Effect of seeding particles on shock structure

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The original goal of our work was to measure the velocity field at the centerline of a supersonic jet produced by the discharge of air through a 4mm cylindrical nozzle using PIV, and superpose the results on a shadowgraph. The idea was to observe the flow field, close to the high density areas near the shocks. Shadowgraphs were made with and without seeding particles (titanium dioxide particles and baby powder). Surprisingly, it was observed that the shock structure with particles was shifted in the direction opposite to the flow with respect to the shock structure obtained without seeds. We used different methods to inject the particles and the effect was observed in all cases. This result might contradict the belief that the seeding particles do not affect the flow. Measurement of the velocity field with other techniques is in progress.

Introduction

Shock waves are disturbances that cause abrupt discontinuities and irreversible changes to the fluid properties such as the local velocity, temperature, pressure, etc. These disturbances are seen in supersonic flows. In this case, the exit pressures used were 5.78 atm and 5.44 atm. We used a 4mm cylindrical nozzle to produce supersonic flow. The shock structure is shown in Figure 1.

The flow field was measured using a PIV technique. A special system was designed to inject the particles as shown in Figure 2.

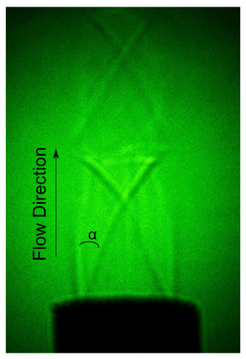

Figure 1 - Shadowgraph photograph of shock waves structure of supersonic air flow.

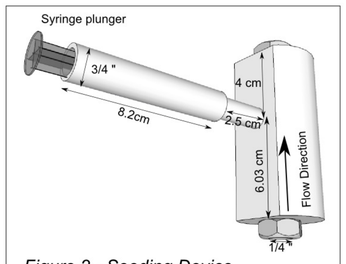

Figure 2 - Seeding Device

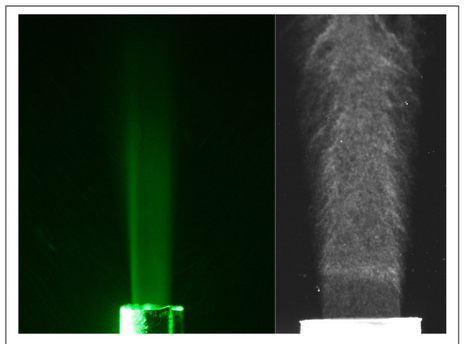

Figure 3 - Seeding test with titanium dioxide.

The main requirements for the seeding particles is that they follow the flow at sufficient particle-seeding density [1]. Seeding air flows is difficult because there are no particles that have a density similar to the medium.

First, qualitative tests were made to determine that the technique worked properly Figure 3.

PIV measurements were conducted at 5.78 atm and 5.44 atm, using titanium dioxide (TiO_2) and at 5.78 atm with baby powder ($Mg_3Si_4O_{10}(OH)_2$).

The results obtained are shown in figures 4, 5 and 6, and table 1. The study was carried out with a Laser NewWave Solo, a Kodak camera Mega Plus ES1.0 and the frames were analyzed with FlowManager v4.60.

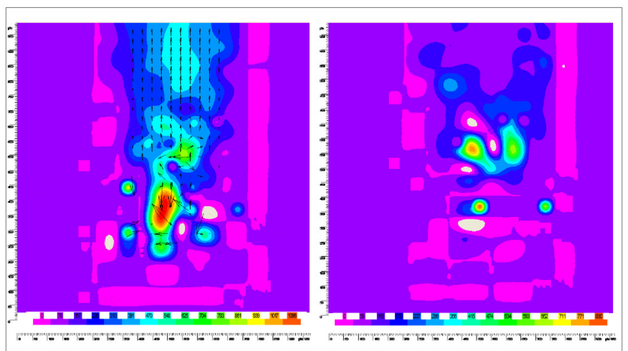

Figure 4 - Flow at 5.78 atm, seeded with titanium dioxide a) Vector field and scalar map of velocities. b) Standard Deviation.

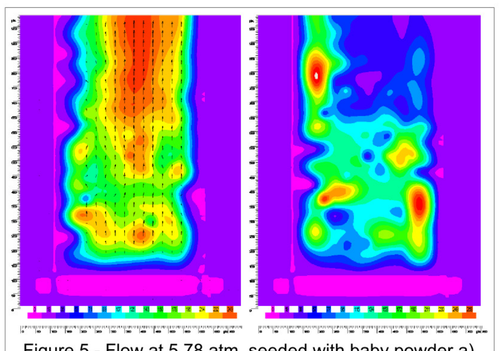

Figure 5 - Flow at 5.78 atm, seeded with baby powder a) Vector field and scalar map of velocities. b) Standard Deviation.

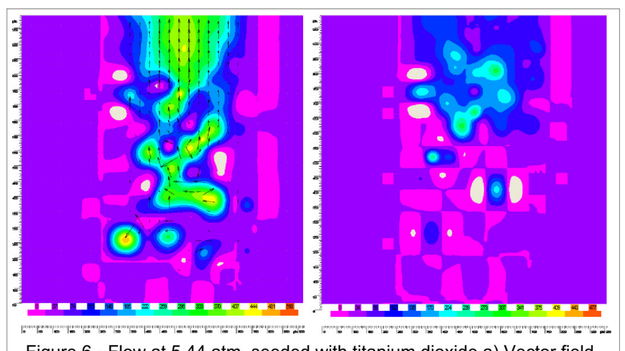

Figure 6 - Flow at 5.44 atm, seeded with titanium dioxide a) Vector field and scalar map of velocities. b) Standard Deviation.

Titanium dioxide (TiO_2)					
	Pressure [atm]	Angle α [rad] ± 10%	Mach number ± 10%	PIV Velocity [m/sec]	PIV Mach number
Frame	5.78			348.42 ±3.7%	1.02 ±3.7%
a)		0.710	1.534		
b)		0.724	1.510		
c)		0.725	1.507		
	5.44			338.81 ±2.9%	0.99 ±2.9%
a)		0.765	1.444		
b)		0.781	1.421		
c)		0.816	1.373		

Baby powder $Mg_3Si_4O_{10}(OH)_2$					
	Pressure [atm]	Angle α [rad]	Mach number	PIV Velocity [m/sec]	PIV Mach number
Frame	5.78			249.48 ±9.4%	0.73 ±9.4%
a)		0.708	1.538		
b)		0.722	1.513		
c)		0.733	1.495		
	5.44				
a)		0.748	1.471		
b)		0.818	1.371		
c)		0.819	1.369		

Table 1 - Comparison of results obtained with PIV and with shadowgraph. The results were obtained from shadowgraph α angle, through the expression:

$$M = 1/\sin(\alpha)$$

To show that the seeding particles were really non intrusive, a shadowgraph was filmed with a video camera, with and without particles. The flow was seeded with 2 different tracers (titanium dioxide and baby powder), at two different pressures 5.74 atm and 5.44 atm.

We observed that in all cases, the shock structure with particles was shifted in the direction opposite to the flow. with respect to the shock structure obtained without seeds.

Figure 8. This particular result might contradict the belief that the seeding particles do not affect the flow and that the speed of the seeds correspond to the local speed of the flow.

The Mach (M) number was measured from the shadowgraphs in Figure 8.

The results are shown in Table 1.

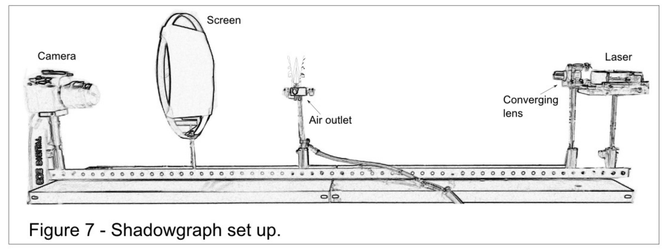

Figure 7 - Shadowgraph set up.

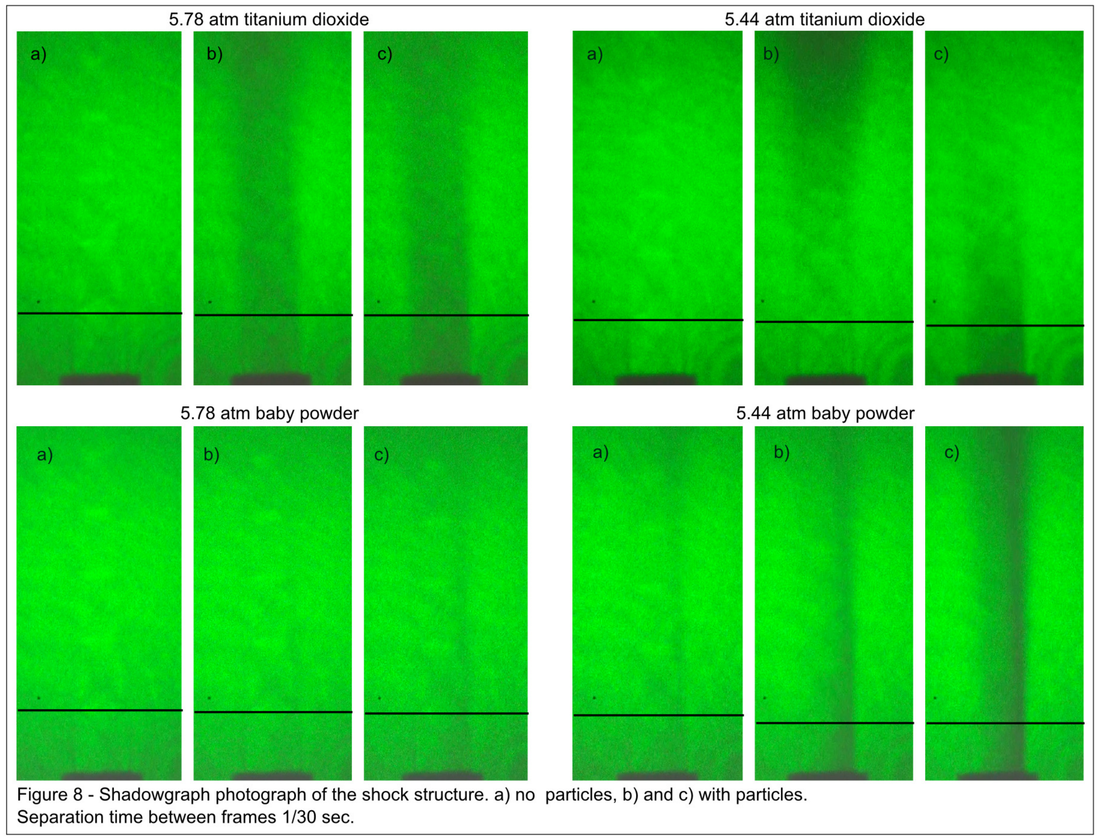

Figure 8 - Shadowgraph photograph of the shock structure. a) no particles, b) and c) with particles. Separation time between frames 1/30 sec.

Conclusions

The velocity in the direction of the flow, measured with PIV at the centerline close to the first shock, is quite different from the value given by the analysis of the shock angle. Table 1 shows the values obtained with both techniques. This difference might be due first, to the fact that the flow is highly three dimensional, and measurements are made in the 2D plane; and second, to the method of seeding even though other methods give similar results.

It must be also considered that the PIV was not carried out in a controlled situation (supersonic wind tunnel).

In our experiments, seeding particles affect the flow and change the position of the shock structure. In particular, the technique shown does not provide a homogeneous flow of particles.

The design of a new injection device is in progress. Also, the flow field is being measured with other techniques.

References

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