AerE 3440: Undergraduate Aerodynamics and Propulsion Laboratory

Lab Instructions

Lab #11: PIV measurement of flow field around and in the wake of an airfoil model

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Objectives:

1. To understand the fundamentals and system setup of the Particle Image Velocimetry (PIV) technique.
2. To get “hands-on” experience on how to make PIV measurements.
3. To know how to do PIV image acquisition, image processing, analysis, and discussion of the result for an experimental study.

The experiment

The flow field that you will study is the same as what you have analyzed in earlier experiments using pitot tube and hot-wire probes. Figure 1 shows the schematic of the experimental setup for this study with NASA GA(W)-1 airfoil mounted in the test section of the wind tunnel. The illumination source for the PIV experiment is dual-cavity Nd:Yag laser capable of providing 200 mJ/pulse of energy at 532 nm with 15 Hz repetition rate. The laser beam is converted into a thin sheet using a pair of convex and cylindrical lenses mounted in the beam path above the test section. Smoke is introduced in the settling chamber to provide the seeding for the PIV measurements. The scattered light from the smoke (oil) particles is imaged onto a CMOS camera.

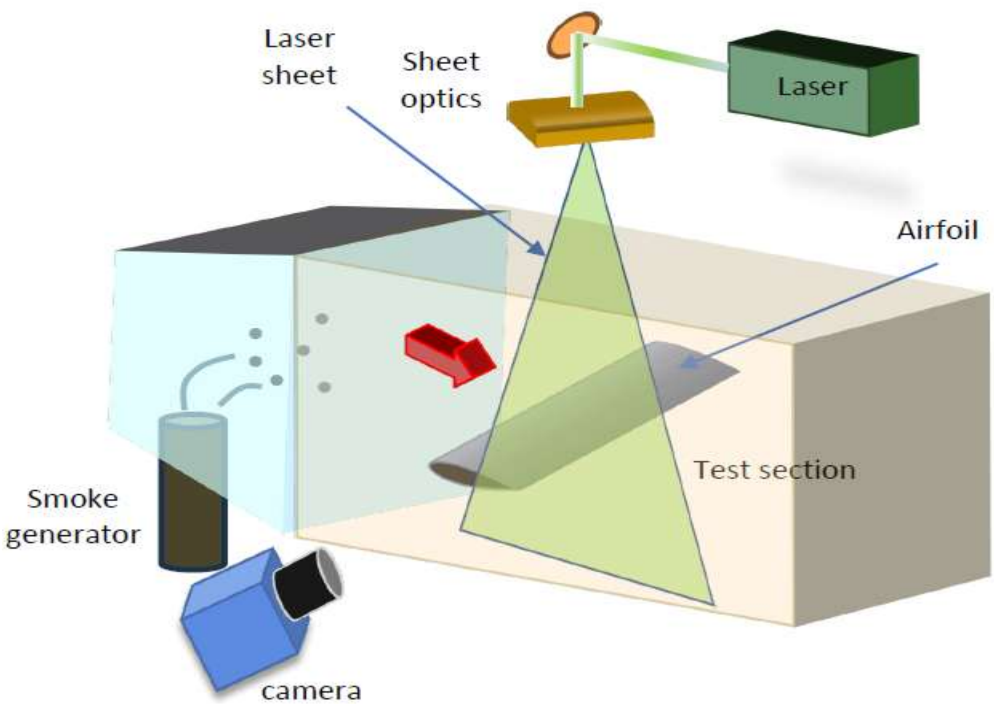

Figure 1 – Schematic of experimental setup for the PIV measurement

In order to convert the ‘pixel’ dimensions of the images into physical coordinates, a calibration image should be acquired with a known target/scale in the same field of view.

What you will have available for this lab

- NASA GA(W)-1 airfoil model mounted in the wind tunnel test section.
- A dual cavity Nd:Yag laser and optical components mounted on a breadboard.
- A CMOS camera fitted with an imaging lens aligned to record the field of view above and behind the airfoil model
- Smoke generator to provide seeding particles.
- A target to be imaged in the camera field of view as the calibration image.

What you will do during the lab

- Follow the TA instructions and designate a group member to set the airfoil and another to operate the camera software and record images.
- Wear laser safety goggles!
- Run the wind tunnel at 10 m/s.
- Record the image of target in the field of view.
- Record the timing information of the PIV setup (repitation rate, and time delay between image pairs).
- Your TA will then turn on the laser and signal the start of the experiment
- Set the airfoil at a small angle of attach (2-4 degrees). Wait for a minute for flow to become steady.
- Start recording about 100 image pairs using Camware software. Stop recording and export the recording into a sequence of image files.
- Move the airfoil into a high angle of attack (10-12 degress).
- Repeat recording and saving PIV images.

Write-up Guidelines

This lab write-up will be a typical formal lab report. You will need to make the required plots (as listed below) and provide a discussion about the measurement results as a part of your lab report.

You will use the open-source program PIVLab (https://pivlab.blogspot.com/) written in Matlab to process the PIV images and obtain the velocity field. Please refer to the accompanying write-up for instructions on how to use PIVLab.

Required Plots:

- Plots of the mean velocity vectors superposed on vorticity contours for both airfoil angles of attack.
- Plots of the mean velocity vectors superposed on the velocity rms contours for both airfoil angles of attack.
- A plot of wake profile (both mean and rms) at ½ chord length downstream of the airfoil.

Report discussion requirements

- Discuss your processing method, including the choice of interrogation window, vector validation, and spurious vector removal. Do you see better results in some portions of the images than in other sections? Why?
- What is the resolution of your PIV measurement? How does that relate to the choice of interrogation window?
- Compare the normalized wake profile with those obtained from hot-wire measurement of lab 7.

PIVLab Guide for AER E 3440 Lab

Introduction

PIVLab is a Matlab® toolbox developed by William Thielicke[1] to process Particle Image Velocimetry images and output velocity vectors as well as various derivatives. You can read more about the package at https://pivlab.blogspot.com/p/what-is-pivlab.html

Please download the toolbox through Mathworks® file exchange or via the assignment page on Canvas.

Installation and Opening of the program

Once you have downloaded the toolbox, install the package either by double-clicking on the installation file or through the APPS tab on Matlab (see fig. 1). Click on Install App, then browse to where the downloaded installation package is.

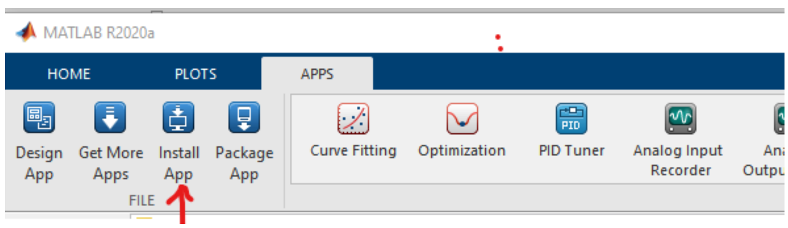

Fig. 1 – APPS menu tab in Matlab R2020a

Once the installation is complete, you can launch the app from the same APPS tab. You may have to click on the small down arrow to the far right of the tab to see all the apps installed.

Importing Images

Choose Load images to bring up the image import window (see Fig. 2). Browse for the folder where the PIV images are stored and select the folder. The list under the current folder entry should populate with

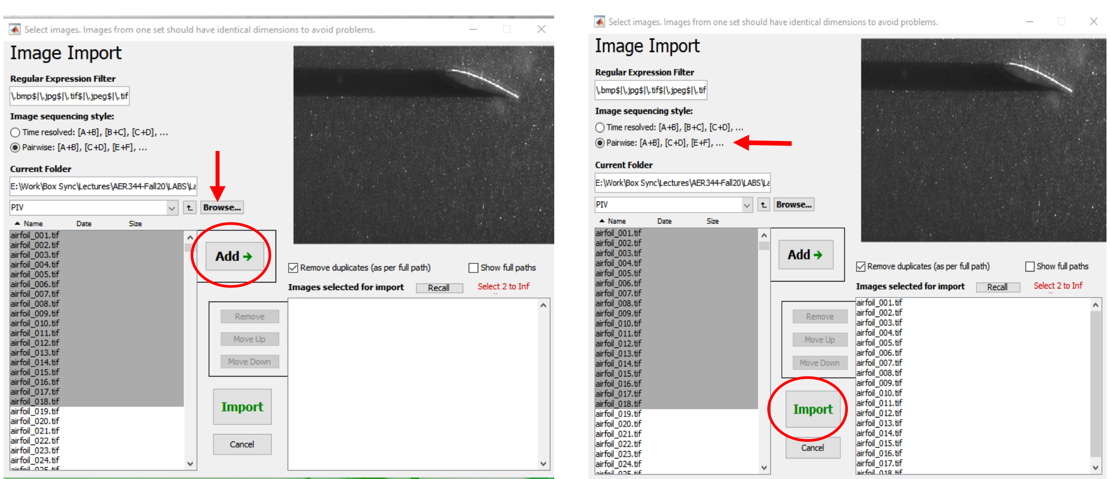

Fig. 2 – Image import window

[1] Thielicke, W. & Stamhuis, E.J. (2014). PIVlab – Towards User-friendly, Affordable and Accurate Digital Particle Image Velocimetry in MATLAB. Journal of Open Research Software 2(1):e30, DOI: http://dx.doi.org/10.5334/jors.bl

the image files within the selected folder. Select the images within the list, then click on the 'Add' button to add those images to the list at the right side of the window. Check and verify that the 'Pairwise' bullet option is selected, then click on the Import button to load the images onto the PIVlab session.

Pre-Processing

There are various pre-processing options that one can apply to enhance contrast and select or mask regions of interest before the PIV processing. Here we only focus on masking the region occupied by the airfoil (and its shadow).

- From the Image settings menu, choose Exclusions (ROI, mask).
- Click on Draw mask(s) for the current frame. The cursor changes to a cross shape, allowing you to draw line segments on the active frame. Start from one point and draw line segments to enclose the area you would like to exclude. Once you close the last segment back on to starting point, the software fills the polygon showing the masked region (Fig. 3).
- Apply the same mask to all the frames within the image set.

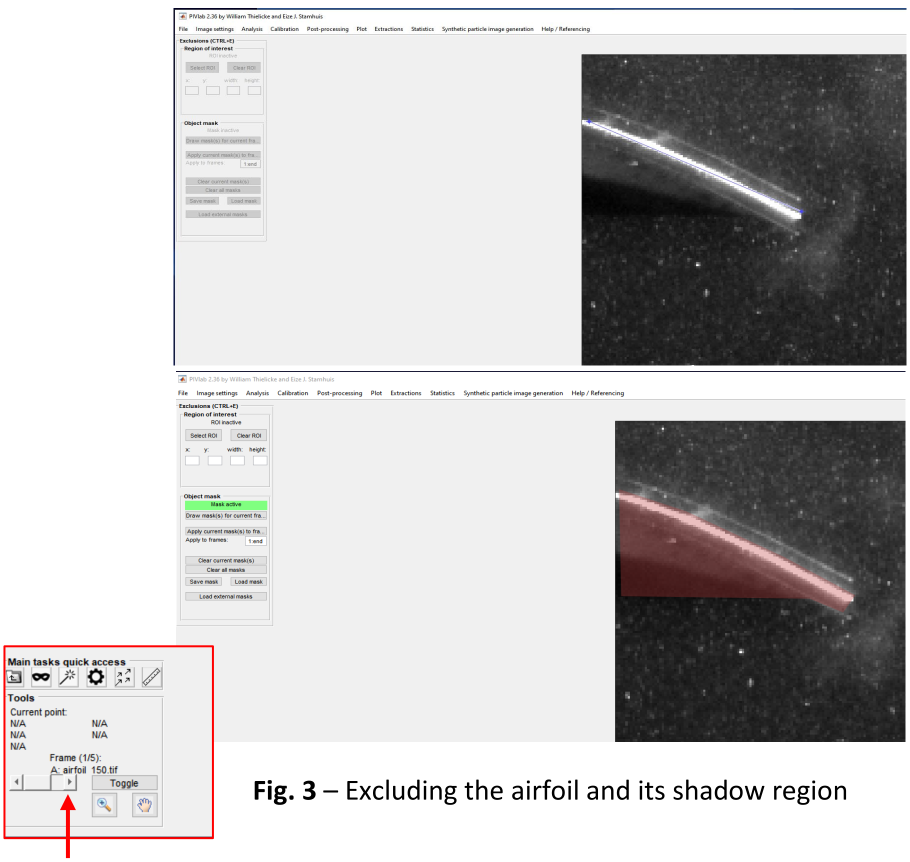

Fig. 3 – Excluding the airfoil and its shadow region

PIV Analysis

This is where the main parameters of the PIV analysis are set. For this lab analysis, we would only focus on the most critical parameter, the interrogation window size. In general, we would like to choose the smallest interrogation window possible, which directly determines the spatial resolution of the PIV measurement (recall that for every interrogation window, we get one velocity vector). However, the window needs to be large enough to contain enough particles within to distinguish that window from its neighboring window uniquely. If the number of particles within a chosen window is too small, the likelihood of miss-correlation increases leading to measurement error and spurious vectors.

Advanced PIV processing algorithms (including ones used in PIVLab) allow for multiple passes on each image pair, where the interrogation window is shrunk at each pass to enhance the measurement resolution further while reducing the chance of miss-correlations. Often the processing starts with a relatively large window size (for example, 64x64 pixels) to obtain a coarse vector field. The window size is then reduced by a factor of 2 in passes 2 and 3 as needed to refine the analysis.

It is also common in PIV analysis to allow neighboring windows to overlap (usually by 50%). This allows for a denser vector field. However, it is important to note this does not improve spatial resolution. This is similar to an interpolation between two measurement points.

- From the Analysis menu, select PIV settings.
- For Pass 1, choose an interrogation window size of 64 with a step size of 32 (this is 50% overlap).
- For Pass 2, choose an interrogation window size of 32 with a step size of 16. Uncheck Pass 3 and 4, as a smaller window size is unrealistic for the images you will be using.
- Leave the other options as default.
- Click on Analyze current frame to see the result (velocity vectors) for the current image pair. If overall, the vector fields appear reasonable, you can move on to analyze the entire set.
- From the Analysis menu, select Analysis and choose Analyze all frames (fig. 4).

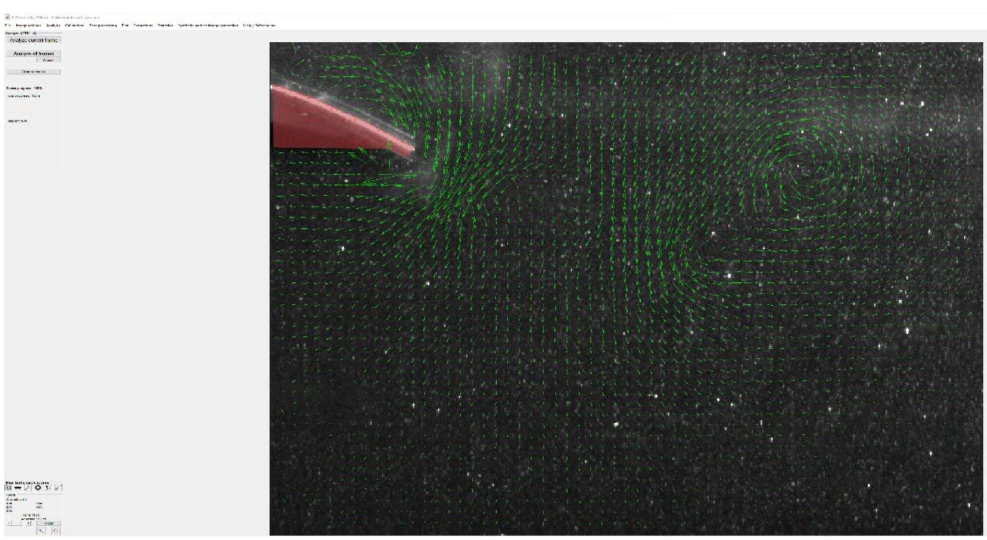

Fig. 4 – Analysis window showing the processed vector field

Post-processing

Depending on the signal-to-noise ratio of the original images, non-uniformity over the image field, or the presence of objects leading to specular reflection, often some of the processed vectors are not valid velocity vectors of the flow field and need to be corrected. This post-processing step usually involves one or a combination of methods, including enforcing limits on velocity magnitude, identification, and removal of spurious vectors, and filtering of the velocity field.

The fundamental idea behind identifying spurious vectors is that the velocity vector field is continuous, and there should not be a sudden change of velocity vector (both magnitude and direction) between two neighboring points. In the vector-validation process, the algorithm scans the vector field and flags every vector that is 'too' different from the mean of its adjacent points. These flagged vectors are then removed and replaced by the mean of their surrounding 'good' vectors.

- From the Post-processing menu, choose Vector validation
- The default setting should be a standard deviation filter threshold of 7 (times the standard deviation) with interpolate missing data checked and the local median filter threshold unchecked.
- Apply the default setting by clicking on Apply to current frame button. The vectors that are flagged/updated will be highlighted with a different color (see Fig. 5). If there are still many spurious vectors left that are not marked, you can decrease the threshold and redo the process.
- It is possible that the automatic process could still miss a few spurious vectors. You can then use the manual rejection option to manually mark such vectors for replacement. Click on Manually reject vector and use the cursor to select all the spurious vectors you like to replace. Once finished left click and choose Apply to current frame.
- You may apply the automatic process to all the frame. Then go through individual frames to apply any manual rejection necessary.

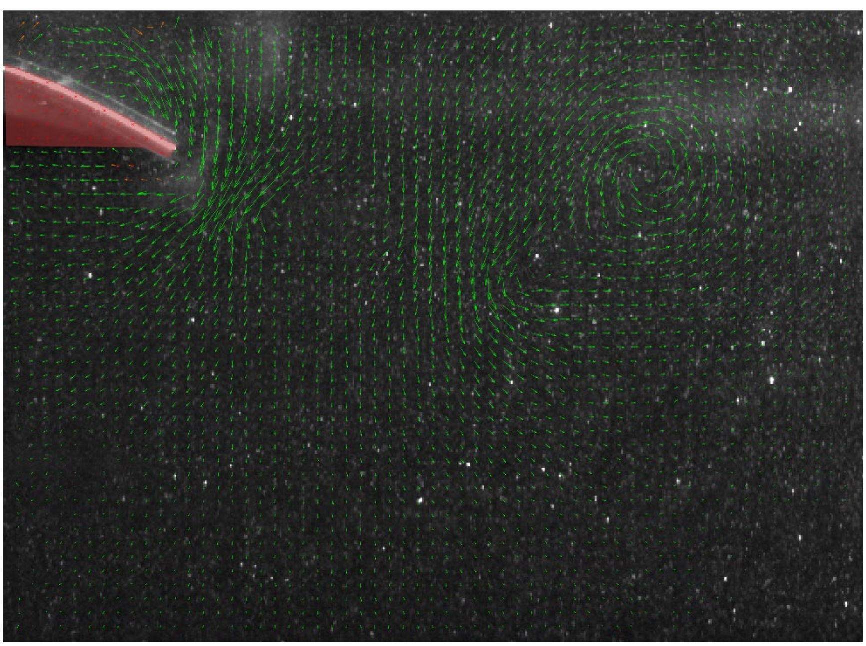

Fig. 5 – Velocity vector field with vector validation applied

Calibration

The processing is completed in raw units, and velocity vectors are in units of pixels/frame. To convert the velocity field to physical units, a calibration image along with the inter-frame time is needed.

- Select the calibration menu and calibrate using current or external image.
- Click on Load calibration image and browse for the target image you have recorded (or provided with).
- Choose Select reference distance and draw a line over a known distance on the calibration image by clicking on beginning and the end (Fig. 6).
- Enter the real distance in the appropriate box in **mm** unit
- Enter the time step in the **millisecond** unit.
- Apply the calibration.

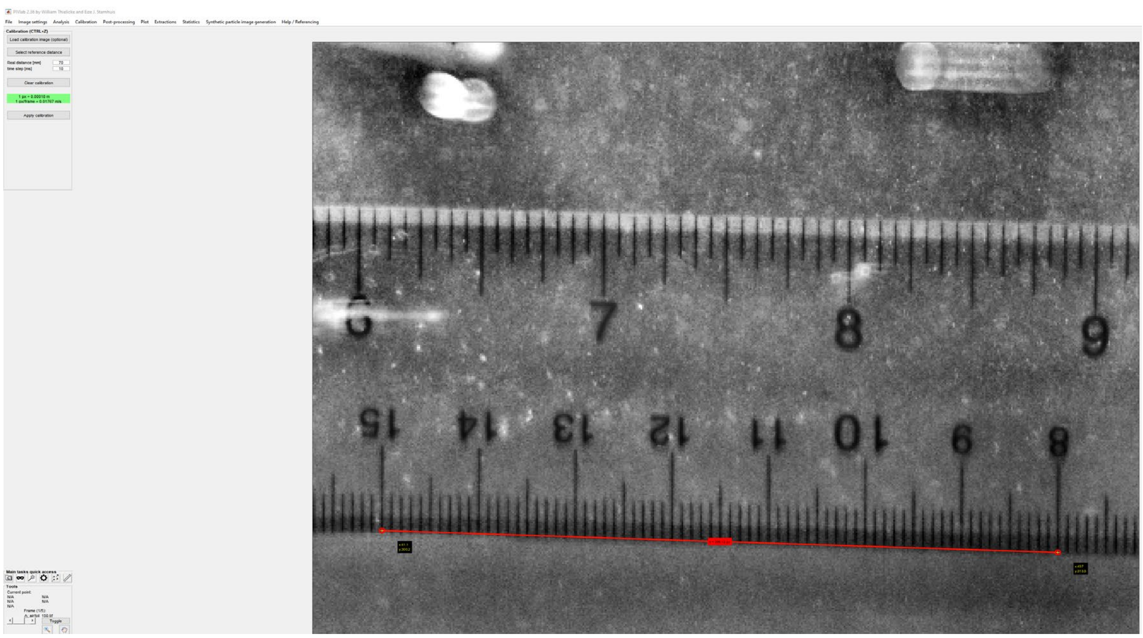

Fig. 6 – Calibration image setting

Plotting vorticity field

The PIVLab can calculate various velocity derivatives and vorticity.

- From the Plot menu, choose Derive parameters/modify data
- From the drop menu bar, choose Vorticity
- Choose Apply to all frames
- You may modify the appearance of the vorticity field by unchecking the autoscale option and manually entering the maximum and minimum limits (Fig. 7).
- From the plot menu, choose modify plot parameters, then check display color bar, position and hit Apply to show the colormap.
- Note that since PIVLab uses image coordinates (with y positive pointing downward), the sign of calculated vorticity is the negative of the actual vorticity.

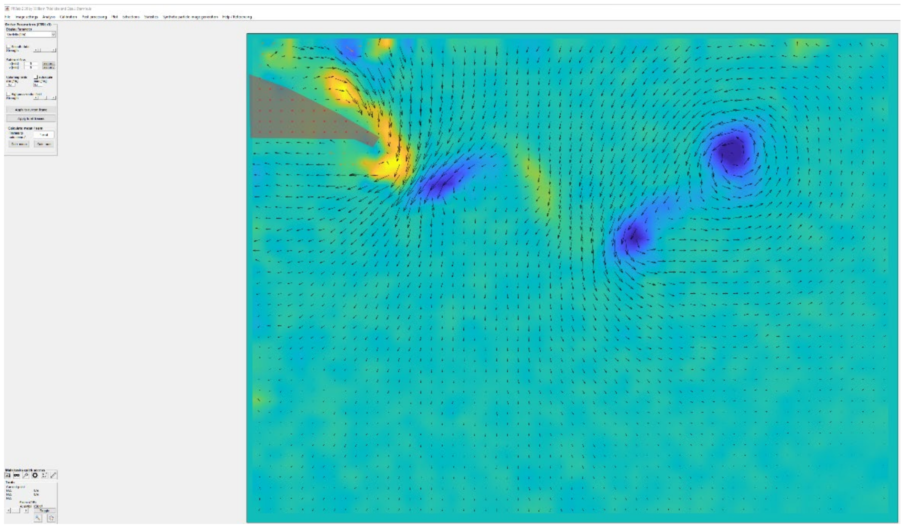

Fig. 7 – Vorticity field

Extracting profiles

- From the Extraction menu, choose Parameters from polyline.
- Verify that polyline is selected as Type and select the parameter of interest (velocity, vorticity, etc.)
- Click on Draw and draw a single straight line where you like to extract a profile. Do a mouse right-click to complete the extraction.
- You may click on Plot data to show the profile (Fig. 8).
- Choose Save results as text file(s) to save the extracted profile for the current frame.
- Note that the horizontal axis on the profile plot (and the saved text file) is the physical distance along the line you drew in meters.

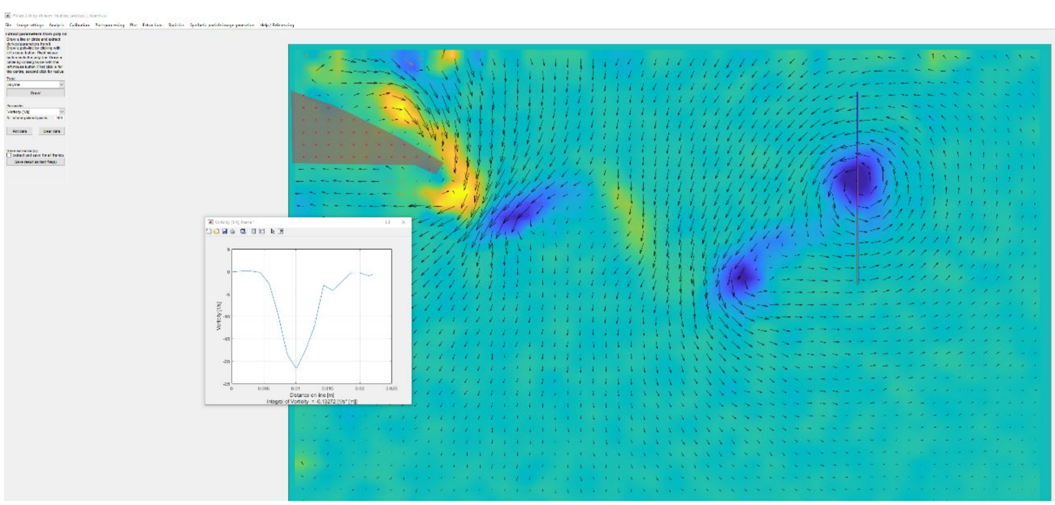

Fig. 8 – Extraction of vorticity profile through a region of interest