

Visualizing Fluid Dynamics of Flow Around Pin Fins using Particle Image Velocimetry



Changmin Oh, Mechanical Engineering
Mentor: Dr Beomjin Kwon, Associate Professor
School for Engineering of Matter, Transport and Energy (SEMTE)

Introduction

Particle Image Velocimetry (PIV) is a non-intrusive optical technique used to measure fluid flow velocity fields. It involves seeding the flow with tracer particles, which are illuminated by a laser light sheet. A high-speed camera captures pairs of images at precise intervals, and by analyzing the displacement of particles between these images, PIV calculates detailed velocity vectors, revealing complex flow structures like wakes and vortices. In the context of pin-fin arrays, which are widely used in gas turbines, power electronics, and other compact devices to manipulate fluid dynamics, PIV is valuable. Accurate PIV measurements require tuning of the variables, which are investigated in this study.

1) Time between pulses Δt

The laser fires twice inside one camera exposure. The choice of Δt is critical: a long Δt allows larger particle displacements, suitable for slower flows but risks losing correlation in high-speed or turbulent flows due to particles exiting the laser plane or camera frame. Conversely, a short Δt ensures accurate tracking in high-speed flows but may yield insufficient displacement in slow flows, increasing measurement errors. Our experiment tests Δt of 4000, 6000, 8000 μs , giving about 0.5px displacement at $Re \approx 496$.

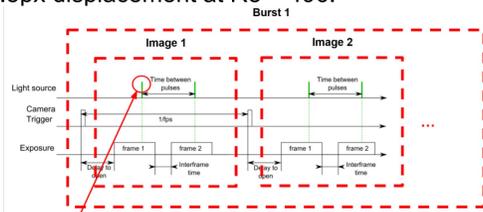


Fig. 1: Pulse timing in a single burst

2) Interrogation area (IA)

Large windows (left) give strong correlation but smear fine eddies; small windows (right) resolve fine detail but raise noise. Each interrogation area is a square group of pixels used for cross correlation. The window must include enough tracer particles to produce a clear peak yet remain small enough that velocity gradients inside the window are nearly uniform.

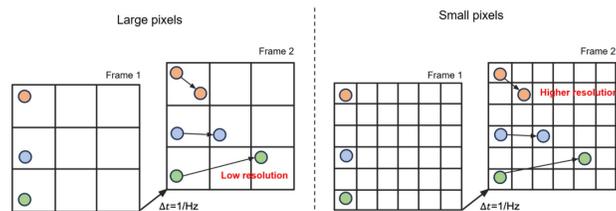


Fig. 2: Window size controls spatial resolution

Research Questions

- What is the optimum interrogation area in PIV measurements?
- How does the choice of time between pulses impact particle displacement and velocity calculation in PIV?

Methodology

The working fluid is degassed deionized (DI) water. The PIV system comprises an Nd:YAG laser operating at 532 nm with a maximum pulse frequency of 15 Hz and a charge couple device (CCD) camera (Dantec Dynamics, FlowSense USB 2M-165). The camera records images at 1920 by 1200 pixel resolution and 165 frames per second. Laser exposure time is 28 microsecond and the lens aperture is F2.8. For seeding, polyamide particles 20 micrometer in diameter are added at 1.25 milligram per liter. The laser head forms a vertical 532 nm sheet that enters the acrylic channel from above, while the high speed camera (5 MP, 10 Hz) views the flow directly through the side wall, normal to the channel plane. Flow enters at the left inlet, passes the pin fin test section, and exits through the right outlet.

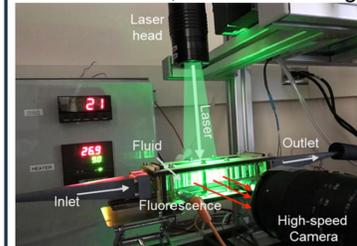


Fig. 3: Photograph of PIV setup

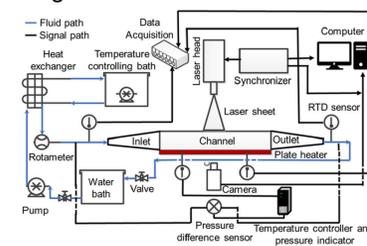


Fig. 4: Schematic of the experimental setup

Interrogation window matrix

To assess the impact of interrogation window (IA) settings on PIV image quality, five different configurations were tested

Grid Step Size (50% of Min IA size)	Min IA Size	Max IA Size
4px	8 x 8px	32 x 32px
8px	16 x 16px	64 x 64px
8px	16 x 16px	96 x 96px
16px	32 x 32px	64 x 64px
16px	32 x 32px	96 x 96px

Table 1: IA Settings & Grid Step Size

Conclusions & Future Work

- For Optimal acquisition settings at $Re \approx 496$ A trigger rate of 5Hz, pulse gap **4000 microsecond**, **grid step 8px**, and **interrogation windows 16x16 to 96x96 pixel** yield the smoothest and most complete velocity field.
- Study the effects of shorter pulse gaps and explore vortex mapping - Test $\Delta t \leq 2000\mu s$ or less and use time resolved or phase locked PIV to track vortex paths and measure shedding frequency.
- Take PIV in a broader Reynolds range - Extend experiments from $Re \approx 300$ to ≈ 2500 to examine how wake structure evolves and to pinpoint the onset of shedding.

Results & Discussion

Interrogation Window Effect

The Figure 5 shows that interrogation window settings significantly affect the quality of PIV results; red boxes outline the individual windows in the sample frame. The smallest window (4px, 8x8-32x32px) produced noisy and unstable vectors. As the grid step and IA size increased, the velocity fields became smoother and more coherent. Among the five configurations, the setting with 8px grid and 16x16-96x96 px IA range showed the best overall clarity and stability. These results demonstrate that proper selection of IA parameters is essential for achieving accurate and reliable flow visualization.

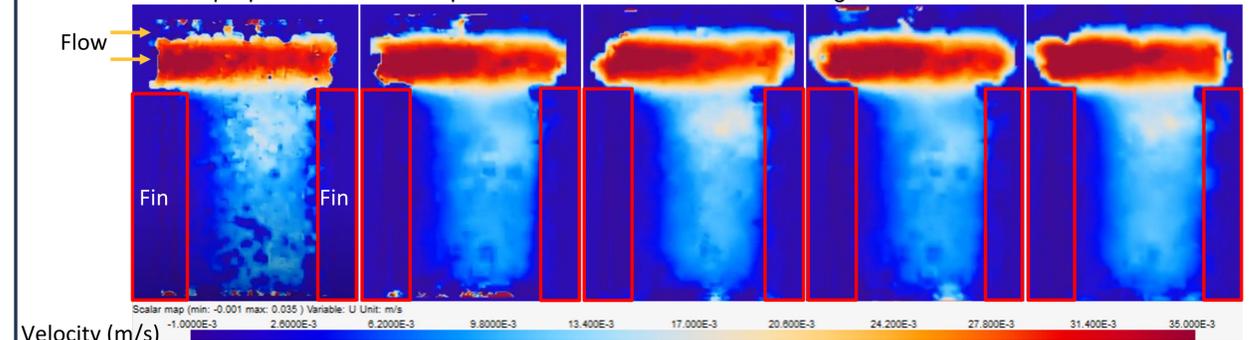


Fig. 5: Grid: 4px, IA: 8-32px Grid: 8px, IA: 16-64px Grid: 8px, IA: 16-96px Grid: 16px, IA: 32-64px Grid: 16px, IA: 32-96px

Pulse Interval Effect

With the balanced window fixed (Grid 16 px, IA 32x32 - 96x96 px) three laser pulse gaps were compared.

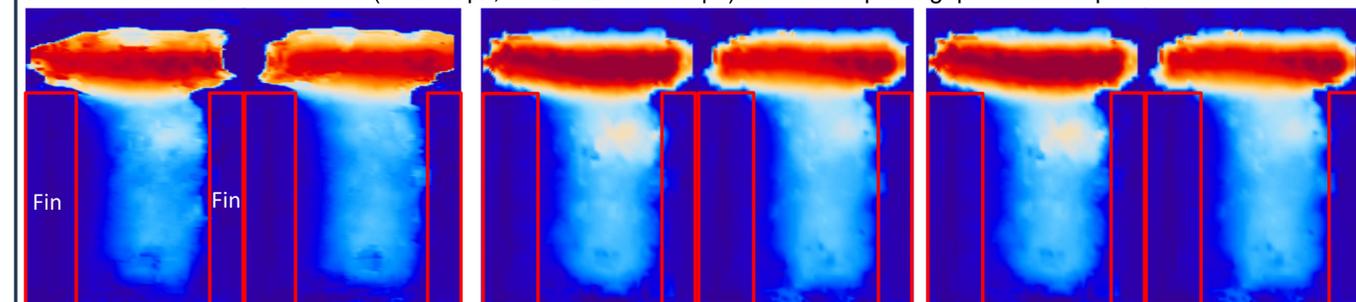


Fig. 6: $\Delta t = 8000 \mu s$. Two consecutive frames (Frame 1 left, Frame 2 right)

Fig. 7: $\Delta t = 6000 \mu s$. Two consecutive frames (Frame 1 left, Frame 2 right)

Fig. 8: $\Delta t = 4000 \mu s$. Two consecutive frames (Frame 1 left, Frame 2 right)

Figures 6 to 8 show two consecutive frames for each pulse gap, moving from the largest (8000 μs) to the smallest (4000 μs).

- $\Delta t = 8000 \mu s$ (Fig. 6): The red high-velocity core shifts a full fin width downstream between frames. Vector drop-outs create blue gaps along the upper shear layer, and fine wake details are blurred.
- $\Delta t = 6000 \mu s$ (Fig. 7): Displacement is smaller than in Fig. 7 and only minor gaps appear near the pin wall. The wake remains readable but some small structures fade.
- $\Delta t = 4000 \mu s$ (Fig. 8): The core moves only slightly; vectors stay continuous across the field and the wake is fully resolved.

Pulse gap Δt (μs)	Vector Continuity	Visual Quality Summary
4000	Continuous	Wake is clean and fully resolved
6000	Minor gaps	Small drop out appear near the pin wall and upper shear layer but the wake remains readable
8000	Frequent gaps	Many vectors are lost which makes the velocity map patchy and blurs fine details

Table 2: Effect of pulse interval on PIV data quality

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References

- [1] N. P. Nguyen, et al., Int. J. Heat Mass Transf., vol. 222, p. 125198, 2024.
- [2] C. Ji, Z. Liu, et al., Chem. Eng. Process. Process Intensif., vol. 179, p. 109058, 2022.
- [3] M. Otto, et al., J. Turbomach., vol. 143, no. 2, p. 021009, 2021.
- [4] F. Xu, Z. Pan, et al., Microfluid. Nanofluid., vol. 22, p. 11, 2018.
- [5] P. Dupuis, et al., Int. J. Heat Mass Transf., vol. 98, pp. 650-661, 2016.

