IMAGING TECHNIQUES FOR MEASURING PARTICLE SIZE
SSA AND GSV

APPLICATION NOTE SSA-001 (A4)

Particle Sizing through Imaging

TSI provides several optical techniques for measuring particle size. Two of the major techniques for measuring particle size involve imaging: using a camera. The first technique, Size Shape Analysis (SSA) uses direct imaging to determine the particle size. The second, Global Sizing Velocimetry (GSV), uses a diffraction technique in order to determine particle size. What are the advantages and disadvantages of each technique, and when would a user be advised to choose one technique over the other? This application note seeks to answer these questions.

Size Shape Analysis (SSA)

The first technique covered will be SSA. SSA is also referred to as "shadowgraphy." The reason for this is that, instead of using a light-sheet (as would be done in GSV or PIV), a light source is used to illuminate a background. The particles of interest are between the camera and the background, and the images obtained consist of the shadows of the particles. A schematic of a typical SSA setup can be seen in fig. 1, and an image of a camera capturing SSA images can be seen in fig. 2.

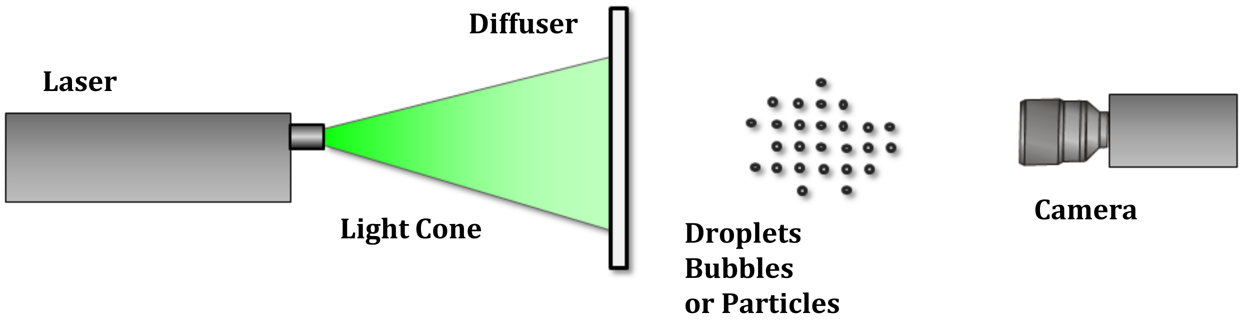

Fig. 1. Schematic representation of the SSA experimental setup

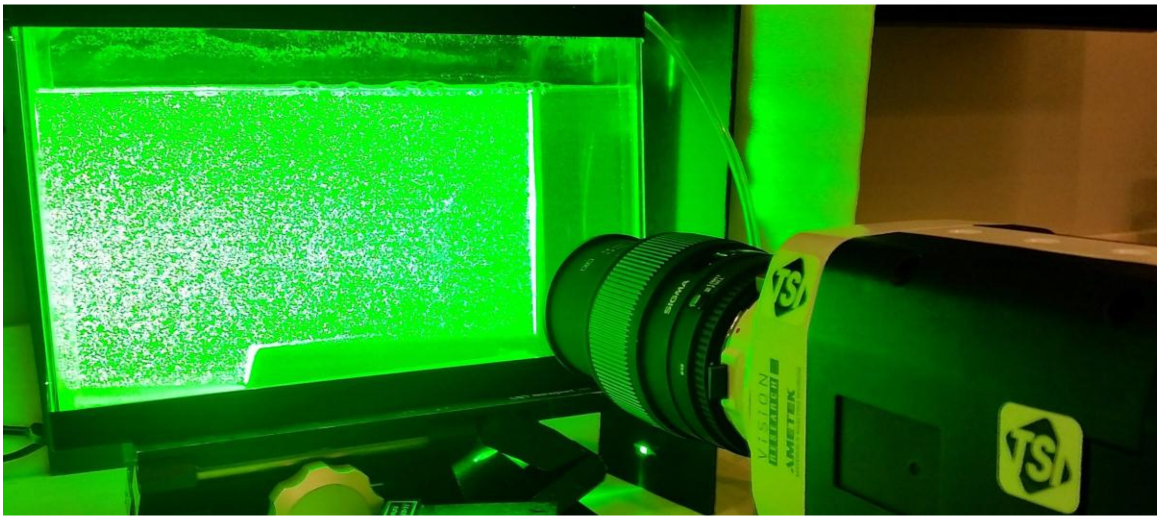

Fig. 2. A camera capturing images of bubbles backlit using the SSA method

A laser beam is expanded into a larger spot, and is used to illuminate a *diffuser*, which acts as a bright background, providing a sharp contrast between the particles of interest and the background. In most cases, when the particles are moving, it is important that the light source is not constant, but rather has short pulses of high intensity, in order to freeze the motion of the particles and avoid streaking of the particle images. If two images are captured in rapid succession, particle tracking can be performed to provide velocity information. A portion of a typical SSA image showing illuminated bubbles is shown in fig. 3, with the processed image shown on the right.

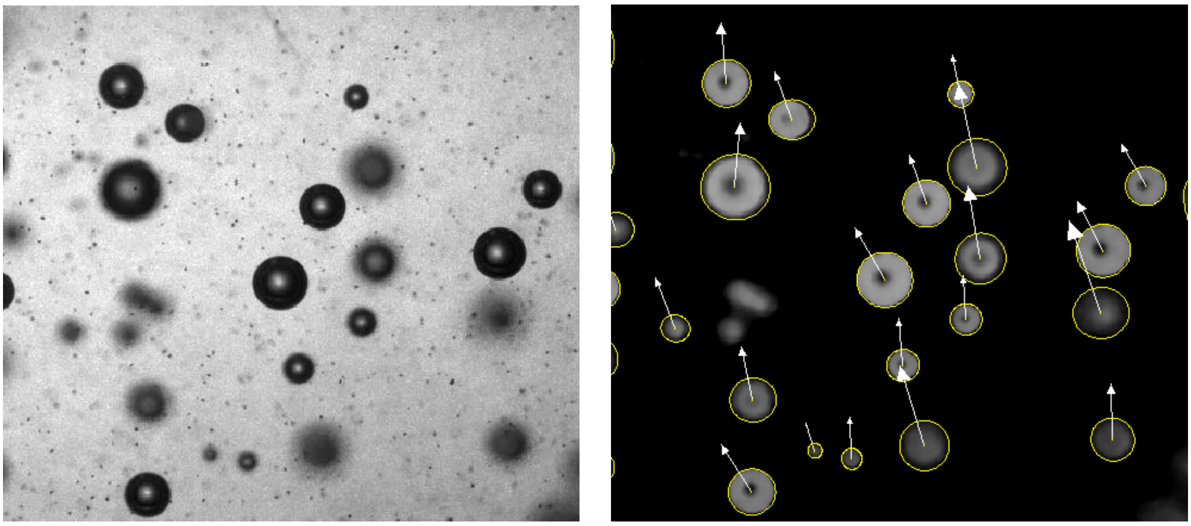

Fig. 3. Portion of a typical raw SSA image, *left*, same image processed, *right*

The advantages of SSA over other techniques typically relate to the dynamic range, versatility and measurable quantities. The advanced edge-detection and particle tracking algorithms contained in the INSIGHT4G™ software package allow for size, velocity, and even shape to be determined. The term "shape" refers to the fitting of an ellipse to the particle, so that in addition to the diameter, information related to the circularity, major and minor axis, area, perimeter, Feret's diameter, as well as other quantities, are calculated for every particle. Experimental results from a bubble study can be seen in fig. 4.

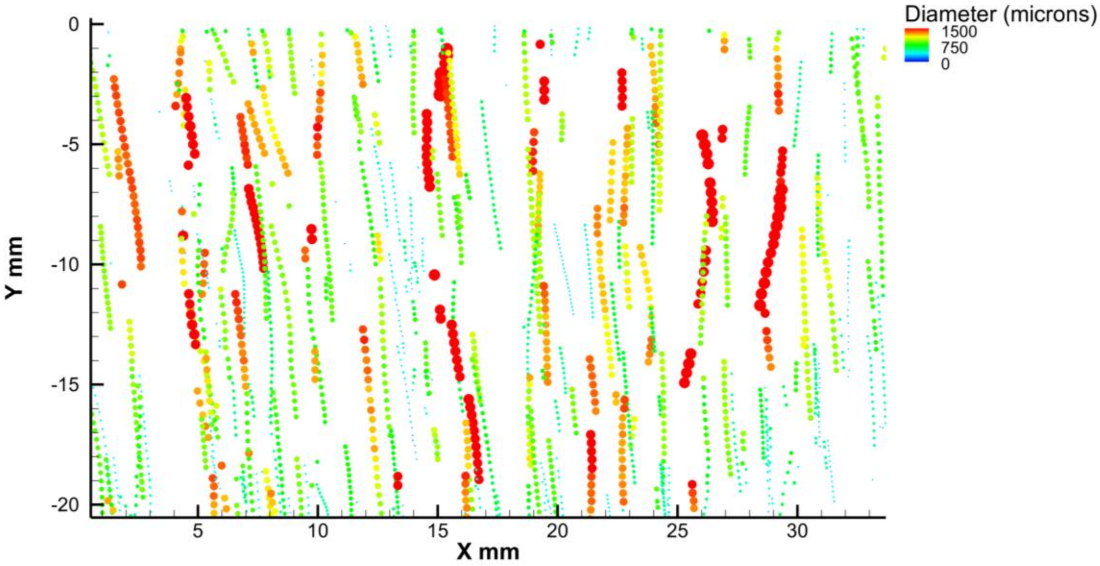

Fig. 4. Experimental results of a bubble study showing bubble diameters and trajectories

The measurable size range of particles depends on several factors including: the magnification of the camera lens, the depth of focus, the stand-off distance of the camera, and the illuminated spot size, among others. Particle sizes down to several microns, up to millimeters or much larger have been measured using the SSA technique. The field of view is dependent upon the camera magnification and image sensor size.

Global Sizing Velocimetry (GSV)

GSV, sometimes called *interferometry*, is a sizing and velocity technique used to measure spherical particles. The most commonly measured particles with GSV are droplets. A laser sheet is used to illuminate a slice within the spray or droplet field. A camera is positioned at an angle to the light sheet in order to capture the interference between light both *reflected* and *refracted* off of the particle. Fig. 4 illustrates a schematic representation of a top view of a typical GSV experimental arrangement, and fig. 5 shows a photograph of a GSV experimental setup with the laser sheet and droplet locations overlaid.

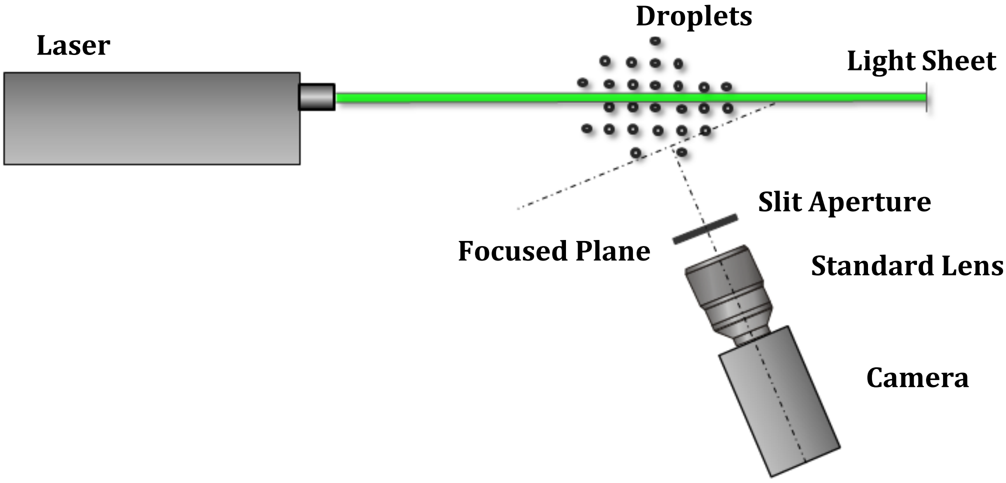

Fig. 4. Top-view schematic representation of the GSV experimental setup. The laser is shown on the left emitting a laser sheet (in this "top" view, the laser sheet appears as a green line) that illuminates a droplet field.

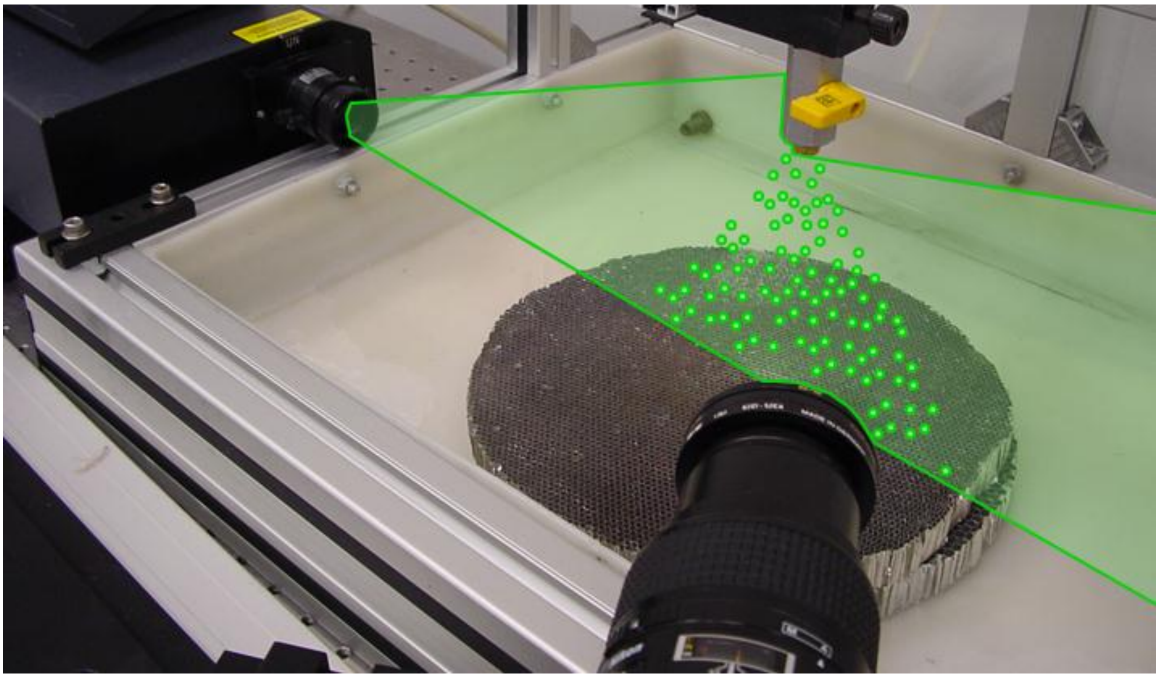

Fig. 5. Photograph of a GSV experimental setup, with the location of the laser sheet and illuminated droplets drawn in green

A camera is positioned at an angle to capture the forward scattered light from the particles. The camera is defocused from the laser plane, and a slit is placed between the camera lens and the particles. The purpose of the slit is to reduce the amount of particle overlap, and thus increase the density of droplet fields that can be imaged. The interference between the different light scattering modes causes the droplets to appear as a pattern of fringes, one such pattern for each droplet in the field of view. Fig. 6 shows an image without the slit (left) and with the slit (right). From the figure it is clear that the image with the slit has less particle overlap, thus increasing the robustness of the measurement.

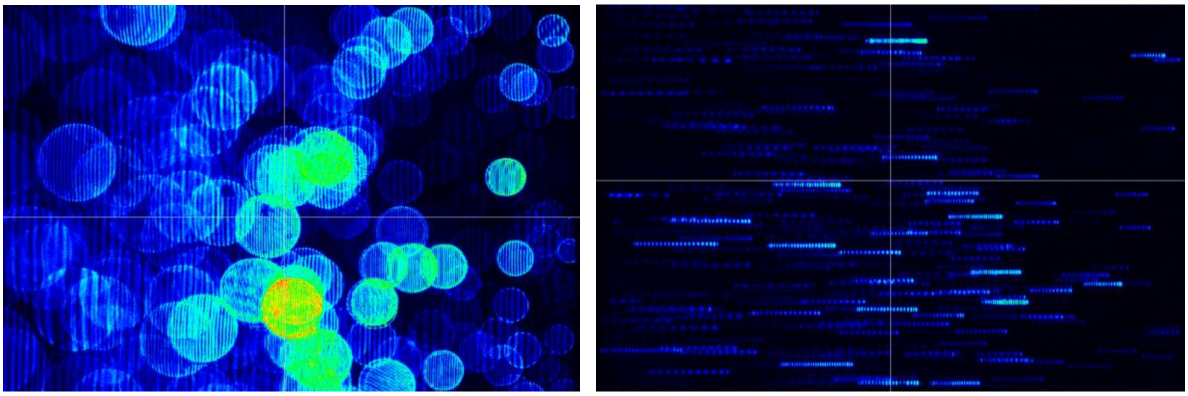

Fig. 6. GSV image without (left) and with (right) the slit. Note that with the slit, there is less particle overlap, and denser particle fields can be examined

An example GSV raw-data image is shown in fig. 7. Note that each "line" is comprised of a series of dots or fringes. The fringe spacing (or "dot spacing" within the fringe pattern) is a result of the interference between the laser light both reflected *and* refracted from the droplet. This fringe spacing is inversely proportional to the droplet size.

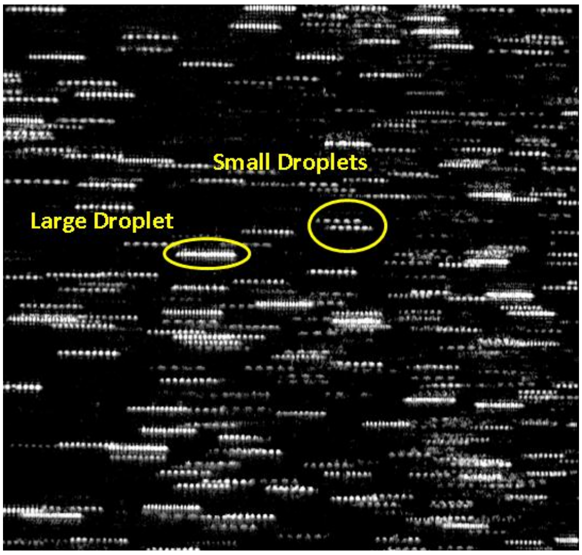

Fig. 7. GSV raw-data image, showing the locations of "small" and "large" droplets based on the fringe spacing

As mentioned previously, the purpose of the slit is to reduce the size information onto a narrow horizontal line in the raw-data image, effectively compressing the data, so that denser particle fields can be achieved by reducing particle overlap.

The images are then processed and the output consists of particle location, velocity, and diameter for each identified particle. An example of data captured from a single image can be seen in fig. 8. From this information, various statistical properties of the flow can be calculated.

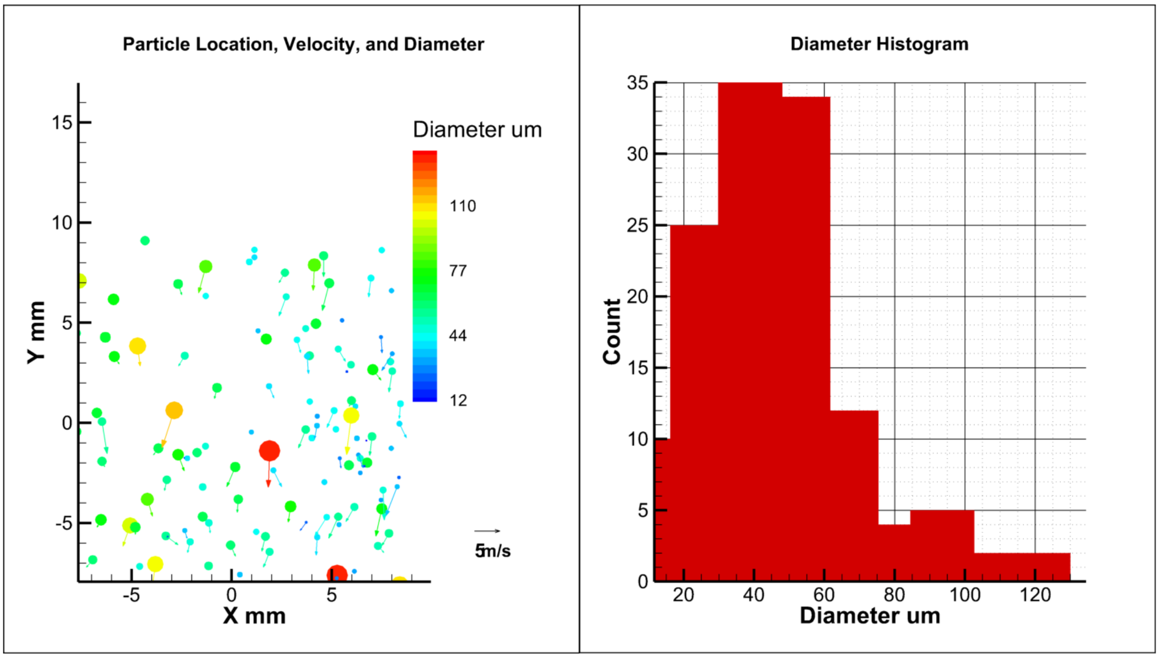

Fig. 8. Results of a GSV measurement. (left) individual particle locations, velocities, and diameters. (right) A diameter histogram of droplets within the measurement region.

Particle diameters within a range of approximately 10 to 600 microns can effectively be measured using GSV. A typical field of view would be in the range of 10 to 400 mm^2.

Summary

This application note has covered some of the advantages and disadvantages of two optical techniques for determining particle size.

In general, GSV works best for small fields of view (on the order of 1 to 10 cm^2) and spherical particles (typically droplets) in the size range of 10 to 600 microns. The particle diameter is calculated based on the interference fringes of reflected and refracted light through the particle.

SSA works well for both spherical and irregularly shaped particles. A general rule of thumb is that the particles must be at least 2 to 3x larger than the pixel size times the magnification. The magnification must be such that particles encompass a relatively large groups of pixels (the more the better), to more accurately determine the size.

Both techniques require particle densities to be such that individual particles are resolved. For GSV, the particle density can be higher due to the fact that the illumination is through side-scatter, and in the form of a thin sheet, and due to the unique slit aperture used on the front of the camera lens. SSA on the other hand, relies on volume illumination, so particle density of out-of-focus particles becomes important. Both techniques can be used to determine particle velocity, in addition to size, by tracking particle centroids in time.

References

For more information, and examples of these techniques being applied, please refer to the following publications:

Pan G, Shakal J, Lai W, Calabria R, Massoli P (2005) "Simultaneous Global Size and Velocity Measurements of Droplets and Sprays," *20th Annual Conference on Liquid Atomization and Spray Systems, ILASS* - Europe, Orleans, France, August 2005.

Calabria R, Massoli P (2006) Generalized scattering imaging laser technique for 2D characterization of non-isothermal sprays, *Experimental Thermal and Fluid Science* **31**, pp. 445-451.

Rauch B, Calabria R, Chiariello F, Clercq P, Massoli P, Rachner M (2011) Accurate analysis of multicomponent fuel spray evaporation in turbulent flow, *Exp in Fluids*, DOI 10.1007/s00348-011-1169-0.

Johnson B, Leishman J.G., Sydney A (2009) Investigation of Sediment Entrainment in Brownout Using High-Speed Particle Image Velocimetry, *65th Annual National Forum of the American.*

Helicopter Society, Inc., May 27–29, 2009, Grapevine, TX.

Bissell D, Lai W, Stegmeir M, Troolin D, Pothos S, Lengsfeld C (2014) An Approach to Spray Characterization by Combination of Measurement Techniques, *ILASS Americas 26th Annual Conference on Liquid Atomization and Spray Systems,* Portland, OR, May 2014.

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