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Wind Tunnel Seeding Particles for Laser Velocimeter

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INTRODUCTION

The design of an optimal air foil has been a major challenge for aerospace industries. The main objective is to reduce the drag force while increasing the lift force in various environmental air conditions.

Various techniques, over several decades, have been utilized in search of efficient air foil, namely analytical, computational and experimental. Today each of these methods have been improved, expanded or advanced to provide better insight in understanding of physics of air foils.

Experimental verification of theoretical and computational results is a crucial part of the analysis because of errors buried in the solutions, due to the assumptions made in theoretical work. Experimental studies are an integral part of a good design procedure; however, empirical data are not always error free due to environmental obstacles or poor execution, etc. The reduction of errors in empirical data is a major challenge in wind tunnel testing. One of the recent advances of particular interest is the use of a non-intrusive measurement technique known as laser velocimetry (LV) which allows for obtaining quantitative flow data without introducing flow disturbing probes, e. g. pitot tube. This laser velocimeter technique is based on measurement of scattered light by seeding particles introduced into flow stream in the wind tunnel (1). LV measures the velocity of the particles present in the flow but not velocity of the flow. Therefore for an accurate flow velocity measurement with laser velocimeters two criterions have to be investigated. First is how well the particles track the local flow field. A complex relationship exists between the particle motion and the local flow field. and this relationship is dependent on particle size, size distribution, shape and density. The smaller the particle the better the response to flow fluctuations and gradients and therefore the more accurate velocity measurement. Second is the requirement of light scattering efficiency to obtain signals with the LV which, in general, is better as particle size is increased. These two criteria are in a direct conflict for which particles should be (2):

- Small enough to follow the flow field
    - Size
    - Shape
    - Density
- Large enough for the LV to "see" it
    - Size
    - Shape
    - Index of refraction

In order to demonstrate the concept of predicting the flow velocity by velocity measurement of particle seeding, the theoretical velocity of the gas flow is computed and compared with experimentally obtained velocity of particle seeding. The result of such a comparison is shown in figure 1, where the theoretically predicted gas velocity is compared with measured laser velocimeter data for a variety of particle sizes with a 0.6 Mach number velocity (3). This figure shows the curve trend for small particles is much closer to predicted gas velocity and for a successful laser velocimeter system the particles would have to be much smaller than 10 microns. Furthermore, figure 2 indicates that one micron particle size has exactly the same velocity as theoretically predicted gas velocity. This illustrates that one micron particle seeding will follow the flow streamline very well.

The desired characteristics of wind tunnel seeding particles can be defined as follows (4):

A. Monodispersed particle size distribution
B. Selectable particle size
C. Large scattering cross section
D. Low mass density
E. Non-toxic, non-contaminating
F. Readily available and reasonably priced

The choice of seeding material for LV applications is limited to using:

- Particles naturally present in the flow
- Injecting liquid droplet in the flow
- Injecting solid particles in the flow

The size of natural particles is generally unknown and very few in number yielding low data rate. This leads to unknown measurement accuracies and long test times. Liquid seeding however usually have fairly wide size distribution which are typically skewed toward the large sizes. Solid particle seeding is the best because of being able to provide large numbers of particles while maintaining their size distribution.

Typical seeding material are Kerosene, Kaolin and Polystyrene. The kerosene vapor after injection into the test section of wind tunnel begins to condense and form larger particles. It has low data rate, therefore undesirable as seeding material. Kaolin (hydrated aluminum silicate clay) is inexpensive, however it is polydisperse, and has nonspherical platelets having aspect ratio of 4/1. Specific gravity and index of refraction for Kaolin are 2.58 and 1.56 respectively.

The best seeding material for wind tunnel is Polystyrene (2) which satisfy the following characteristics:

- Solid particles
- Low density (1 gm/cc)
- High index of refraction (1.56)
- Capable of being made monodisperse
- Capable of being made spherical

The above wind tunnel seeding materials are not suitable for high temperature flow testing. For high temperature testing various metal oxide powders are used because of their high melting points (3). Typical material used are:

Material	Index of reflection	Density(gm/cc)	Melting temp. °F
MgO	1.74	3.98	5072
Al_2O_3	1.76	3.96	3660
TiO_2	2.6-2.9	3.7-4.1	3326

These materials however are polydispersed and not very desirable for LV seeding purposes because of formation of large agglomerates which do not closely follow the flow velocity. A hydrophilic material described as flame phase silica is usually used in break up of agglomerates. However it will only reduce the agglomerates in metal oxide power aerosols yielding a narrow band polydispersed seeding.

POLYSTYRENE PREPARATION

The preparation of wind tunnel seeding particles is well developed. A typical procedure used here to produce polystyrene seeding was formulated in LaRC (5). The monodisprese spherical polystyrene can be prepared for various particle diameter sizes according to table 1. The particle diameter depends on the required flow velocity in wind tunnel and LV used in velocity measurement. Following is the procedure used here to prepare polystyrene seeding particles:

- A water bath filled with tap water is heated to reach 65 °C.
- A pyrex reaction kettle is filled with 2369 (ml) high purity distilled water, 56 (ml) magnesium sulfate, and 265 (ml) styrene. An agitator is also placed in reactor and then it is covered.
- The reactor is placed in the water bath until the temperature of the mixture reaches 65 °C. During this period nitrogen gas is flowing through the mixture to purge all oxygen with the agitator turning at a rate of 150 RPM.
- Potassium persulfate solution was added to the reactor at 65 °C.
- For polymerization to take place, the mixture was run for 18-24 hours. At the end of this period the reactor was removed from the water bath and filtered through 100 mesh cheese cloth into a clean storage container. The measurement of particle size showed that polystyrene particle of 1.9 μM diameter size was produced. Polystyrene of typical sizes are shown in figure 3.

This procedure seemed simple and straight forward, however, it has to be done carefully, with exactness and most of all it needs experience to produce particles with the desired diameter size. In general repeatability is the hardest part because a slight change in the variables causes the particle diameter change drastically.

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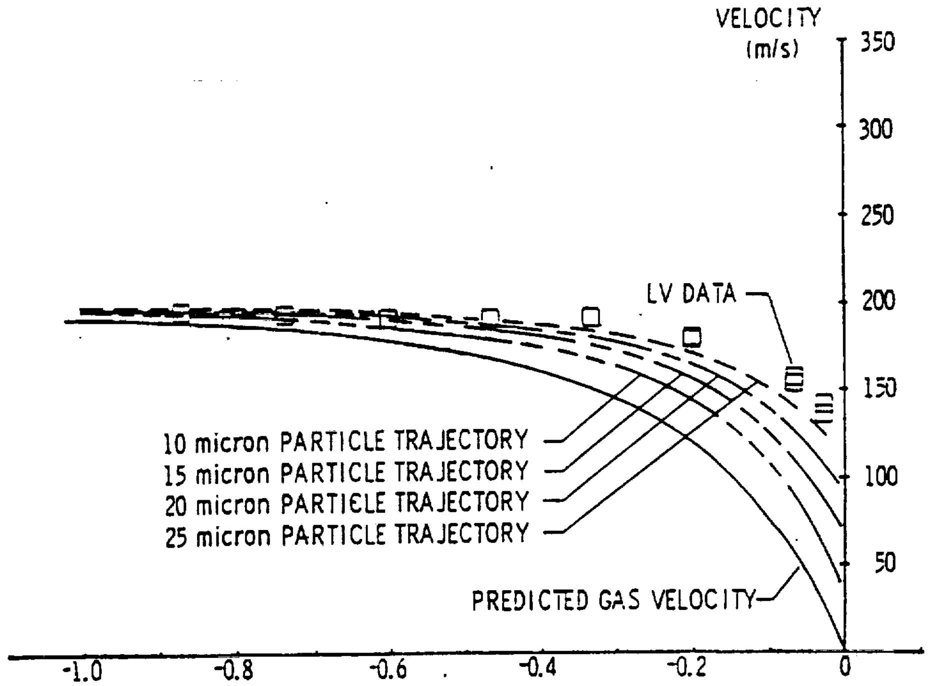

FIGURE 1

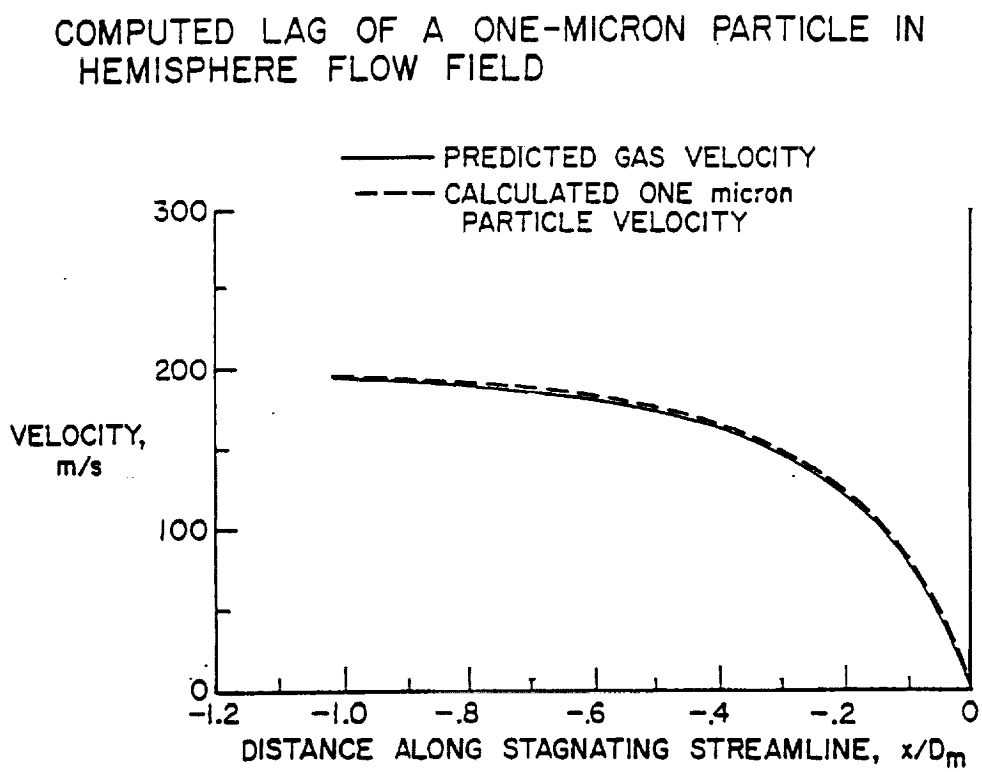

FIGURE 2

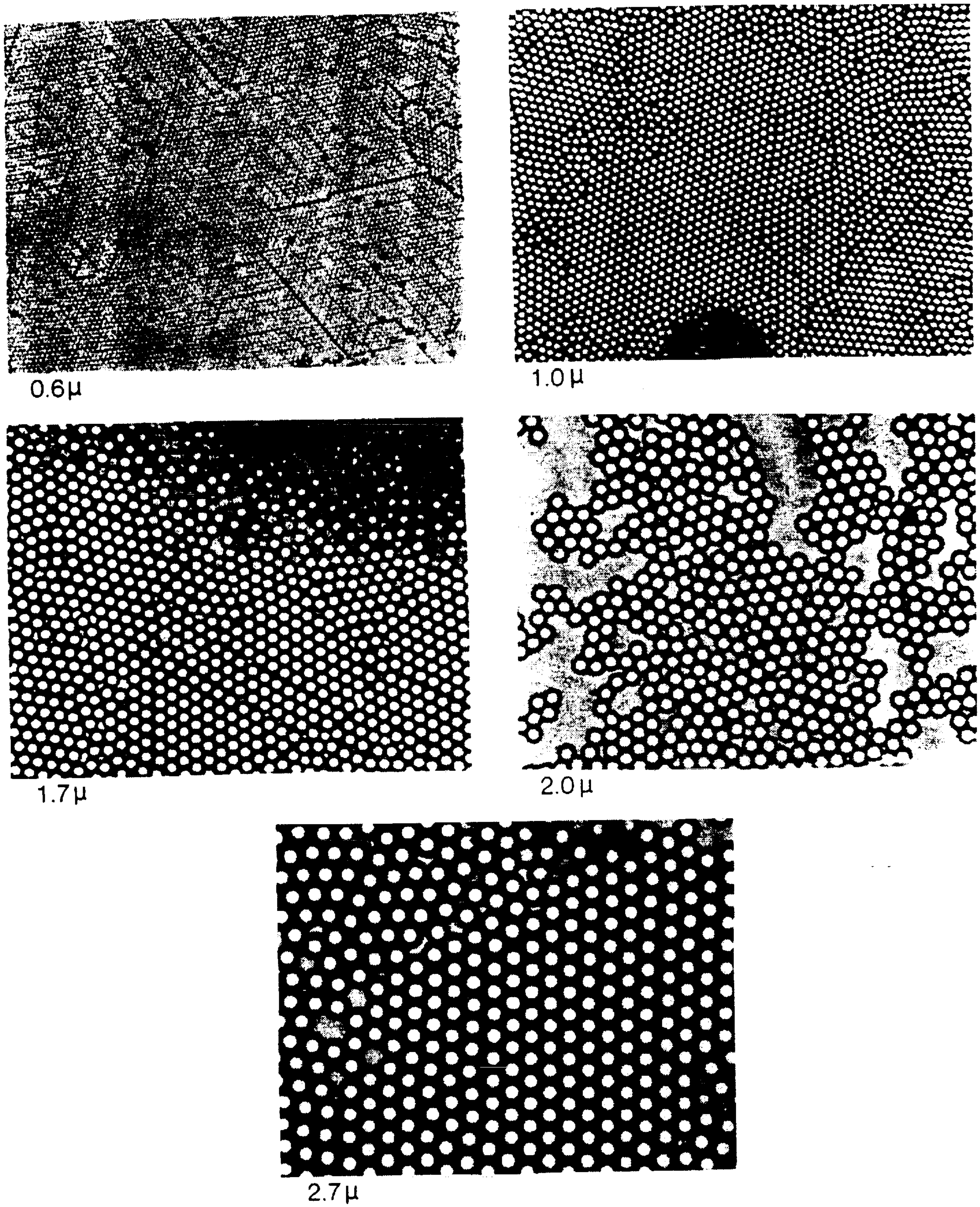

Figure 3 – Polystyrene Microspheres (2000x)

TABLE 1

FORMULATIONS FOR POLYSTYRENE LATEX, MONODISPERSE, SPHERICAL

	Particle diameter, microns				
	0.6	1.0	1.7	2.0	2.7
Water (ml)	2849	2329	2369	2200	2339
Magnesium Sulfate (ml)	-0-	56	56	56	56
Styrene (ml)	265	265	265	265	263
Potassium Persulfate (ml)	46	150	110	278	139