



*Because u' matters*

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## User Manual

Version 0.4 · Alpha Release

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 [github.com/CmdrRyder/uPrime](https://github.com/CmdrRyder/uPrime)

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## Abstract

uPrime is an open-source, cross-platform desktop application for the post-processing and turbulence analysis of planar velocity fields obtained from particle image velocimetry (PIV) and computational fluid dynamics (CFD). The software provides an integrated graphical environment covering the full range of standard turbulence diagnostics: Reynolds normal and shear stresses, turbulent kinetic energy (TKE) budgets, one-dimensional and two-dimensional spatial and temporal power spectral densities, two-point spatial and temporal correlation functions with automatic integral length and time scale extraction, turbulence anisotropy analysis via the Lumley triangle and barycentric maps, snapshot Proper Orthogonal Decomposition (POD) with modal energy spectra and low-order flow field reconstruction, Dynamic Mode Decomposition (DMD) with frequency-growth rate spectra and spatial mode visualization, and vortex identification using five scalar criteria including gradient-based methods and the Graftieaux  $\Gamma$  functions. All analyzes are accessible through a labeled graphical interface without requiring programming knowledge, making the tool accessible to students and researchers new to quantitative flow analysis.

uPrime reads multi-snapshot Tecplot ASCII .dat files exported from LaVision DaVis and supports both 2D two-component (2D2C) and stereo three-component (2D3C) PIV datasets. It includes coordinate transformation tools for correcting camera calibration misalignment and a snapshot subsampling interface for efficient handling of large time-resolved datasets. Figures are exportable as PNG (300 DPI) or vector graphics (PDF, SVG) with editable text, facilitating direct integration into publication workflows.

**Keywords:** particle image velocimetry; turbulence post-processing; Reynolds stresses; turbulent kinetic energy budget; power spectral density; two-point correlation; integral length scale; Lumley triangle; Proper Orthogonal Decomposition; Dynamic Mode Decomposition; vortex identification; open-source software; LaVision DaVis

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## Chapter 1

# Getting Started

### 1.1 What is uPrime?

uPrime reads Tecplot `.dat` files exported from LaVision DaVis and provides a graphical interface for turbulence post-processing. You do not need to know Python, MATLAB, or any programming language to use it. Everything is point-and-click.

The workflow is always the same:

1. Load your PIV snapshots.
2. Set the acquisition type and sampling frequency.
3. Align the coordinate system if needed.
4. Open any analysis module and explore your data.

### 1.2 What uPrime can do

- Load 2D2C and 2D3C (stereo) PIV data from multiple `.dat` files simultaneously.
- Display mean velocity fields, standard deviation, vorticity, velocity vectors, and streamlines.
- Compute all Reynolds stress components with 2D maps, line profiles, and uncertainty bands.
- Compute and plot the full TKE budget (production, convection, turbulent diffusion, residual).
- Perform spatial, temporal, and space–time spectral analysis.
- Compute two-point spatial and temporal correlations with integral length and time scales.
- Analyze turbulence anisotropy via the Lumley triangle and barycentric maps (stereo only).
- Perform Proper Orthogonal Decomposition (POD) with energy spectra, mode shapes, and flow reconstruction.
- Perform Dynamic Mode Decomposition (DMD) with frequency spectra and spatial mode visualization (TR only).
- Identify vortex cores and boundaries using five scalar criteria: vorticity, Q-criterion, swirling strength,  $\lambda_2$ , and  $\Gamma_1/\Gamma_2$  (Graftieaux).
- Apply and manage non-destructive spatial masks.
- Correct camera calibration misalignment, shift the coordinate origin, and mirror the dataset.

- Export all results as Tecplot `.dat` or `.csv` files, and figures as PNG (300 DPI), PDF, or SVG with editable text.

### 1.3 System requirements

Table 1.1: Minimum system requirements.

Item	Requirement
Operating system	Windows 10/11 (primary); macOS 12+; Linux (Ubuntu 20+)
Python	3.10 or later (source installation only)
RAM	8 GB minimum; 16 GB or more recommended for large datasets
Display	1920×1080 or larger strongly recommended
<i>Python dependencies (source installation)</i>	
<code>numpy</code>	Array operations and numerical core
<code>scipy</code>	Signal processing and spectral analysis
<code>matplotlib</code>	Plotting and figure export
<code>PyQt6</code>	Graphical user interface
<code>pyfftw</code>	Fast Fourier transforms (accelerates spectral analysis)

#### **i** Note

All Python dependencies are installed automatically via `pip install -r requirements.txt`. The Windows executable requires no Python or dependency installation.

## 1.4 Installation

### 1.4.1 Option A: Windows executable (recommended for non-developers)

Download `uPrime_v0.4.0.exe` from the [GitHub Releases](#) page and double-click to launch. No Python or any other software is required.

#### **i** Note

Windows Defender may show a security warning on first launch. Click **More info** then **Run anyway**. This is normal for executables built with PyInstaller that have not been code-signed.

### 1.4.2 Option B: Run from source

1. Clone the repository:

```
git clone https://github.com/CmdrRyder/uPrime.git
cd uPrime
```

2. Install dependencies:

```
pip install -r requirements.txt
```

3. Launch:

```
python main.py
```

## 1.5 Input file format

uPrime reads **Tecplot ASCII .dat files** in the standard DaVis export format. Each file contains one PIV snapshot. Select multiple files at once to load a full time series.

uPrime automatically reads the physical units from the variable name strings in the file header (e.g. "**x [mm]**", "**Velocity u [m/s]**"). If units are not specified in the header, it defaults to millimetres for coordinates and m/s for velocity. All internal computations are performed in SI units regardless of the input.

### Note

uPrime auto-detects variable names. It expects **x**, **y**, **U** (or **Velocity u**), **V** (or **Velocity v**), and optionally **W** for stereo. Extra columns (vorticity, acceleration, etc.) are ignored silently. An **isValid** or **mask** column is used to exclude invalid vectors; this column is present by default in DaVis exports. Files exported directly from DaVis will load without any configuration.

## Chapter 2

# Main Window

### 2.1 Overview

When uPrime launches you will see a welcome screen. The sidebar on the left is your control panel. All steps are numbered in the order you should use them.

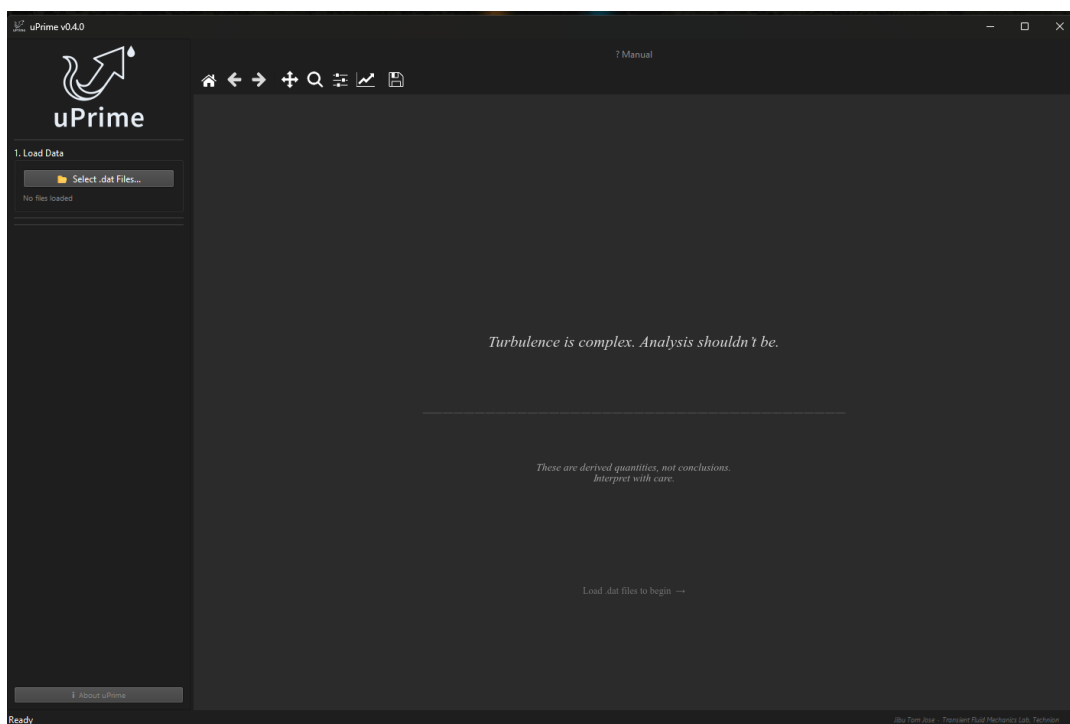


Figure 2.1: uPrime v0.4.1 welcome screen on launch. The sidebar shows Step 1 (Load Data) only. The ? **Manual** button is visible in the top right. Load **.dat** files from the sidebar to begin.

#### **Note**

All sample images in this manual were generated from a representative dataset of 200 snapshots only, which is insufficient for statistically converged turbulence quantities. They are included for illustration purposes only. In practice, at least 2000 snapshots are recommended for non-time-resolved data and at least 2 seconds of recording for time-resolved data.

### 2.2 The sidebar steps

Always work through the sidebar from top to bottom when starting with a new dataset.

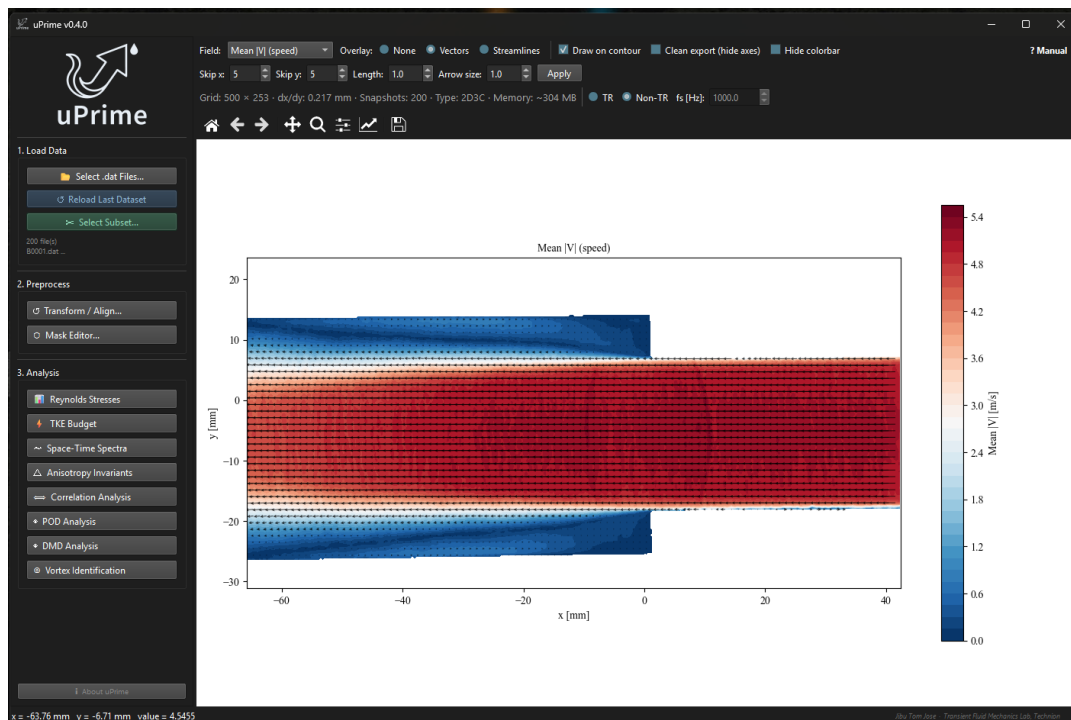


Figure 2.2: Main window after loading a 2000-snapshot time-resolved 2D2C dataset at  $f_s = 10,000$  Hz. The dataset info ribbon shows grid size, spatial resolution, snapshot count, acquisition type, sampling frequency, and estimated memory usage. The three numbered sidebar steps guide the workflow.

### 2.2.1 Step 1: Load Data

Click **Select .dat Files...** and choose all your snapshot files at once. Hold **Ctrl** or **Shift** to select multiple files. uPrime stacks them into a single dataset in memory.

For large datasets, a subsampling dialog appears before loading; see Section 2.6.

After a successful load, two additional buttons appear:

- **Reload Last Dataset:** reloads the same files without the file browser. Use this to undo a bad transform.
- **Select Subset...**: carve out a subset of the already-loaded snapshots without re-reading from disk (see Section 2.6).

A dialog appears immediately after loading asking you to confirm the acquisition type and sampling frequency. These settings can also be adjusted at any time from the dataset info ribbon.

### 2.2.2 Step 2: Preprocess

Click **Transform / Align...** to open the coordinate correction tool. This is where you fix camera tilt, shift the coordinate origin, and optionally mirror the dataset. **Always do this before running any analysis.** Full details are in Chapter 3.

Click **Mask Editor...** to draw additional spatial masks over regions you want to exclude from analysis (e.g. reflections, shadows, or wall regions not detected by the DaVis isValid flag). Masks are non-destructive: the raw velocity data is never modified. Toggling a mask on or off does not require reloading.

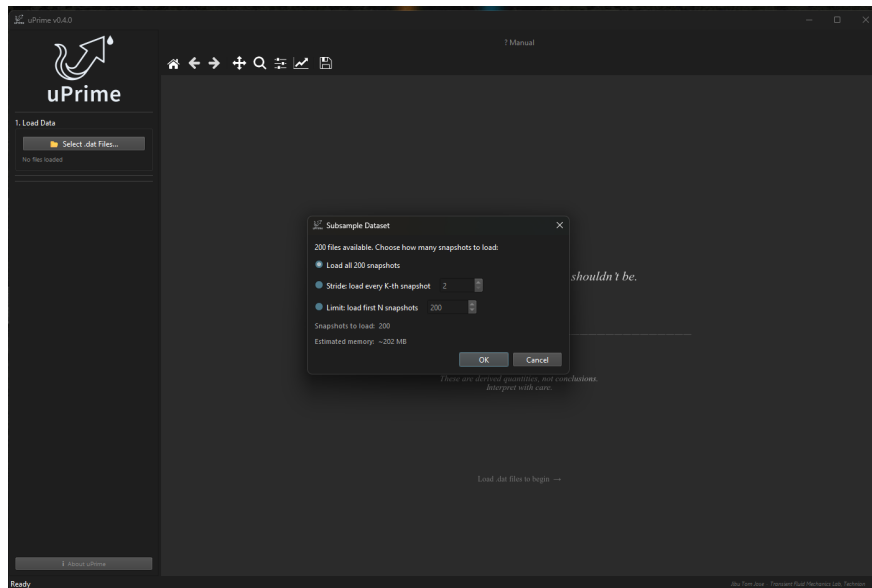


Figure 2.3: Subsampling dialog shown when selecting files. The user can load all snapshots, use every  $K$ -th frame (stride), or limit to the first  $N$  snapshots. Snapshot count and estimated memory usage update live. A warning is shown when the dataset exceeds 4 GB (see Section 2.6).

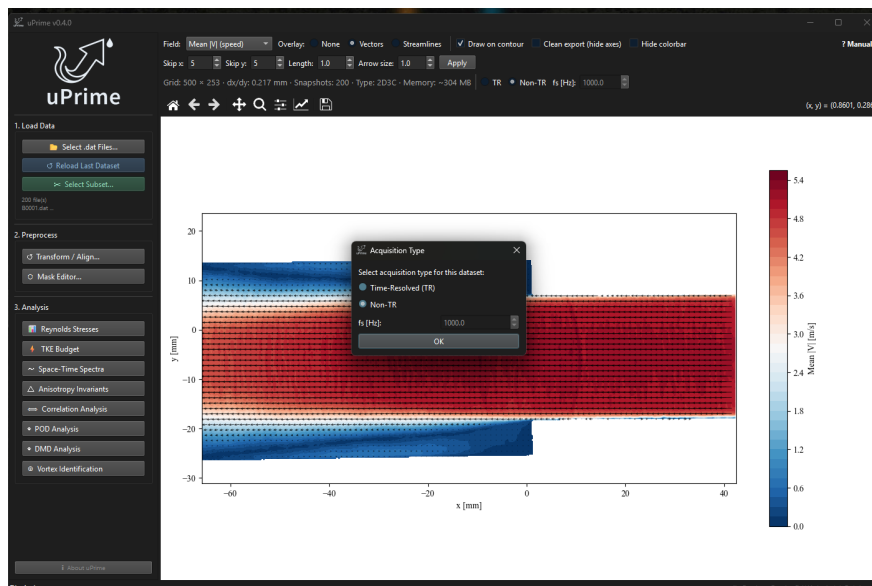


Figure 2.4: Acquisition type dialog shown automatically after each data load. Select TR and enter  $f_s$  to enable temporal analysis modules. The  $f_s$  spinbox is greyed out when Non-TR is selected.

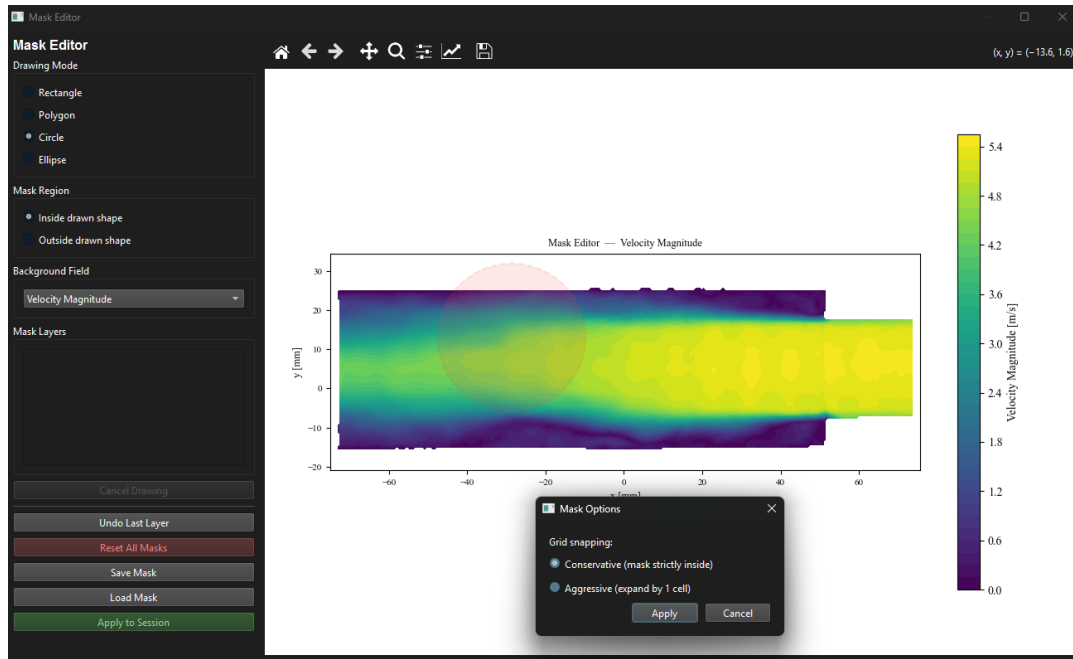


Figure 2.5: Mask Editor window. The user is drawing a polygon (red) over a region to exclude. Drawing modes include Rectangle, Polygon, Circle, and Ellipse. The mask can be applied inside or outside the drawn shape. Multiple layers can be stacked and each can be undone independently.

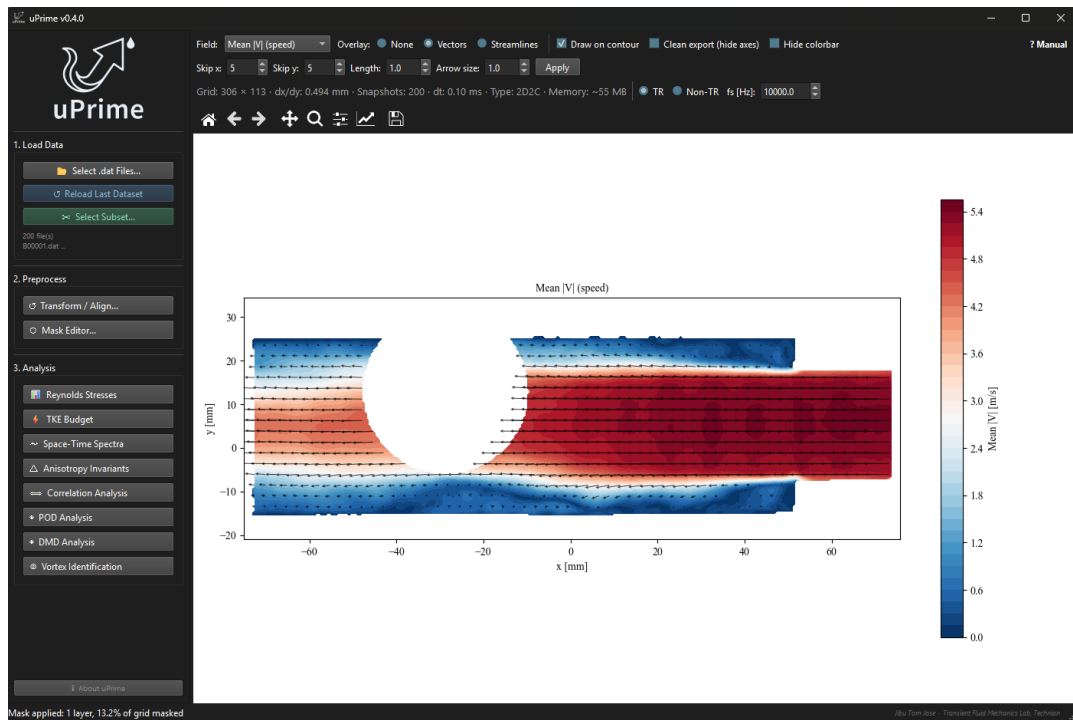


Figure 2.6: Main window after applying a drawn mask. The masked region is shown in white. The status bar at the bottom reports the number of mask layers and the fraction of the grid that is masked.

### 2.2.3 Step 3: Analysis

Click any analysis button to open that module in its own window. Multiple analysis windows can be open at the same time and can be compared side by side.

All heavy computations (POD, DMD, TKE budget, correlation, vortex identification) run in a background thread so the main window remains fully responsive during computation. A progress indicator appears below the compute button while the calculation is in progress.

## 2.3 Acquisition type and sampling frequency

The acquisition type and sampling frequency  $f_s$  are set in the dataset info ribbon at the top of the main window, immediately below the field options strip. A dialog to set these values also appears automatically after each data load.

- **TR**: snapshots are acquired at a fixed rate. Enter  $f_s$  in Hz (enabled only for TR). Temporal analyzes (temporal spectra, temporal correlation, POD temporal coefficients, DMD) become available.
- **Non-TR**: snapshots are statistically independent (e.g. double-frame PIV). Temporal analyzes are greyed out.

#### Warning

Set the correct acquisition type and  $f_s$  before opening any analysis window. Analysis windows read these settings when they open.

## 2.4 Dataset info ribbon

A compact info strip appears just below the options strip after loading:

Grid:  $507 \times 248$  · dx/dy: 0.165 mm · Snapshots: 2000 · dt: 0.10 ms · Type:  
2D2C · Memory: ~2012 MB

- **Grid**: number of velocity vectors in  $x$  and  $y$ .
- **dx / dy**: spatial resolution in mm.
- **Snapshots**: how many snapshots are currently active (reflects subsampling).
- **dt**: time between frames in milliseconds (TR data only; updates if  $f_s$  or stride changes).
- **Type**: 2D2C for planar PIV; 2D3C for stereo PIV with  $W$ .
- **Memory**: estimated RAM used by the velocity arrays. For datasets exceeding 4 GB, this reflects the size of the memory-mapped file on disk rather than physical RAM consumed (see Section 2.6).

## 2.5 Field viewer

The right panel shows the selected velocity field as a filled contour plot with optional velocity vectors.

### 2.5.1 Display controls

Table 2.1: Field viewer display controls.

Control	Description
Field	Quantity to show: Mean U/V/W, speed $ V $ , vorticity, Std(U), Std(V)
Overlay	None, Vectors, or Streamlines
Draw on contour	When checked, overlays the selected overlay on the filled contour
Clean export	Hides all axis labels, tick marks, and the plot title for a clean exported image
Hide colorbar	Removes the colorbar from the plot
? Manual	Opens the user manual PDF

### 2.5.2 Streamlines

Streamlines trace the instantaneous mean velocity field and give a cleaner visual impression of the flow topology than arrow vectors, especially in regions with complex recirculation.

#### ☰ Step-by-step

1. Set **Overlay** to **Streamlines**.
2. The vector ribbon appears. Left-click and drag on the field to draw a rake seed line. Multiple rakes can be drawn cumulatively.
3. Adjust **Length**, color, and line width in the ribbon.
4. Click **Apply** to redraw.
5. Click **Reset** in the ribbon to clear all seed rakes and start over.

#### 📘 Note

Streamlines are drawn from the mean velocity field only. They do not reflect instantaneous snapshot structure.

### 2.5.3 Toolbar

Table 2.2: Toolbar button functions.

Button	Function
Home	Resets the view to the original limits, regardless of zoom history
Back / Forward	Step through zoom history
Pan	Click and drag to pan the view
Zoom	Click and drag a rectangle to zoom in
Save	Save the figure as PNG (300 DPI), PDF, or SVG

### 2.5.4 Saving figures

Click the Save button in the toolbar. PNG is saved at 300 DPI. PDF and SVG use vector graphics; all text is saved as editable text and can be restyled in Adobe Illustrator or Inkscape.

 **Tip**

For publication figures: (1) enable **Clean export** to hide axes, (2) enable **Hide colorbar** if not needed, (3) save as SVG and open in Illustrator to set your journal's font and size requirements.

## 2.6 Snapshot subsampling and large dataset handling

A subsampling dialog appears whenever files are selected, giving you control over how many snapshots to load:

- **Load all:** load every file in the selection.
- **Stride:** load every  $K$ -th snapshot. Stride 5 on a 10,000-snapshot dataset gives 2000 samples, which is sufficient for mean fields, Reynolds stresses, and correlations.
- **Limit:** load only the first  $N$  snapshots.

The dialog shows the estimated snapshot count and memory usage, updating live as you change the options.

After loading, click **Select Subset...** to adjust the active snapshot range without re-reading from disk.

 **Tip**

For 10,000+ snapshot datasets, start with Stride 5 (~2000 samples). Mean fields and Reynolds stresses converge well at this level. Run POD and DMD on the full set once you know what you are looking for.

### 2.6.1 Large dataset handling (datasets exceeding 4 GB)

When the estimated dataset size after subsampling exceeds 4 GB, uPrime automatically switches to a **memory-mapped** loading strategy. Instead of loading all velocity data into RAM, uPrime writes the data to a temporary binary file on your system's temp drive (typically `C:\Users\username\AppData\Local\Temp`) and accesses it as needed. The actual path is shown in the warning label inside the subsampling dialog.

 **Note**

Memory-mapped loading requires free disk space on your system temp drive equal to the dataset size. For a 10,000-snapshot 2D2C dataset at a typical grid size, this is approximately 10 GB. The temporary file is deleted automatically when uPrime closes normally.

 **Warning**

If uPrime crashes or is forcibly closed, the temporary file may not be deleted. In that case, navigate to your system temp folder and delete any files named `uprime_memmap_*.bin` manually to recover disk space.

The key practical differences when memory-mapped loading is active:

- **Initial load is slower:** uPrime writes the full dataset to disk before opening it. On a fast SSD, expect 30–90 seconds for a 10 GB dataset in addition to the normal file reading time.

- **All analysis works normally:** POD, DMD, TKE budget, spectra, correlation, and vortex identification all function identically. Memory-mapped arrays behave like regular numpy arrays.
- **RAM usage is reduced:** only the pages of data currently being accessed are held in RAM. The operating system manages this automatically.
- **Do not load from external drives:** if your `.dat` files are on an external HDD, copy them to a local drive first. Reading from an external drive while also writing the memory-mapped cache to the temp drive simultaneously will be very slow.

 **Tip**

If your system temp drive (usually C:) does not have enough free space, use Stride subsampling to reduce the dataset to under 4 GB before loading. For example, Stride 3 on a 10,000-snapshot dataset gives  $\sim 3333$  snapshots ( $\sim 3.3$  GB for a typical 2D2C grid), which stays below the threshold and loads entirely into RAM.

## Chapter 3

# Coordinate Transform

Open from **2. Preprocess** → **Transform / Align...**

### Warning

Transforms modify the dataset **in memory** and cannot be undone. If you make a mistake, click **Reload Last Dataset** in the sidebar to reload from disk and start again.

In PIV experiments, the camera is rarely perfectly aligned with the flow geometry. Even a  $1^\circ$  tilt introduces errors in all derived quantities, including mean profiles, Reynolds stresses, line profiles, and integral scales. Always apply the transform *before* opening any analysis module.

## 3.1 Rotation

### Step-by-step

1. Left-click and drag on the field preview to draw a reference line along any feature that should be perfectly horizontal or vertical (wall, step edge, pipe centerline).
2. The misalignment angle is computed automatically and shown in the **Correction angle** field.
3. Choose **Linear** (fast) or **Cubic** (smoother, recommended for final results).
4. Click **Apply Rotation**.

### Note

Rotation is limited to  $\pm 10^\circ$ . For larger corrections, fix the calibration in DaVis and re-export your data.

## 3.2 Origin shift

Moves the coordinate origin  $(0, 0)$  to a physically meaningful reference point such as a step corner, pipe inlet, or cylinder center. Two modes are available: **Set new origin** (click on the point that should become  $(0, 0)$ ) and **Set known point** (click a point and enter what its real-world coordinates should be).

## 3.3 Mirror

Flips the entire dataset along an axis through the current origin. **Mirror X** negates all  $x$ -coordinates and the  $U$  component; **Mirror Y** negates all  $y$ -coordinates and the  $V$  component.

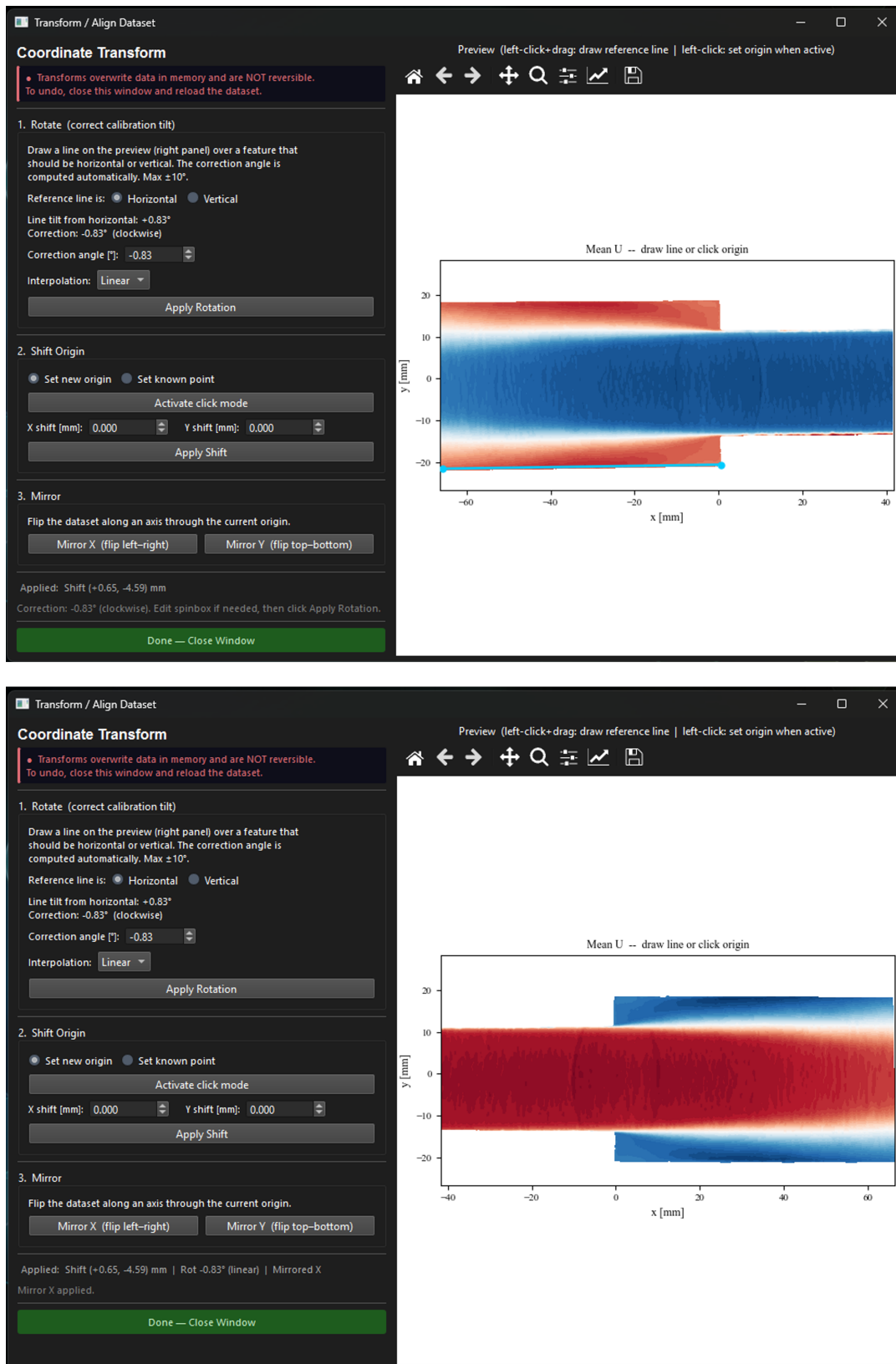


Figure 3.1: Coordinate Transform window. Left: controls. Right: live preview of the mean field. A reference line drawn along the lower pipe wall is shown in cyan. The computed correction angle appears automatically in the left panel.

## Chapter 4

# Reynolds Stress Analysis

Open from **3. Analysis** → **Reynolds Stresses**.

In turbulent flows, the instantaneous velocity can be decomposed into a time-averaged mean  $\langle U_i \rangle$  and a fluctuating component  $u'_i$ , such that  $U_i = \langle U_i \rangle + u'_i$ . The Reynolds stress tensor  $\langle u'_i u'_j \rangle$  quantifies the statistical intensity and directionality of these fluctuations and appears as a closure term in the Reynolds-Averaged Navier–Stokes (RANS) equations (Pope, 2000):

$$\rho \frac{D\langle U_i \rangle}{Dt} = -\frac{\partial \langle p \rangle}{\partial x_i} + \mu \nabla^2 \langle U_i \rangle - \rho \frac{\partial \langle u'_i u'_j \rangle}{\partial x_j}$$

The diagonal components  $\langle u'u' \rangle$ ,  $\langle v'v' \rangle$ ,  $\langle w'w' \rangle$  are the normal stresses, directly related to the turbulent kinetic energy by  $k = \frac{1}{2}(\langle u'u' \rangle + \langle v'v' \rangle + \langle w'w' \rangle)$ . The off-diagonal components  $\langle u'v' \rangle$ ,  $\langle u'w' \rangle$ ,  $\langle v'w' \rangle$  are the shear stresses, which are responsible for the turbulent momentum transfer across shear layers and boundary layers.

For 2D2C data, only  $\langle u'u' \rangle$ ,  $\langle v'v' \rangle$ , and  $\langle u'v' \rangle$  are available. All six components are computed for stereo (2D3C) data.

### 💡 Tip

The shear stress  $\langle u'v' \rangle$  is particularly useful for identifying shear layers and recirculation zones: it changes sign across the centreline of a jet or shear layer, and its peak magnitude locates the region of maximum turbulent momentum transfer.

**Reference:** Pope, S.B. (2000). *Turbulent Flows*. Cambridge University Press.

## 4.1 2D contour map

### ☰ Step-by-step

1. Select **2D Contour Map** under Plot Mode.
2. Choose the component from the **Component** dropdown.
3. Optionally check **Scale by  $U_m^2$**  and enter the bulk velocity  $U_m$  to non-dimensionalise.
4. Click **Plot Contour**.

## 4.2 Line profile

### ☰ Step-by-step

1. Select **Line Profile** under Plot Mode.
2. Choose line orientation: **Free**, **Horizontal**, or **Vertical**.
3. For Horizontal/Vertical, set **Spatial avg ± pts** to average over neighboring rows or columns and reduce noise.
4. Left-click and drag on the left field panel to draw the line.

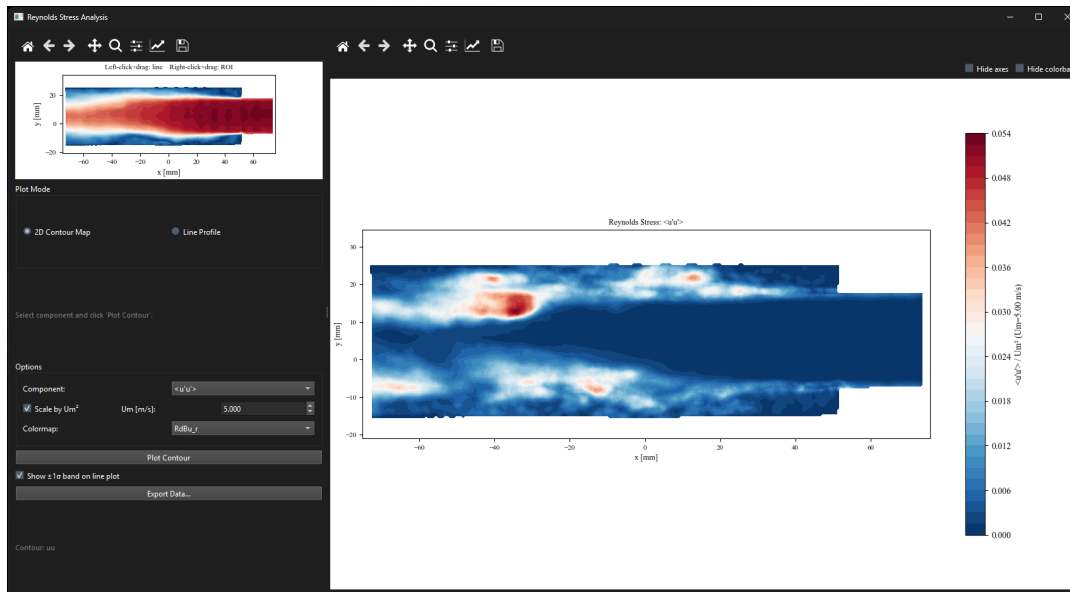


Figure 4.1: Reynolds stress window in 2D contour mode showing  $\langle u'v' \rangle$ . The mean field is shown in the small reference panel on the left.

#### 5. Click **Plot Line Profile**.

All available stress components are plotted together. Check **Show  $\pm 1\sigma$  band** to display uncertainty bands.

### 4.3 Exporting

Click **Export Data...** to save all stress components simultaneously in a single Tecplot .dat file.

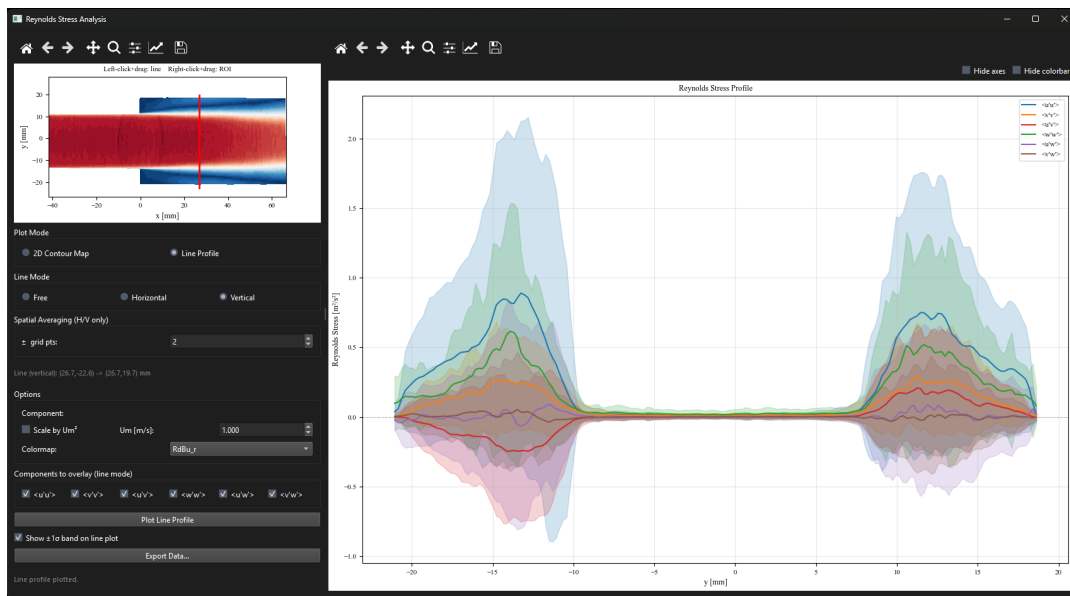


Figure 4.2: Reynolds stress window in line profile mode. All stress components are plotted simultaneously in different colors. Shaded bands show  $\pm 1\sigma$  statistical uncertainty. The x-axis shows the physical coordinate measured from the coordinate origin.

## Chapter 5

# TKE Budget

Open from **3. Analysis** → **TKE Budget**.

The turbulent kinetic energy  $k = \frac{1}{2}\langle u'_i u'_i \rangle$  evolves according to the TKE transport equation (Pope, 2000, Ch. 5):

$$\underbrace{\frac{\partial k}{\partial t}}_{\text{unsteady}} + \underbrace{\langle U_j \rangle \frac{\partial k}{\partial x_j}}_C = \underbrace{-\langle u'_i u'_j \rangle \frac{\partial \langle U_i \rangle}{\partial x_j}}_P - \underbrace{\frac{\partial}{\partial x_j} \left( \frac{1}{2} \langle u'_i u'_i u'_j \rangle + \frac{\langle p' u'_j \rangle}{\rho} \right)}_D - \underbrace{\nu \left\langle \frac{\partial u'_i}{\partial x_j} \frac{\partial u'_i}{\partial x_j} \right\rangle}_{\varepsilon}$$

Production  $P$  represents the rate at which turbulent energy is generated by the interaction of Reynolds stresses with the mean velocity gradients. Convection  $C$  describes the transport of  $k$  by the mean flow. Turbulent diffusion  $D$  redistributes energy in space via triple velocity correlations. Viscous dissipation  $\varepsilon$  converts kinetic energy irreversibly into heat at the small scales.

From planar PIV, the dissipation  $\varepsilon$  and pressure diffusion cannot be computed directly. uPrime therefore computes a residual  $R = P + D - C$  (for stationary turbulence with  $\partial k / \partial t \approx 0$ ), which absorbs dissipation and any missing out-of-plane contributions. A non-zero  $R$  is physically expected and is not an error.

Spatial gradients are computed using central differences with NaN-inpainting near mask boundaries to prevent spurious gradients at wall and shadow edges. Triple correlations for turbulent diffusion are optionally smoothed with a median filter before differentiation to reduce noise amplification.

### Note

The residual  $R$  absorbs pressure diffusion and viscous dissipation, which cannot be computed from planar PIV. A non-zero residual is expected and is *not* an error in the calculation.

**Reference:** Pope, S.B. (2000). *Turbulent Flows*. Cambridge University Press.

Table 5.1: TKE budget terms in uPrime.

Symbol	Name	Availability
$k$	Turbulent kinetic energy	Always
$P$	Production	Always
$C$	Convection	Always
$D$	Turbulent diffusion	Always
$R$	Residual	Always
$\partial k / \partial t$	Unsteady term	TR data only

## 5.1 Using the window

### ☰ Step-by-step

1. Set parameters: enter  $U_m$  and  $L$  if normalising. Adjust the smoothing kernel if the field is noisy.
2. Click **Compute Budget** (only needs to be done once per session).
3. Select a term from the **Term** dropdown.
4. Choose **2D Contour** or **Line Profile**.
5. Click **Plot**.

In line profile mode, TKE  $k$  is always overlaid as a dashed reference line regardless of which budget term is selected.

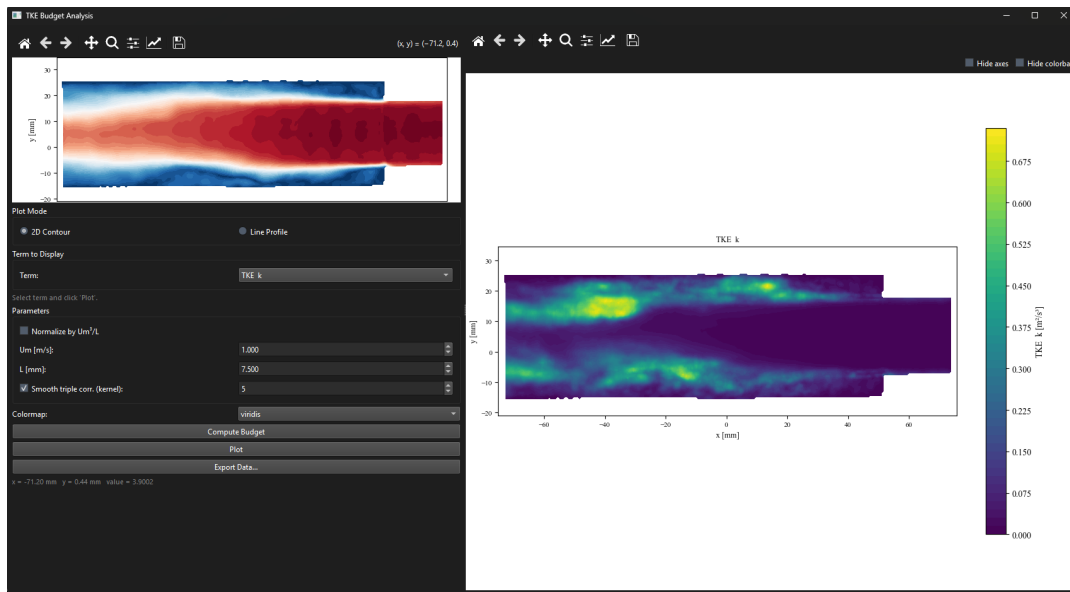


Figure 5.1: TKE Budget window showing the production term  $P$  as a 2D contour map. The mean field reference is shown in the left panel. Production peaks in the shear layers where Reynolds stresses interact with the mean velocity gradients.

### 💡 Tip

Enable **Normalize by  $U_m^3/L$**  to make the budget terms non-dimensional. TKE  $k$  is normalized by  $U_m^2$ . This is essential when comparing results across different flow conditions or Reynolds numbers.

## 5.2 Exporting

Click **Export Data...** to save all budget terms together in a single file.

## Chapter 6

# Space–Time Spectral Analysis

Open from **3. Analysis** → **Space-Time Spectra**.

The spectral window has four tabs. **Spatial (Welch)** is always available. **Temporal** and **Spatiotemporal** require time-resolved data. **Spatial (FFT)** is always available and provides a complementary 2D ROI-based spatial spectrum.

### 6.1 Spatial Spectra – Welch (Tab 1)

The one-dimensional spatial energy spectrum  $E(k)$  characterizes the distribution of turbulent kinetic energy across spatial scales. For homogeneous isotropic turbulence, Kolmogorov’s similarity theory predicts an inertial subrange where  $E(k) \propto k^{-5/3}$  (Kolmogorov, 1941). The spatial spectrum is computed along a user-defined line using Welch’s method: the line is divided into overlapping segments, each Hann-windowed and Fourier-transformed, and the periodograms are averaged to reduce variance. The wavenumber  $k$  is in rad/m.

#### ☰ Step-by-step

1. Choose **Horizontal** ( $k_x$ ) or **Vertical** ( $k_y$ ) mode.
2. Left-click and drag on the field to draw the line.
3. Select which velocity components to include (U, V, W).
4. Set the number of Welch segments and overlap.
5. Click **Compute**.

Results are plotted on a log–log scale. The Kolmogorov  $-5/3$  reference slope can be toggled on/off. You can also compensate the spectrum by multiplying by  $k^{5/3}$  to flatten the inertial range.

**Reference:** Kolmogorov, A.N. (1941). The local structure of turbulence in incompressible viscous fluid for very large Reynolds numbers. *Proceedings of the USSR Academy of Sciences*, 30, 301–305.

### 6.2 Temporal Spectra (Tab 2, TR Only)

The power spectral density  $E(f)$  of the velocity fluctuations at a fixed point reveals the temporal frequency content of the turbulence. Dominant peaks correspond to periodic or quasi-periodic phenomena such as vortex shedding, shear layer flapping, or acoustic resonances. The temporal spectrum is computed using Welch’s method with a Hann window.

#### ☰ Step-by-step

1. Left-click on the field to pick a reference point, or right-click drag to draw an ROI.
2. Set the number of Welch segments. More segments give a smoother spectrum at the cost of frequency resolution.

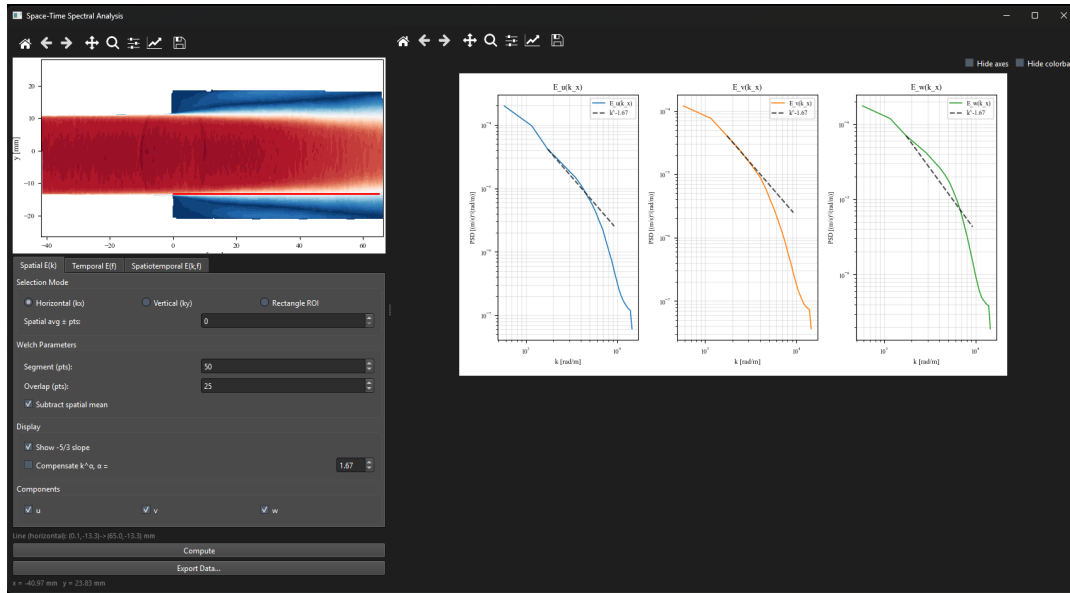


Figure 6.1: Spatial spectra (Welch tab) showing  $E(k_x)$  for the U and V components along a horizontal line through the shear layer. The dashed line shows the Kolmogorov  $-5/3$  reference slope. The inertial subrange is visible between approximately  $k = 100$  and  $k = 1000$  rad/m.

3. Click **Compute**.

#### Tip

Looking for a shedding frequency or flapping mode? Use fewer segments (higher frequency resolution). Just want the spectral shape? Use more segments for a smoother curve.

### 6.3 Space-Time Spectra (Tab 3, TR Only)

The two-dimensional space-time spectrum  $E(k, f)$  jointly characterizes the spatial and temporal structure of convecting turbulent structures. It is computed by applying a 2D Fourier transform in both space (along a streamwise line) and time. Diagonal ridges in the resulting map correspond to spatially coherent structures convecting at a fixed speed. The slope of a ridge gives the convection velocity  $U_c = 2\pi f/k$ , providing a direct test of Taylor's frozen turbulence hypothesis (del Álamo & Jiménez, 2009).

**Reference:** del Álamo, J.C. & Jiménez, J. (2009). Estimation of turbulent convection velocities and corrections to Taylor's approximation. *Journal of Fluid Mechanics*, 640, 5–26.

### 6.4 Spatial Spectra – FFT (Tab 4)

Computes the 2D spatial energy spectrum over a rectangular ROI using a direct FFT (via pyFFTW), averaged over all snapshots. The result is shown as 1D marginal spectra  $E(k_x)$  and  $E(k_y)$  alongside the 2D spectral map.

## Chapter 7

# Anisotropy Invariant Analysis

Open from **3. Analysis** → **Anisotropy Invariants**.

### Note

This module requires **stereo PIV (2D3C)** data. It is not available for 2D2C datasets.

The Reynolds stress tensor  $b_{ij} = \langle u'_i u'_j \rangle / (2k) - \delta_{ij}/3$  is a symmetric, traceless tensor that describes the anisotropy of the turbulence. Its eigenvalues  $\lambda_1 \geq \lambda_2 \geq \lambda_3$  satisfy  $\lambda_1 + \lambda_2 + \lambda_3 = 0$ . The invariants of  $b_{ij}$ ,

$$\eta^2 = \frac{1}{6} b_{ij} b_{ji}, \quad \xi^3 = \frac{1}{6} b_{ij} b_{jk} b_{ki},$$

define a two-dimensional state space. All physically realizable turbulence states lie within the Lumley triangle, bounded by the one-component ( $\lambda_1 = 2/3$ ), two-component ( $\lambda_3 = -1/3$ ), and isotropic ( $\lambda_i = 0$ ) limits (Lumley, 1978). The barycentric map is an alternative linear representation of the same anisotropy state space introduced by Banerjee et al. (2007), which maps the three limiting states to the vertices of an equilateral triangle with coordinates that vary linearly between limits.

**References:** Lumley, J.L. (1978). Computational modeling of turbulent flows. *Advances in Applied Mechanics*, 18, 123–176. Banerjee, S., Krahl, R., Durst, F. & Zenger, Ch. (2007). Presentation of anisotropy properties of turbulence. *International Journal of Heat and Fluid Flow*, 28(3), 939–946.

## 7.1 Lumley triangle mode

### Step-by-step

1. Ensure **Line (Lumley triangle)** is selected.
2. Choose **Free**, **Horizontal**, or **Vertical** line orientation.
3. Left-click and drag on the mean field to draw the sampling line.
4. Click **Compute**.

Reading the triangle: the top vertex represents one-component turbulence; the bottom-left vertex represents two-component axisymmetric (disk-like) turbulence; the bottom-right vertex represents two-component axisymmetric (rod-like) turbulence; the origin represents isotropic turbulence. Points outside the boundary indicate numerical issues (insufficient snapshots or masked regions).

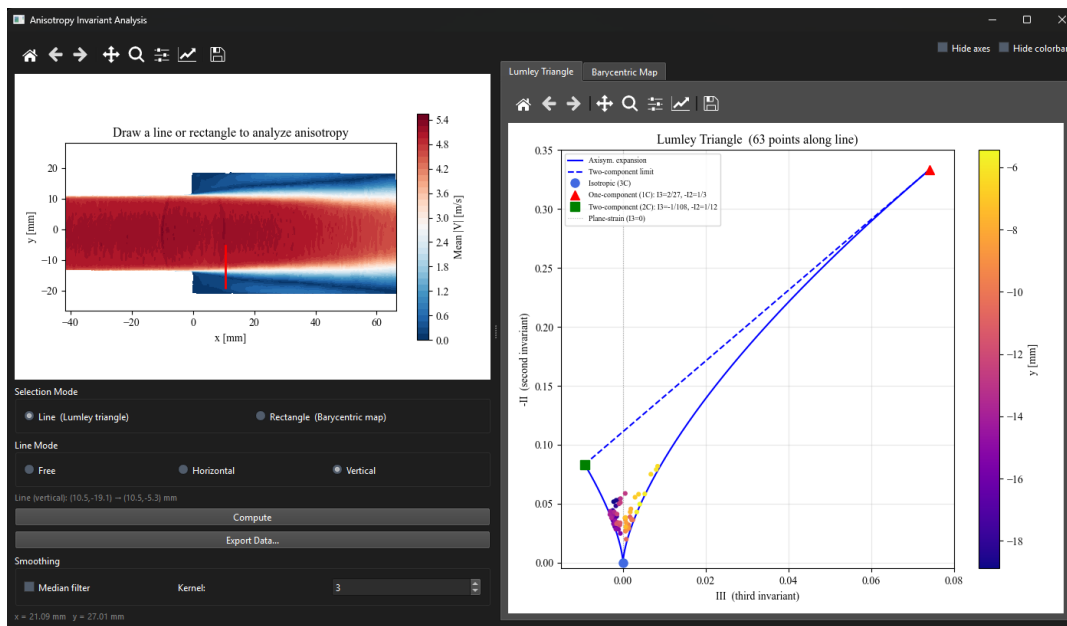


Figure 7.1: Anisotropy window in Lumley triangle mode. Left: the vertical sampling line crosses the shear layer on the mean field. Right: each sampled point appears in the triangle, colored by its distance along the line. Points migrate from near-isotropic (center) toward the one-component vertex (top) inside the high-turbulence shear layer.

## 7.2 Barycentric map mode

### ☰ Step-by-step

1. Select **Rectangle (Barycentric map)**.
2. Left-click and drag to draw a rectangular region on the field.
3. Click **Compute**.

The map colors each grid point by its anisotropy state: red = one-component, blue = two-component axisymmetric, green = three-component (near isotropic). Check **Median filter** to apply a  $3 \times 3$  spatial smoothing to reduce noise.

## Chapter 8

# Correlation Analysis

Open from **3. Analysis** → **Correlation Analysis**.

The two-point spatial correlation function

$$R_{uu}(\Delta x, \Delta y) = \frac{\langle u'(\mathbf{x}, t) u'(\mathbf{x} + \mathbf{\Delta}, t) \rangle}{\sigma(\mathbf{x}) \sigma(\mathbf{x} + \mathbf{\Delta})}$$

measures the degree to which velocity fluctuations at two different locations are statistically related. When  $R_{uu}$  decays from 1 at  $\Delta = 0$  to 0, the separation at which it crosses zero defines the integral length scale  $L$ , a measure of the size of the largest energy-containing eddies (Pope, 2000). The temporal autocorrelation  $R(\tau)$  plays an analogous role in time, with the integral time scale  $T = \int_0^\infty R(\tau) d\tau$ .

**Reference:** Pope, S.B. (2000). *Turbulent Flows*. Cambridge University Press.

### 8.1 Selecting a reference

- **Point mode:** left-click on the mean field to select a single reference point. Enable **3 × 3 kernel average** to reduce sensitivity to noisy vectors at that point.
- **ROI mode:** left-click and drag to draw a rectangle. The correlation is computed as a spatial average over the region.

### 8.2 Spatial correlation

#### ☰ Step-by-step

1. Select Point or ROI mode and pick your reference on the field.
2. Choose the velocity component:  $R_{uu}$ ,  $R_{vv}$ , or  $R_{ww}$ .
3. Select the **Scale method** (Table 8.1).
4. Click **Compute Spatial Correlation**.

In Point mode you see the full 2D correlation map and two independent 1D slice panels. In ROI mode only the 1D panels are shown. The computed  $L_x$  and  $L_y$  are displayed in the readout strip at the bottom of the window. A vertical dashed line marks the crossing lag used by the selected scale method; for the zero-crossing method, this line is placed at the lag where  $R$  first crosses zero, while  $L$  is reported as the integral of  $R$  up to that crossing. Click **Show Diagnostic Plot** to see the cumulative integral of  $R(\Delta r)$ .

#### 💡 Tip

If unsure, start with **Zero crossing**. If the correlation does not have a clean crossing (common for low-Reynolds-number flows or short datasets), switch to **Exponential fit**.

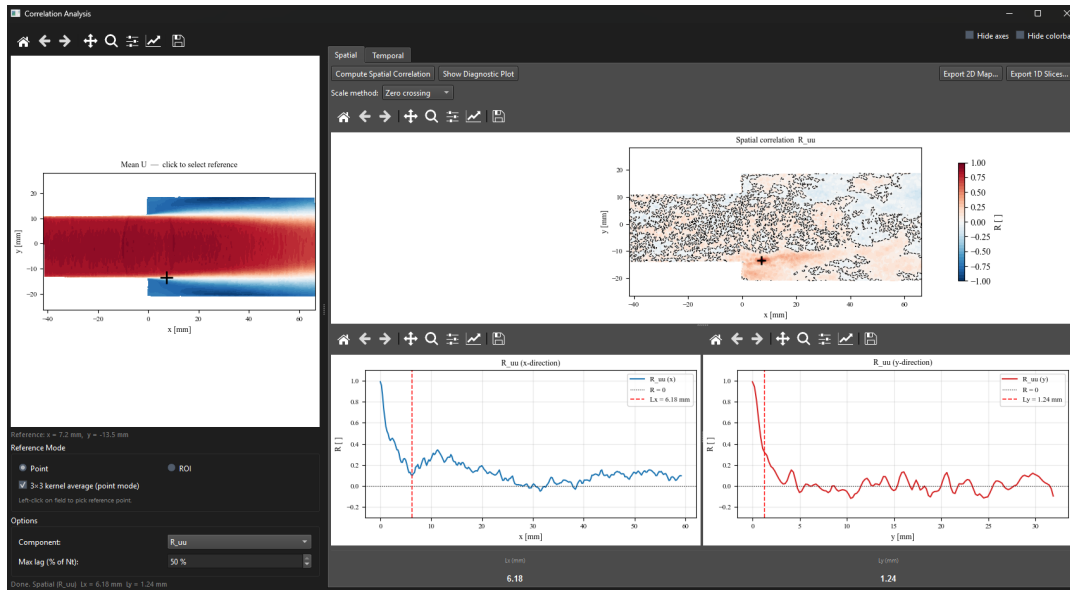


Figure 8.1: Correlation window in ROI mode showing  $R_{uu}$  in the  $x$ - and  $y$ -directions. The vertical dashed red line marks the zero-crossing lag used to compute the integral length scale.  $L_x$  and  $L_y$  are reported in the readout strip at the bottom.

Table 8.1: Integral scale methods.

Method	When to use
Zero crossing	Clean, well-resolved correlations with a clear zero crossing. Standard choice.
Exponential fit	Noisy correlations without a clear zero crossing. Robust to noise in the tail.
1/e point	Returns the lag at which $R$ first drops to $e^{-1} \approx 0.368$ (interpolated).
Domain integral	When no zero crossing exists and you want a conservative upper bound.

### 8.3 Temporal correlation (TR only)

#### ☰ Step-by-step

1. Click the **Temporal** tab.
2. Pick a reference point or draw an ROI as before.
3. Set **Max lag (% of Nt)**: 50% is usually sufficient.
4. Select the Scale method.
5. Click **Compute Temporal Correlation**.

Results show  $R(\tau)$  vs time lag  $\tau$  in milliseconds, with integral time scale  $T$  and Taylor microscale  $\lambda_t$  marked.

## Chapter 9

# POD Analysis

Open from **3. Analysis** → **POD Analysis**.

Proper Orthogonal Decomposition (POD) finds the most efficient low-dimensional representation of the velocity field by decomposing the fluctuation field into a set of orthogonal spatial modes  $\phi_n(\mathbf{x})$  and corresponding temporal coefficients  $a_n(t)$ :

$$\mathbf{u}'(\mathbf{x}, t) = \sum_{n=1}^N a_n(t) \phi_n(\mathbf{x})$$

The modes are ordered by their energy content: Mode 1 captures the largest fraction of the total TKE, Mode 2 the next largest, and so on. This property, known as optimality, means that the POD is the most efficient basis for representing the flow in a least-squares sense (Lumley, 1967; Holmes et al., 1996). In practice, a small number of modes often captures the dominant coherent structures (recirculation zones, vortex shedding, shear layer flapping), while the remaining modes represent incoherent noise.

uPrime implements the snapshot POD method (Sirovich, 1987), which is efficient when the number of spatial grid points exceeds the number of snapshots. The SVD of the fluctuation snapshot matrix directly yields the POD modes and their energy content.

**References:** Lumley, J.L. (1967). The structure of inhomogeneous turbulent flows. In *Atmospheric Turbulence and Radio Wave Propagation*, 166–178. Holmes, P., Lumley, J.L. & Berkooz, G. (1996). *Turbulence, Coherent Structures, Dynamical Systems and Symmetry*. Cambridge University Press. Sirovich, L. (1987). Turbulence and the dynamics of coherent structures. *Quarterly of Applied Mathematics*, 45(3), 561–590.

## 9.1 Computing POD

### ☰ Step-by-step

1. Set **Modes to compute** (default 25). Increasing this takes longer.
2. Click **Compute POD**. For large datasets this may take several seconds to a minute.
3. All four tabs populate automatically when done.

### 📘 Note

POD uses all velocity components simultaneously (U+V for 2D2C; U+V+W for 2D3C). The energy percentage of each mode reflects the combined energy across all components.

## 9.2 Energy Spectrum tab

Use the energy spectrum to decide how many modes to use for reconstruction and interpretation. A steep drop after Mode 1 or 2 indicates a flow dominated by one or two strong coherent

structures. A slow gradual decay indicates broadband turbulence with energy distributed across many scales.

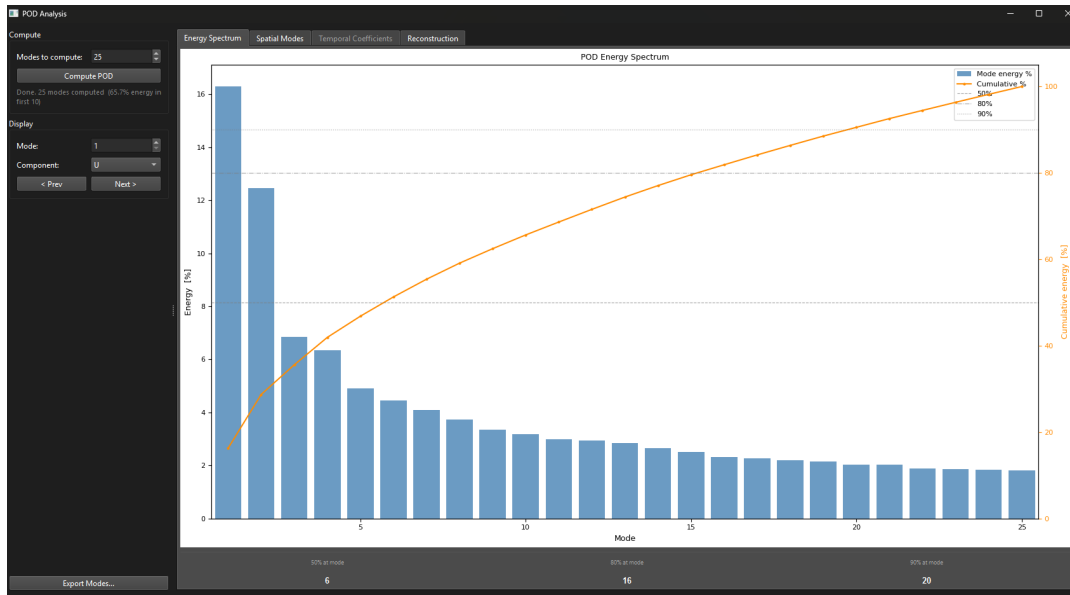


Figure 9.1: POD Energy Spectrum tab. Bars show the energy percentage per mode; the orange curve shows cumulative energy. Dashed horizontal lines mark the 50%, 80%, and 90% thresholds. The readout strip at the bottom shows how many modes are needed to reach each threshold.

### 9.3 Spatial Modes tab

Use the **Mode** spinbox or **< Prev / Next >** buttons to step through modes. Use the **Component** dropdown to inspect different velocity directions. The title shows the mode number and its energy fraction.

### 9.4 Temporal Coefficients tab (TR only)

Shows the temporal coefficient time series  $a_n(t)$  for the selected mode and its power spectral density. A sharp peak in the PSD indicates a periodic structure at that frequency (e.g. vortex shedding or shear layer flapping).

### 9.5 Reconstruction tab

#### ☰ Step-by-step

1. Drag the **Snapshot** slider to select a snapshot.
2. Set **Modes for reconstruction** (minimum 1).
3. Click **Reconstruct**.

The three panels show the original field, the low-order reconstruction, and the residual. A residual below 10–20% RMS generally means the selected modes capture the dominant structure.

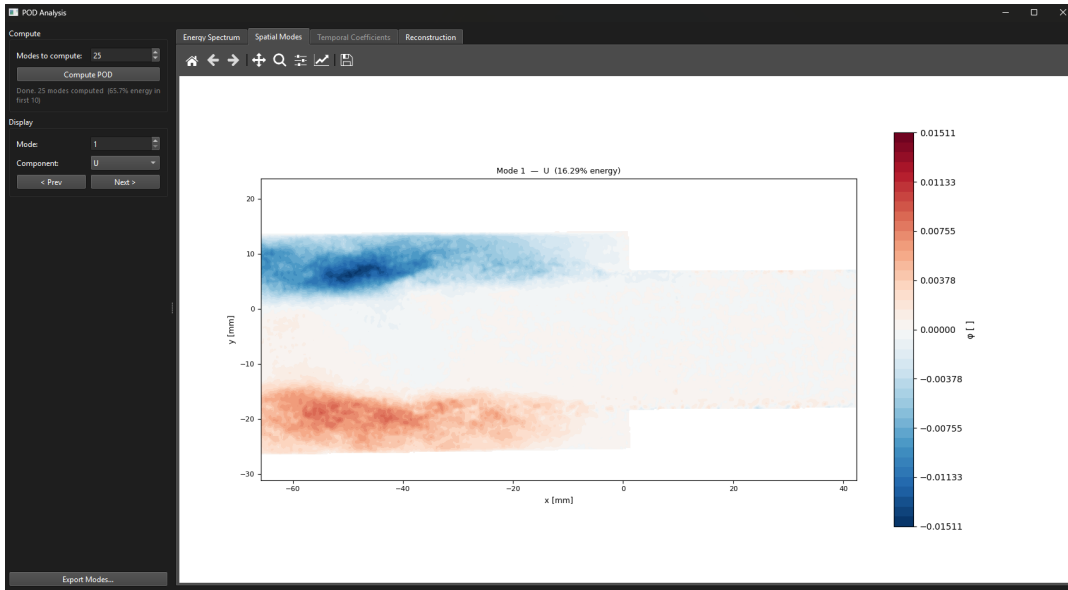


Figure 9.2: POD Spatial Modes tab showing Mode 1 of the  $U$  component. Red and blue regions represent opposite-signed velocity fluctuations associated with the dominant coherent structure in the flow. The energy fraction of the mode is shown in the plot title.

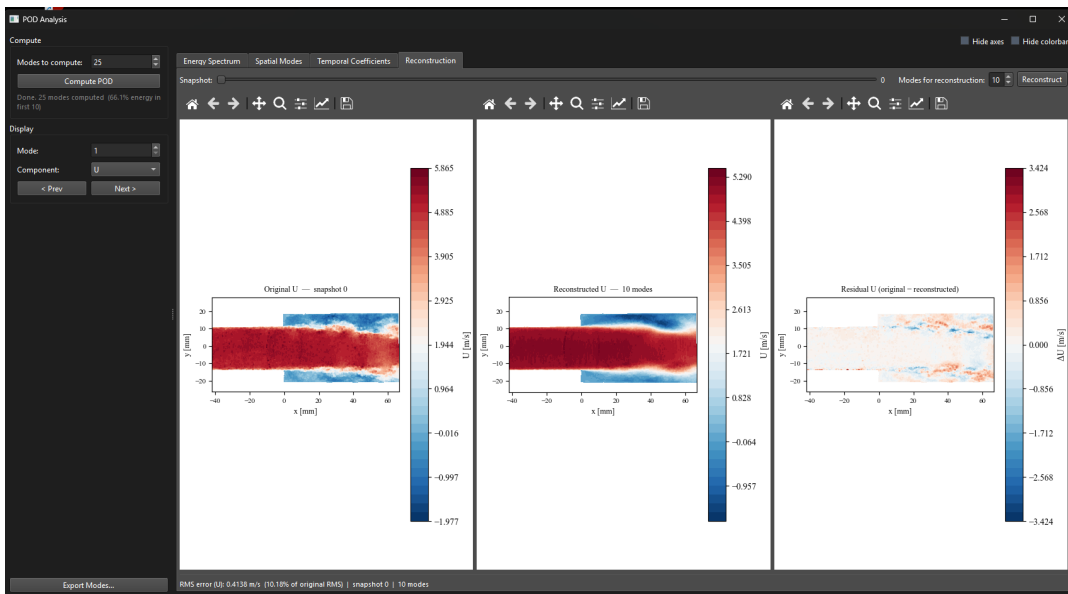


Figure 9.3: POD Reconstruction tab. Left: original snapshot. Center: low-order reconstruction with selected modes. Right: residual (original minus reconstructed). The RMS reconstruction error is shown at the bottom.

## 9.6 Exporting

Click **Export Modes...** to save all spatial modes as a Tecplot `.dat` file and temporal coefficients as a `.csv` file.

## Chapter 10

# DMD Analysis

Open from [3. Analysis](#) → [DMD Analysis](#).

### Note

DMD requires **time-resolved (TR)** data. The button is greyed out for Non-TR datasets. A minimum of 50 snapshots is required; 200 or more are recommended.

Dynamic Mode Decomposition (DMD) decomposes the time-resolved velocity sequence into a set of spatially coherent modes, each oscillating at a single frequency  $f$  and growing or decaying at a fixed rate  $\sigma$  (Schmid, 2010). Unlike POD, which ranks modes by energy, DMD ranks modes by their temporal frequency content. Each DMD mode  $\Phi_j$  satisfies:

$$\mathbf{u}(\mathbf{x}, t) \approx \sum_j b_j \Phi_j(\mathbf{x}) e^{(\sigma_j + 2\pi i f_j) t}$$

where  $b_j$  is the mode amplitude,  $\sigma_j$  is the growth rate (positive = growing, negative = decaying, zero = neutrally stable), and  $f_j$  is the oscillation frequency in Hz. For stationary turbulence, the physically meaningful modes are those with  $\sigma_j \approx 0$ : they represent persistent oscillatory structures such as vortex shedding, shear layer flapping, or acoustic resonances.

DMD is implemented using the exact DMD algorithm (Tu et al., 2014) with a POD-based rank truncation that projects onto the leading singular vectors of the snapshot matrix before computing the DMD operator. This reduces sensitivity to measurement noise. For stereo data, the snapshot matrix stacks U, V, and W velocity components vertically so that each DMD mode captures spatially coherent structures across all three components simultaneously.

### Warning

DMD is sensitive to PIV measurement noise. Modes at very high growth rates ( $|\sigma| \gg 0$ ) are typically numerical artifacts. Use the growth rate filter ( $|\sigma| < \text{threshold}$ ) to focus on physically meaningful near-neutral modes.

**References:** Schmid, P.J. (2010). Dynamic mode decomposition of numerical and experimental data. *Journal of Fluid Mechanics*, 656, 5–28. Tu, J.H., Rowley, C.W., Luchtenburg, D.M., Brunton, S.L. & Kutz, J.N. (2014). On dynamic mode decomposition: Theory and applications. *Journal of Computational Dynamics*, 1(2), 391–421.

## 10.1 Computing DMD

### ☰ Step-by-step

1. Select the velocity component: **Stacked (all components)**, **U only**, **V only**, or **W only**.
2. Set the number of modes to compute (default 50; maximum is  $N_t - 1$ ).
3. Check **Subtract mean** (recommended) to perform DMD on the fluctuation field.
4. Click **Compute DMD**. The first non-zero-frequency mode is displayed automatically.

## 10.2 DMD Spectrum tab

The spectrum shows each DMD mode as a bubble at its position in the frequency–growth rate plane. Bubble size and color represent the mode amplitude. The dashed horizontal line marks  $\sigma = 0$  (neutral stability). Modes above this line are growing; modes below are decaying. For stationary turbulence, modes of physical interest cluster near  $\sigma = 0$ .

Click any bubble to immediately display the corresponding spatial mode in the Mode Viewer tab. The mode number, frequency, and growth rate are shown in the readout strip.

Use the **Growth rate filter** to hide modes with  $|\sigma|$  above a threshold. Use **Min frequency** to suppress the near-zero mean-flow artifact that commonly appears at  $f \approx 0$ . Use the **Strouhal number** toggle to non-dimensionalize the frequency axis as  $St = fL/U_m$ .

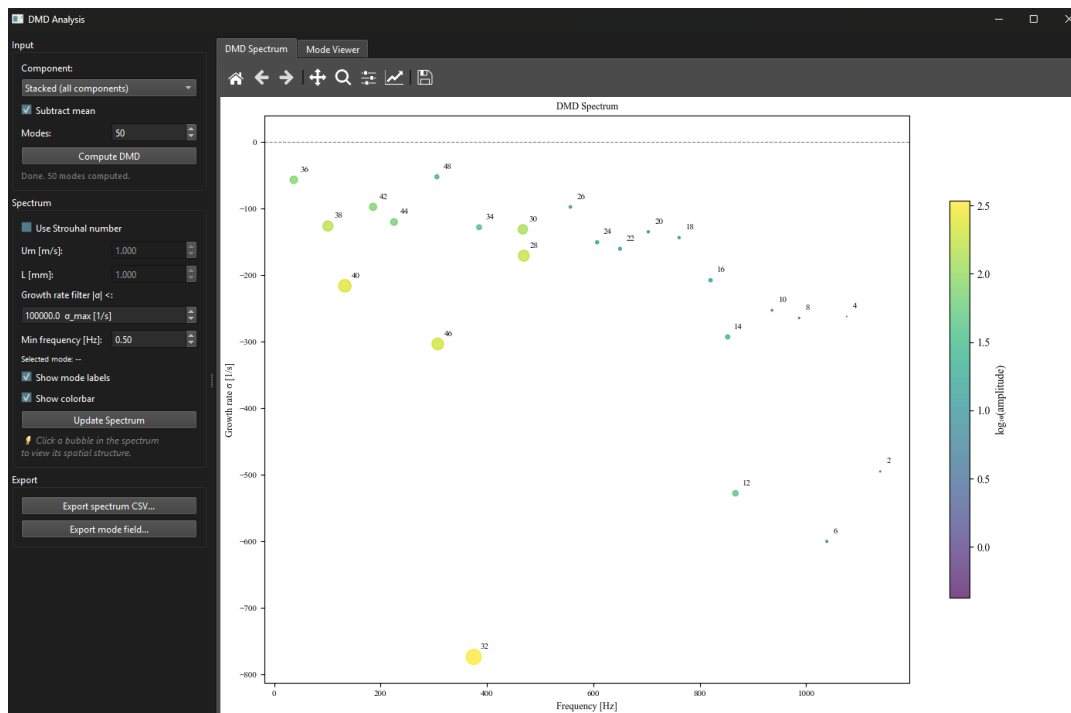


Figure 10.1: DMD Spectrum tab showing 50 computed modes for a 2D2C dataset at  $f_s = 1000$  Hz. Each bubble represents one mode; bubble size and color (viridis) indicate log-amplitude. Mode indices are shown adjacent to each bubble. The dashed horizontal line marks  $\sigma = 0$  (neutral stability). Modes clustering near  $\sigma = 0$  are the physically meaningful persistent oscillatory structures.

### 10.3 Mode Viewer tab

The Mode Viewer shows the spatial structure of the selected DMD mode. For stacked decompositions, three panels display the U, V, and W components of the mode. Toggle between **Real part**, **Imaginary part**, and **Magnitude**. Use **Prev** and **Next** to step through all modes sorted by amplitude (largest first).

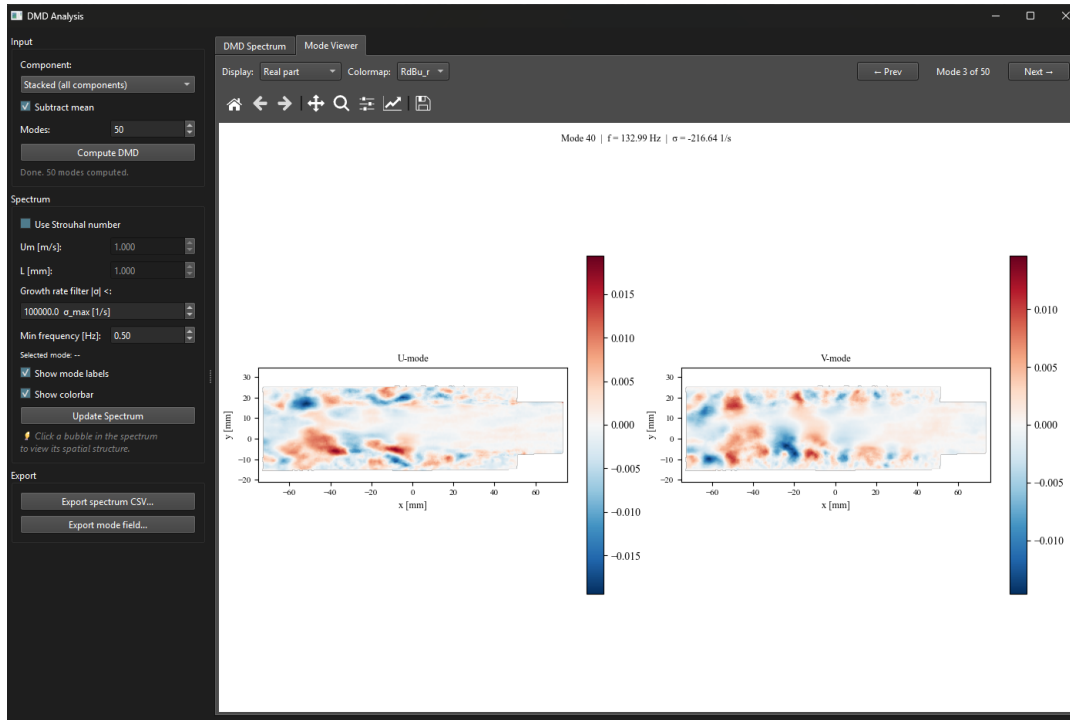


Figure 10.2: DMD Mode Viewer showing Mode 40 ( $f = 132.99$  Hz,  $\sigma = -216.64$  1/s) for a stacked U+V decomposition. The U-mode (left) and V-mode (right) show the spatial structure of the oscillation at this frequency. Red and blue regions represent opposite phases of the oscillatory motion. The Prev/Next buttons step through all modes sorted by amplitude.

#### Tip

The real and imaginary parts of a DMD mode represent the two phases of the oscillation separated by a quarter period. Animating between them (real  $\rightarrow$  imaginary  $\rightarrow$   $-\text{real}$   $\rightarrow$   $-\text{imaginary}$ ) gives a physical sense of how the structure evolves in time.

### 10.4 Exporting

Click **Export spectrum CSV...** to save a table of all modes with their frequency, growth rate, and amplitude. Click **Export mode field...** to save the spatial structure of the currently selected mode as a Tecplot `.dat` file.

## Chapter 11

# Vortex Identification

Open from [3. Analysis](#) → [Vortex Identification](#).

Vortex identification methods seek to objectively define the boundary and core of a vortex from the instantaneous or mean velocity field. uPrime implements five scalar criteria, which can be broadly divided into gradient-based (Eulerian) methods and the integral-based Graftieaux criteria.

### Gradient-based methods

All four gradient-based methods derive from the 2D velocity gradient tensor:

$$\nabla \mathbf{u} = \begin{pmatrix} \partial u / \partial x & \partial u / \partial y \\ \partial v / \partial x & \partial v / \partial y \end{pmatrix}$$

which is decomposed into its symmetric strain rate  $\mathbf{S} = \frac{1}{2}(\nabla \mathbf{u} + \nabla \mathbf{u}^\top)$  and antisymmetric rotation rate  $\mathbf{\Omega} = \frac{1}{2}(\nabla \mathbf{u} - \nabla \mathbf{u}^\top)$ .

- **Vorticity**  $\omega = \partial v / \partial x - \partial u / \partial y$ : the simplest measure of local rotation, but nonzero in shear layers even without a vortex core.
- **Q-criterion** (Hunt et al., 1988):  $Q = -\frac{1}{2}(\partial_x u^2 + \partial_y v^2 + 2 \partial_y u \partial_x v)$ . A vortex core is identified where  $Q > 0$ , meaning rotation dominates strain. Q is the most widely used criterion in PIV literature.
- **Swirling strength**  $\lambda_{ci}$  (Zhou et al., 1999): the imaginary part of the complex eigenvalue of  $\nabla \mathbf{u}$ . Complex eigenvalues exist only where the flow is locally swirling;  $\lambda_{ci}$  is therefore immune to pure shear contamination that inflates  $\omega$  and  $Q$  in shear layers. uPrime multiplies by  $\text{sign}(\omega)$  to retain rotation direction.
- **$\lambda_2$ -criterion** (Jeong & Hussain, 1995): identifies a vortex core as a connected region where the second eigenvalue of  $\mathbf{S}^2 + \mathbf{\Omega}^2$  is negative. This criterion has a direct physical motivation:  $\lambda_2 < 0$  marks regions where the centrifugal tendency of the pressure field overcomes both strain and unsteady effects.

**References:** Hunt, J.C.R., Wray, A. & Moin, P. (1988). Eddies, stream, and convergence zones in turbulent flows. *CTR Report CTR-S88*, 193–208. Zhou, J., Adrian, R.J., Balachandar, S. & Kendall, T.M. (1999). Mechanisms for generating coherent packets of hairpin vortices in channel flow. *Journal of Fluid Mechanics*, 387, 353–396. Jeong, J. & Hussain, F. (1995). On the identification of a vortex. *Journal of Fluid Mechanics*, 285, 69–94.

### Graftieaux $\Gamma$ functions

The  $\Gamma$  functions (Graftieaux et al., 2001) are computed directly from the velocity vectors without differentiation, making them substantially more robust to PIV measurement noise:

$$\Gamma_1(P) = \frac{1}{N} \sum_{M \in \mathcal{S}} \sin(\widehat{\mathbf{PM}}, \widehat{\mathbf{U}}_M), \quad \Gamma_2(P) = \frac{1}{N} \sum_{M \in \mathcal{S}} \sin(\widehat{\mathbf{PM}}, \widehat{\mathbf{U}}_M - \tilde{\mathbf{U}})$$

where  $\mathcal{S}$  is a local neighborhood of  $N$  points around  $P$ ,  $\widehat{(\cdot, \cdot)}$  denotes the angle between two vectors, and  $\tilde{\mathbf{U}}$  is the local mean velocity over  $\mathcal{S}$ . Both functions are bounded between  $-1$  and  $+1$ . The sign gives the rotation direction ( $+1 = \text{CCW}$ ,  $-1 = \text{CW}$ ). A vortex *core* is identified where  $|\Gamma_1| > 0.6$ – $0.7$ ; the vortex *boundary* is where  $|\Gamma_2| > 2/\pi \approx 0.64$ . The neighborhood half-width  $S$  (default 2, corresponding to a  $5 \times 5$  stencil) is user-adjustable.

**Reference:** Graftieaux, L., Michard, M. & Grosjean, N. (2001). Combining PIV, POD and vortex identification algorithms for the study of unsteady turbulent swirling flows. *Measurement Science and Technology*, 12(9), 1422–1429.

## 11.1 Field View tab

### ☰ Step-by-step

1. Select the scalar field and input (mean or instantaneous frame).
2. Click **Compute Field**.
3. Set the threshold fraction and sign filter, then click **Detect Vortices**.
4. Check **Show vortex boundaries** to overlay detected contours on the colormap.

The threshold is expressed as a fraction of the field maximum, making it dataset-agnostic. The actual physical value is shown in the readout next to the slider. For the  $\Gamma$  criteria the threshold has a universal meaning ( $|\Gamma_1| = 0.6$  corresponds to the standard core boundary); for gradient-based criteria it is dataset-dependent and must be chosen by the user.

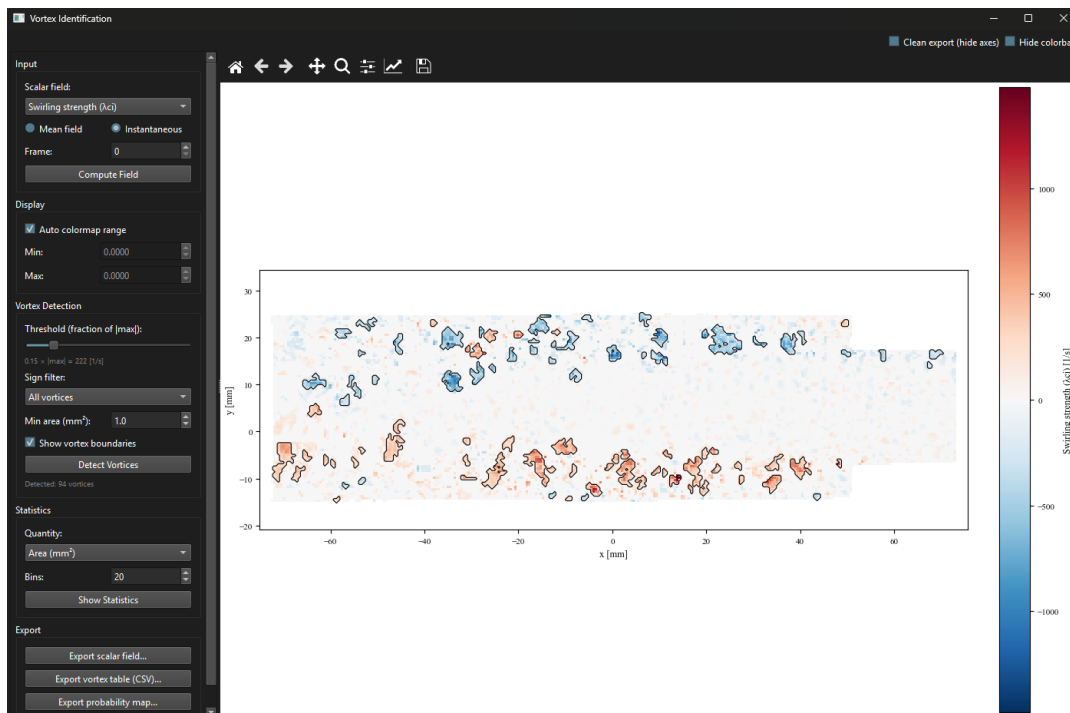


Figure 11.1: Vortex Identification window showing the swirling strength  $\lambda_{ci}$  field for an instantaneous snapshot. Detected vortex boundaries (black contour lines) are overlaid on the colormap. The threshold is set to 15% of the field maximum. Red regions indicate positive (CCW) rotation; blue regions indicate negative (CW) rotation. A total of 94 vortices are detected above the minimum area threshold.

### Tip

For PIV data, start with  $\Gamma_1/\Gamma_2$ , which is most robust to measurement noise. Cross-check with Q-criterion or  $\lambda_{ci}$ . If the two methods agree, the detected structures are reliable.

## 11.2 Vortex Statistics tab

After clicking **Show Statistics**, two plots appear: a spatial probability map showing how often a vortex is detected at each grid point across all snapshots, and a histogram of the selected per-vortex quantity (area, circulation, or aspect ratio) with positive and negative vortices shown separately in red and blue.

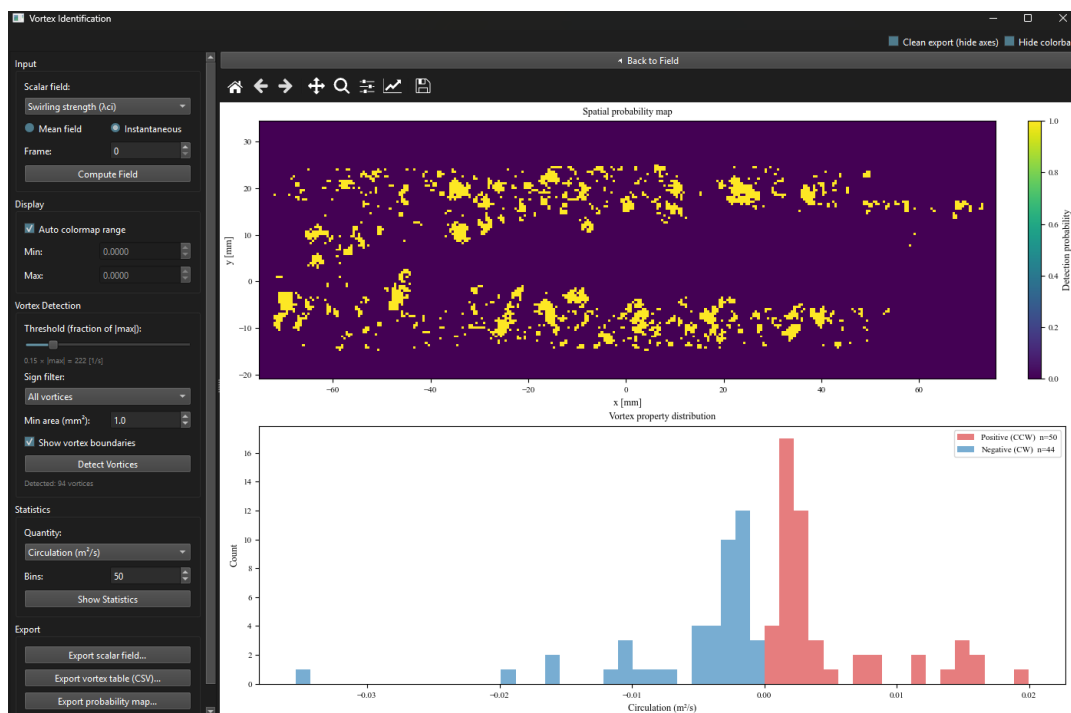


Figure 11.2: Vortex Statistics view. Top: spatial probability map showing the fraction of snapshots in which a vortex is detected at each grid point (viridis colormap, 0–1). Yellow regions indicate persistent vortex locations concentrated in the shear layers. Bottom: circulation histogram for 94 detected vortices (50 CCW in red, 44 CW in blue). The near-symmetric distribution about zero is consistent with a turbulent shear layer with no mean rotation bias.

## 11.3 Exporting

Click **Export scalar field...** to save the scalar field as a Tecplot `.dat` file. Click **Export vortex table (CSV)...** to save a per-vortex table with columns: vortex ID, centroid position, area, sign, circulation, aspect ratio, and frame index. This CSV is designed to be imported into post-processing scripts for vortex tracking or further statistical analysis.

## Chapter 12

# Tips, Workflow, and Troubleshooting

### 12.1 Recommended workflow

For any new dataset, follow this order:

1. **Load** your files. Use stride subsampling if the dataset is large.
2. **Set** acquisition type and  $f_s$  in the popup dialog or the info ribbon.
3. **Transform**: rotate to correct tilt, shift the origin to a physical reference.
4. **Inspect** the mean field. Does the flow look correct? Right direction, sensible magnitudes?
5. **Reynolds stresses**: identify turbulent regions and shear layers.
6. **TKE budget**: understand energy production and transport.
7. **Correlations**: measure integral length and time scales.
8. **POD**: identify dominant coherent structures.
9. **DMD** (TR only): extract frequency-specific coherent modes.
10. **Vortex identification**: locate and quantify vortex cores.
11. **Export** results.

### 12.2 Performance tips

- POD and DMD computation time scales as  $N_t^2$ . For 5000+ snapshots use stride subsampling to  $\sim 1000$ – $2000$  samples first.
- Velocity data is loaded as 32-bit floats (float32), halving RAM usage compared to the 64-bit default.
- Close unused analysis windows to free RAM.
- Use **Reload Last Dataset** to undo a bad transform without restarting.
- For spatial spectra over a region, the FFT tab is faster than running multiple Welch lines.
- The  $\Gamma_1/\Gamma_2$  computation involves a Python loop over all grid points and can be slow for large grids. Start with a subsampled dataset or a small neighborhood size  $S$  while exploring.

### 12.3 Exporting figures for publication

- **PDF / SVG:** all text is embedded as editable text objects. Open in Adobe Illustrator or Inkscape to change fonts, sizes, and labels to match journal requirements.
- **PNG:** 300 DPI by default. Suitable for Word, PowerPoint, and reports.
- Enable **Clean export** and/or **Hide colorbar** for plain field images without annotations.

### 12.4 Known limitations

- 3D (tomographic) PIV data is not supported.
- Pressure and viscous dissipation are not computed; the TKE budget residual absorbs these terms.
- Taylor hypothesis (for converting temporal to spatial scales) is only valid at low turbulence intensity ( $u'/\langle U \rangle \ll 1$ ).
- Anisotropy analysis requires stereo data (2D3C) and will be unavailable for 2D2C datasets.
- DMD requires time-resolved data and a minimum of 50 snapshots.
- The  $\Gamma_1/\Gamma_2$  computation is slower than gradient-based methods for large grids due to the neighborhood summation loop.
- All exported results are time-averaged unless otherwise noted. Per-snapshot export will be added in a future version.

### 12.5 Common issues

Table 12.1: Common issues and solutions.

<b>Issue</b>	<b>Solution</b>
Files do not load	Confirm files are Tecplot ASCII format from DaVis. Binary <code>.dat</code> files are not supported.
Anisotropy module is greyed out	Data is 2D2C. This module requires stereo (2D3C) data with a $W$ component.
DMD button is greyed out	Set Acquisition Type to TR in the info ribbon and ensure at least 50 snapshots are loaded.
Temporal tabs are greyed out	Set Acquisition Type to Time-Resolved and enter $f_s$ before opening the analysis window.
PDF save fails: permission denied	The file is open in Adobe Acrobat. Close it in Acrobat first, then save again.
Rotation gives a blank result	Mirror the dataset <i>before</i> rotating, not after.
Lumley triangle points outside boundary	Insufficient snapshots or masked/invalid vectors near the sampling line. Avoid masked regions when drawing the analysis line.
DMD spectrum dominated by high- $ \sigma $ modes	Apply the growth rate filter ( $ \sigma  < \text{threshold}$ ) to focus on near-neutral physically meaningful modes.
$\Gamma$ computation is very slow	Reduce the neighborhood half-width $S$ , or subsample the dataset before computing.

## Chapter 13

# Mouse and Keyboard Reference

### 13.1 Mouse interactions by window

Table 13.1: Mouse interactions in analysis windows.

Window	Action	Effect
All windows	Left-click on toolbar Home	Reset to original zoom
Main (Streamlines)	Left-click drag on field	Draw streamline seed rake
Reynolds, TKE	Left-click drag on field	Draw line profile
Spectra	Left-click drag on field	Draw analysis line
Spectra	Right-click drag on field	Draw rectangular ROI
Anisotropy	Left-click drag on field	Draw Lumley triangle line
Anisotropy	Left-click drag on field	Draw barycentric ROI (in Rectangle mode)
Correlation	Left-click on field	Pick reference point (Point mode)
Correlation	Left-click drag on field	Draw ROI (ROI mode)
Transform	Left-click drag on preview	Draw rotation reference line
Transform	Left-click on preview	Set new origin (Shift Origin mode)
DMD Spectrum	Left-click on bubble	Select mode and show spatial structure
Vortex	Left-click drag on field	Draw ROI (field view)

### 13.2 Keyboard shortcuts

Table 13.2: Keyboard shortcuts.

Key	Action
F1	Open user manual

### 13.3 Field Viewer: Display Controls Summary

Table 13.3: Quick reference for display controls.

<b>Control</b>	<b>Shortcut / location</b>
Change displayed field	<b>Field</b> dropdown in the options strip
Toggle overlay type	<b>Overlay</b> radio buttons
Adjust vector density	<b>Skip x</b> and <b>Skip y</b> spinboxes
Scale arrow/streamline length	<b>Length</b> spinbox
Scale arrowhead size	<b>Arrow size</b> spinbox
Draw streamline rake	Left-click drag on field (Streamlines overlay active)
Hide all axes and labels	<b>Clean export</b> checkbox
Hide colorbar	<b>Hide colorbar</b> checkbox
Reset view	<b>Home</b> button in toolbar
Save figure	Save button in toolbar (PNG 300 DPI, PDF, SVG)
Open manual	? <b>Manual</b> button (top right) or F1

## Appendix A

# Citing uPrime

If uPrime contributes to your research, please cite:

Jibu Tom Jose, & Ram, O. (2026). *uPrime: Open-source software for velocity field and turbulence analysis from PIV and CFD data*. Transient Fluid Mechanics Laboratory (TFML), Technion (v0.4.0-alpha). Zenodo.  
<https://doi.org/10.5281/zenodo.19376184>

The citation text and DOI are also accessible directly from within the application via **About uPrime** at the bottom of the sidebar. The DOI can be copied to the clipboard using the copy button next to it.

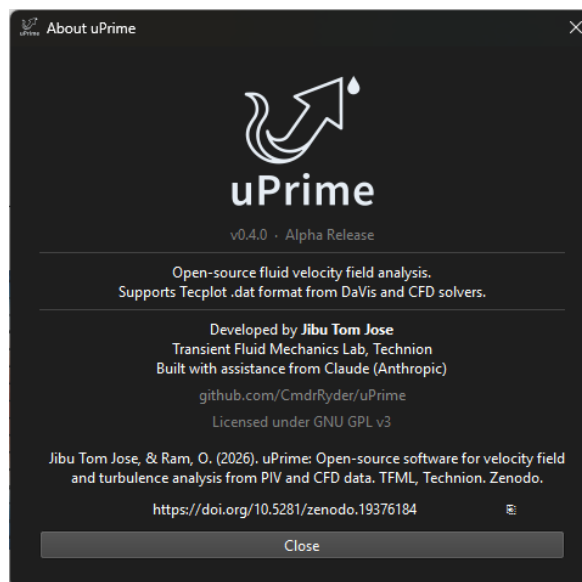


Figure A.1: About uPrime dialog (v0.4.0). The citation text and DOI are displayed with a one-click copy button. The GitHub link opens the repository in the default browser.

## Appendix B

# Sample Dataset

A sample dataset is available for testing and evaluating uPrime workflows without needing your own experimental data.

**Download:** <https://doi.org/10.5281/zenodo.19539711>

The dataset includes one non-time-resolved stereo PIV dataset (2D3C) with 100 snapshots, suitable for testing Reynolds stress, TKE budget, correlation, anisotropy, POD, and vortex identification modules; and one time-resolved planar PIV dataset (2D2C) with 200 snapshots, suitable for testing temporal spectra, temporal correlation, TR-POD, and DMD workflows.

Both datasets are provided in Tecplot ASCII .dat format and load directly into uPrime without any configuration.

### Warning

This dataset is provided strictly for testing and evaluation of uPrime. It must not be used for research, publications, or redistribution without explicit written permission from the authors.

## Appendix C

# Version history

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Version	Summary
v0.1	Initial release: Reynolds stresses, TKE visualisation, basic spectral analysis.
v0.2	TKE budget, anisotropy invariants, correlation analysis, coordinate transform. Migrated from PyQt5 to PyQt6.
v0.3	POD analysis, improved correlation module (multiple scale methods, diagnostic plots), expanded transform tool.
v0.3.3	Bug fixes (home button, mirror-rotate sequence, correlation ROI drawing). UI improvements: sidebar reorganized, dataset info ribbon, Times New Roman export font, 300 DPI PNG. New features: snapshot sub-sampling and subset selection, reload button, mirror transform, exit confirmation dialog, hide axes/colorbar in all windows.
v0.3.4	Streamline overlay: rake-based seed drawing, cumulative rakes, color picker, line width control. Spatial FFT tab: 2D ROI-based spatial spectra via pyFFTW. Memory halved: velocity arrays loaded as float32. Improved subset loading. Export improvements: 300 DPI PNG, improved PDF quality.
v0.4.0	New modules: DMD Analysis (TR only, frequency-growth rate spectrum, spatial mode viewer, Strouhal number support); Vortex Identification (vorticity, Q-criterion, $\lambda_{ci}$ , $\lambda_2$ , $\Gamma_1/\Gamma_2$ , per-vortex statistics, spatial probability map). Non-destructive masking: raw velocity data never modified; mask stored as single 2D boolean array. Unit auto-detection from <code>.dat</code> file header. Acquisition type moved to dataset info ribbon with popup dialog on load. Correlation: 1/e method now returns interpolated crossing lag; zero-crossing marker placed at actual crossing position. Logo added to application and manual. User manual accessible via F1 or top-right button.
v0.4.1	Performance: all heavy computations (POD, DMD, TKE budget, correlation, spectra, vortex identification) moved to background QThread workers – main window stays responsive during computation; progress indicator shown below compute button. Large dataset support: datasets exceeding 4 GB are automatically memory-mapped to a temporary file in the system temp folder instead of being loaded into RAM; a warning with the temp path and required disk space is shown in the subsampling dialog. Bug fix: cursor value readout now reports correct values after mirror transform.

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