at z=100 and x=15 along the flow direction

The contour plot in this position is full of squares, and not very even in intensity. The curve is also shows very high levels of turbulence.

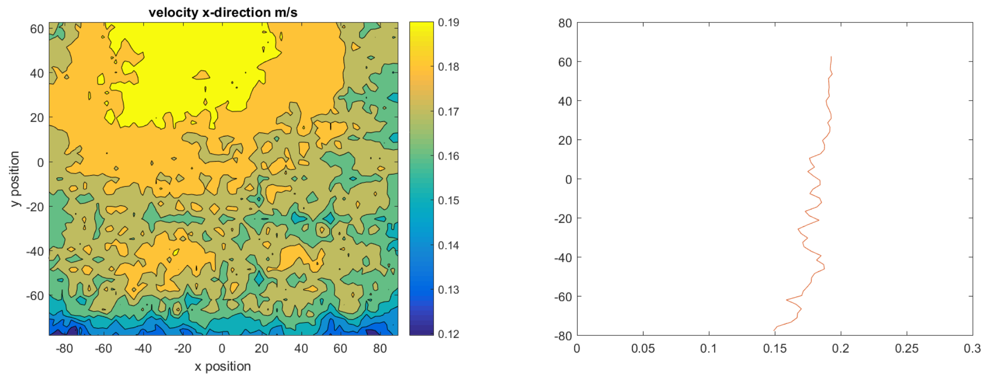


Figure 5.9: Velocity for the plane at z=100 and x=15 along the flow direction

The velocity in this countourplot is very uneven over the plane, and the curve varies in the same way.

Chapter 6

Discussion and Conclusion

6.1 Discussion

The investigations were made in two main parts, the parametric study and the characterization of the flow. The results in the parametric study matches great with each other and the expected. In the measuring system there is a lot of insecurities, which might be the explanation of some of the results that dos not match the rest and the expected. Especially in the characterization of the flow.

From the theory and goal of a uniform velocity profile, it would be expected to see a contour plot with almost the same velocity all over, except at the bottom at the boundary layer, where the velocity should be zero. In the plots, the boundary layer is well recognizable, but in the sides versus the middle of the contour plot big differences where spotted. These differences is not explainable by the theory and some kind of measuring error must have caused this. The intensity of the illumination of the particles might be one, as the particles where stronger illuminated in the middle due to the lens on the laser. If fewer particles where illuminated at the sides of the field of view, this might have caused Dynamic studio to create more errors in the vector maps. It was noted during the measuring that the field with the highest velocity was not always in the same position on the field of view. For example figure 5.5, where the right side of the plot seem a lot more reasonable than the left side, compared to almost any other contour plot where the velocity is highest in the middle.

As the optics where in the mount which is very fragile and of poor quality, it is also very possible that the picture had not been in focus all over, and a part of the picture might be out of focus and therefore full of errors. Sometimes it was experienced that the lens and/or camera would change position due to movement of the fabric it was covered with.

Despite these uncertainties, there was found data in the parametric study which match each other quite well as well as the expected. Except of cause the difference in the sides of the field compared to the middle. The velocity profile especially was as expected, as seen in figure 5.2.

In the parametric study, there were differences between the measurements, of a magnitude that seemed quite possible to be true. Though the configuration with two plates, guide vanes and fine nets was found to have the lowest turbulent intensity, the differences was not big and with a more throughout investigation it could might be found that another setup would be better. Though it is not all given that the chosen setup is the best, it is very likely to be of the best 3-5 configurations, as some of the setups were obviously worse, if the measurements is trusted. All of the plots for the setups are found in appendix D.

In the characterization of the flume, the results are very different from the parametric study and the expected. In these measurements, the measurements were very little consistent and matched the results from the parametric studio very poorly. There was large variations in both the velocity and the turbulent velocity, in all of the measurements. None of the measurements had the results expected, and it is found likely that the same cause of error is common for all of the measurements. As the same configuration of flow management devices where used, the same procedure for setup, same amount of frames, same data processing and several laser and camera setups were used, one obvious reason is not clear. But as the flow was observed with the naked eye, and compared with the previous measurements, it is not likely that these measurements is true. For z=55cm and x=15cm, this is expected to match the measurement from the parametric study quite well, as this was conducted only 10cm apart. These however was not alike at all.

It is found likely that the flow either was not as uniform in this series of measurements, or the measurements were wrong. As it was discovered that if there is bubbles in the screens, it can have a great effect on the flow. If not all of the bubbles were forced out of the screens, it could might be the reason for the strange measurements. It could also be that the screens had been full of dirt yet again, so that they again did not have the wanted effect.

If however the measurements are valid, the water flume is performing significantly worse than what was found in [1].

Figure 6.1: The mount for the screens that are falling apart

6.2 Further work

6.2.1 Water Flume

Measurements has been conducted several times, but the measurements on the current setup is not sufficient to say with certainty. The measurements indicates that the turbulent intensity is lower than before the new improvements, but still not all the way down to 1%. It is guested, that under 2% in some regions is not unrealistic. Nevertheless, before any other projects, experiments on vortex generators or similar, it is needed to find out how the flow quality actually is. To make throughout analysis of how often the flume needs cleaning and if the bobbles is actually fully removed by banging a hammer onto the screens or it might also need time for the last bobbles to disappear.
The screens also needs a renovation or remake, as they are falling apart, figure6.1 If the quality is found sufficient, the water flume might need some configuration if new mounts and measuring is implemented. For example the prisms might need to be moved.

6.2.2 PIV setup

6.2.3 Camera mounts

In this project only 2D-PIV was conducted, but the equipment for 3D-PIV is present. For a good setup of 3 component PIV, more work is required. To do higher quality 2-D PIV, more work is also needed. For both setups, a new mount is needed. Currently the scheimpflug mount is used, where the lens and the camera is not aligned the adjustment is very imprecise and it is not possible to read the angle or distance between the camera and lens. Furthermore and most crucial, the lens does not fit very well in the mount, and is unstable, creating an unwanted angle between the lens and camera in the vertical direction. This mount is a problem both using scheimpflug or not.
A if it is desired to make stereo PIV using scheimpflug, a new mount could have many of the same features as the current, only if better quality and with better adjustment possibilities and options for measuring angle and distance.
If only 2D PIV is wanted, a stationary mount without the possibility of adjustment in any directions is sufficient.
This is all if new cameras are not purchased.

6.2.4 Trigger

In the current setup, a temporary trigger box is created. If the system is to run a lot of experiments, a more permanent solution would be preferable. The current trigger box can supply any voltage. For the cameras used in the project it has supplied $12V$, but new cameras might need a different trigger voltage.

6.2.5 Mounting of cameras and laser

For this project, mounting cameras and laser with Bosch profiles have been sufficient, but if a lot of measurements were to be conducted, a more permanent mounting is needed for precision and efficiency of work.

6.2.6 Software

The pictures from the Mini-PIV LabVIEW program, first taken in .bin format and then converted to .jpeg. These pictures is as earlier not possible to import in Dynamic Studio 2015b, but in Dynamic Studio 3.4(older version). If the system is to continue running on the Mini-PIV LabView program, the conversion software properly needs an update to convert pictures that Dynamic Studio 2015a can import.

6.3 Conclusion

From the investigations and analysis done during this project, a lot of discoveries about the flume and the measuring system have been made. In the attempt of implementing a full scheimpflug in the measuring system, the opportunity of using it in the original configuration vanished. By doing this is was proved that the schimpflug system can quite easily be implemented and it can be concluded that a new mount on the foundation of the existing and the experience of this project can be created quite easily. Before this is done though, it is difficult to conduct quality measuring and a final verification of the quality of the flow cannot be performed. But visual inspection and some measurements, for example figure 5.3 indicates that the flow quality overall seems to be of fine quality. It can finally be concluded that more work on the measuring system is needed before the final analysis of the flume can be conducted with certainty.

Bibliography

[1] Kristina Bach Rose. Design and piv measurement of waterflume.

[2] Fox and Mcdonald. *Introduction to fluid mechanics*.

[3] Donald R. Boldman and Paul F. Brinich. Mean velocity, turbulence intensity, and scale in a subsonic turbulent jet impinging normal to a large flat plate. *Nasa Technical paper 1037*, 72, 1977. URL https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19770025487.pdf.

[4] Dorte Brandt Andersen og Magnus Kopytko. Optimering af vortex generatorer p vindmller.

[5] S. Wereley J. Kompenhans M.Raffel, C.Willert. *Particle Image Velocimetry*.

[6] By H. S. Ribner and Mo Tucker. Spectrum of turbulence in a contracting stream. January 1952.

[7] J.O. Hinze. 1975.

[8] URL http://www.mit.edu/course/1/1.061/www/dream/SEVEN/SEVENTHEORY.PDF.

Appendices

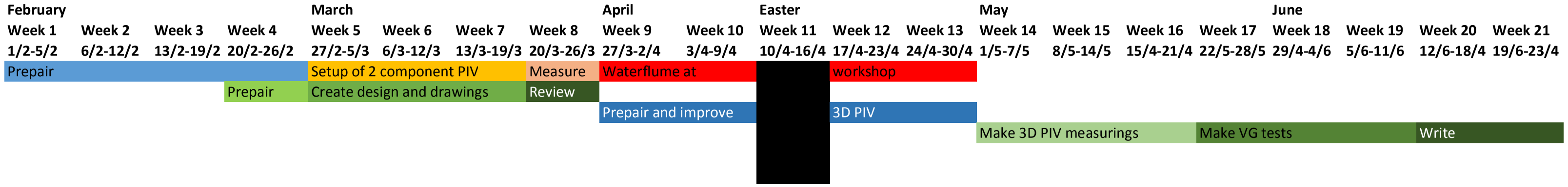
Appendix A

A

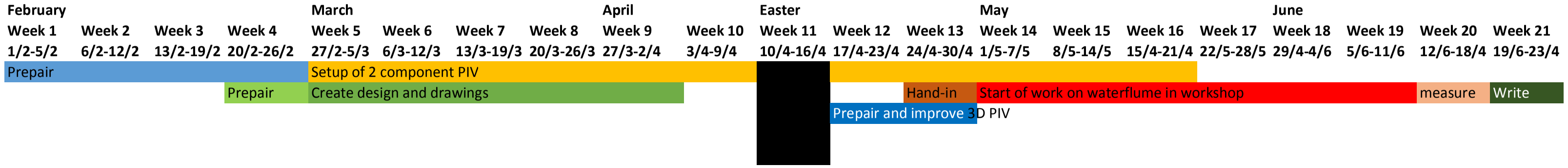
A.1 Gant

GANT

Expected:



Acturral :



A.2 2-component PIV

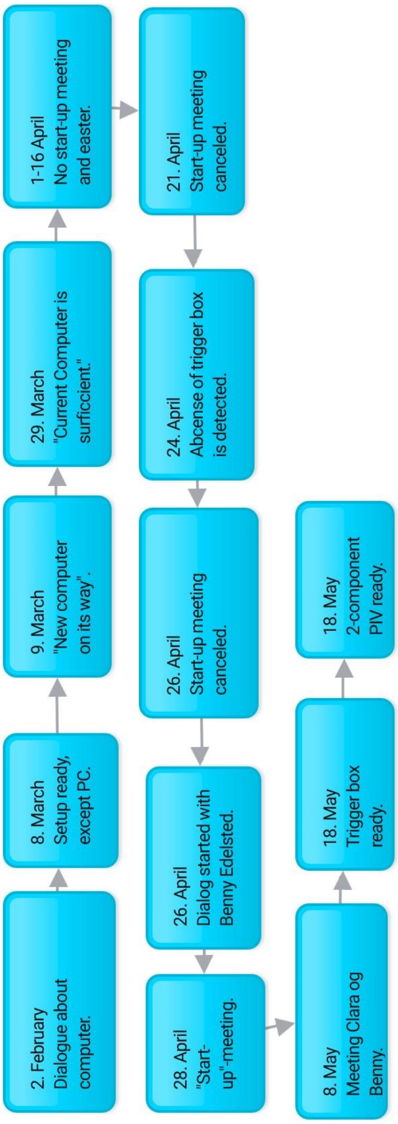


Figure A.1: Process of setting up 2-Component PIV

A.3 Project plan

This project has not reached the goals set, primarily due to misunderstandings, the state of the setup and a way longer construction time than expected. In appendix A1 a gant scheme is included, where it is obvious that the setup of the 2-component PIV has been way over due and has delayed the project. A figure showing the whole process is included in appendix A2.

A.3.1 Goals

The Gant Scheme also shows what was reached and what was not. As the project got more and more delayed, goals had to be removed along the way. After the waterflume came back from the workshop, it was intended that the flow schold be charecterized thoughout, making stereo-PIV measuring with the new Scheimpflug and testing Vortex Generator's. This had all to be removed from the plan, and only a quick chareterazion with 2 component PIV was made.

A.3.2 Setup of 2-component PIV

First a misunderstanding about the computer in the lab, and its ability to be used in for this project delay the project a lot. At a point it was told, that a new computer was on its way, but it was later on told that the existing one was sufficient, which is seen in the quoting marks in the scheme. Later on a meeting had to be held to make the first measuring, though finding a time suitable was difficult, and two meetings got canceled. Before reaching a meeting, it was discovered that the system was not complete, but a trigger box was missing. Finally a meeting was held and a trigger box was made, but putting the whole process a lot behind schedule.
Though it was intended to make new measuring on the water flume and evaluate the new design before seending it to manufacturing, it was send to manufacturing without measuring as the process was already delayed a lot.

A.3.3 Construction work

The work on the Water flume was done by Jan Horne Hansen from the workshop in building 414. Both the outlet and the setteling champer raises the weight of the flume significantly, therefore more support was needed. Also the flume top of the flume was prolonged, the tubes in the bottom also needed to be the same. As the work procceded, it became clear that the waterflume had not been build to the standards of the drawings made earlier. Measurings of the crookedness of the flume was not made, but was obviously seen with the naked eye. This prolonged the construction time of the flume. The flume was sent to constuction monday 24. of April, the work then began the 3. May and expected done latest the 19. May, then this date was postponed to the 25. May and yet again to the 6. June there it was actually done. This was way over what was expected. At first it was estimated by the workshop that about 2 weeks would be sufficient.

Appendix B

B

B.1 Experimental procedure

B.1.1 Adjust laser

First the laser is possioned along the z-axis, which is along the flow direction, to the position where it the investigation is wanted, secoundly it is adjusted along the x-axis, which is the witdth of the flume, to the position where the investigation is wanted. Lastly the laser is adjusted to be parallel with the flow, pendicular with the x-axis. This is done by adjusting turning the lens on the laser. On top of the flume, two rulers is placed parallel on the x-axis. The laser now have to hit the same numers on each of the rulers, to be parallel to the flow.

B.1.2 Adjust camera

First the camera position is adjusted along the z-axis, as this is the mount which is furthest away from the camera and closest to the waterflume. If this was adjusted last, it might change the adjustment of the two other dimentions.
Secoundly the camera position is adjusted in the x and y dimention, by loosening both screw holding these. Then the two dimentions is adjusted at the same time, so that both the top and bottom of the plane of the flow that is illuminated is in the picture.
Focus is adjusted lastly, so that the whole plane is in focus. The focus is adjusted on the lens mostly, but some times it might be nessecary to adjust the distance between the lens and the camera, due to the bad mounts.

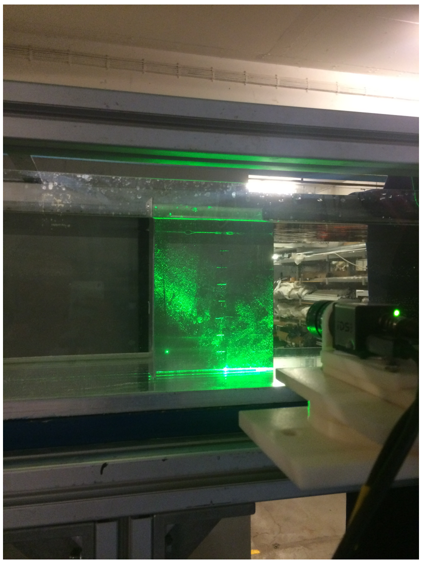


FIGURE B.1: Target used for calibration

B.1.3 Calibration

For every measurement, a unique calibration have to be conducted. This is done by taking a picture of a ruler or similar to scale the pictures, if 2 component PIV is conducted. For 3-component PIV, a target in 2D is necessary to calibrate the cameras. In this project a target made as a ruler is used instead of a actural ruler, as seen in figure B.1

B.1.4 Measuring

After the whole practical setup, a measuring is conducted and analysed in matlab. A whole guide for this is found in appendix.

Appendix C

C

C.1 Matlab script 1 ”read in data”

This script is based on a script created by [4]

```
clear all; close all; clc;

% data on experiment
ni=79;          % number of vectors in x-direction - denne værdi kan ændres afhængig
af datasættet.
nk=63;          % number of vectors in y-direction - denne værdi kan ændres afhængig
af datasættet.
T=23.2;         % temperature - denne værdi burges ikke til noget, og er blot
information.
dt=1/60;        % time between pulses
directory='9/';   % mappen hvorfra dataen hentes


%%%%%%%%%%%%%%%%%%%%%%%%
%%%   READ IN DATA   %%%
%%%%%%%%%%%%%%%%%%%%%%%%
files=dir([directory '*.txt' ] )    % filer i directory - string (fil-navne)

%files=dir(directory)    % filer i directory - string (fil-navne)
ns=length(files)                 % number of samples - antallet af samples
U=zeros(ni,nk,ns); V=zeros(ni,nk,ns); W=zeros(ni,nk,ns);% pre-allocation af U, V og
W.
for n=1:ns          % løkke der gennemløber antallet af samples
    disp(n);        % hvilken fil er der nået til
    comma2point_overwrite([directory files(n).name])
    fid =fopen([directory files(n).name]);% åbner filen den er nået til
    data=fscanf(fid,'%c');  % danner en matrice med alt dataen fra filen
    data=str2num(data);        % Omdanner evt. tekst til tal
    fclose(fid);
    data=textread([directory files(n).name],'','headerlines',9); % fjerne alt der ikke
er tal - tjek om der er 9 linjers tekst i .txt-filen.
    U(:,:,n)=reshape(data(:,5),ni,nk); % reshaper data, så der dannes selvstændige
matricer fra U, V og W og deres respektiver x og y koordinater.
    V(:,:,n)=reshape(data(:,6),ni,nk);
    W(:,:,n)=-reshape(data(:,7),ni,nk);
    x=reshape(data(:,3),ni,nk);        % x og y koordinaterne i mm.
    y=reshape(data(:,4),ni,nk);
end

save U U; save V V; save W W; save x x; save y y; % gemmer de forskellige variabler i
current folder.
```

C.2 Matlab script 2 ”plots”

This script is based on a script created by [4]

```
%clear all; close all; clc;

load U; load V; load W; load x; load y;
u1=abs(1/ns*(sum(U(:,:,:),3)));%u gennemsnitshastigheden udregnes
u2=bsxfun(@minus,U(:,:,:),u1);% gennemsnit hastigheden fratrækkes de enkelte
hastighedskomonenter
u3=sqrt(1/ns*sum(u2.^2,3));%U_rms udregnes
I_u=u3./u1%den turbulente intencitet udregnes

figure(1)
contourf(x,y,I_u);hold on; colorbar; %contourplot af turbulent intensitet
print(figure(1),'-dpng')

figure(2)
plot((I_u(35,:)),y); %plot over den turbulente intensitet ved vectorere nummer 35 i x
retningen
axis([0 0.4 -80 80])
print(figure(2),'-dpng')

figure(3)
shading interp;
contourf(x,y,mean(U(:,:,:),3)); hold on; colorbar; % hastighedsplot i x retningen
xlabel('x position')
ylabel('y position')
title('velocity x-direction m/s')
print(figure(3),'-dpng')

figure(4)
plot(u1(35,:),y); %hastighedsplot ved vectorere ved x vector nummer 35.
axis([0 0.3 -80 80])
print(figure(4),'-dpng')
```

Appendix D

D

D.1 Results parametric study

All of the measurments were conducted at z=45cm and x=15cm.

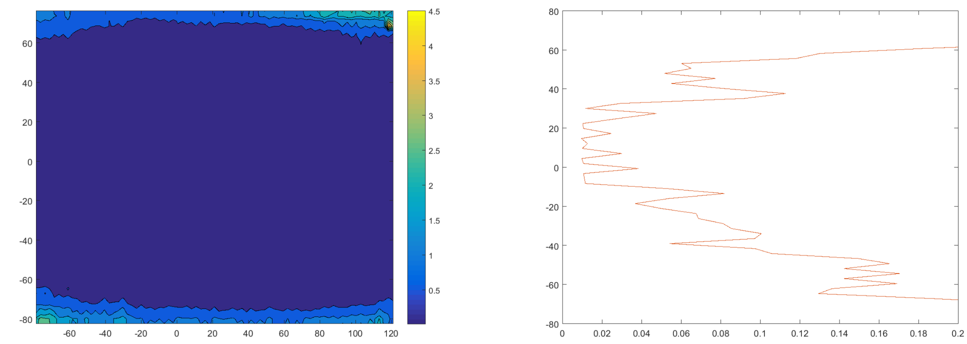


FIGURE D.1: Turbolent intensity with 4 cause screens, 4 plates and guidevanes

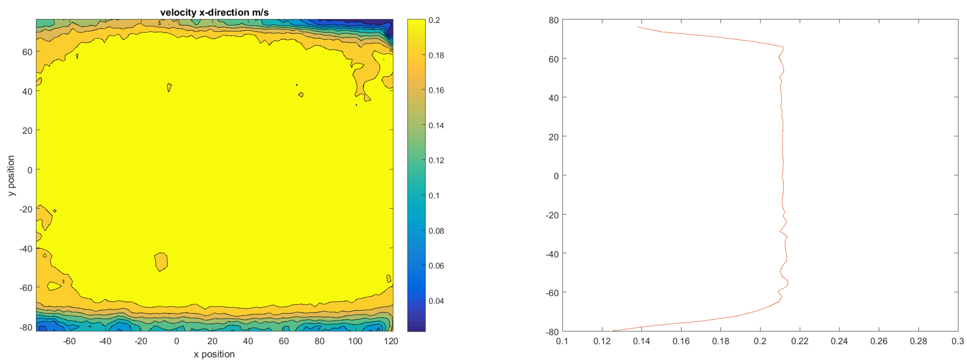


FIGURE D.2: Velocity with 4 cause screens, 4 plates and guidevanes

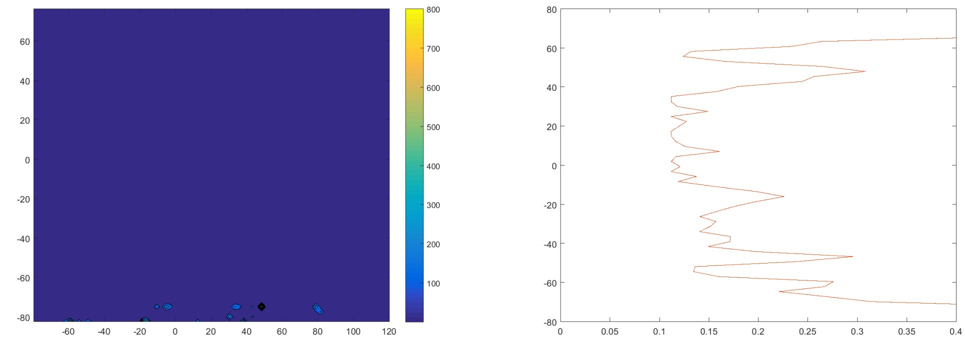


FIGURE D.3: Turbolent intensity with 4 cause screens, plates and guidevanes

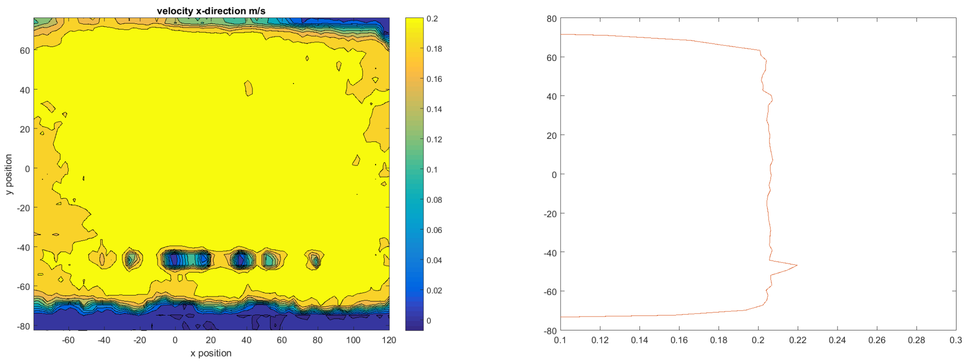


FIGURE D.4: Velocity with 4 cause screens, 3 plates and guidevanes

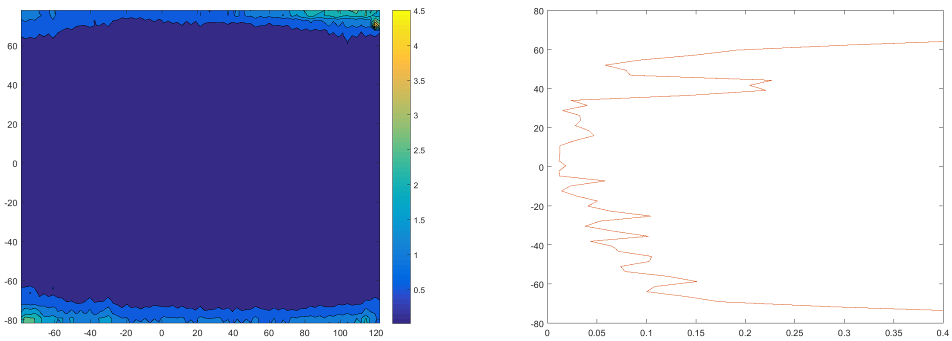


FIGURE D.5: Turbolent intensity with 4 cause screens, 2 plates and guidevanes

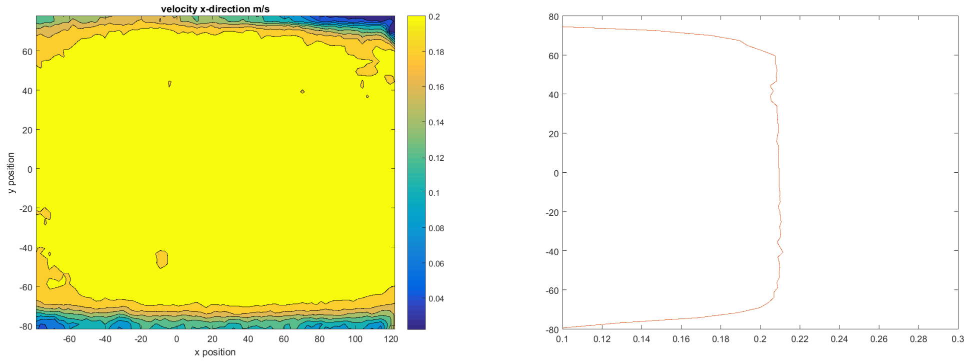


FIGURE D.6: Turbolent intensity with 4 cause screens, 2 plates and guidevanes

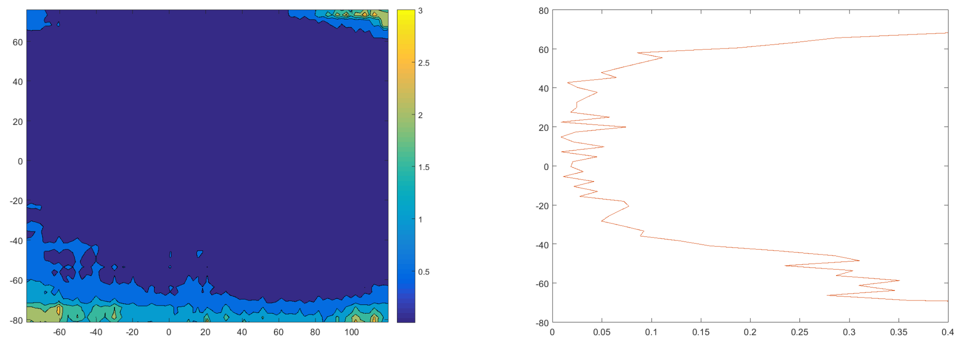


FIGURE D.7: Velocity with 4 cause screens, 1 plate and guidevanes

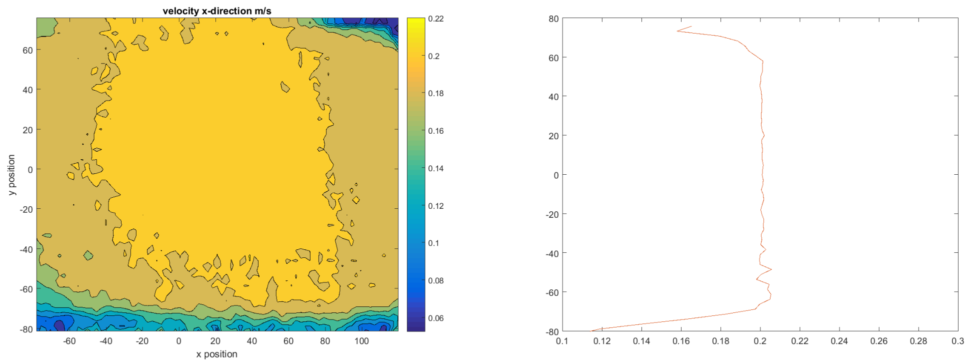


FIGURE D.8: Velocity with 4 cause screens, 1 plate and guidevanes

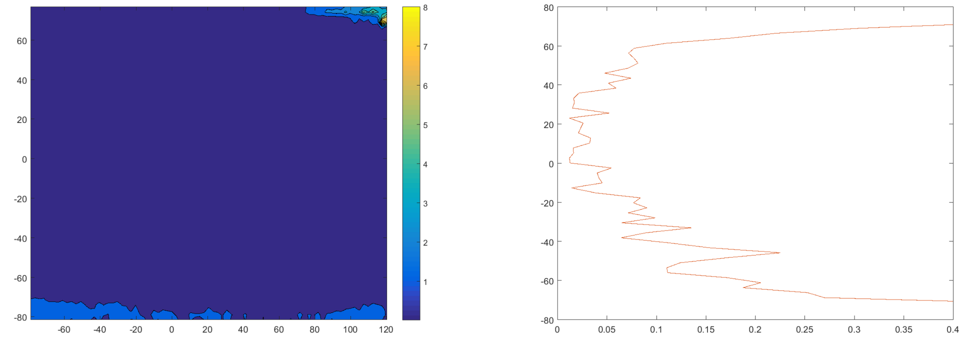


FIGURE D.9: Turbulent intensity with 4 cause screens, 0 plate and guidevanes

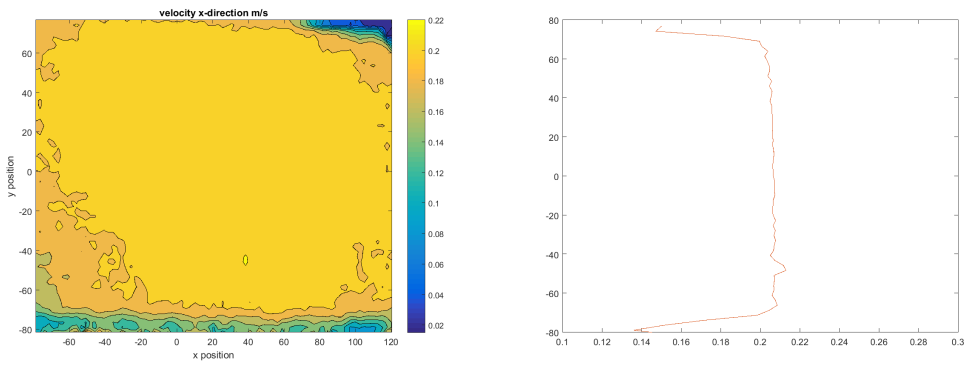


FIGURE D.10: Velocity with 4 cause screens, 0 plates and guidevanes

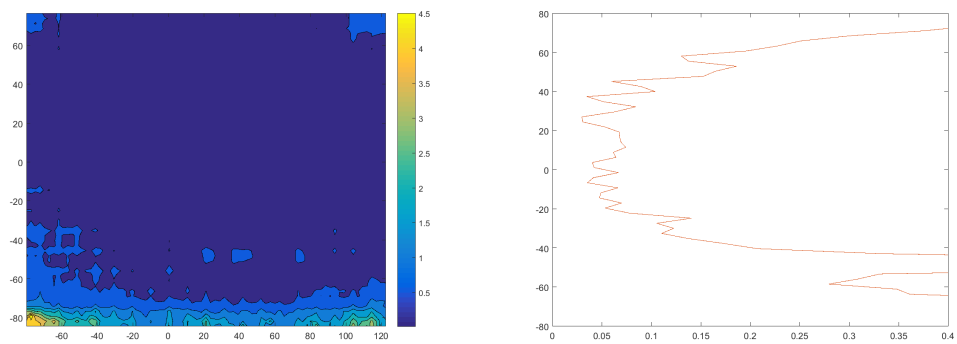


FIGURE D.11: turbulent intensity with 4 cause screens, 0 plates and no guidevanes

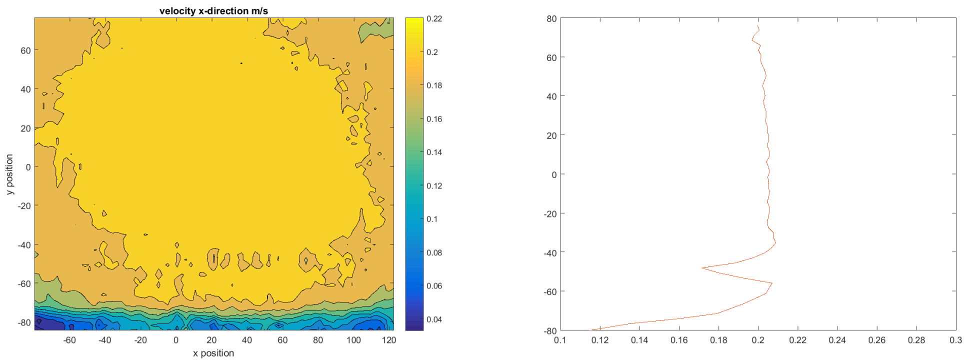


FIGURE D.12: Velocity with 4 cause screens, 0 plates and no guidevanes

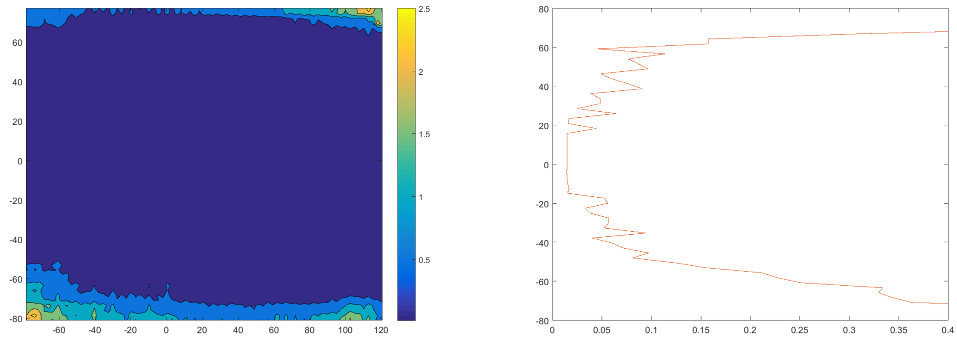


FIGURE D.13: Turbulent intencity with 1 cause screen and 3 fine, 0 plate and no guidevanes

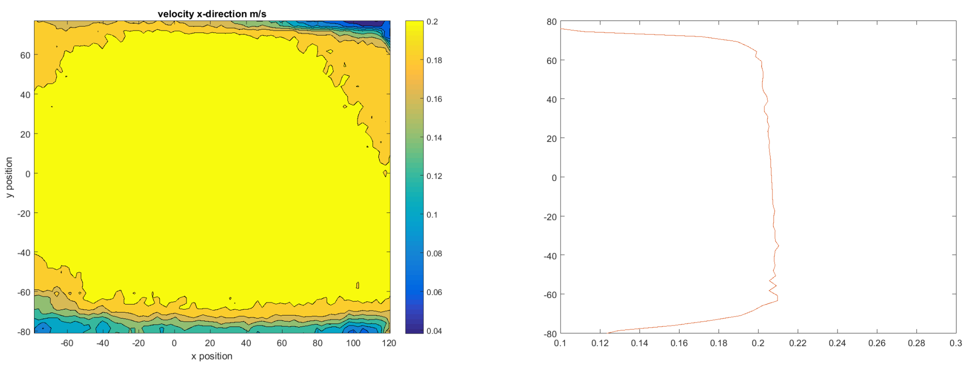


FIGURE D.14: Velocity with 1 cause screen and 3 fine, 0 plate and no guidevanes

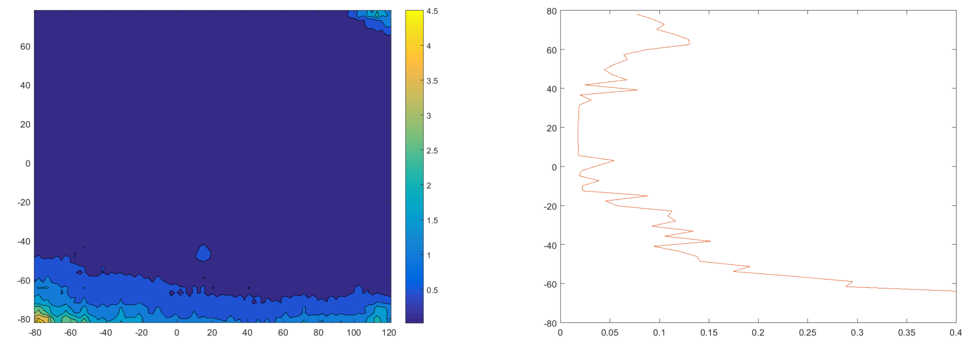


FIGURE D.15: Turbulent intensity with 1 cause screen and 3 fine, 0 plate and guidevanes

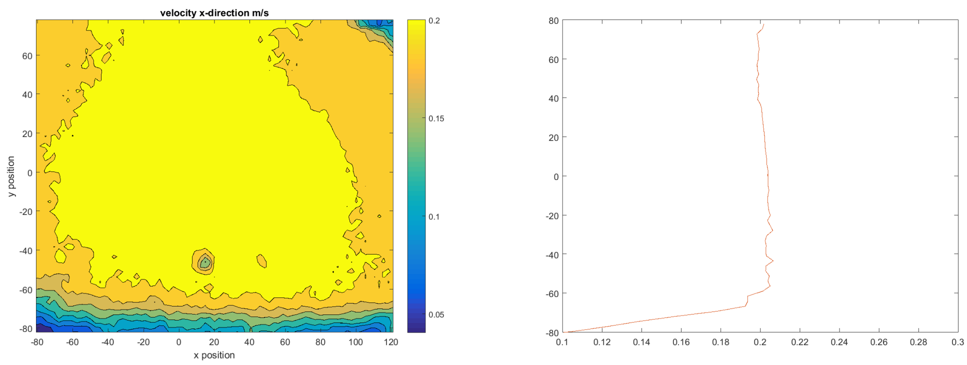


FIGURE D.16: Velocity with 1 cause screen and 3 fine, 0 plate and guidevanes

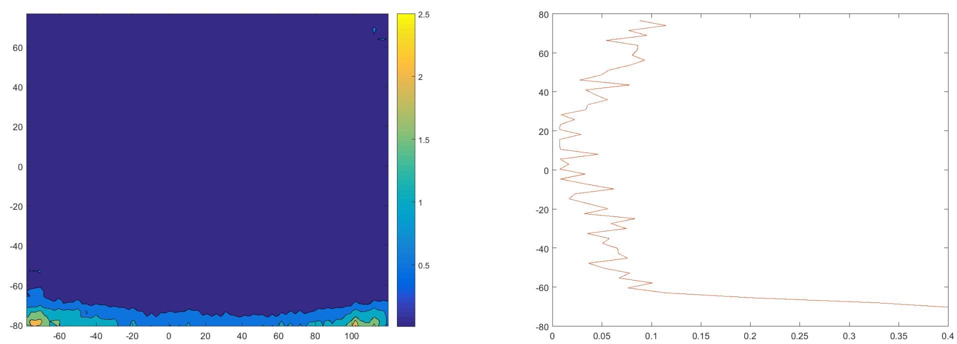


FIGURE D.17: Turbulent intensity with 1 cause screen and 3 fine, 1 plate and guidevanes

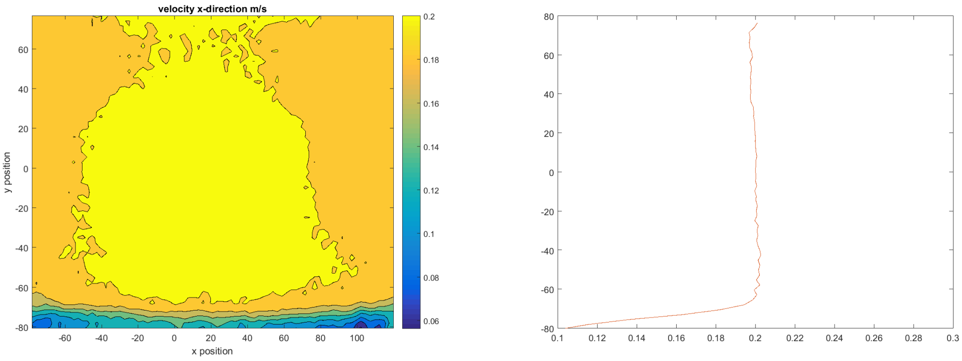


FIGURE D.18: Velocity with 1 cause screen and 3 fine, 1 plate and guidevanes

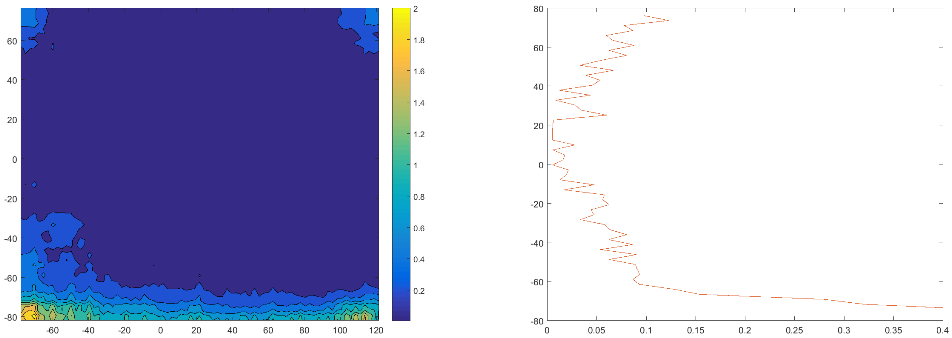


FIGURE D.19: Turbulent intensity with 1 cause screen and 3 fine, 2 plates and guide-vanes

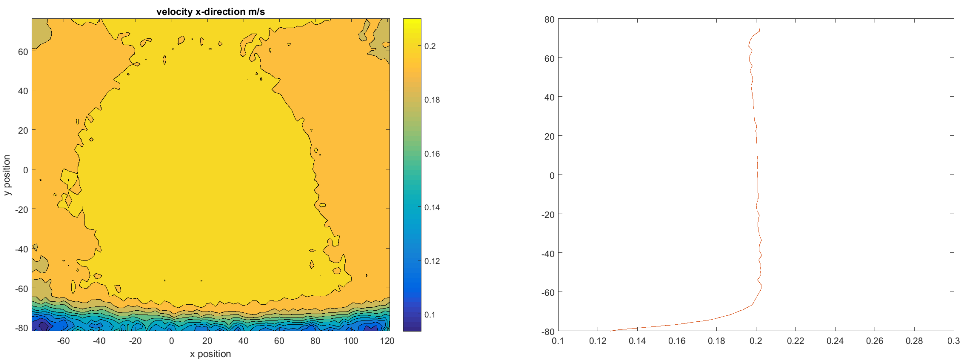


FIGURE D.20: velocity with 1 cause screen and 3 fine, 2 plates and guidevanes

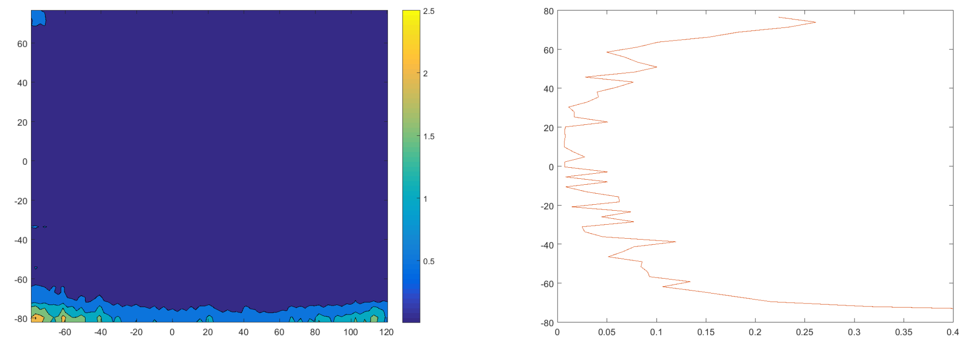


FIGURE D.21: Turbulent intensity with 1 cause screen and 3 fine, 3 plates and guide-vanes

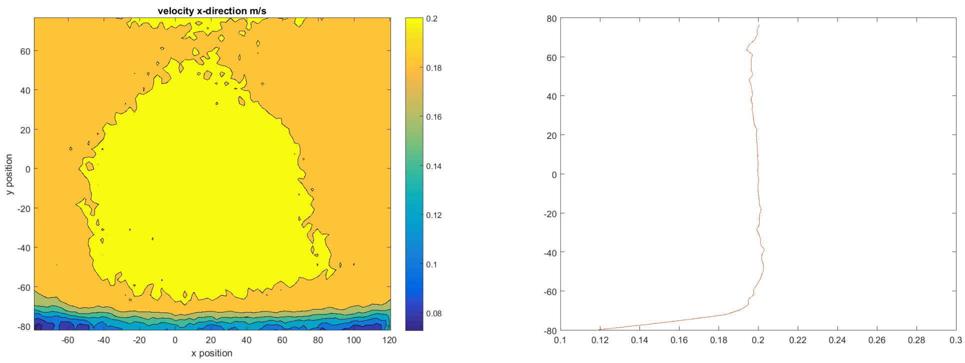


FIGURE D.22: velocity with 1 cause screen and 3 fine, 3 plates and guidevanes

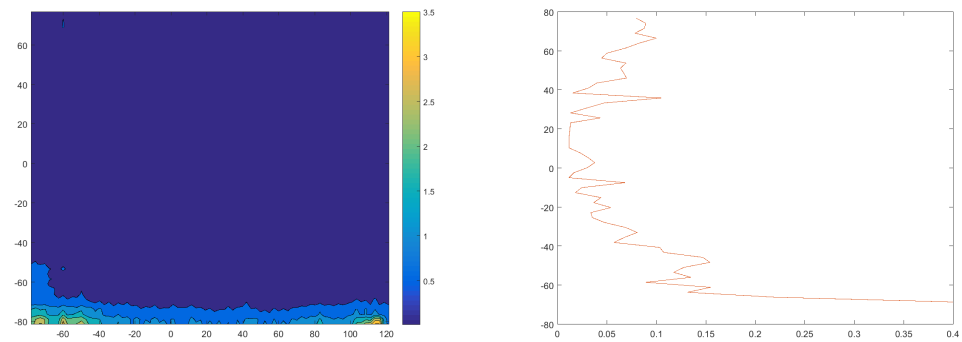


FIGURE D.23: Turbulent intensity with 1 cause screen and 3 fine, 4 plates and guide-vanes

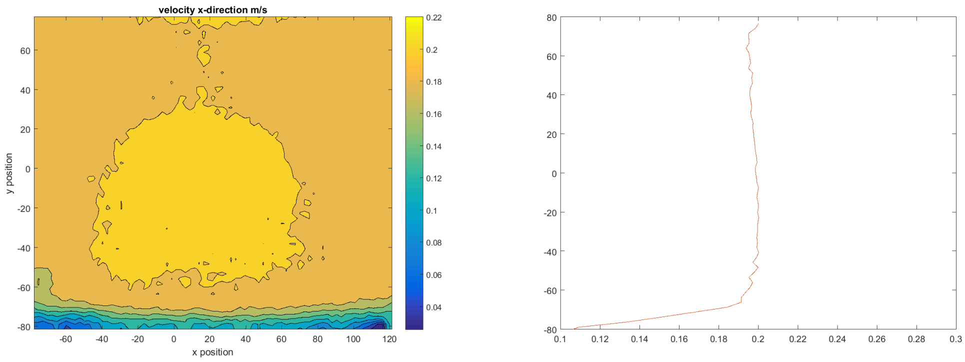


FIGURE D.24: velocity with 1 cause screen and 3 fine, 4 plates and guidevanes

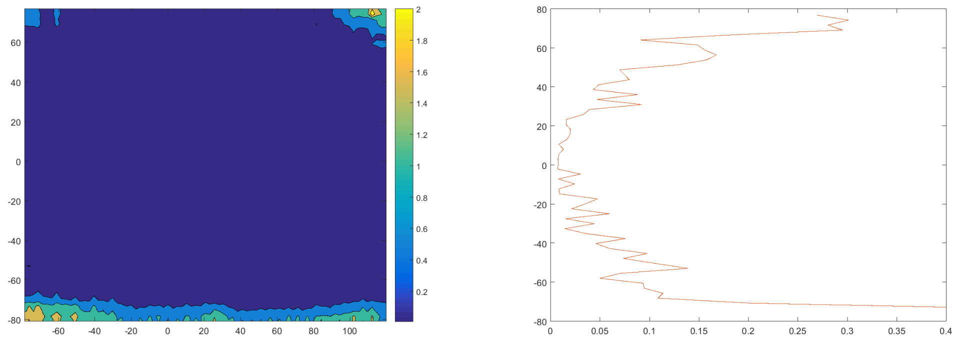


FIGURE D.25: Turbulent intensity with 1 cause screen and 3 fine, 4 plates guidevanes and a fine net at the guidevanes

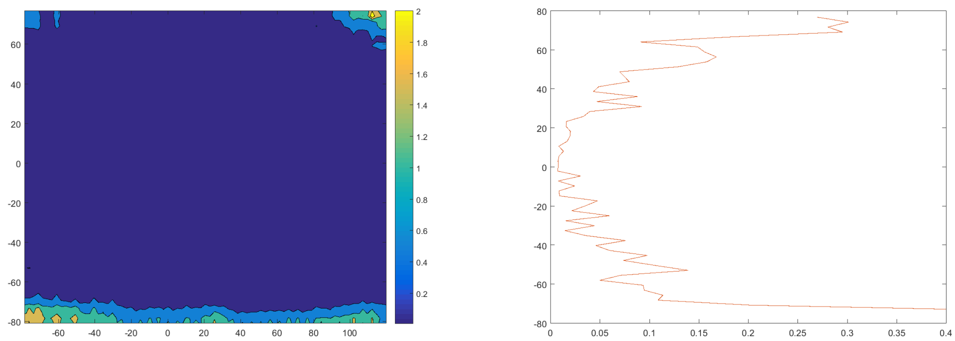


FIGURE D.26: velocity with 1 cause screen and 3 fine, 4 plates guidevanes and a fine net at the guidevanes

Appendix E

E

E.1 Characterization

All of measurements were conducted with 1 cause screens and 3 fine, 2 plats and guide-vanes

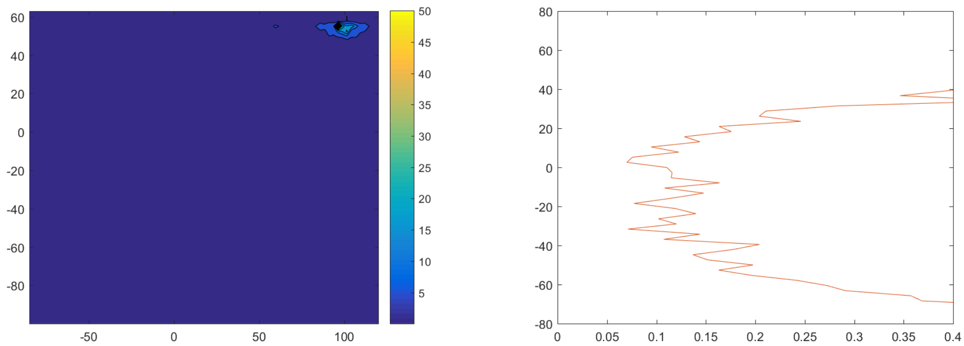


FIGURE E.1: Turbulent intencity at z=15 x=25

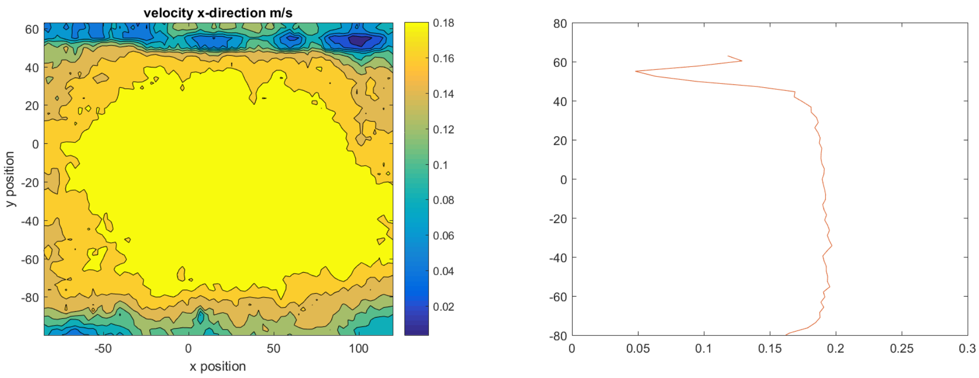


FIGURE E.2: velocity at z=15 x=25

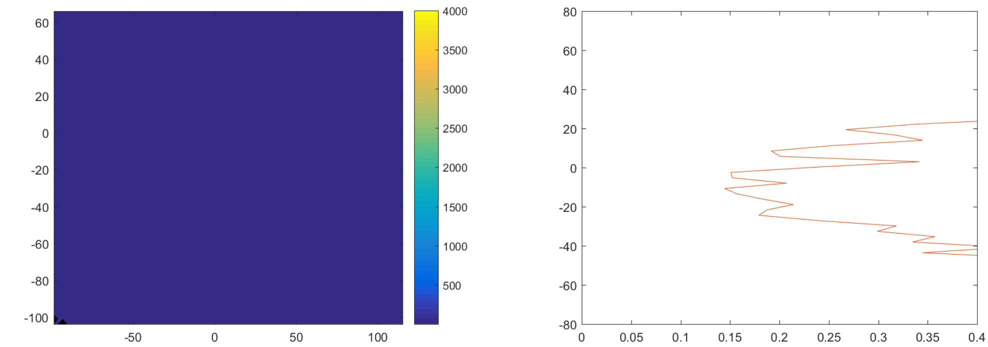


FIGURE E.3: Turbulent intencity at z=15 x=15

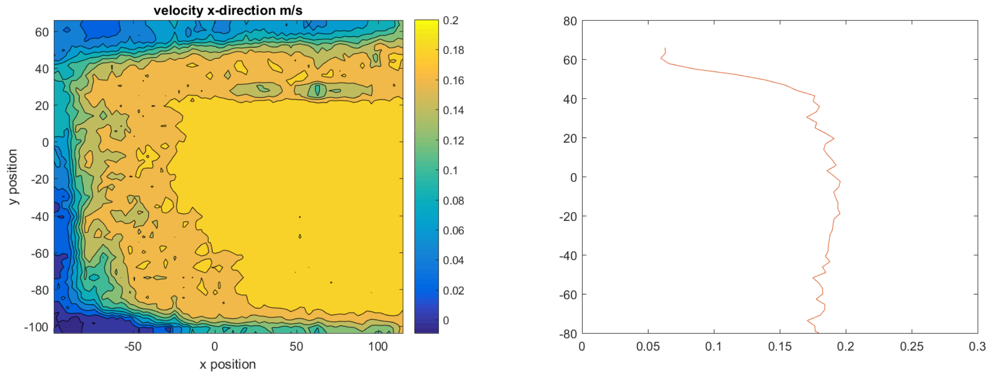


FIGURE E.4: Velocity at z=15 x=15

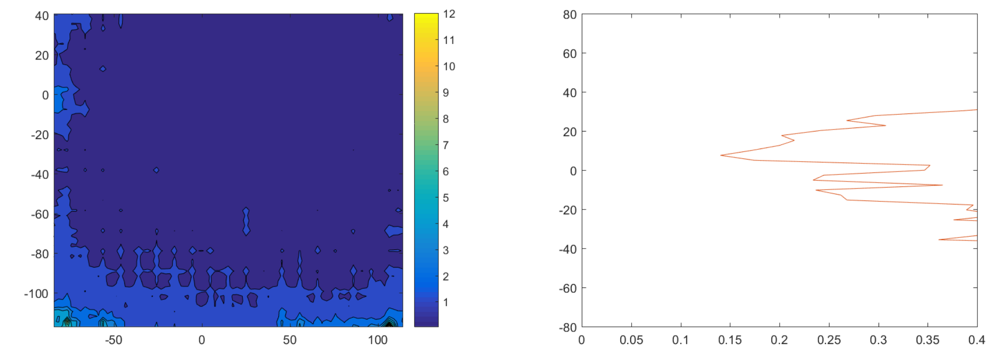


FIGURE E.5: Turbulent intencity at z=15 x=5

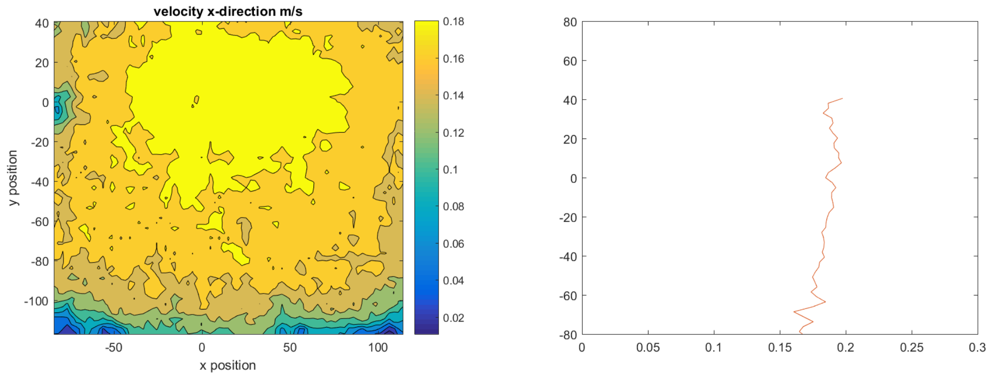


Figure E.6: velocity at z=15 x=5

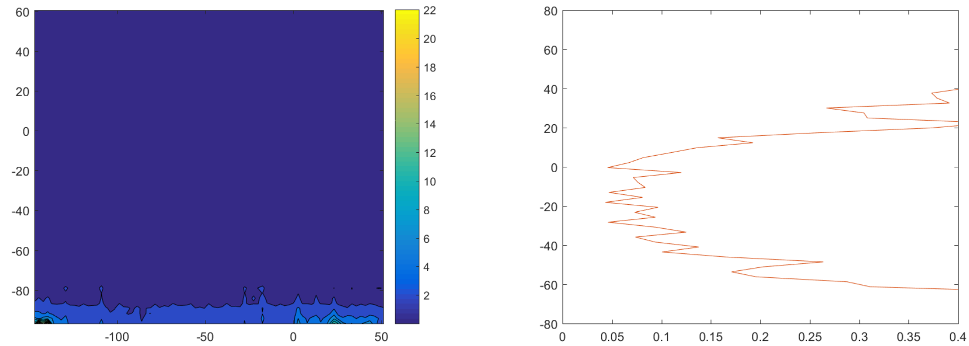


Figure E.7: Turbulent intensity at z=55 x=5

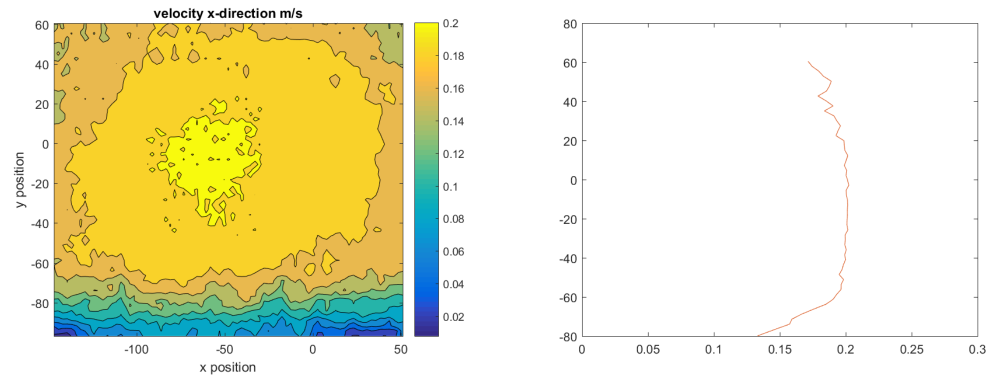


Figure E.8: velocity at z=55 x=5

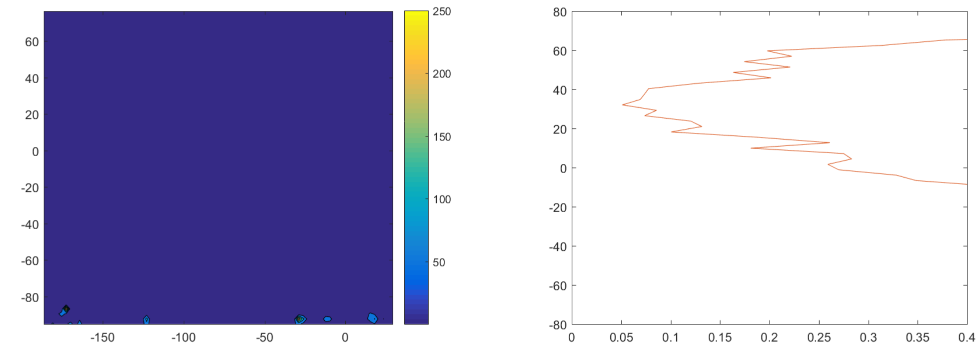


FIGURE E.9: Turbulent intencity at z=55 x=15

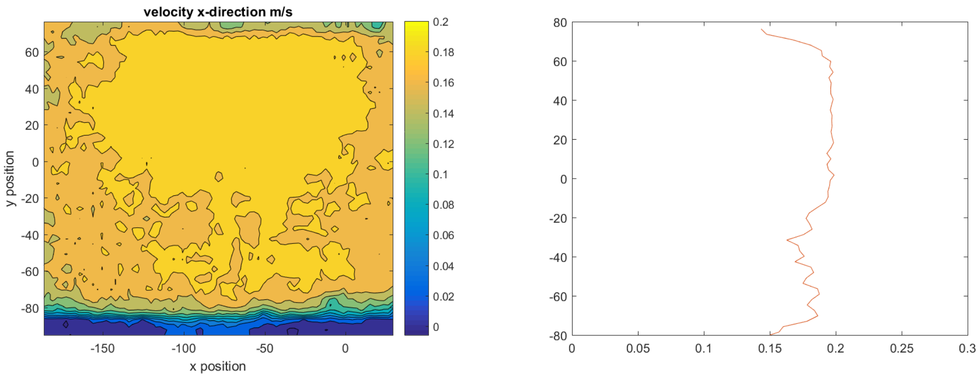


FIGURE E.10: velocity at z=55 x=15

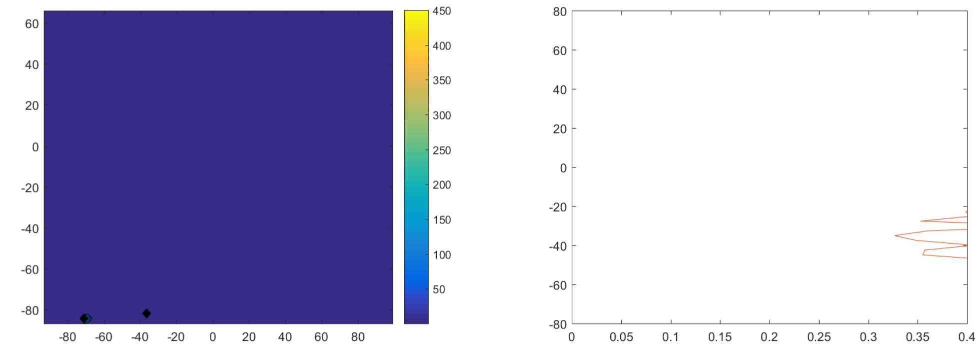


FIGURE E.11: Turbulent intencity at z=55 x=25

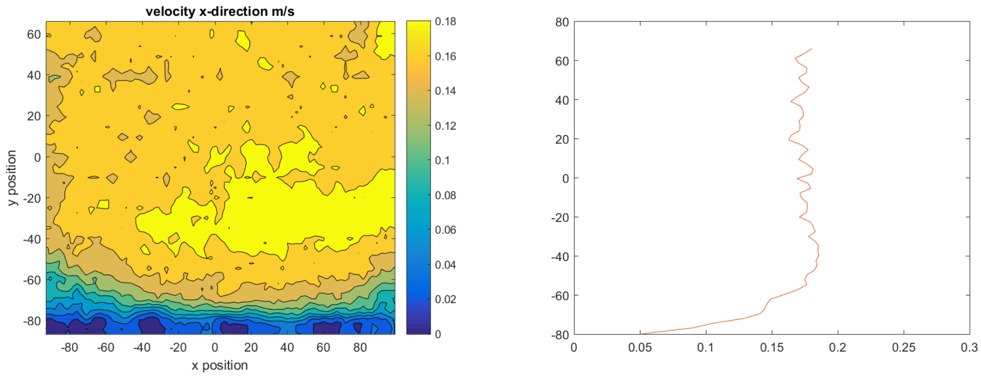


Figure E.12: velocity at z=55 x=25

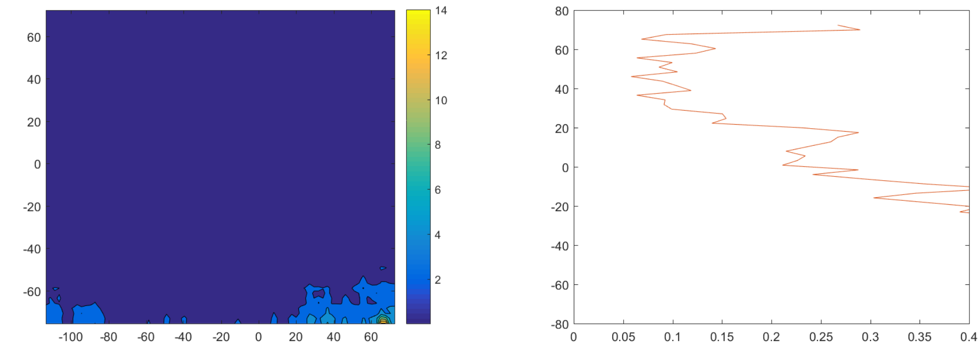


Figure E.13: Turbulent intencity at z=100 x=25

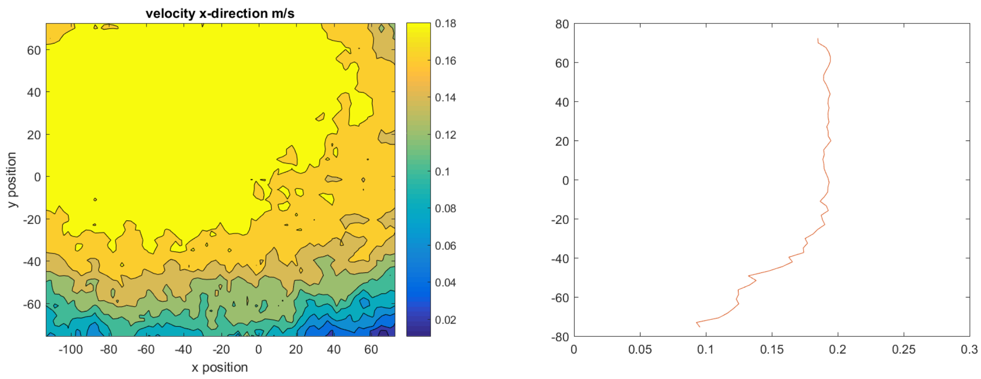


Figure E.14: velocity at z=100 x=25

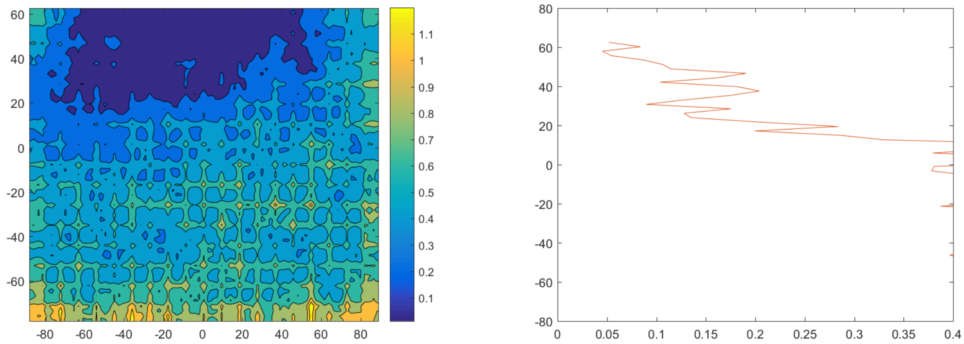


FIGURE E.15: Turbulent intencity at z=100 x=15

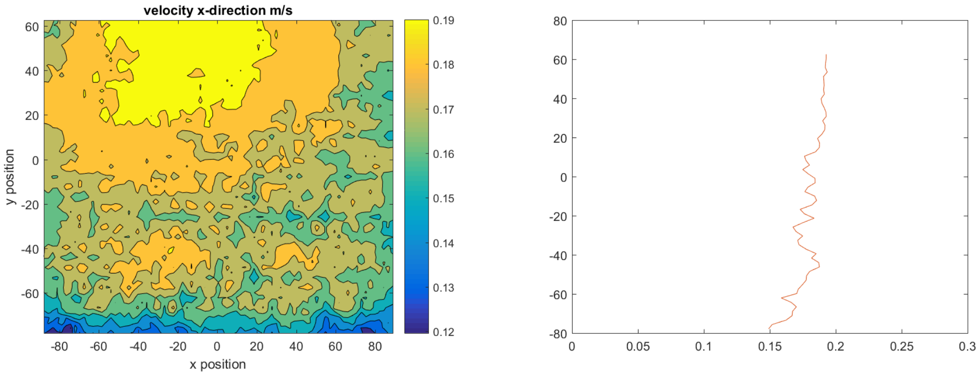


FIGURE E.16: velocity at z=100 x=15

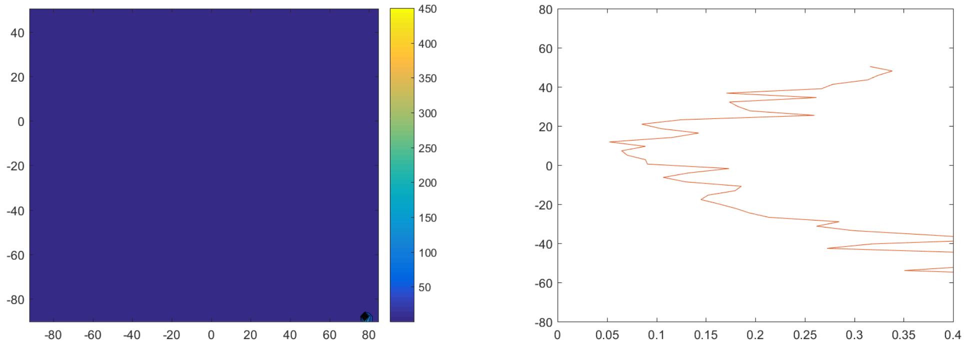


FIGURE E.17: Turbulent intencity at z=100 x=5

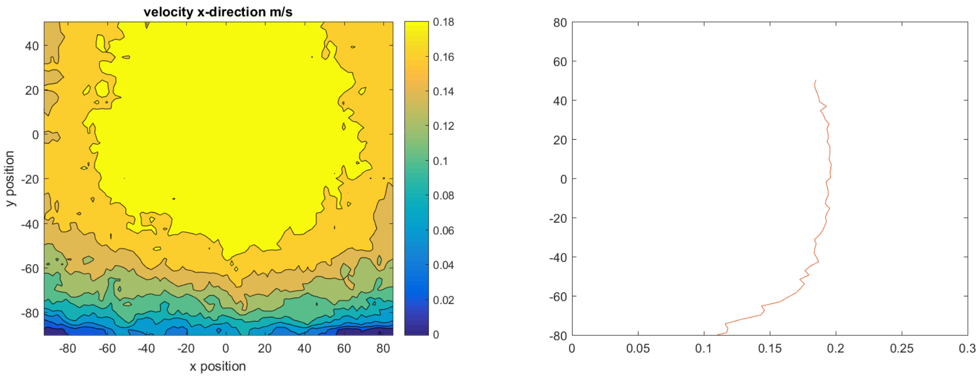


FIGURE E.18: velocity at z=100 x=5