

# SUPER RESOLUTION PARTICLE VELOCIMETRY

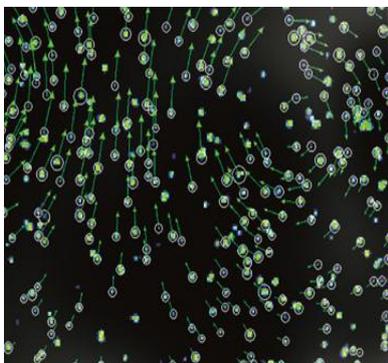
APPLICATION NOTE (A4)

The Super Resolution Particle Velocimetry approach provides the velocity field information with the highest possible spatial resolution and superior accuracy. The analysis approach is included in the Insight 4G™ Global Imaging Software package.

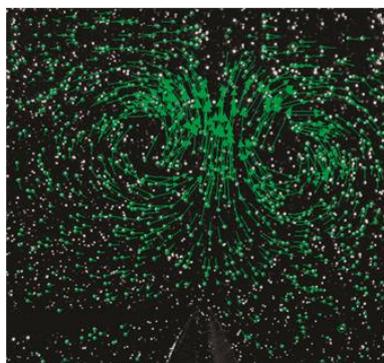
The processing approach employs a multi-step processing scheme to extract the velocity field with the hybrid method of correlation and tracking techniques. In Particle Image Velocimetry (PIV), velocity values obtained at each interrogation region represent the velocity of the group of particles within each region. The ability to go from the velocity for the group of particles to the velocity of each individual particle within the interrogation region, separately, represents the highest possible spatial resolution. From a pair of image fields, the analysis process is given as follows

- Multi-pass correlation to get estimate of the vector field which accounts for flow motion in translation, rotation, and deformation
- The estimate vector field providing the direction for particle tracking technique to get vector for each possible particle pair
- Identifying each particle using unique image processing tools
- Tracking each particle motion using the powerful ICP Scheme
- Solving the particle correspondence using a robust iterative convergent process
- Providing an accurate data set with super spatial resolution using embedded match validation
- Interpolating the randomly analyzed vectors to vector field in a regular grid locations for higher order flow statistics, like vorticity and Reynolds stress

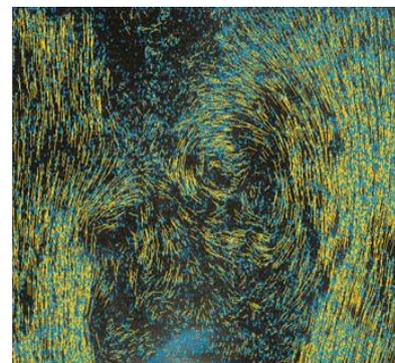
A typical vector map using the super resolution analysis is shown in Figure 1. The figure demonstrates the ability to get each vector for almost every particle in the flow field. Results are given in Figures 2 and 3 for the super resolution technique applied to a vortex flow and circulating flow, respectively.



**Figure 1:**  
Result of the Flow Field from  
Super Resolution Analysis



**Figure 2:**  
Individual Particle Vector Field  
for a Vortex Flow



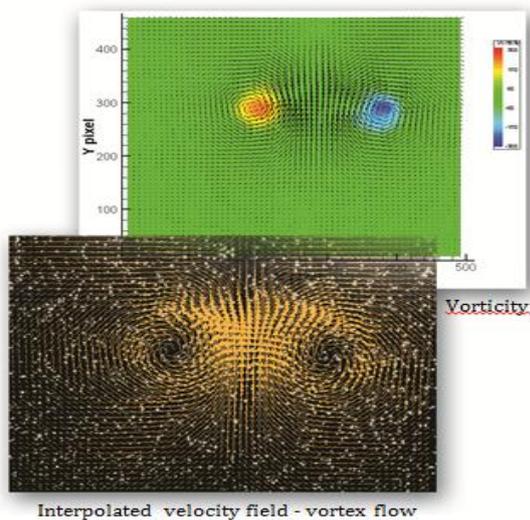
**Figure 3:**  
Individual Particle Vector Field  
for a Circulating Flow

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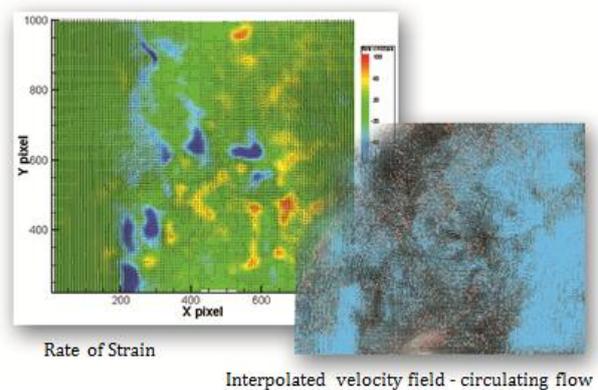
## Statistics, Data Analysis, and Interpretation from the Velocity Field

Detailed statistical properties of the flow are computed, generally using velocity values available in a regular or equally spaced grid arrangement. Special interpolation schemes have been developed to arrive at the super resolution velocity field in a regular grid format from the individual particle image velocity field. This ability to get the velocity field in a regular grid format is selectable in the Insight 4G software package.

In Super Resolution Particle Velocimetry, the interpolation on a regular grid is performed adapting the Delaunay Triangulation method combined with a powerful bi-cubic scheme, providing a robust scheme to go from the individual particle velocity field to the velocity field values at evenly spaced grid locations. Figure 4 provides the vector field in the uniform grid locations and the vorticity plot based on the vector field. Figure 5 shows similar results with the vector field in uniform grid and its rate of strain plot.



**Figure 4:**  
Vector Field in Regular Grid Locations and its  
Vorticity Plot of the Vortex Flow



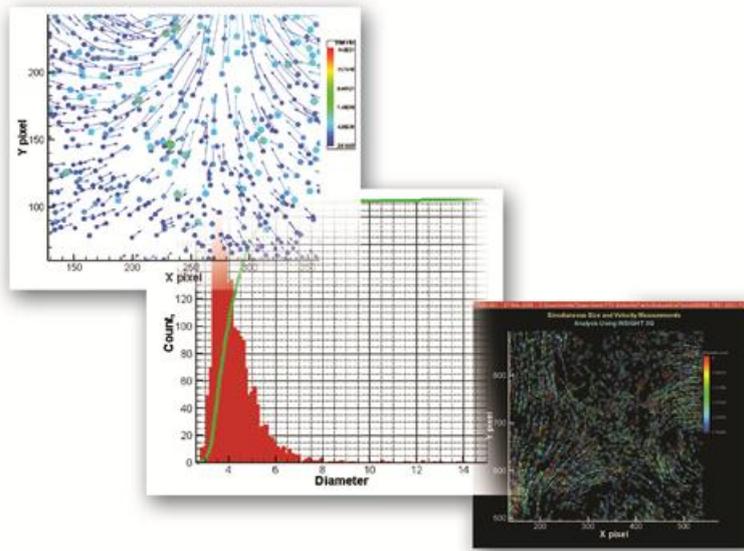
**Figure 5:**  
Vector Field in Regular Grid Locations and its Rate  
of Strain Plot of the Circulating Flow

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## Velocity Field with Particle Image Size

In many practical flow situations, the size of the particle in addition to the velocity field is of interest. During the process of determining the velocity field with super resolution, individual particles are identified along with their velocity. Thus, in Super Resolution Particle Velocimetry, the size of each particle image is also obtained along with the particle velocity. From these, size histograms, correlation of size and velocity, estimation of flux, and other statistical properties can be estimated.

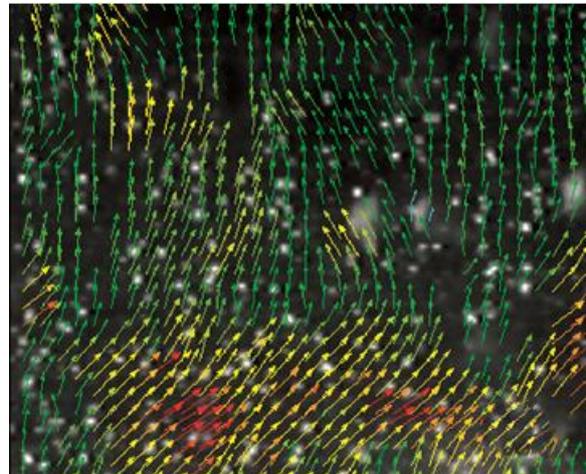
One of the major advantages of having size information is its application to multiphase flow analysis. Based on the size information, average velocity and other statistical properties of particles within a selected size range can be estimated. This sub-ranging of data based on size and velocity enables one to study transport, particle dynamics, and other related aspects. This approach can be further extended to separate the phases and obtain their velocity, size distribution, and associated properties. Figure 6 shows the particle size distribution analyzed using the super resolution approach.



**Figure 6:**  
Particle Size Information Obtained from the Super Resolution Technique

## Multiphase Flow Analysis

Another unique feature of the Super Resolution Particle Velocimetry is the analysis of multiphase flows. Solid particles in liquid flows, spray droplets in gases, and gas bubbles in liquids represent some common examples of multiphase flows that are of interest. With Super Resolution Particle Velocimetry, sub-ranging based on image size can be advantageously used to separate the phases. Further, separating or removing the sub-ranged images enables one to examine the image field for each phase separately. The result is the ability to study the flow dynamics, transport, and interactions in great detail for each phase. These are only some of the abilities of the innovative new Super Resolution Particle Velocimetry approach. Figure 7 demonstrates the ability to “remove” the large bubbles in the flow field with the subsequent flow field to be calculated without the “bubbles”.



**Figure 7:**  
Velocity Flow Field with the Bubbles Removed  
in Multiphase Situation



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