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DEVELOPMENT AND APPLICATION OF A LASER VELOCIMETER TO MEASURE V--ETC(U)

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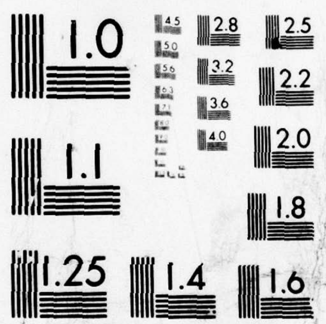
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AFFDL-TR-79-3067

DEVELOPMENT AND APPLICATION OF A LASER VELOCIMETER TO MEASURE VERY HIGH SPEED PARTICLE VELOCITIES

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June 1979

TECHNICAL REPORT AFFDL-TR-79-3067
FINAL REPORT FOR PERIOD NOVEMBER 1977 THROUGH SEPTEMBER 1978

AIR FORCE FLIGHT DYNAMICS LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
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A laser velocimeter was developed for the measurement of the velocity of particles in the size range from 10 to 100 micrometers diameter and velocities up to 5000 meters per second. The instrument was successfully employed in accelerator tests which were conducted during the development of a reentry nose tip erosion and ablation facility.

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FOREWORD

This technical report is the result of a contract effort conducted by Dr. J. D. Trolinger of Spectron Development Laboratories, Inc. of Costa Mesa, California. The performance period was from November 1977 through September 1978. The work was performed under a visiting scientist arrangement through the University of Dayton under task number 34 of Air Force Contract F33615-76-C-3145. The effort was carried out with assistance from Air Force Flight Dynamics Laboratory (AFFDL) personnel as an element of in-house work unit 24041304, "Development of Thermal and Flow Measurement Techniques" of task 240413, "Aerodynamic Ground Test Technology." Mr. Daniel M. Parobek of the Experimental Engineering Branch was contract monitor and in-house work unit engineer. Mr. Arthur Stringer of AFFDL was responsible for much of the optical system development and applications. Mr. Charles O'Heren, AFFDL, was responsible for the majority of the electronics, data handling and computer programming in the system. All participated in the velocimeter measurements at McDonnell-Douglas.

The author and the contract monitor wish to acknowledge the contributions of persons to this velocimeter project without whose participation the work could not have been done. Mr. Kenneth Cramer, AFFDL project engineer for the development of the accelerator, assisted in making the velocimeter tests possible. Mr. James Painter and his staff of McDonnell-Douglas Research Laboratories who conducted the particle accelerator tests at their test site supported the velocimeter work in many ways.

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SECTION I

INTRODUCTION

BACKGROUND

The U.S. Air Force and its contractors employ a wide variety of facilities to simulate reentry into the earth's atmosphere. Such simulations must not only account for aerodynamic ablation of a nose tip but also must account for erosion caused by passage through dust and ice clouds. Therefore, many of these facilities have incorporated a capability to introduce high-speed dust or other particles into the flow to simulate erosion by high velocity impact of dust with the nose tip during the ablation process. Ablation itself is simulated by the passage of a high enthalpy gas over the nose tip. An accurate simulation requires both effects of erosion and ablation to take place simultaneously since one seems to have an effect on the other. Facilities of this type with varying capabilities are currently operated by a large number of contractors and government agencies. At the present time, these existing facilities fall short in capability to produce and measure both the high-velocity dust and ablation simulation simultaneously, although several facilities are approaching useful conditions.

An outstanding problem in almost every facility of this type is the calibration of the test flows. These high-energy flows are sufficiently complex that theoretically computed test conditions cannot be heavily relied upon. Therefore, a great deal of effort has been spent in developing diagnostics and instrumentation to calibrate these facilities. Such measurement techniques include: (1) spectroscopy for thermochemical properties and states of the gas flows, (2) laser Doppler instruments for gas and particle velocity measurements, (3) double pulsed holography instruments for particle velocity measurement, (4) shadowgraph instruments for flow visualization, (5) particle sizing instruments and (6) instruments to monitor surface features of the reentry test model. The severe environment of the test flows and their surroundings that are imposed on such instruments have caused considerable problems and delays in the development of these devices. The present report is a description of a study to develop and apply a laser instrument to measure velocity of very high speed particles which are intended to be injected into an erosion/ablation facility. Another part of the study included the measurement of particle size and density as well. These latter two will be described in a separate report. This particular report will be restricted to a description of the first item; namely, velocity of high speed particles which will be injected into a reentry test flow.

High particle velocities can be attained by injecting particles in a high speed gas stream. They are accelerated by a carrier gas by drag forces to some maximum velocity which depends upon particle size and shape as well as the properties of the gas stream. Therefore, the velocity obtained by the particle along its flow path depends upon its size at injection and its ablation history as it is being accelerated. It is impossible to predict, without some measurement, the velocity attained in practice using real particles. Both velocity and size of the particles are critical measurements and they are, in fact, related.

This study began as a review of existing particle sizing and velocity techniques for the range of conditions of interest here. The first test requirement involved supporting a particle accelerator development program which was conducted at McDonnell-Douglas Aircraft in St. Louis, Missouri, during the months of June and July 1978. The anticipated conditions involved particle sizes in the range from approximately 30 to 100 microns and particle velocities in the range from 1000 to 5000 meters per second. No instruments or routine technique could be found which could cover this range of size and velocities at the time the program was initiated.

OBJECTIVES OF THE STUDY

The objectives of this study included (1) the development of a prototype velocity instrument which could be used in the above-mentioned McDonnell-Douglas accelerator tests and (2) which could be further refined and developed for use in the facilities of the Flight Dynamics Laboratory (AFFDL) on a routine basis.

At the beginning of the study, the constraints included that the prototype instrument must be built primarily with existing Air Force equipment and that it be built on a time frame such that it would be ready in time for the McDonnell-Douglas tests.

Two techniques that might be further developed for this program involved both double-pulsed holography and some form of laser velocimetry. A double-pulsed holographic system has been previously developed to measure particle velocities to 7,000 feet per second at a dust erosion facility. The author has worked extensively in development of both laser velocimetry and holographic techniques. It appeared, based on the experience, that the measurement capability desired in this project coupled with the short time frame for development worked equally well with both approaches. However, since it appeared that it would be possible to assemble and convert existing laser velocimetry components to one which would have the capabilities required in the particle accelerometer tests, this course was chosen. Therefore, part of the objectives of this program was to make the conversion of this equipment for use in the preliminary tests and to use knowledge gained from these tests as the basis for specifying ultimate equipment to be acquired by AFFDL.

SUMMARY OF THE ACCOMPLISHMENTS IN THIS PROJECT

During the course of this project the following items were achieved:

1. The laser Doppler velocimeter was assembled and tested at AFFDL.
2. The modifications of this system were designed and made such that it could be used in the McDonnell-Douglas tests.
3. The modified system was evaluated to as great an extent as possible in the optics laboratory at AFFDL without benefit of an actual particle test flow.
4. The system was transported to McDonnell-Douglas at St. Louis and set up for use with the accelerator tests.
5. The system was used to make measurements of the velocity of particles flowing from the nozzle of the accelerator.
6. Velocities of particles in the range from 5000 to 15,000 feet per second were measured.
7. A refined design was completed based on information learned during this study.

In this report the rationale is presented which was used in the design of this system and a description of the various components of the system and their use. The system shortcomings and recommendations for change are also made.

SECTION II

LASER VELOCIMETER DESIGN

The design and use of laser Doppler velocimeters (LDV) possibly extendible to this type of application are described in separate reports[2,3]. The usual system configuration of a cross-beam laser Doppler velocimeter is shown in Figures 1-3. Two parallel beams of coherent light are focused and crossed. The crossover region is known as the probe volume. A set of parallel interference fringes is generated in the probe volume. The intensity of light in this volume can be described as a sinusoid which has a Gaussian envelope. The fringes are spaced by D_f where:

$$D_f = \frac{\lambda}{2 \text{ Sin } (\theta/2)} \tag{1}$$

When a particle passes through the probe volume, it scatters light (from the fringe patterns) which is collected by a receiving system and imaged into a photodetector. The form of the detected signal is shown in Figure 2. The frequency of such a signal is determined by the rate at which the particle passing through the sample volume crosses the fringes in the sample volume and, therefore, in this frequency lies the measure of velocity of the particle. When a particle is very small compared to the fringe spacing, this signal is characterized by full modulation depth; that is, the intensity goes from maximum to zero. When the particle is of comparable size as the spacing of the fringes, the particle itself is never completely in a dark region and, therefore, some light is always scattered. Therefore, the modulation depth of the scattered light signal is less than complete. This characteristic of the scattered light signal, called the fringe contrast, is given by the ratio of the modulation depth to the pedestal height and provides a measure of particle size. Therefore, such a system is capable, in principle, of simultaneously providing particle size and velocity.

LDV's of this type have been used in a wide range of applications, including the measurement of particle size and velocity in dust erosion facilities. However, to our knowledge, the highest velocity ever measured with such a system is approximately 3000 meters per second. Because of frequency response limitations, the equipment for achieving this velocity

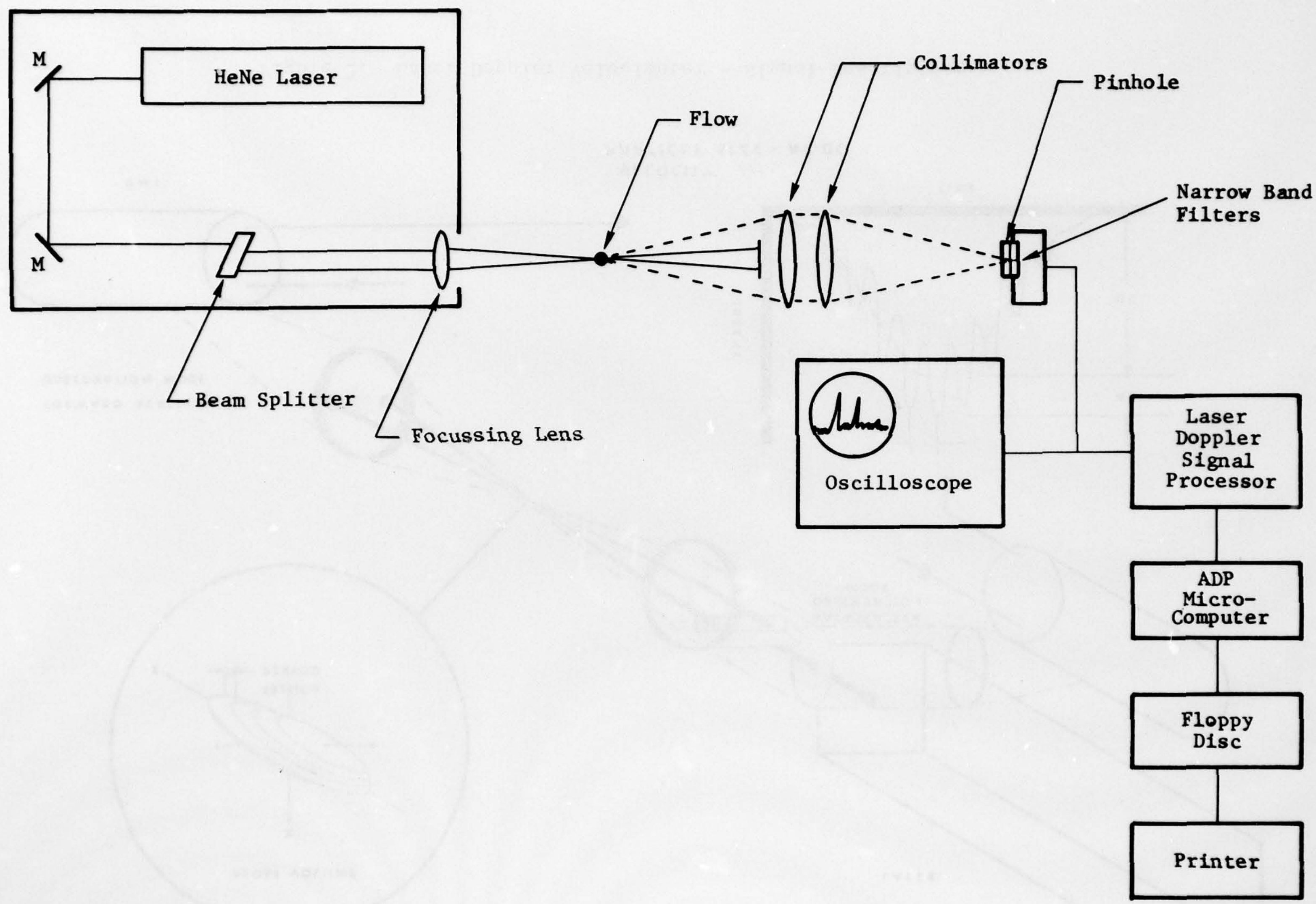


Figure 1. The FDL Laser Doppler Velocimeter.

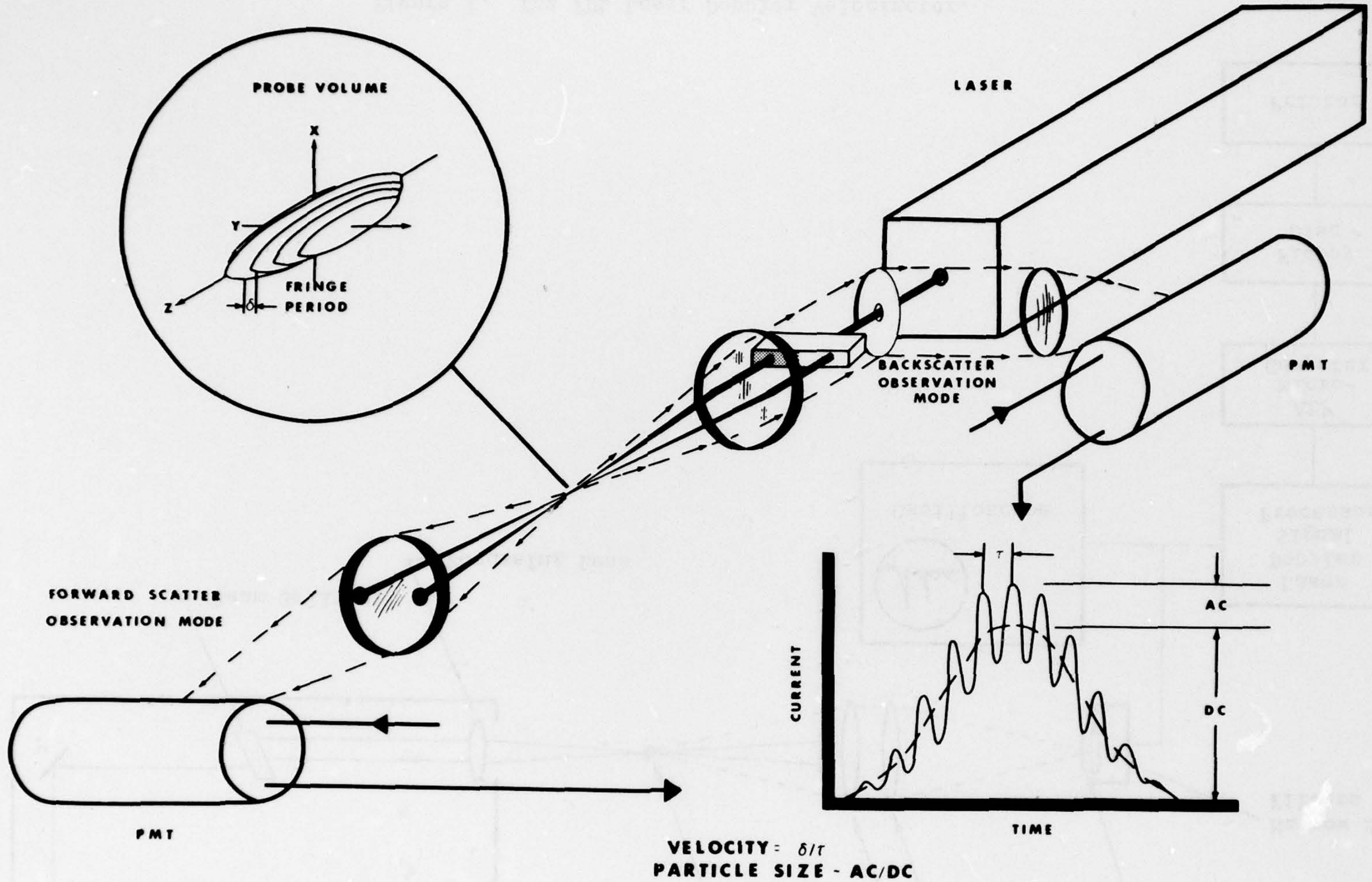


Figure 2. Laser Doppler Velocimeter - Signal Description.

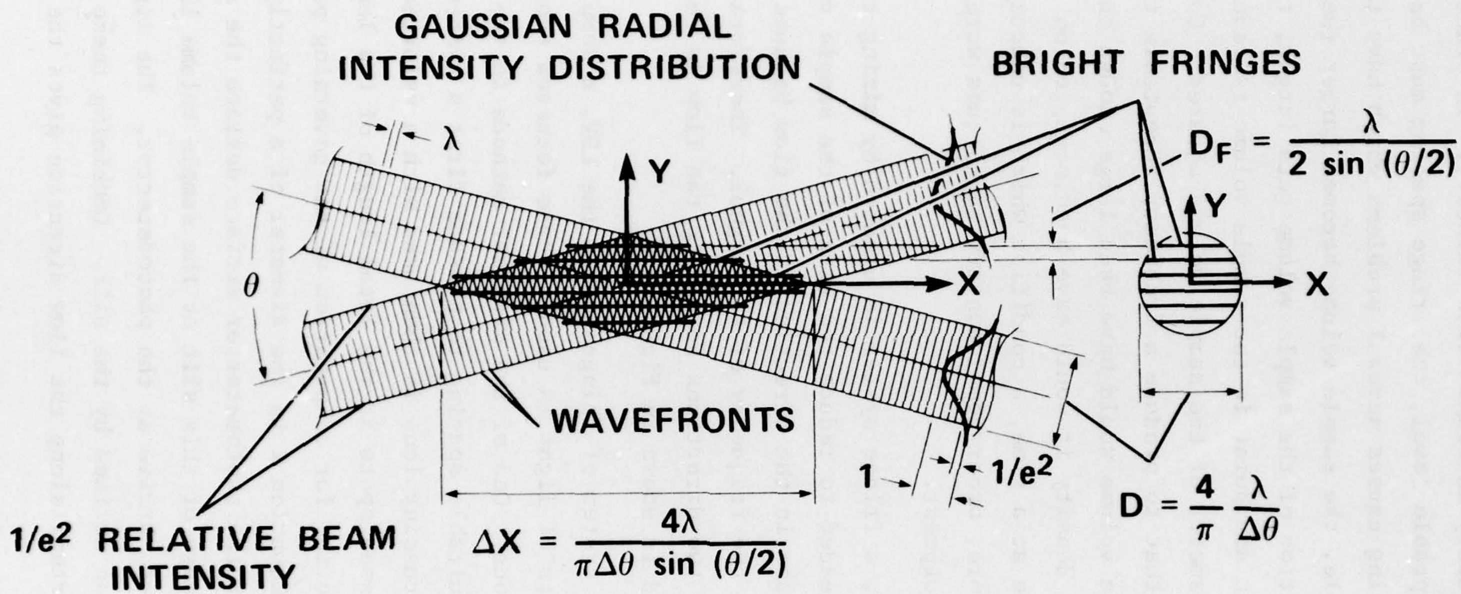


Figure 3. Enlarged Cross-Sectional Views of the Beam Crossover Region.

level was not capable of being used at much higher levels. For a given fringe spacing, the frequency increases with velocity. In order to reduce the frequency to an acceptable level, the fringe spacing must be widened. Widening the fringe spacing causes several problems which have to be considered here. For example, the sample volume becomes larger (see Figure 3). Also, when the cross section of the sample volume gets larger, the intensity of the laser beam at any point in the sample volume is reduced by a ratio of one over the diameter of the sample volume squared. Computations for this project showed that to produce a frequency acceptable to the existing equipment, the sample volume would have been large enough that under the expected particle number density it would have been occupied on the average by more than one particle at a time, a condition which is unacceptable for the measurement. Therefore, other complementary techniques were sought to use with the existing equipment.

In the standard LDV, a fringe system is created by mixing crossed laser beams. Some method is needed to reduce the size of the sample volume. This reduction cannot take place in the direction of the flow because that dimension is needed to reduce the frequency of the signal. Therefore, a reduction in dimension in the two directions normal to the flow is required. The system which was used is shown in Figure 4.

Rather than using a system of fringes as in the LDV, a sample volume occupied by focussed spots of light is used. These focussed spots can be produced by several methods. One of the simplest methods is the use of a diffraction grating of suitable spacing to produce first a system of collimated light beams. A focussing lens is then used with a selected number of light beams to form focussed spots at the focal length of the lens. Equations 2 through 5 provide for computation of the governing properties of this sample volume. Equation 2 is the diameter of a perfectly focussed beam of light. A slit at the photodetector surface defines the sample volume length, P. The image of this slit at the sample volume limits the region from which light can arrive at the photodetector. The light of the sample volume, S^1, is also defined by the slit. Combining these dimensions with the sample volume extent along the flow direction gives the magnitude, V.

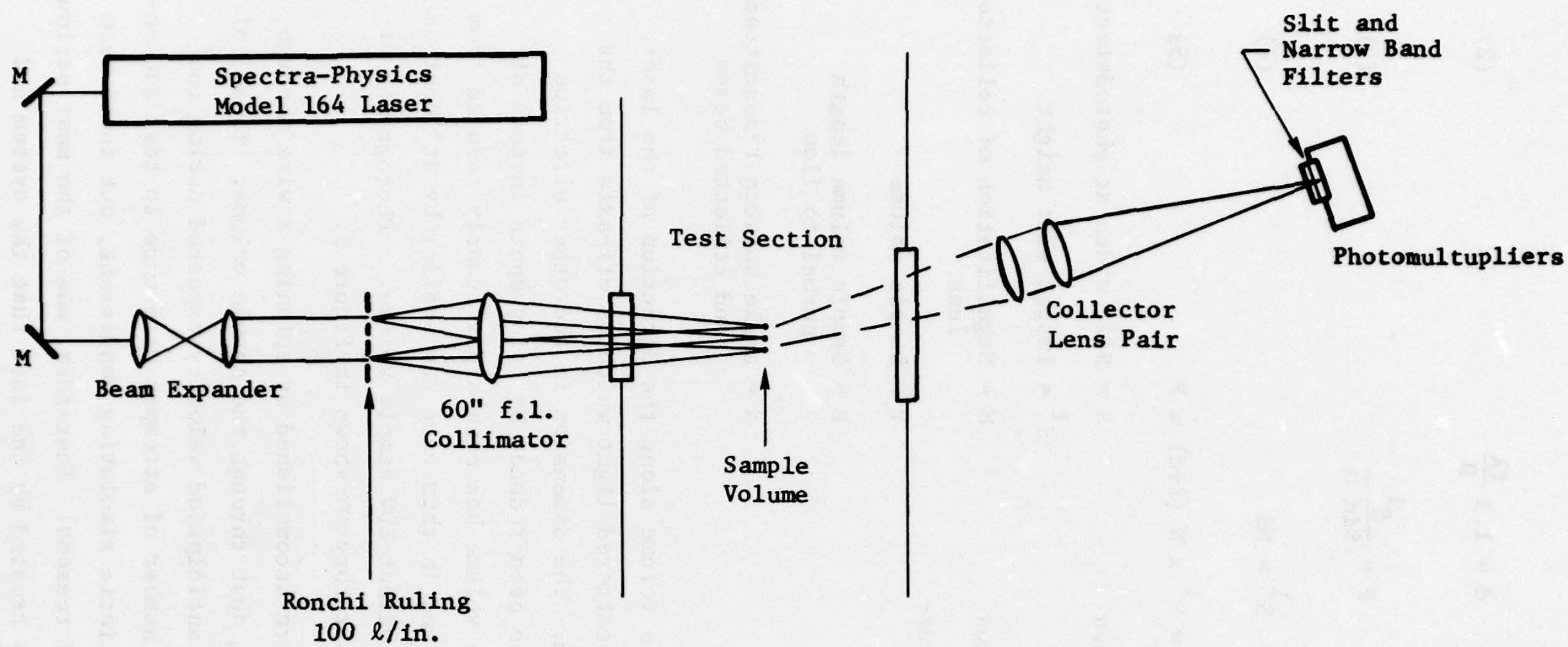


Figure 4. Velocimeter Concept Developed for the Particle Accelerator Tests.

$$d = 1.3 \frac{f\lambda}{D} \qquad (2)$$

$$P = \frac{S^1}{\sin \alpha} \qquad (3)$$

$$S^1 = MS \qquad (4)$$

$$V = S^1 \times N (\ell + d) \times P \qquad (5)$$

where N = Number of spots chosen

ℓ = Spot separation

d = Spot diameter at focus

D = Beam diameter at focussing lens

λ = Wavelength

f = Focal length

S = Slit width at photodetector

S^1 = Imaged slit height

M = Magnification of collector lens

V = Sample volume

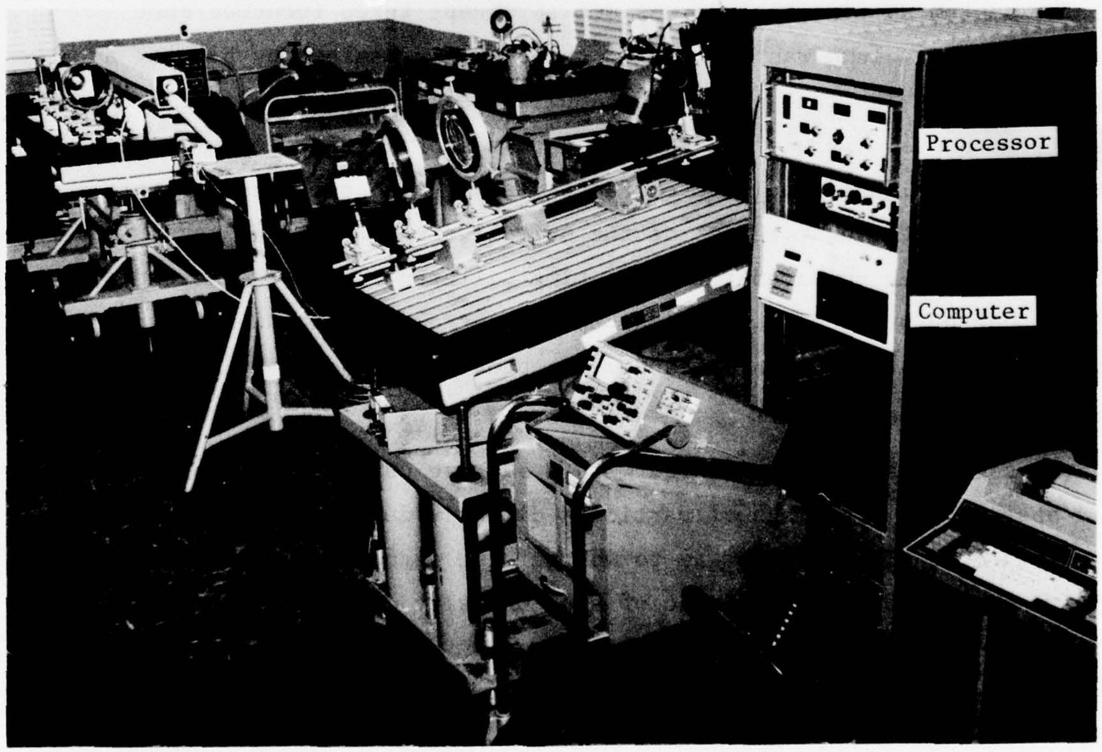
P = Sample volume length normal to flow

α = Angle between transmitted and collected beams

The dimension of the sample volume along the direction of the laser beam is reduced by collecting scattered light which is off-axis from the line of sight of the laser beam. The dimension in the other direction normal to the flow direction has been reduced by using spots instead of fringes. Therefore, the sample volume has been significantly reduced from its size in the applicable LDV and in this case was smaller by at least an order of magnitude than an equivalent LDV sample volume. Photographs of the system as set up in the laboratory are shown in Figure 5.

Preliminary experiments were accomplished by spinning a wire through the sample volume or by blowing dust through the sample volume. These, of course, could not simulate the anticipated velocity expected during the particle accelerator tests. A number of attempts were made to test and refine the system under more realistic simulating conditions, but these were not achievable for a variety of reasons. Therefore, one of the most serious shortcomings of this system was created by the fact that the system had never been tested under conditions approximating the real application until

(a) Transmitter System



(b) Receiver System and Electronics

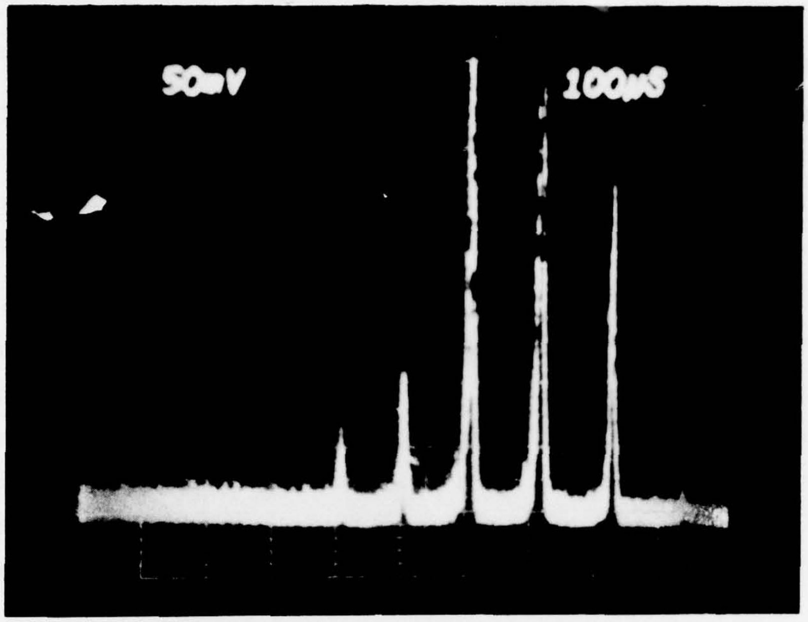
Figure 5. Photographs of the System as Set Up in the Lab.

measurements with it would be attempted for the actual particle accelerator tests.

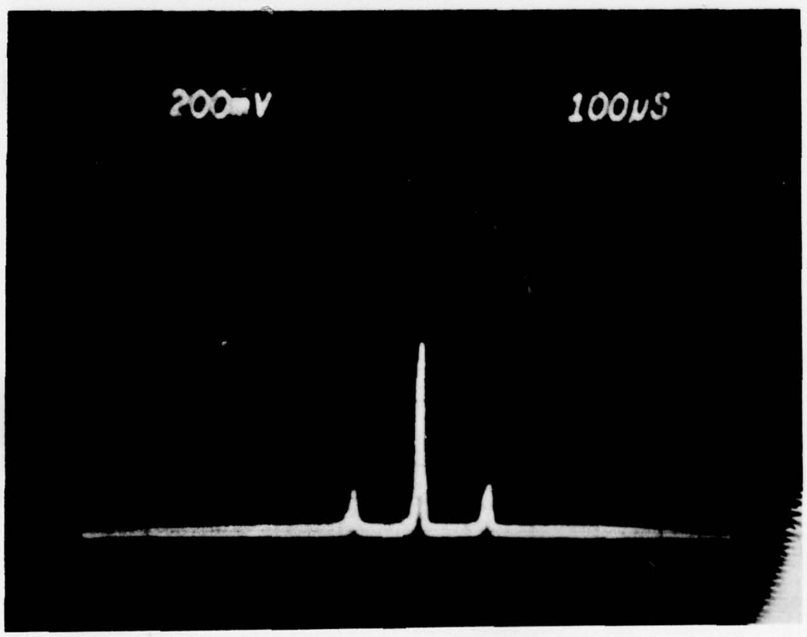
The scattered illumination was collected off-axis by a pair of collimated lenses and focussed into an EMI 931 photodetector. The photodetector voltage was operated between 700 and 800 volts. The 2 watt laser used in the final setup was a Spectra-Physics argon-ion Model 164. The electronic signal emerging from the photodetector was passed into a modified Spectron Development Laboratories, Inc. (SDL) Model 554 laser Doppler velocimeter (LDV) processor. The processor was modified to handle signals such as that shown in Figure 6, generated by spinning a wire through the sample volume. Therefore, at this particular point in the project the intention was to measure only velocity, for there appeared no simple and quick way to develop particle sizing measurement capability for these high velocities. The signal from the LDV processor was then passed into an Applied Data Processing (ADP) Model 8080 microcomputer which was capable of printing out individual particle velocities and velocity histograms.

The system as finally used was set to accept three focussed spot crossings. The volume was limited to three spot crossings by placing a slit immediately in front of the photomultiplier that passed light from these three spots. It was possible to choose spot intensities with the hopes that the signals would be characterized by some special signature and would be easier to separate out of the overall signal. The processor had a comparator which compared the first time difference with the second and would accept only cases in which the three scattered light signals were equally spaced in time. This feature was provided to add to the system's noise rejection capability.

The signal was also monitored with a storage oscilloscope so that one could observe the crossings of particles directly during the actual data recording to provide judgment as to whether the signal was sufficiently noise free and was characteristic of the intensity distribution chosen. The storage scope could be set to be internally triggered only at a sufficient level to be above what appeared to be a realistic noise level for the system. Then for any given recording it was possible to get at least one



(a) Collection of Six Orders



(b) Limiting the Signal to Three Orders with a Slit

Figure 6. Signals Generated by the Laser Velocimeter From a Spinning Wire.

velocity per oscilloscope trace, and in cases of high number density, it would be possible to get more than one velocity reading per scope triggering.

One of the greatest concerns in this experiment was that of electrical noise, which is commonly associated with arc-heated facilities. The system was operated in this configuration over a period of approximately three months in the lab to shake down different shortcomings and to learn as much as possible about the system before it was put into actual use.

While it was not possible to simulate the actual particles passing through the sample volume at the velocity experienced during the test, it was possible to perform electronic simulations by passing signals similar to that anticipated into the electronics system. Such signal simulation was used to set up and check out every phase of the electronics. However, it was not possible to simulate such things as electronic noise and optical noise.

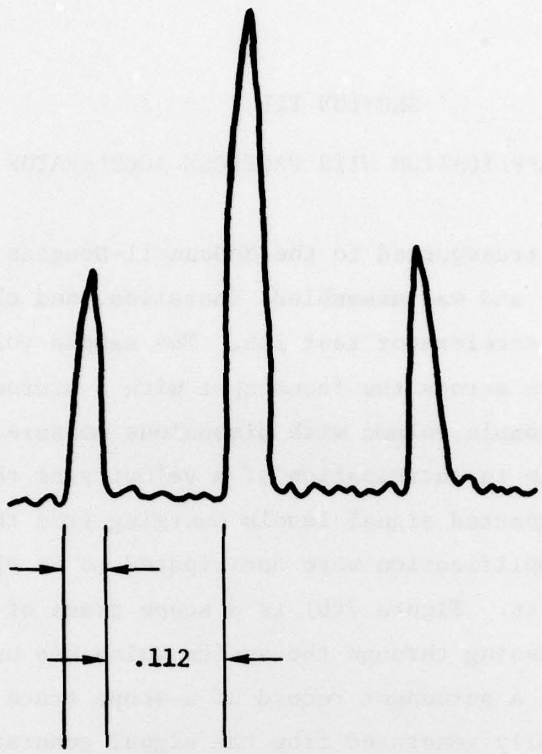
SECTION III

SYSTEM APPLICATION WITH PARTICLE ACCELERATOR

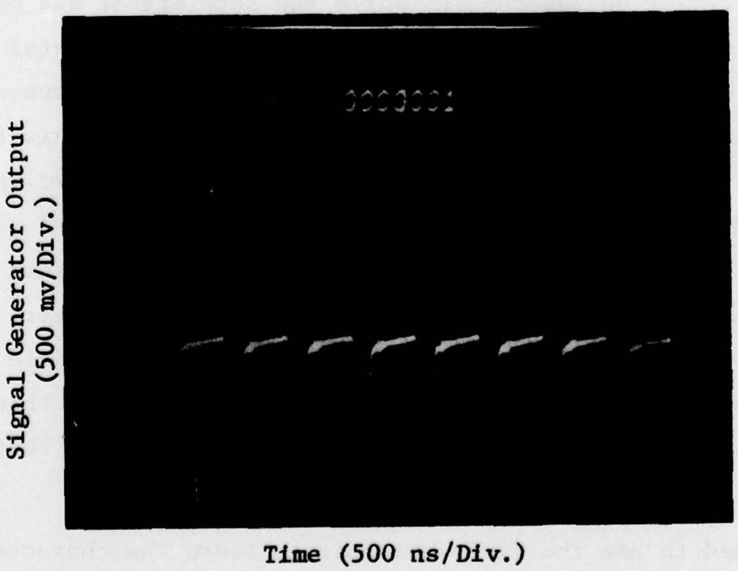
The system was transported to the McDonnell-Douglas test site in St. Louis, Missouri, and was assembled, installed, and checked out in the arc-driven particle accelerator test lab. The sample volume was measured by translating a wire across the focus spot with a micrometer. Figure 7(a) is a sketch of the sample volume with dimensions measured at the facility. The system was set up in anticipation of a velocity of the order of 10,000 feet per second. Expected signal levels emerging from the photomultiplier tube after its preamplification were anticipated to be of the order of a few hundred millivolts. Figure 7(b) is a scope trace of this simulated electronic signal passing through the system which was used to set up the oscilloscope so that a permanent record of a scope trace could be made. This signal is actually generated from the signal generator of the SDL Model 550 processor.

Perhaps the most serious problem during the actual tests was a lack of time to properly set up instruments while the accelerator was operating. In order to insure a reasonable operating life of the experimental accelerator nozzle it was decided during the tests to restrict the operating time for each run to five seconds. It was hoped that during this time it would be possible to observe the signal on the oscilloscope, set the oscilloscope threshold so that it triggered only on signal at a level somewhat above the noise, set the amplification such that the entire signal could be observed on the scope after the trigger level was properly set, set the timing of the scope such that one complete traversal of a particle through the sample volume could be observed accurately, and then, with this knowledge, set up the SDL processor and the associated computer so that large quantities of data could be obtained.

It was planned to use the first few runs to learn the character and limits of the signal so that the instrumentation could be properly set up to take reasonably large quantities of data on later runs. Unfortunately, five seconds during the run was not enough time to achieve completely satisfactory results. The first run during which recording was done is



(a) Space Measurements Describing the Sample Volume



(b) Time Calibration Signal Generated by the Signal Processor

Figure 7. System Calibration Parameters.

Run 18. The scope trace of a typical signal recorded during this run is shown in Figure 8. It was possible during this time to get the complete signal on the screen as can be observed in this figure. The data from the SDL processor was virtually meaningless during this run and it was concluded that the signal level was not properly set so that the LDV processor was effectively operating on electronic noise.

From Figure 8 it appears that two widely variant velocities can be derived. Using the short spacing of the signal spikes seen in this figure, a velocity measurement of 4475 meters per second was obtained. This velocity level is expected to be approximately the gas velocity level and not the particle velocity level.

Using the two highest spikes as a signal representing a transit through two of the focus spots, a velocity of 1604 meters per second was attained. This is about 20 percent lower than the expected velocity of the particles for this case.

The next run, Run 19, was made to more closely define the signal which had to be processed. This run provided information to set the system threshold properly so that the scope triggered at a level somewhat above the noise. Also the oscilloscope amplification was set so that it was possible to see the entire signal.

A third factor which had not been anticipated was the need to adjust the DC level on the scope. The scope had been AC coupled because a shift in the basic level of the signal was not expected. However, it was not anticipated that the test chamber would be filled with a very heavy cloud of dust which continuously scattered a significant detectable level of signal and in turn caused a basic shift in the DC level output from the photomultiplier tube. This would not have created a problem since the data system was AC coupled to the photomultiplier tube except for the fact that the DC was not a constant level signal because the flow from the nozzle caused it to oscillate at a fairly high frequency and this was passed by the scope. Therefore, it was necessary to offset this DC level on the scope as part of the preliminary setup that had to be accomplished during the five second run. As can be seen in Figure 9, this was achieved

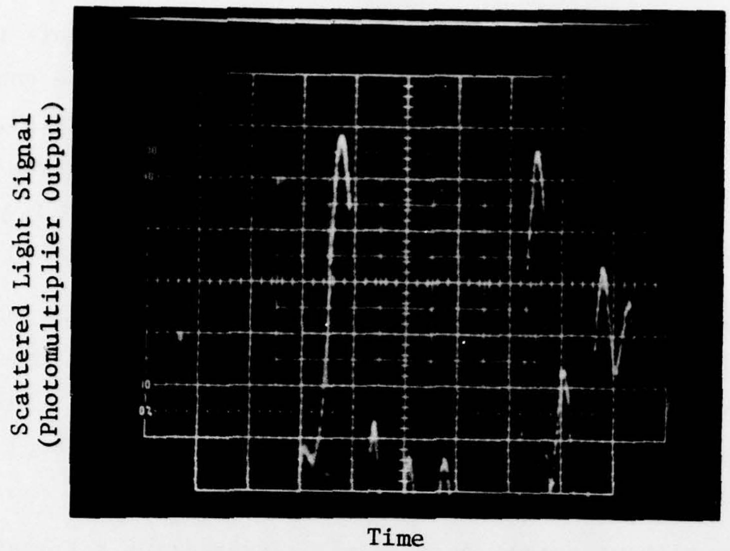


Figure 8. Run Number 18.

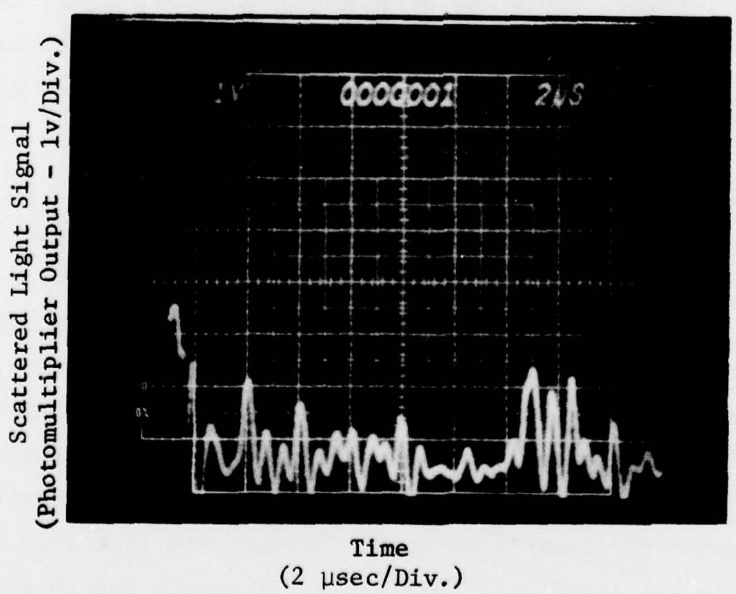


Figure 9. Run Number 19.

in Run 19. This problem did create trouble in the threshold setting since the basic level of the signal was oscillating at a significant level.

Even though a high threshold was set, the scope was triggered quite regularly by electronic noise. In Run 19 once again two frequencies were present in the signal, one at a high frequency corresponding to a velocity of 4000 meters per second which was the anticipated gas velocity. The second frequency, a considerably lower frequency, gives a velocity 1645 meters per second, again somewhat below the anticipated particle velocity.

Before this run a 50 megahertz low pass filter had been used to attempt to improve the signal entering the electronics system. Observing the signal on the oscilloscope it was concluded that the signals were being significantly rounded off by the 50 megahertz filter and it was decided to remove this filter from the system. Unfortunately, this allowed the signal level to raise and once again the total signal amplitude and DC offset surpassed levels within the proper range settings on the scope which had been made for the previous run. This resulted in Figure 10 for Run 20.

From this figure the velocity of 1780 meters per second was derived for the lower frequency component, representing larger particles.

Finally, Figure 11 was produced with proper ranging, on Run 21, which is actually the first reasonably clean data point taken. From this figure a velocity of 7184 feet per second was derived.

Figure 12 represents Run 22. From this figure a velocity of 8380 feet per second was derived.

It was still not possible to get the SDL processor satisfactorily processing the data which was being supplied to it. Apparently, there was still too much electronic noise which could not be handled with the processor. Therefore, because of the short duration of the test time and because of the limited number of tests remaining, it was decided that the only reliable source of data for that test sequence would be oscilloscope traces. Therefore, changes were made to take as many oscilloscope traces during the remaining runs as possible. To check the nature of the signals, some runs were made with no particles and with cold gas flow to see if the parameters observed in the recorded signals varied in the proper fashion.

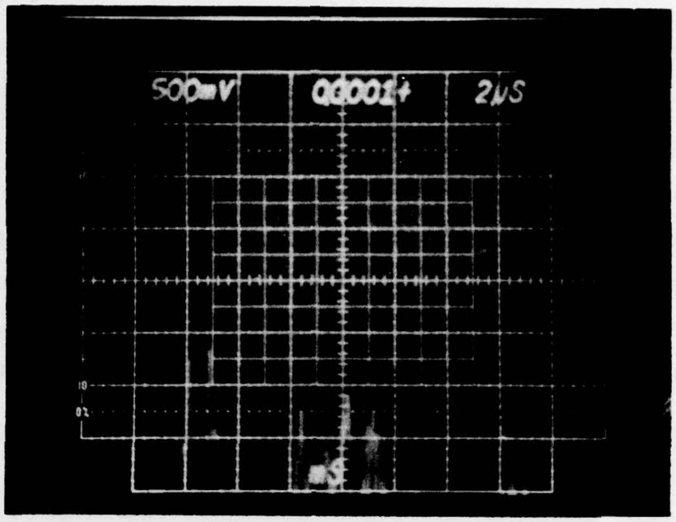


Figure 10. Run Number 20.

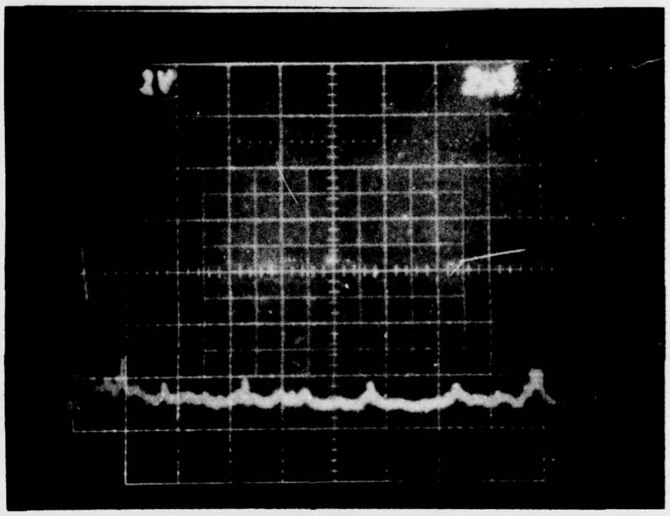


Figure 11. Run Number 21.

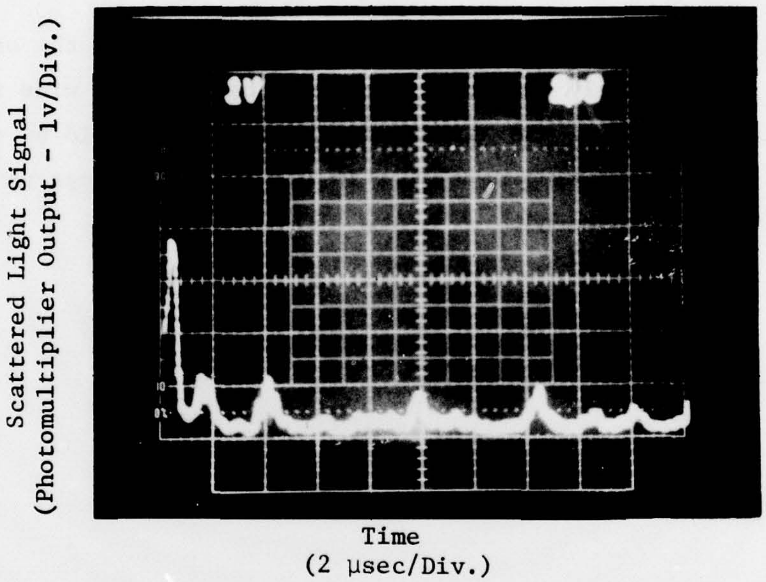


Figure 12. Run Number 22.

Figure 13 was taken from Run 23 with cold flow. As can be seen, the observed spikes are much more widely spaced, representing significantly lower velocity for the cold flow. Figures 14 through 18 include data taken from subsequent runs. In these figures the velocity measurements for the 50 atmosphere stagnation pressure conditions of the accelerator were in the range of 7000 to 8000 feet per second for most of the cases recorded (Figure 14-16).

Stagnation pressure of the accelerator was then increased to 75 and 100 atmospheres (Figures 17 and 18). Measured values of velocities increased to a range of 10,000 and 13,000 feet per second.

It was clear that in any given run the data taken from the oscilloscope was not statistically sufficient to describe a fairly wide range of velocities occurring. From the data taken, however, it could be concluded that the nozzle was generating particles in the velocity range up to as high as 13,000 feet per second.

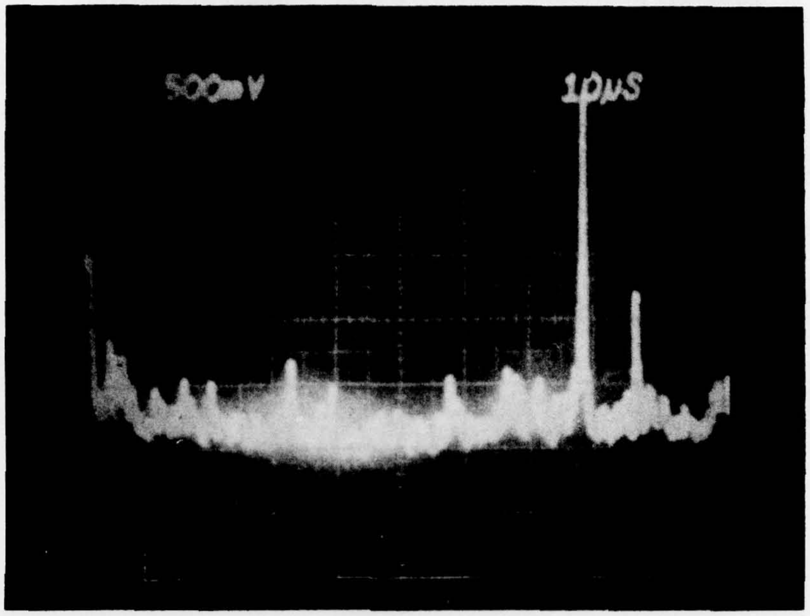
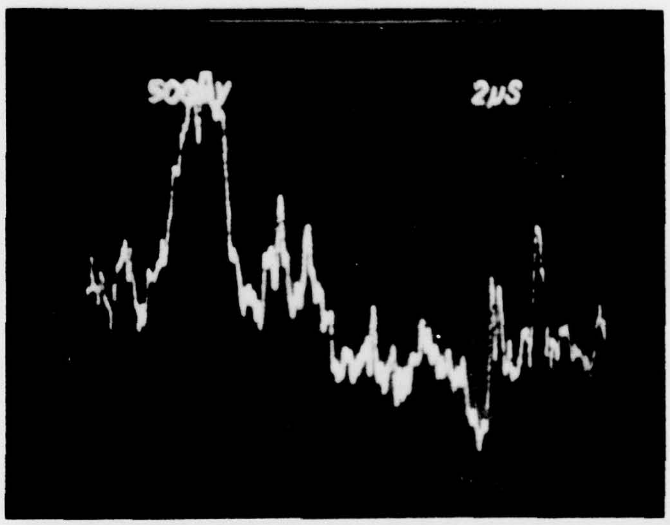
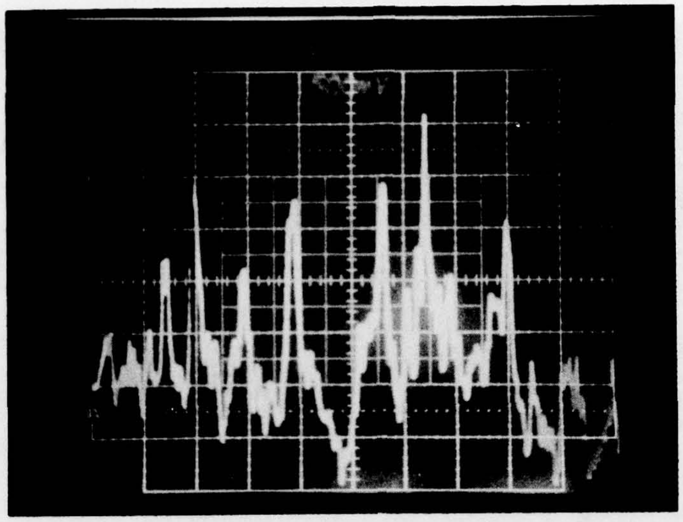


Figure 13. Run Number 23.



Condition -- 50 Atmospheres Stagnation Pressure
Velocity -- 8220 ft/sec

Figure 14. Run Number 23.



Scattered Light Signal
(Photomultiplier Output - 50 mv/Div.)

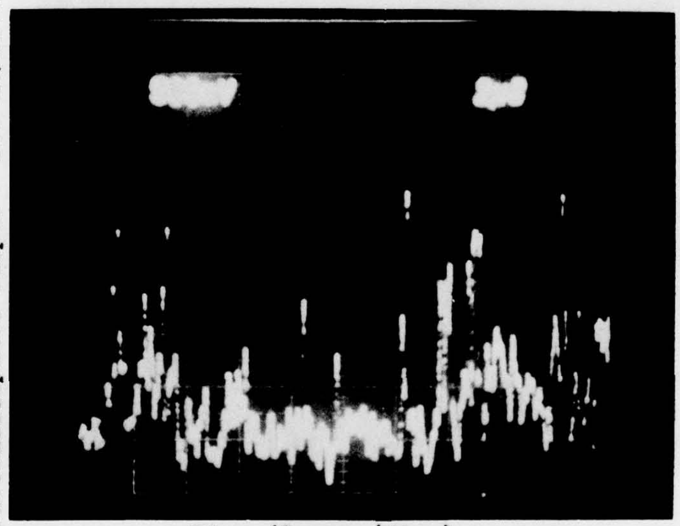
Time (2 μsec/Div.)

Three values of velocity obtained from this photograph: V_1 = 8220 ft/sec

V_2 = 6250 ft/sec

V_3 = 6300 ft/sec

Figure 15. Run Number 23.

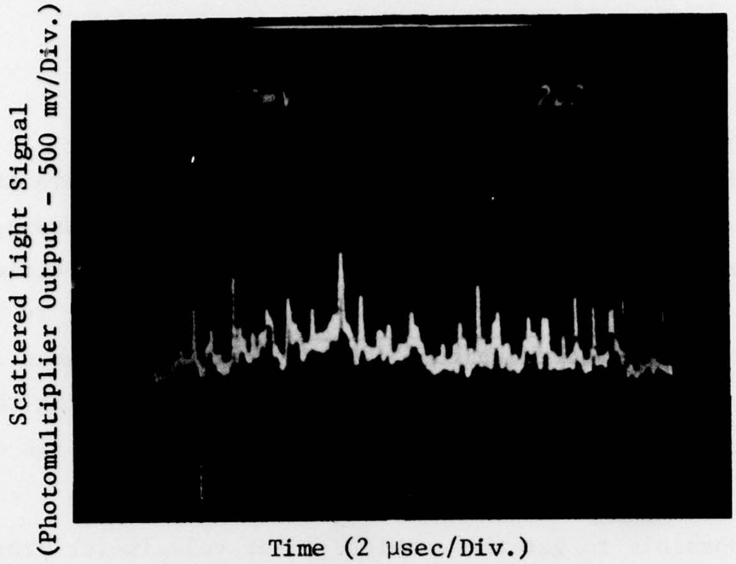


Scattered Light Signal
(Photomultiplier Output - 500 mv/Div.)

Time (2 μsec/Div.)

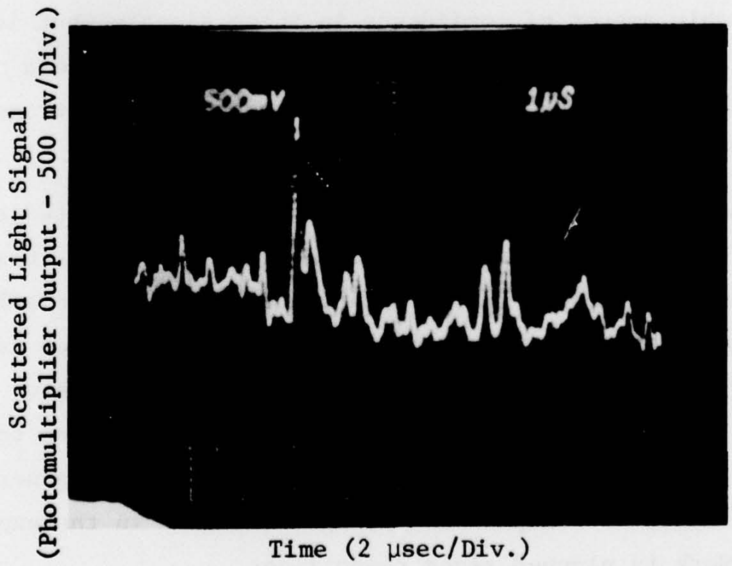
Condition -- 50 Atmospheres Stagnation Pressure
Velocity -- 8380 ft/sec

Figure 16. Run Number 23.



Condition -- 100 Atmospheres Stagnation Pressure
Velocity -- 13,209 ft/sec

Figure 17. Run Number 26.



Condition -- 100 Atmospheres Stagnation Pressure
Velocity -- V_1 = 7752 ft/sec
V_2 = 10,480 ft/sec

Figure 18. Run Number 28.

SECTION IV

CONCLUSIONS AND RECOMMENDATIONS

During the described test sequence it was possible to learn the nature of the types of signals that would be observed by particles passing through focussed laser beams in an arc-heated facility. Particle velocities as high as 13,000 feet per second were successfully measured. It is believed that higher velocities measured up to 15,000 feet per second were actually extremely small particles which were almost capable of following the gas velocity itself, while lower velocities were those characteristic of the larger erosion particles.

It was not possible to get the complete laser velocimeter processor and associated computer functional during this test sequence because of problems encountered in the signal-to-noise characteristics. The computer was not capable of handling the type of signals which were fed to it during these tests; therefore, all useful data was taken from oscilloscope traces of the actual output from the photomultiplier tube. It is believed that there is a reasonable amount of confidence in these signals, but it is clear that there are not a sufficient number of them to produce a statistical evaluation of data. For this type of measurement an instrument is still needed which can produce large quantities of data.

It is recommended that further development work be conducted to refine this or a similar instrument using the knowledge gained during these tests. Methods must be used to improve the signal-to-noise ratio. The AFFDL now has in its instrument capability a laser Doppler processor which is capable of performing analysis of signals up to 100 megahertz. Therefore, it appears practical to return to a conventional laser Doppler mode to make this measurement. In many respects, this mode can be used to generate signals with reduced noise by bandpass filtering the signal in the expected velocity range. Work is planned along these lines.

A significant amount of background light existed in this facility which had not previously existed in the laboratory tests and which caused problems. Therefore, an added effort must be made to reject background light. It is possible that bandpass filtering which could be done on a

Doppler signal will remove the lower frequency signal caused by the variation in background light.

From the nature of the signal seen in this test series, several problems were observed that exist in interpreting the signals. First, the number density of particles was apparently higher than had been anticipated. Secondly, it was observed in almost every case that more than one particle entered the sample volume during one sweep of the oscilloscope. In fact, in many cases, more than one particle was observed in the sample volume at one time. When this condition exists, it makes it almost impossible to separate out signals from the separate particles. Therefore, a system must be developed which is capable of having a smaller sample volume.

Another problem observed during these tests is that apparently particles were not lined up in their velocity vector precisely with the spots in the sample volume. The original alignment of the spots was accomplished by projecting the laser beam through the nozzle along its centerline such that it passed through the three spots. In almost no case were observations made from scattered light signals from particles passing through the center of all three spots. This suggests that the fringe system would have been superior from an alignment point of view, although the sample volume would have been somewhat larger. To solve this problem it is now recommended to use a fringe system with a dimension along the direction of the flow which has been decreased and the direction normal to the flow increased so that particles can be guaranteed to pass through the proper part of the sample volume. This can be achieved with a higher frequency processor.

An alternate approach is the use of the so-called "two spot" transit anemometer which incorporates a rotating focussed spot pair which can actively find the proper spot orientation along the velocity vector. In some respects this class of system offers much for this type of application.

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3. V. A. Cline, "Application of the Laser Velocimeter in the AFFDL Trisonic Gasdynamic Facility," ASD Reserve Project Report 76-108-B5, 15 April 1978.

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