MEASUREMENTS OF VELOCITY PROFILES BY USING PARTICLE IMAGE VELOCIMETER

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ABSTRACT

MEASUREMENTS OF VELOCITY PROFILES BY USING PARTICLE IMAGE VELOCIMETER

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Particle Image Velocimetry (PIV) is an optical technique used to display and evaluate the motion of fine particles in a flow. In this experimental study, velocity profiles are examined by PIV system and basic analysis methods are compared.

Keywords: Particle Image Velocimetry (PIV), Flow Visualization Techniques, Laser

ÖZ

HIZ PROFİLLERİNİN PARÇACIK İMGELİ HIZÖLÇER KULLANILARAK BELİRLENMESİ

KEMALLİ, Onur
Yüksek Lisans, İnşaat Mühendisliği Bölümü
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Parçacık İmgeli Hızölçümü (PIV), akım içerisindeki küçük parçacıkların hareketini görüntülemek ve değerlendirmek için kullanılan optik bir yöntemdir. Bu deneysel çalışmada, hız profilleri PIV sistemiyle incelenmiş ve temel analiz yöntemleri karşılaştırılmıştır.

Anahtar kelimeler: Parçacık İmgeli Hızölçümü (PIV), Akım Görüntüleme Teknikleri, Lazer

To my family

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LIST OF SYMBOLS

λ	:	wave length
Δt	:	time interval between the pulses
ΔX	:	displacement of particles
Ar	:	Argon
CCD	:	Charge Coupled Device
CID	:	Charge Injection Device
CMOS	:	Complementary Metal-Oxide Semiconductor
Cr	:	Chromium
Cu	:	Copper
FFT	:	Fast Fourier Transform
H	:	horizontal axis
He	:	Helium
IA, I_1, I_2	:	interrogation areas
N	:	number of vectors
Nd:YAG	:	Neodymium: Yttrium-Aluminum-Garnet
Nd:YLF	:	Neodymium: Yttrium-Lithium-Fluoride
Ne	:	Neon
PIV	:	Particle Image Velocimetry
Q	:	discharge
Re	:	Reynolds number
U	:	horizontal velocity
V	:	vertical axis, vertical velocity

CHAPTER 1

INTRODUCTION

1.1. Overview of Flow Visualization

In fluid mechanics, various flow visualization techniques can be used to measure the whole, instantaneous fields of scalars and vectors [2].

The techniques for the whole, instantaneous fields of scalars are

- Tomographic Interferometry and
- Planar Laser Induced Fluorescence [2].

Similarly, the techniques for the whole, instantaneous fields of vectors are

- Nuclear Magnetic Resonance Imaging,
- Planar Laser Induced Fluorescence,
- Laser Speckle Velocimetry,
- Particle Tracking Velocimetry,
- Molecular Tracking Velocimetry and
- Particle Image Velocimetry [2].

Among these techniques, the development of Particle Image Velocimetry (PIV) has begun in the eighties. The PIV, which was once mainly employed in the laboratories, is now extensively used in the industrial applications [8].

1.2. Scope of the Study

This thesis can be seen as both a brief guide and an example for the application of PIV. The study is aimed to illustrate the essentials of the technique and to compare some of the major analysis options offered.

Chapter 1 depicts an overview of the flow visualization and introduces the scope of the text. Then, Chapter 2 starts with the principal of the PIV, continues with its technical aspects and explains the processing stages of the system. Afterwards, Chapter 3 presents the laboratory work and portrays the software usage. Subsequently, Chapter 4 consists of the findings and discussions while Chapter 5 comprises the conclusions.

CHAPTER 2

PARTICLE IMAGE VELOCIMETRY (PIV)

2.1. Principal of Particle Image Velocimetry (PIV)

Particle Image Velocimetry (PIV) is an optical technique used to monitor and analyze the motion of fine particles in a flow. Considered as a nonintrusive system, PIV causes almost no distortion to the flow [1].

Tracer particles, a laser, a camera and a computer are the essential components of the PIV.

A planar sheet of laser light is pulsed twice and images of fine particles are recorded by the camera. The displacement of the particle images is measured and used to determine the displacement of particles in the flow.

For an accurate analysis, the image plane is divided into small interrogation areas. Special correlation methods are applied to the images obtained in any two consecutive exposures. The displacement, which yields the maximum correlation, is processed to approximate the average displacement of the particles [1]. Then, velocity is obtained via dividing this displacement by the time between the laser pulses (Figure 2.1).

From the vector data, various derivatives like the velocity maps, profiles and vorticity plots can be obtained. Likewise, the third velocity component can be found using a second camera and “stereoscopic imaging” [5].

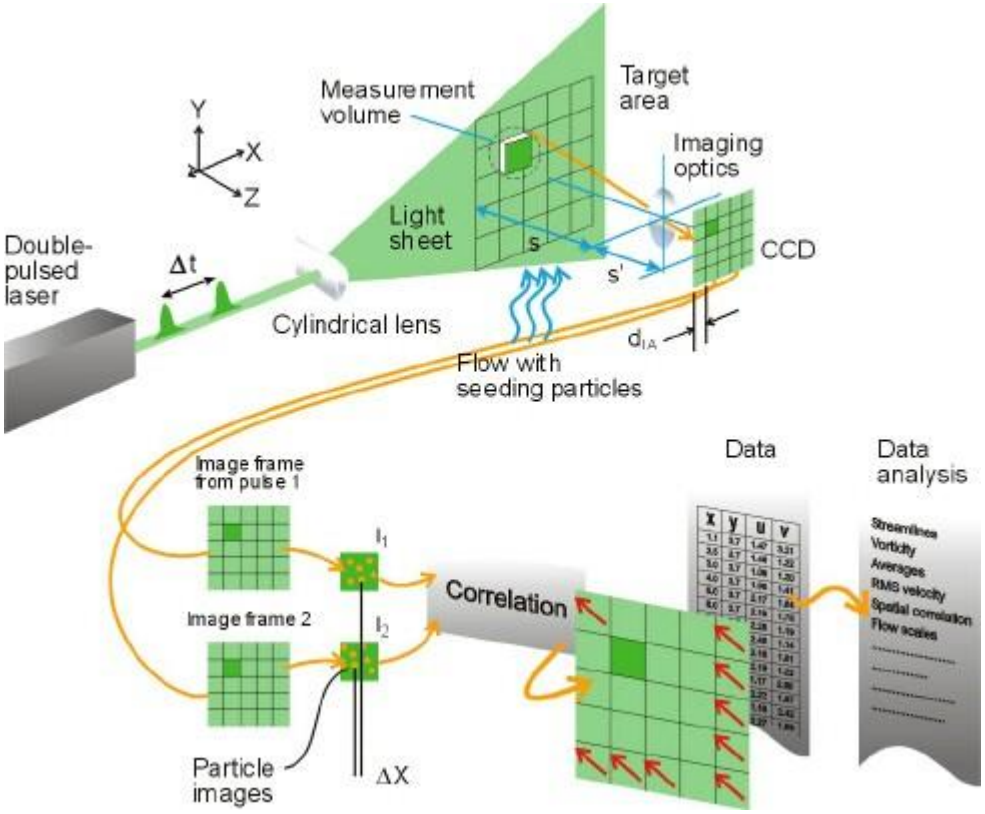

Figure 2.1: PIV processing stages [5].

Lasers are used as the light sources. Because, only the laser light can be transformed into a thin light sheet to limit the imaging by the plane enlightened. Moreover, laser pulses, which are just 6-10 ns long, can practically freeze any motion [9].

Furthermore, special cameras, which can very quickly store the two successive frames, are utilized. The time interval between the two consecutive frames is only 200 ns [9].

PIV can be employed in a grand spectrum of areas, varying from aerospace engineering to medicine. Beside the fluid dynamics, some of the other application areas include

- spray research,
- combustion research,
- wave dynamics,
- coastal engineering,
- tidal modeling,
- river hydrology [5] and
- observation of household appliances [14].

2.2. Components of the PIV System

2.2.1. Tracer Particles

The length and the time, which are the essentials of the velocity, can be measured directly in PIV. However, it is still referred as an "indirect" method since it measures the particle velocity rather than the fluid velocity [8].

PIV uses tracer particles (or "seeds") to analyze the flow. These particles must be small enough to follow the flow accurately but large enough to scatter the light sufficiently. Preferably, their density should be approximate to the fluid's density in order to be neutrally buoyant within the flow. However, seeds should not be dirty, toxic, corrosive, abrasive, volatile or chemically active [1].

Moreover, selection of the seeding material depends on the cost and availability. Table 2.1 and Table 2.2 show the typical seeds used for liquid and gas flows, respectively.

Table 2.1: Seeding materials for liquid flows [1, 8, 11].

Type	Material	Mean Diameter (µm)
Solid	Polystyrene	10 – 100
	Polymethyl methacrylate	0.3 – 1000
	Aluminum flakes	2 – 7
	Hollow glass spheres	10 – 100
	Granules for synthetic coatings	10 – 500
	Pine pollen	30 – 50
	Latex beads	0.5 – 90
Liquid	Different types of oils	50 – 500
	Milk	0.3 – 3
Gaseous	Oxygen bubbles	50 – 1000

Table 2.2: Seeding materials for gas flows [1, 8, 11].

Type	Material	Mean Diameter (µm)
Solid	Polystyrene	0.5 – 10
	Alumina (Al_2O_3)	0.2 – 5
	Titania (TiO_2)	0.1 – 5
	Silica (SiO_2)	1 – 5
	Glass micro-spheres	0.2 – 3
	Glass micro-balloons	30 – 100
	Granules for synthetic coatings	10 – 50
	Dioctylphathalate	1 – 10
	Smoke	< 1
Liquid	Different types of oils	0.5 – 10
	Di-ethyl-hexyl-sebacate (DEHS)	0.5 – 1.5
	Helium-filled soap bubbles	1000 – 3000

2.2.2. Lasers

Tracer particles are illuminated by the thin sheets of single-colored light produced by the lasers.

Every laser is composed of three basic components:

- The laser material (an atomic or molecular gas, a semiconductor or a solid material),
- The pump source (which excites the laser by electromagnetic or chemical energy) and
- The mirror arrangement [8].

The major types of lasers are listed in Table 2.3.

Table 2.3: Laser types [8].

Type	**Material**	**Wave Length, λ**
Gas	Helium-Neon (He-Ne)	633 nm
	Copper-vapor (Cu)	510 nm, 578 nm
	Argon-ion (Ar^{+})	488 nm, 514 nm
Solid	Ruby (Cr^{+3})	694 nm
	Neodymium: Yttrium-Aluminum-Garnet (Nd:YAG)	532 nm, 1064 nm
	Neodymium: Yttrium-Lithium-Fluoride (Nd:YLF)	526 nm, 1053 nm

2.2.3. Cameras

Motion of the illuminated tracer particles is captured by the cameras.

Synchronized with the laser pulses, the camera records the particles' initial positions on the first frame and final positions on the second frame. This is the usual case, where the camera runs in "cross-correlation" mode [1].

However, some cameras work in "autocorrelation" mode, where the images of both the initial and the final positions of the particles are saved on the same frame [1].

Cameras can be classified according to their sensor types like

- Charge Coupled Device (CCD),
- Charge Injection Device (CID) and
- Complementary Metal-Oxide Semiconductor (CMOS) [8].

2.3. Acquisition of Data

The basic inputs to acquire data in PIV are

- The recording mode (single frame, double frame or single frame with double exposure, etc.),
- Number of images,
- Time between the pulses and
- Time between the images.

Here, the main recording modes can be listed as:

- Single Frame/Multi-Exposure Mode (Figure 2.2) and
- Multi-Frame/Single Exposure Mode (Figure 2.3) [2].

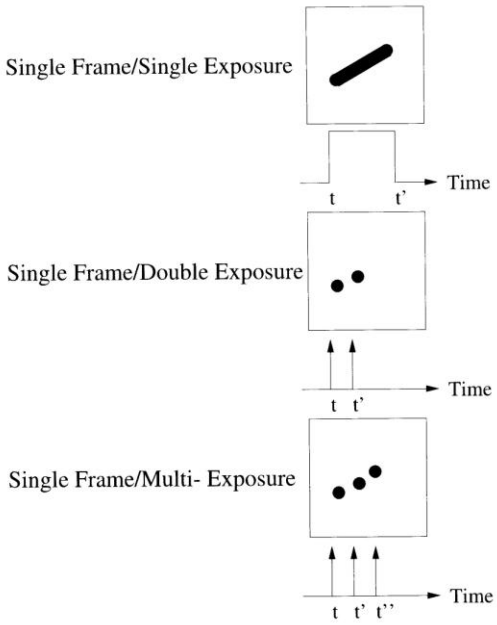

Figure 2.2: Single frame techniques [8].

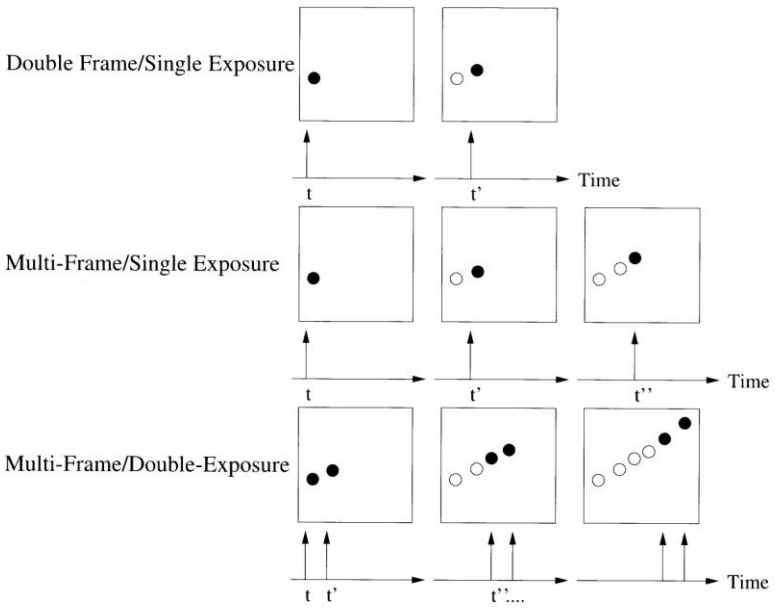

Figure 2.3: Multi-frame techniques (positions of particles in previous frames are shown by open circles) [8].

2.4. Processing of Data

After the acquisition of data, PIV recordings are subdivided into “interrogation areas” and evaluated. At this stage, the images can be processed optically or digitally.

In the past, due to speed and memory limits of computers, the optical evaluation techniques were used. However, today, being parallel to the technological enhancement, the digital evaluation techniques have become popular [10].

Here, some of the major digital techniques like autocorrelation, cross-correlation, average correlation and adaptive correlation will be presented.

2.4.1. Autocorrelation

In autocorrelation, both the initial and final positions of the seeds are saved on the same camera frame.

Fast Fourier Transform (FFT) is used in the calculations. Since the saved image is correlated to its shifted forms, a large central peak occurs in the correlation plane. However, this large peak prevents the detection of displacements smaller than 2-3 pixels and reduces the dynamic range of autocorrelation [1].

For a convenient analysis in autocorrelation, the number of seeds per interrogation area should be at least 10. If there is sufficient seeding, using multiple exposures can improve the results [1].

2.4.2. Cross-Correlation

In cross-correlation, the initial and the final positions of the seeds are saved in distinct frames.

Fast Fourier Transform (FFT) [3] is also used in cross-correlation. Particles are matched up to detect their spatially shifted partners. The match, which yields the maximum correlation (i.e. the peak value), is used to find the average displacement in the interrogation area considered (Figure 2.4) [1].

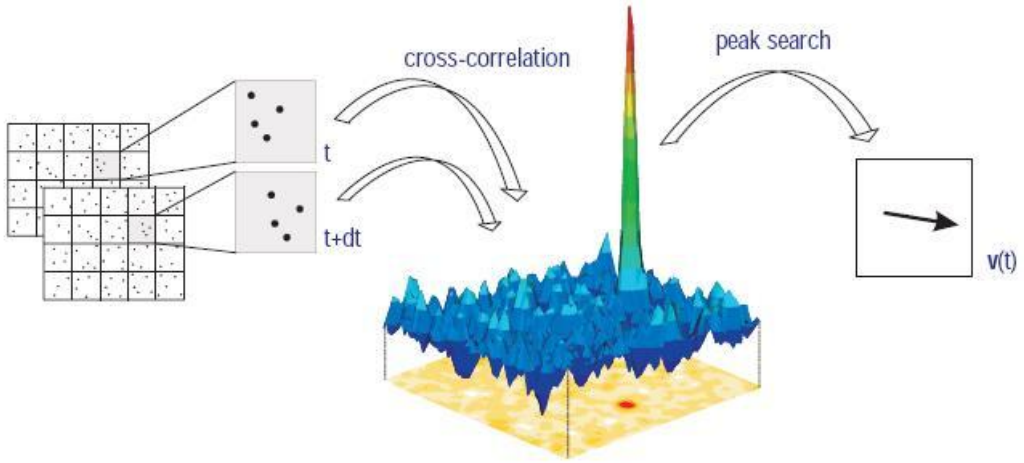

Figure 2.4: Schematic view of cross-correlation [9].

For better results in cross-correlation,

- the number of seeds per interrogation area should be at least 5 and
- the maximum particle displacement in an interrogation area should be equal to $1/4$ of the interrogation area size [1].

2.4.3. Average Correlation

In average correlation, for all the images, the correlation functions from all interrogation areas are averaged at all locations. Then, addition of the correlation functions gradually forms the peak (Figure 2.5) [6].

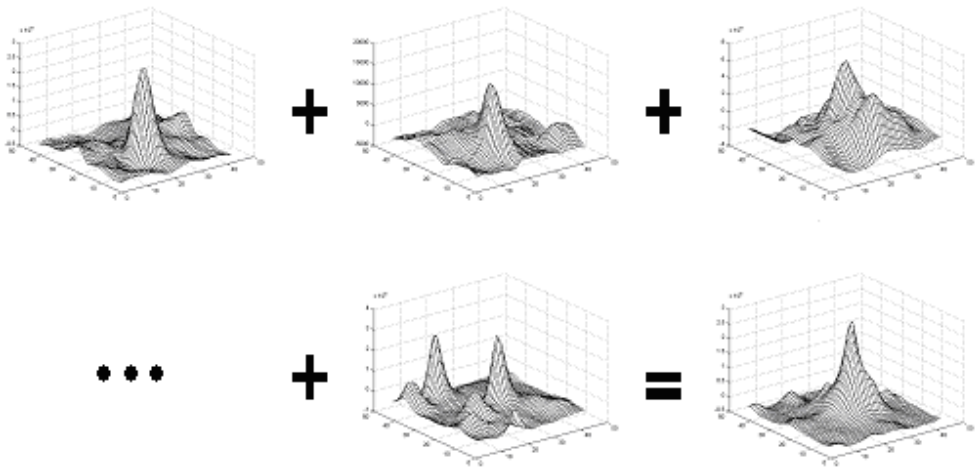

Figure 2.5: Schematic view of average correlation [6].

The average correlation can be employed where it is hard to apply sufficient amount of seeding [6].

2.4.4. Adaptive Correlation

In adaptive correlation, at first, the intended sizes of the interrogation area are entered. However, the computer starts calculating vectors in an initial interrogation area with sizes greater than the entered values. Then, it gradually decreases the sizes of this initial interrogation area until the final (intended) sizes are reached [6].

Various validation parameters can be used in order to improve the results in correlation. For instance, during the correlation process, information at the boundaries of the interrogation area is lost. To regain this information, interrogation areas can be overlapped (by 25% – 75%) in both horizontal and vertical directions [1].

Moreover, “second” interrogation areas can be offset relative to the “first” interrogation areas to enlarge the measurable area of displacement [1].

Examples of correlation techniques with different overlap ratios and sizes of interrogation areas can be found in Appendix A.

2.5. Post-Processing of Data

After the acquisition and processing stages, vectors are further evaluated to obtain better results. “Post-processing” may include inspection and replacement of incorrect vectors and validation of the data.

In PIV, major operators for data validation can be noted as

- Global Histogram Operator and
- Dynamic Mean Value Operator [7].

CHAPTER 3

LABORATORY WORK

3.1. Experimental Setup

The setup used in the experiment consists of two basic components:

- The flow system and
- The PIV system.

The flow system is a water circulating closed loop, which includes

- The major tank (length: 0.62m, width: 0.47m, height: 0.40m), which further contains
  - The reservoir (length: 0.37m, width: 0.47m, height: 0.40m)
  - The supply tank (length: 0.10m, width: 0.47m, height: 0.40m)
  - The discharge tank (length: 0.10m, width: 0.47m, height: 0.40m)
- The measurement tank (length: 0.38m, width: 0.13m, height: 0.24m)
- The storage tank (length: 0.60m, width: 0.60m, height: 0.20m)
- The pump (maximum capacity: 90 lt/min).

This flow system was formerly used to study the behavior of outlets under constant head. The system, which was designed by Çobanoğlu [4], can be seen in Figures 3.1, 3.2 and 3.3.

The pump fills the supply tank via a 0.015m-diameter-pipe. Then, through a horizontal slit (0.005m $\times$ 0.42m), water passes from the supply tank into the reservoir.

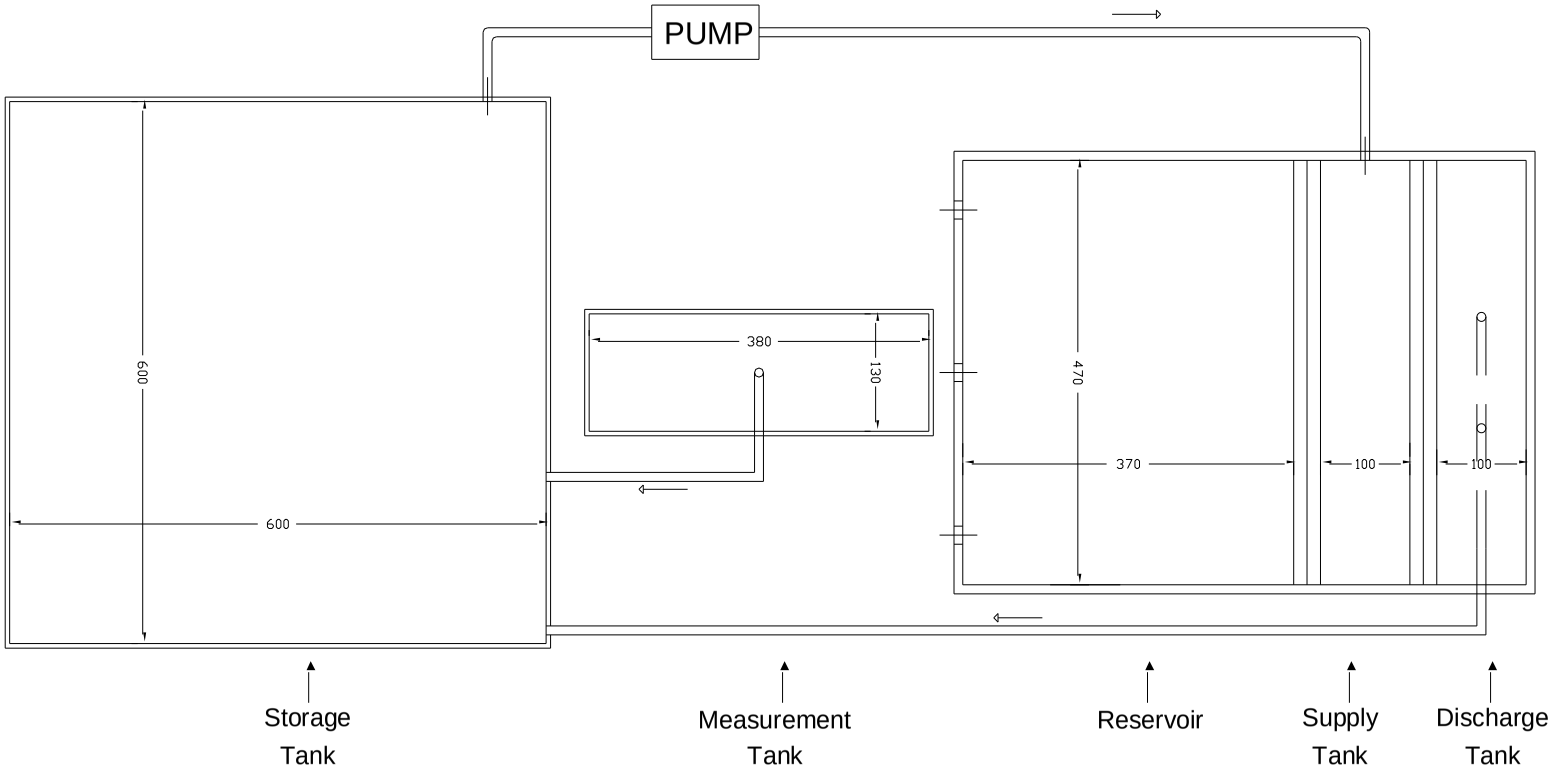

Figure 3.1: Top view of the setup (Dimensions are in mm) [4].

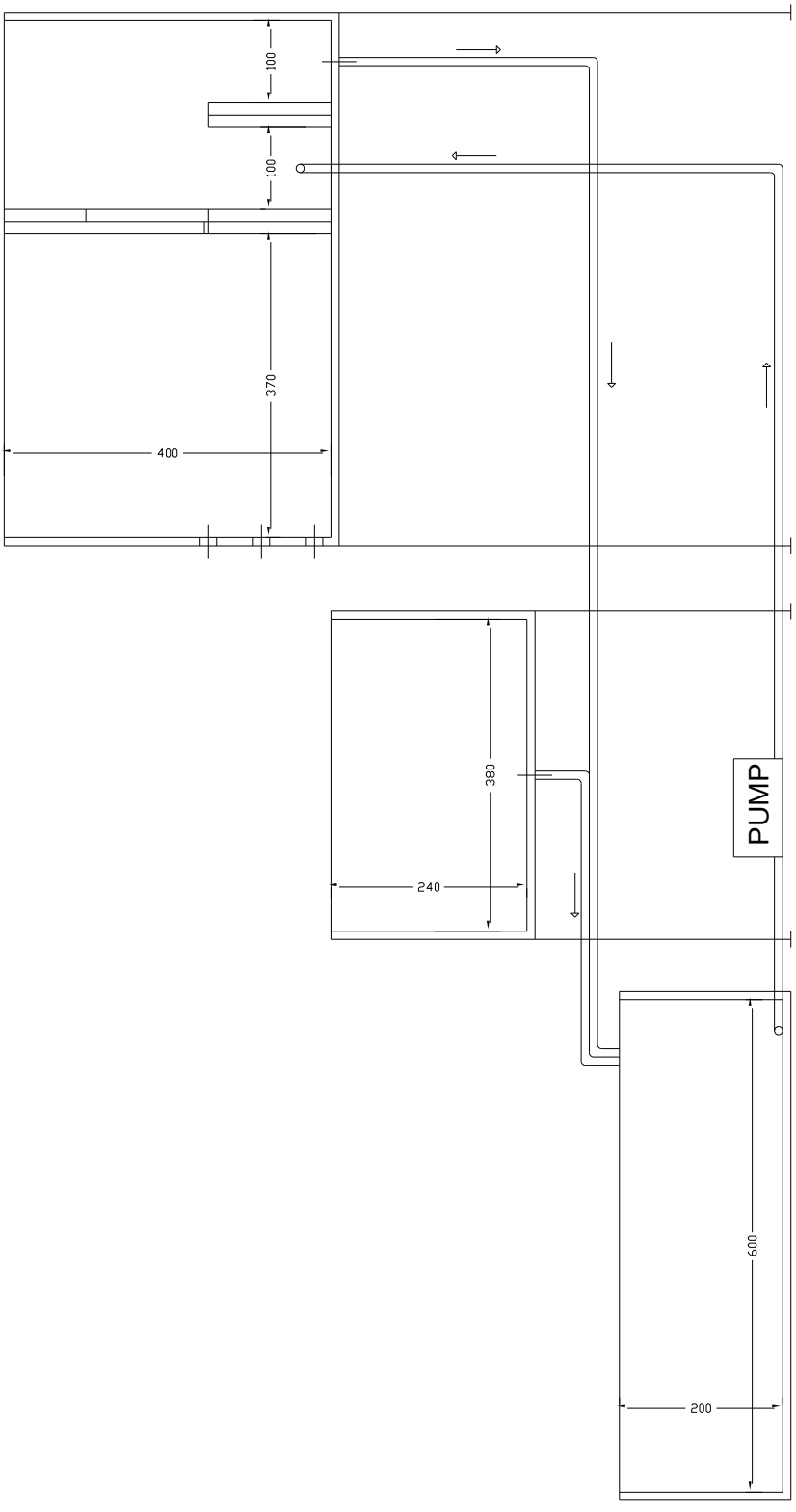

Figure 3.2: Side view of the setup (Dimensions are in mm) [4].

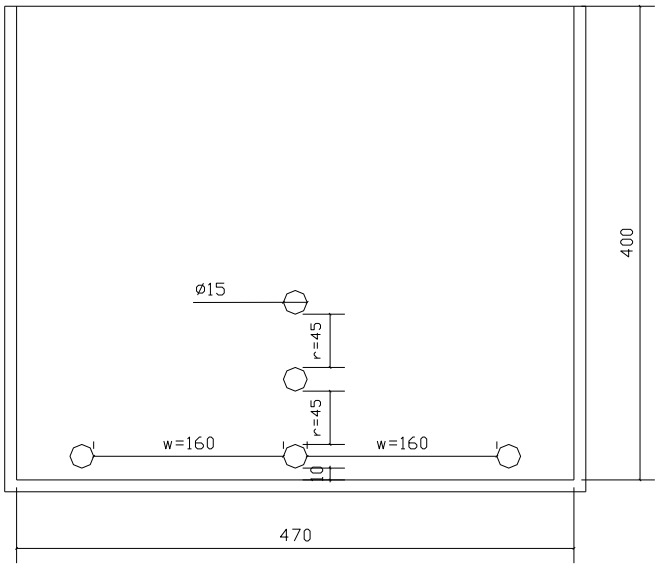

Figure 3.3: Front view of the setup (Dimensions are in mm) [4].

There are five outlets on the front face of the reservoir, which discharge water from the reservoir into the measurement tank. All outlets have the same diameter of 15.00 mm.

Among these openings, the one, which counts the second from the top (on the central plane), is further plugged to have a diameter of 6.00 mm and used in the experiments.

Thus, water coming from the reservoir discharges through this outlet into the measurement tank (Q = 36.98 cm^3/s).

Afterwards, water in the measurement tank is transmitted to the storage tank and is subsequently pumped back into the supply tank.

On the other side, the second component of the setup, the PIV system comprises

- A computer,
- A laser (Nd:YAG type with a wave length of 532 nm),
- A camera (CCD type with a sensor size of 1600×1200 pixels) and
- Tracer particles (Polymethyl Methacrylate particles with mean diameters of 20–50 μm and densities of 1.19 g/cm^3).

The photographs of the experimental setup can be seen in Figures 3.4, 3.5 and 3.6.

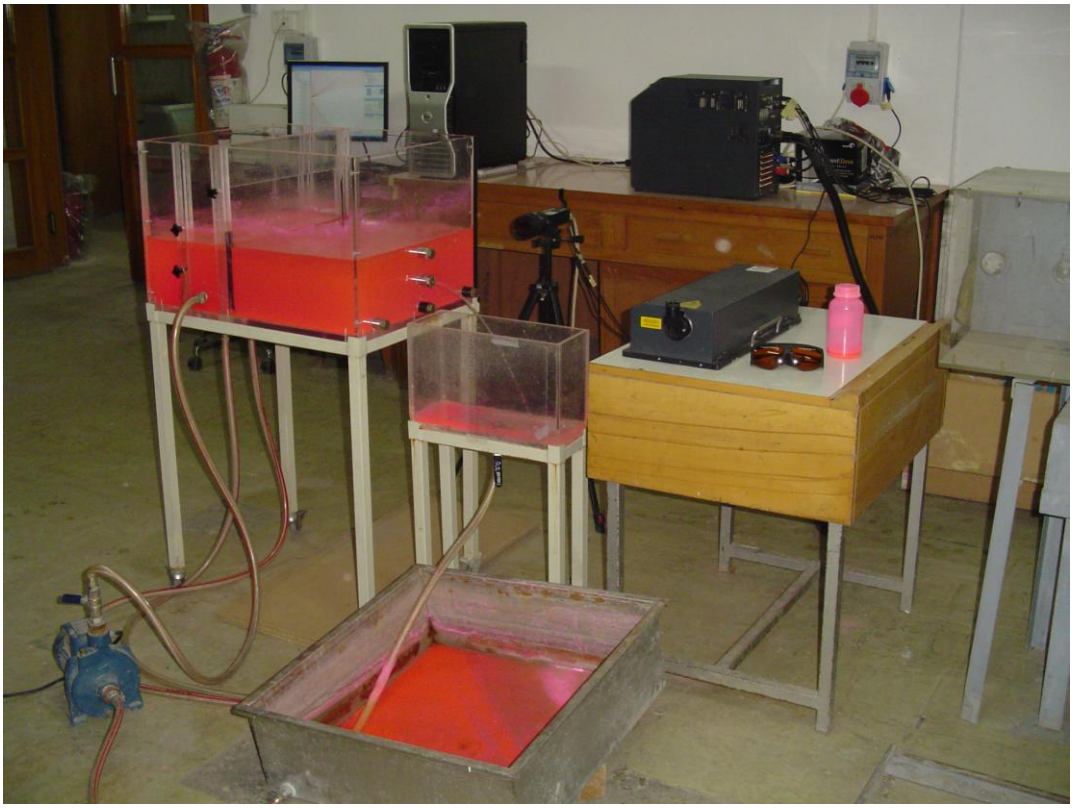

Figure 3.4: General view of the flow system and the PIV system.

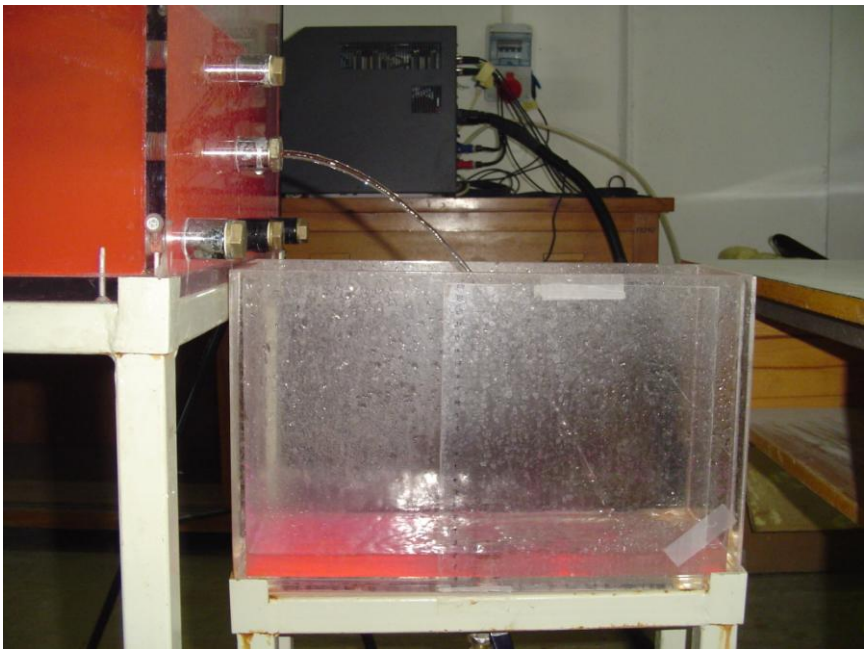

Figure 3.5: The reservoir and the measurement tank.

Figure 3.6: The laser and the camera.

3.2. Software Configuration

The PIV software utilized in this study is called the “DynamicStudio”. This software is capable of managing all the PIV stages, presenting the results in various different forms and exporting data to other program types.

The program is used either in “normal mode” or in “acquisition mode”. The layout of the screen, shown in Figure 3.7, may display diverse windows like “Device Properties”, “Record Properties”, “System Control” and “Database”, etc.

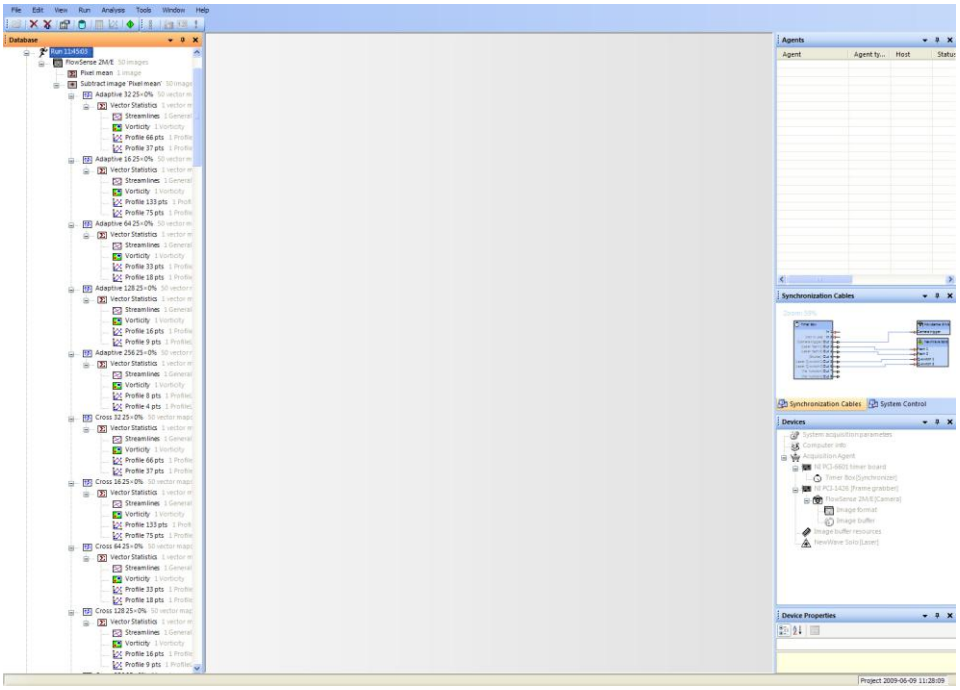

Figure 3.7: Normal mode in PIV software.

At this point, the basic steps to use the DynamicStudio can be listed as follows:

- From the “File” menu, a new database is created or an existing database is opened.
- The program is switched to “acquisition mode” (Figure 3.8).

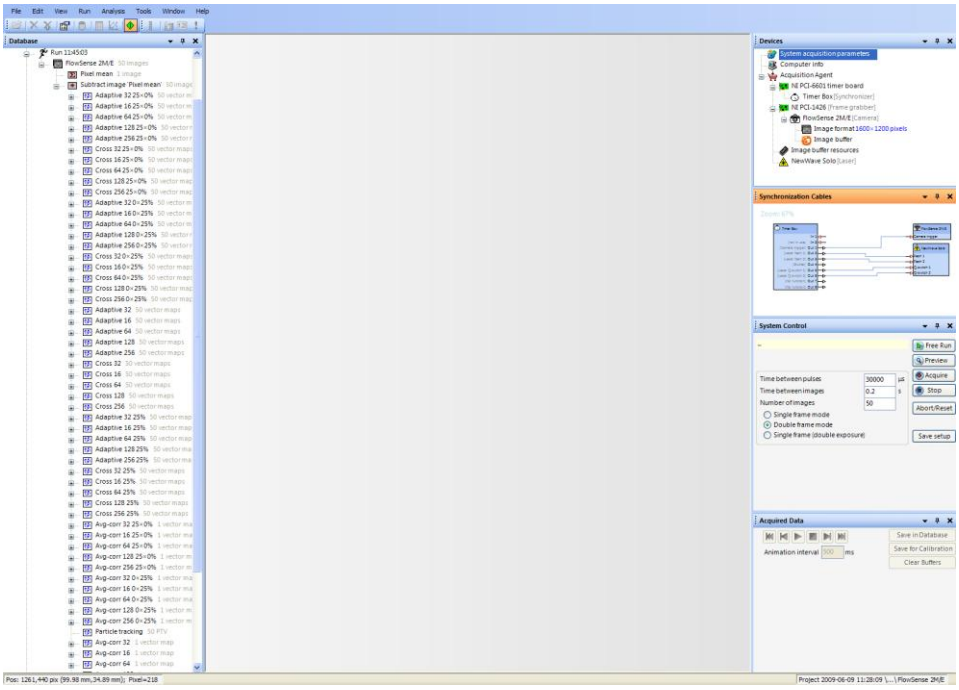

Figure 3.8: Acquisition mode in PIV software.

- In acquisition mode, the basic inputs for data attainment are entered via the “System Control” window (Figure 3.9).

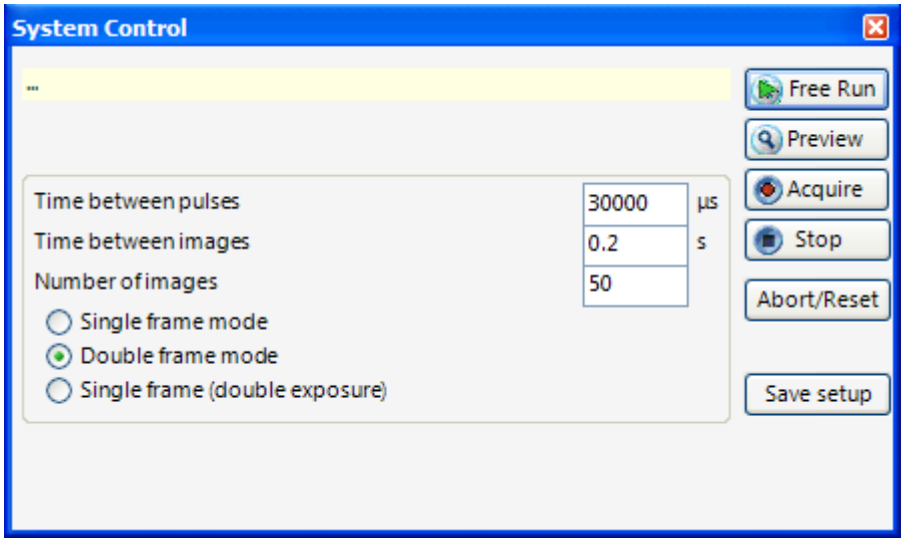

Figure 3.9: "System Control" window.

- For the calibration, the system is run in "single frame mode". However, after the calibration, for the data acquisition, "double frame mode" is chosen.
- At this point, the required inputs like the time between pulses, the time between images and the number of images are specified.
- After the completion of necessary inputs, in order to receive data from the camera and the laser, the "Acquire" button is pressed.
- Then, the data is saved through the "Acquired Data" window (Figure 3.10).
- Next, the analysis method is chosen via the "Select Analysis Method" window (Figure 3.11).
- At that stage, necessary information (like interrogation area size, interrogation area offset preference, overlap ratio, etc.) is provided for the selected analysis method.
- Subsequently, the analyses are done and the results are presented in numerical and visual forms.

If needed, the outcomes of analyses can be exported to other programs in different file formats.

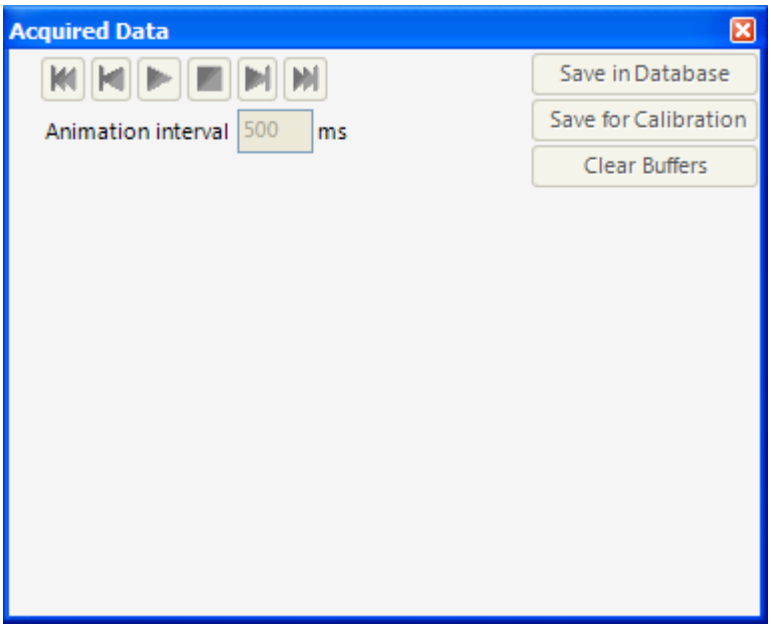

Figure 3.10: "Acquired Data" window.

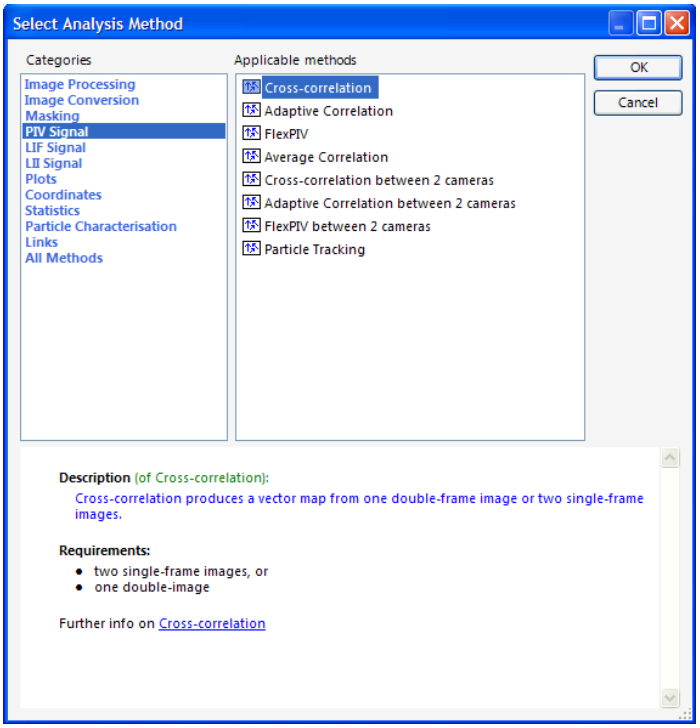

Figure 3.11: "Select Analysis Method" window.

3.3. Procedure and Measurements

In this study, the velocity profiles within a reservoir are examined near one of the outlets. That specific outlet is kept open, while the others are left closed (see Figure 3.5).

Velocity profiles are investigated inside the vertical plane that passes through the central axis of the reservoir (along the longer dimension). To determine the coordinates of the measurement area, a transparent grid plane (having $4\text{cm} \times 4\text{cm}$ squares) is immersed into the water.

The camera is positioned perpendicular to a side of the reservoir while the laser is placed under the reservoir.

The experimental procedure can be summarized as follows:

- The computer and the pump are turned on and the measurement outlet is opened. Then, the transparent grid plane is submerged into the reservoir, coinciding with the measurement plane.
- The system is waited for a while until a stable depth of water is maintained.
- The PIV lens is mounted on the camera.
- Afterwards, laser glasses are worn and the laser is adjusted at low energy.
- The PIV lens is taken off.
- The camera is adjusted in single frame mode.
- The image of the grid plane is calibrated.
- The PIV lens is again mounted on the camera.
- The camera is set to double frame mode.
- Flow is seeded.
- The grid plane is taken out of the reservoir.
- Laser is started at high energy.
- The data is received and analyzed.
- With chronometer, the flowrate into the measurement tank is calculated.

CHAPTER 4

DISCUSSION OF RESULTS

In this study, PIV technique is used to display and evaluate the motion of fine particles in a flow system. Experiments are conducted to compare the responses of diverse analysis methods. To observe the difference in outcomes, adaptive correlation, cross-correlation and average correlation are applied to the same raw data.

Each time a parameter, such as the interrogation area size, overlap percentage or overlap direction is changed. The results are presented as vector maps, streamline patterns and velocity profiles.

4.1. Vector Maps and Streamlines

Vector maps and streamlines are shown in Appendix A. Observing the images, it is possible to state that

- For the velocity range used ($\mathrm{Re} \leq 7846$), the optimum visual results for vector maps and streamlines are achieved at interrogation area sizes of
  - 32×32 and 64×64 pixels in adaptive correlation,
  - 64×64 and 128×128 pixels in cross- and average correlations.

- Contrary to the cases in cross- and average correlations, the adaptive correlation technique produces “green vectors”. These green vectors symbolize the corrections for the velocity field.

- Implementation of “interrogation area overlapping” enhances the vector maps. Thus, it can be used in both horizontal and vertical directions, at desired percentages.

4.2. Velocity Profiles

Velocity profiles are shown in Appendix B. The horizontal components of the velocities are drawn along the outlet axis, while the vertical components are plotted at the outlet side.

Along the outlet axis, as the flow approaches the outlet, the horizontal velocities increase. Thus, the maximum values are reached just at the outlet. In addition, while crossing the outlet axis, vertical velocities change signs.

In agreement with the profiles presented by Rajaratnam et al. [12, 13], the flow gradually adapts itself to the outlet and conforms to the Potential Flow Theory. Development of the flow upstream of the outlet can be seen in Figure 4.1.

4.3. Sources of Errors

At this point, it should be noted that the experimental results might have errors. The possible sources of errors can be listed as

- Nonuniform distribution of tracer particles,
- Low concentration of the particles,
- Loss of image pairs due to considerable velocity components perpendicular to the light sheet,
- Geometrical distortion of the setup and
- Insufficient focusing [7].

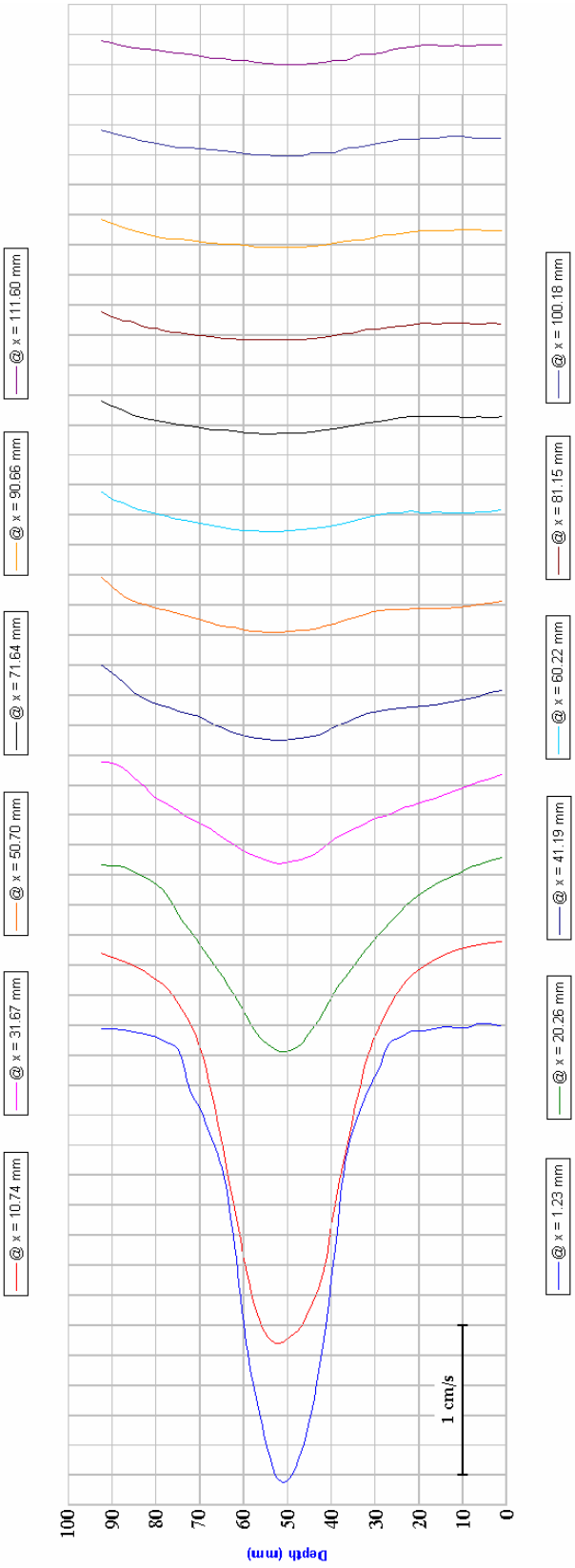

Figure 4.1: Velocity profiles upstream of the outlet.

CHAPTER 5

CONCLUSION

In this thesis, velocity vector fields have been investigated by using the Particle Image Velocimeter.

From the experimental observations, following conclusions can be derived:

- In the flow system considered, going downstream along the outlet axis, the horizontal velocities increase. Additionally, while crossing the outlet axis, signs of the vertical velocities change.

- Upstream of the outlet, the flow gradually develops and adopts the shape of the outlet. The behavior of the flow seems to be in accordance with the earlier findings on Potential Flow Theory.

- In PIV technology, selection of a suitable pixel size is essential for attaining the visual quality. In order to have better outcomes, the interrogation areas should be at least 32×32 pixels.

- To improve the analyses, interrogation areas can be overlapped by 25% or more in both horizontal and vertical directions.

Finally, it should be stated that the PIV system can be used to study various topics in fluid mechanics. Future experiments may include airflows or two-phase flows. Moreover, by the addition of a second camera, three-dimensional vector fields can be obtained.

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APPENDIX A

VECTOR MAPS AND STREAMLINES

In this section, vector maps and streamlines are presented. On each vector map, a representative vector, which is enclosed by a box at the bottom-center of the map, is shown with its velocity components.

The calibration image shown below is used for the “scaling”.

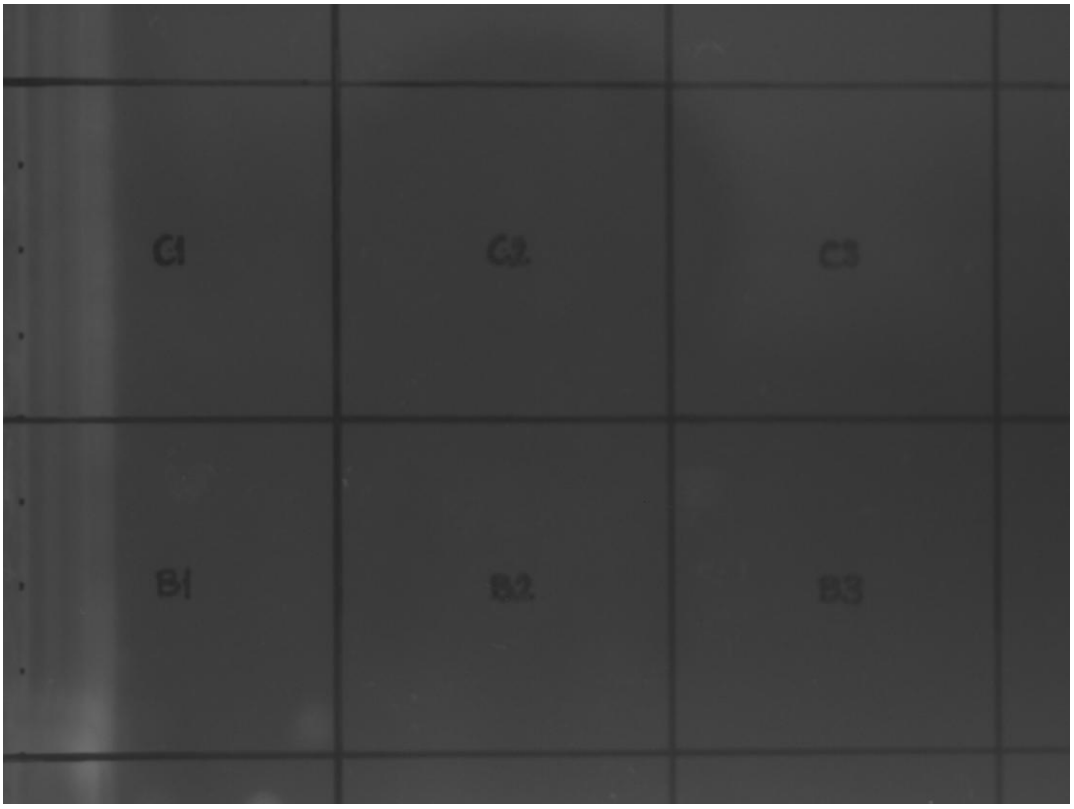

Figure A.1: Calibration image

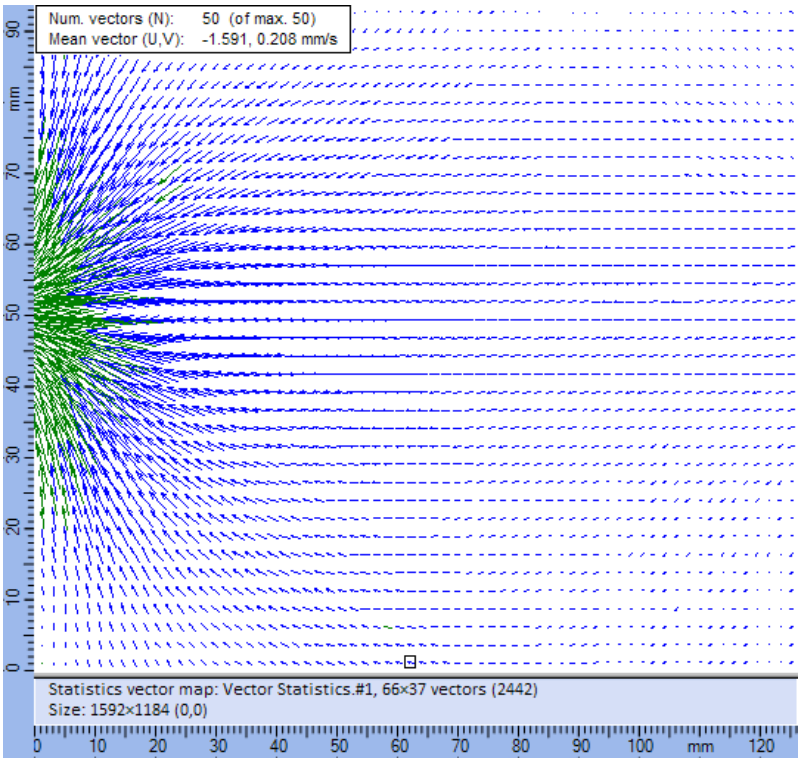

Figure A.2.1: Vector Map

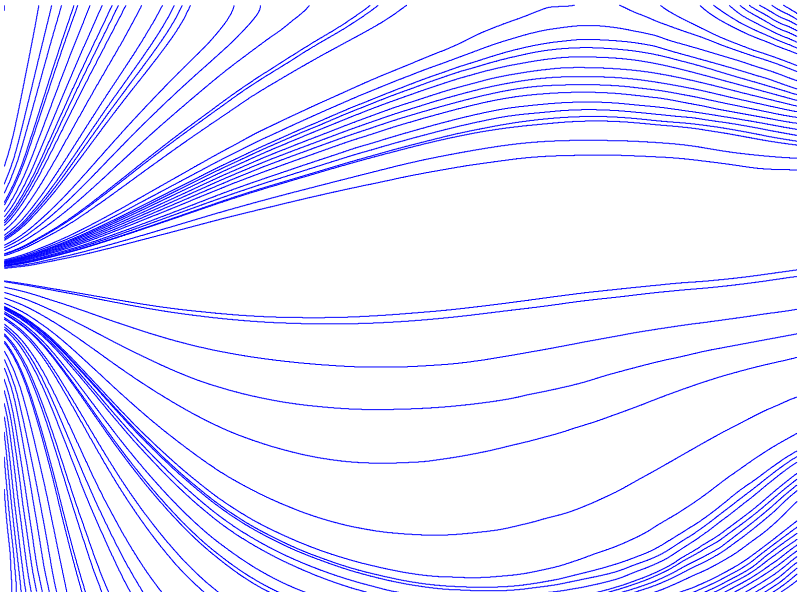

Figure A.2.2: Streamlines

Figure A.2: Vector Map and Streamlines for Adaptive Correlation
[IA Size: 32×32 pixels and Overlap Percentage (H%, V%): 25%, 0%]

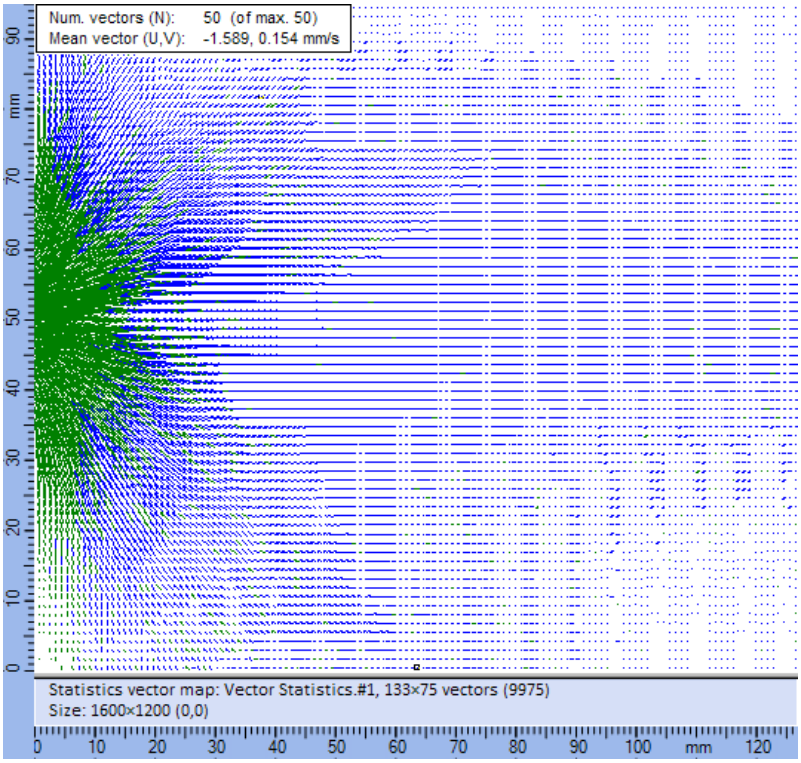

Figure A.3.1: Vector Map

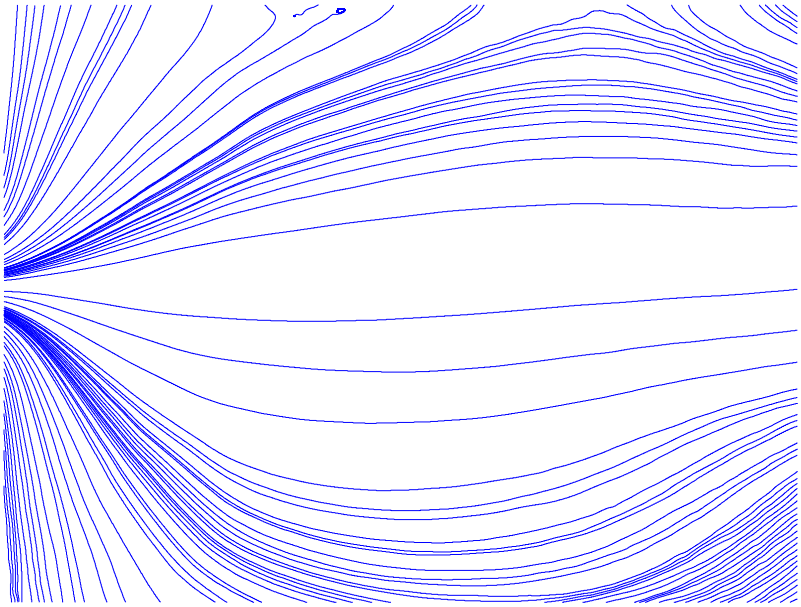

Figure A.3.2: Streamlines

Figure A.3: Vector Map and Streamlines for Adaptive Correlation
[IA Size: 16× 16 pixels and Overlap Percentage (H%, V%): 25%, 0%]

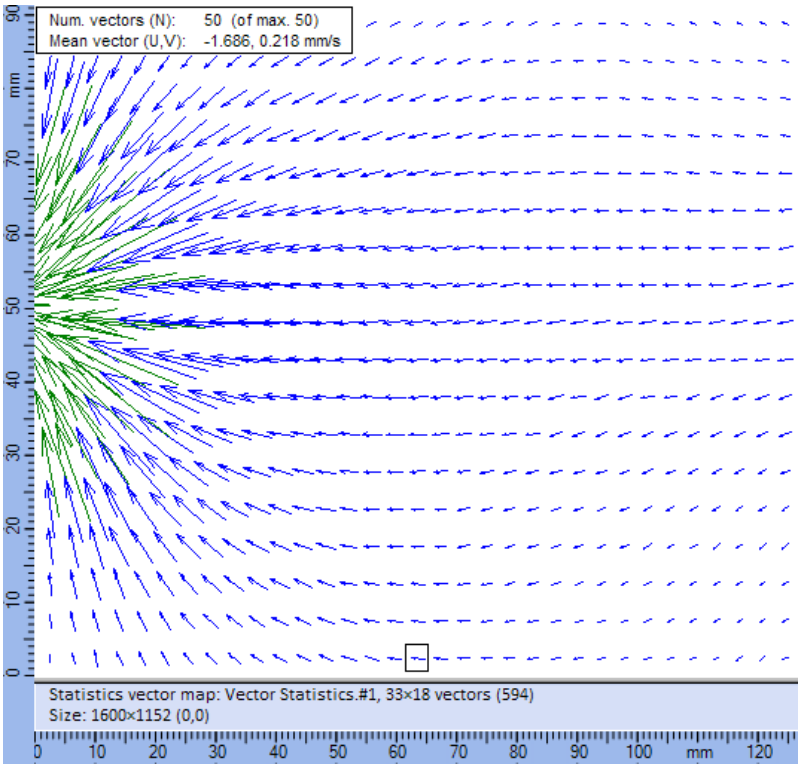

Figure A.4.1: Vector Map

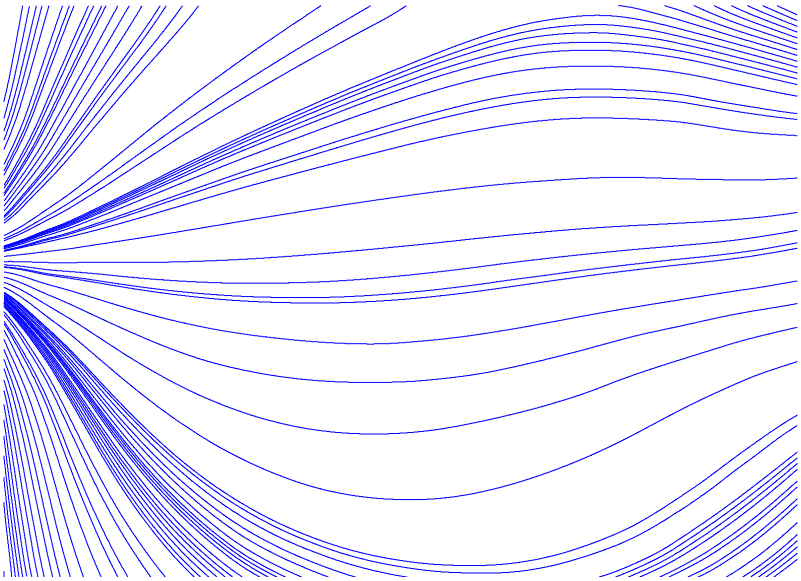

Figure A.4.2: Streamlines

Figure A.4: Vector Map and Streamlines for Adaptive Correlation
[IA Size: 64× 64 pixels and Overlap Percentage (H%, V%): 25%, 0%]

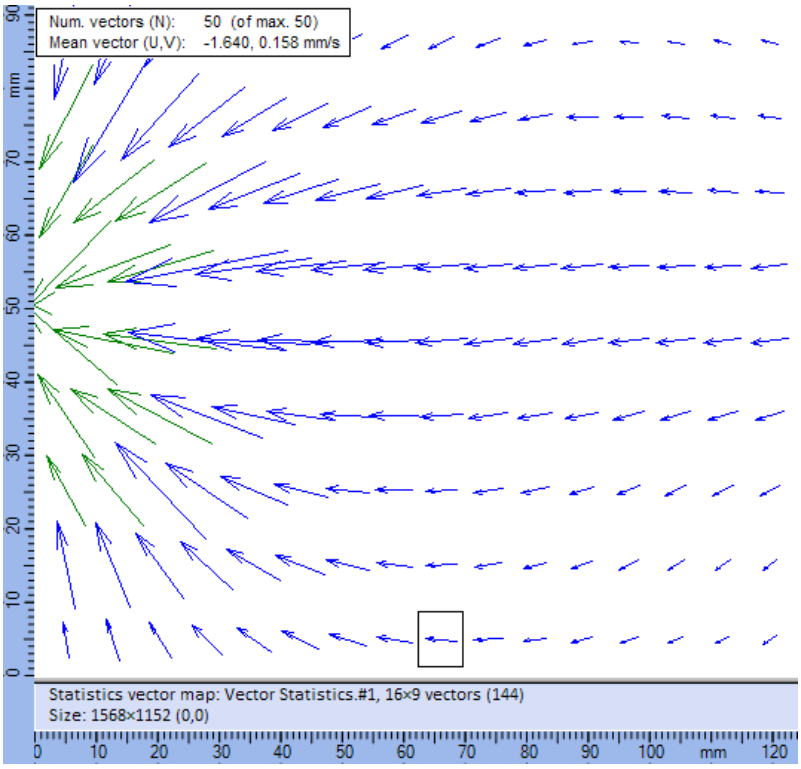

Figure A.5.1: Vector Map

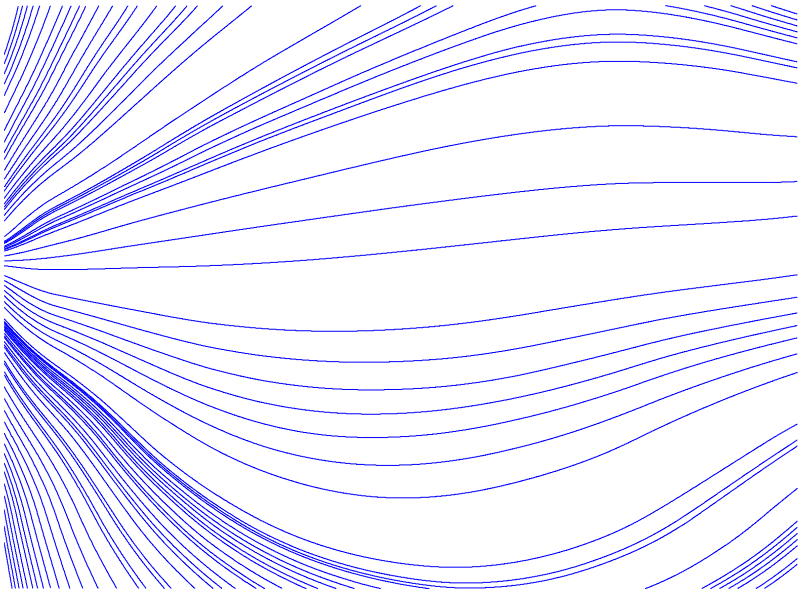

Figure A.5.2: Streamlines

Figure A.5: Vector Map and Streamlines for Adaptive Correlation
[IA Size: 128× 128 pixels and Overlap Percentage (H%, V%): 25%, 0%]

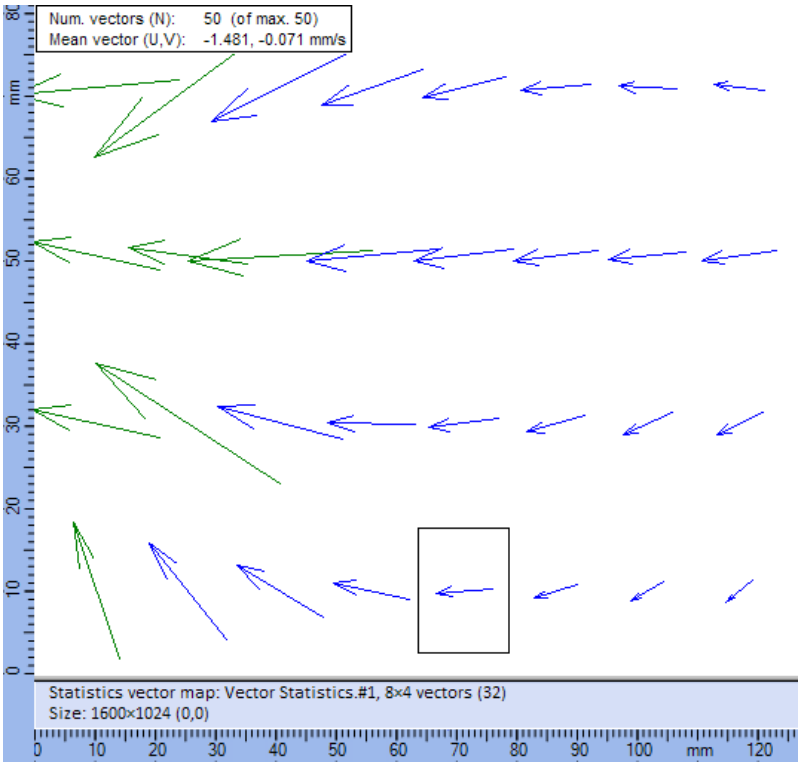

Figure A.6.1: Vector Map

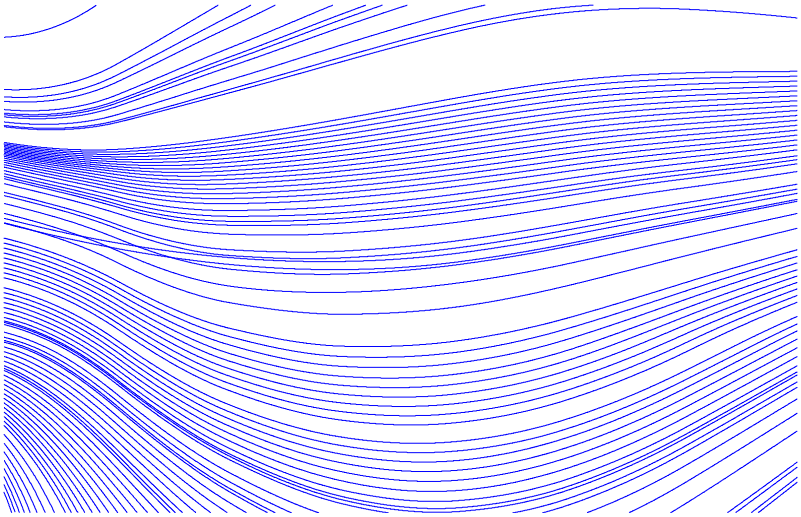

Figure A.6.2: Streamlines

Figure A.6: Vector Map and Streamlines for Adaptive Correlation
[IA Size: 256× 256 pixels and Overlap Percentage (H%, V%): 25%, 0%]

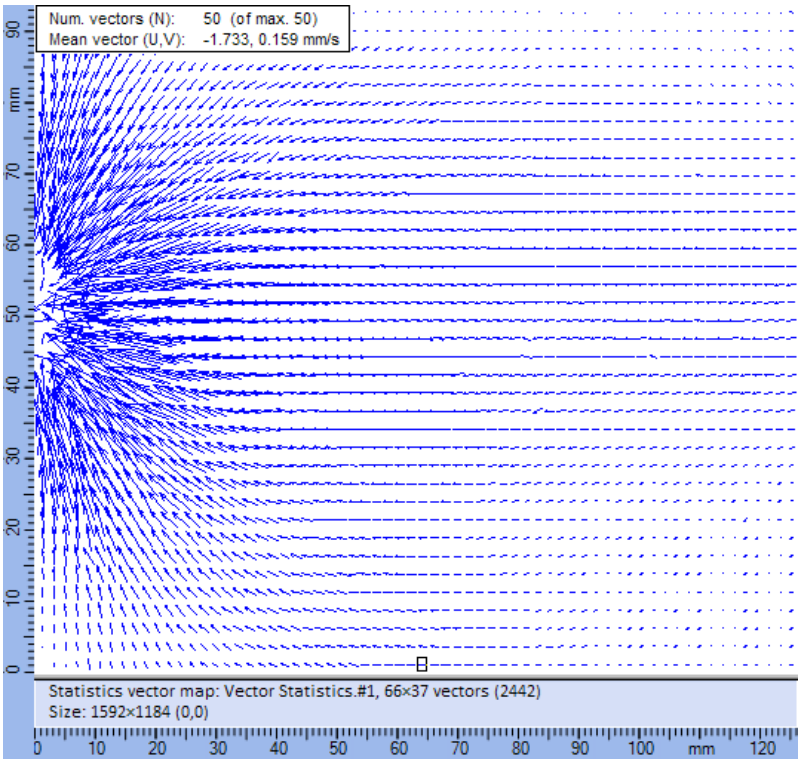

Figure A.7.1: Vector Map

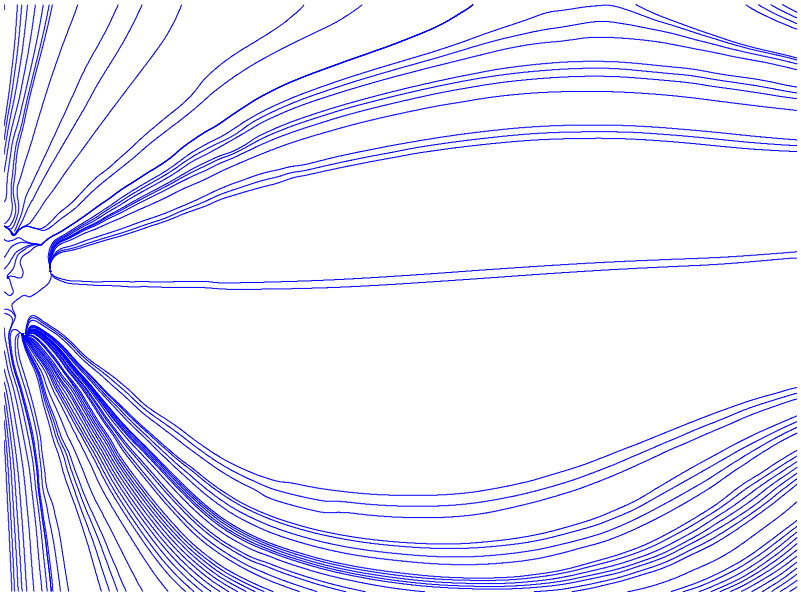

Figure A.7.2: Streamlines

Figure A.7: Vector Map and Streamlines for Cross Correlation
[IA Size: 32× 32 pixels and Overlap Percentage (H%, V%): 25%, 0%]

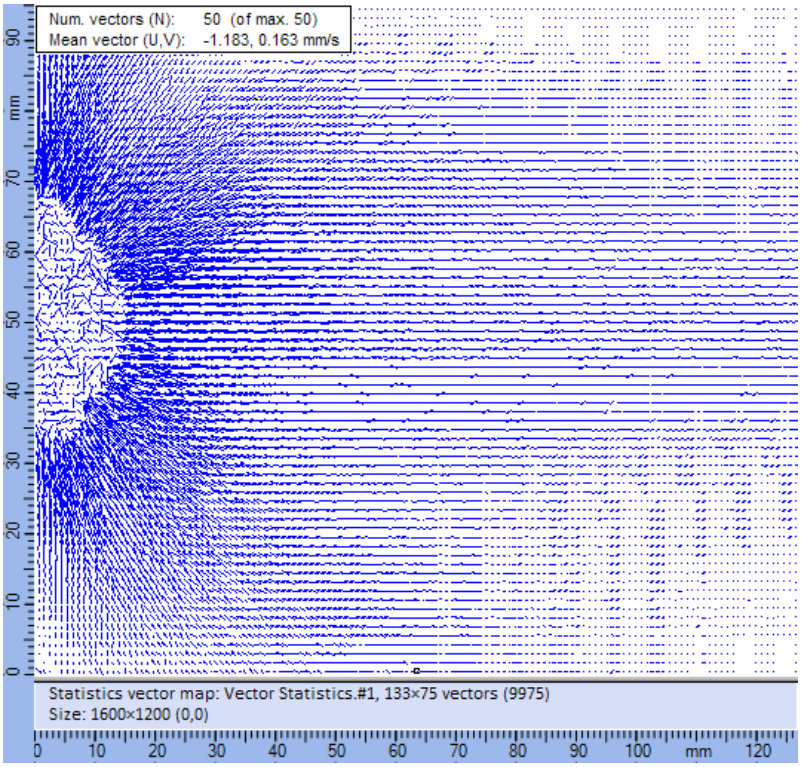

Figure A.8.1: Vector Map

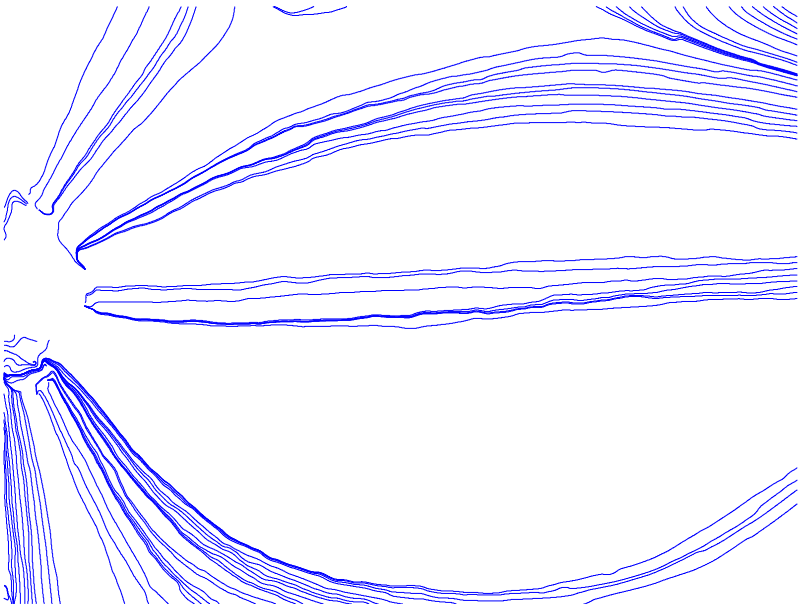

Figure A.8.2: Streamlines

Figure A.8: Vector Map and Streamlines for Cross Correlation
[IA Size: 16× 16 pixels and Overlap Percentage (H%, V%): 25%, 0%]

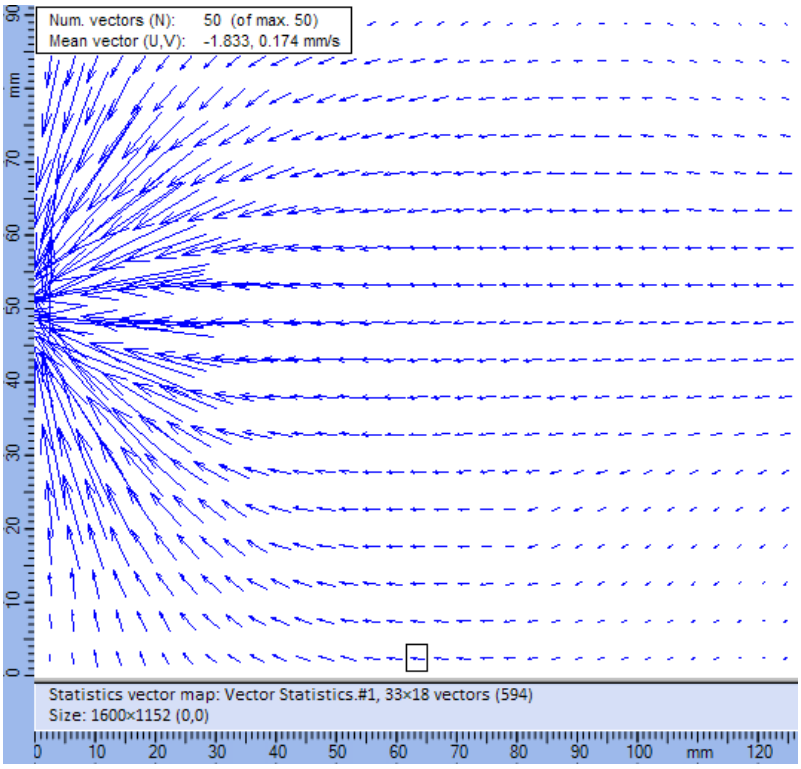

Figure A.9.1: Vector Map

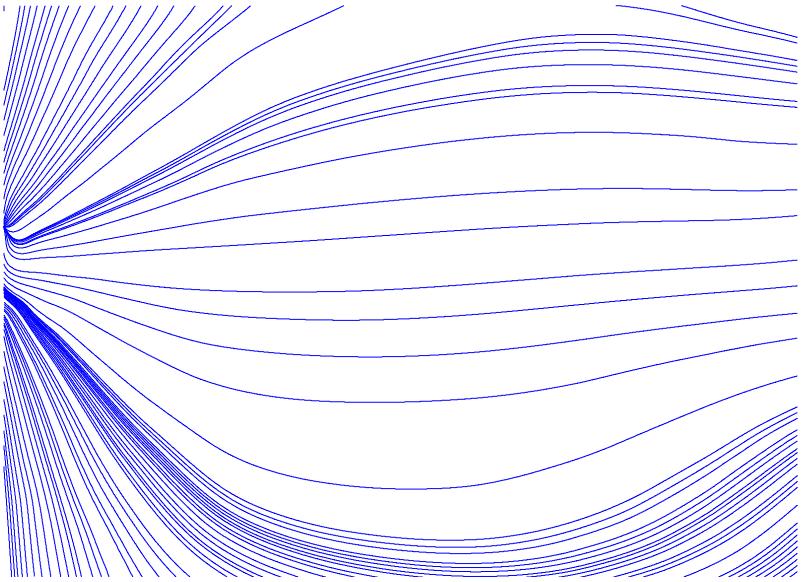

Figure A.9.2: Streamlines

Figure A.9: Vector Map and Streamlines for Cross Correlation
[IA Size: 64× 64 pixels and Overlap Percentage (H%, V%): 25%, 0%]

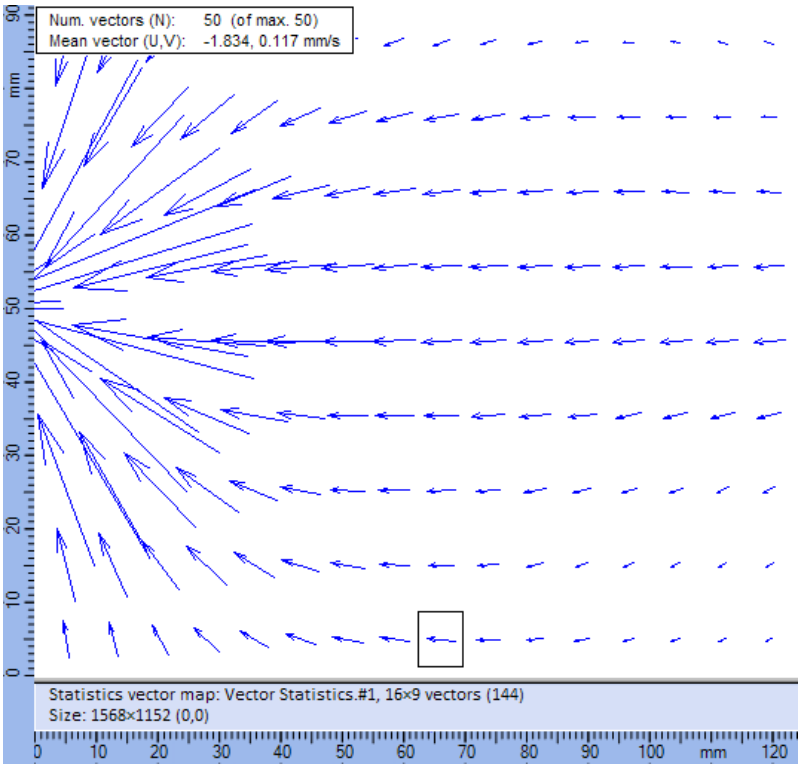

Figure A.10.1: Vector Map

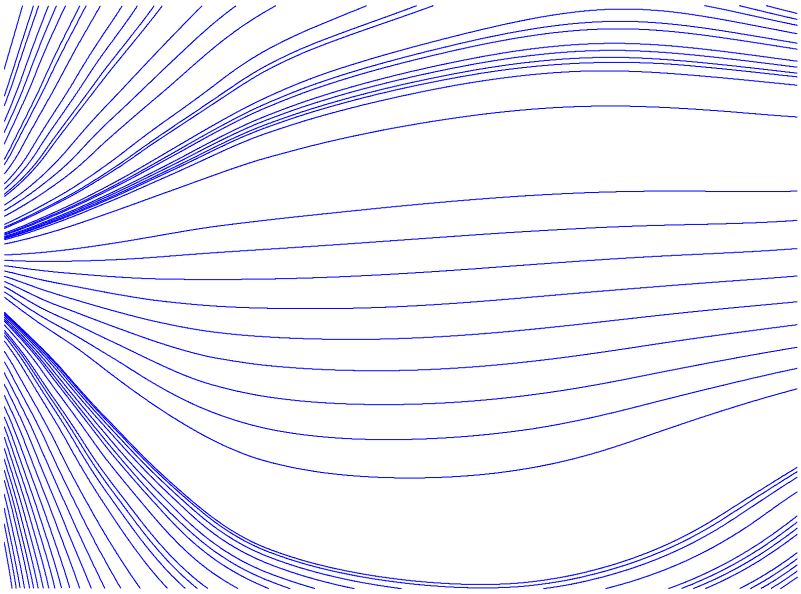

Figure A.10.2: Streamlines

Figure A.10: Vector Map and Streamlines for Cross Correlation
[IA Size: 128× 128 pixels and Overlap Percentage (H%, V%): 25%, 0%]

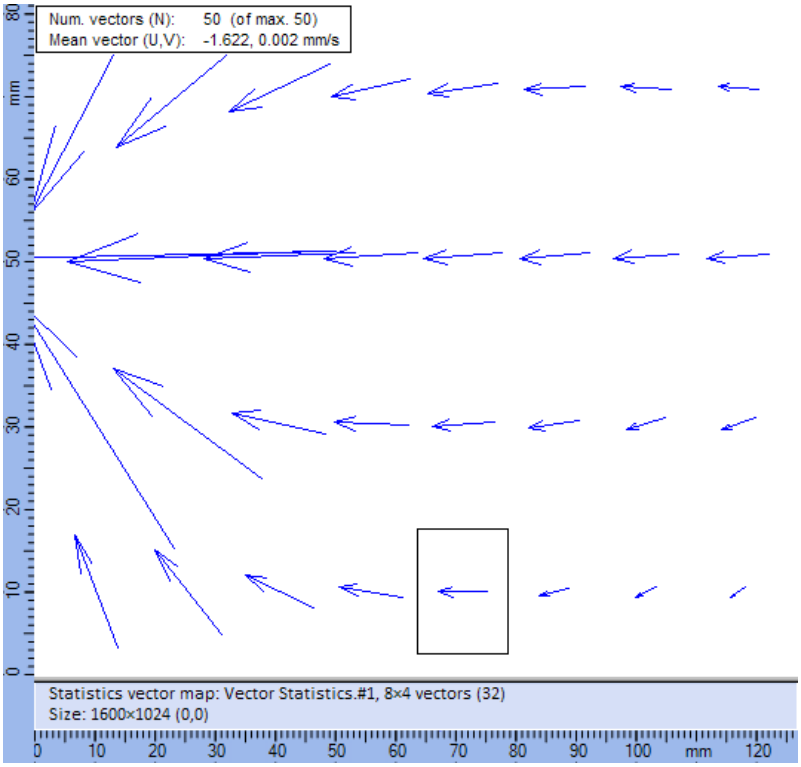

Figure A.11.1: Vector Map

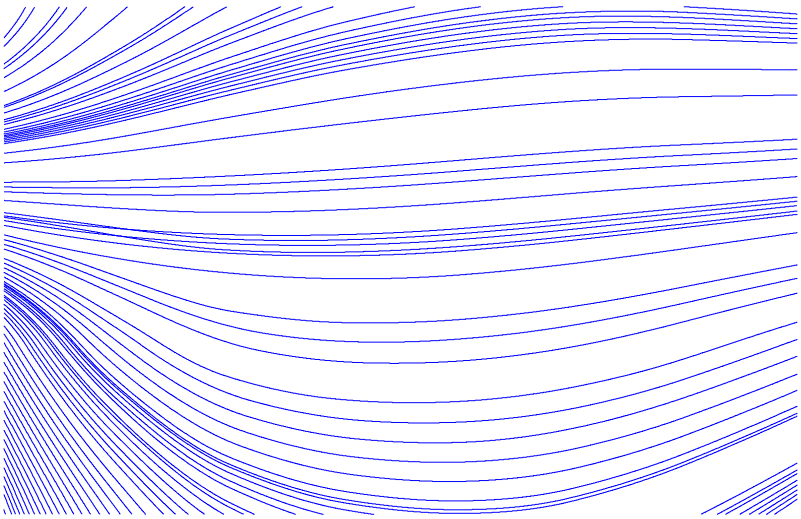

Figure A.11.2: Streamlines

Figure A.11: Vector Map and Streamlines for Cross Correlation
[IA Size: 256× 256 pixels and Overlap Percentage (H%, V%): 25%, 0%]

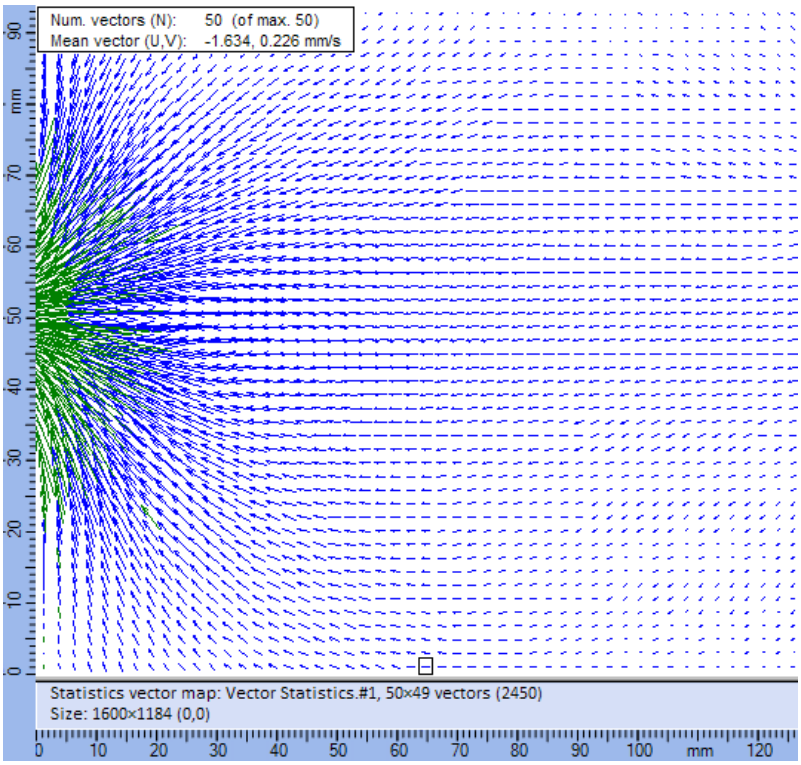

Figure A.12.1: Vector Map

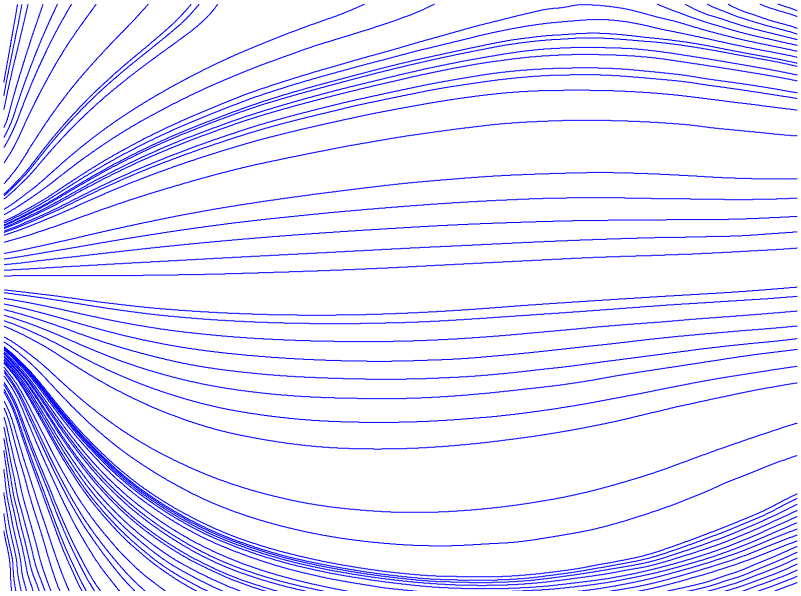

Figure A.12.2: Streamlines

Figure A.12: Vector Map and Streamlines for Adaptive Correlation
[IA Size: 32×32 pixels and Overlap Percentage (H%, V%): 0%, 25%]

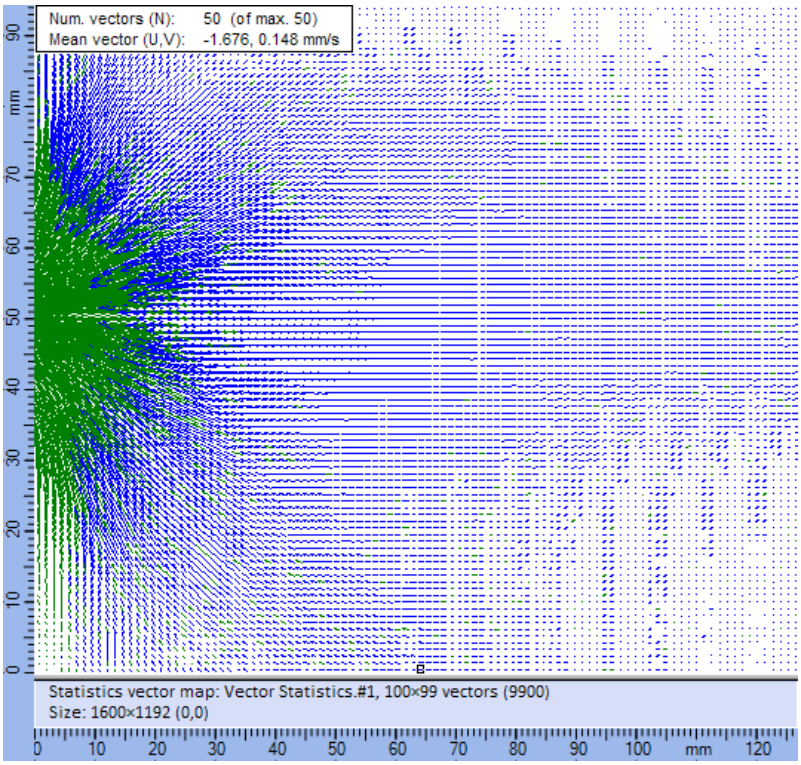

Figure A.13.1: Vector Map

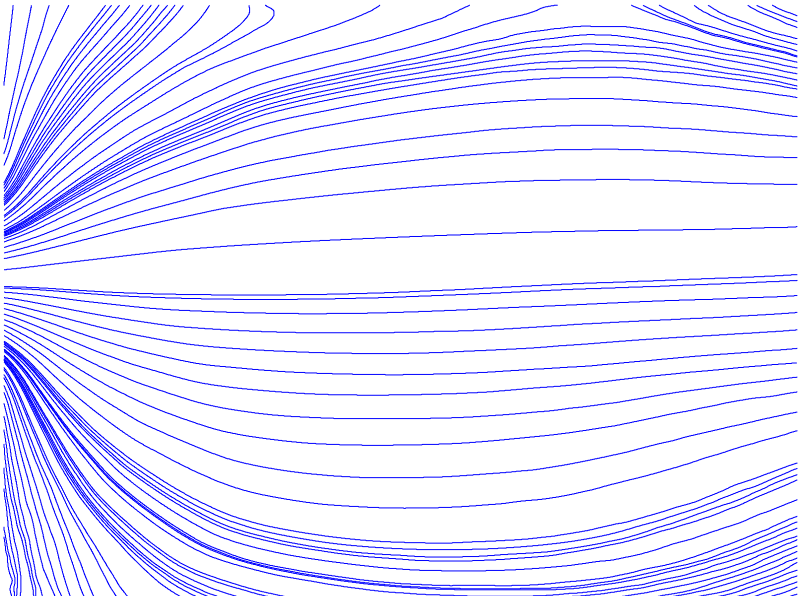

Figure A.13.2: Streamlines

Figure A.13: Vector Map and Streamlines for Adaptive Correlation
[IA Size: 16× 16 pixels and Overlap Percentage (H%, V%): 0%, 25%]

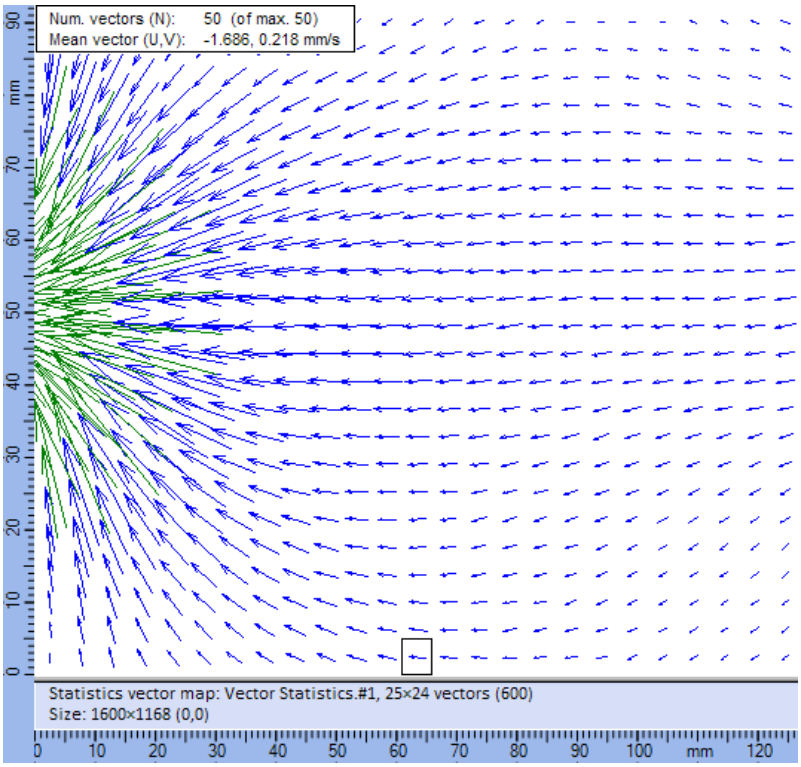

Figure A.14.1: Vector Map

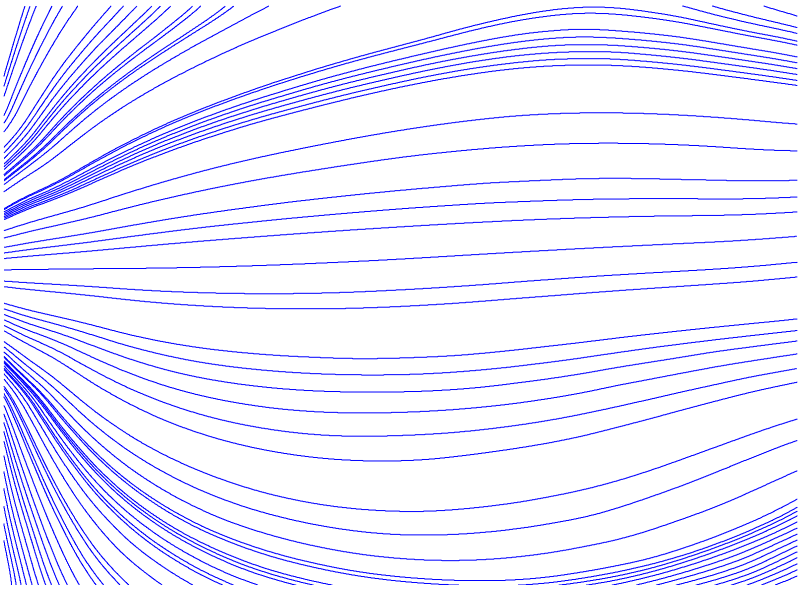

Figure A.14.2: Streamlines

Figure A.14: Vector Map and Streamlines for Adaptive Correlation
[IA Size: 64× 64 pixels and Overlap Percentage (H%, V%): 0%, 25%]

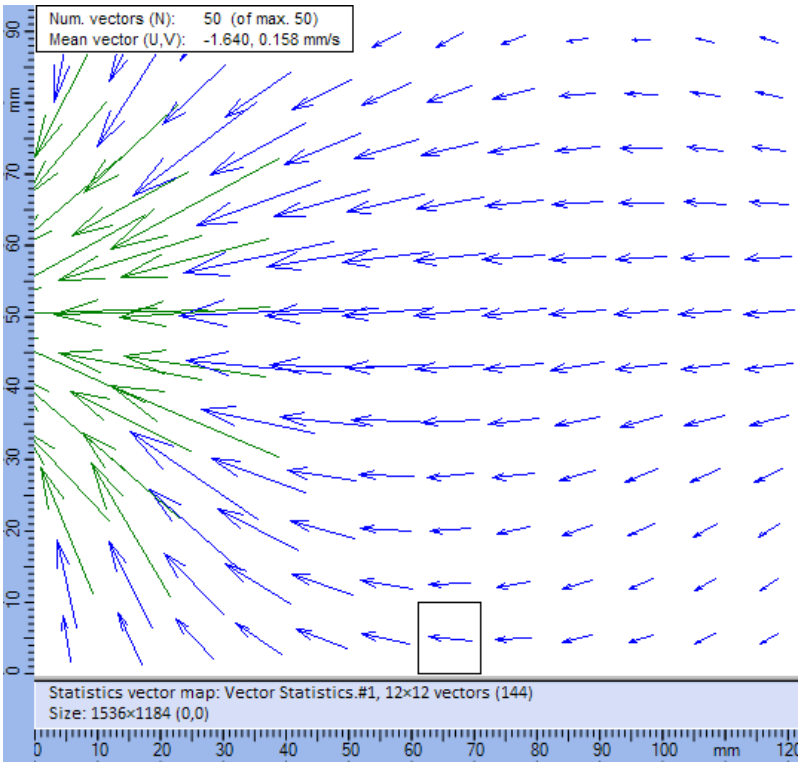

Figure A.15.1: Vector Map

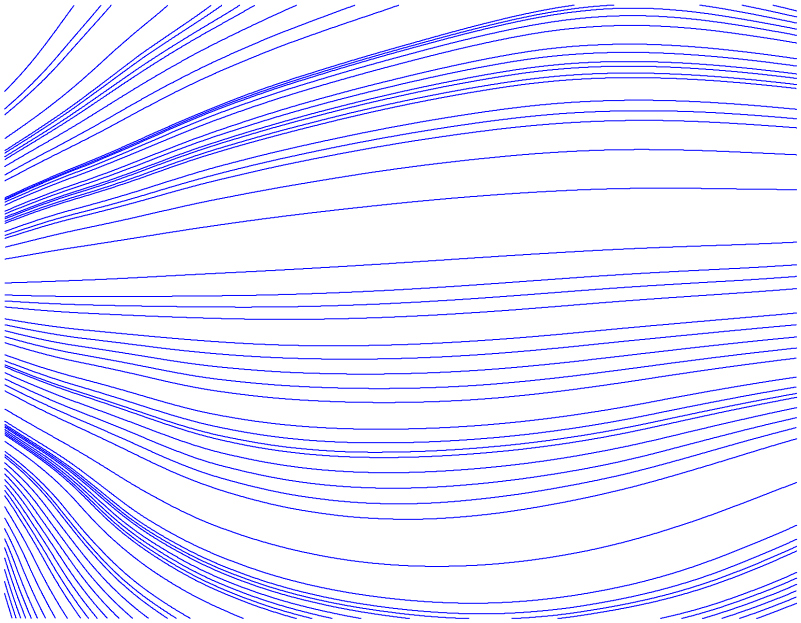

Figure A.15.2: Streamlines

Figure A.15: Vector Map and Streamlines for Adaptive Correlation
[IA Size: 128× 128 pixels and Overlap Percentage (H%, V%): 0%, 25%]

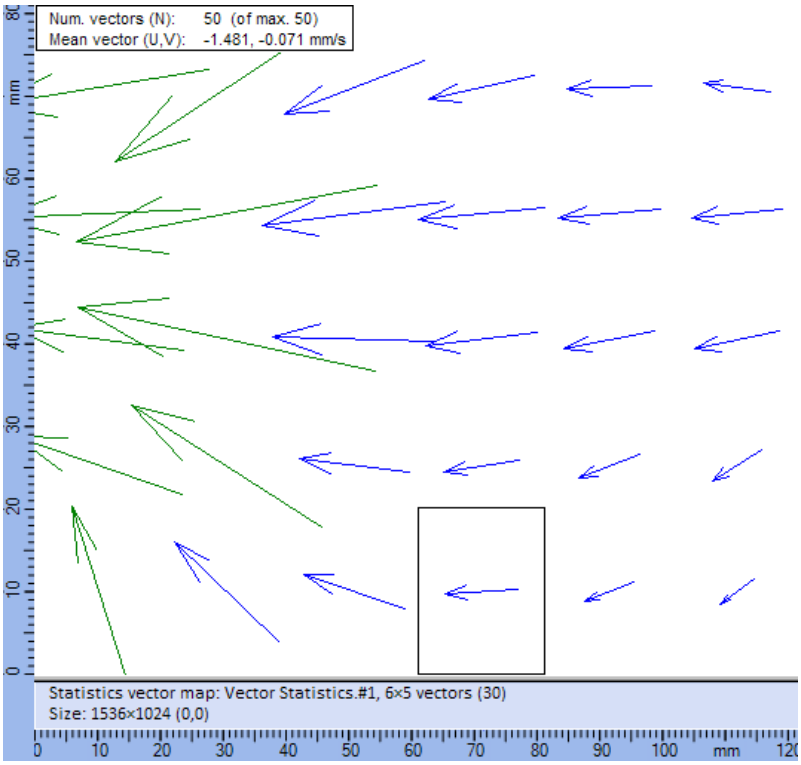

Figure A.16.1: Vector Map

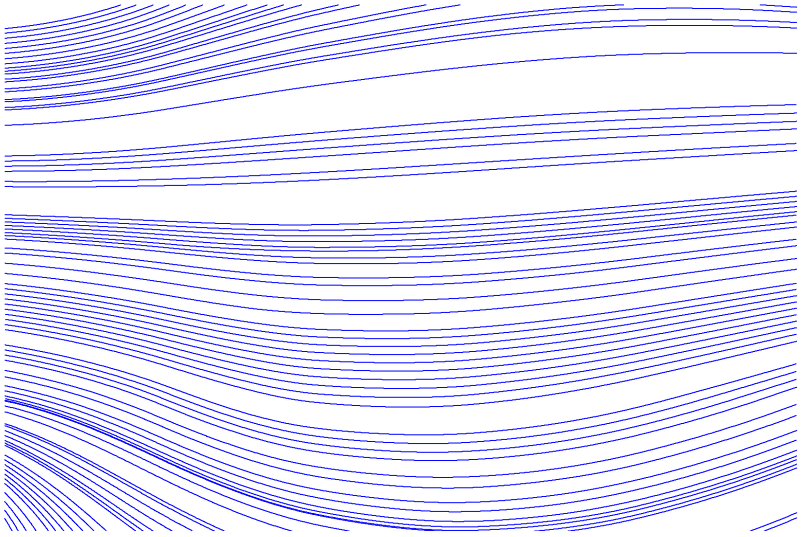

Figure A.16.2: Streamlines

Figure A.16: Vector Map and Streamlines for Adaptive Correlation
[IA Size: 256× 256 pixels and Overlap Percentage (H%, V%): 0%, 25%]

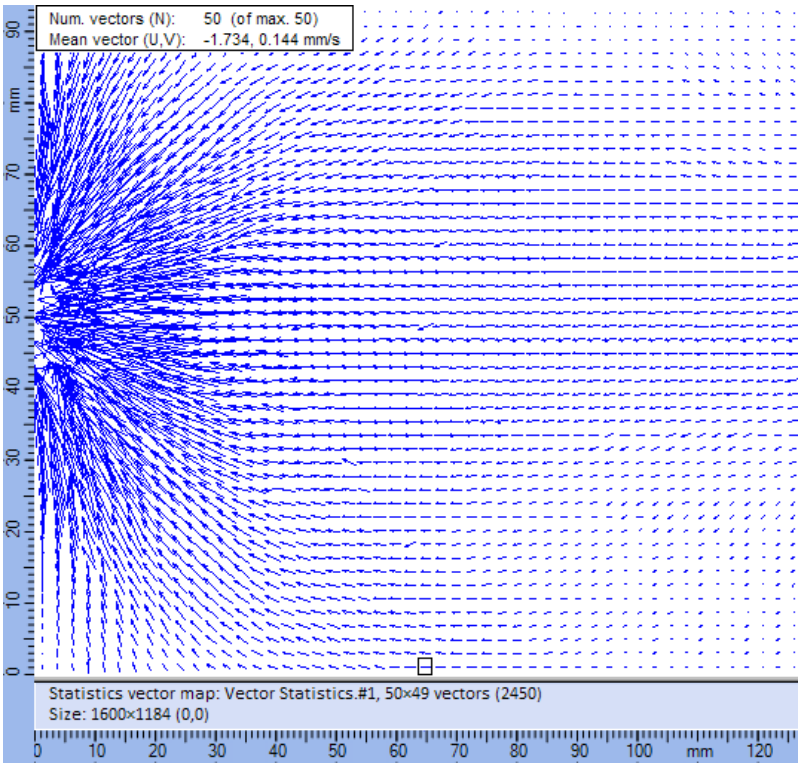

Figure A.17.1: Vector Map

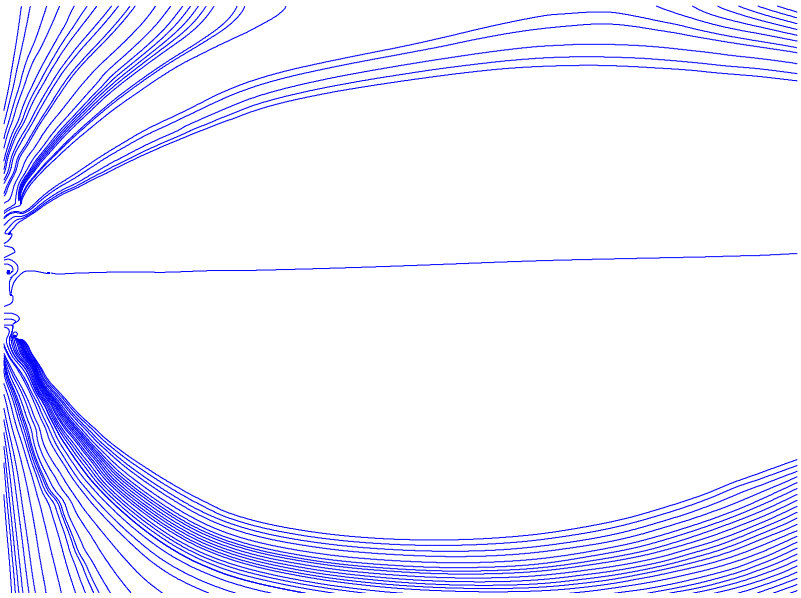

Figure A.17.2: Streamlines

Figure A.17: Vector Map and Streamlines for Cross Correlation
[IA Size: 32× 32 pixels and Overlap Percentage (H%, V%): 0%, 25%]

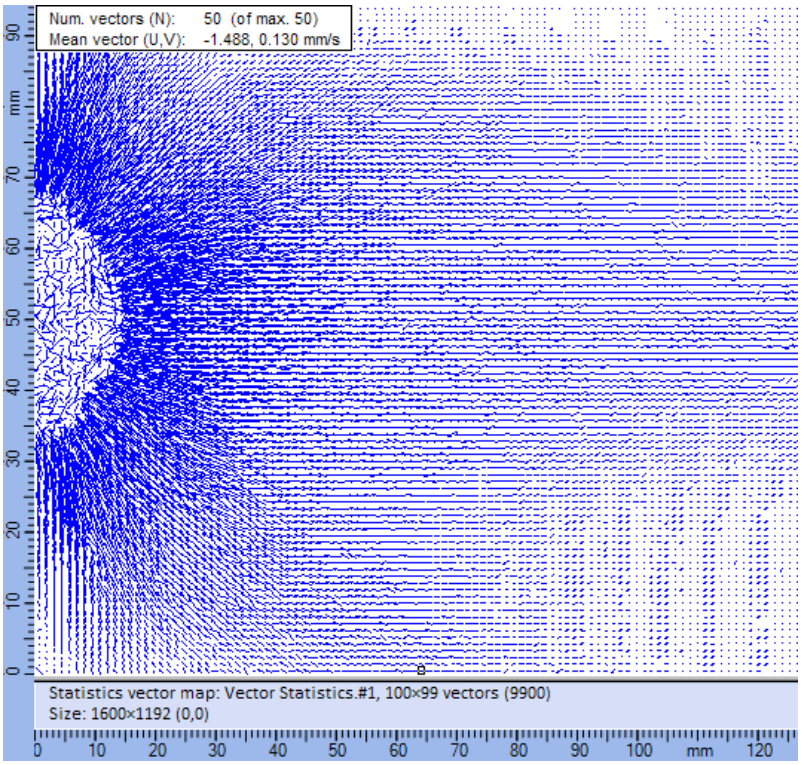

Figure A.18.1: Vector Map

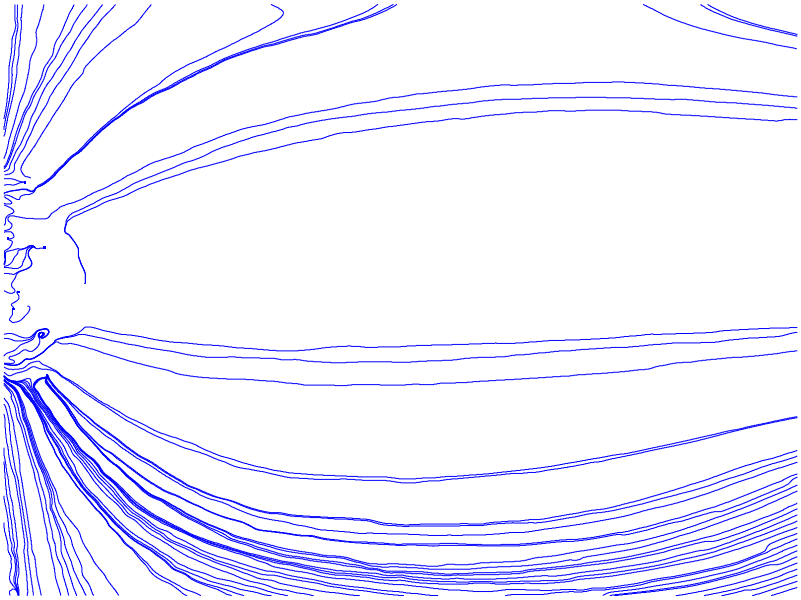

Figure A.18.2: Streamlines

Figure A.18: Vector Map and Streamlines for Cross Correlation
[IA Size: 16× 16 pixels and Overlap Percentage (H%, V%): 0%, 25%]

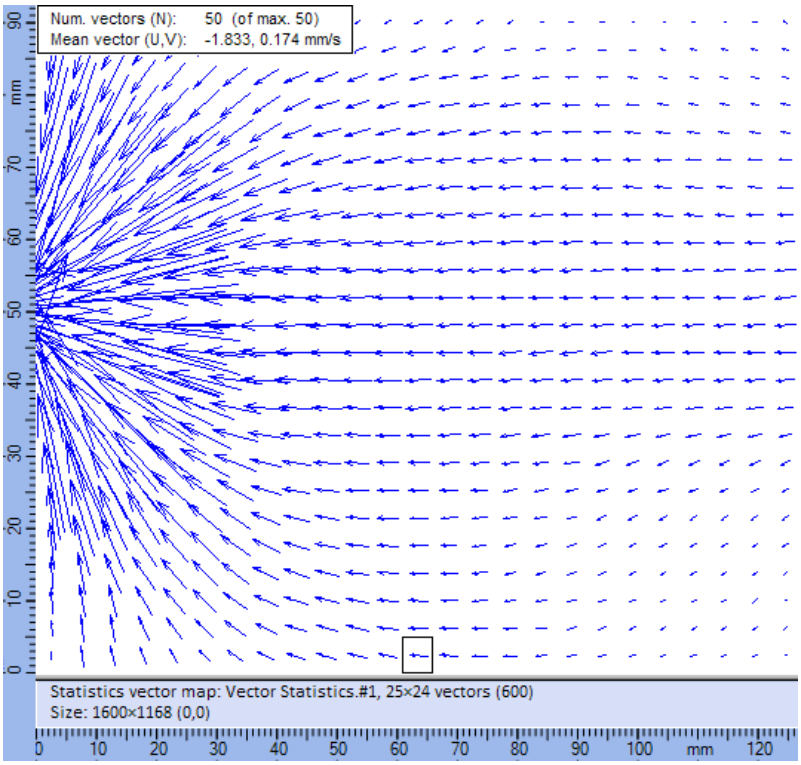

Figure A.19.1: Vector Map

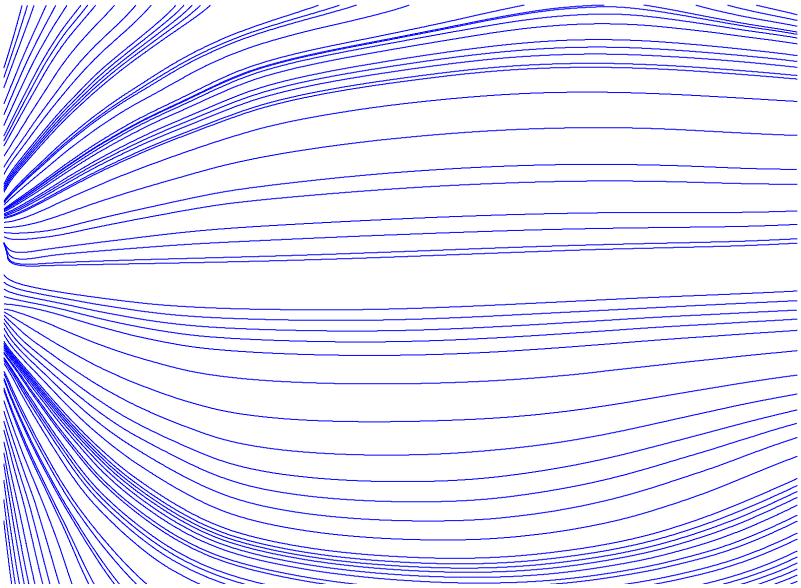

Figure A.19.2: Streamlines

Figure A.19: Vector Map and Streamlines for Cross Correlation
[IA Size: 64× 64 pixels and Overlap Percentage (H%, V%): 0%, 25%]

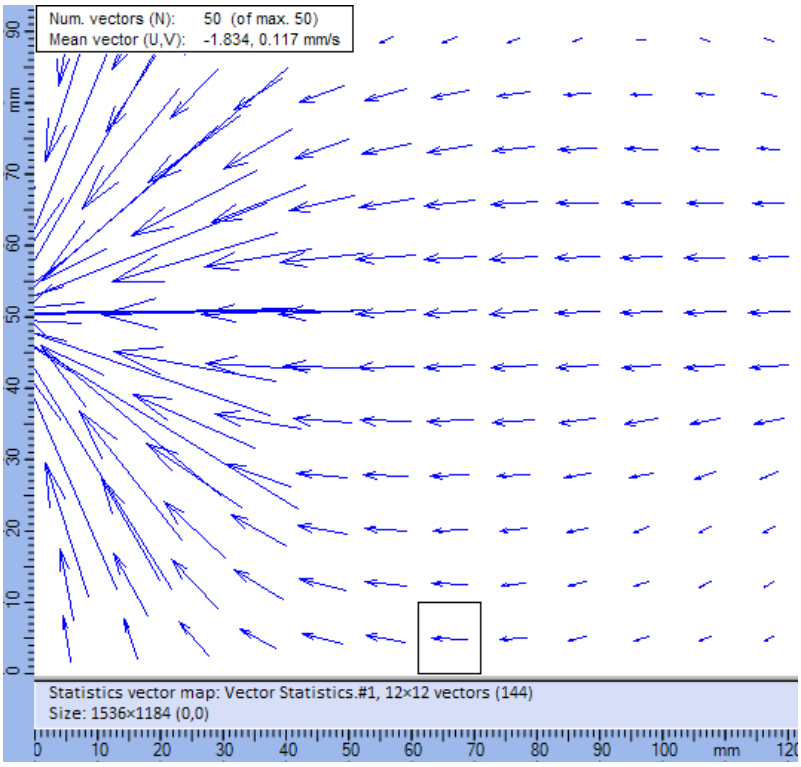

Figure A.20.1: Vector Map

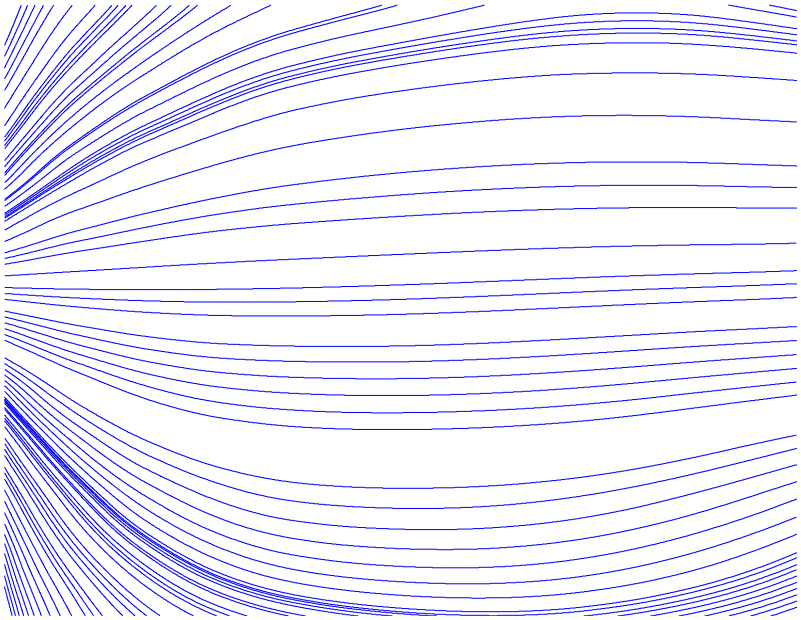

Figure A.20.2: Streamlines

Figure A.20: Vector Map and Streamlines for Cross Correlation
[IA Size: 128× 128 pixels and Overlap Percentage (H%, V%): 0%, 25%]

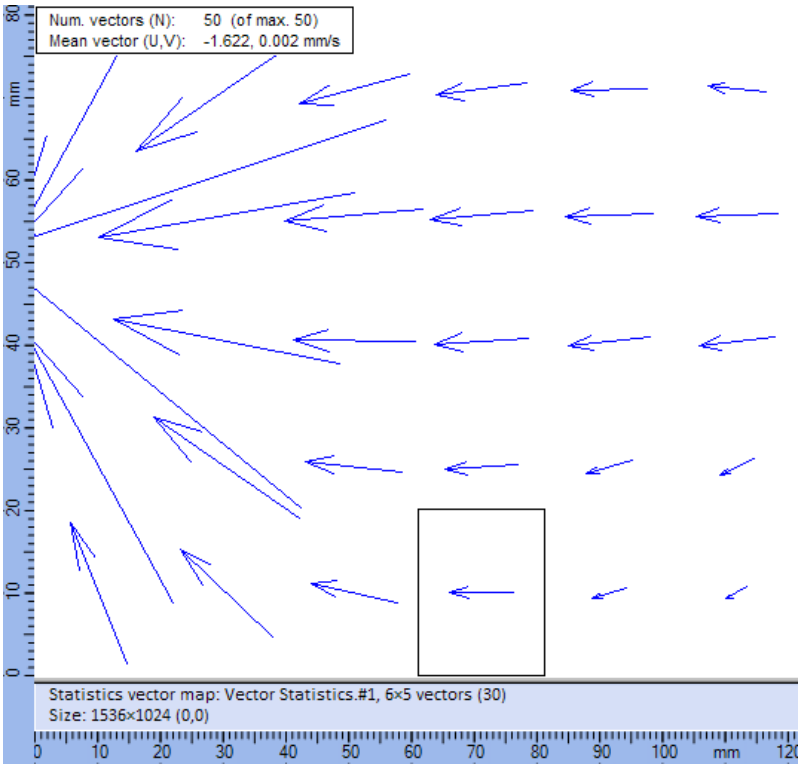

Figure A.21.1: Vector Map

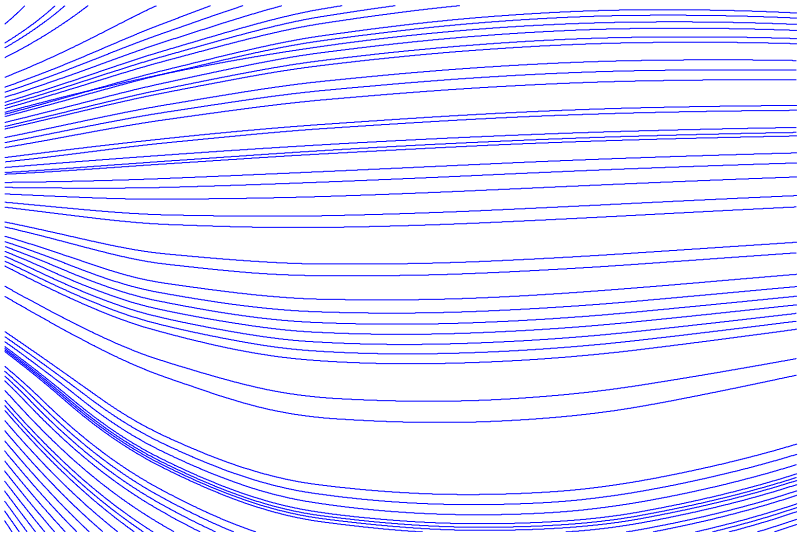

Figure A.21.2: Streamlines

Figure A.21: Vector Map and Streamlines for Cross Correlation
[IA Size: 256× 256 pixels and Overlap Percentage (H%, V%): 0%, 25%]

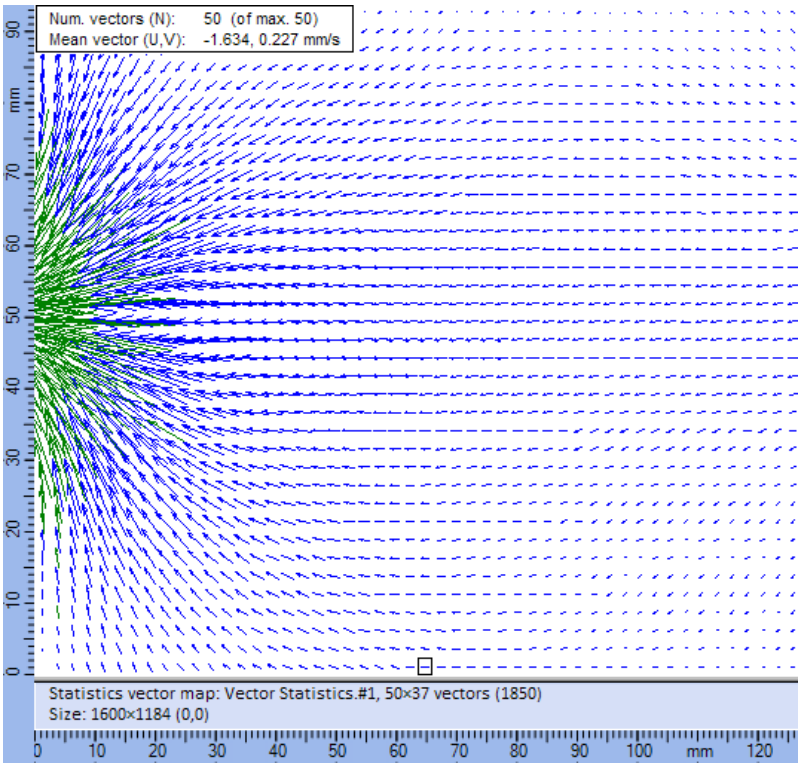

Figure A.22.1: Vector Map

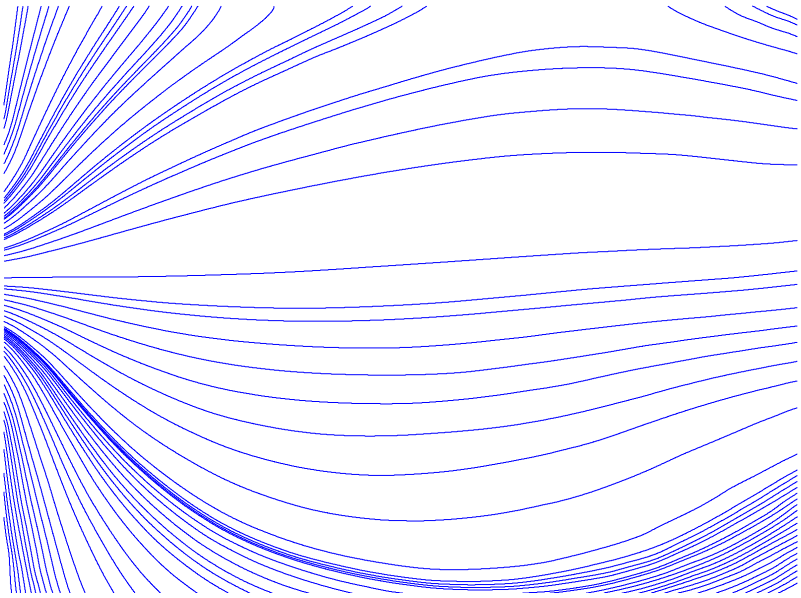

Figure A.22.2: Streamlines

Figure A.22: Vector Map and Streamlines for Adaptive Correlation
[IA Size: 32 × 32 pixels and Overlap Percentage (H%, V%): 0%, 0%]

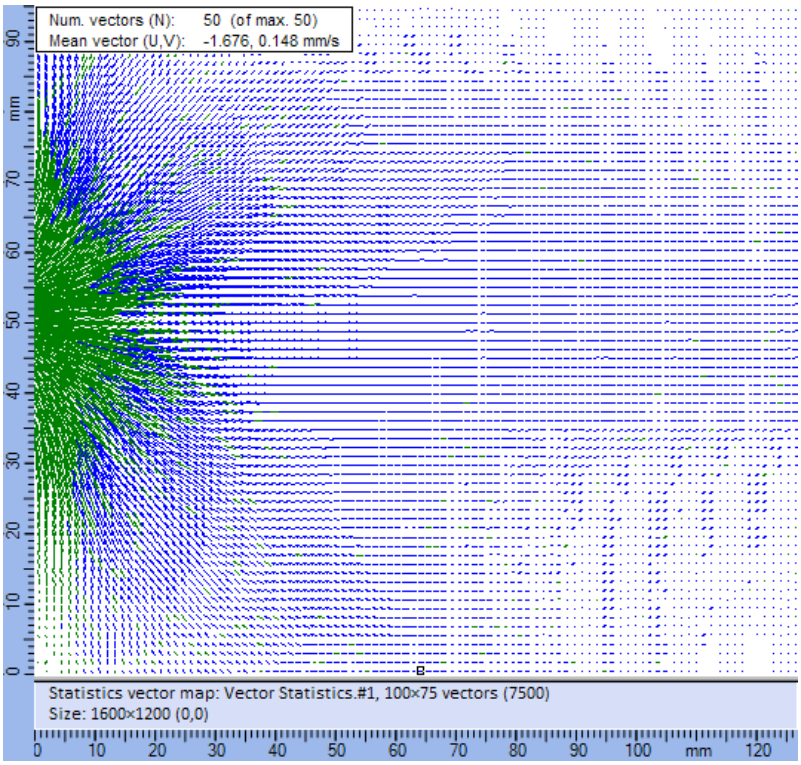

Figure A.23.1: Vector Map

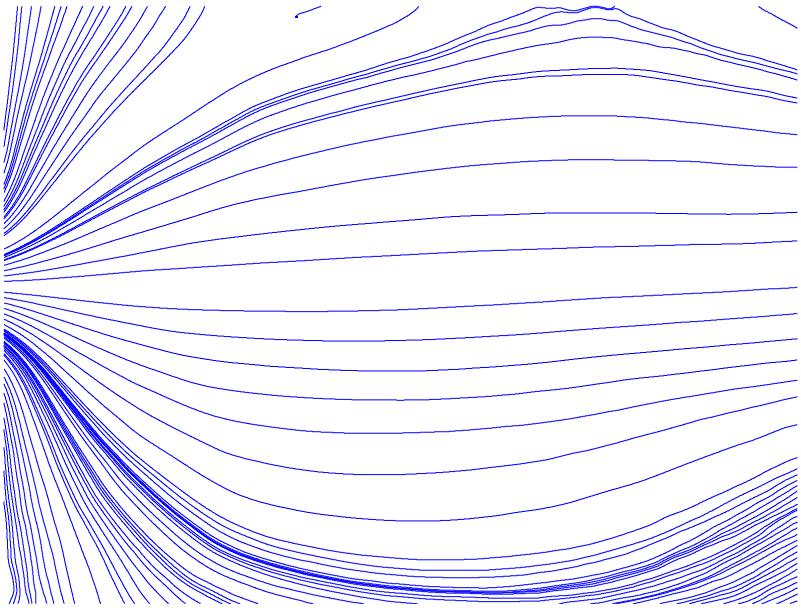

Figure A.23.2: Streamlines

Figure A.23: Vector Map and Streamlines for Adaptive Correlation [IA Size: 16× 16 pixels and Overlap Percentage (H%, V%): 0%, 0%]

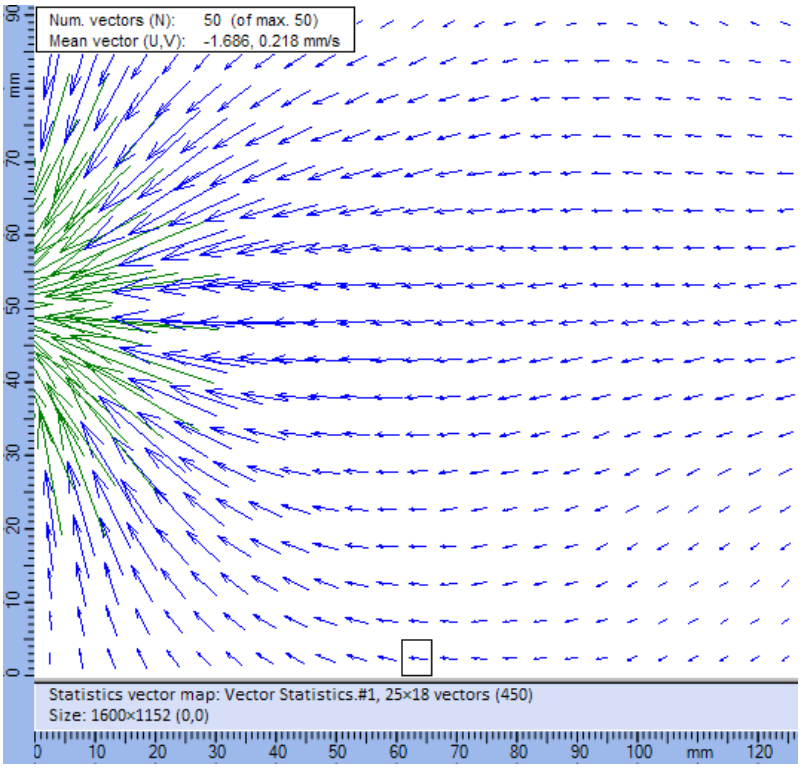

Figure A.24.1: Vector Map

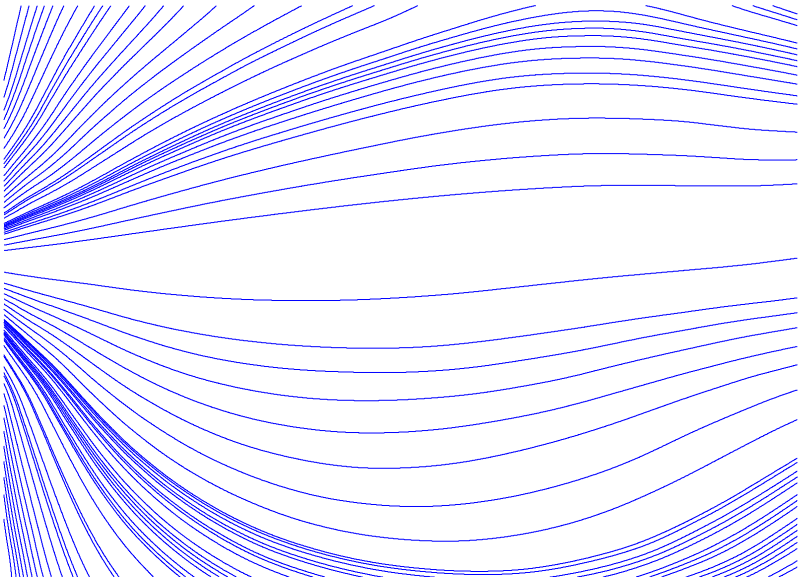

Figure A.24.2: Streamlines

Figure A.24: Vector Map and Streamlines for Adaptive Correlation [IA Size: 64× 64 pixels and Overlap Percentage (H%, V%): 0%, 0%]

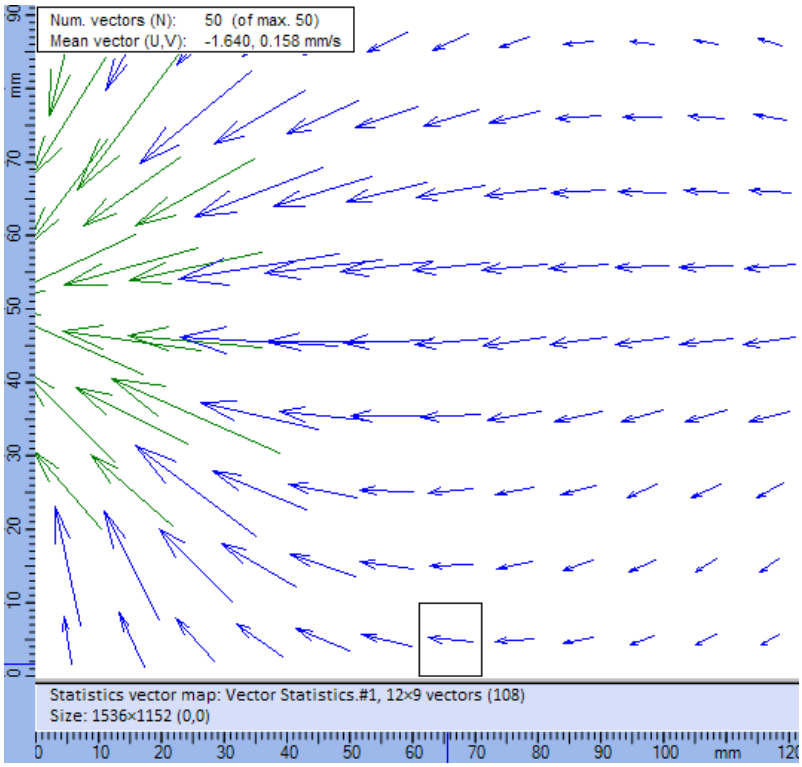

Figure A.25.1: Vector Map

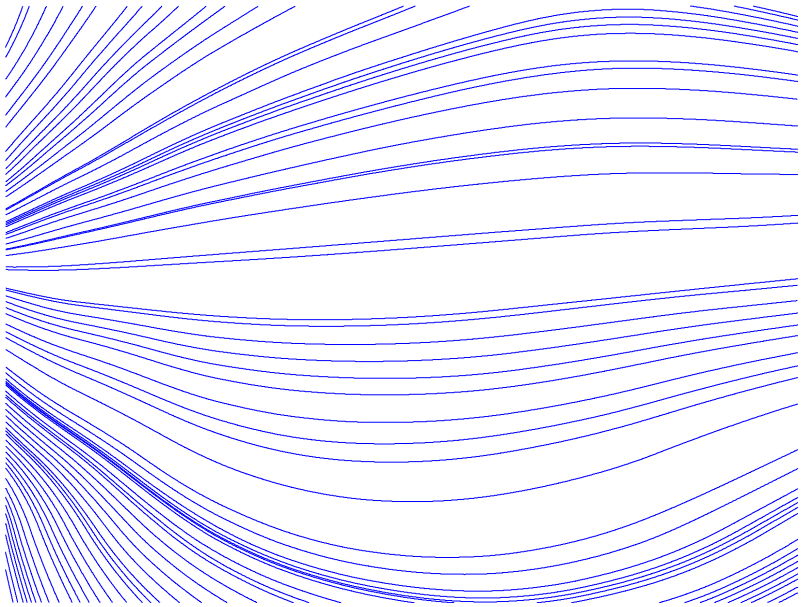

Figure A.25.2: Streamlines

Figure A.25: Vector Map and Streamlines for Adaptive Correlation
[IA Size: 128× 128 pixels and Overlap Percentage (H%, V%): 0%, 0%]

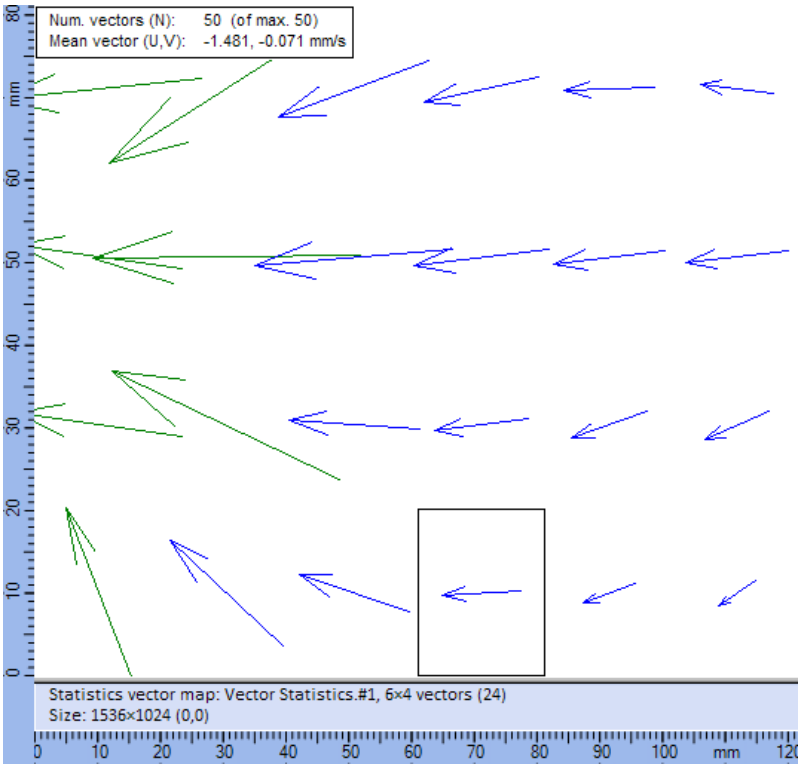

Figure A.26.1: Vector Map

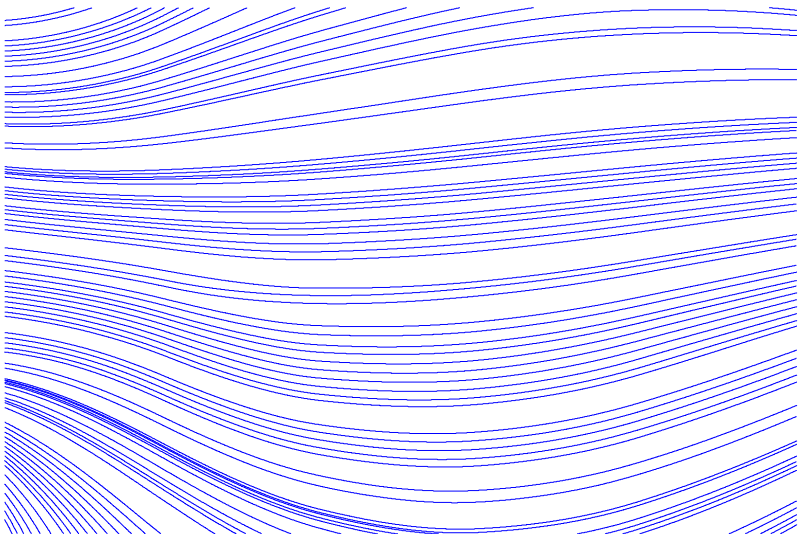

Figure A.26.2: Streamlines

Figure A.26: Vector Map and Streamlines for Adaptive Correlation
[IA Size: 256× 256 pixels and Overlap Percentage (H%, V%): 0%, 0%]

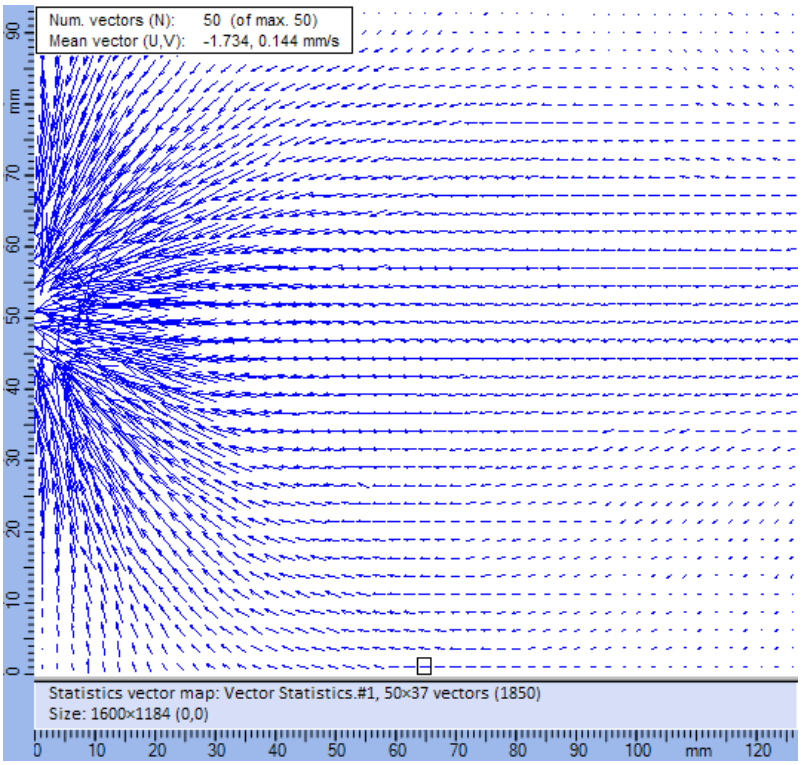

Figure A.27.1: Vector Map

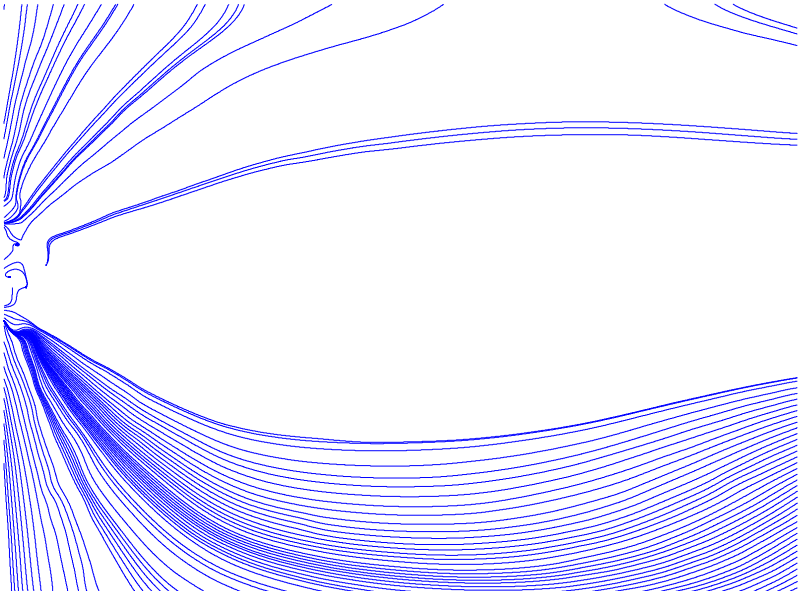

Figure A.27.2: Streamlines

Figure A.27: Vector Map and Streamlines for Cross Correlation
[IA Size: 32 × 32 pixels and Overlap Percentage (H%, V%): 0%, 0%]

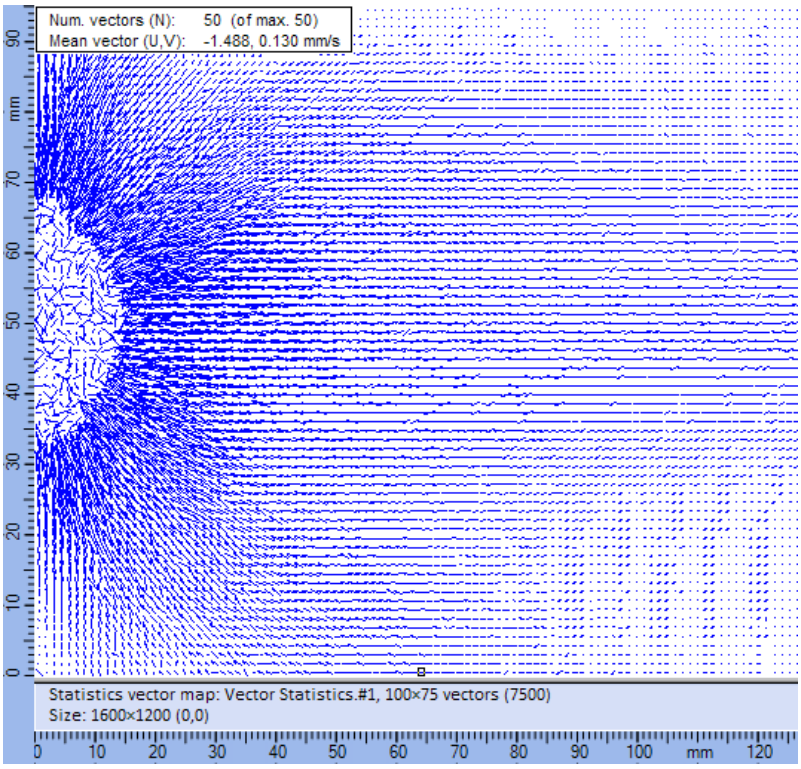

Figure A.28.1: Vector Map

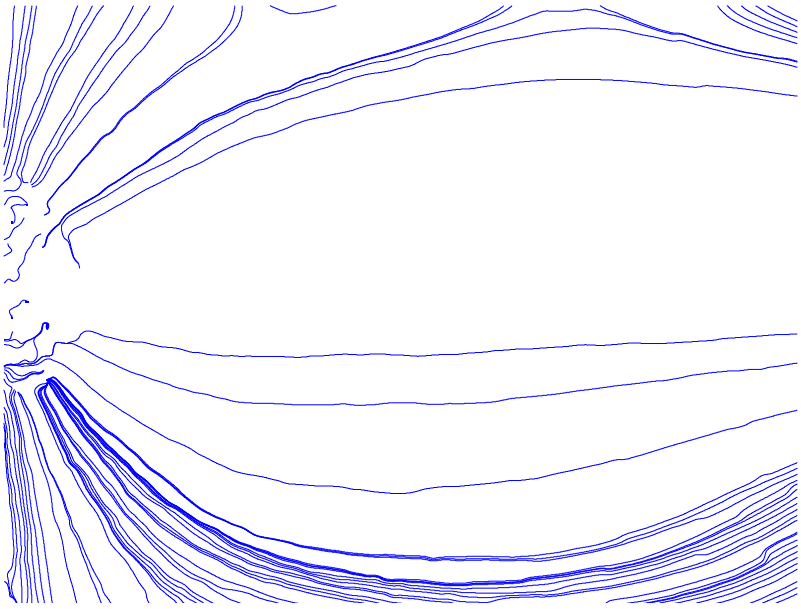

Figure A.28.2: Streamlines

Figure A.28: Vector Map and Streamlines for Cross Correlation
[IA Size: 16× 16 pixels and Overlap Percentage (H%, V%): 0%, 0%]

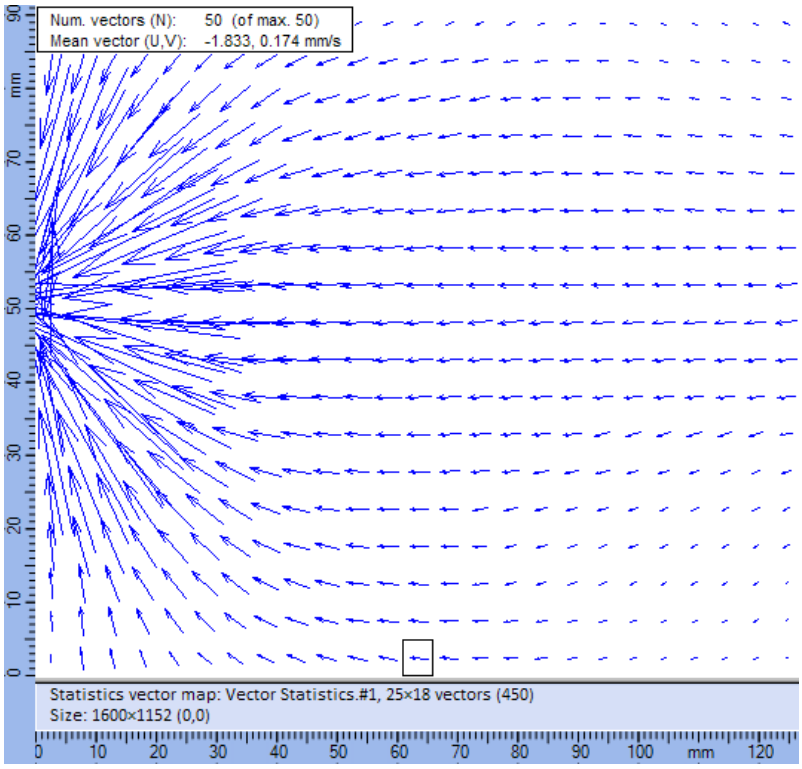

Figure A.29.1: Vector Map

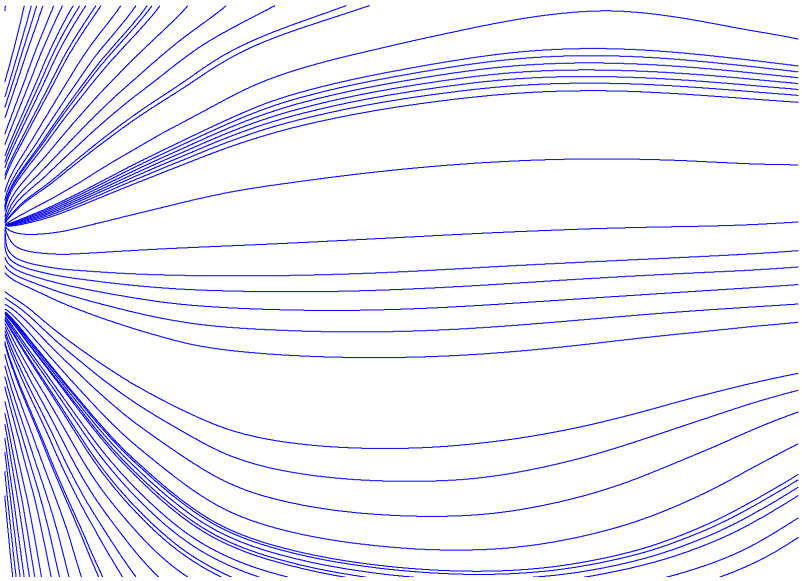

Figure A.29.2: Streamlines

Figure A.29: Vector Map and Streamlines for Cross Correlation
[IA Size: 64× 64 pixels and Overlap Percentage (H%, V%): 0%, 0%]

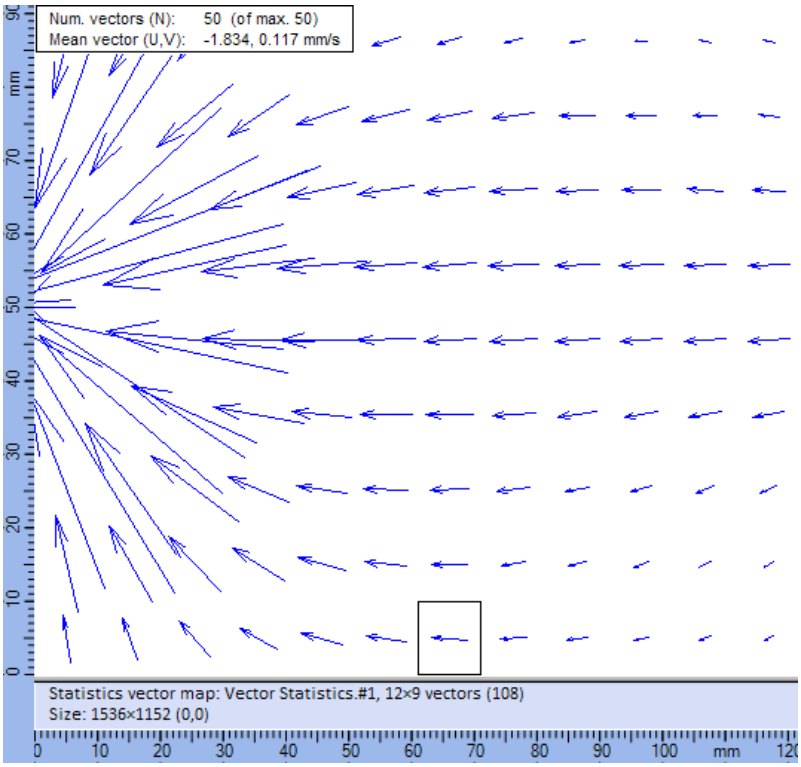

Figure A.30.1: Vector Map

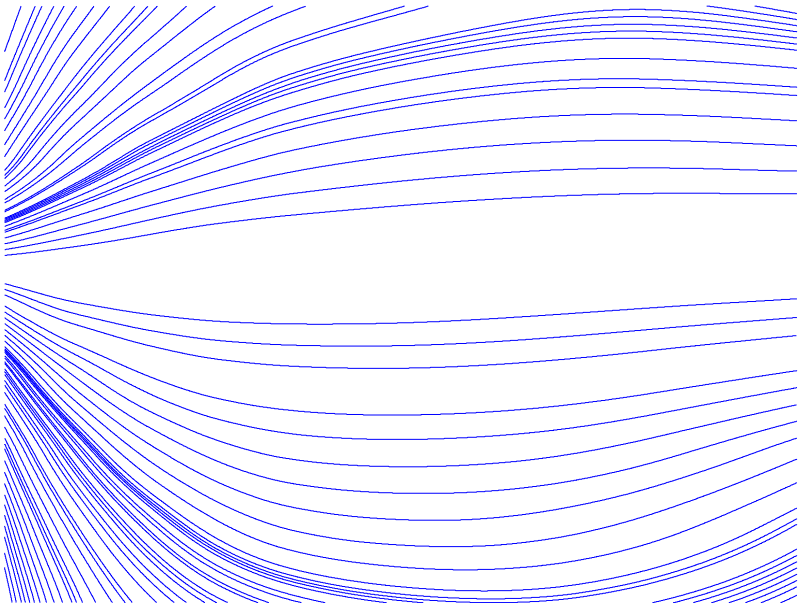

Figure A.30.2: Streamlines

Figure A.30: Vector Map and Streamlines for Cross Correlation
[IA Size: 128× 128 pixels and Overlap Percentage (H%, V%): 0%, 0%]

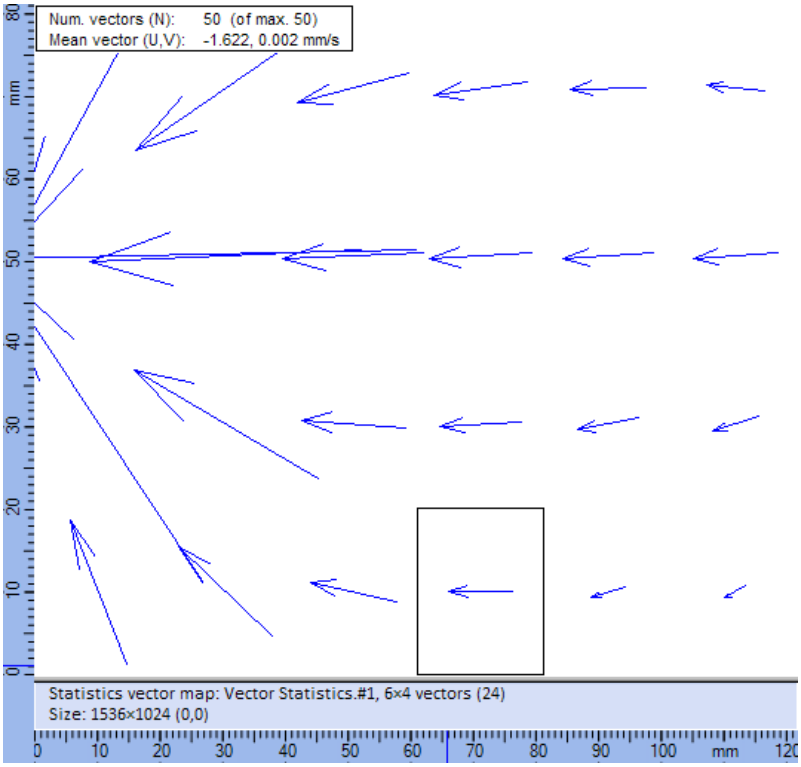

Figure A.31.1: Vector Map

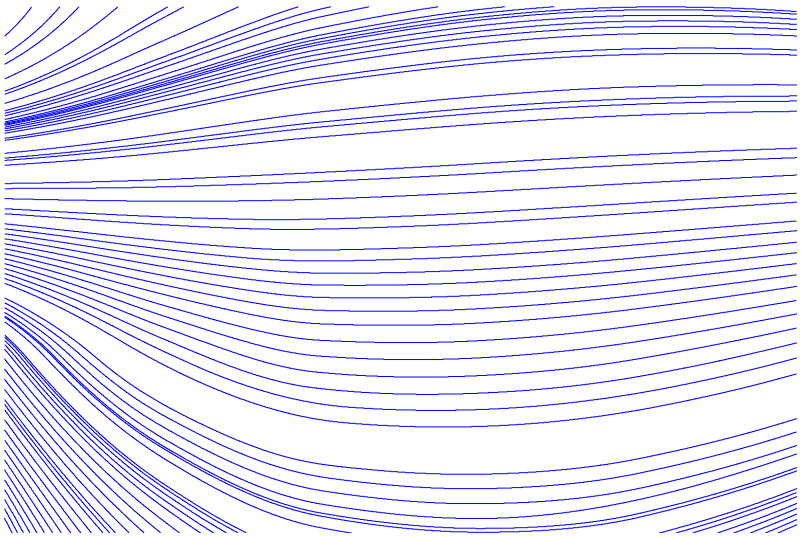

Figure A.31.2: Streamlines

Figure A.31: Vector Map and Streamlines for Cross Correlation
[IA Size: 256× 256 pixels and Overlap Percentage (H%, V%): 0%, 0%]

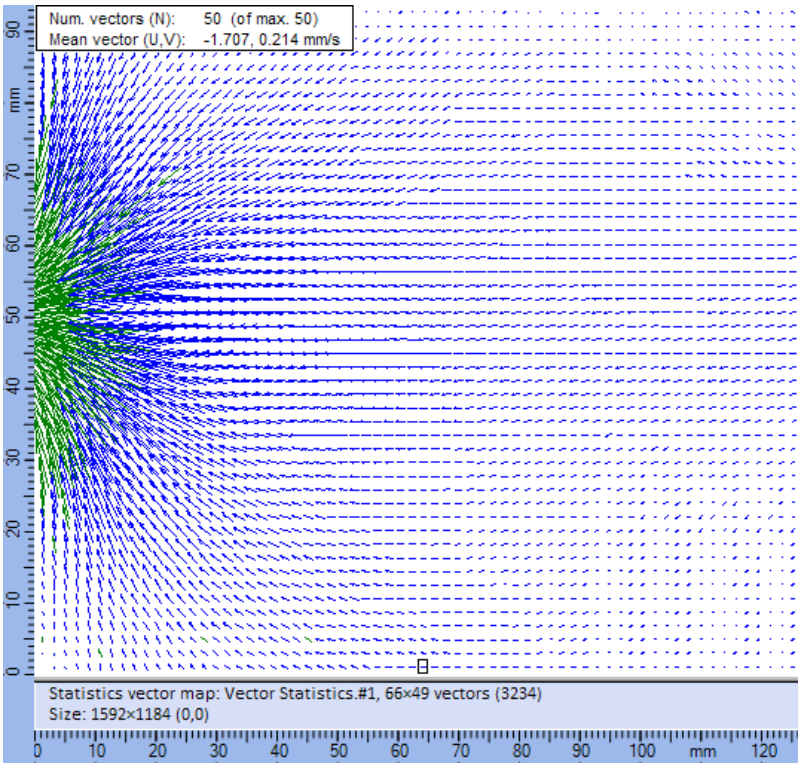

Figure A.32.1: Vector Map

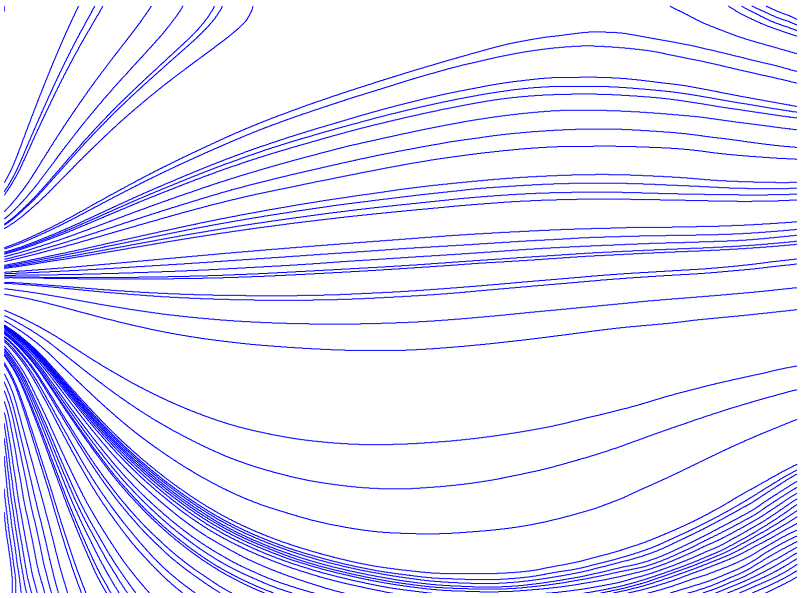

Figure A.32.2: Streamlines

Figure A.32: Vector Map and Streamlines for Adaptive Correlation
[IA Size: 32 × 32 pixels and Overlap Percentage (H%, V%): 25%, 25%]

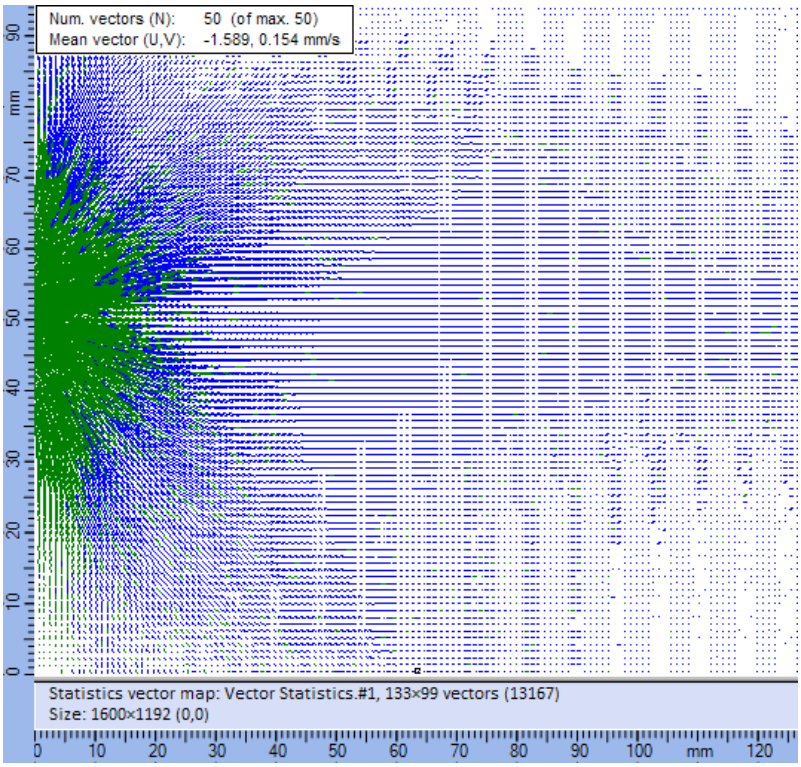

Figure A.33.1: Vector Map

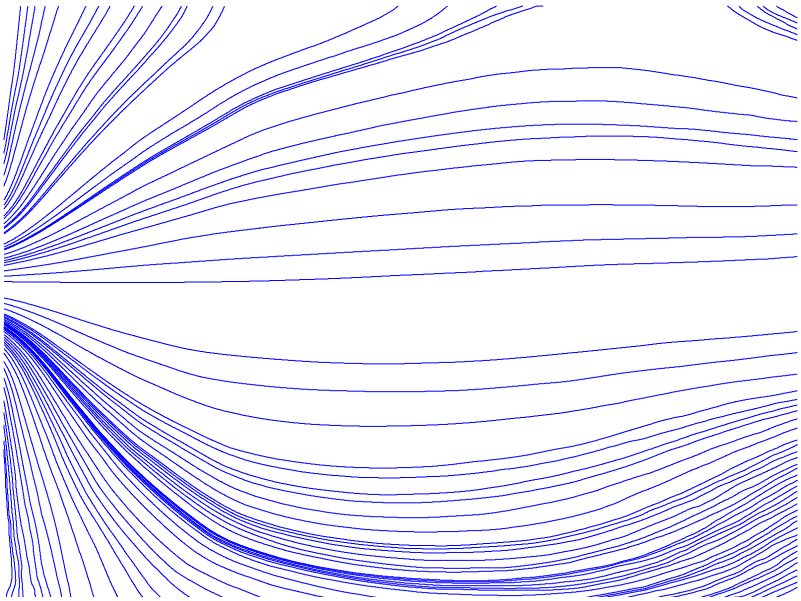

Figure A.33.2: Streamlines

Figure A.33: Vector Map and Streamlines for Adaptive Correlation
[IA Size: 16× 16 pixels and Overlap Percentage (H%, V%): 25%, 25%]

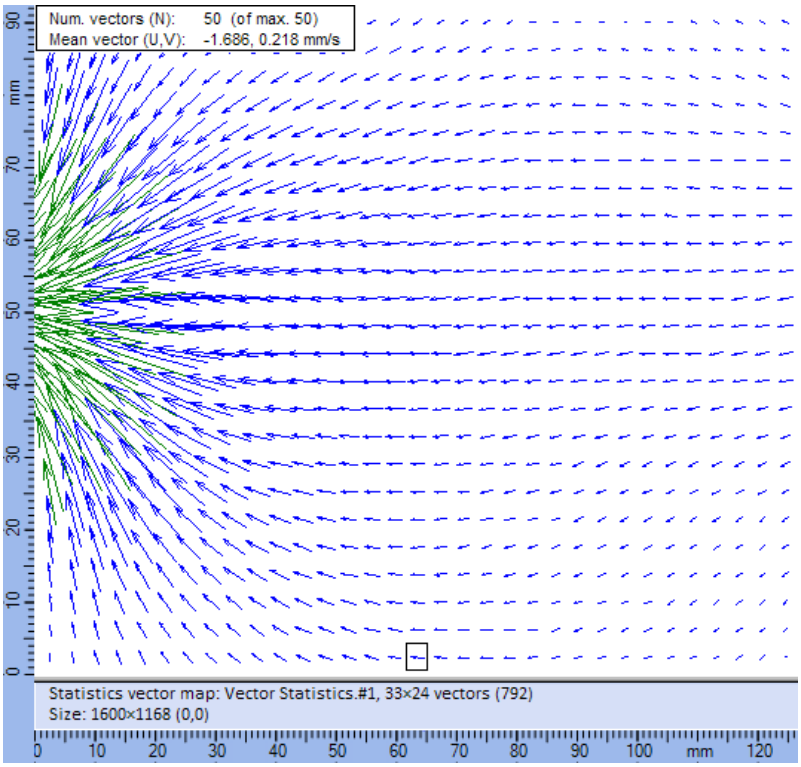

Figure A.34.1: Vector Map

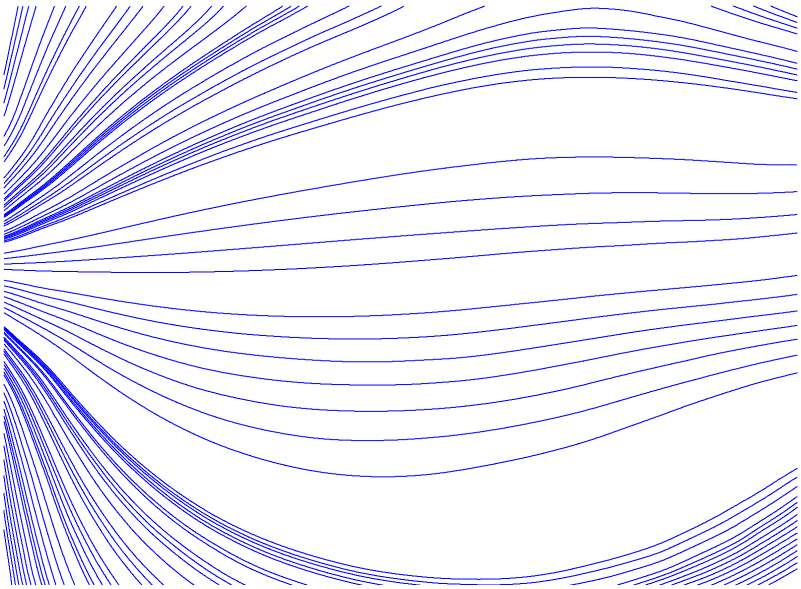

Figure A.34.2: Streamlines

Figure A.34: Vector Map and Streamlines for Adaptive Correlation
[IA Size: 64× 64 pixels and Overlap Percentage (H%, V%): 25%, 25%]

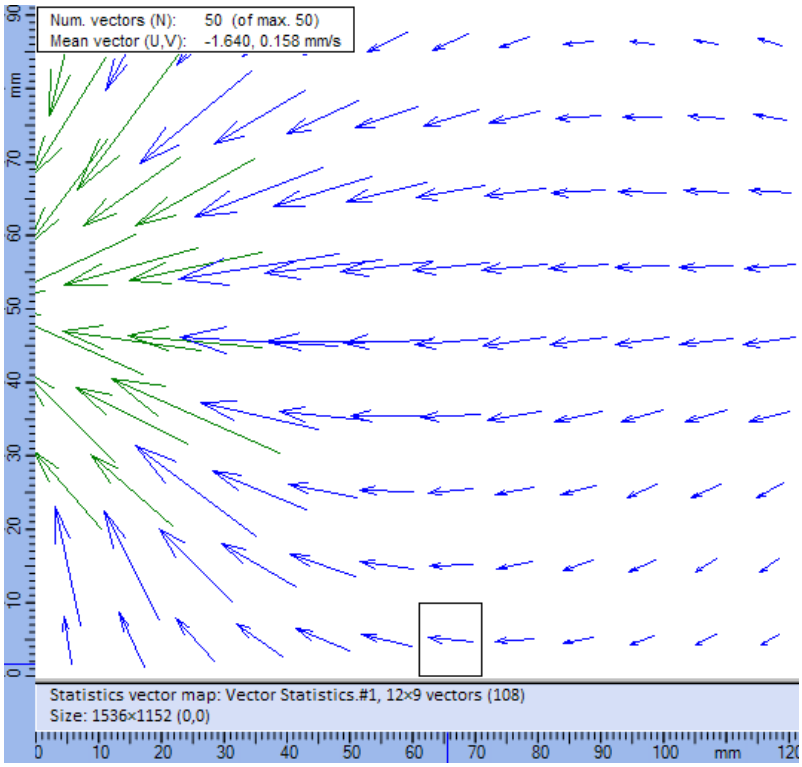

Figure A.35.1: Vector Map

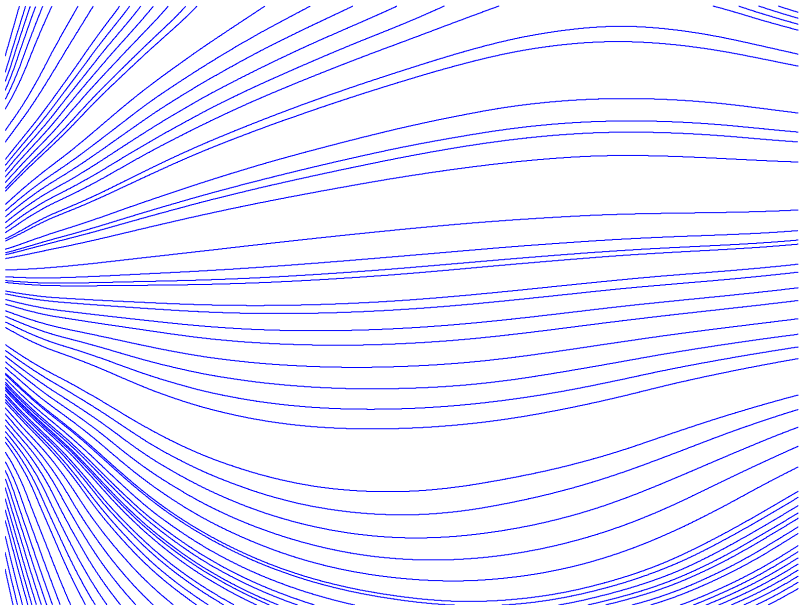

Figure A.35.2: Streamlines

Figure A.35: Vector Map and Streamlines for Adaptive Correlation
[IA Size: 128× 128 pixels and Overlap Percentage (H%, V%): 25%, 25%]

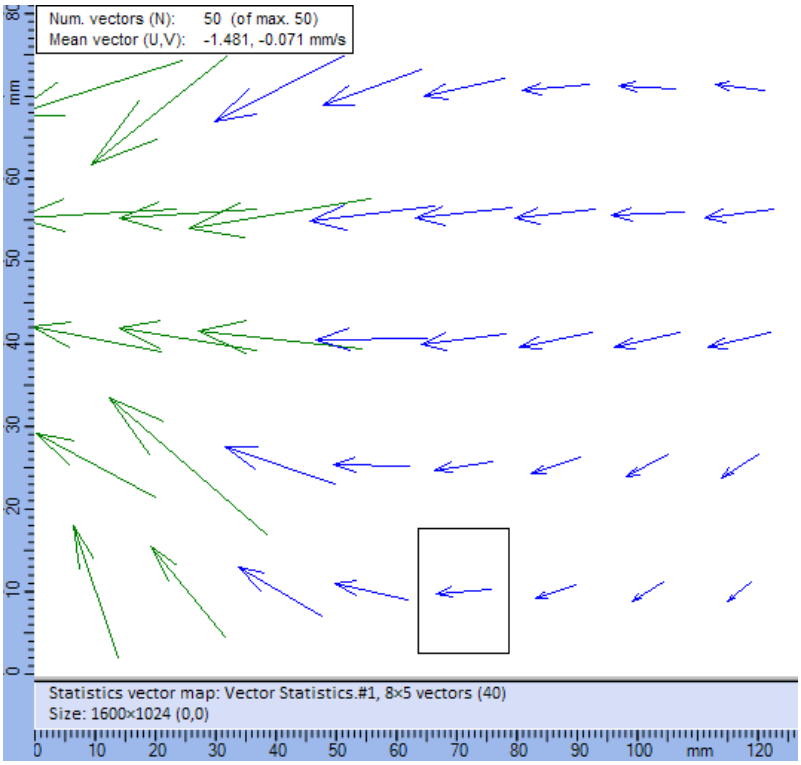

Figure A.36.1: Vector Map

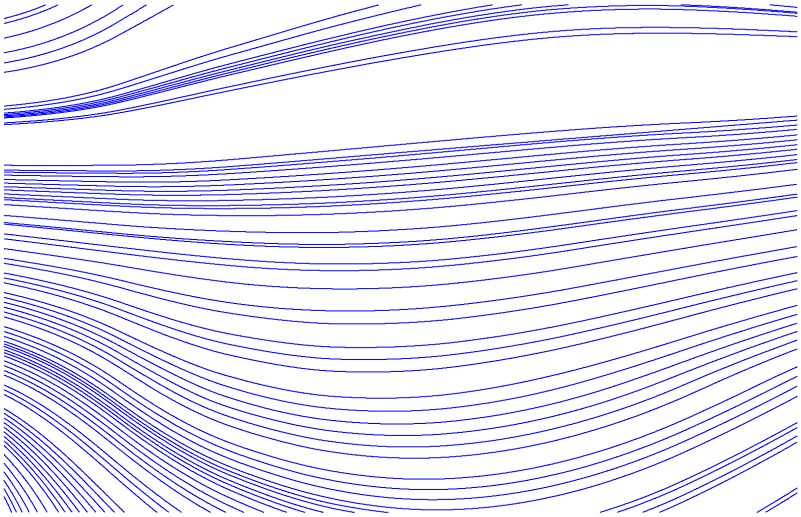

Figure A.36.2: Streamlines

Figure A.36: Vector Map and Streamlines for Adaptive Correlation
[IA Size: 256× 256 pixels and Overlap Percentage (H%, V%): 25%, 25%]

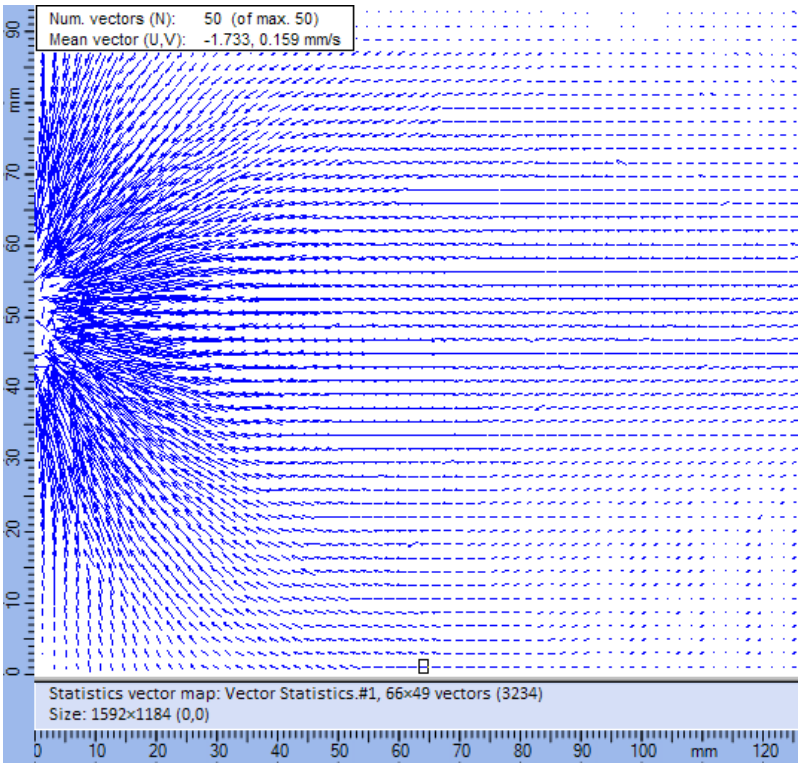

Figure A.37.1: Vector Map

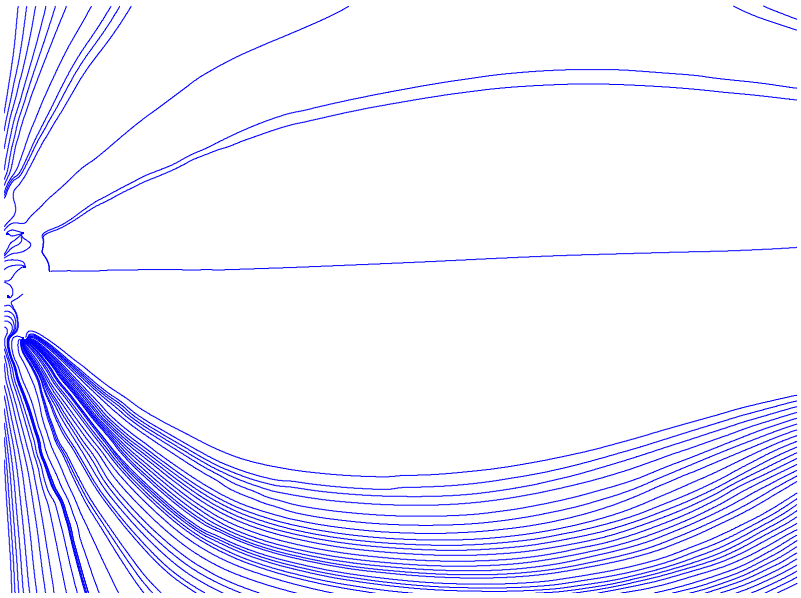

Figure A.37.2: Streamlines

Figure A.37: Vector Map and Streamlines for Cross Correlation
[IA Size: 32 × 32 pixels and Overlap Percentage (H%, V%): 25%, 25%]

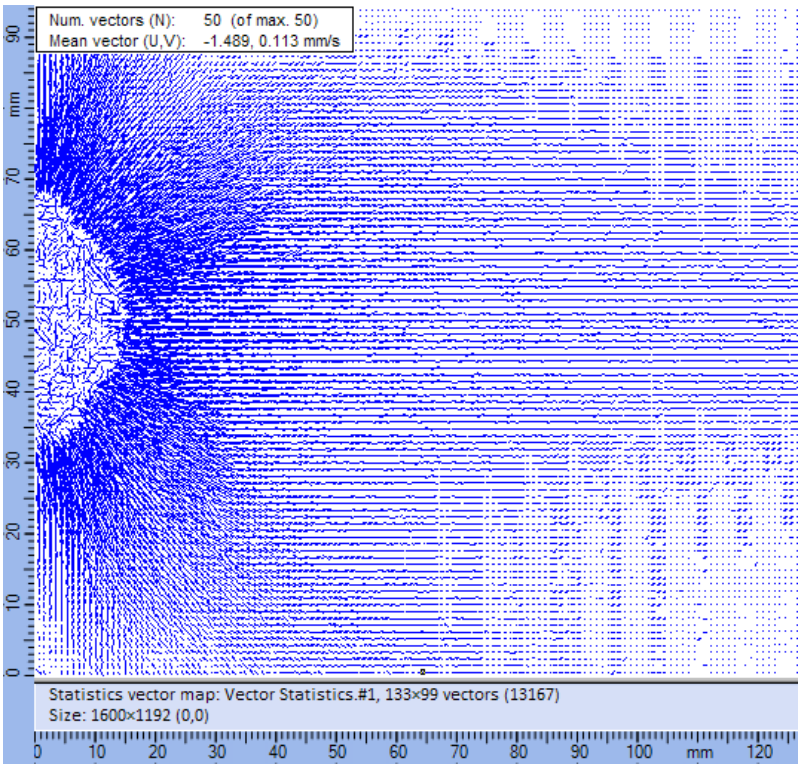

Figure A.38.1: Vector Map

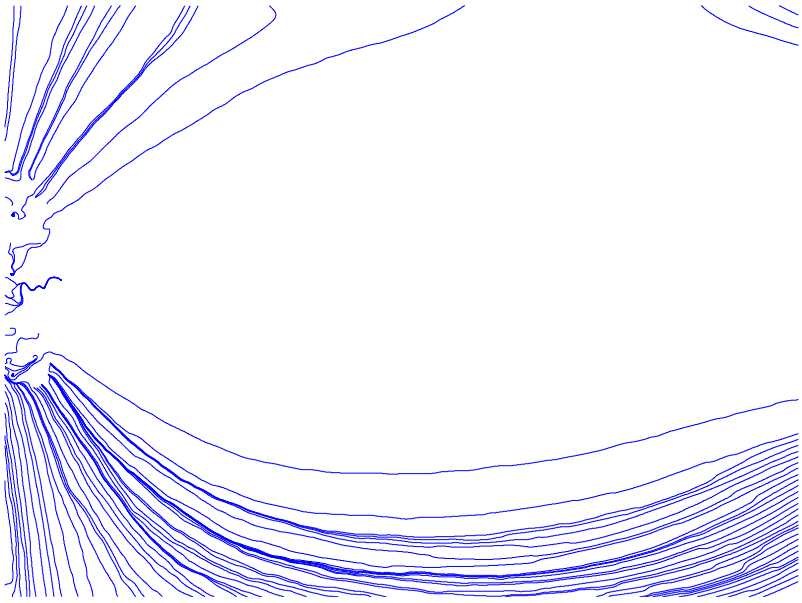

Figure A.38.2: Streamlines

Figure A.38: Vector Map and Streamlines for Cross Correlation
[IA Size: 16× 16 pixels and Overlap Percentage (H%, V%): 25%, 25%]

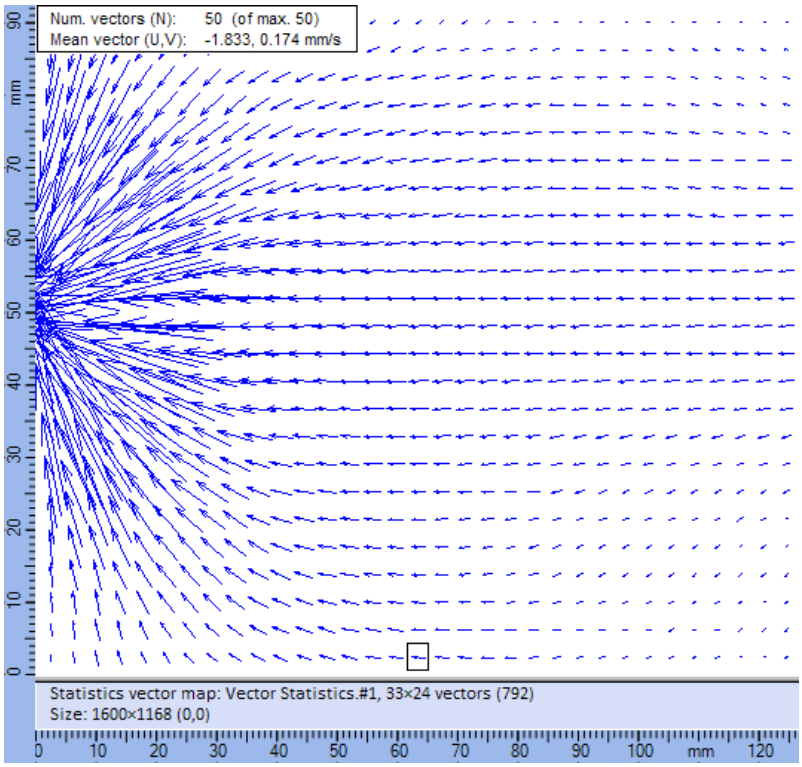

Figure A.39.1: Vector Map

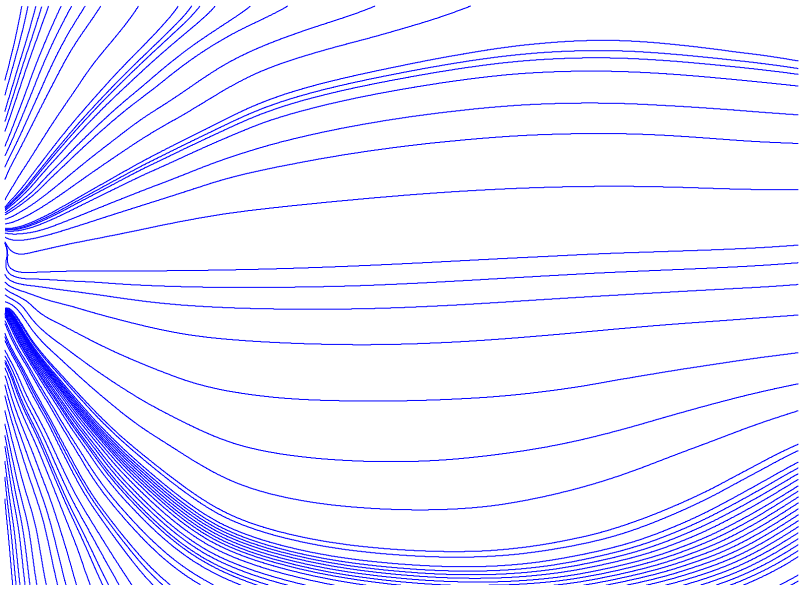

Figure A.39.2: Streamlines

Figure A.39: Vector Map and Streamlines for Cross Correlation
[IA Size: 64× 64 pixels and Overlap Percentage (H%, V%): 25%, 25%]

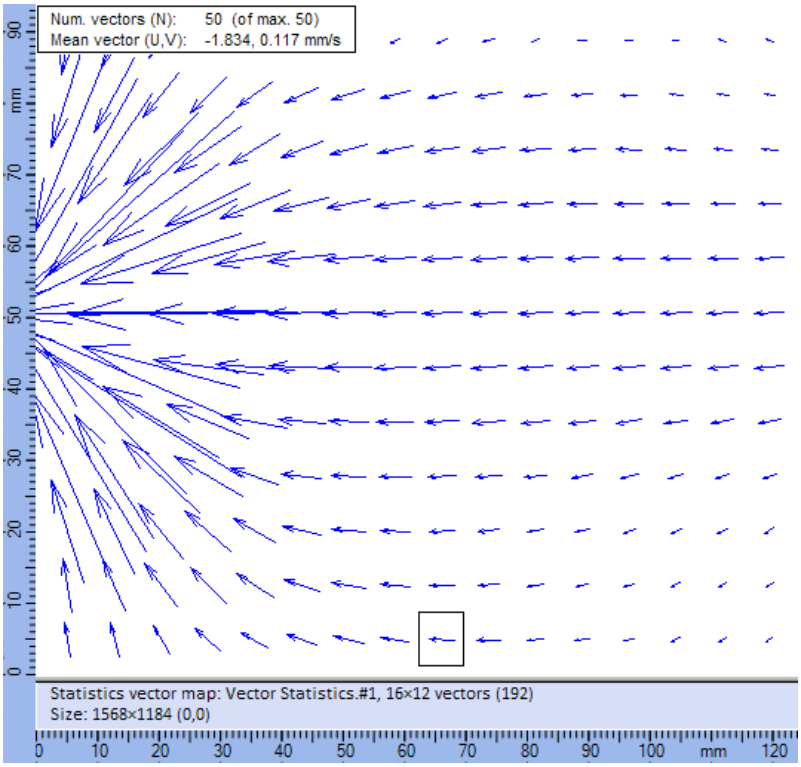

Figure A.40.1: Vector Map

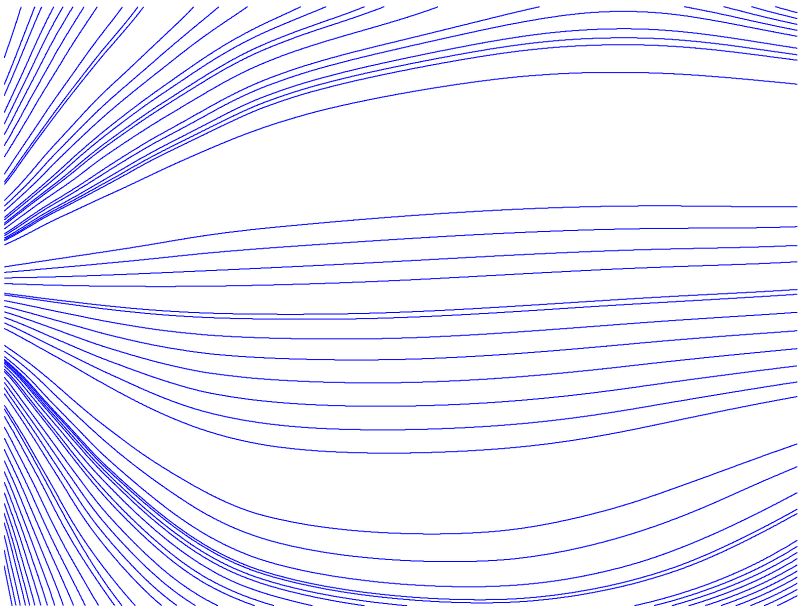

Figure A.40.2: Streamlines

Figure A.40: Vector Map and Streamlines for Cross Correlation
[IA Size: 128× 128 pixels and Overlap Percentage (H%, V%): 25%, 25%]

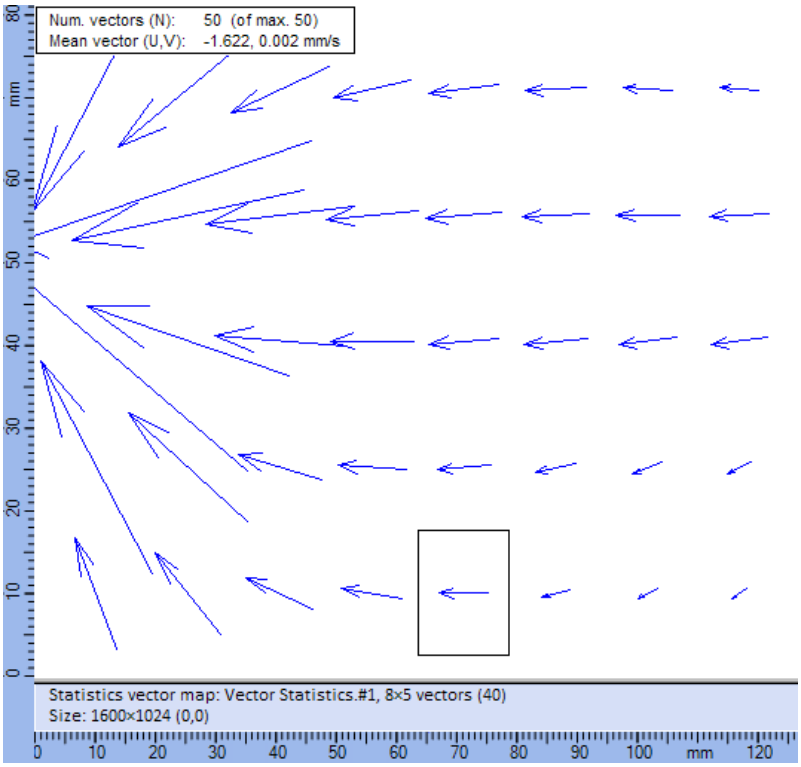

Figure A.41.1: Vector Map

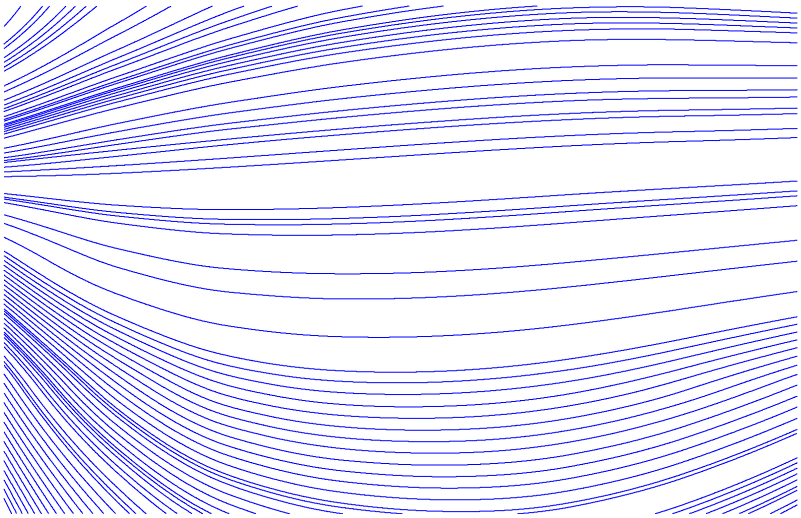

Figure A.41.2: Streamlines

Figure A.41: Vector Map and Streamlines for Cross Correlation
[IA Size: 256× 256 pixels and Overlap Percentage (H%, V%): 25%, 25%]

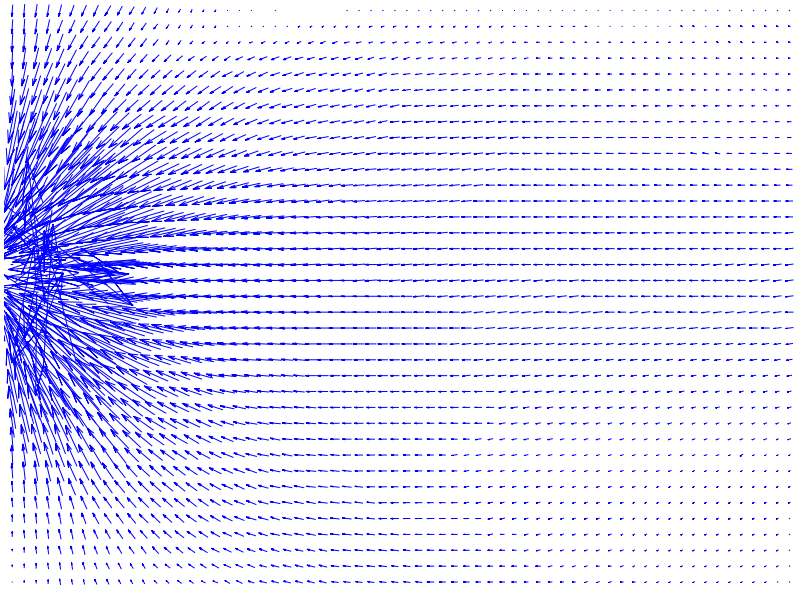

Figure A.42.1: Vector Map

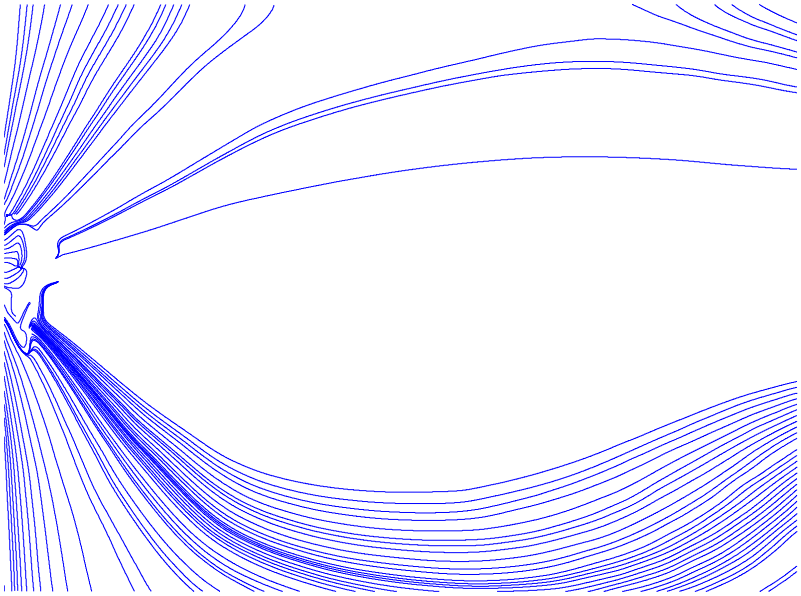

Figure A.42.2: Streamlines

Figure A.42: Vector Map and Streamlines for Average Correlation
[IA Size: 32 × 32 pixels and Overlap Percentage (H%, V%): 25%, 0%]

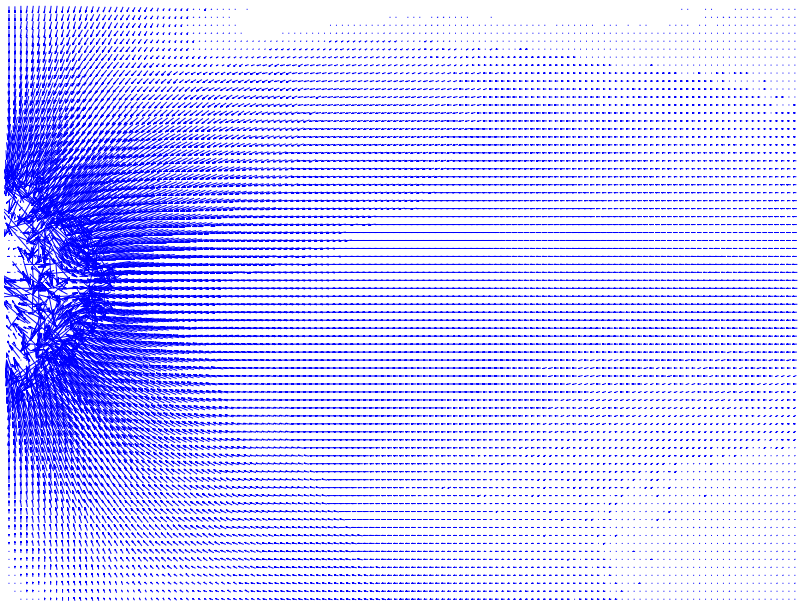

Figure A.43.1: Vector Map

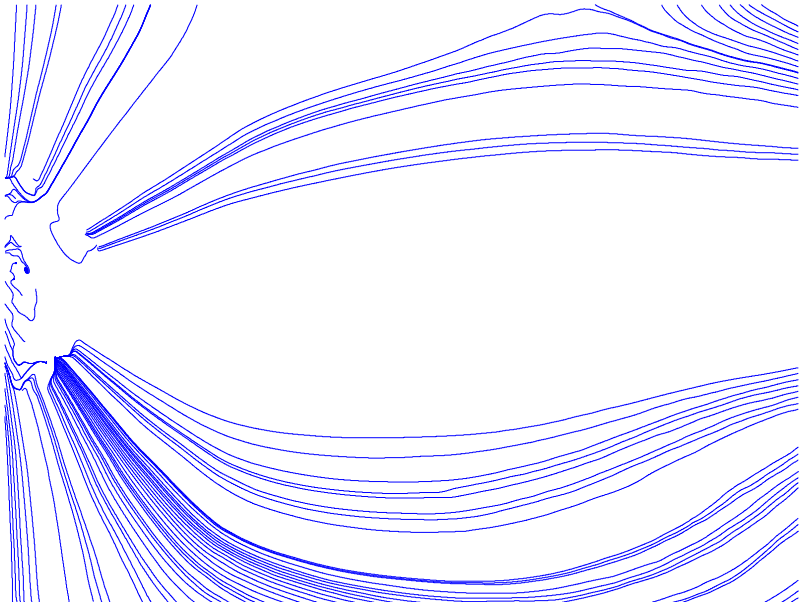

Figure A.43.2: Streamlines

Figure A.43: Vector Map and Streamlines for Average Correlation
[IA Size: 16× 16 pixels and Overlap Percentage (H%, V%): 25%, 0%]

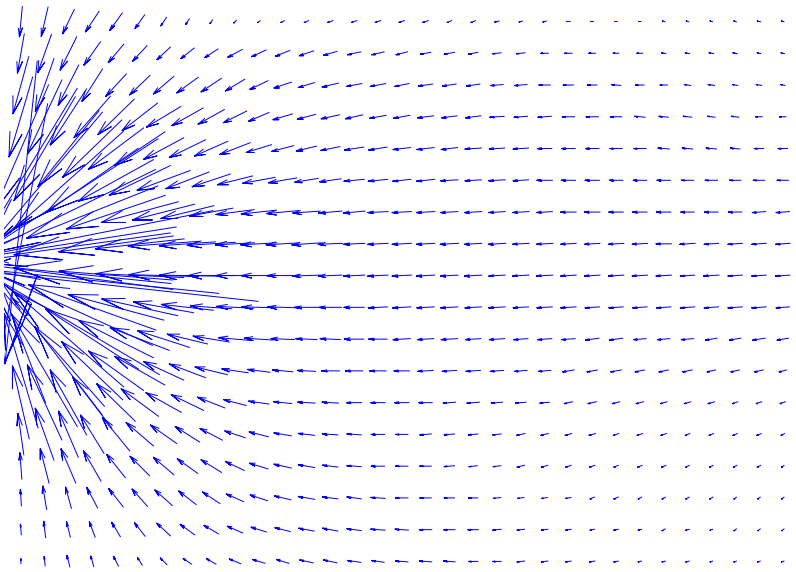

Figure A.44.1: Vector Map

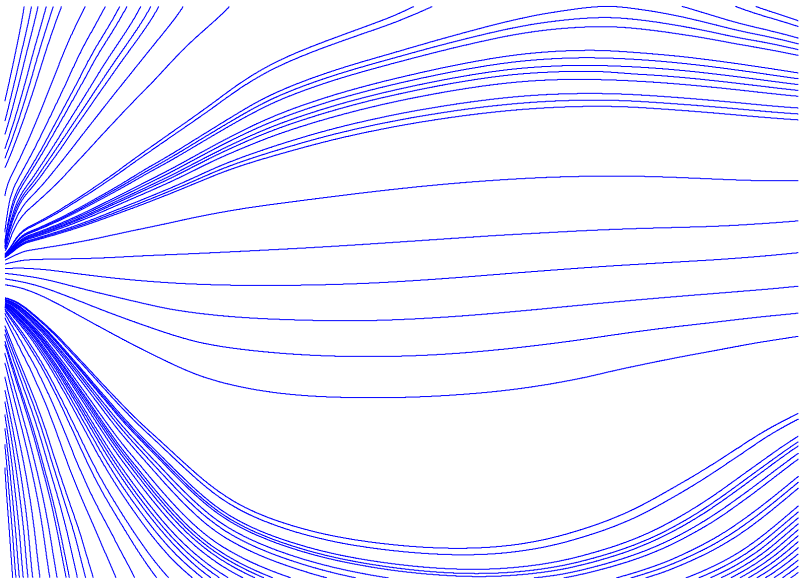

Figure A.44.2: Streamlines

Figure A.44: Vector Map and Streamlines for Average Correlation
[IA Size: 64× 64 pixels and Overlap Percentage (H%, V%): 25%, 0%]

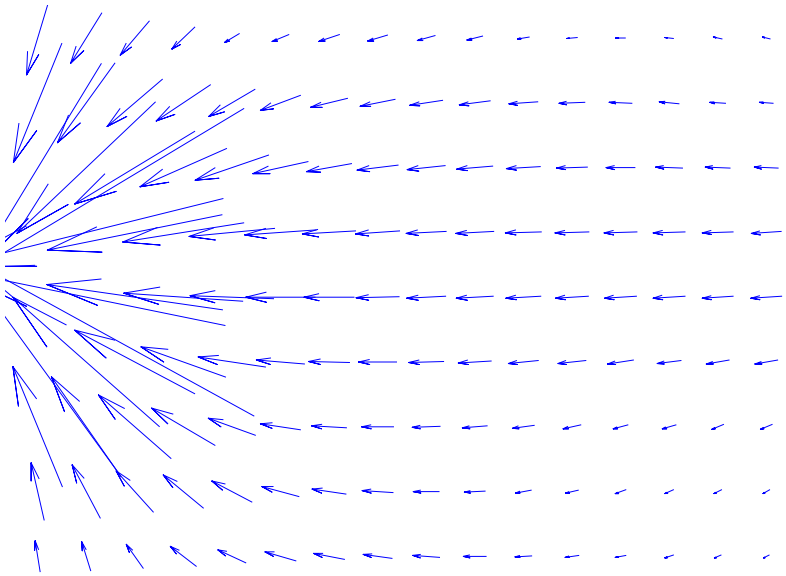

Figure A.45.1: Vector Map

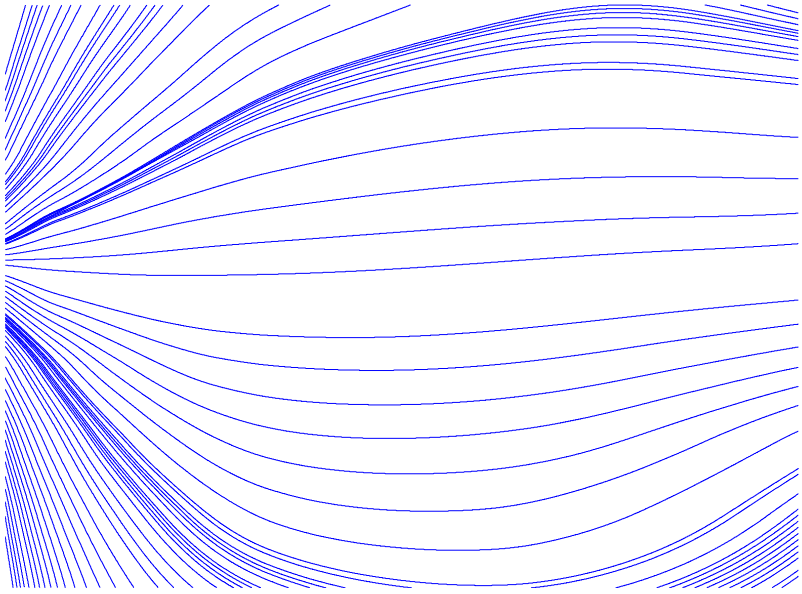

Figure A.45.2: Streamlines

Figure A.45: Vector Map and Streamlines for Average Correlation
[IA Size: 128× 128 pixels and Overlap Percentage (H%, V%): 25%, 0%]

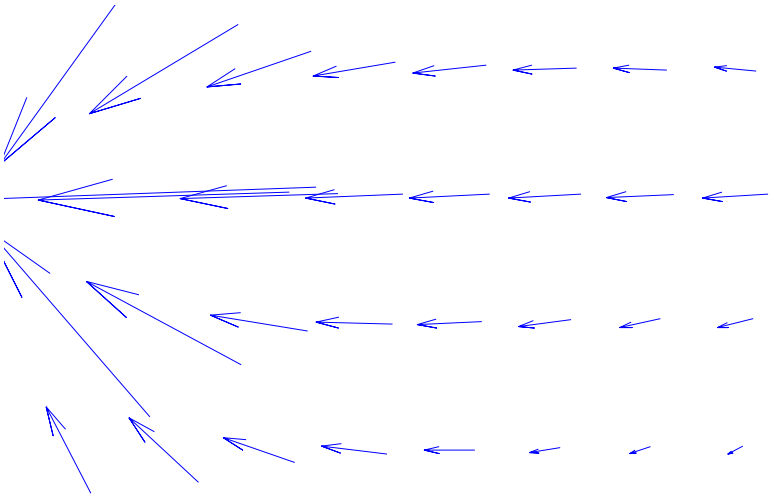

Figure A.46.1: Vector Map

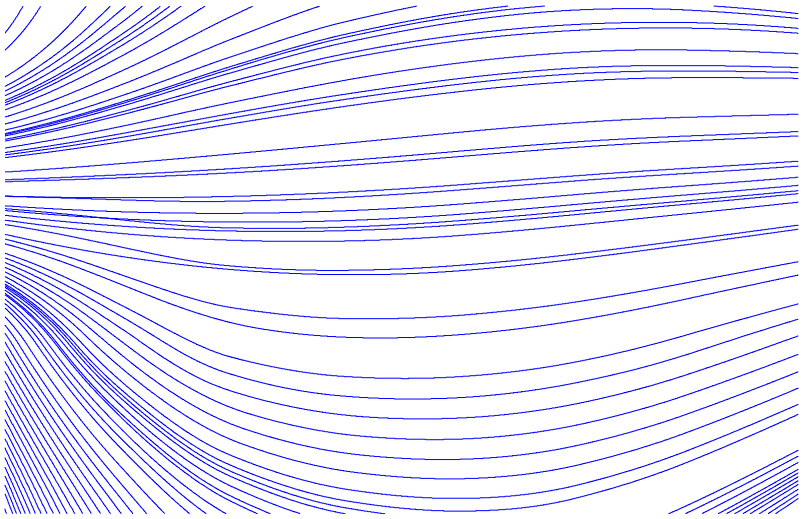

Figure A.46.2: Streamlines

Figure A.46: Vector Map and Streamlines for Average Correlation
[IA Size: 256× 256 pixels and Overlap Percentage (H%, V%): 25%, 0%]

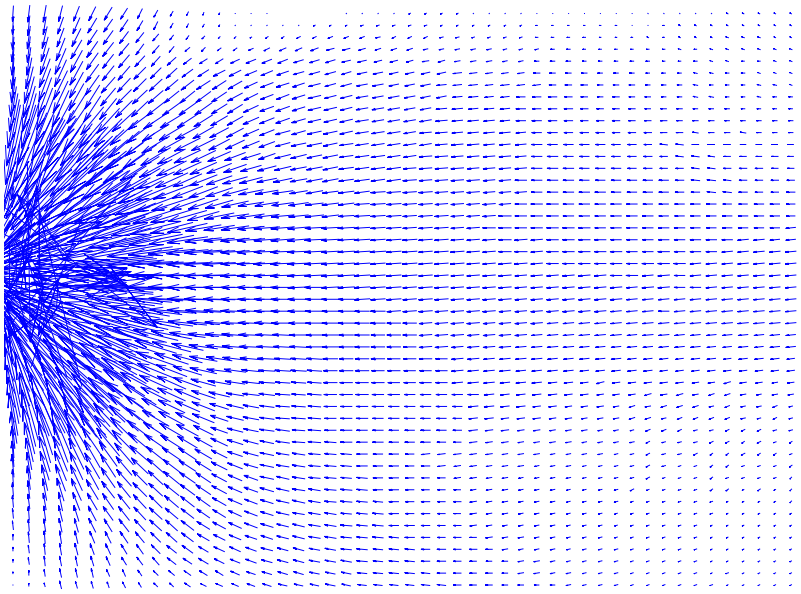

Figure A.47.1: Vector Map

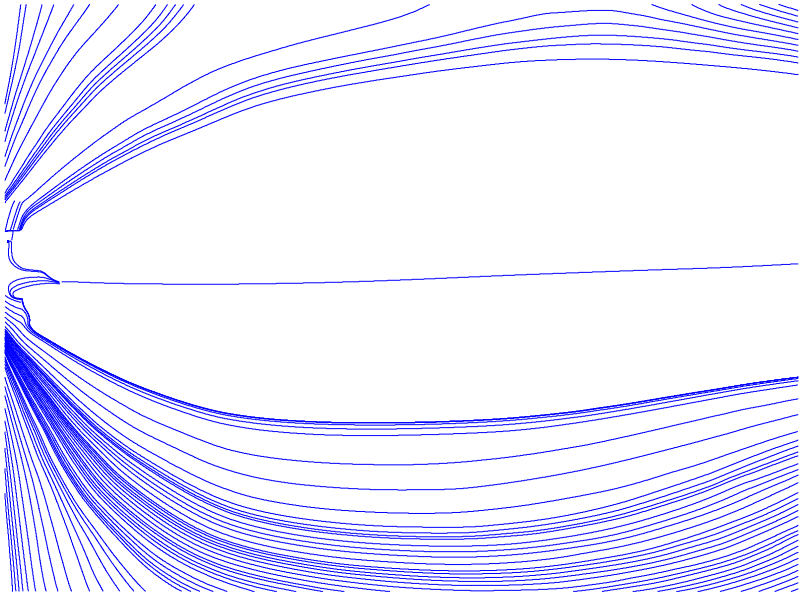

Figure A.47.2: Streamlines

Figure A.47: Vector Map and Streamlines for Average Correlation
[IA Size: 32×32 pixels and Overlap Percentage (H%, V%): 0%, 25%]

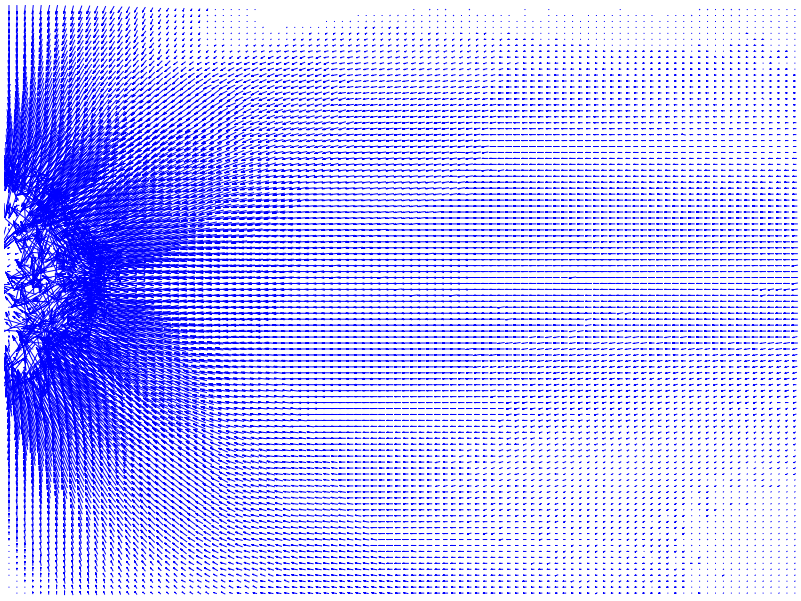

Figure A.48.1: Vector Map

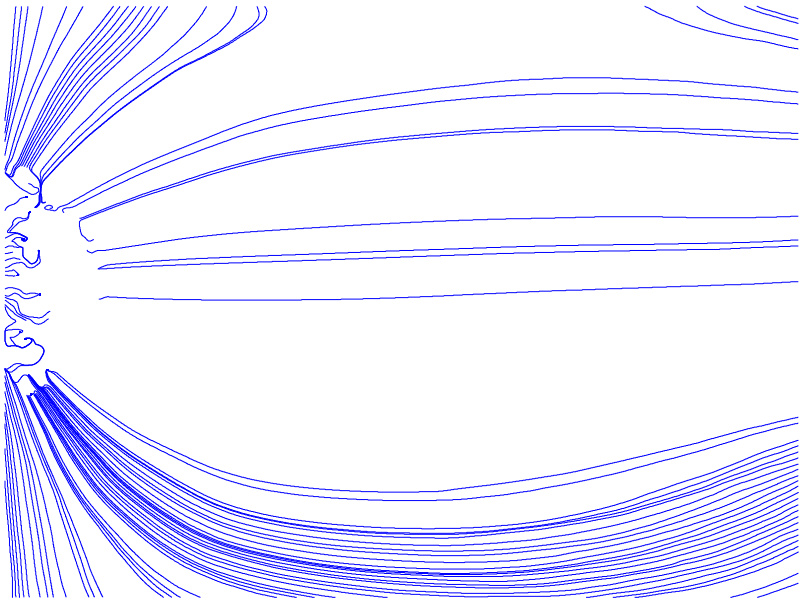

Figure A.48.2: Streamlines

Figure A.48: Vector Map and Streamlines for Average Correlation
[IA Size: 16× 16 pixels and Overlap Percentage (H%, V%): 0%, 25%]

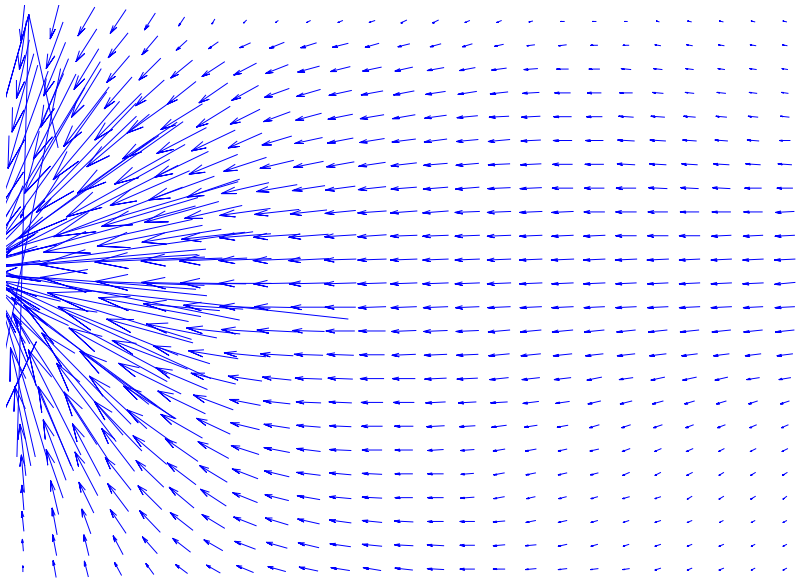

Figure A.49.1: Vector Map

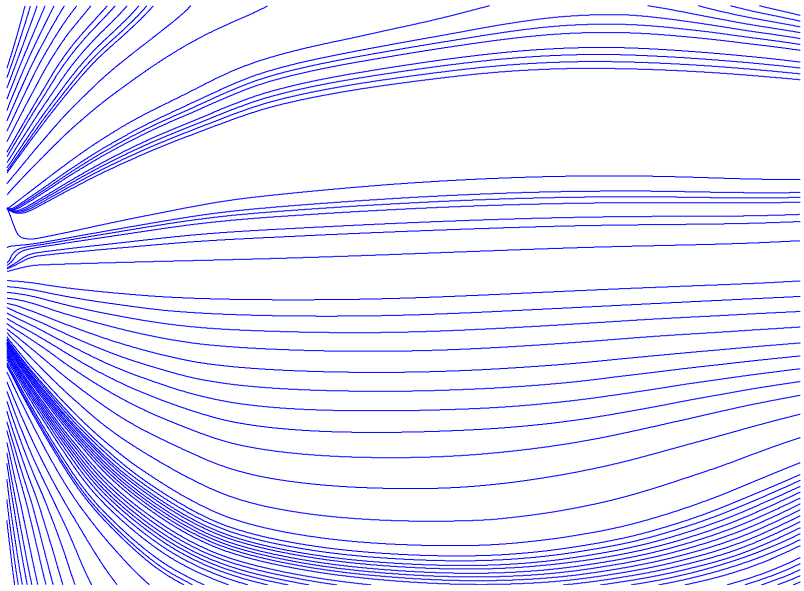

Figure A.49.2: Streamlines

Figure A.49: Vector Map and Streamlines for Average Correlation
[IA Size: 64 × 64 pixels and Overlap Percentage (H%, V%): 0%, 25%]

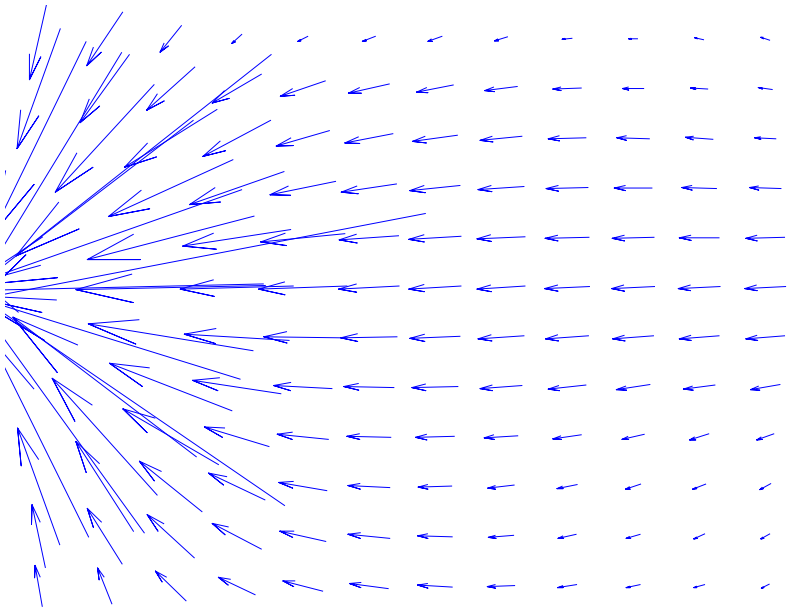

Figure A.50.1: Vector Map

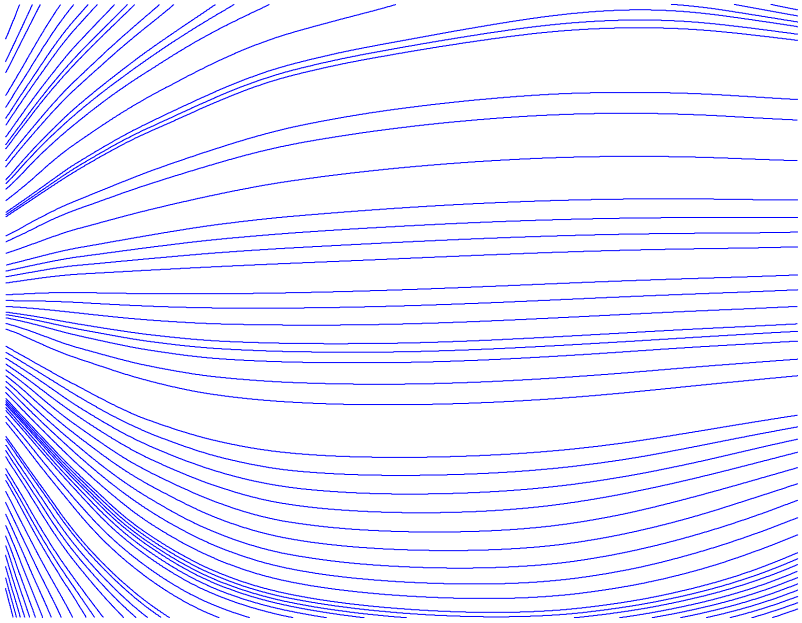

Figure A.50.2: Streamlines

Figure A.50: Vector Map and Streamlines for Average Correlation
[IA Size: 128× 128 pixels and Overlap Percentage (H%, V%): 0%, 25%]

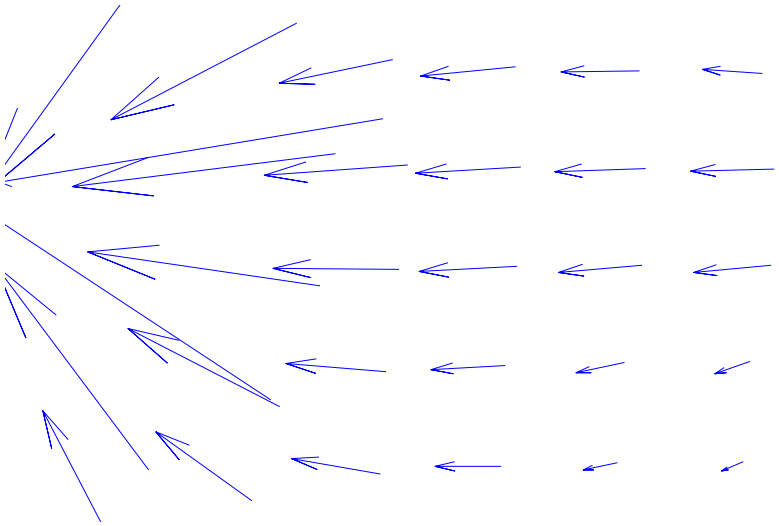

Figure A.51.1: Vector Map

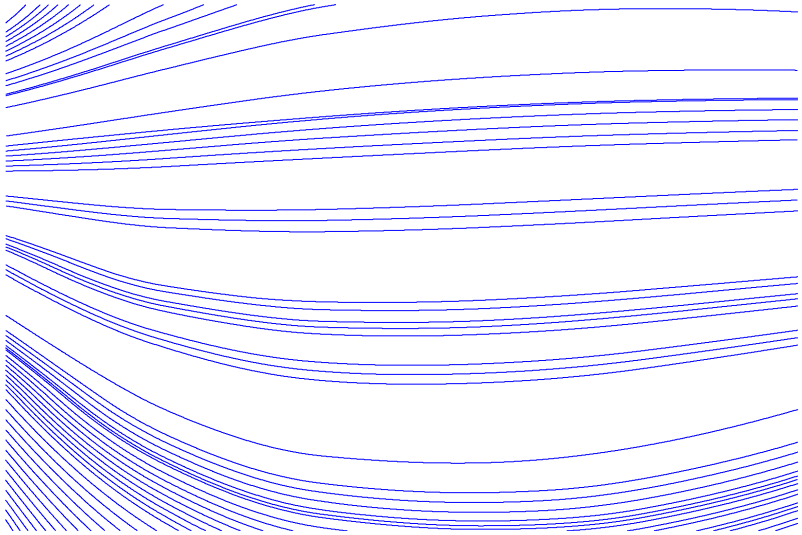

Figure A.51.2: Streamlines

Figure A.51: Vector Map and Streamlines for Average Correlation
[IA Size: 256× 256 pixels and Overlap Percentage (H%, V%): 0%, 25%]

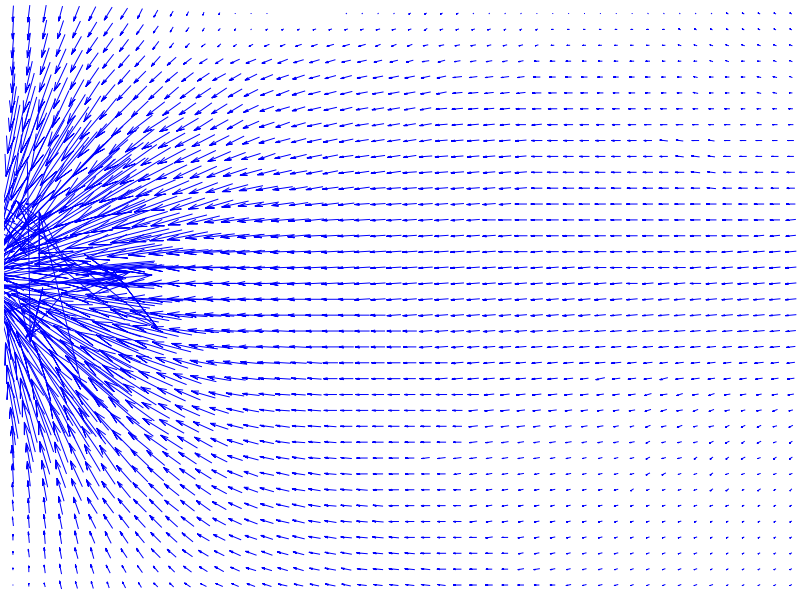

Figure A.52.1: Vector Map

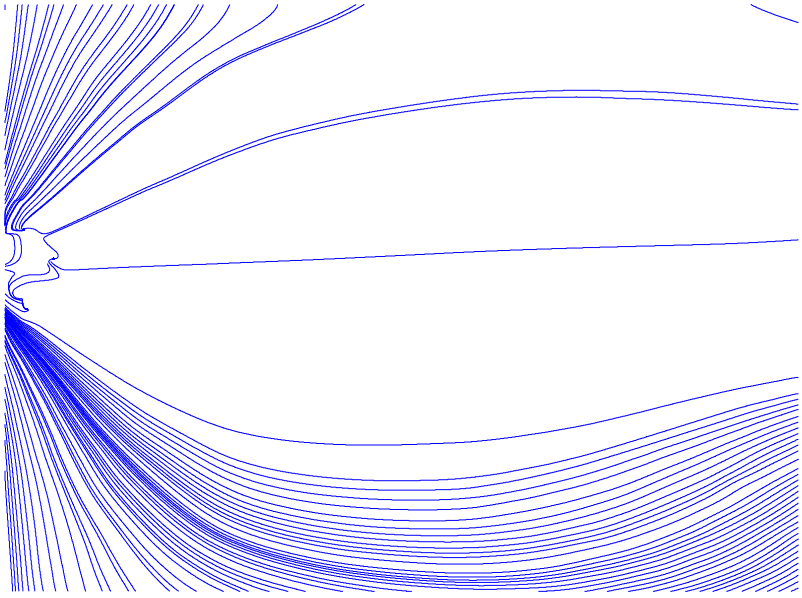

Figure A.52.2: Streamlines

Figure A.52: Vector Map and Streamlines for Average Correlation
[IA Size: 32 × 32 pixels and Overlap Percentage (H%, V%): 0%, 0%]

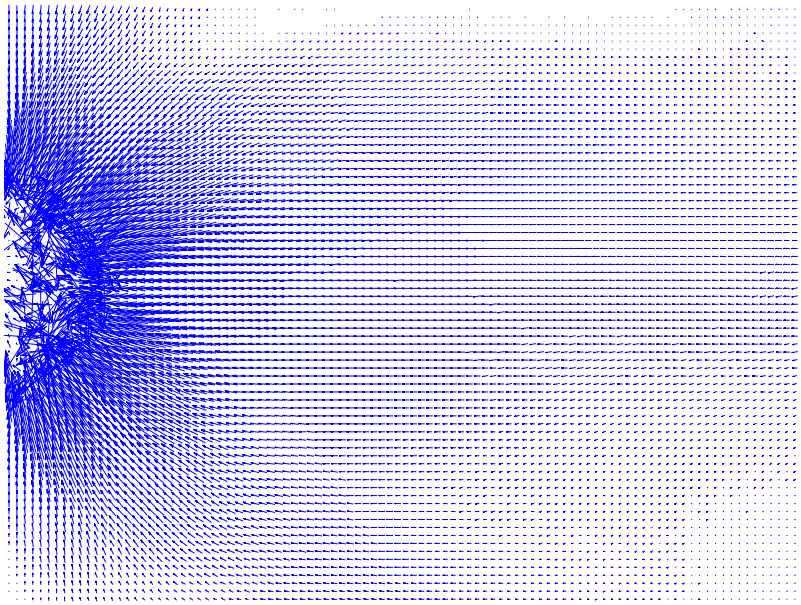

Figure A.53.1: Vector Map

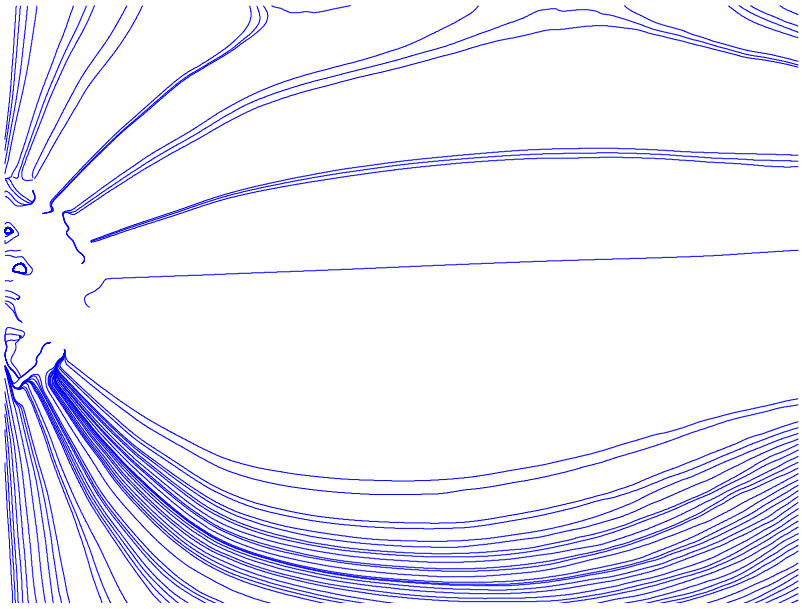

Figure A.53.2: Streamlines

Figure A.53: Vector Map and Streamlines for Average Correlation
[IA Size: 16× 16 pixels and Overlap Percentage (H%, V%): 0%, 0%]

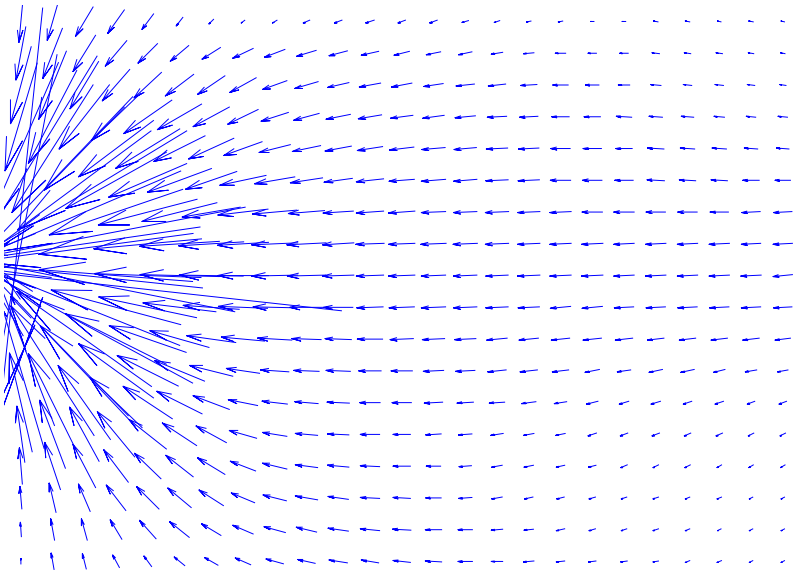

Figure A.54.1: Vector Map

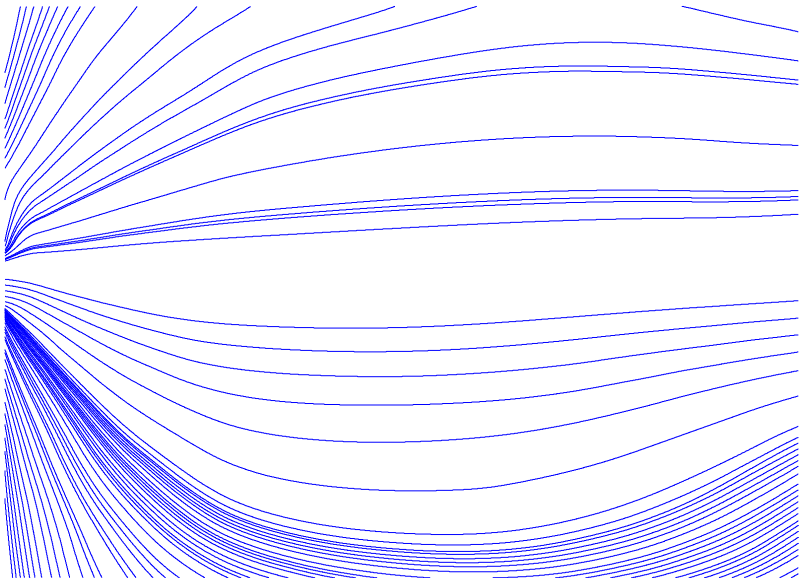

Figure A.54.2: Streamlines

Figure A.54: Vector Map and Streamlines for Average Correlation
[IA Size: 64× 64 pixels and Overlap Percentage (H%, V%): 0%, 0%]

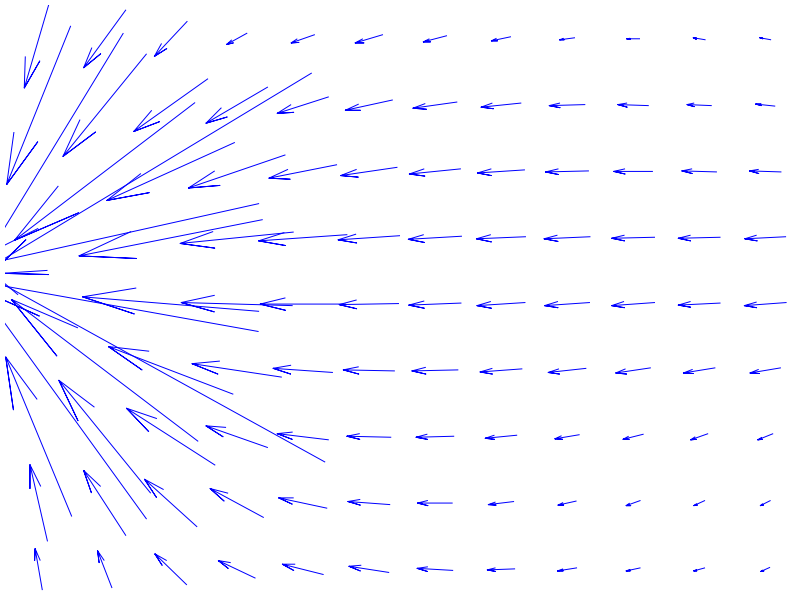

Figure A.55.1: Vector Map

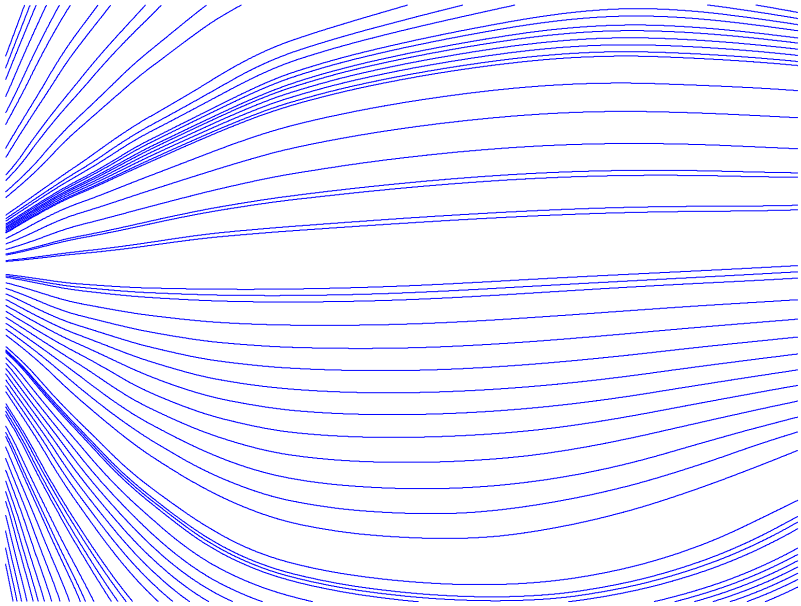

Figure A.55.2: Streamlines

Figure A.55: Vector Map and Streamlines for Average Correlation
[IA Size: 128× 128 pixels and Overlap Percentage (H%, V%): 0%, 0%]

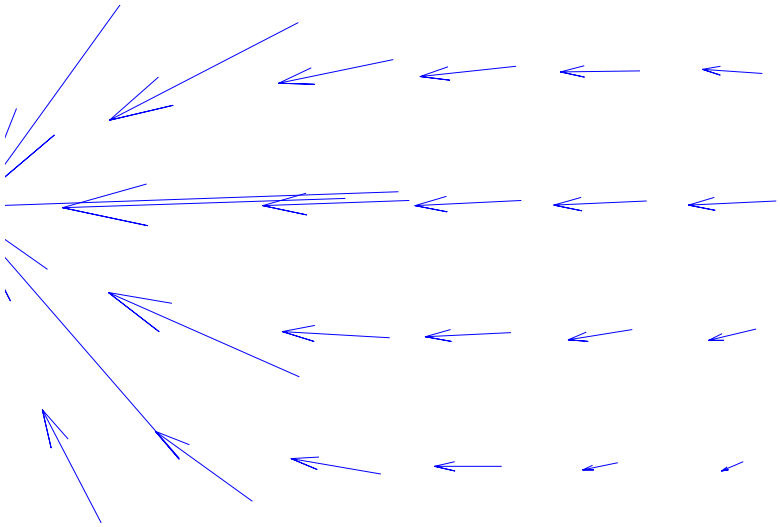

Figure A.56.1: Vector Map

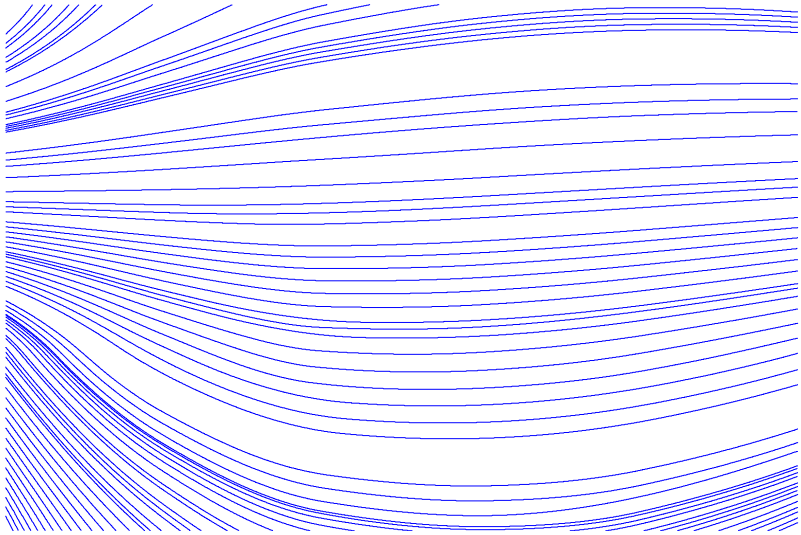

Figure A.56.2: Streamlines

Figure A.56: Vector Map and Streamlines for Average Correlation
[IA Size: 256× 256 pixels and Overlap Percentage (H%, V%): 0%, 0%]

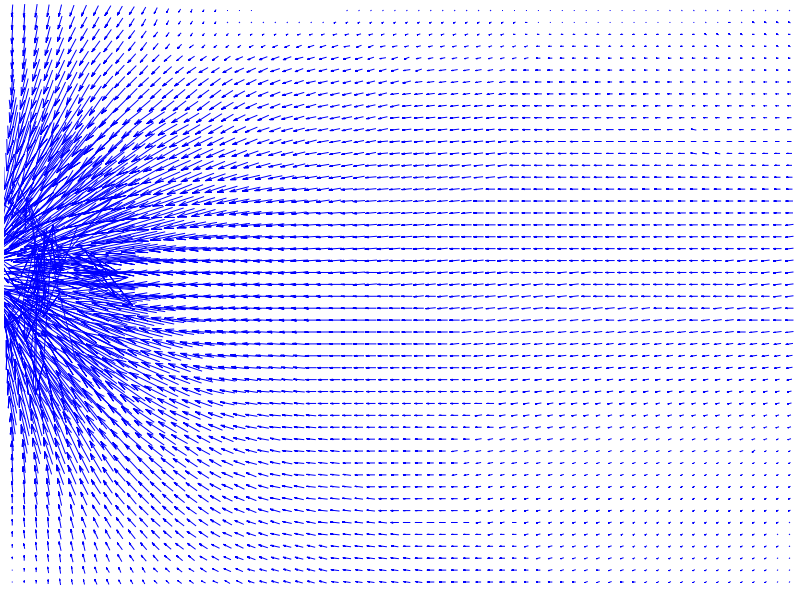

Figure A.57.1: Vector Map

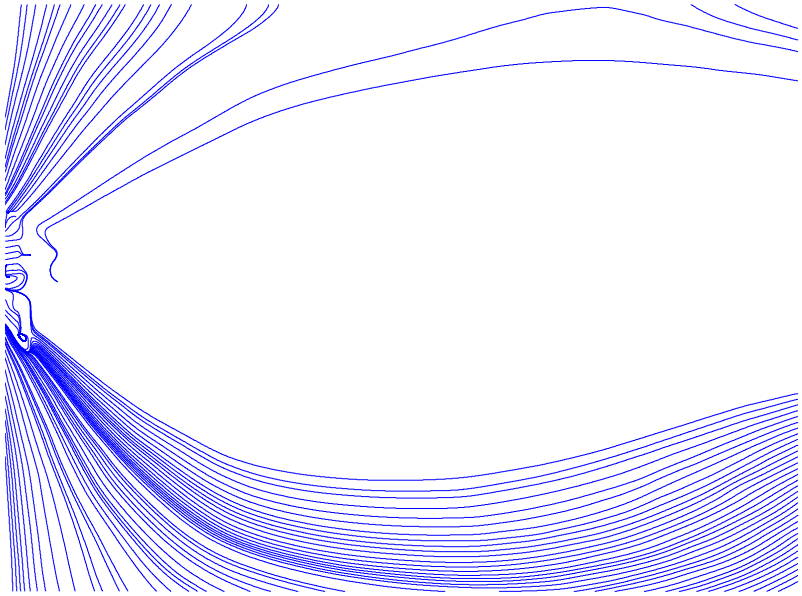

Figure A.57.2: Streamlines

Figure A.57: Vector Map and Streamlines for Average Correlation
[IA Size: 32 × 32 pixels and Overlap Percentage (H%, V%): 25%, 25%]

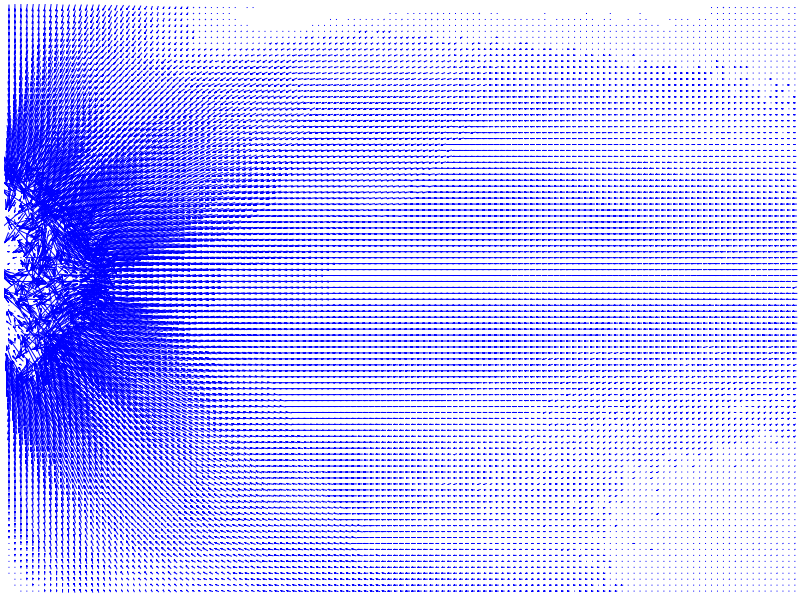

Figure A.58.1: Vector Map

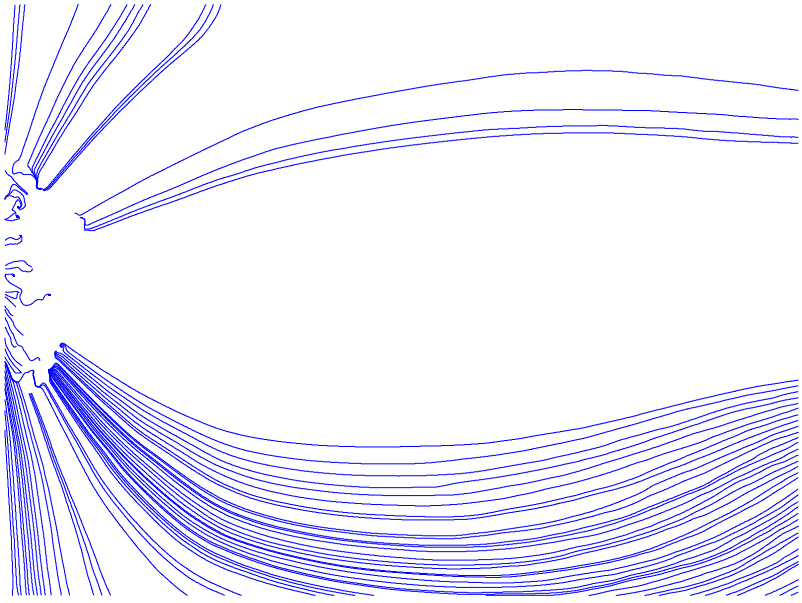

Figure A.58.2: Streamlines

Figure A.58: Vector Map and Streamlines for Average Correlation
[IA Size: 16× 16 pixels and Overlap Percentage (H%, V%): 25%, 25%]

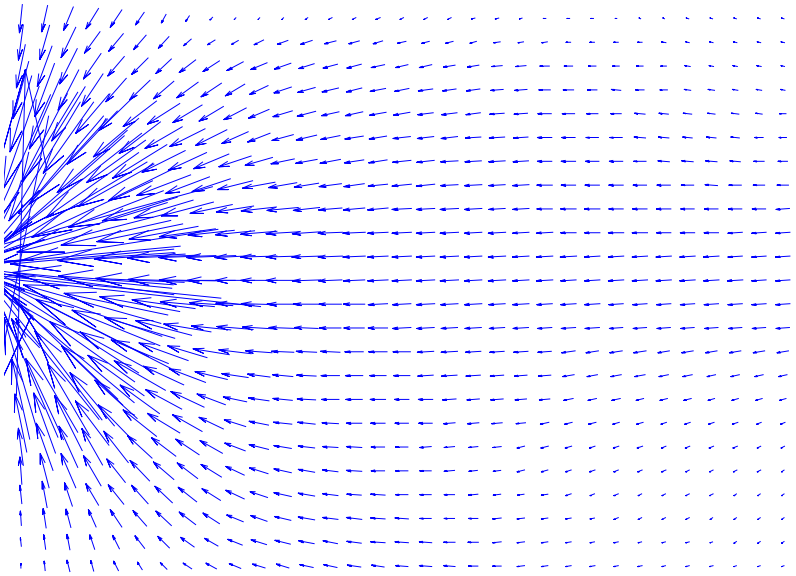

Figure A.59.1: Vector Map

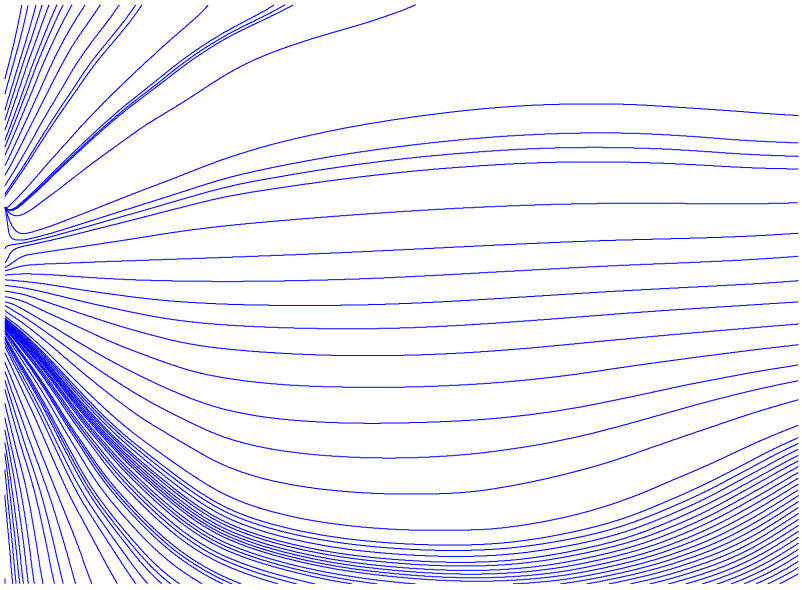

Figure A.59.2: Streamlines

Figure A.59: Vector Map and Streamlines for Average Correlation
[IA Size: 64× 64 pixels and Overlap Percentage (H%, V%): 25%, 25%]

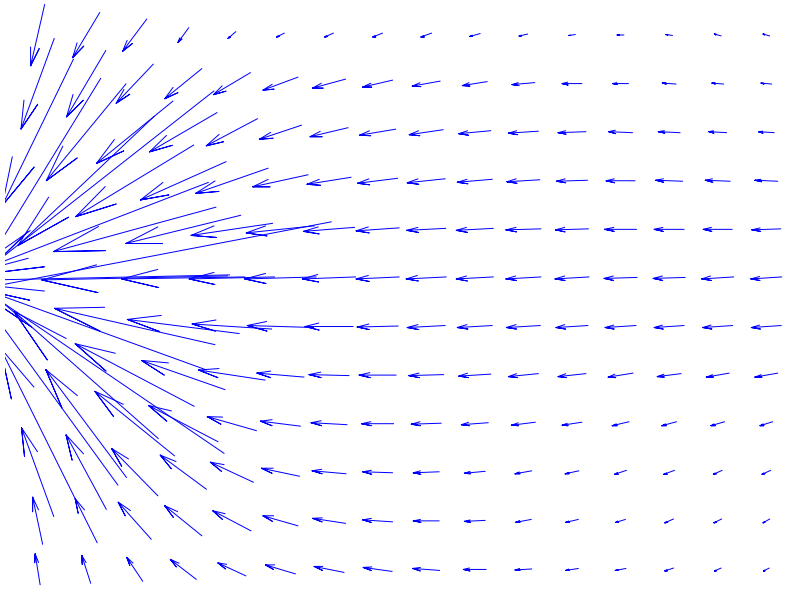

Figure A.60.1: Vector Map

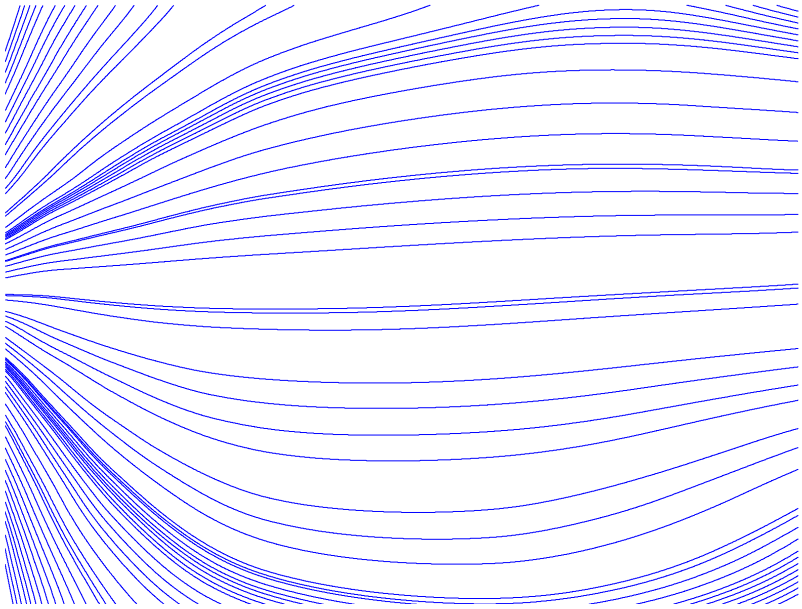

Figure A.60.2: Streamlines

Figure A.60: Vector Map and Streamlines for Average Correlation
[IA Size: 128× 128 pixels and Overlap Percentage (H%, V%): 25%, 25%]

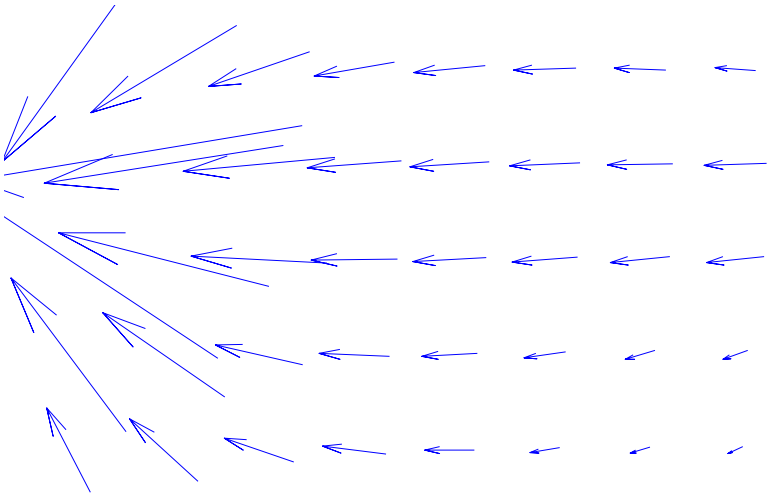

Figure A.61.1: Vector Map

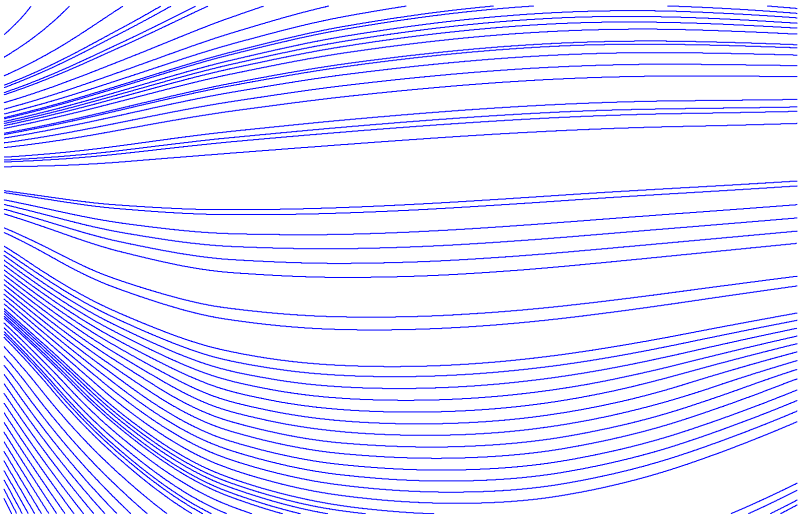

Figure A.61.2: Streamlines

Figure A.61: Vector Map and Streamlines for Average Correlation
[IA Size: 256× 256 pixels and Overlap Percentage (H%, V%): 25%, 25%]

APPENDIX B

VELOCITY PROFILES

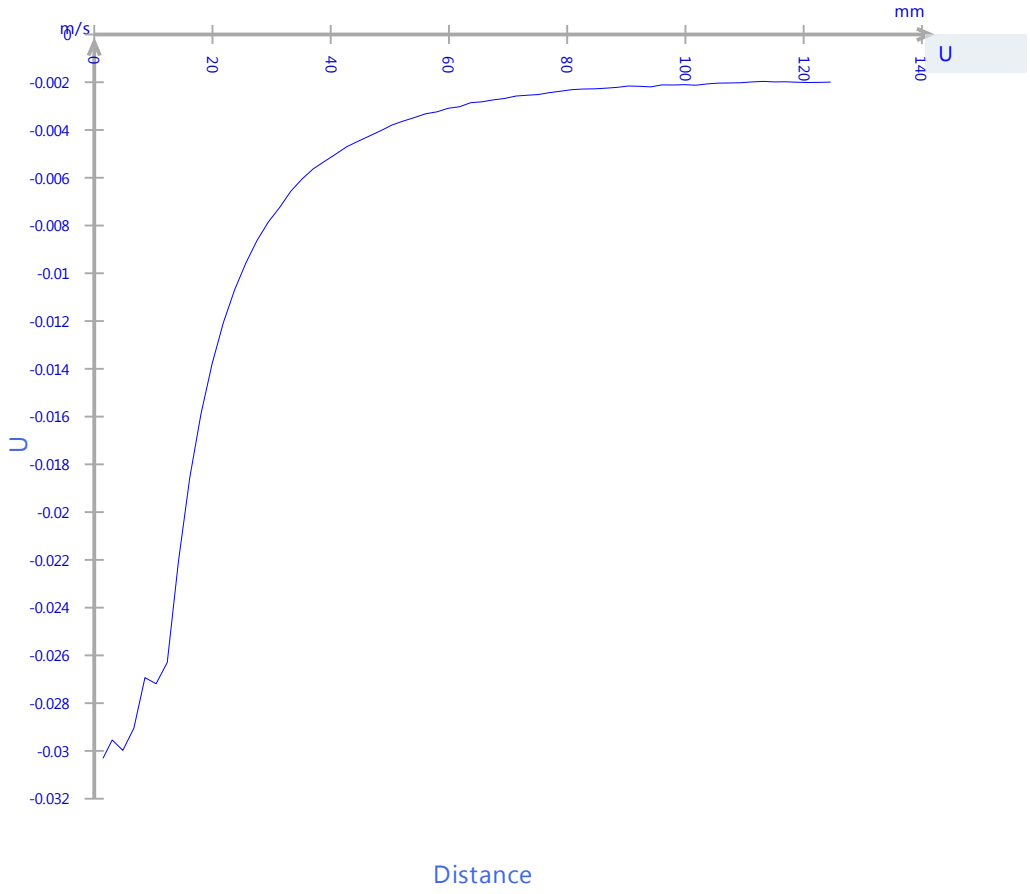

Figure B.1: Horizontal Velocity (U) along the Outlet Axis in Adaptive Correlation [IA Size: 32×32 pixels and Overlap Percentage (H%, V%): 25%, 0%]

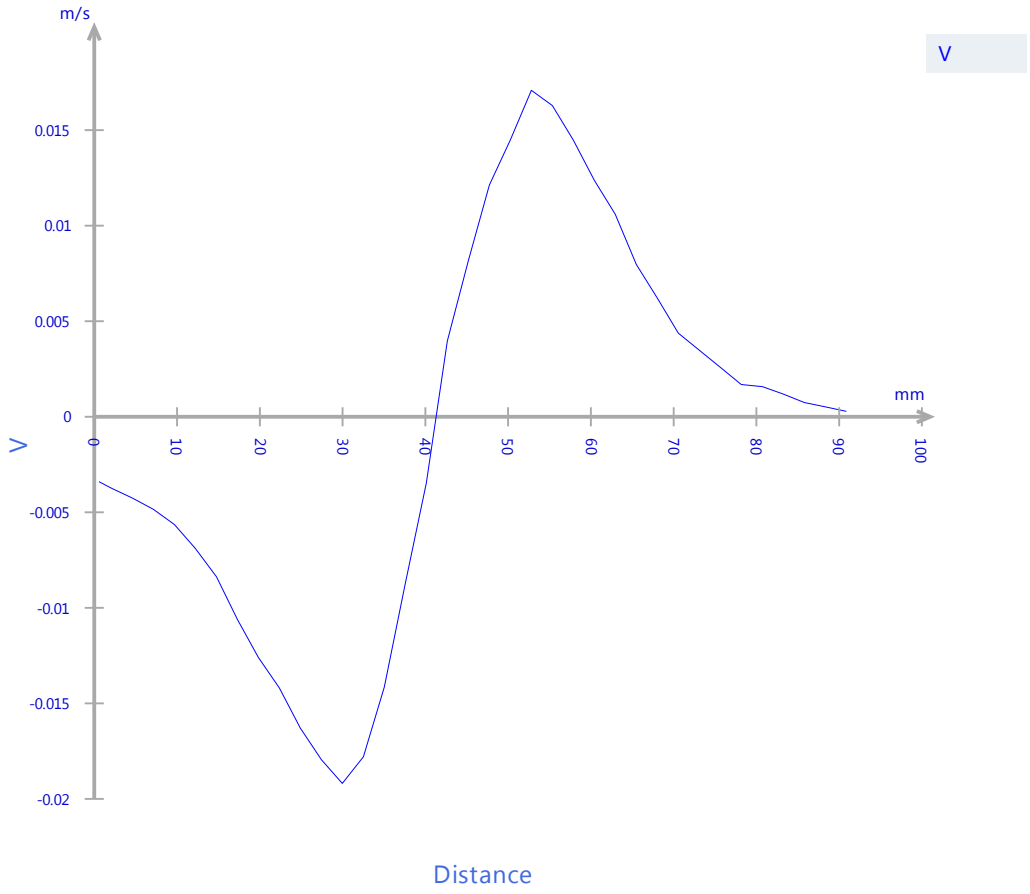

Figure B.2: Vertical Velocity (V) at the Outlet Side in Adaptive Correlation [IA Size: 32 × 32 pixels and Overlap Percentage (H%, V%): 25%, 0%]

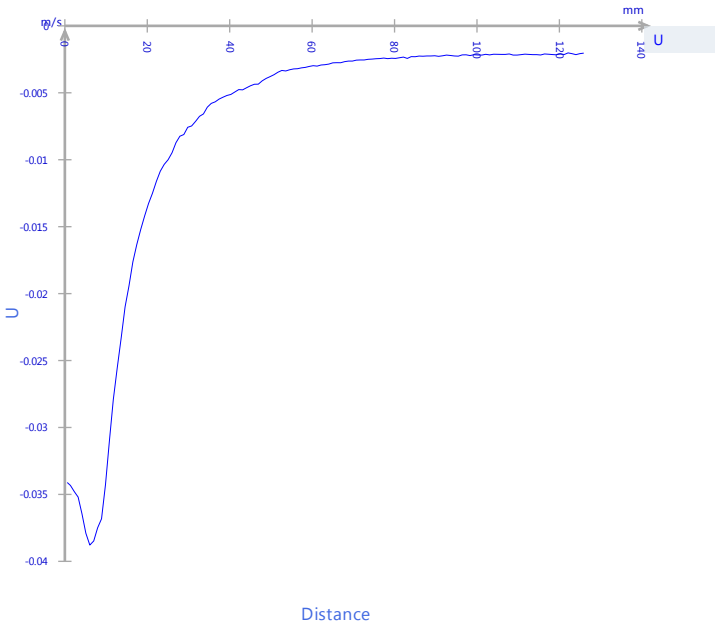

Figure B.3.1: Horizontal Velocity (U) along the Outlet Axis

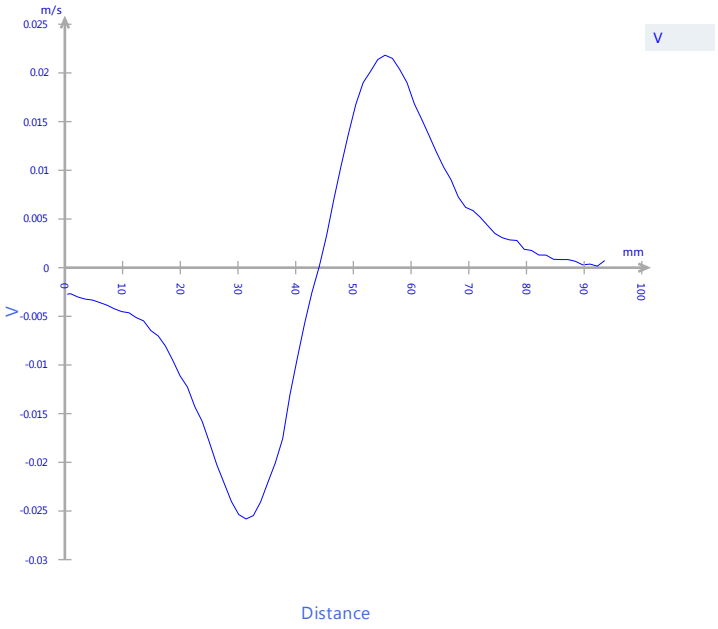

Figure B.3.2: Vertical Velocity (V) at the Outlet Side

Figure B.3: Velocity Profiles for Adaptive Correlation
[IA Size: 16× 16 pixels and Overlap Percentage (H%, V%): 25%, 0%]

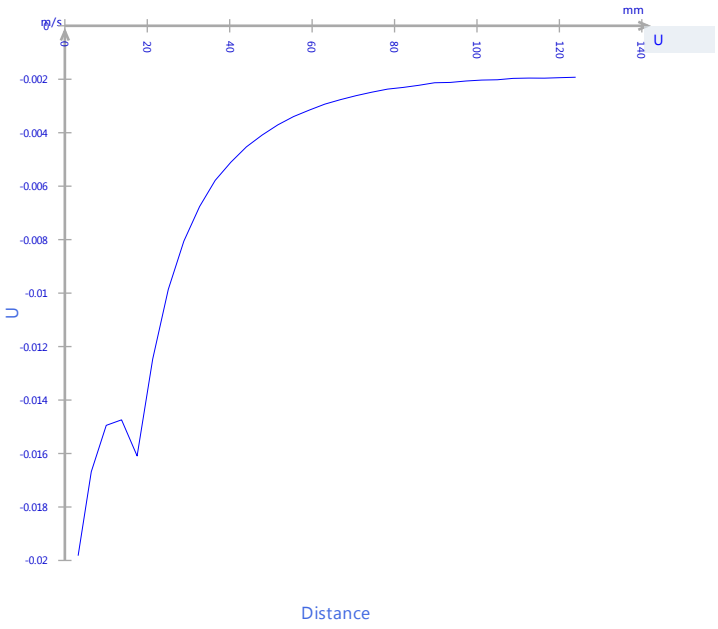

Figure B.4.1: Horizontal Velocity (U) along the Outlet Axis

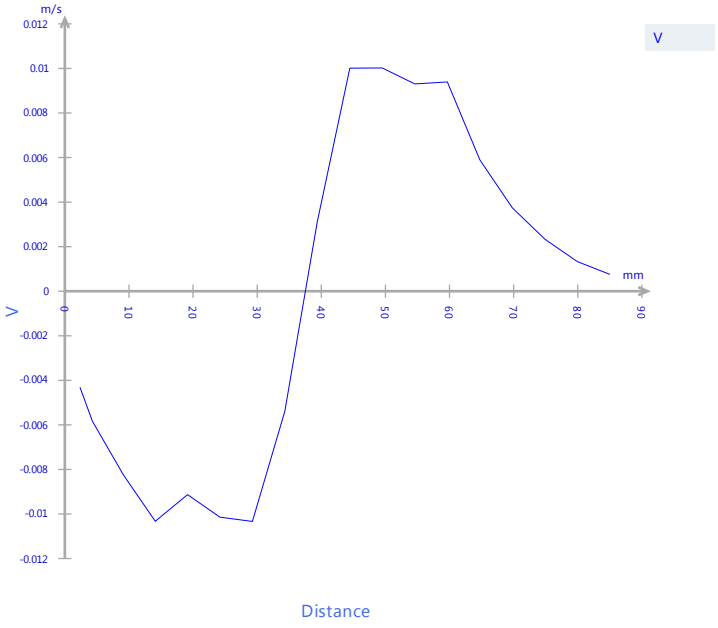

Figure B.4.2: Vertical Velocity (V) at the Outlet Side

Figure B.4: Velocity Profiles for Adaptive Correlation
[IA Size: 64× 64 pixels and Overlap Percentage (H%, V%): 25%, 0%]

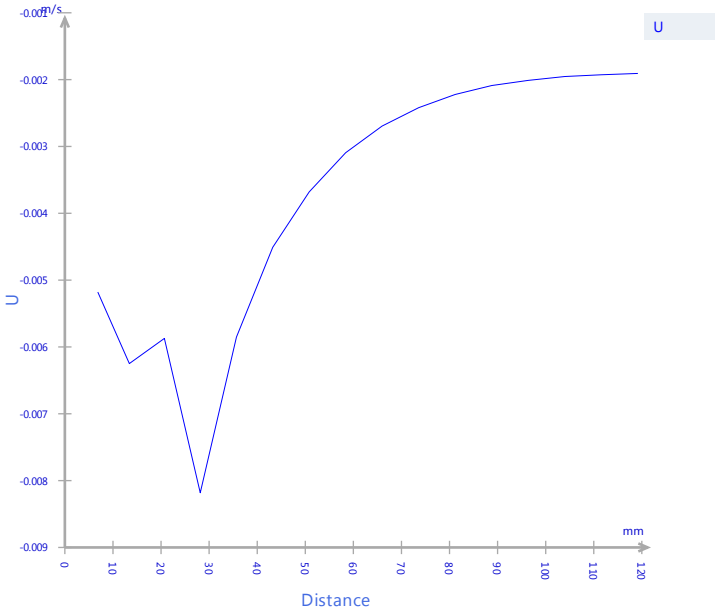

Figure B.5.1: Horizontal Velocity (U) along the Outlet Axis

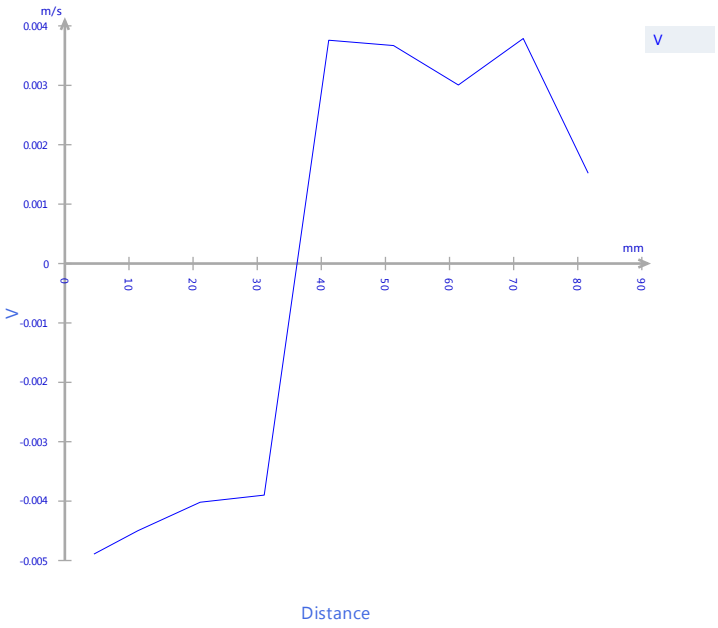

Figure B.5.2: Vertical Velocity (V) at the Outlet Side

Figure B.5: Velocity Profiles for Adaptive Correlation
[IA Size: 128× 128 pixels and Overlap Percentage (H%, V%): 25%, 0%]

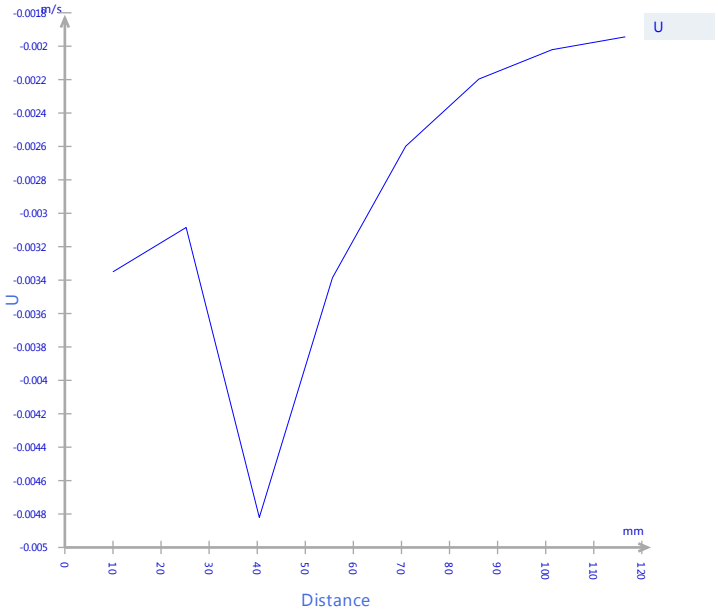

Figure B.6.1: Horizontal Velocity (U) along the Outlet Axis

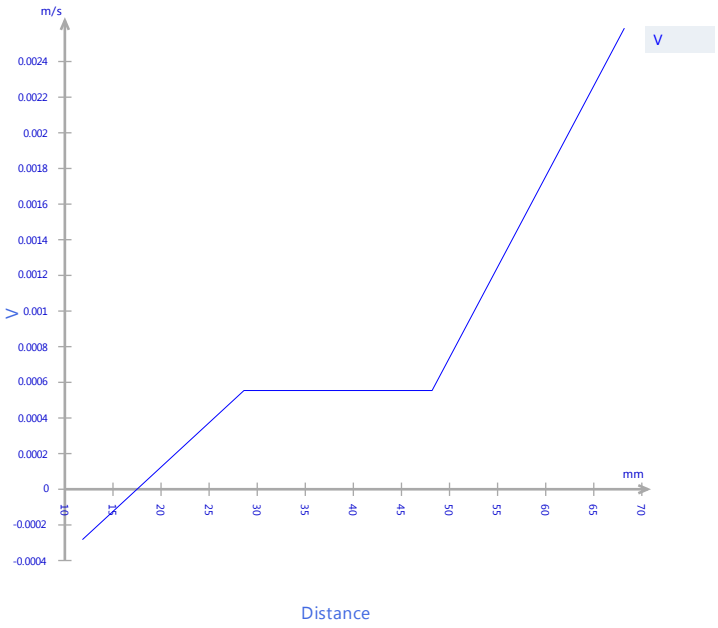

Figure B.6.2: Vertical Velocity (V) at the Outlet Side

Figure B.6: Velocity Profiles for Adaptive Correlation
[IA Size: 256× 256 pixels and Overlap Percentage (H%, V%): 25%, 0%]

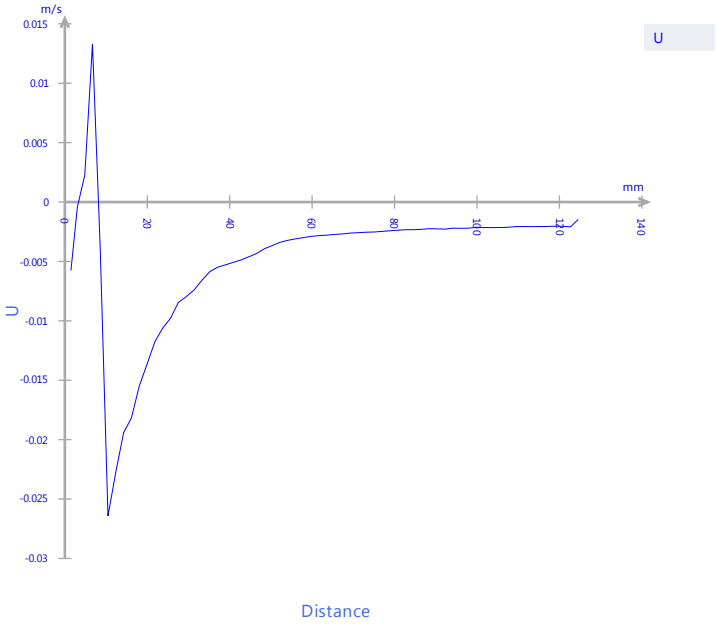

Figure B.7.1: Horizontal Velocity (U) along the Outlet Axis

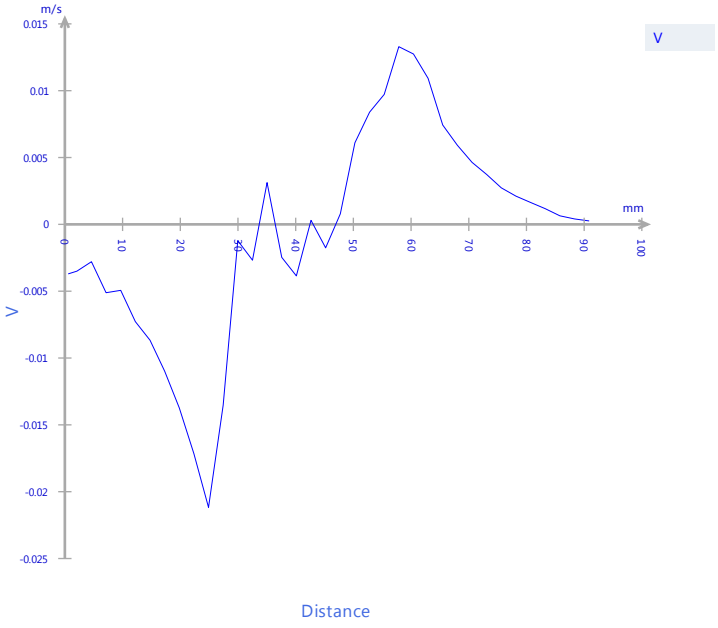

Figure B.7.2: Vertical Velocity (V) at the Outlet Side

Figure B.7: Velocity Profiles for Cross Correlation
[IA Size: 32×32 pixels and Overlap Percentage (H%, V%): 25%, 0%]

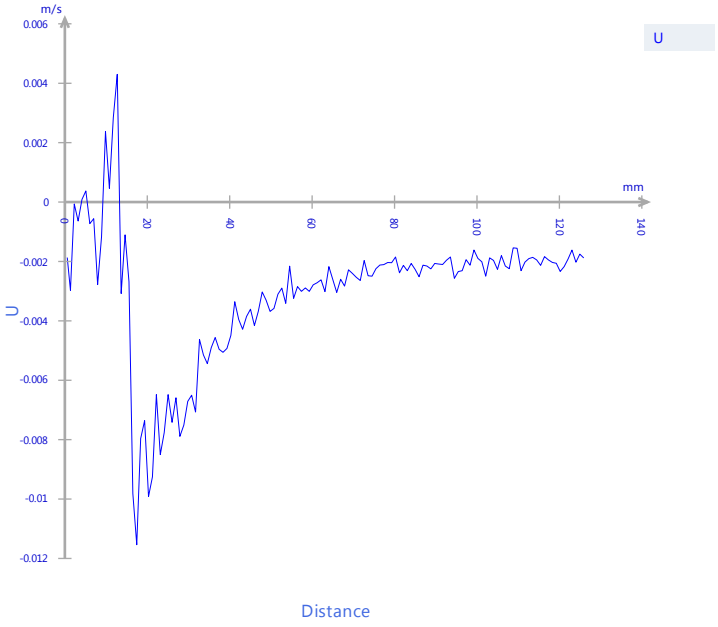

Figure B.8.1: Horizontal Velocity (U) along the Outlet Axis

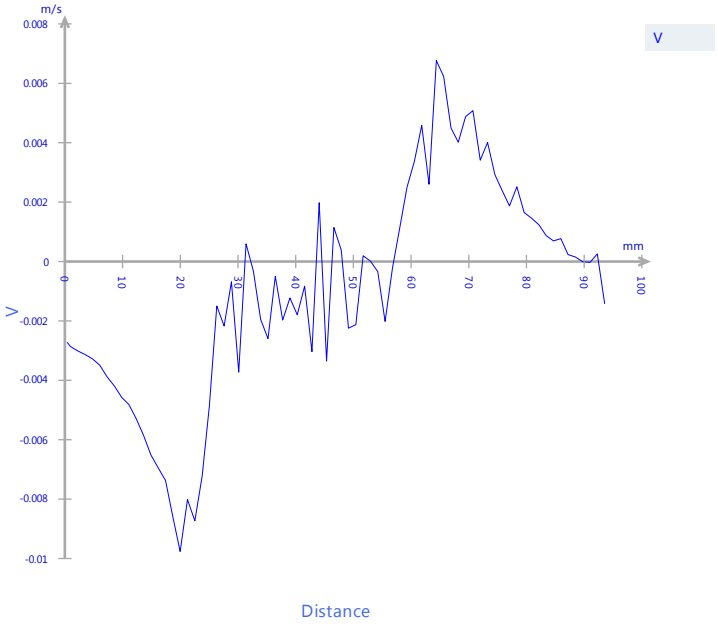

Figure B.8.2: Vertical Velocity (V) at the Outlet Side

Figure B.8: Velocity Profiles for Cross Correlation
[IA Size: 16× 16 pixels and Overlap Percentage (H%, V%): 25%, 0%]

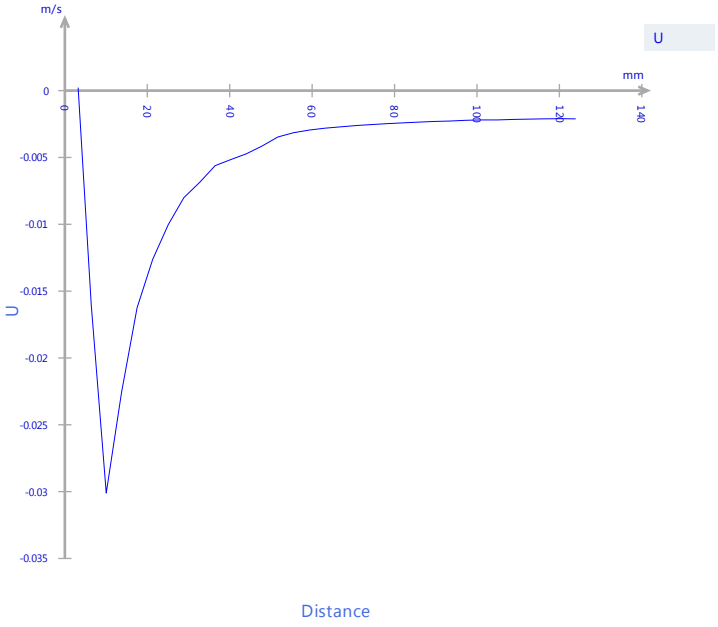

Figure B.9.1: Horizontal Velocity (U) along the Outlet Axis

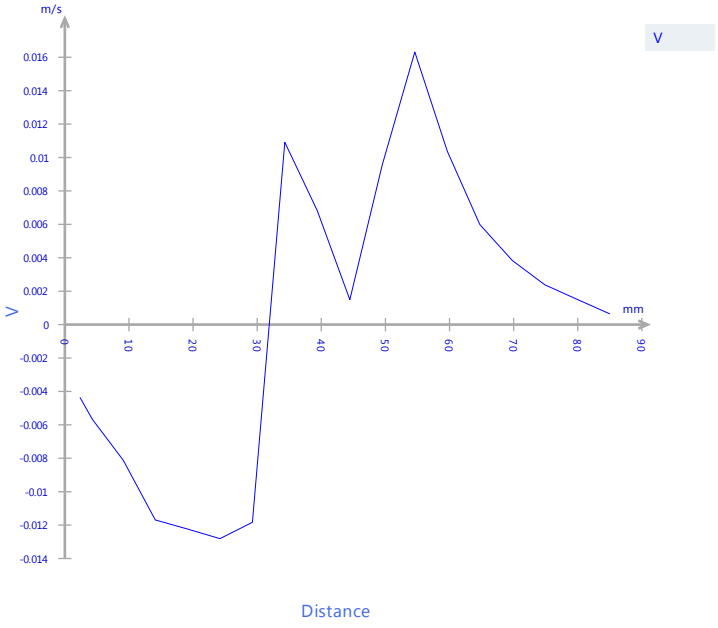

Figure B.9.2: Vertical Velocity (V) at the Outlet Side

Figure B.9: Velocity Profiles for Cross Correlation
[IA Size: 64× 64 pixels and Overlap Percentage (H%, V%): 25%, 0%]

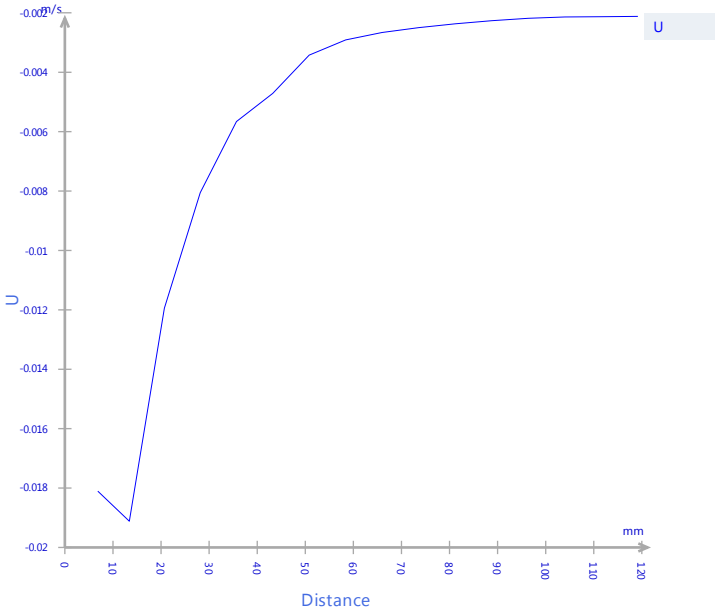

Figure B.10.1: Horizontal Velocity (U) along the Outlet Axis

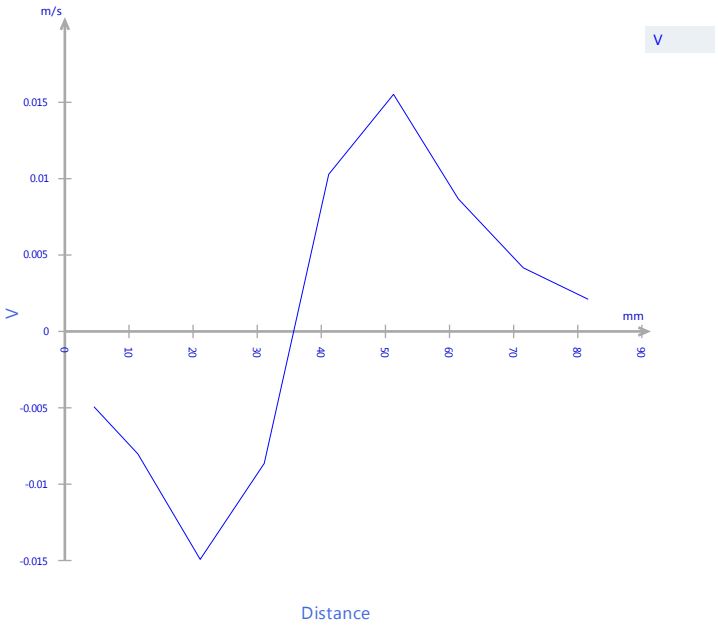

Figure B.10.2: Vertical Velocity (V) at the Outlet Side

Figure B.10: Velocity Profiles for Cross Correlation
[IA Size: 128× 128 pixels and Overlap Percentage (H%, V%): 25%, 0%]

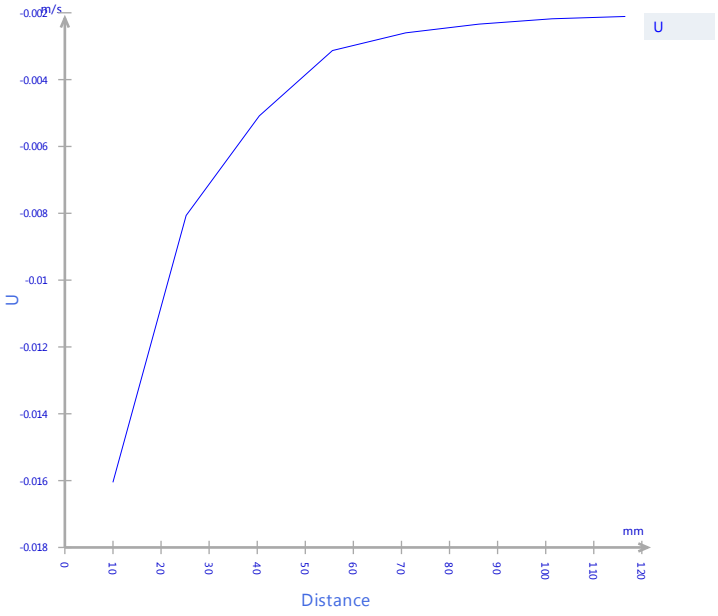

Figure B.11.1: Horizontal Velocity (U) along the Outlet Axis

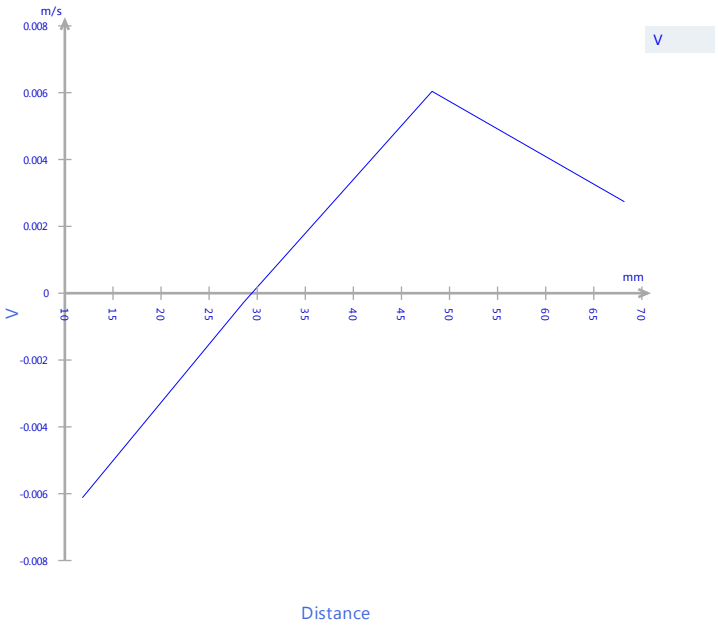

Figure B.11.2: Vertical Velocity (V) at the Outlet Side

Figure B.11: Velocity Profiles for Cross Correlation
[IA Size: 256× 256 pixels and Overlap Percentage (H%, V%): 25%, 0%]

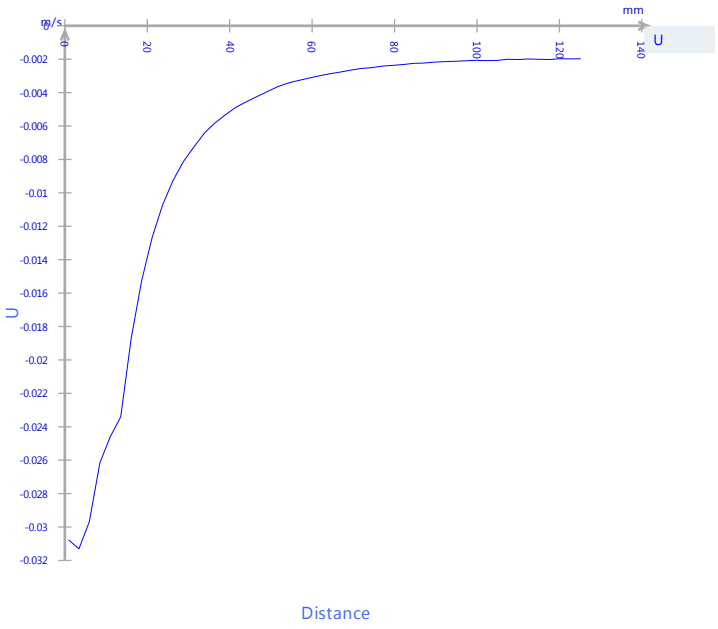

Figure B.12.1: Horizontal Velocity (U) along the Outlet Axis

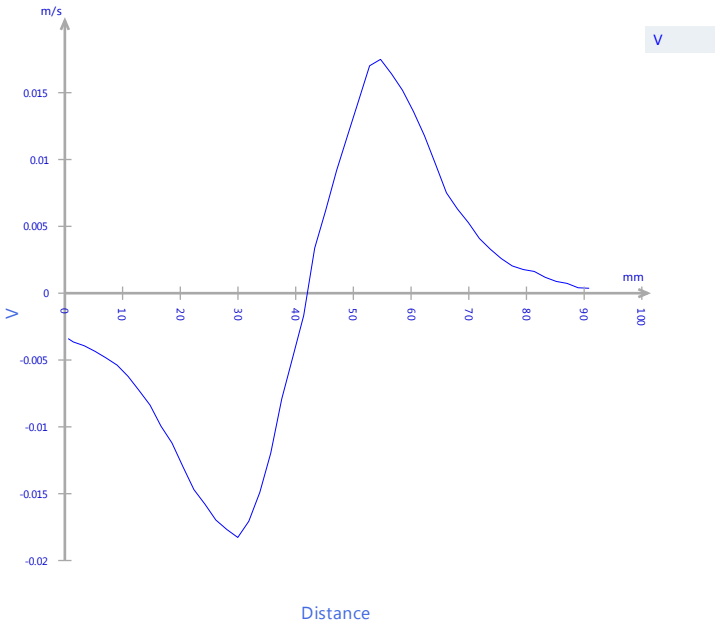

Figure B.12.2: Vertical Velocity (V) at the Outlet Side

Figure B.12: Velocity Profiles for Adaptive Correlation
[IA Size: 32×32 pixels and Overlap Percentage (H%, V%): 0%, 25%]

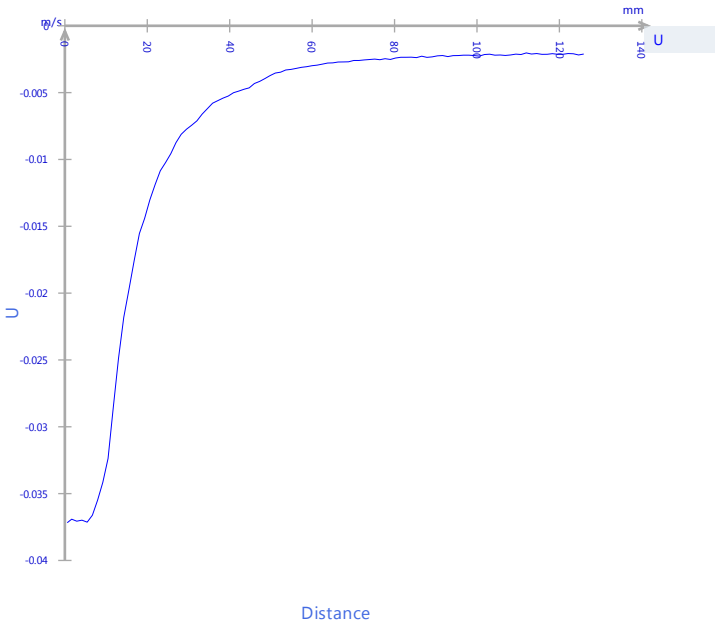

Figure B.13.1: Horizontal Velocity (U) along the Outlet Axis

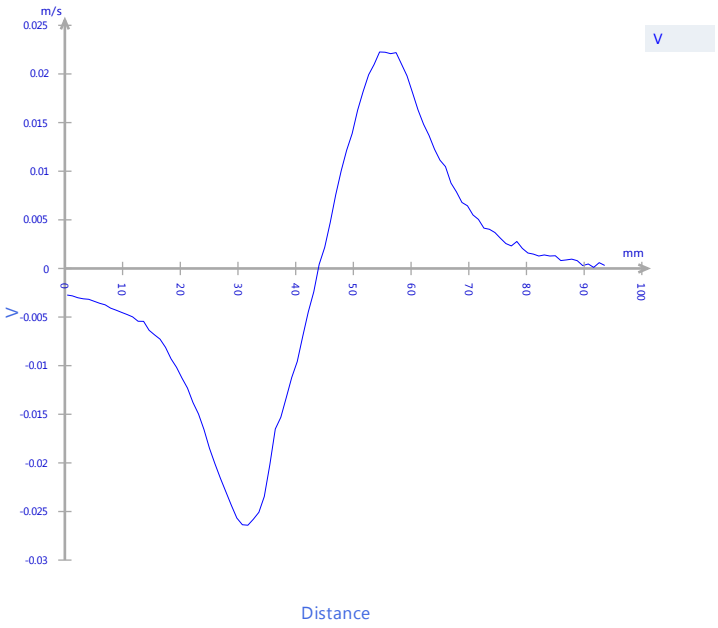

Figure B.13.2: Vertical Velocity (V) at the Outlet Side

Figure B.13: Velocity Profiles for Adaptive Correlation
[IA Size: 16× 16 pixels and Overlap Percentage (H%, V%): 0%, 25%]

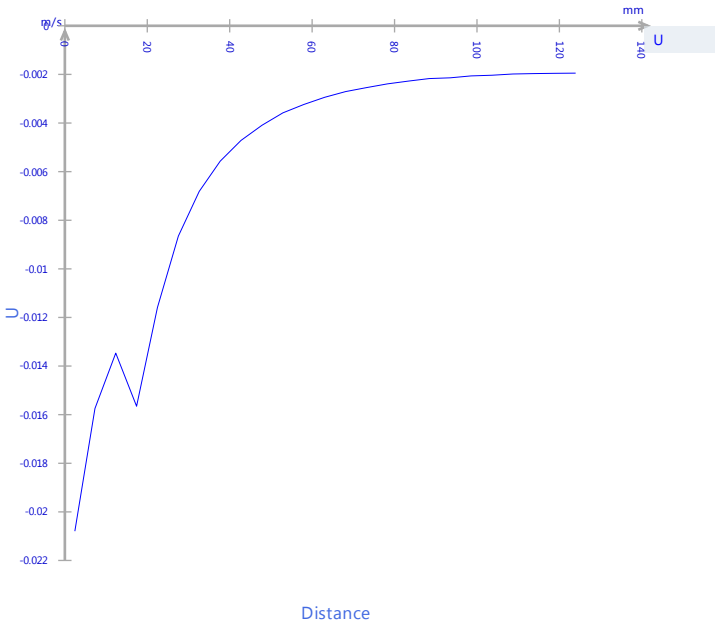

Figure B.14.1: Horizontal Velocity (U) along the Outlet Axis

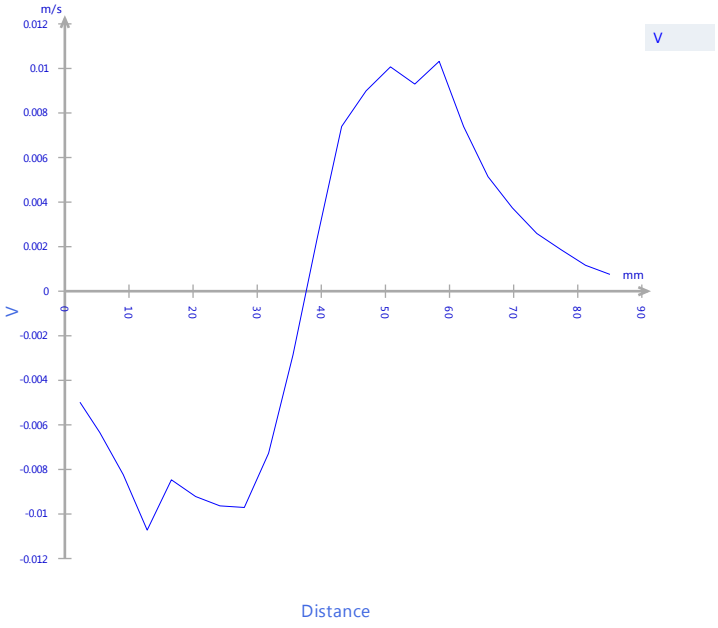

Figure B.14.2: Vertical Velocity (V) at the Outlet Side

Figure B.14: Velocity Profiles for Adaptive Correlation
[IA Size: 64× 64 pixels and Overlap Percentage (H%, V%): 0%, 25%]

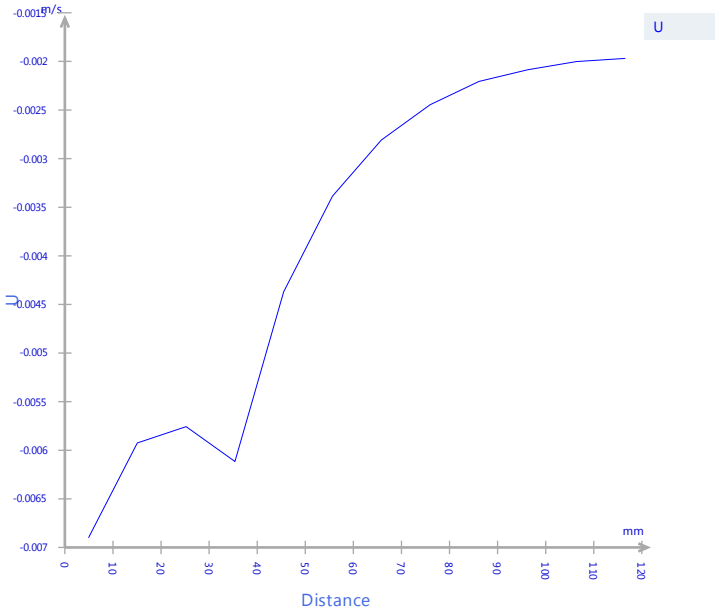

Figure B.15.1: Horizontal Velocity (U) along the Outlet Axis

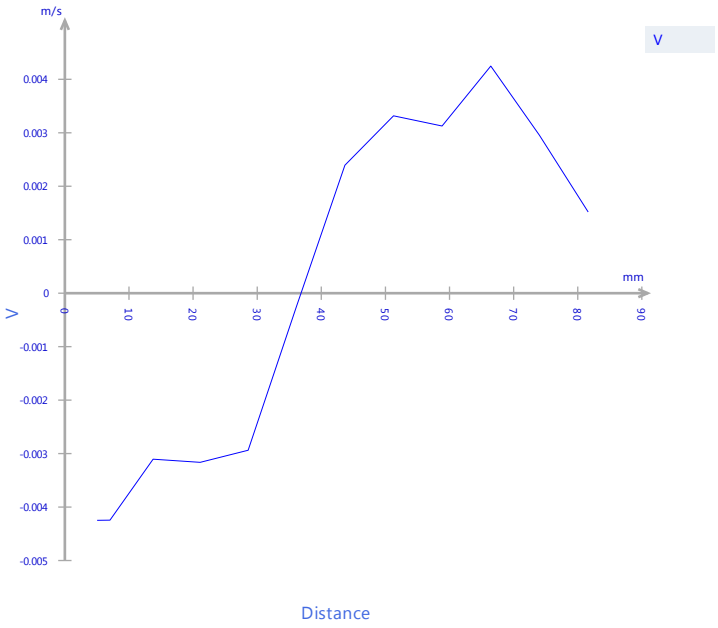

Figure B.15.2: Vertical Velocity (V) at the Outlet Side

Figure B.15: Velocity Profiles for Adaptive Correlation
[IA Size: 128× 128 pixels and Overlap Percentage (H%, V%): 0%, 25%]

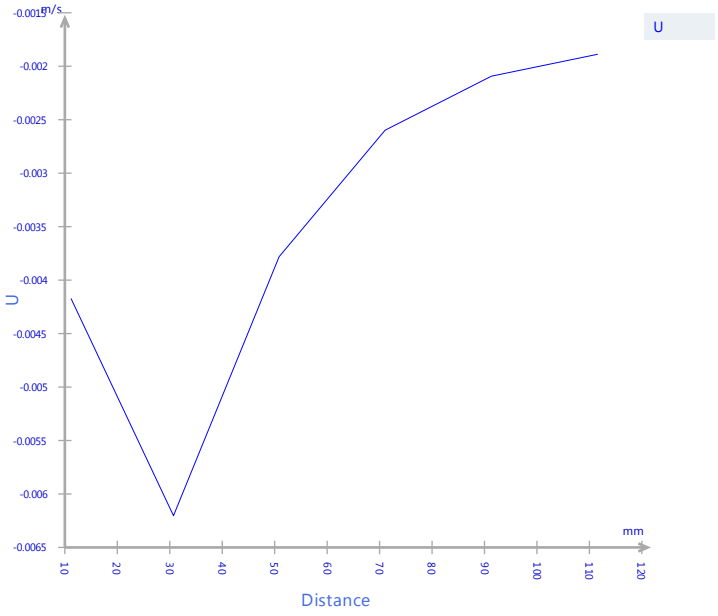

Figure B.16.1: Horizontal Velocity (U) along the Outlet Axis

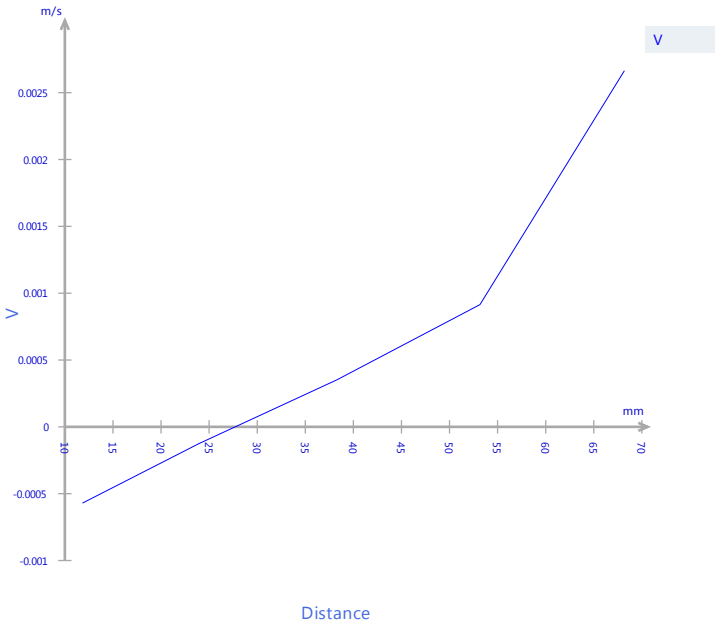

Figure B.16.2: Vertical Velocity (V) at the Outlet Side

Figure B.16: Velocity Profiles for Adaptive Correlation
[IA Size: 256× 256 pixels and Overlap Percentage (H%, V%): 0%, 25%]

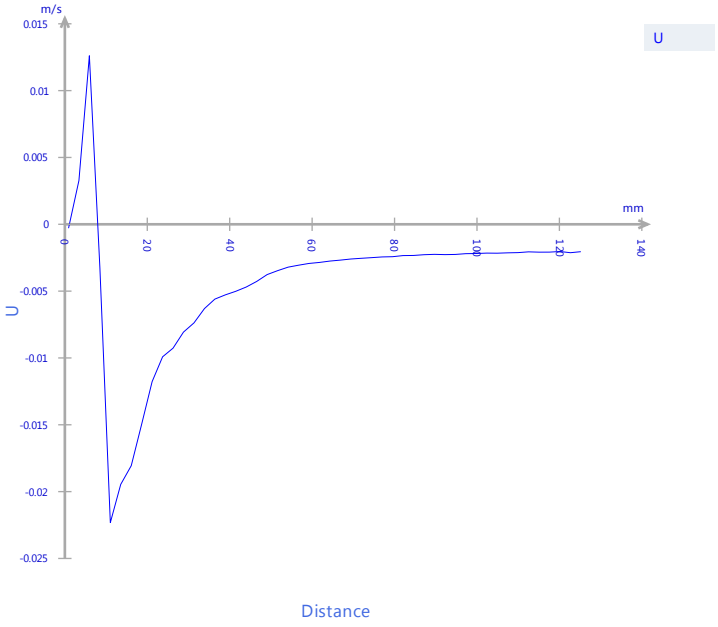

Figure B.17.1: Horizontal Velocity (U) along the Outlet Axis

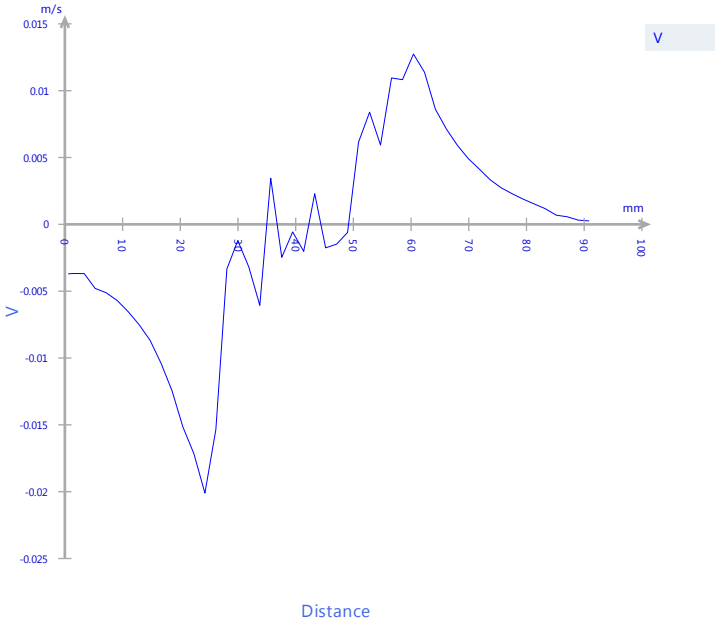

Figure B.17.2: Vertical Velocity (V) at the Outlet Side

Figure B.17: Velocity Profiles for Cross Correlation
[IA Size: 32×32 pixels and Overlap Percentage (H%, V%): 0%, 25%]

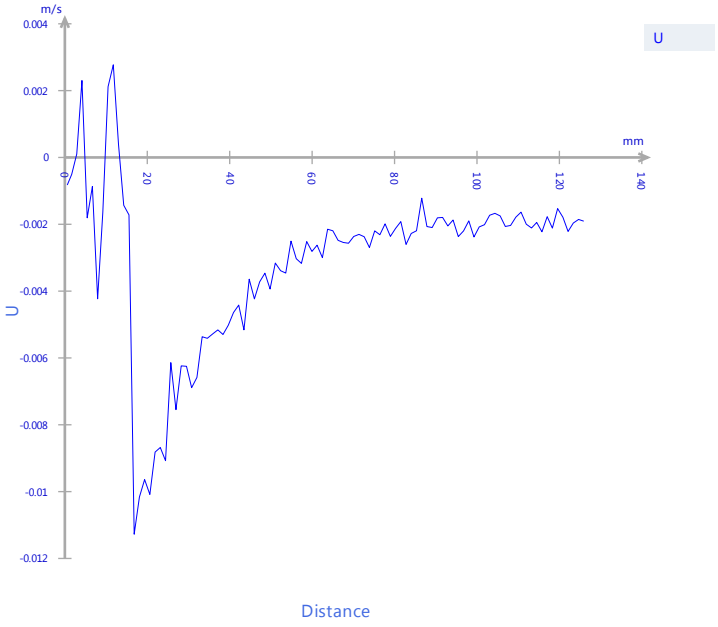

Figure B.18.1: Horizontal Velocity (U) along the Outlet Axis

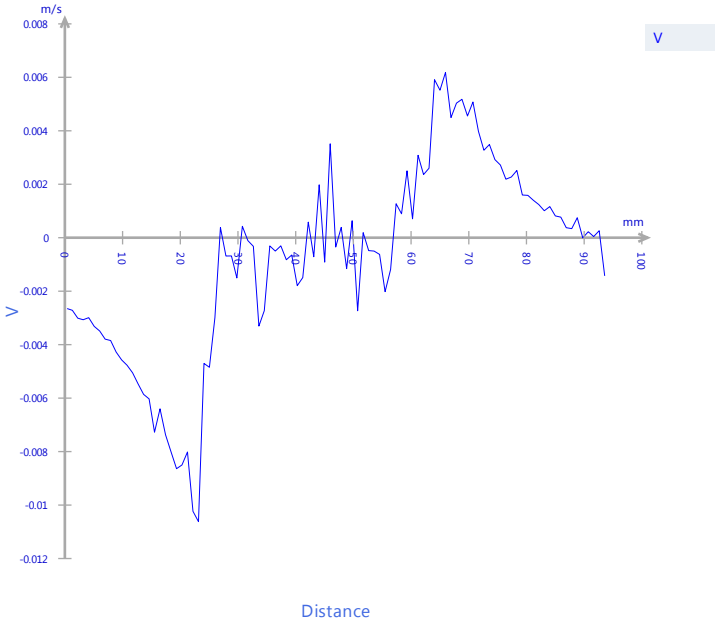

Figure B.18.2: Vertical Velocity (V) at the Outlet Side

Figure B.18: Velocity Profiles for Cross Correlation
[IA Size: 16× 16 pixels and Overlap Percentage (H%, V%): 0%, 25%]

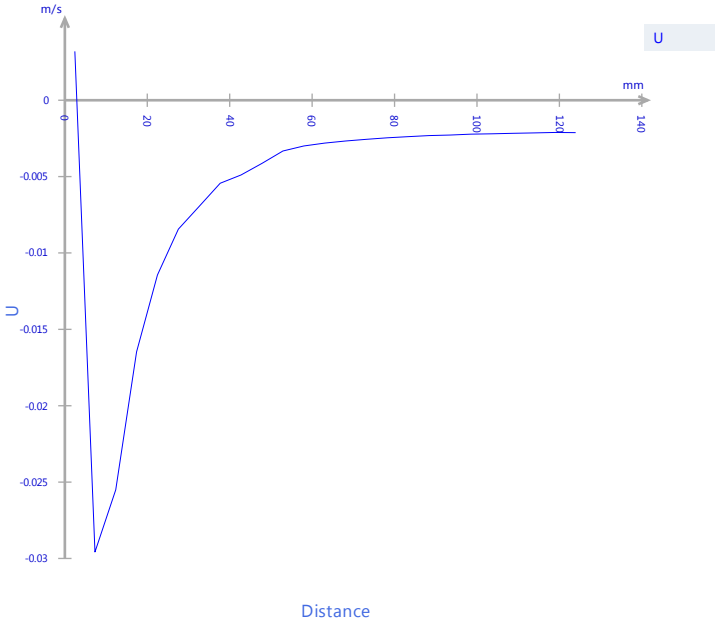

Figure B.19.1: Horizontal Velocity (U) along the Outlet Axis

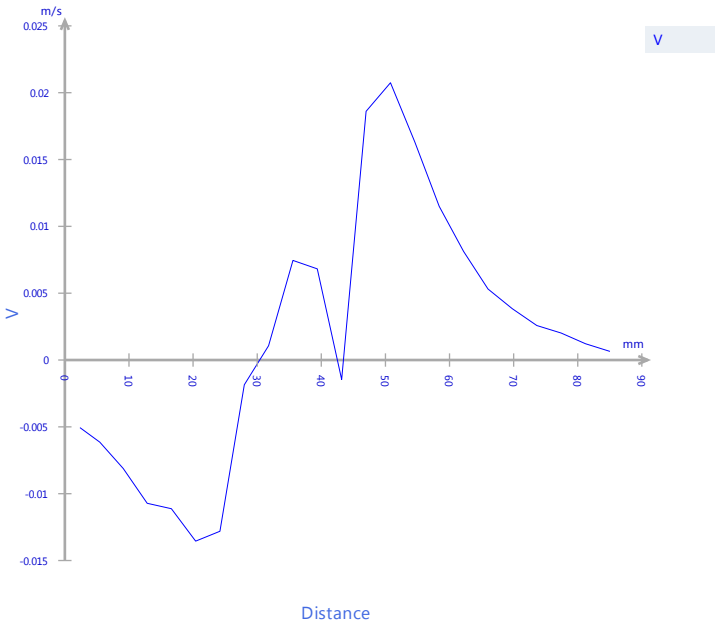

Figure B.19.2: Vertical Velocity (V) at the Outlet Side

Figure B.19: Velocity Profiles for Cross Correlation
[IA Size: 64× 64 pixels and Overlap Percentage (H%, V%): 0%, 25%]

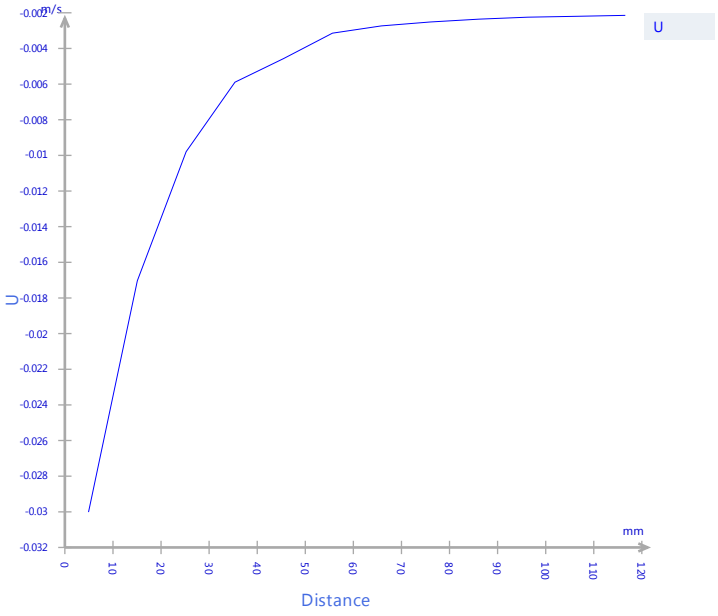

Figure B.20.1: Horizontal Velocity (U) along the Outlet Axis

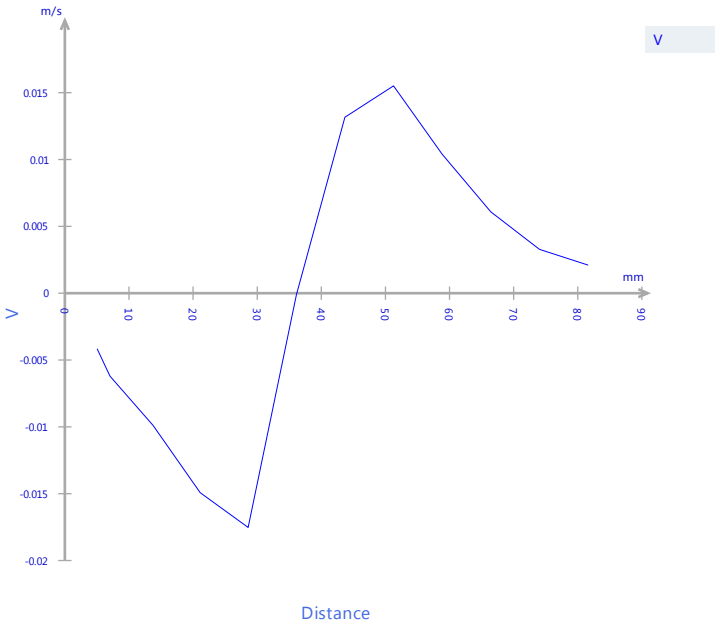

Figure B.20.2: Vertical Velocity (V) at the Outlet Side

Figure B.20: Velocity Profiles for Cross Correlation
[IA Size: 128× 128 pixels and Overlap Percentage (H%, V%): 0%, 25%]

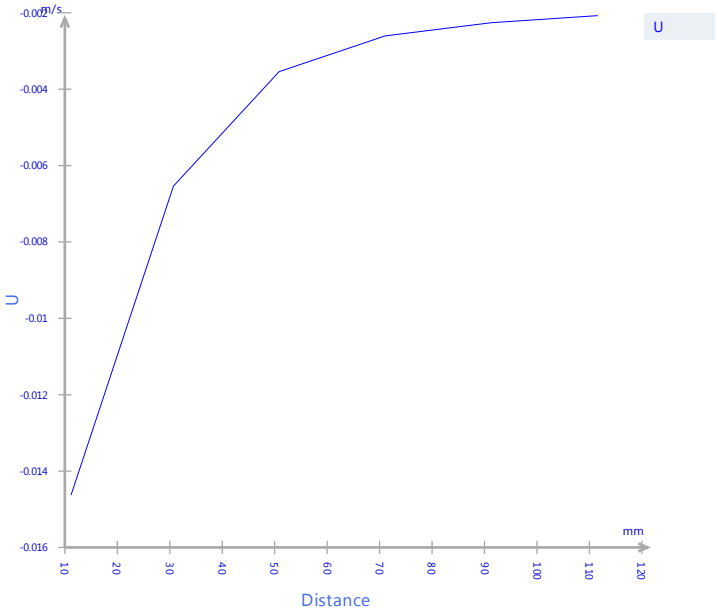

Figure B.21.1: Horizontal Velocity (U) along the Outlet Axis

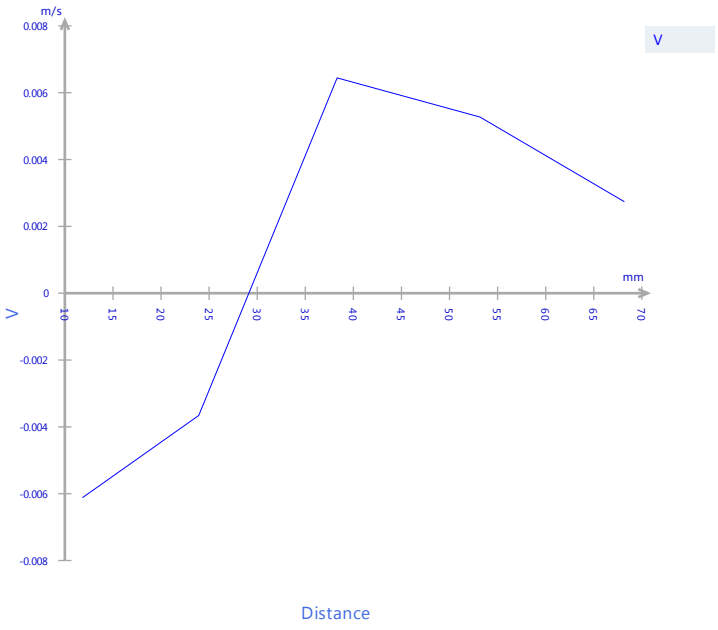

Figure B.21.2: Vertical Velocity (V) at the Outlet Side

Figure B.21: Velocity Profiles for Cross Correlation
[IA Size: 256× 256 pixels and Overlap Percentage (H%, V%): 0%, 25%]

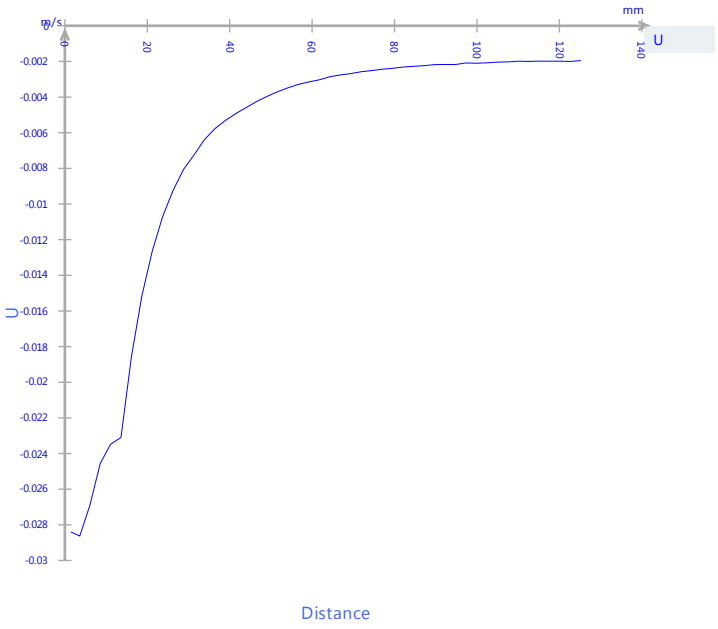

Figure B.22.1: Horizontal Velocity (U) along the Outlet Axis

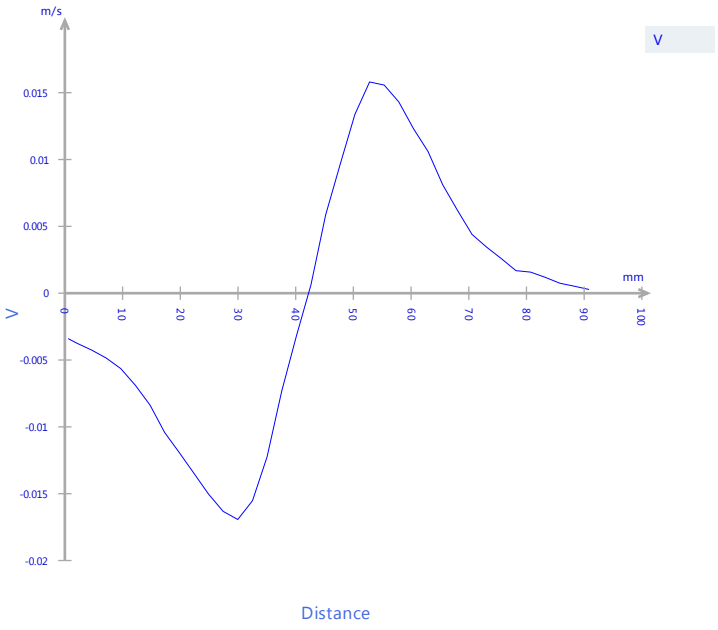

Figure B.22.2: Vertical Velocity (V) at the Outlet Side

Figure B.22: Velocity Profiles for Adaptive Correlation
[IA Size: 32 × 32 pixels and Overlap Percentage (H%, V%): 0%, 0%]

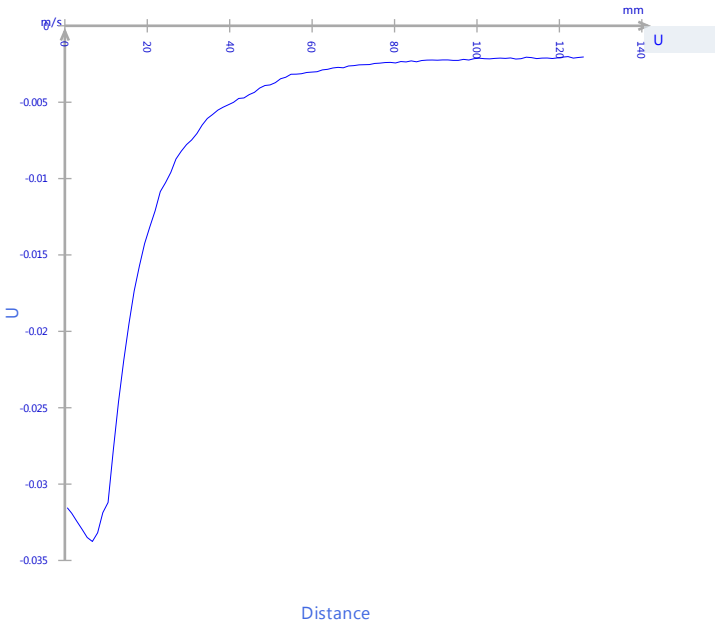

Figure B.23.1: Horizontal Velocity (U) along the Outlet Axis

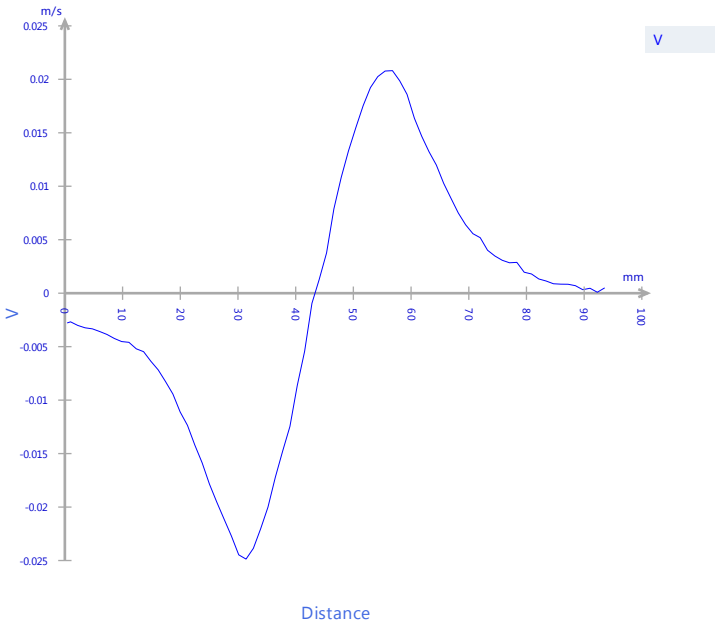

Figure B.23.2: Vertical Velocity (V) at the Outlet Side

Figure B.23: Velocity Profiles for Adaptive Correlation
[IA Size: 16× 16 pixels and Overlap Percentage (H%, V%): 0%, 0%]

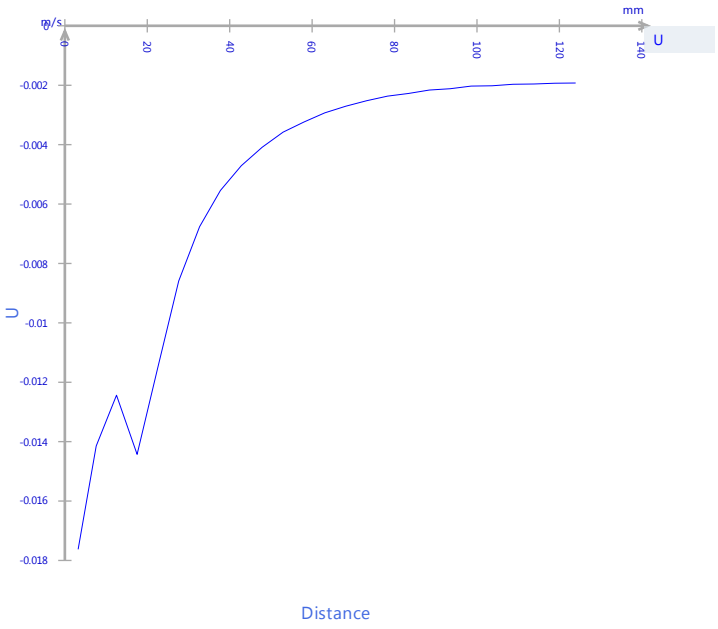

Figure B.24.1: Horizontal Velocity (U) along the Outlet Axis

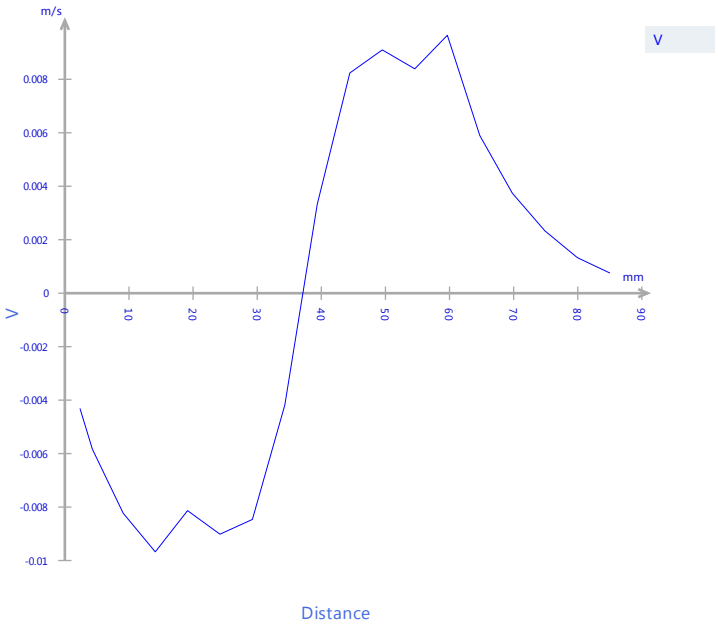

Figure B.24.2: Vertical Velocity (V) at the Outlet Side

Figure B.24: Velocity Profiles for Adaptive Correlation
[IA Size: 64× 64 pixels and Overlap Percentage (H%, V%): 0%, 0%]

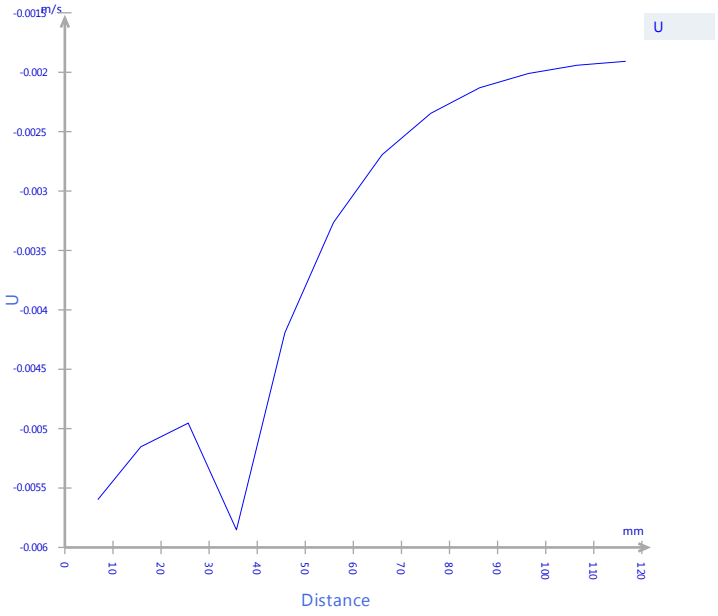

Figure B.25.1: Horizontal Velocity (U) along the Outlet Axis

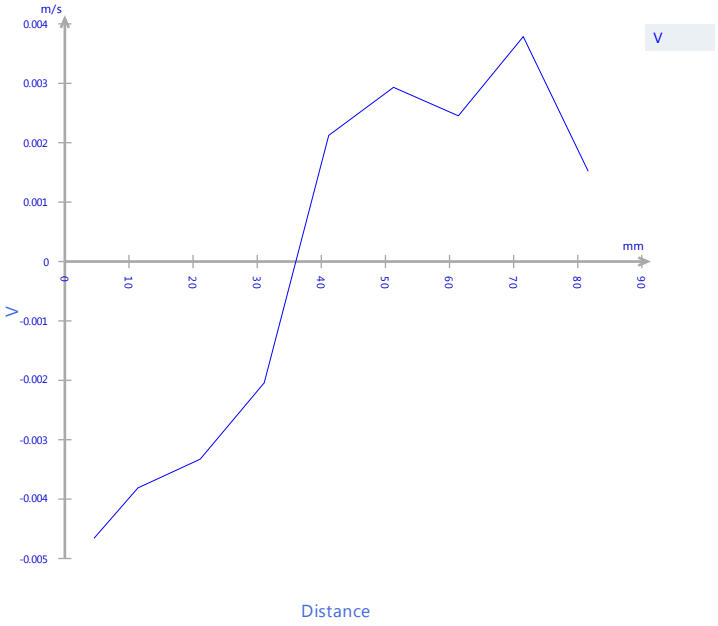

Figure B.25.2: Vertical Velocity (V) at the Outlet Side

Figure B.25: Velocity Profiles for Adaptive Correlation
[IA Size: 128× 128 pixels and Overlap Percentage (H%, V%): 0%, 0%]

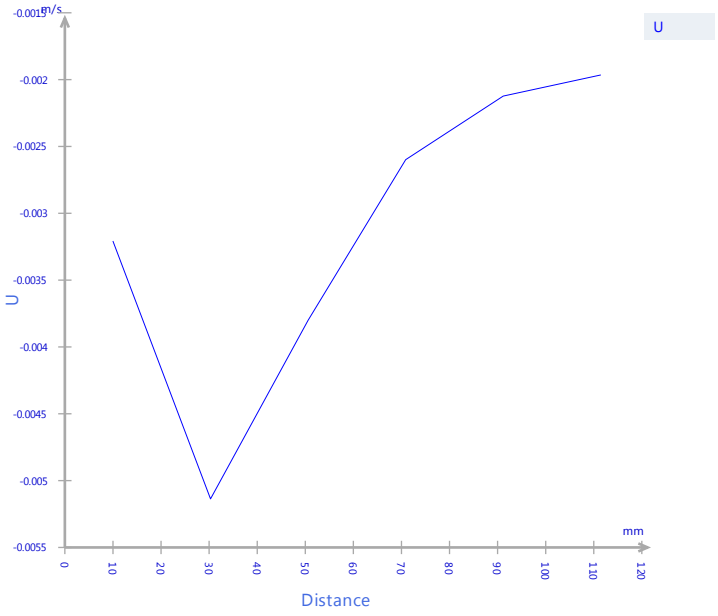

Figure B.26.1: Horizontal Velocity (U) along the Outlet Axis

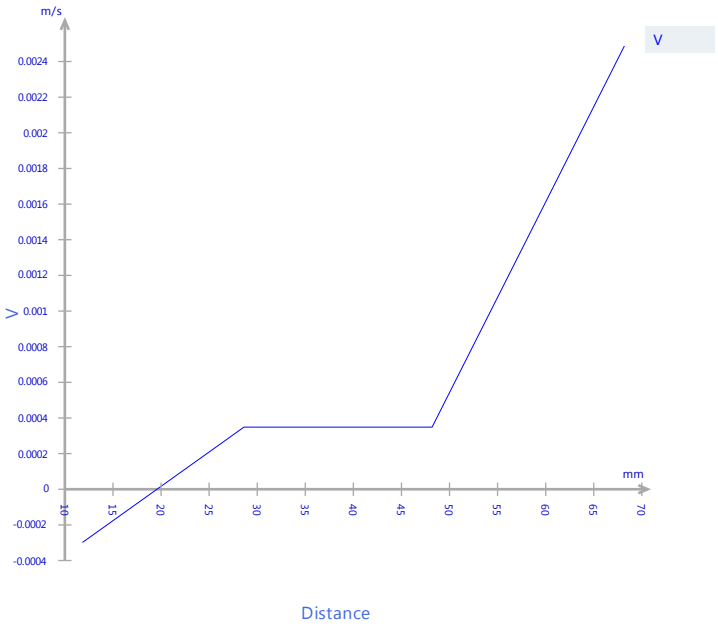

Figure B.26.2: Vertical Velocity (V) at the Outlet Side

Figure B.26: Velocity Profiles for Adaptive Correlation
[IA Size: 256× 256 pixels and Overlap Percentage (H%, V%): 0%, 0%]

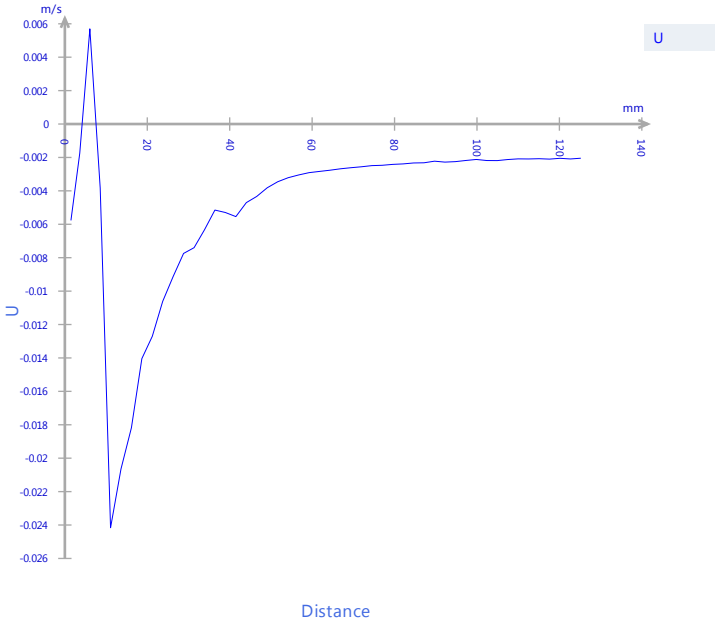

Figure B.27.1: Horizontal Velocity (U) along the Outlet Axis

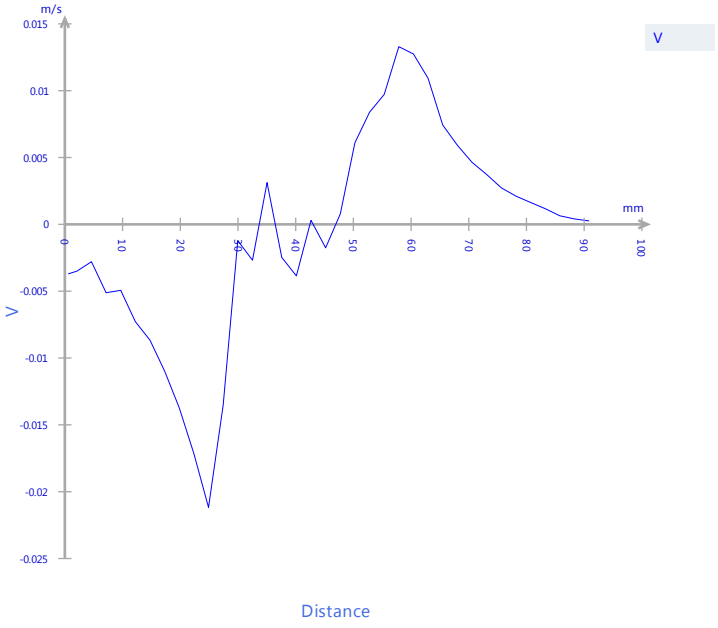

Figure B.27.2: Vertical Velocity (V) at the Outlet Side

Figure B.27: Velocity Profiles for Cross Correlation
[IA Size: 32 × 32 pixels and Overlap Percentage (H%, V%): 0%, 0%]

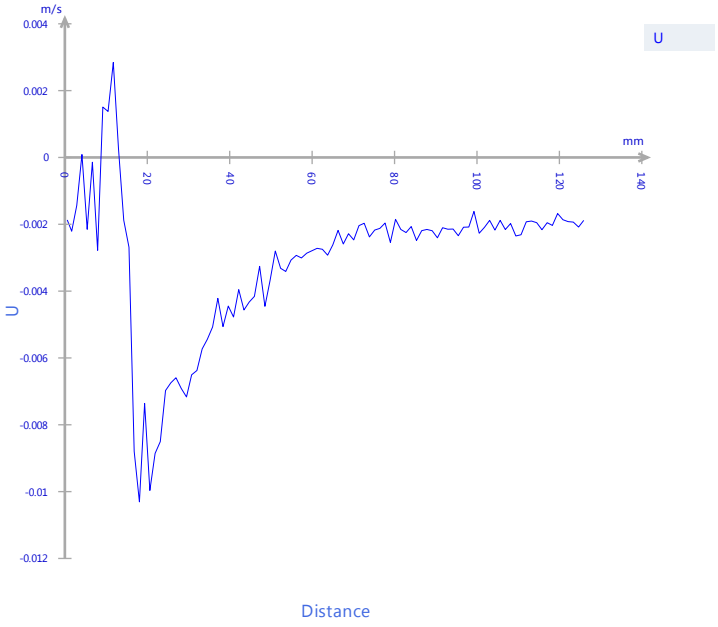

Figure B.28.1: Horizontal Velocity (U) along the Outlet Axis

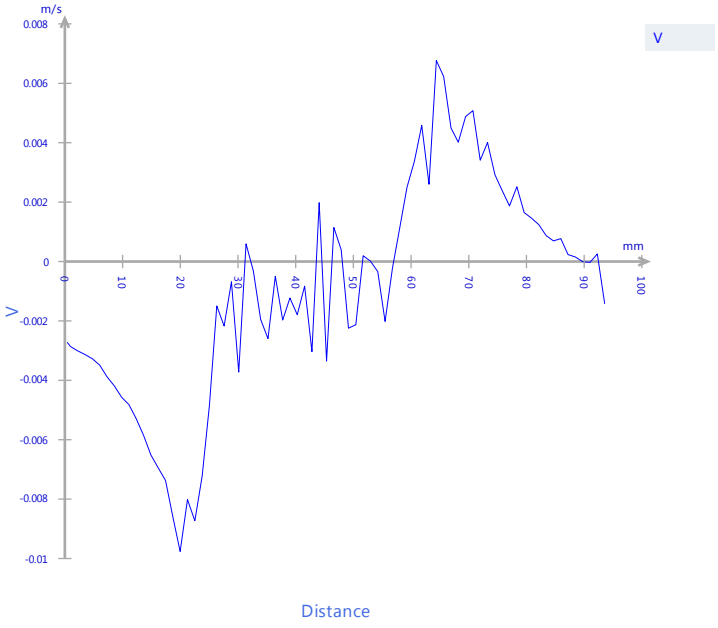

Figure B.28.2: Vertical Velocity (V) at the Outlet Side

Figure B.28: Velocity Profiles for Cross Correlation
[IA Size: 16× 16 pixels and Overlap Percentage (H%, V%): 0%, 0%]

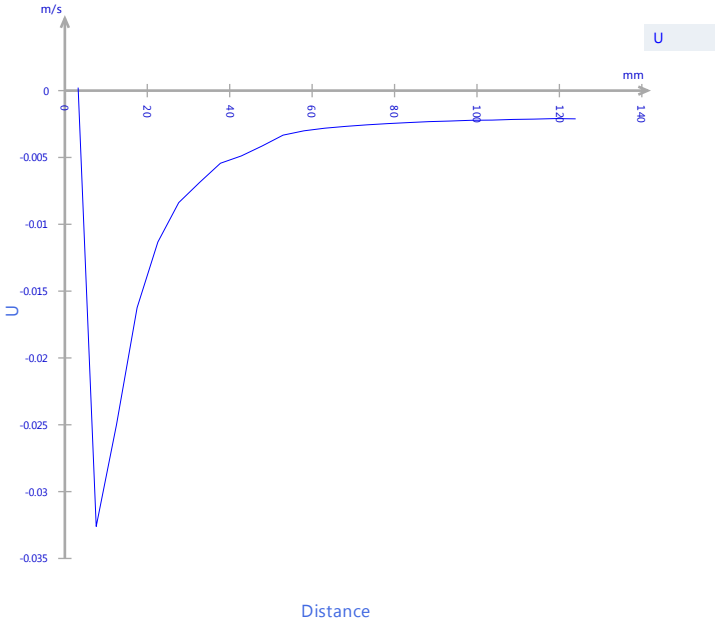

Figure B.29.1: Horizontal Velocity (U) along the Outlet Axis

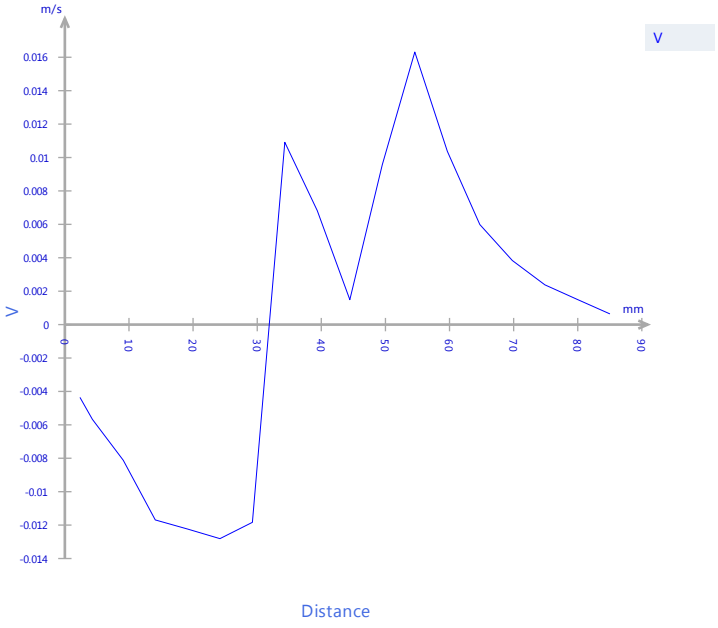

Figure B.29.2: Vertical Velocity (V) at the Outlet Side

Figure B.29: Velocity Profiles for Cross Correlation
[IA Size: 64× 64 pixels and Overlap Percentage (H%, V%): 0%, 0%]

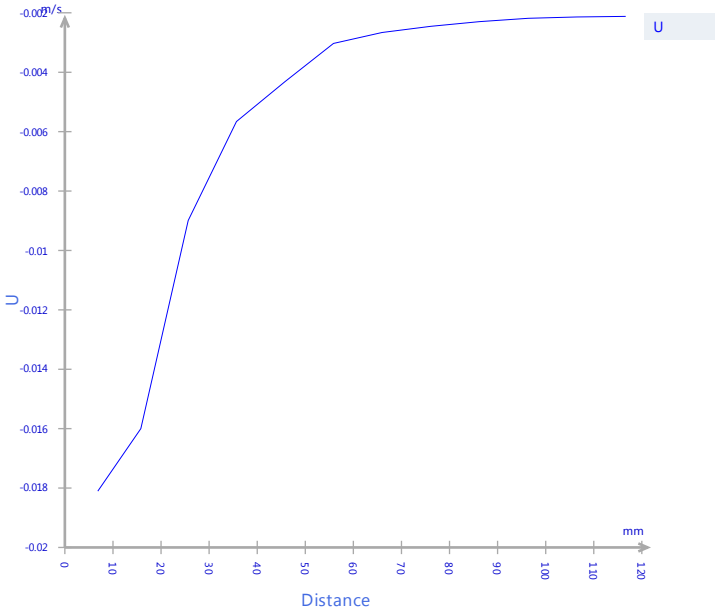

Figure B.30.1: Horizontal Velocity (U) along the Outlet Axis

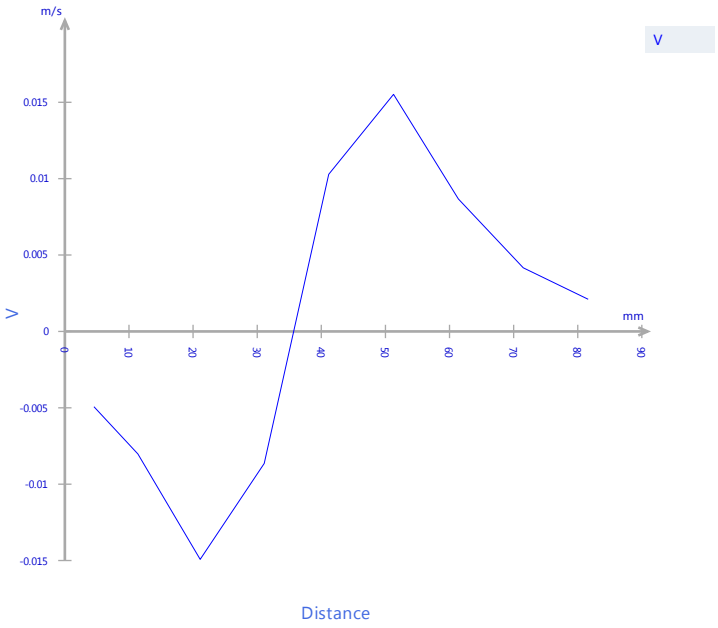

Figure B.30.2: Vertical Velocity (V) at the Outlet Side

Figure B.30: Velocity Profiles for Cross Correlation
[IA Size: 128× 128 pixels and Overlap Percentage (H%, V%): 0%, 0%]

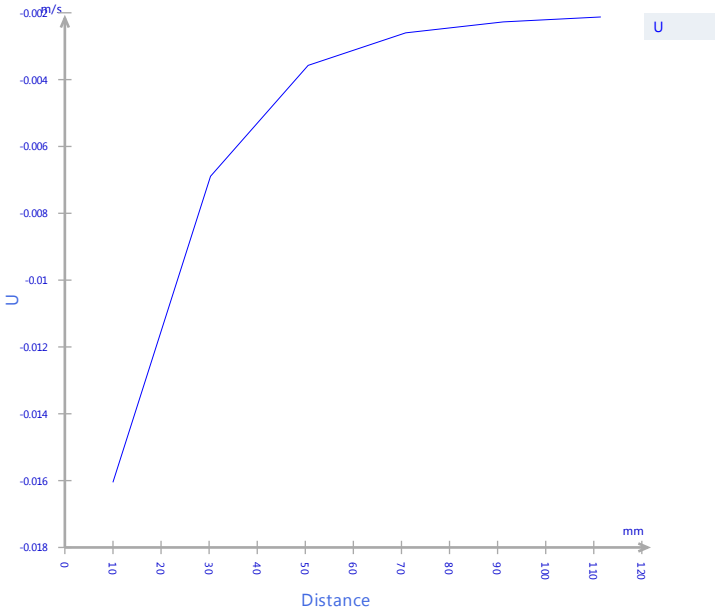

Figure B.31.1: Horizontal Velocity (U) along the Outlet Axis

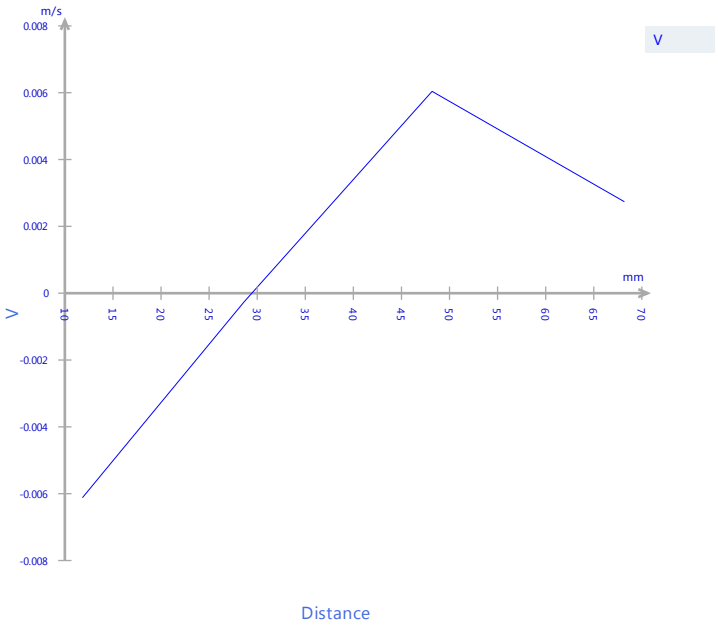

Figure B.31.2: Vertical Velocity (V) at the Outlet Side

Figure B.31: Velocity Profiles for Cross Correlation
[IA Size: 256× 256 pixels and Overlap Percentage (H%, V%): 0%, 0%]

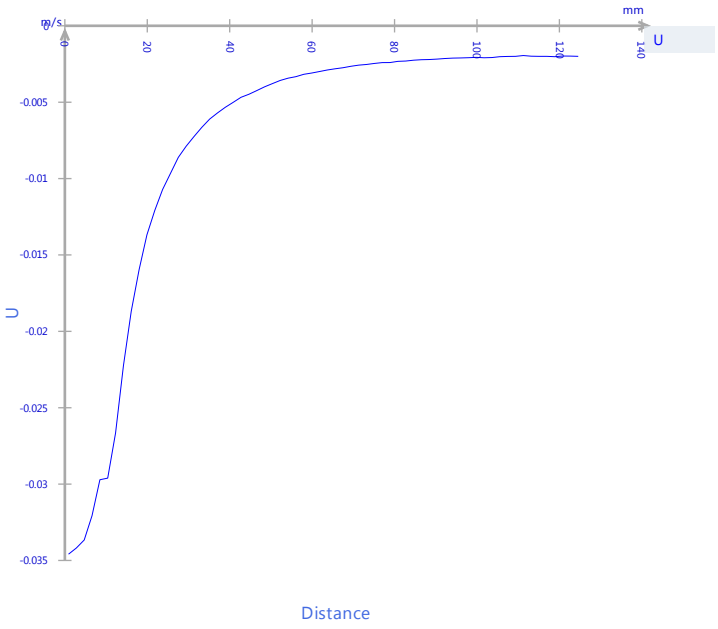

Figure B.32.1: Horizontal Velocity (U) along the Outlet Axis

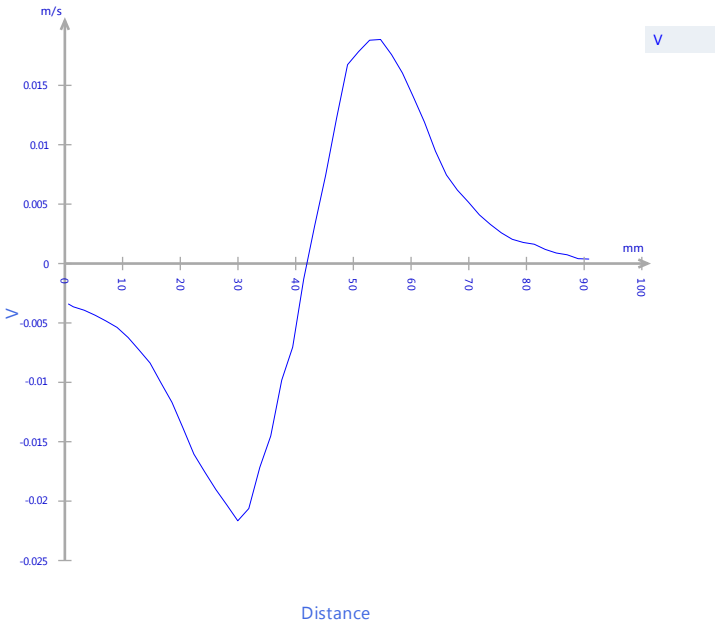

Figure B.32.2: Vertical Velocity (V) at the Outlet Side

Figure B.32: Velocity Profiles for Adaptive Correlation
[IA Size: 32 × 32 pixels and Overlap Percentage (H%, V%): 25%, 25%]

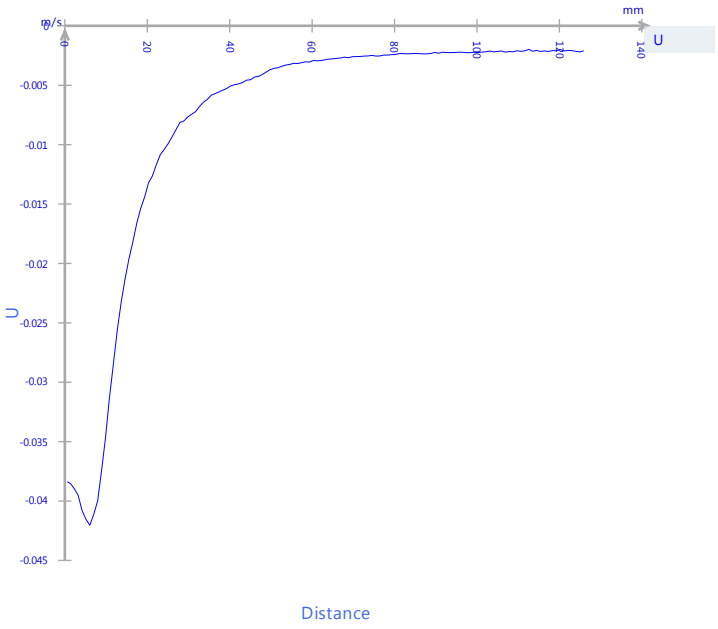

Figure B.33.1: Horizontal Velocity (U) along the Outlet Axis

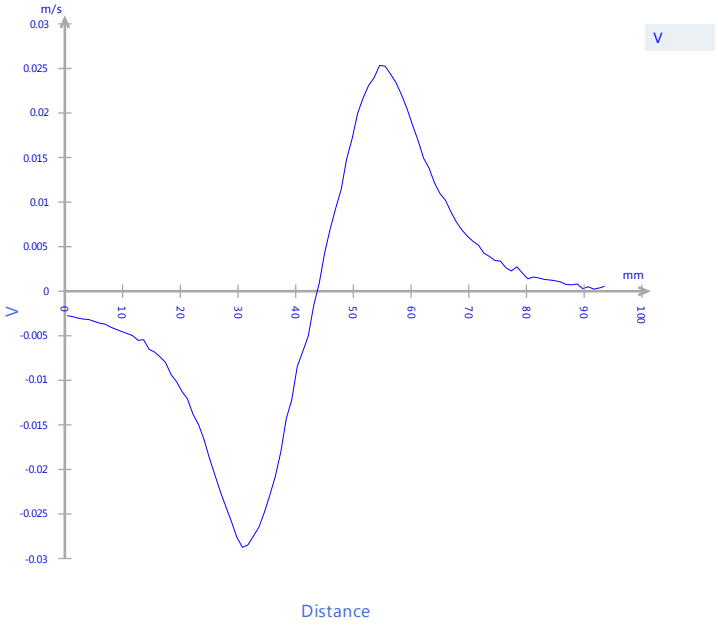

Figure B.33.2: Vertical Velocity (V) at the Outlet Side

Figure B.33: Velocity Profiles for Adaptive Correlation
[IA Size: 16× 16 pixels and Overlap Percentage (H%, V%): 25%, 25%]

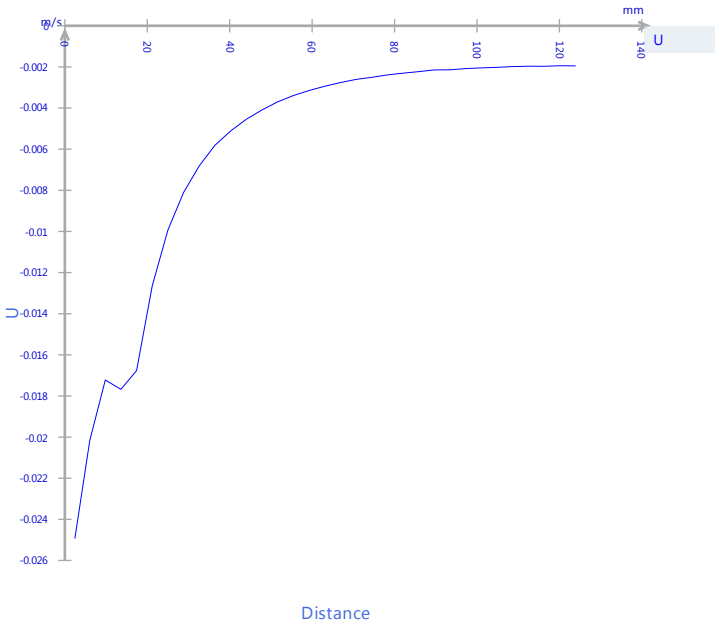

Figure B.34.1: Horizontal Velocity (U) along the Outlet Axis

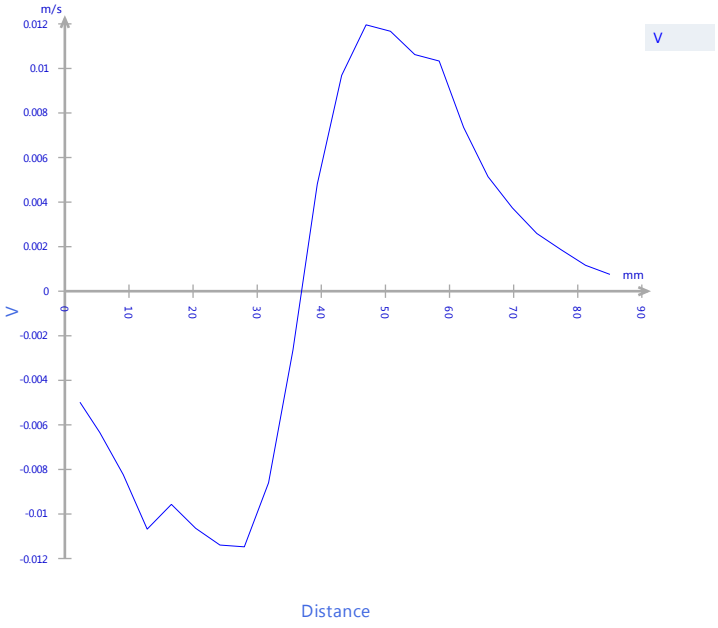

Figure B.34.2: Vertical Velocity (V) at the Outlet Side

Figure B.34: Velocity Profiles for Adaptive Correlation
[IA Size: 64× 64 pixels and Overlap Percentage (H%, V%): 25%, 25%]

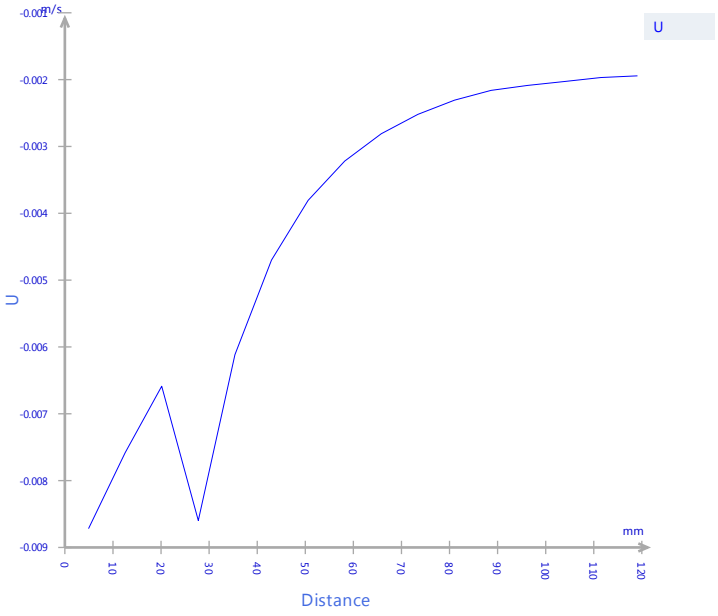

Figure B.35.1: Horizontal Velocity (U) along the Outlet Axis

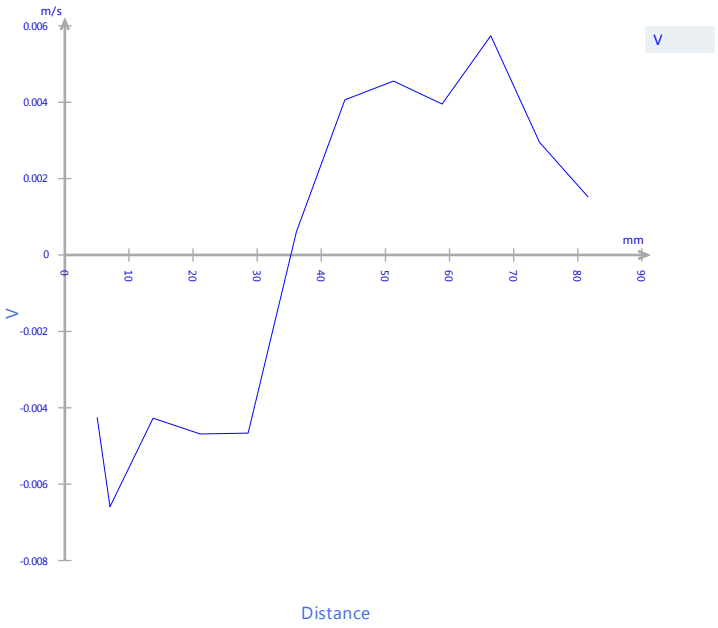

Figure B.35.2: Vertical Velocity (V) at the Outlet Side

Figure B.35: Velocity Profiles for Adaptive Correlation
[IA Size: 128× 128 pixels and Overlap Percentage (H%, V%): 25%, 25%]

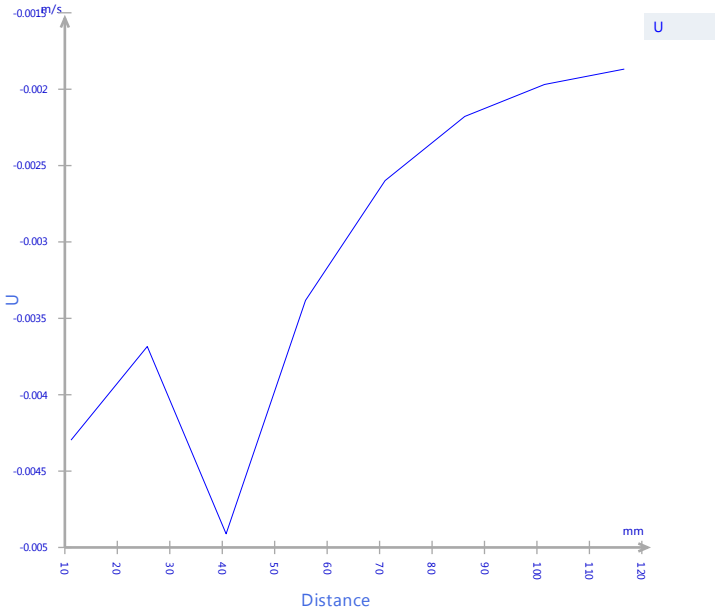

Figure B.36.1: Horizontal Velocity (U) along the Outlet Axis

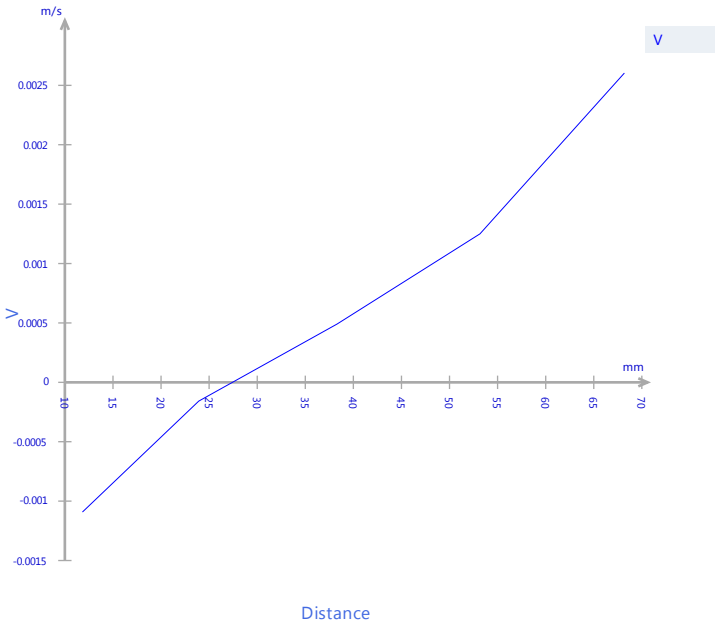

Figure B.36.2: Vertical Velocity (V) at the Outlet Side

Figure B.36: Velocity Profiles for Adaptive Correlation
[IA Size: 256× 256 pixels and Overlap Percentage (H%, V%): 25%, 25%]

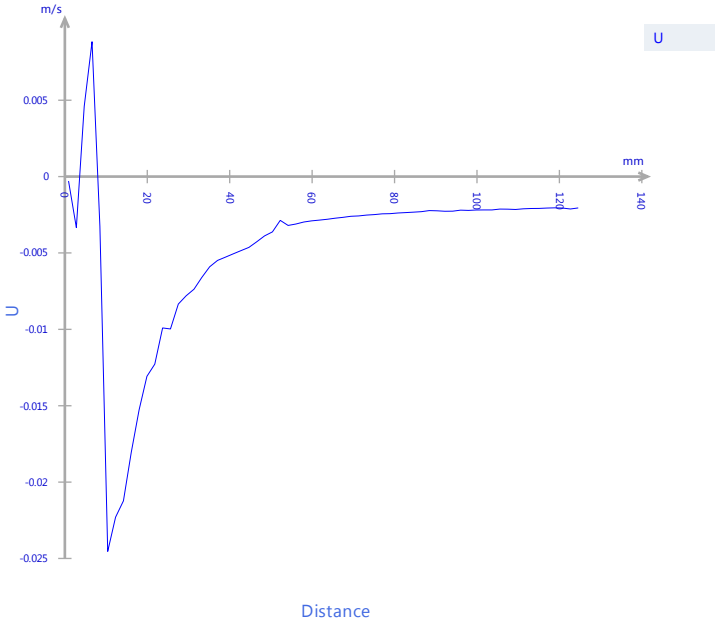

Figure B.37.1: Horizontal Velocity (U) along the Outlet Axis

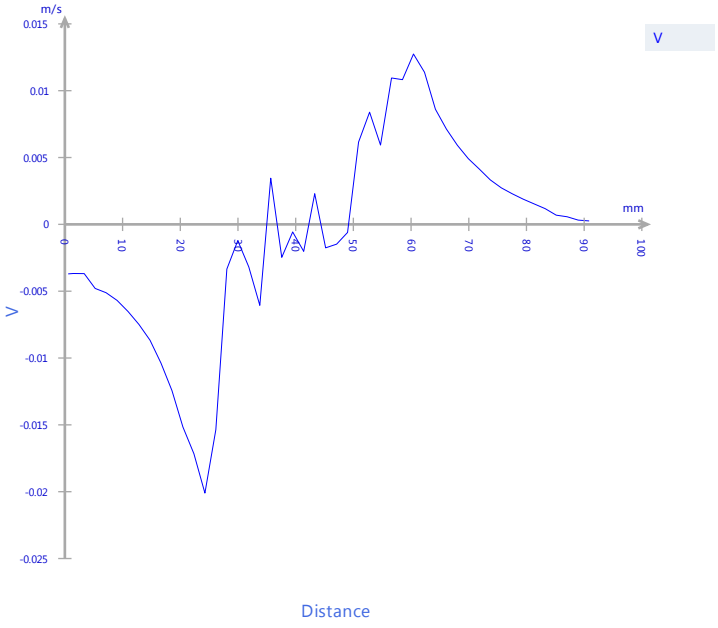

Figure B.37.2: Vertical Velocity (V) at the Outlet Side

Figure B.37: Velocity Profiles for Cross Correlation
[IA Size: 32 × 32 pixels and Overlap Percentage (H%, V%): 25%, 25%]

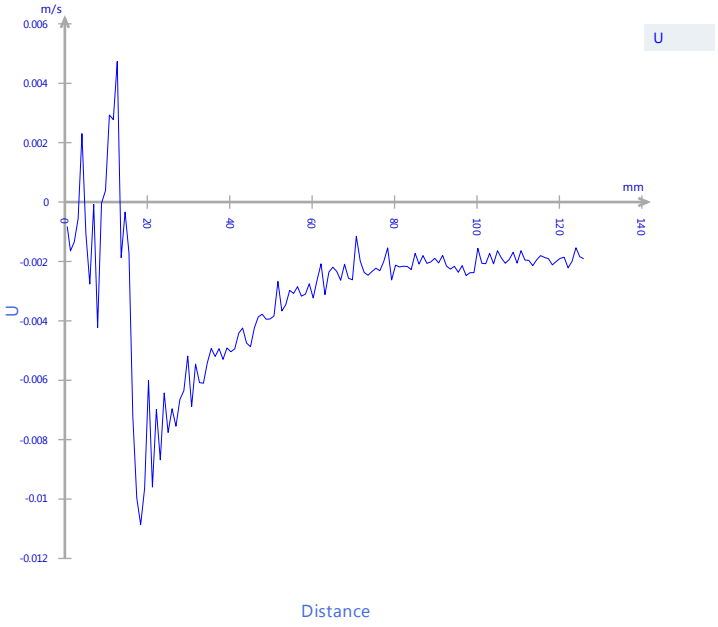

Figure B.38.1: Horizontal Velocity (U) along the Outlet Axis

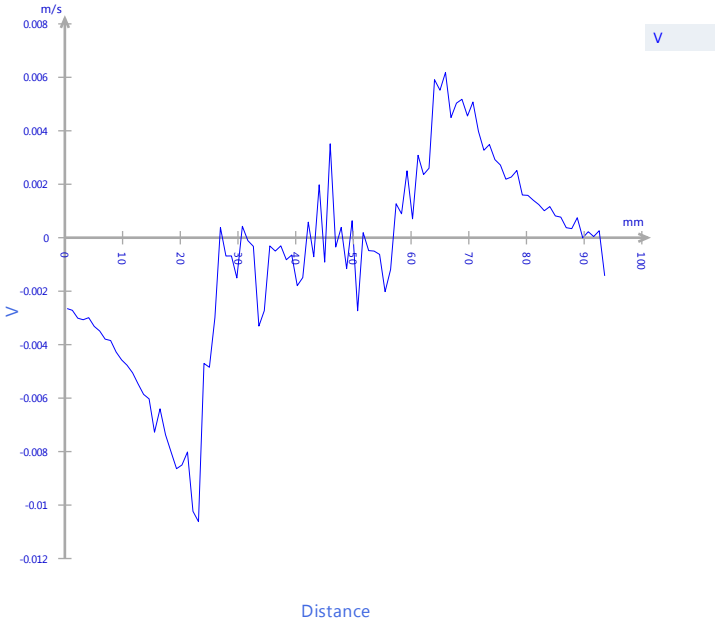

Figure B.38.2: Vertical Velocity (V) at the Outlet Side

Figure B.38: Velocity Profiles for Cross Correlation
[IA Size: 16× 16 pixels and Overlap Percentage (H%, V%): 25%, 25%]

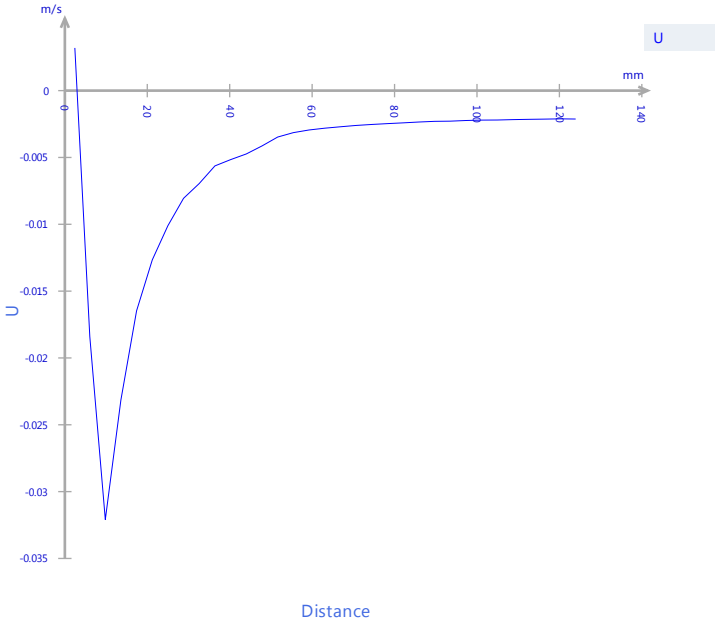

Figure B.39.1: Horizontal Velocity (U) along the Outlet Axis

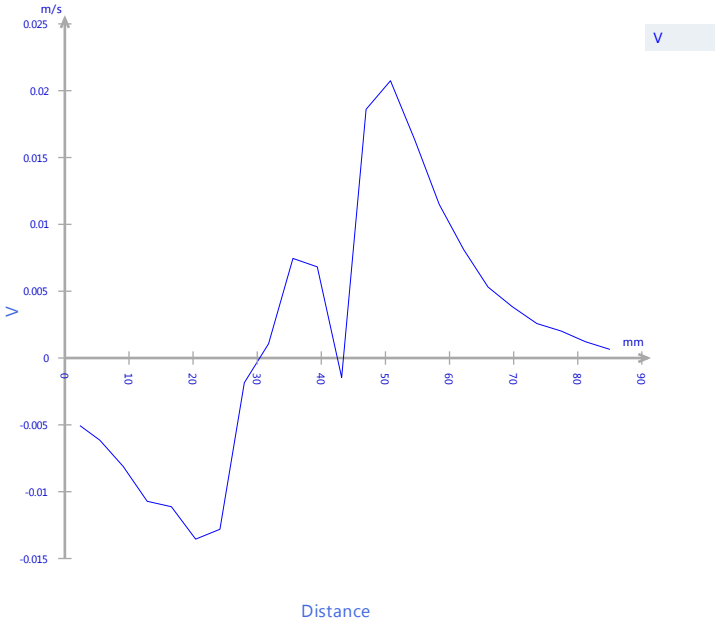

Figure B.39.2: Vertical Velocity (V) at the Outlet Side

Figure B.39: Velocity Profiles for Cross Correlation
[IA Size: 64× 64 pixels and Overlap Percentage (H%, V%): 25%, 25%]

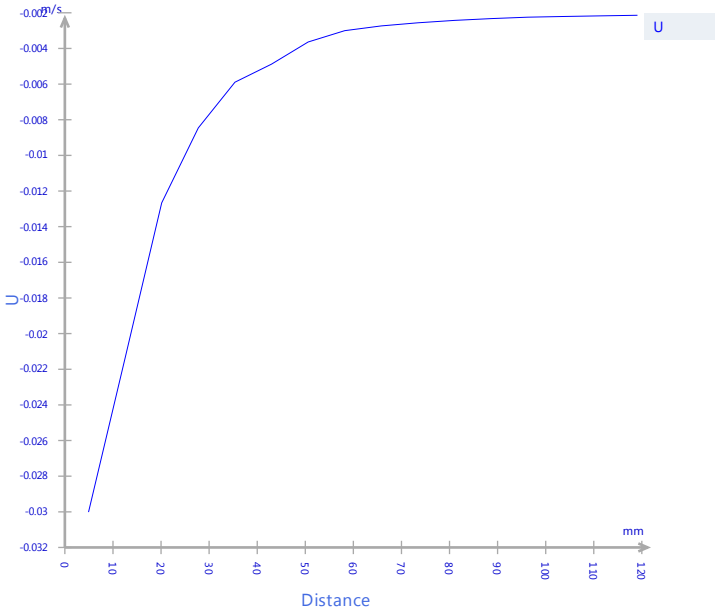

Figure B.40.1: Horizontal Velocity (U) along the Outlet Axis

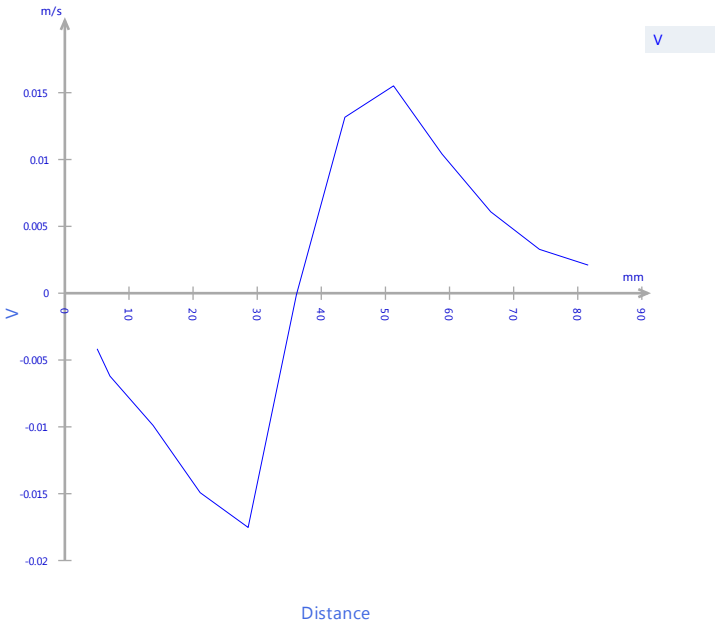

Figure B.40.2: Vertical Velocity (V) at the Outlet Side

Figure B.40: Velocity Profiles for Cross Correlation
[IA Size: 128× 128 pixels and Overlap Percentage (H%, V%): 25%, 25%]

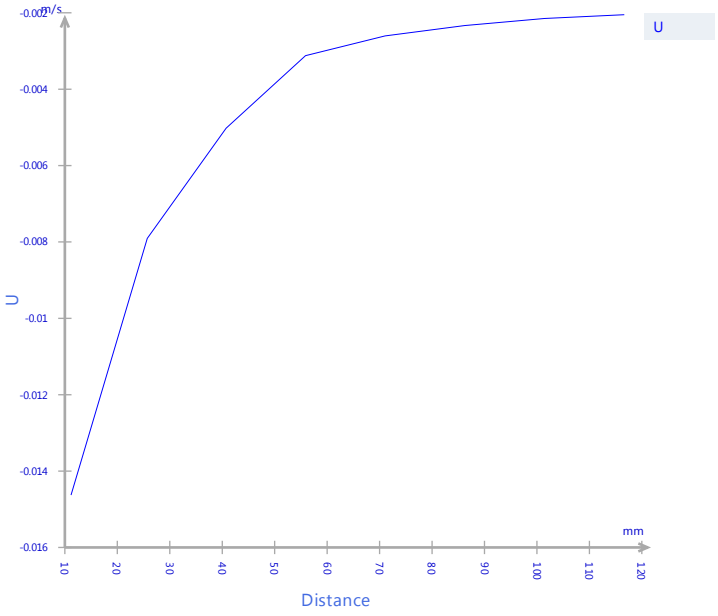

Figure B.41.1: Horizontal Velocity (U) along the Outlet Axis

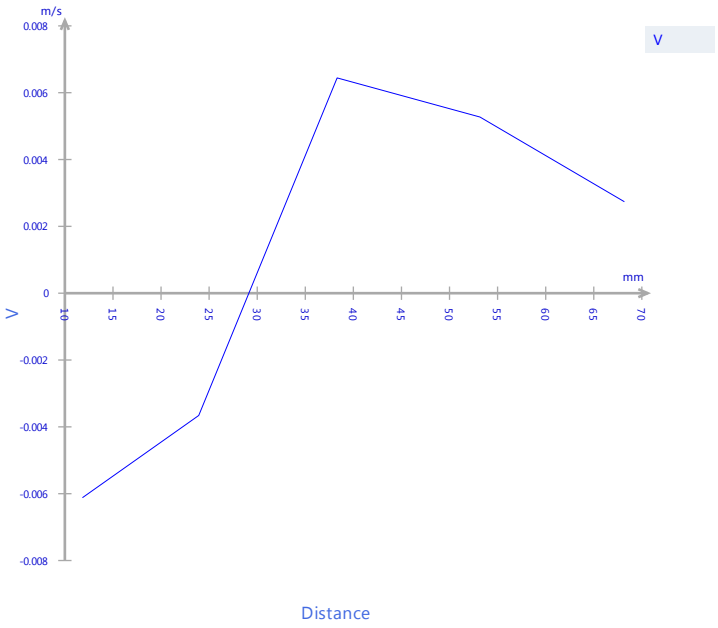

Figure B.41.2: Vertical Velocity (V) at the Outlet Side

Figure B.41: Velocity Profiles for Cross Correlation
[IA Size: 256× 256 pixels and Overlap Percentage (H%, V%): 25%, 25%]

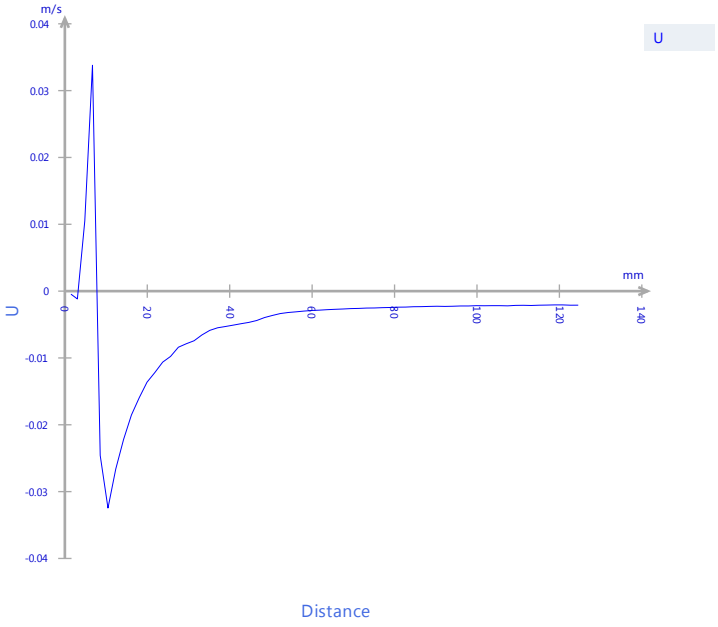

Figure B.42.1: Horizontal Velocity (U) along the Outlet Axis

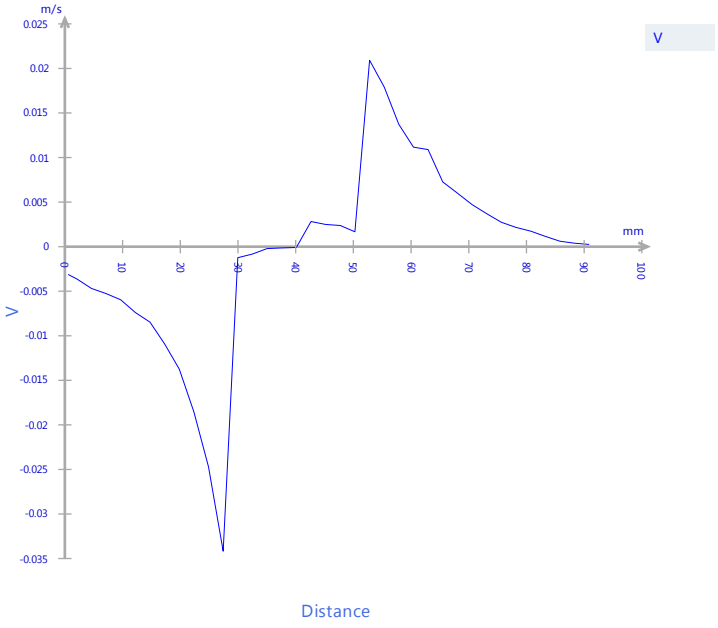

Figure B.42.2: Vertical Velocity (V) at the Outlet Side

Figure B.42: Velocity Profiles for Average Correlation
[IA Size: 32×32 pixels and Overlap Percentage (H%, V%): 25%, 0%]

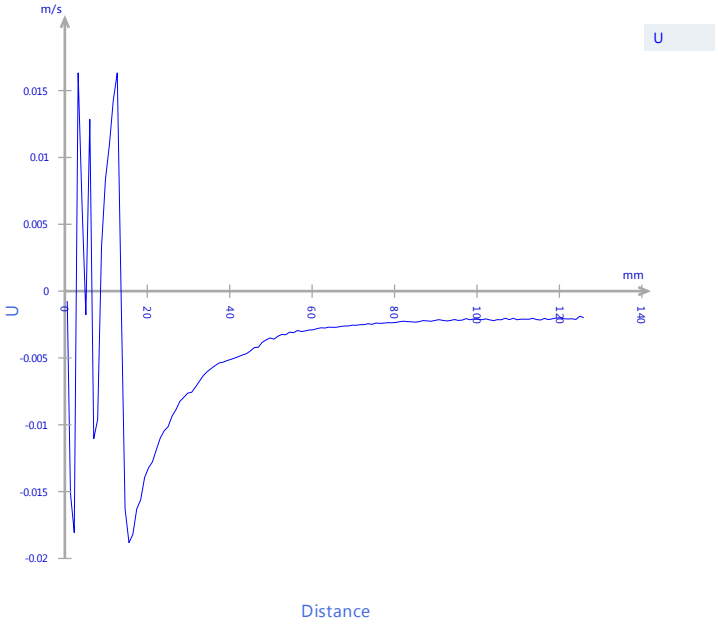

Figure B.43.1: Horizontal Velocity (U) along the Outlet Axis

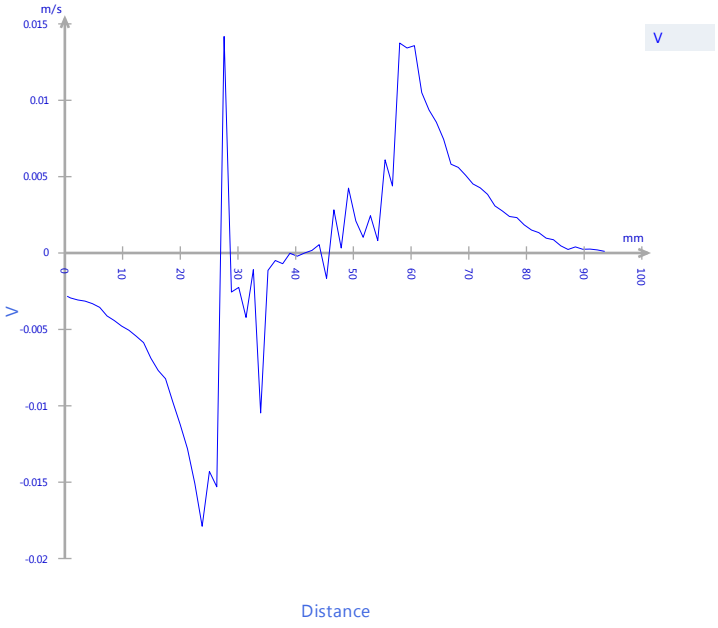

Figure B.43.2: Vertical Velocity (V) at the Outlet Side

Figure B.43: Velocity Profiles for Average Correlation
[IA Size: 16× 16 pixels and Overlap Percentage (H%, V%): 25%, 0%]

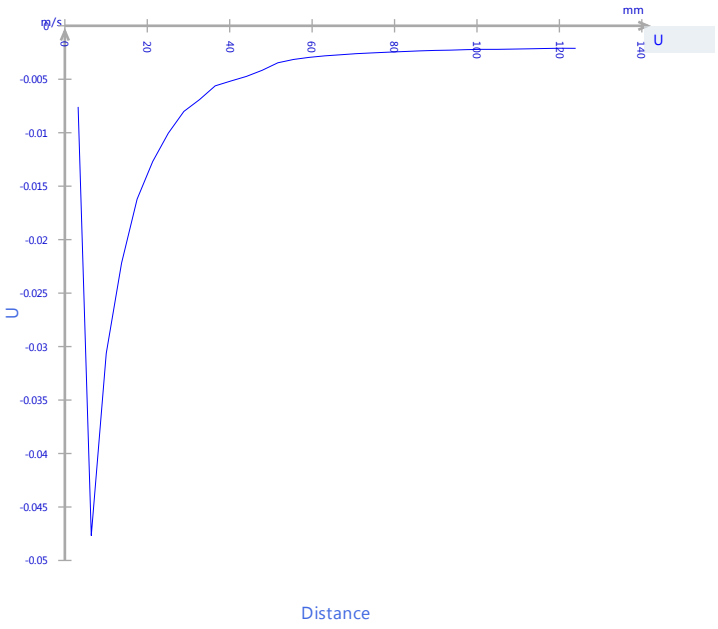

Figure B.44.1: Horizontal Velocity (U) along the Outlet Axis

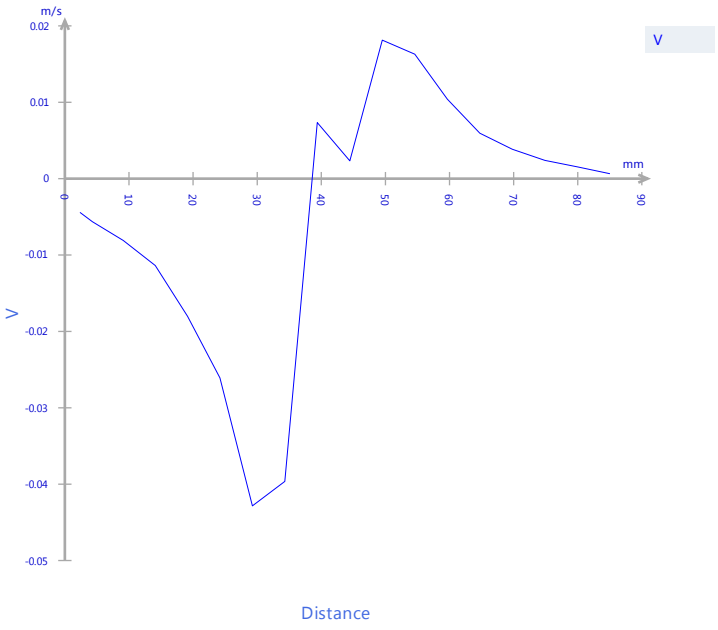

Figure B.44.2: Vertical Velocity (V) at the Outlet Side

Figure B.44: Velocity Profiles for Average Correlation
[IA Size: 64× 64 pixels and Overlap Percentage (H%, V%): 25%, 0%]

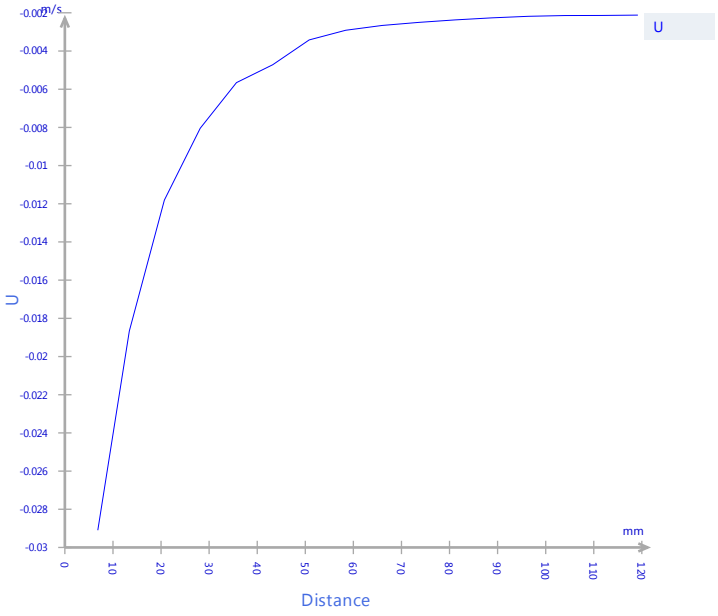

Figure B.45.1: Horizontal Velocity (U) along the Outlet Axis

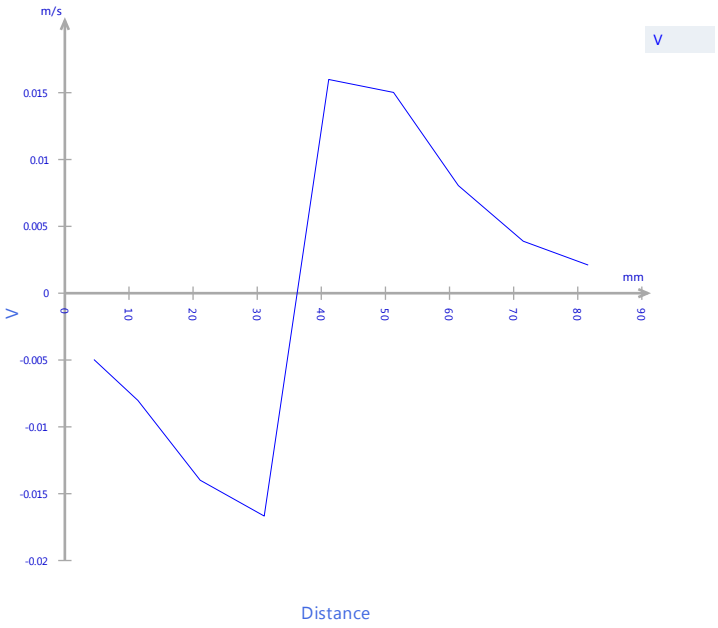

Figure B.45.2: Vertical Velocity (V) at the Outlet Side

Figure B.45: Velocity Profiles for Average Correlation
[IA Size: 128× 128 pixels and Overlap Percentage (H%, V%): 25%, 0%]

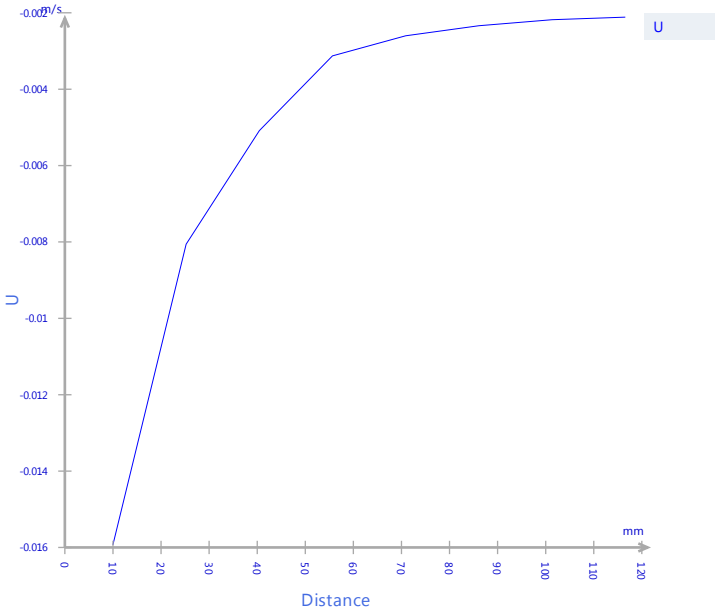

Figure B.46.1: Horizontal Velocity (U) along the Outlet Axis

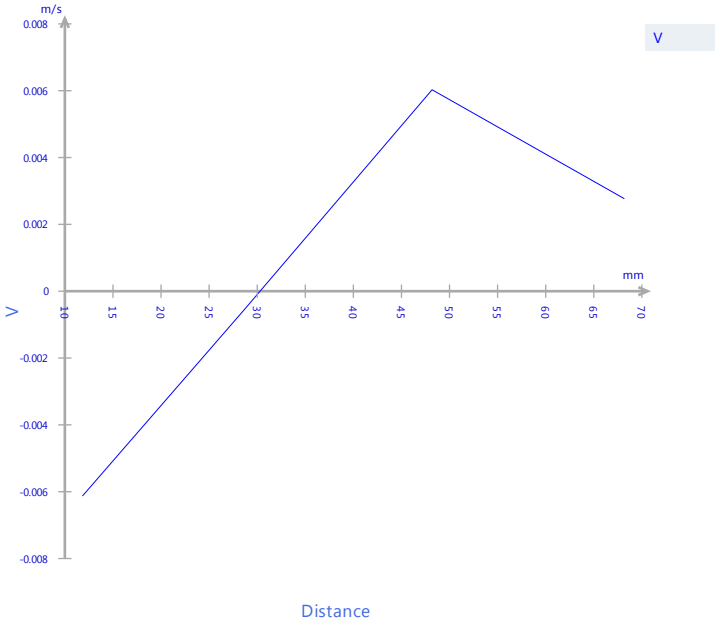

Figure B.46.2: Vertical Velocity (V) at the Outlet Side

Figure B.46: Velocity Profiles for Average Correlation
[IA Size: 256× 256 pixels and Overlap Percentage (H%, V%): 25%, 0%]

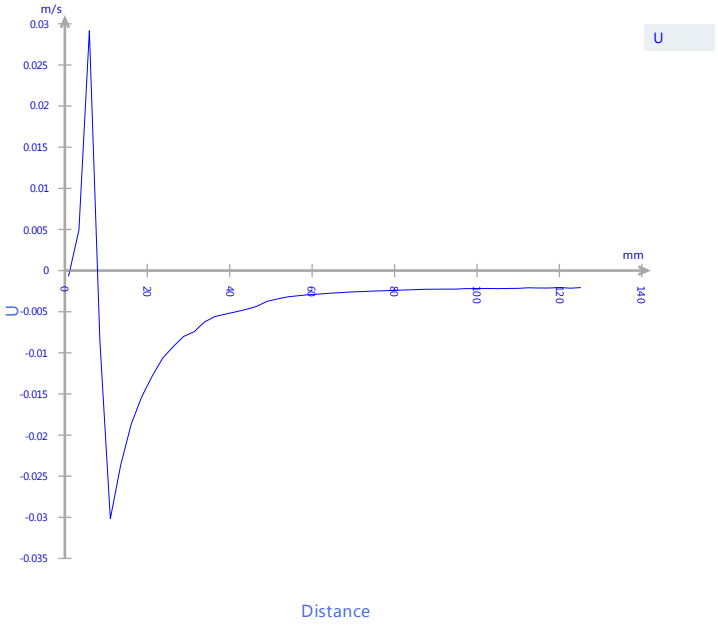

Figure B.47.1: Horizontal Velocity (U) along the Outlet Axis

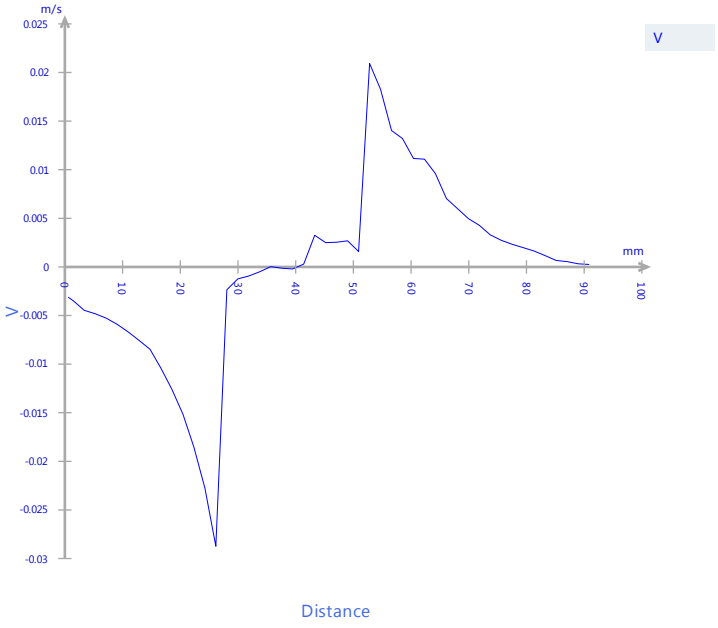

Figure B.47.2: Vertical Velocity (V) at the Outlet Side

Figure B.47: Velocity Profiles for Average Correlation
[IA Size: 32×32 pixels and Overlap Percentage (H%, V%): 0%, 25%]

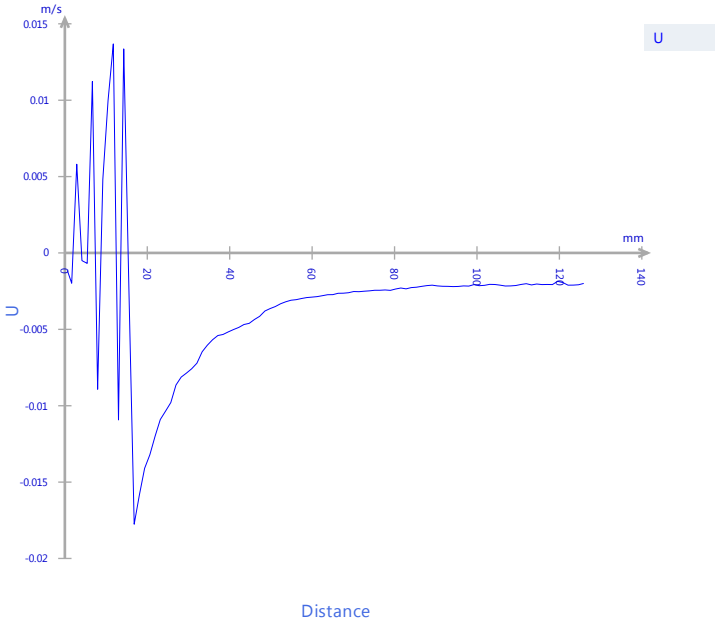

Figure B.48.1: Horizontal Velocity (U) along the Outlet Axis

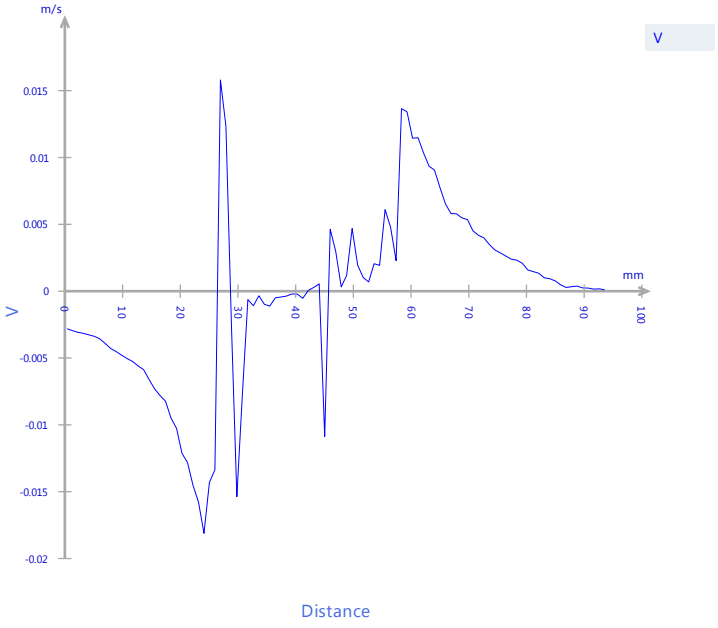

Figure B.48.2: Vertical Velocity (V) at the Outlet Side

Figure B.48: Velocity Profiles for Average Correlation
[IA Size: 16× 16 pixels and Overlap Percentage (H%, V%): 0%, 25%]

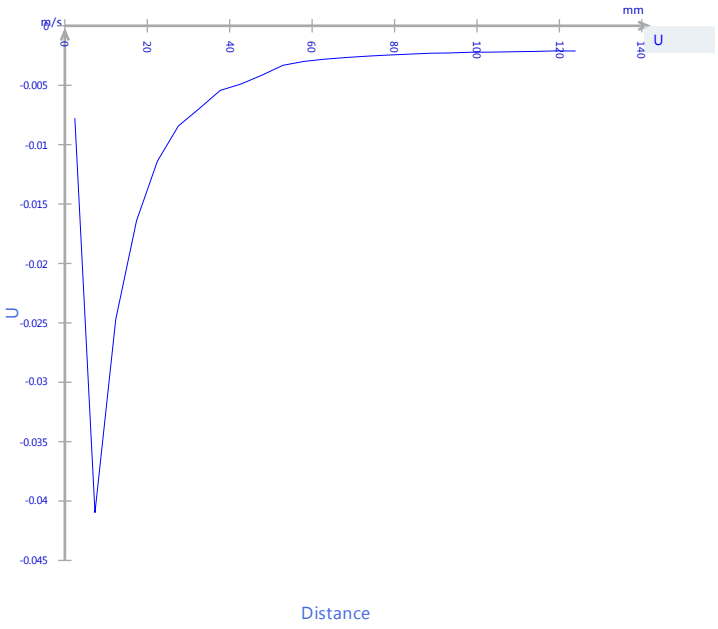

Figure B.49.1: Horizontal Velocity (U) along the Outlet Axis

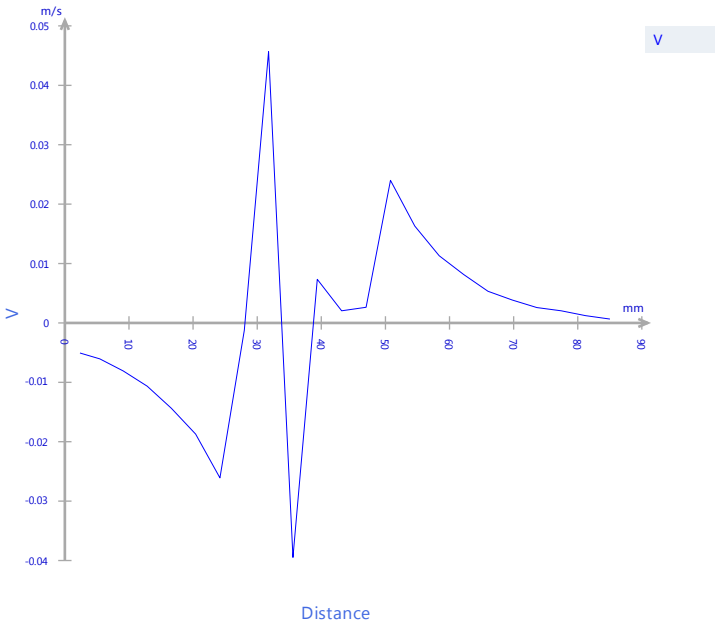

Figure B.49.2: Vertical Velocity (V) at the Outlet Side

Figure B.49: Velocity Profiles for Average Correlation
[IA Size: 64× 64 pixels and Overlap Percentage (H%, V%): 0%, 25%]

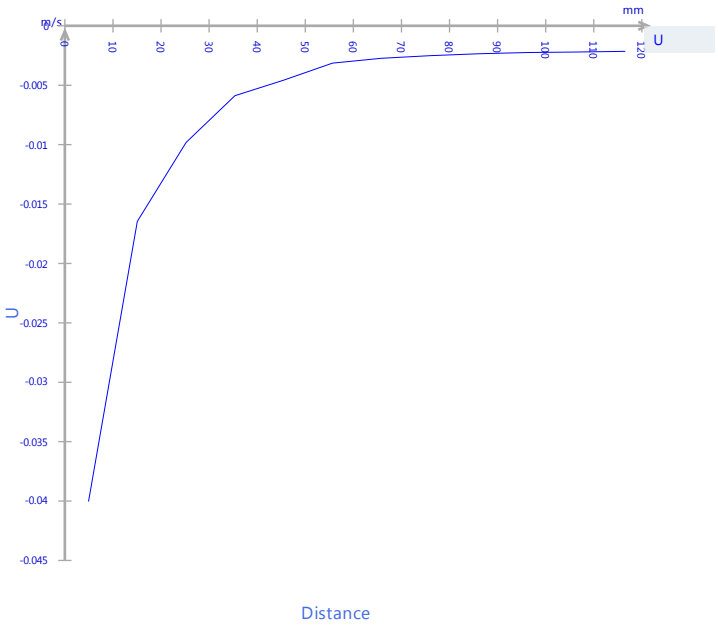

Figure B.50.1: Horizontal Velocity (U) along the Outlet Axis

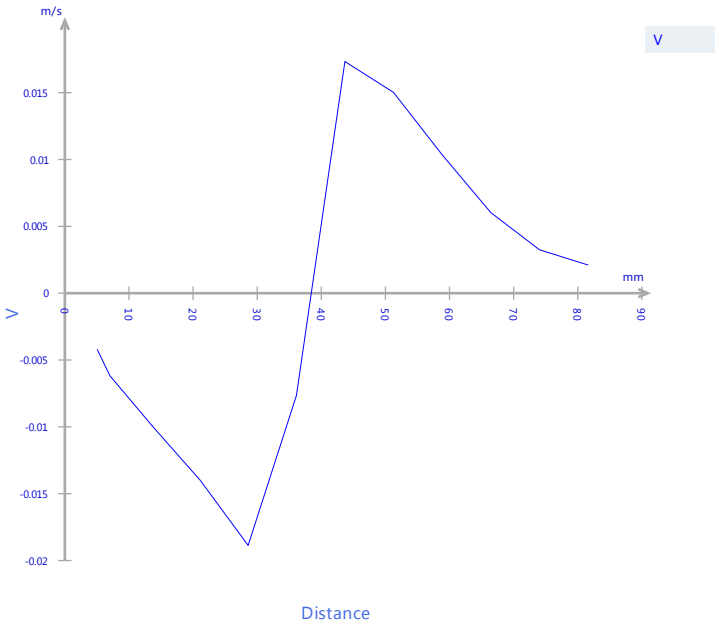

Figure B.50.2: Vertical Velocity (V) at the Outlet Side

Figure B.50: Velocity Profiles for Average Correlation
[IA Size: 128× 128 pixels and Overlap Percentage (H%, V%): 0%, 25%]

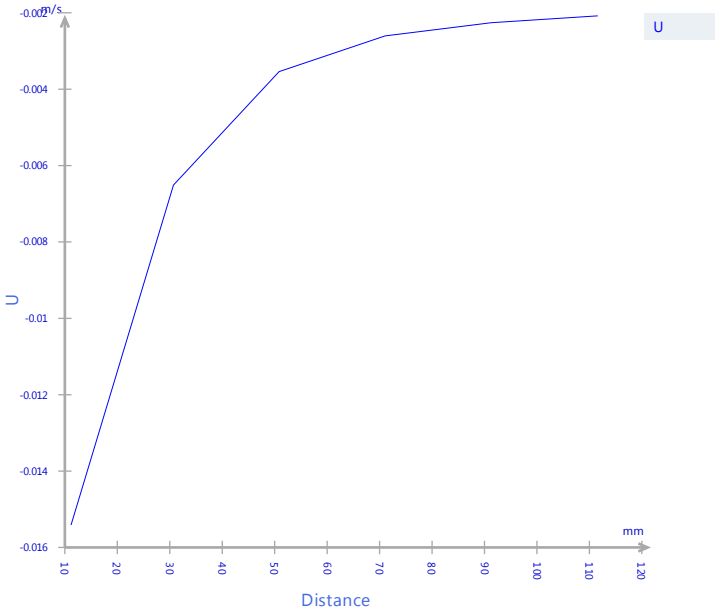

Figure B.51.1: Horizontal Velocity (U) along the Outlet Axis

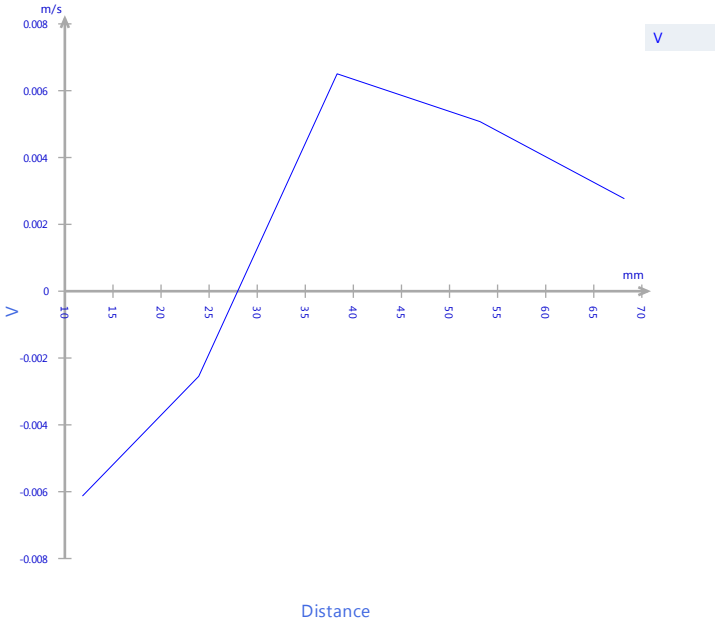

Figure B.51.2: Vertical Velocity (V) at the Outlet Side

Figure B.51: Velocity Profiles for Average Correlation
[IA Size: 256× 256 pixels and Overlap Percentage (H%, V%): 0%, 25%]

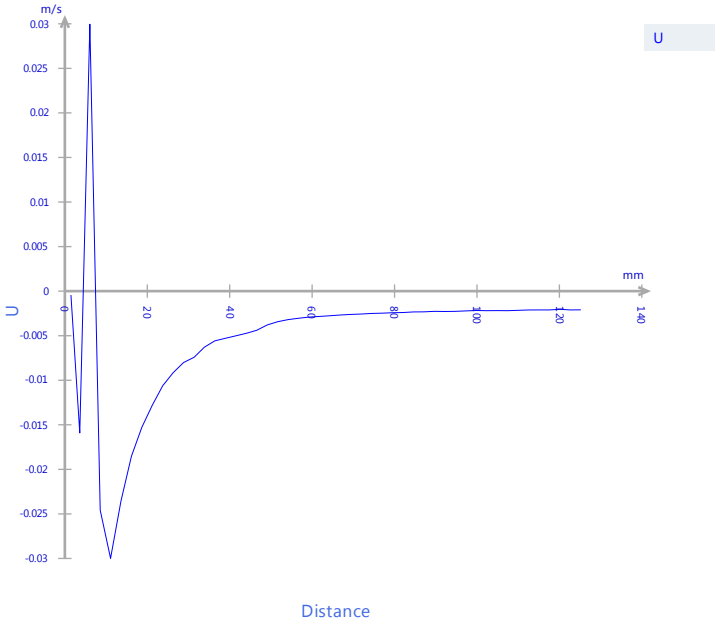

Figure B.52.1: Horizontal Velocity (U) along the Outlet Axis

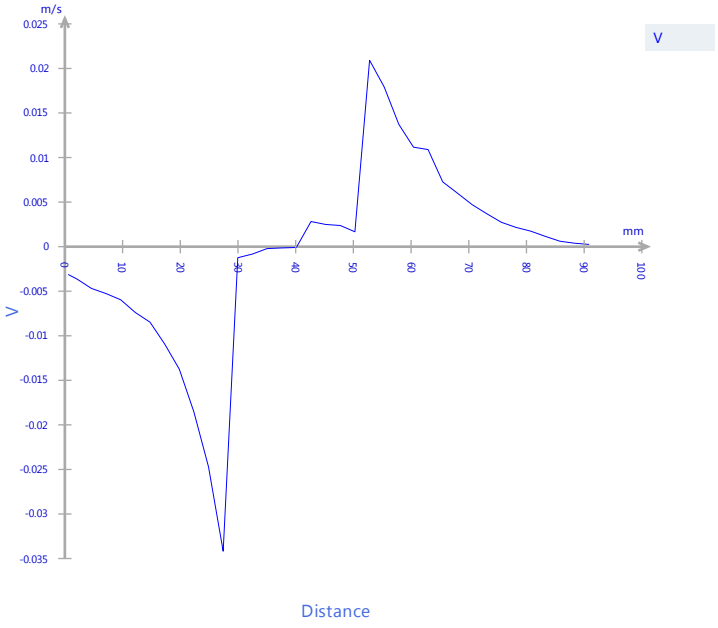

Figure B.52.2: Vertical Velocity (V) at the Outlet Side

Figure B.52: Velocity Profiles for Average Correlation
[IA Size: 32× 32 pixels and Overlap Percentage (H%, V%): 0%, 0%]

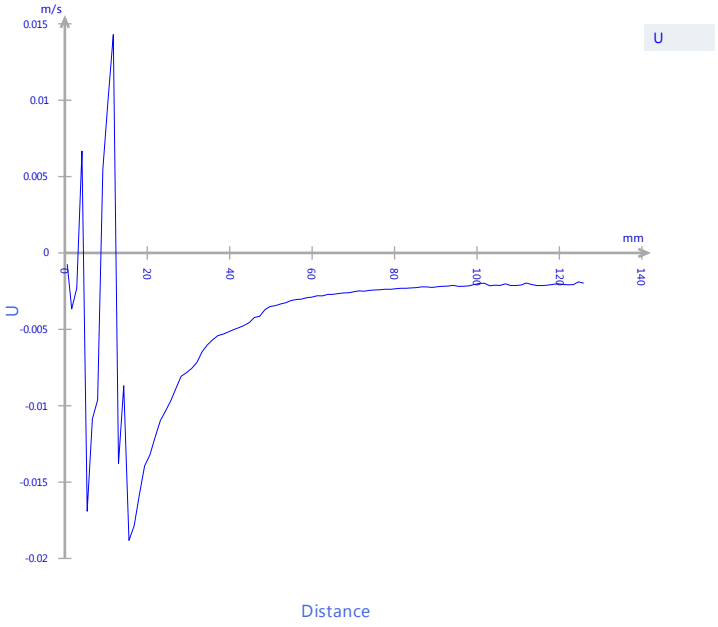

Figure B.53.1: Horizontal Velocity (U) along the Outlet Axis

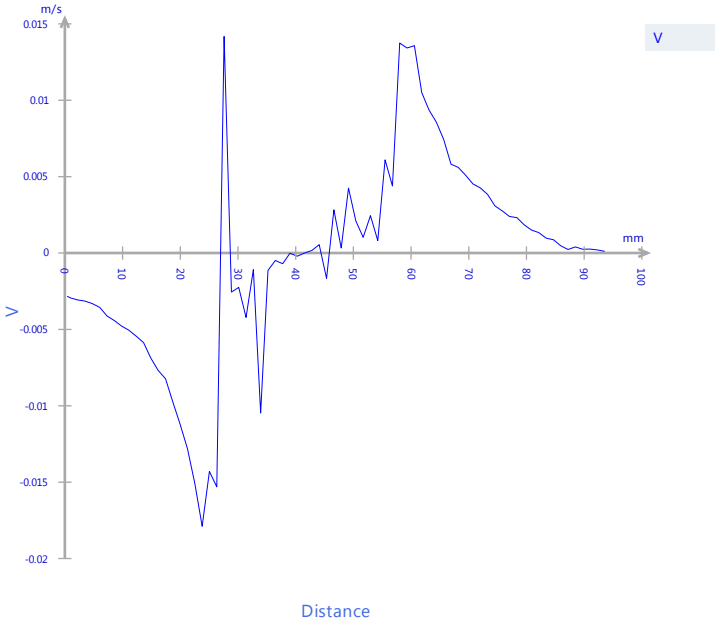

Figure B.53.2: Vertical Velocity (V) at the Outlet Side

Figure B.53: Velocity Profiles for Average Correlation
[IA Size: 16× 16 pixels and Overlap Percentage (H%, V%): 0%, 0%]

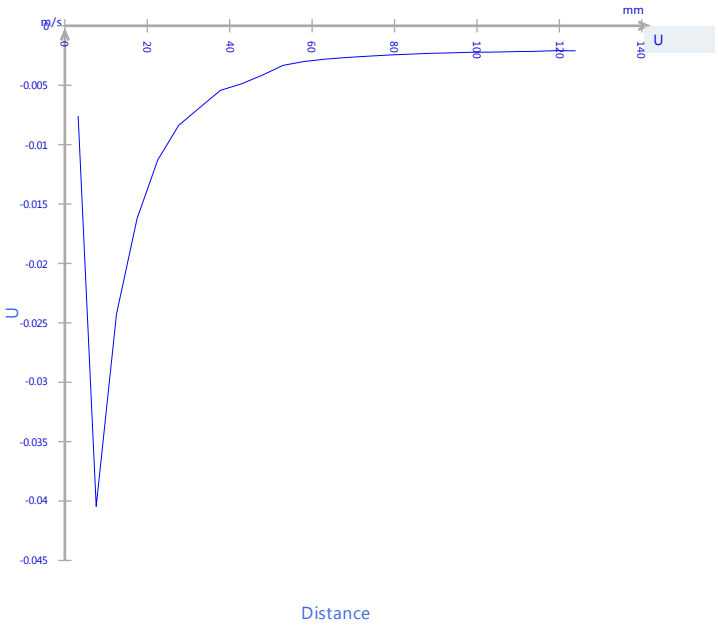

Figure B.54.1: Horizontal Velocity (U) along the Outlet Axis

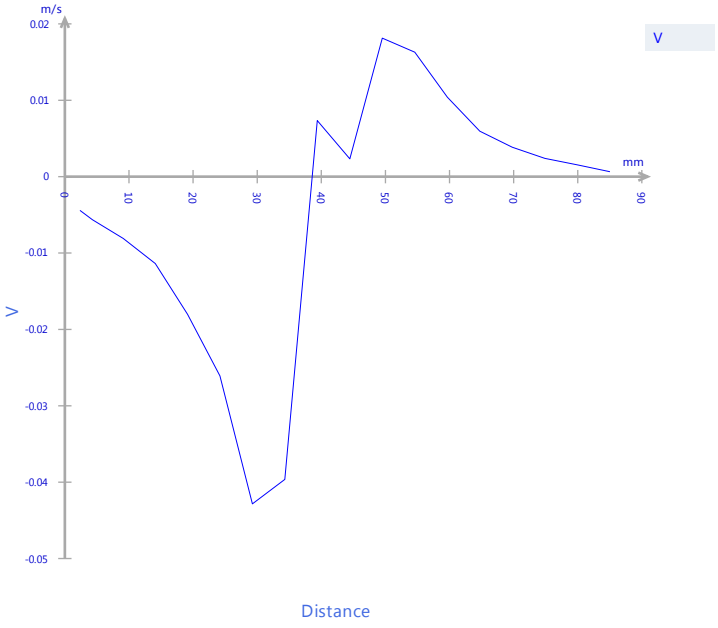

Figure B.54.2: Vertical Velocity (V) at the Outlet Side

Figure B.54: Velocity Profiles for Average Correlation
[IA Size: 64× 64 pixels and Overlap Percentage (H%, V%): 0%, 0%]

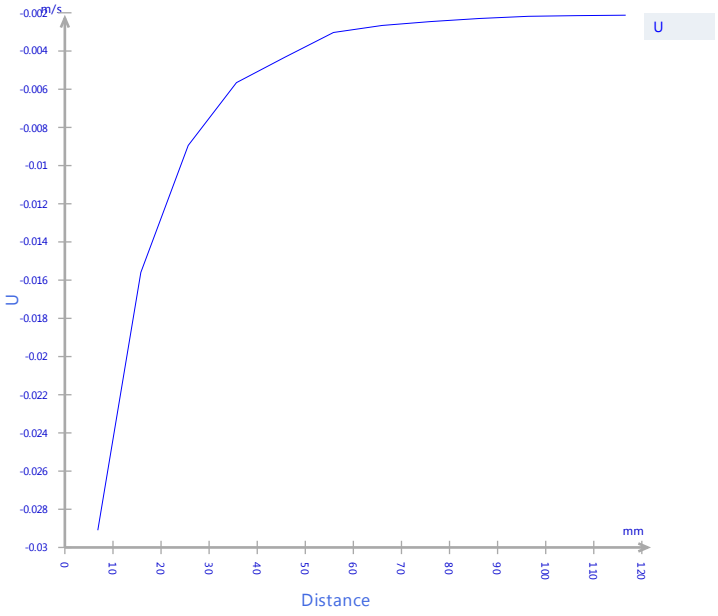

Figure B.55.1: Horizontal Velocity (U) along the Outlet Axis

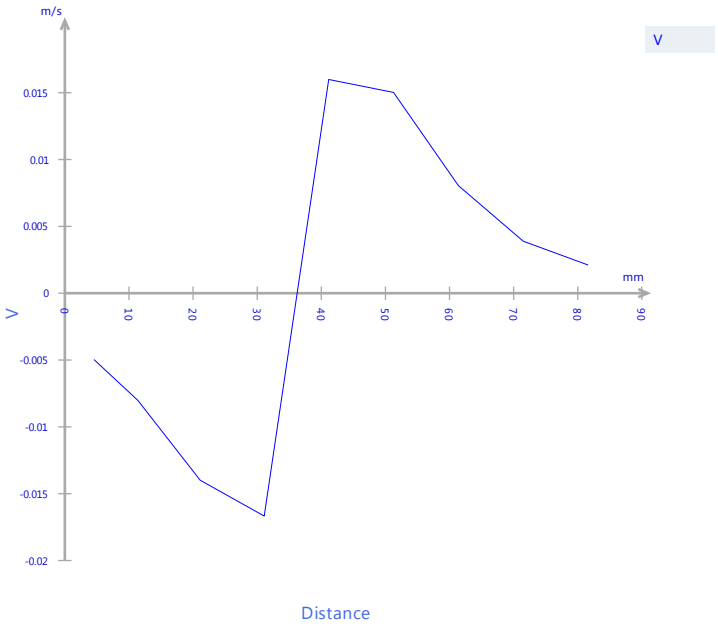

Figure B.55.2: Vertical Velocity (V) at the Outlet Side

Figure B.55: Velocity Profiles for Average Correlation
[IA Size: 128× 128 pixels and Overlap Percentage (H%, V%): 0%, 0%]

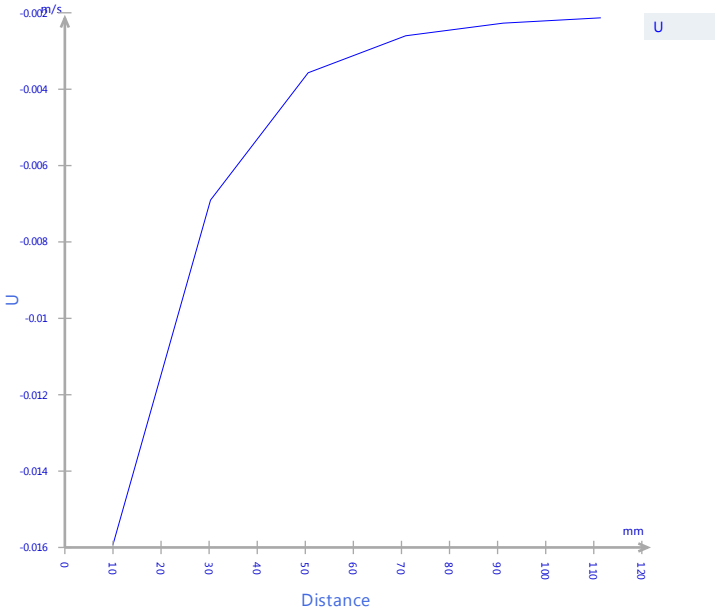

Figure B.56.1: Horizontal Velocity (U) along the Outlet Axis

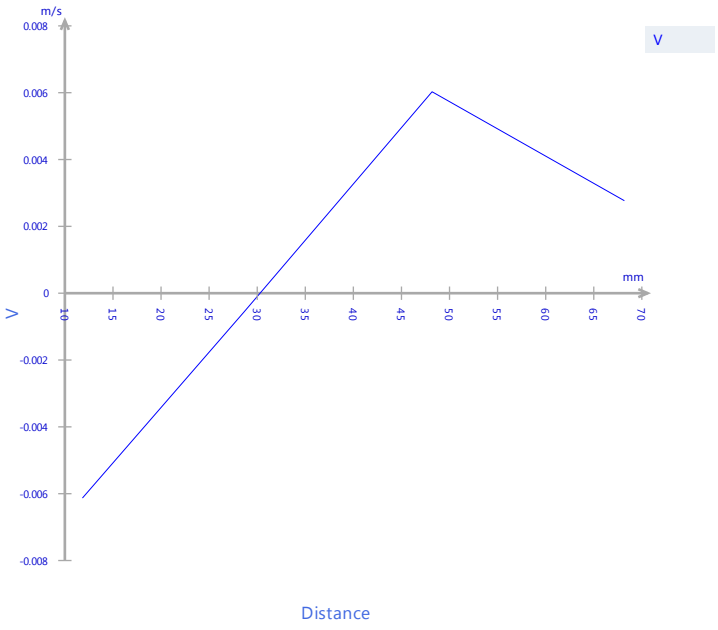

Figure B.56.2: Vertical Velocity (V) at the Outlet Side

Figure B.56: Velocity Profiles for Average Correlation
[IA Size: 256× 256 pixels and Overlap Percentage (H%, V%): 0%, 0%]

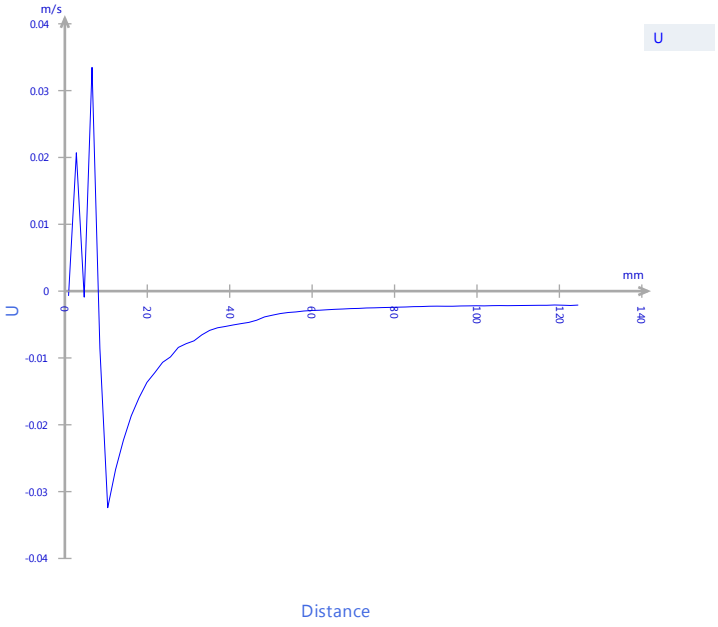

Figure B.57.1: Horizontal Velocity (U) along the Outlet Axis

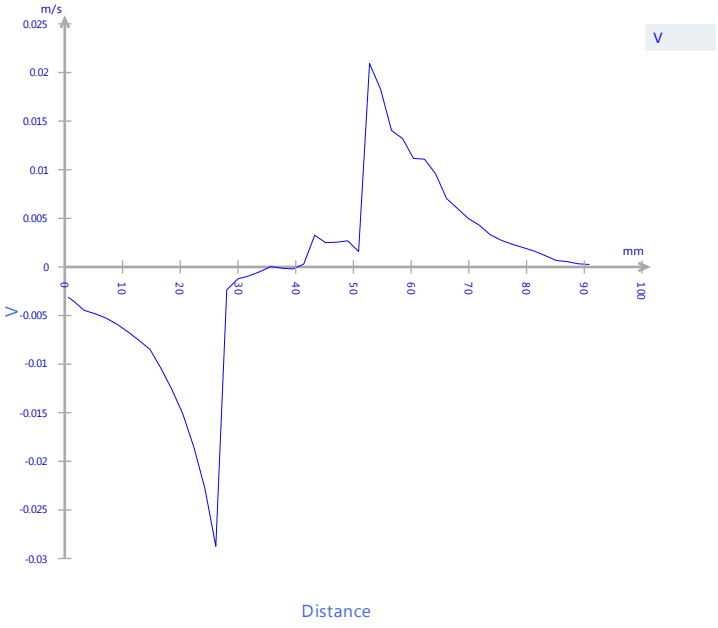

Figure B.57.2: Vertical Velocity (V) at the Outlet Side

Figure B.57: Velocity Profiles for Average Correlation
[IA Size: 32 × 32 pixels and Overlap Percentage (H%, V%): 25%, 25%]

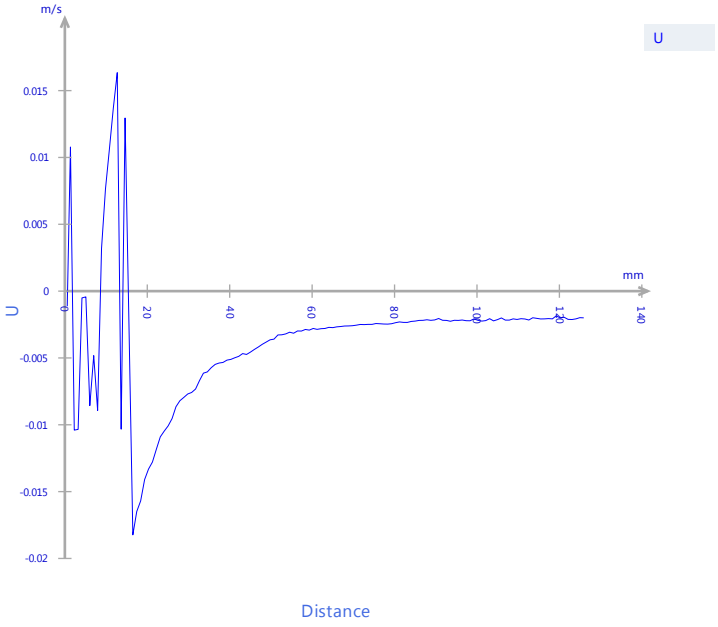

Figure B.58.1: Horizontal Velocity (U) along the Outlet Axis

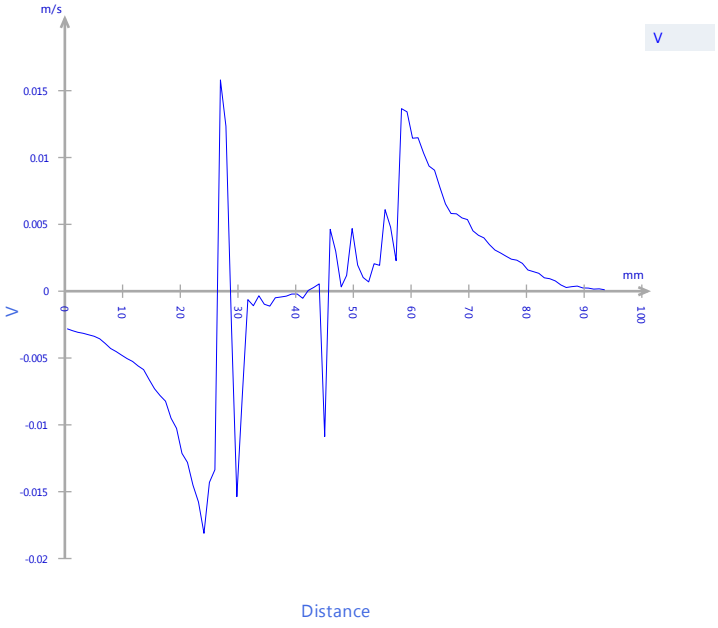

Figure B.58.2: Vertical Velocity (V) at the Outlet Side

Figure B.58: Velocity Profiles for Average Correlation
[IA Size: 16× 16 pixels and Overlap Percentage (H%, V%): 25%, 25%]

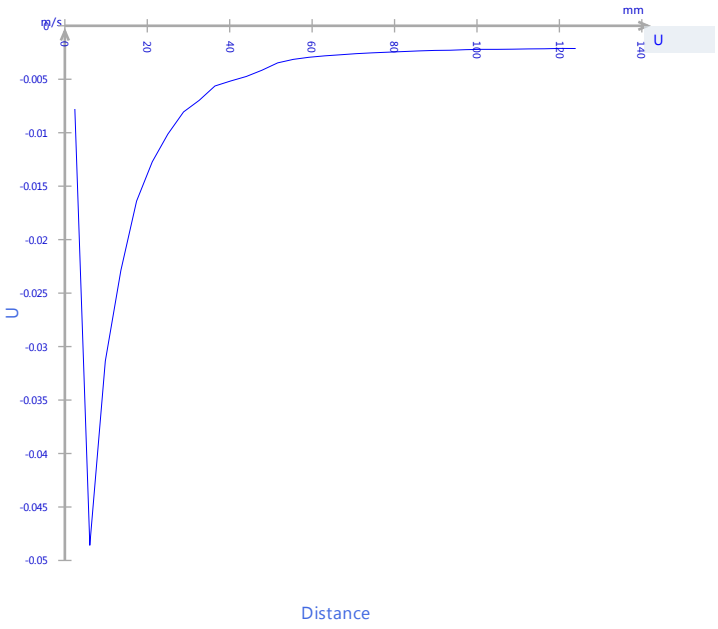

Figure B.59.1: Horizontal Velocity (U) along the Outlet Axis

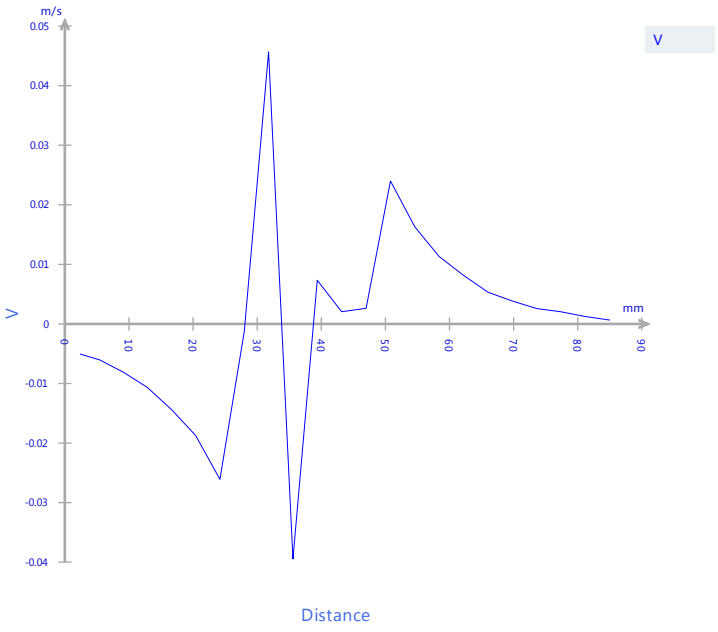

Figure B.59.2: Vertical Velocity (V) at the Outlet Side

Figure B.59: Velocity Profiles for Average Correlation
[IA Size: 64× 64 pixels and Overlap Percentage (H%, V%): 25%, 25%]

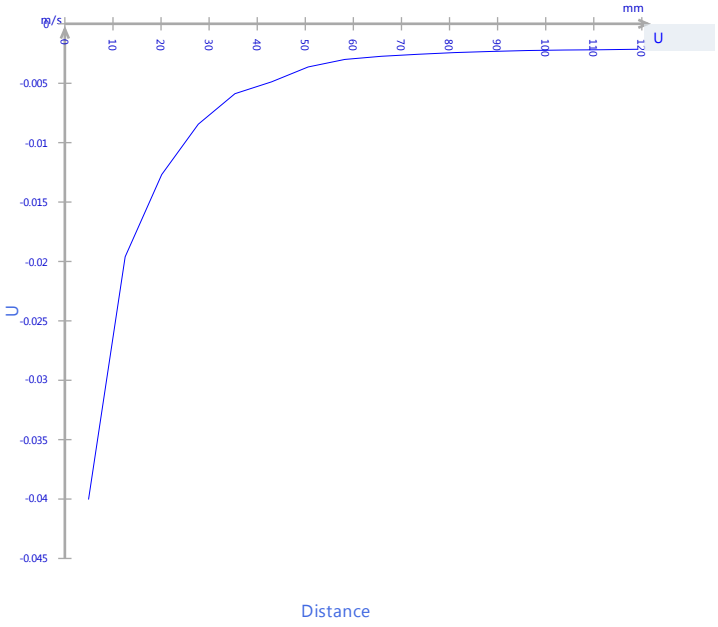

Figure B.60.1: Horizontal Velocity (U) along the Outlet Axis

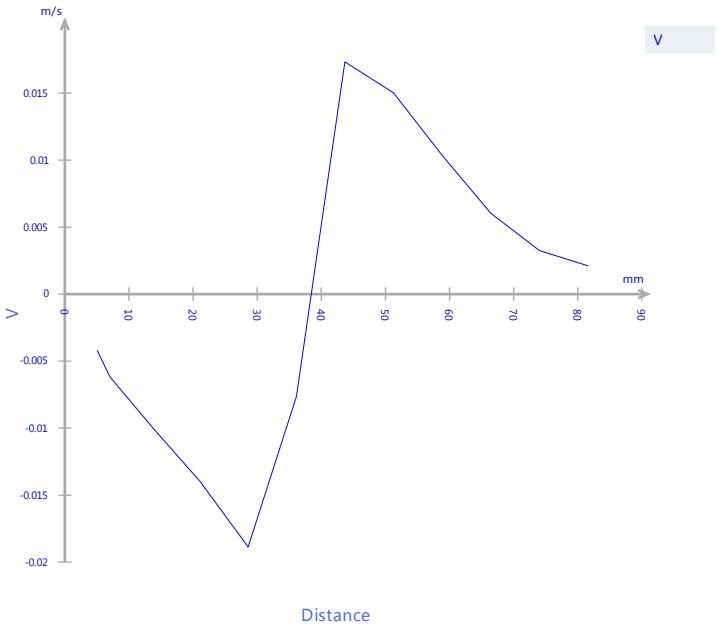

Figure B.60.2: Vertical Velocity (V) at the Outlet Side

Figure B.60: Velocity Profiles for Average Correlation
[IA Size: 128× 128 pixels and Overlap Percentage (H%, V%): 25%, 25%]

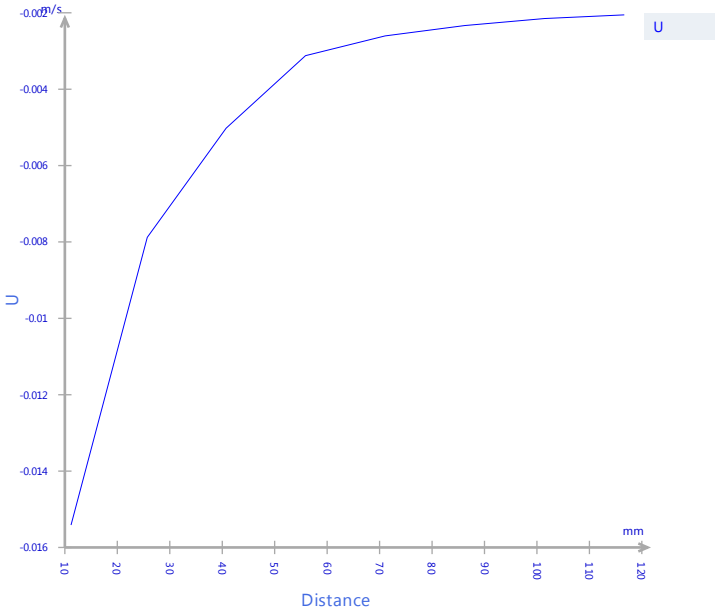

Figure B.61.1: Horizontal Velocity (U) along the Outlet Axis

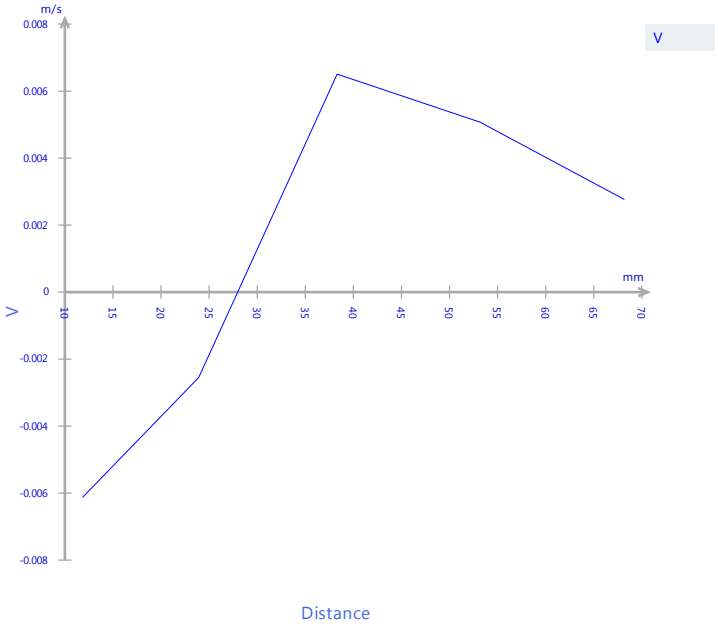

Figure B.61.2: Vertical Velocity (V) at the Outlet Side

Figure B.61: Velocity Profiles for Average Correlation
[IA Size: 256× 256 pixels and Overlap Percentage (H%, V%): 25%, 25%]