MICRO-BUBBLE TRACER PARTICLES FOR PLANAR AND VOLUMETRIC PIV

APPLICATION NOTE V3V-FLEX-008 (A4)

Introduction

Seed particle tracers for airflow and wind tunnel applications must fulfill a challenging set of requirements. In order to faithfully follow the flow, the particles must be nearly neutrally buoyant; they must be bright in order to scatter sufficient light to be seen by a camera or group of cameras, and yet they must be small in order to resolve small turbulent structures.

Traditionally, seed particles comprised of droplets, such as olive oil or DEHS (among others) have been used for LDV or PIV measurements in airflows. However, the size is typically on the order of 1 micron, making them suitable for resolving small scales, but less suitable for large scales, where the amount of scattered light is often insufficient.

Another approach has been very large soap bubbles, on the order of 0.5–1 mm in size. Unfortunately these tracers are too large to resolve meaningful turbulent structures and inadequately follow the flow in most real flow situations (Kerho and Bragg, 1994). Attempts have even been made to fill the large soap bubbles with helium in an attempt to decrease the density, but the expense and recent global helium shortages have made the use of helium in this way a concern for scientists (Richardson 2012, and Reisch 2018).

On the imaging side, illuminated large bubbles (>100 microns) produce multiple 'glare points' which introduce positional ambiguity and contribute significantly to uncertainty in both correlation and tracking techniques. It is also difficult to produce large quantities of large soap bubbles sufficient to seed a typical wind tunnel; therefore, in the past, complicated techniques must be utilized, such as producing many bubbles, storing them up, then releasing them all at once to create a 'capture window' with enough seeding. Or by using single-exposure, multiple-pulsed systems to capture the same particles repeatedly in the same image in order to artificially inflate the seeding density.

Micro-Bubble Generator

In order to address the issues associated with air-flow seeding, a soap bubble generator has been developed that produces tracer bubbles with diameters in the range of 10s of microns, making them ideal for imaging, yet small enough to resolve small structures and follow the flow.

In addition, the bubbles are generated in very large quantities, providing high enough seeding densities for use with standard frame-straddling techniques, which eliminates the problems associated with single-frame multi-exposure setups.

The model# BG-1000 bubble generator utilizes the rapid depressurization of a pressurized mixture of liquid and surfactant that causes gases to leave the liquid media through cavitation. This controlled cavitation produces bubbles in the desired size range in very large quantities. An image of the micro-bubble generator can be seen in Figure 1.

Figure 1. TSI Micro-Bubble Generator, Model BG-1000

Micro-Bubble Sizing

Phase Doppler Particle Analysis (PDPA) is a reference technique used for very accurately measuring the size of spherical particles such as droplets or bubbles. A PDPA system was used to measure the bubble size. The diameter distribution can be seen in Figure 2. The mean diameter was 14.7 microns with a standard deviation of 7.3 microns.

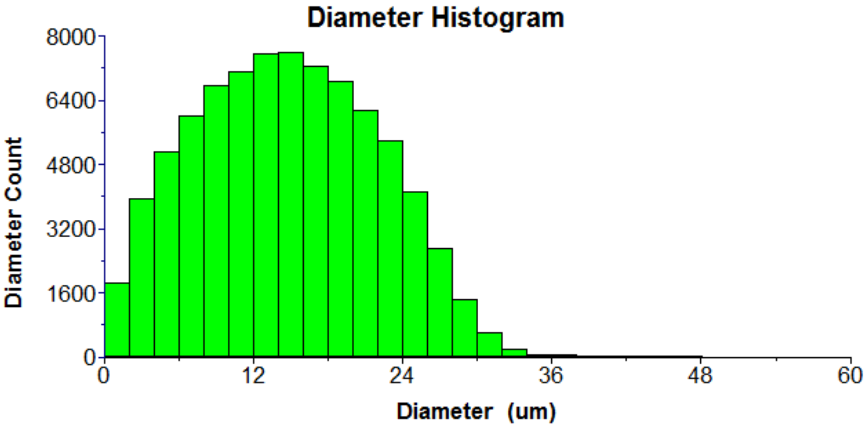

Figure 2. Diameter size distribution of the bubbles generated from the bubble generator under normal conditions.

The micro-bubble generator produces a high concentration of bubbles, on the order of 10^7 bubbles per second, and the bubbles have a very long residence time. A plot of the residence time in a closed-return wind-tunnel operating at 6 m/s can be seen in Figure 3. The bubble generator was left running for 10 minutes in order to achieve an equilibrium state in the wind-tunnel. The micro-bubble generator was then turned off, and with the wind-tunnel still operating, the bubbles were allowed to stabilize in the flow. Measurements of the bubble density were then taken at 5 minute intervals in order to assess the residence time of bubbles in the flow. After 15 and 30 minutes, 50% and 25% of the bubbles (respectively) that were present at 5 minutes, were still circulating in the wind-tunnel.

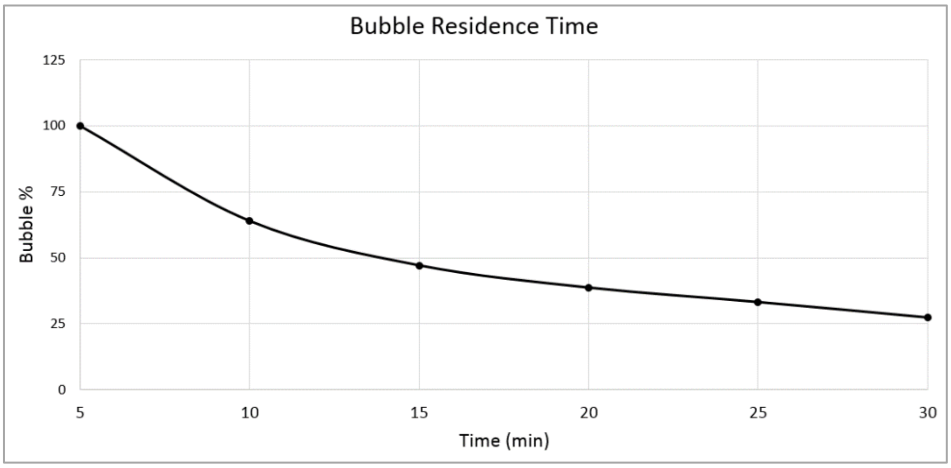

Figure 3. Residence time of bubbles in a closed-return wind-tunnel operating at 6 m/s

Relaxation Time and Stokes Number

A primary factor that affects the ability of the particle to follow the flow in a faithful manner is the drag force acting on the particle. Relaxation time (or, response time) and Stokes number are related to the fidelity of tracer particles accurately following the flow. Relaxation time (τ_p) represents the characteristic time required for a tracer particle to reach an equilibrium condition after a flow disturbance. The relaxation time is commonly calculated using the following form,

$$\tau_p = d_p^2 \frac{\rho_p}{18\mu}$$

Where d_p is the particle diameter, ρ_p is the density of the particle, and μ is the viscosity of the ambient fluid. The Stoke's number (Stk) is defined as the ratio of the characteristic time of a particle to a characteristic time of the flow.

The values for relaxation time and Stoke's number for various particles are given in Table 1 below. The commonly used definitions for these quantities are listed according to those given in Melling (1997), Menon and Lai (1991), and Raffel et al. (2007).

Particle Material	Density (kg/m3)	Particle Diameter (µm)	Stk @ 1kHz	Relaxation Time τ (µs)
Olive Oil	917	1	0.01	3
TSI Micro-Bubbles	40	15	0.12	28
Helium Bubbles	1.1	500	4.14	844
Air Bubbles	4.4	400	3.31	2161

Table 1. Stokes number and relaxation times for several particles and bubbles including the TSI micro-bubbles.

Micro-Bubbles Used for Planar and Volumetric PIV Imaging

In addition to the bubble sizing, several sets of both planar and volumetric PIV experiments were run in the closed-return wind tunnel at the University of Minnesota - Department of Aerospace Engineering. The purpose of these tests was to evaluate the suitability of the bubbles as tracer particles for imaging. The flexible hose delivering the bubbles was inserted downstream of the tunnel as shown in Figure 4. The bubbles traveled more than 50 m before reaching the test section of the tunnel for the measurement

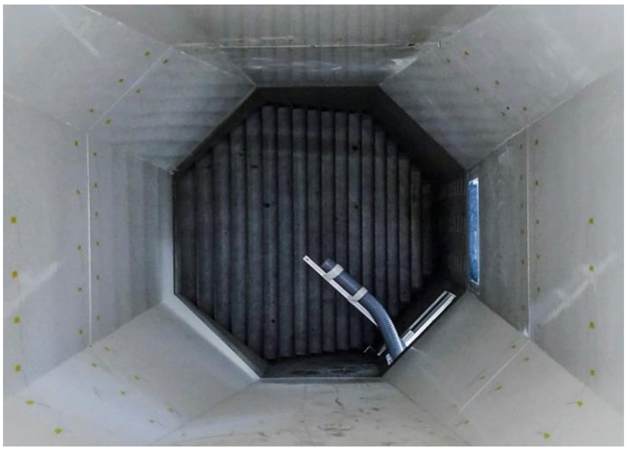

Figure 4. The micro-bubble generator positioned for seeding the wind-tunnel

The laser volume illuminating a section of the measurement section can be seen in Figure 5.

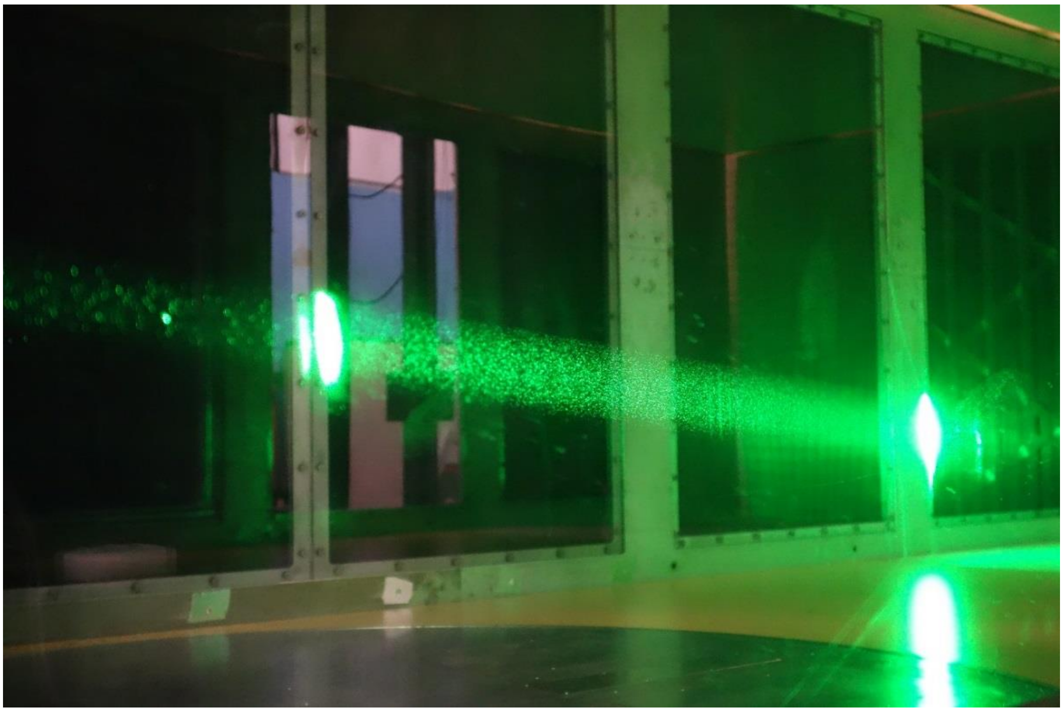

Figure 5. Micro-bubbles being illuminated by a laser in the wind-tunnel

A sample interrogation window, as well as a vector field in the wind-tunnel test section can be seen in Figure 6. The bubble diameter produced particle images on the order of 3 to 16 pixels, depending on the magnification.

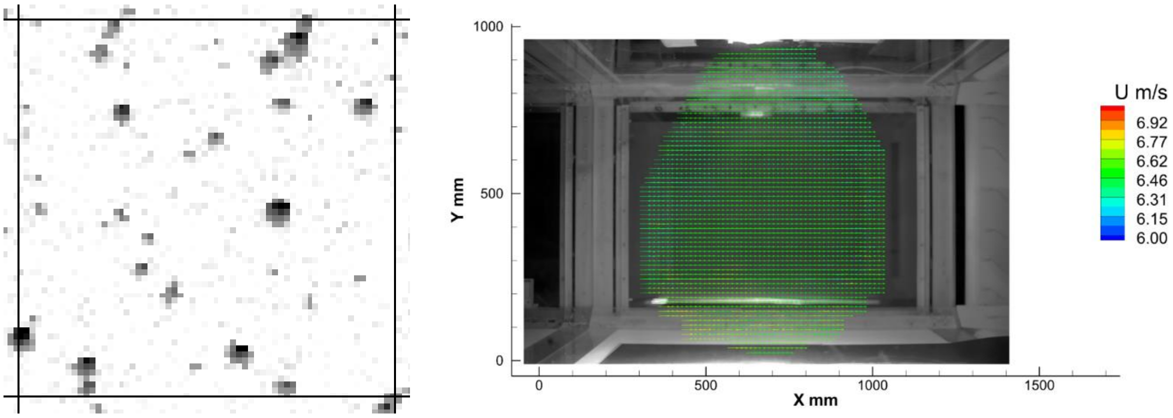

Figure 6. A grayscale-inverted interrogation window (*left*) and an instantaneous PIV vector field (*right*)

Conclusion

A micro-bubble generator was developed for seeding airflow measurements, such as wind-tunnels. The mean bubble size is approximately 15 microns, making the bubbles ideal for seeding LDV, Planar and Volumetric PIV experiments.

References

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