DEFINITION OF “TIME-RESOLVED” FOR PIV DATA

APPLICATION NOTE TRPIV-003 (A4)

Definition of Time Resolution

The data produced from particle image Velocimetry (PIV) consists of one or more instantaneous velocity fields, meaning a field of 2D vectors arranged on a plane (Fig. 1).

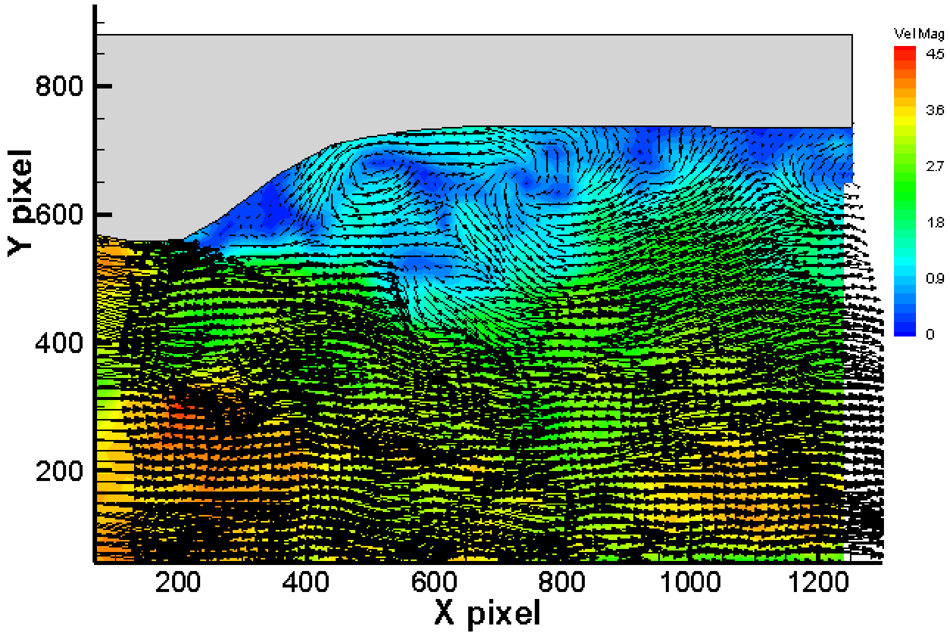

Fig. 1. An example of an instantaneous velocity field acquired using PIV. The flow direction is from left to right.

While the instantaneous velocity is very important to understanding the flow of interest, often other information can be obtained by capturing more than one field. The most common example would be the case where several hundred or thousand (or more) velocity fields are captured, and the “average velocity field” is calculated. The average velocity field is very useful in understanding the mean effect of the fluid on its environment, but again may not tell the whole story. Another quantity may be the root mean squared (RMS) velocity, which provides additional information in regards to the way the flow is varying over time, again, in more of an average sense. For calculating average and RMS velocity, it is recommended to use velocity fields that are not correlated in time, meaning that the flow structures from one capture to the next have “moved on” and are no longer visible in that field of view. For this reason, researchers interested in these types of flow statistics will typically capture data at a “slow” rate, where the term “slow” is relative to the flow in question.

Another type of data is "time-resolved" data. Often times, a clearer picture of the flow can be seen by capturing a series of velocity fields that are correlated, or related, to each other in time. Typically this means that the same fluid structure can be seen in multiple consecutive velocity fields. The data is often analyzed by watching a "movie" or animation of the velocity fields, so that the viewer can see how fluid structures move from frame to frame and how they are interacting over time.

Because fluid structures move at different rates in different fluids, the capture rate of "time-resolved" PIV data can vary widely. For example, a water flow, where the mean freestream velocity is less than 0.1 m/s, can usually be captured in a time-resolved sense, with a PIV system operating at about 15 Hz. As another example, capturing the flow of air in a wind tunnel with a freestream velocity of 5 m/s may require capturing data at 1000 Hz, or more.

How fast do I need to capture to obtain Time-Resolved PIV data?

Whether or not your PIV data is time resolved depends on a number of factors, including the speed of the flow, the magnification of the camera lens, the capture rate of velocity fields, etc. The velocity of the flow is one of the more important factors. In most flows of interest, the velocity of the fluid varies across the field of view, so which velocity should we choose? A representative velocity that is important in determining time-resolution is the "convection velocity". For a more formal definition of convection velocity, see de Kat et al. (2012). In general, this refers to the speed at which structures within the flow are convected, or moved, from one place to another. An example of this can be seen in fig. 2, where the vorticity field is plotted. Areas of red indicate shear layers or vortex cores. In the image on the left, a red vortex core is seen in the lower left part of the field of view, and it is marked with a "+" sign. The vorticity field on the right shows the same flow, but captured approximately 13 frames later. The same vortex is seen marked with a "+" sign, as well as a trail of "+" signs indicating the locations of the vortex core during the intermediate 12 velocity fields. This PIV data is "time-resolved" in the sense that the viewer is able to track the motion of fluid structures within the flow from frame to frame.

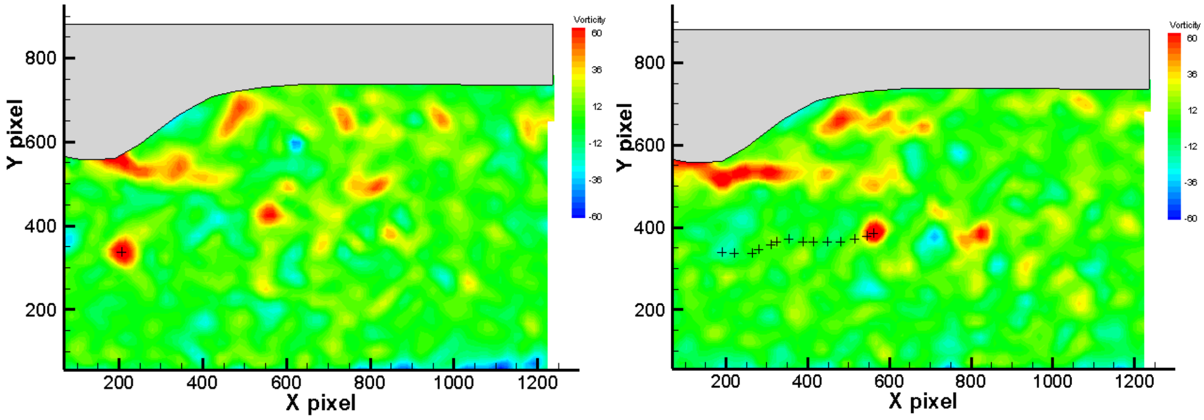

Fig. 2. Example of time-resolved PIV fields. The field on the left shows an instantaneous vorticity field for a given flow in which the dominant flow direction is from left to right. The plot on the right shows the same flow 13 time steps later, in which the red vortex (marked with a "+" sign) has moved from its location shown in the left plot, to its location shown in the right plot. Intermediate locations of the vortex core are also seen marked with "+" signs in the right plot, in order to track the location of the vortex core.

An example of a series of velocity fields that are not time-resolved would be one where a vortex was clearly visible in one frame, and in the next, this vortex has "left" the field of view, and other structures have "moved in" to the field of view. This suggests that there is a sort of gray area, delineation between time—resolved and non-time-resolved data. As a rule of thumb, if the same structure can be identified in 3 to 4 velocity fields and following a clear trend, before it leaves the field of view, then the data is marginally time-resolved. A slower capture rate will render the data non-time-resolved, and a faster capture rate will result in time-resolved data.

Frequency Spectra

Once time-resolved PIV data has been obtained, a further method of analysis involves calculating the frequency spectrum. Determining the frequency spectrum is especially useful for periodic flows, where a given flow phenomena occurs repeatedly. Frequency spectra give information about the frequencies that dominate the flow. In the past, PIV was too slow to be used for most applications in determining frequency spectra, and so other measurement techniques were used to take data at a very high rate at a single point. Some of these techniques include hotwire anemometry or laser Doppler Velocimetry, to name a few. PIV data can be analyzed by selecting a single point (or averaging a group of points) and plotting that velocity versus time; then, an FFT is performed in order to transform the data from the time-domain into the frequency domain. The result is information relating to the energy in the flow at different frequencies. For a highly periodic flow, one would expect to see a peak in the frequency spectrum at the dominant frequency of the flow. To see an early example of this approach being used for time-resolved PIV data, please refer to Troolin et al. (2006).

Conclusion

In general, time-resolved PIV data means that if you animate the velocity fields, you will be able to identify and follow the same fluid structure from one velocity field to the next. If this is not possible, then it is likely that the data is not time-resolved.

References

De Kat, Gan, Dawson, Ganapathisubramani (2012) Limitations of estimating turbulent convection velocities from PIV, 16th Int. Symp. on Applications of Laser Techniques to Fluid Mechanics, Lisbon, Portugal, 9-12 July 2012.

Troolin D R; Longmire E K; Lai WT (2006) "Time-resolved PIV analysis of flow over a NACA 0015 airfoil with Gurney flap," *Experiments in Fluids*, **41**, pp. 241-54.

UNDERSTANDING, ACCELERATED

TSI Incorporated – Visit our website **www.tsi.com** for more information.

USA	**Tel:** +1 800 874 2811	**India**	**Tel:** +91 80 67877200
UK	**Tel:** +44 149 4 459200	**China**	**Tel:** +86 10 8219 7688
France	**Tel:** +33 4 91 11 87 64	**Singapore**	**Tel:** +65 6595 6388
Germany	**Tel:** +49 241 523030		

TRPIV-004-A4 (6/3/2014) Printed in U.S.A.