NASA-TM-83534

NASA Technical Memorandum 83534

NASA-TM-83534 19840006053

Multicomponent Velocity Measurements in a Piston-Cylinder Configuration Using Laser Velocimetry

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December 1983

NASA

48 1 1 RN/NASA-TM-83534
DISPLAY 48/2/1
84N14121*# ISSUE 5 PAGE 627 CATEGORY 2 RPT#: NASA-TM-83534 E-1835
NAS 1.15:83534 83/12/00 19 PAGES UNCLASSIFIED DOCUMENT

UTTL: Multicomponent velocity measurement in a pison-cylinder configuration using laser velocimetry

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CORP: National Aeronautics and Space Administration. Lewis Research Center, Cleveland, Ohio. AVAIL.NTIS SAP: HC A02/MF A01

MAJS: /*AIR FLOW/*INTERNAL COMBUSTION ENGINES/*LASER DOPPLER VELOCIMETERS/*VELOCITY MEASUREMENT

MINS: / CYLINDRICAL CHAMBERS/ OPTICAL PROPERTIES/ PISTONS/ SIGNAL PROCESSING/ STATISTICAL ANALYSIS

ABA: Author

ABS: Because of its nonintrusive nature, Laser Doppler Velocimetry (LDV) has become a popular tool for velocity measurements in internal combustion engines. This work shows how one can use an on-axis measurement technique, in conjunction with the standard two channel LDV technique, to make simultaneous three-component measurements using a single focusing lens. Simultaneous measurement of two of these three components in a piston-cylinder configuration is demonstrated.

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SUMMARY

Because of its nonintrusive nature, Laser Doppler Velocimetry (LDV) has become a popular tool for velocity measurements in internal combustion engines. This work shows how one can use an on-axis measurement technique, in conjunction with the standard two channel LDV technique, to make simultaneous three-component measurements using a single focusing lens. Simultaneous measurement of two of these three components in a piston-cylinder configuration is demonstrated.

INTRODUCTION

Laser Doppler Velocimetry (LDV) has become an important research tool in experimental fluid mechanics. The small nonintrusive probe volume makes measurement of velocity and turbulence possible in applications which would not be amenable to more conventional techniques.

One such application is flow measurement in the combustion chamber of an internal combustion engine. Laser velocimetry has been extensively used to measure single velocity components in reciprocating internal combustion engines. Summaries of the most extensive work in this area can be found in selected references 1 to 4*. Witze (ref. 5) recently demonstrated the simultaneous use of LDV and laser shadowgraph photography in a reciprocating engine fitted with a flat window. Other publications (refs. 6 and 7) have demonstrated LDV techniques for cycle-resolved velocity measurements.

In the described experiments, detailed flow measurements were made along the diametral line of an axisymmetric piston-cylinder configuration. The model engine was operated in a cold motored condition. The eventual goal of this research is to compare actual measured velocities with theoretical predictions for internal combustion engine flow modeling. The first phase of this work was to integrate the necessary components for a multichannel LDV system (fig. 1) and become familiar with its operation. Both radial and longitudinal velocities were simultaneously measured and analyzed as a function of crank angle.

*Numbers in parentheses indicate references listed at the end of this report.

AXISYMMETRIC ENGINE

The model engine used in this experiment was specifically designed to provide an axisymmetric flow inside the cylinder. A standard four-stroke single-cylinder engine was retrofitted with a second piston and cylinder as shown in figure 2. This upper stage piston was bolted directly to the lower stage piston. The upper cylinder was seated into a groove which was machined into the lower cylinder. A special cylinder head was constructed to replace the standard two-valve configuration, so that a single valve could be located at the center of the head. This special cylinder head incorporated a large manifold, so that incoming and exhaust air could be kept as near to ambient pressure as possible. The manifold had a series of tubes connected to the top and bottom of it. Seeding particles were introduced into the bottom set of tubes and flowed around a baffle before being swept into the cylinder. Outgoing exhaust air exited through the top of the manifold. The model engine was fitted with a pressure transducer located near the center line of the head and a 10 bit rotary shaft angle encoder was connected to the crankshaft. The four-stroke cycle was divided into 2048 windows using first or second revolution information (table 2) and an optical shaft angle encoder with a 0.352° resolution. Under its present configuration, the engine can be motored from speeds of approximately 300 RPM to 1500 RPM.

The upper cylinder was constructed of quartz and was polished to a surface finish of 40/20 scratch dig as per mil spec MIL-0-13830A. The refractive index of the quartz cylinder was 1.46 and the wall thickness was 0.36 in. This relatively thin wall cylinder provided adequate signals, as long as the interior surface could be kept clean. A 5/8 in. thick sapphire cylinder with an 80/20 polish was tried, but it did not give adequate signals to make measurements. In addition to problems with a thick wall and high refractive index, machining marks in this cylinder were found to act like a diffraction grating and inhibited the formation of intense fringes in the measurement volume.

A new use of holographic optical elements has made it possible to bring multiple laser beams into coincident focus inside a container with an arbitrarily shaped window. This new development allows one to make simultaneous three-component measurements at an arbitrary location within a cylinder or any irregularly shaped window (ref. 8). The authors believe that this new development will allow LDV measurements to be made in previously unmeasurable locations.

OPTICAL MEASUREMENT TECHNIQUE

Historically, LDV velocity measurements have been restricted to either one or two components of velocity. Measuring the third component, i.e., on-axis, has been the most difficult, particularly in an internal combustion engine where accessibility is limited. Also the alignment of such a system has been a major deterrent. This paper describes an optical system that uses a patented technique employing a single lens to measure the on-axis velocity (ref. 9). Longitudinal and azimuthal velocities can also be measured using the same optical system.

This optical system is a commercially available three-component configuration (modified TSI Model 9100-11, see fig. 3). It consists of a four-watt Argon-Ion laser incorporating a temperature controlled etalon. The laser is operated in the multiline mode in order to create both a blue (488 nm) and green (514.5 nm) line. A dispersion prism separates these lines and a set of mirrors is used to steer the beams into the optical train. Modular optics are used to derive a five-beam configuration exiting the focusing lens. Two of the exiting beams are blue and correspond to a standard single component LDV system (azimuthal component). The other three beams are green and are used to obtain both the longitudinal and radial (on-axis) velocity components. Thus, all three orthogonal velocity components could be simultaneously measured at a point, using the five-beam arrangement.

The measurement of the radial (on-axis) velocity component is as follows. When the three green beams intersect, they form three discrete measuring volumes, one for each beam pair (fig. 4). One of these measuring volumes, formed by the intersection of the two outer beams, can directly measure the longitudinal velocity component. The other two measuring volumes (each formed by the center beam and one of the outer beams) are located symmetrically at an angle to the optical axis of the focal lens. When a particle simultaneously crosses both of these measuring volumes, it will produce Doppler frequencies corresponding to nonorthogonal velocity components. Frequencies corresponding to orthogonal velocity components are obtained from the nonorthogonal ones by first separating the signals and then recombining them in a mixer. The mixer gives the sum and difference frequencies. Due to the symmetry of the three beam geometry, the sum and difference frequencies directly correspond to the longitudinal and radial velocity components. Since the longitudinal component can be directly measured without mixing, the sum frequency is discarded and only the difference frequency is used.

In order to distinguish signals originating from individual green (514.5 nm) measuring volumes and to distinguish flow direction, the signals are frequency separated by imposing artificial frequencies generated with two separate frequency shifters (Bragg cells), one located on each outer beam. One Bragg cell shifts (increases) the frequency of an outer beam by 40 MHz. The other Bragg cell shifts (decreases) the frequency of an outer beam by 60 MHz in the opposite direction. The center beam is unshifted. The various combinations of frequency shift, seen between any pair of green beams, creates an effective fringe movement of the corresponding measuring volume. These various fringe movements are at 40, 60 and 100 MHz. The arrows shown in figure 4 indicate the direction of fringe motion. Thus, a zero velocity particle will produce a signal having Doppler frequencies of 40, 60 and 100 MHz. A moving particle will produce a signal which has Doppler frequencies larger or smaller than these values, depending on the flow direction. The signal from the photomultiplier (for the green scattered light) is frequency separated and then recombined in a mixer to obtain the difference frequency. It can be shown that this will effectively result in a system of "virtual" fringes moving in the on-axis (radial) direction: in this case, at 20 MHz in the direction of beam propagation. Thus, the on-axis (radial) component of velocity would have an effective frequency shift of 20 MHz. Also, it can be seen that the axial component of velocity has a direct frequency shift of 100 MHz. Both these signals are down mixed by appropriate amounts and then fed to separate signal processors and analyzed in the usual manner.

Forward scatter light collection typically improves the signal-to-noise ratio (SNR) by several orders of magnitude over back scattered light collection. A better SNR can be directly translated into higher validated data rates and shorter engine run times for a given sample size. The geometry of the model engine allowed optical access from all sides, so off-axis forward scatter light collection was easily employed. Light scattered from particles in the flow was collected at a 28° off-axis forward scatter location.

This optical system is capable of making simultaneous three-component orthogonal velocity measurements. Using the available configuration of electronic hardware (two counters) and software, any two of the three possible components can be measured. Measuring volume dimensions are shown in Table 1.

SIGNAL PROCESSING

Counter type signal processors (TSI Model 1990) are used to process the signal once it has passed through the downmixers. Counters are ideally suited for internal combustion engine applications due to their frequency response, accuracy, and the fact that they are fully digital by nature. A particle had to pass through eight fringes to produce a valid measurement. The transit time across eight fringes was measured, as was the time to cross four fringes. If these two times were not within seven percent of a 2:1 ratio, the measurement was rejected. The seven percent comparison was chosen arbitrarily. This helped to prevent noise from being included in the measurements. This system uses two counter processors which were operated in the coincident mode. A valid data point was obtained when both counters made a measurement within an adjustable time window, i.e., 700 microseconds in this experiment. Proper adjustment of the time window assures that a measurement was made by both counters on the same particle. A vector can be constructed in a plane if two velocity components can be measured simultaneously. Analysis can be done on the vector, rather than on the components. In order to effectively analyze the data, six 16-bit words are transferred from the counters to the computer each time a coincident measurement is made (table 2).

When a particle crosses the measuring volume, it produces a scattered light signal that has information about all three orthogonal velocity components. This signal is conditioned in order to obtain the velocity components of interest. Each scattered light signal has a Doppler component and a frequency shift component associated with it. The frequency shifted component is downmixed to get an effective frequency shift just large enough so that the processor can measure the signal and directional ambiguity is eliminated.

DATA PROCESSING

Data was transferred from the counter processors to a DEC PDP 11/23 minicomputer via direct memory access. The computer incorporated two hard disks, a graphics terminal and a graphics printer. A software package (modified TSI Model DRP-3) acquires data at a rate of 250 000 words per second. After the first 32 K words have been transferred to the computer, the transfer rate slows to about 2000 words per second because the rate becomes dependent upon the transfer time to the disk. Data is taken in this fashion until a specified number of data points has been obtained. The engine is then shut off, and the data is read back off of the disk and analyzed in its entirety. This method of operation keeps engine run-time to a minimum. Another mode of operation allows analysis to take place while data is being acquired. However, the effective long-term through rate drops substantially, thus, this method is not employed. A list of the different types of analysis that can be performed is displayed in table 3.

Due to the wide variety of statistics that can be analyzed and displayed, and the configuration of the computer, a limit of 409 crank angle locations can be analyzed at any one time. This 409 crank angle location limitation is based upon limited computer capability, speed of processing and resolution of the graphics terminal. This interval will accomodate approximately one stroke of the four-stroke engine. Thus, the direction and magnitude of frequency shift and the filter settings of the processor can be optimized for that particular engine stroke. An electronic windowing circuit is incorporated to turn the counters on for 180° of the 720° total cycle. This 180° window is selectable in increments of 90°. The electronic windowing mechanism essentially assures that all data entering the computer will be analyzed and displayed.

SYSTEM OPERATION

Before starting the experiment, the engine cylinder wall is examined to see if it is contaminated with seeding material or engine oil. Starting the experiments with an uncontaminated cylinder wall means that more data can be taken before the engine has to be disassembled for cleaning. The cleaning procedure involves removing the cylinder head, lifting off the quartz cylinder, and washing the combustion cylinder assembly with a mild soap solution. This operation takes approximately 10 to 15 min. to complete.

The computer is turned on and the software is initialized with the current operating parameters. The probe volume is traversed (TSI traverse model 9500) to the location of interest and an engine speed is selected. An electronic window is chosen corresponding to the 409 angle increments of interest. Based on the above parameters, an estimate of the magnitude and direction of velocity is made over the electronic window. These estimates are used to select appropriate frequency shifts and optimize the processor settings, i.e., filter settings, number of cycles to be measured, etc.

For the data being displayed, the engine speed was 300 RPM. The valve was held open over the entire 720° rotation. Data was obtained over an electronic window of 306.5 to 450°. The probe volume was positioned near the inlet/exhaust valve as shown in figure 5, with positive and negative sense being indicated on this schematic diagram. This particular location and crank angle interval were chosen to test the system, because it gave us the opportunity to examine system performance in a high-velocity reversing flow. Crank angle resolution was 0.352° and the notation used to designate piston position in terms of crank angle motion was chosen to be consistent with the four-stroke cycle. A sample size was selected to be 100 000 crank angle/velocity pairs. The counters were set in coincidence mode. This allowed the software to process the data either by individual components, or by analyzing the vector created by the discrete component measurements. The sample size of 100 000 data points typically took 4 to 5 min. to collect and one hour to process using a DEC PDP 11/23.

The seed material being used in this experiment is dioctyl phthalate (DOP) particles. The DOP was atomized using a six-jet atomizer and was introduced in the bottom of the intake manifold. The mean particle diameter was 0.8 μm. In order for the seed to enter the cylinder, it had to flow over a baffle and down past the valve. Tubes at the top of the manifold allowed a limited amount of air exchange to take place. Since the engine contained only one valve, there is no significant flow into or out of the manifold. Thus, whatever seed was introduced into the manifold could be reused over many engine cycles. However, due to normal loss mechanisms and impaction of the seed upon the piston, new seed had to be introduced into the engine at periodic intervals. Since the required particle generation rate was very low, the seed was periodically injected into the manifold rather than being allowed to run continuously. A pneumatic valve was installed in one of the on-off valves which controls two jets of the six-jet atomizer. The seeder was turned on for about one-half of a second at five second intervals. Validated counter data rates were typically maintained at 2000 counts per second. When data rates fell below 1000 counts per second, it was typically due to contamination of the cylinder. Introducing seed at higher generation rates than described created premature fouling of the cylinder and a concentration of particulate so high that it decreased the signal-to-noise ratio. After the desired measurements were made, the engine was shut down and the data analyzed. This method of separate data acquisition and analysis means that engine run-time can be kept at a minimum, thus, many experiments can be made before the engine needs to be disassembled for cleaning. Under normal operating conditions, up to one million measurements could be taken before the cylinder required cleaning.

EXPERIMENTAL RESULTS

The plots presented in figure 6 do not exclude any raw data points. These measurements were made with a 2 MHz effective frequency shift in the longitudinal direction and a 1 MHz shift in the radial direction.

Figure 6(a) shows ensemble averaged longitudinal measurements at each crank angle increment from 306.5° ATDC (After Top Dead Center) to 450.0° ATDC. Some comments on the overall flow pattern can be made based on the measurements. The longitudinal velocity first shows the flow to be moving out of the engine. The flow reverses slightly past Top Dead Center (TDC) and changes again to the negative direction. For the remainder of the cycle, the flow remains basically downward toward the piston face. One interesting feature of this plot is that substantial velocity changes can be found to occur over a 10° crank angle window; thus, ensemble averaging should take place over a smaller window than this. For the speed under consideration, the 0.35° window is thought to be sufficient.

The radial velocity measurements were taken using a 1 MHz frequency shift. Examination of the radial velocity component in figure 6 shows the flow directed out of the engine (away from the cylinder wall and toward centerline) from 306.5 to 380° ATDC. After that point, the velocity changes direction so that it is toward the cylinder wall. Significant velocity gradients are found to occur within a 5° window.

The results produced by statistical analysis of velocity measurements made in the combustion chamber of an internal combustion engine can be strongly influenced by cycle-to-cycle variability. Also, it is desirable to verify that the data presented can be shown to be independent of system operational parameters, i.e., filter settings, directional bias, etc. In order to establish the repeatability of the data and its independence from system operational parameters, a second set of data was obtained. This second set was taken at frequency shifts of 5 MHz and 2 MHz for the longitudinal and radial velocity components, respectively. The sample size was maintained at 100 000 data points and, again, no raw data points were excluded. The results in figure 7 show that there is reasonably good agreement between the two sets of data for this type of experiment.

In figures 6(c) and 7(c), graphs are given which show the number of validated data points at each crank angle increment. At certain crank angle increments, the number of validated data points dropped substantially. Validated data rates are functions of particle velocity and signal-to-noise ratio. Also, when counter processors are operated in the coincidence mode, the effective data rate will be determined by the counter which has the lowest validated data rate.

To obtain the greatest amount of useful information in a given experiment, this would indicate that an electronic window should be chosen which is small enough so that the counter processors are more likely to count velocities during certain crank angle intervals.

Velocity histograms were examined at several characteristic locations. Figure 8 depicts a longitudinal and a radial velocity histogram. These histograms are based on 317 measurements of velocity at a 309.7° crank angle. When the number of validated data points acquired at a particular crank angle was over 100, the velocity histograms appeared to resemble a normal distribution. If less than 100 points were acquired, the velocity histograms did not resemble any known distribution.

The spread of velocities measured at a particular crank angle is primarily due to turbulence and cycle-to-cycle variability. The exact contribution of each variable is not known; however, one could determine the influence of cycle-to-cycle variability by comparing several single cycle measurements to the ensemble averaged results. The observed data rate during these experiments was sufficient to characterize the airflow during a single cycle.

CONCLUSIONS

An on-axis velocity measurement system was demonstrated for use in a piston-cylinder configuration. This technique makes it possible to measure three components of velocity while simultaneously using a single focusing lens. Reversing flows were simultaneously measured in the radial and longitudinal directions.

When measurements are to be made with counter processor systems in a highly reversing flow, such as in a piston-cylinder configuration, the ability to control window size is important from the standpoint of optimizing useful data acquired.

A crank angle increment of no more than 0.5° should be used for ensemble averaged measurements. Samples of greater than 300 points at each crank angle increment provided normal distributions. Samples of 100 to 300 points at each crank angle increment appeared to tend toward a normal distribution and samples below 100 were generally insufficient to determine the character of the distributions.

The seeding method used allowed up to 1 000 000 measurement points to be taken before the cylinder fouled with seed.

A 0.36 in. thick quartz cylinder with a surface quality of 40/20 polish was found to be sufficient to give good signals.

The laser velocimetry technique used provides data rates high enough to quantify velocities within a cycle.

REFERENCES

1. Morse, A. P., and Whitelaw, J. H., "Measurements of the In-Cylinder Flow of a Motored Four-Stroke Reciprocating Engine," Proc. Roy. Soc. A, pp. 309, 377 (1981).

2. Arcoumanis, C., Bicen, A. F., and Whitelaw, J. H., "Measurements in a Motored Four-Stroke Reciprocating Model Engine," Journal of Fluids Engineering, pp. 104, 235 (1982).

3. Arcoumanis, C., Bicen, A. F., and Whitelaw, J. H., "Effect of Inlet Parameters on the Flow Characteristics in a Four-Stroke Model Engine," SAE Paper No. 820750 (1982).

4. Rask, R. B., "Laser Doppler Anemometer Measurements in an Internal Combustion Engine," SAE Paper No. 790094 (1979).

5. Combustion Research Facility News, Volume 5, No. 2, Sandia National Laboratories, Livermore, California, March 1983.

6. Klick, D., et al, "Laser Anemometry for Engine Flow Studies," SAE Paper No. 830417 (1983).

7. Liou, T. M., and Santavicca, D. A., "Cycle Resolved Turbulence Measurements in a Ported Engine With and Without Swirl," SAE Paper No. 830419 (1983).

8. Schock, H. J., Case, S., and Konicek, L., "Window Aberration Correction in Laser Velocimetry Using Multifaceted Holographic Optical Elements," Submitted for Publication in Applied Optics, August 1983.

9. Sathyakumar, R., U. S. Patent No. 4263002 (1981).

TABLE 1. - MEASUREMENT VOLUME DIMENSIONS

Notation	Description	Axial	Azimuthal	Radial
d_f	Fringe spacing	1.58 μm	1.50 μm	19.0 μm
N_{FR}	Number of fringes in the measuring volume	22	22	11
l_m	Length of the measuring volume	206 μm	196 μm	206 μm
d_m	Diameter of the measuring volume	34 μm	32.3 μm	33.6 μm
d_e-2	Diameter of the beam at the focal point of the transmitting lens	33.6 μm	31.9 μm	33.6 μm
d	Distance between the outer beams before focusing lens	82.5 mm	82.5 mm	82.5 mm
k	Half angle	9.37°	9.37°	--

TABLE 2. - INFORMATION SENT FROM THE COUNTERS TO THE COMPUTER

Description	No. of bits	(Each word is 16 bits long)
Measured time for the 1st counter	12 - mantissa 4 - exponent	1st word
Measured no. of cycles for the 1st counter Address of the 1st counter Random or coincidence mode flag	8 2 1	2nd word
Measured time for the 2nd counter	12 - mantissa 4 - exponent	3rd word
Measured no. of cycles for the 2nd counter Address of the 2nd counter	8 2	4th word
Encoder Angle of Engine Engine Pressure 1st or 2nd cycle of the engine (720° is a complete event)	10 10 1	Combination of 5th and 6th word

TABLE 3. - COMPUTED STATISTICS

1st component	Mean velocity versus crank angle RMS velocity versus crank angle Total number of data points versus crank angle Number of "good" data points versus crank angle Number of "bad" data points versus crank angle (Bad data points only occur when a refinement analysis is performed) Velocity histogram at a particular crank angle
2nd component	Mean velocity versus crank angle RMS velocity versus crank angle Total number of data points versus crank angle Number of "good" data points versus crank angle Number of "bad" data points versus crank angle (Bad data points only occur when a refinement analysis is performed) Velocity histogram at a particular crank angle
Derived vector from 1st and 2nd component	Total mean velocity versus crank angle Total RMS velocity versus crank angle Total flow directional angle versus crank angle Total number of data points versus crank angle Number of "good" data points versus crank angle Number of "bad" data points versus crank angle (Bad data points only occur when a refinement analysis is performed) Reynolds stress versus crank angle Cross correlation versus crank angle Total velocity histogram at a particular crank angle Total flow directional angle histogram at a particular crank angle
Cylinder pressure	Mean pressure versus crank angle RMS pressure versus crank angle

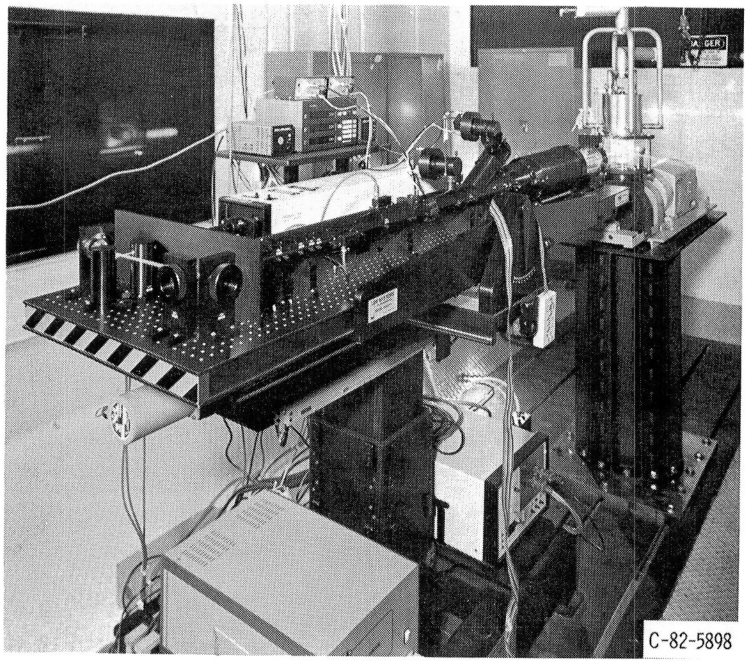


Figure 1. - Multichannel LDV system.

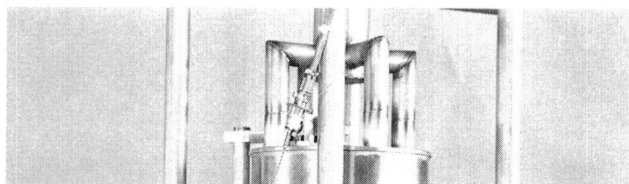
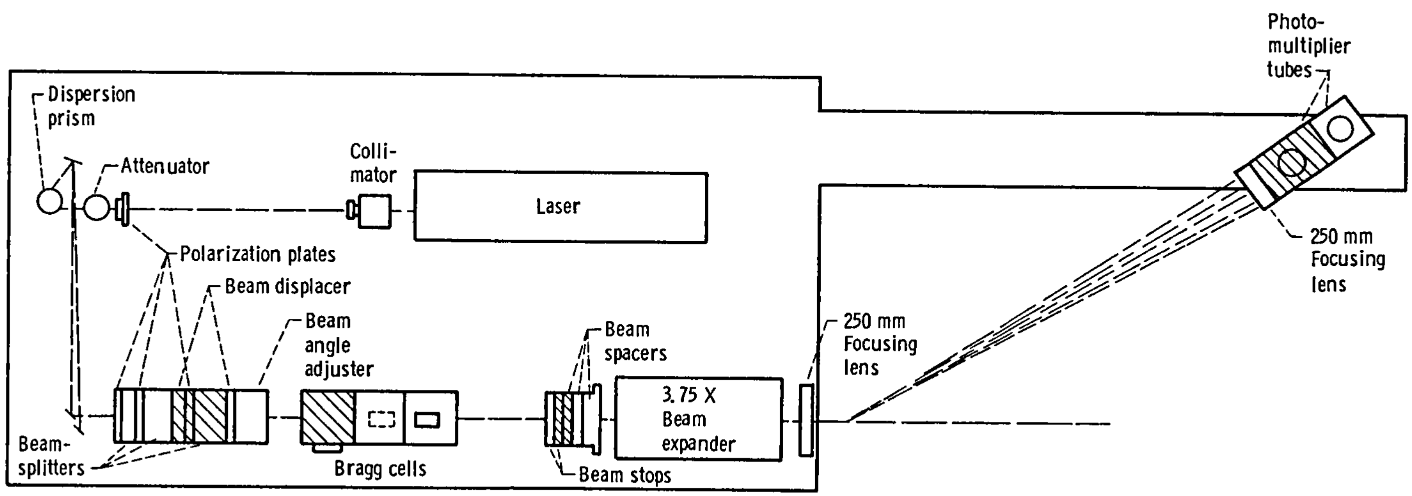


Figure 2. - Piston-cylinder configuration.



Note: Shaded components are for 488 nm beam.

Figure 3. - Optical configuration.

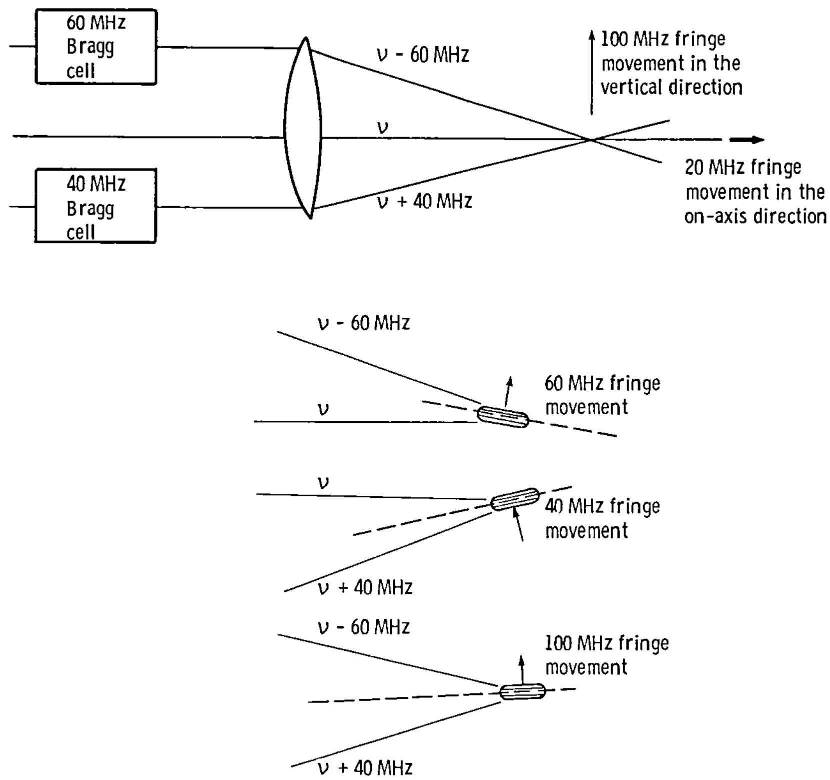


Figure 4. - Fringe model.

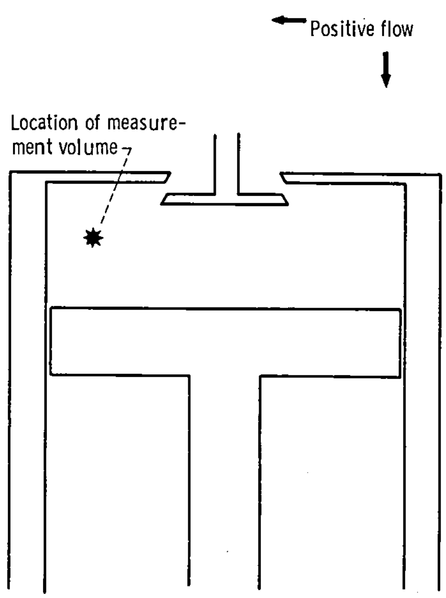


Figure 5. - Location of measurement volume in cylinder.

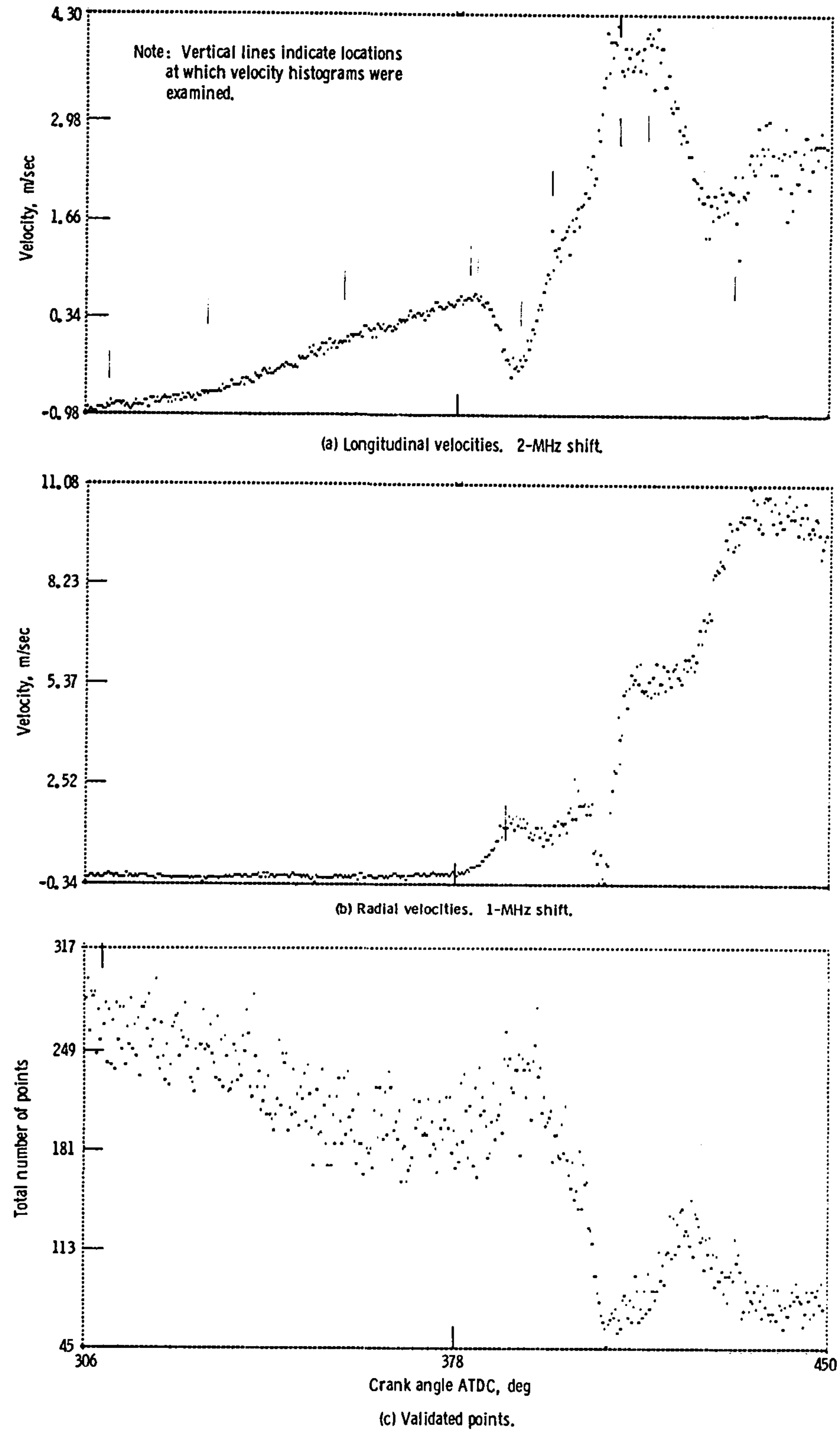
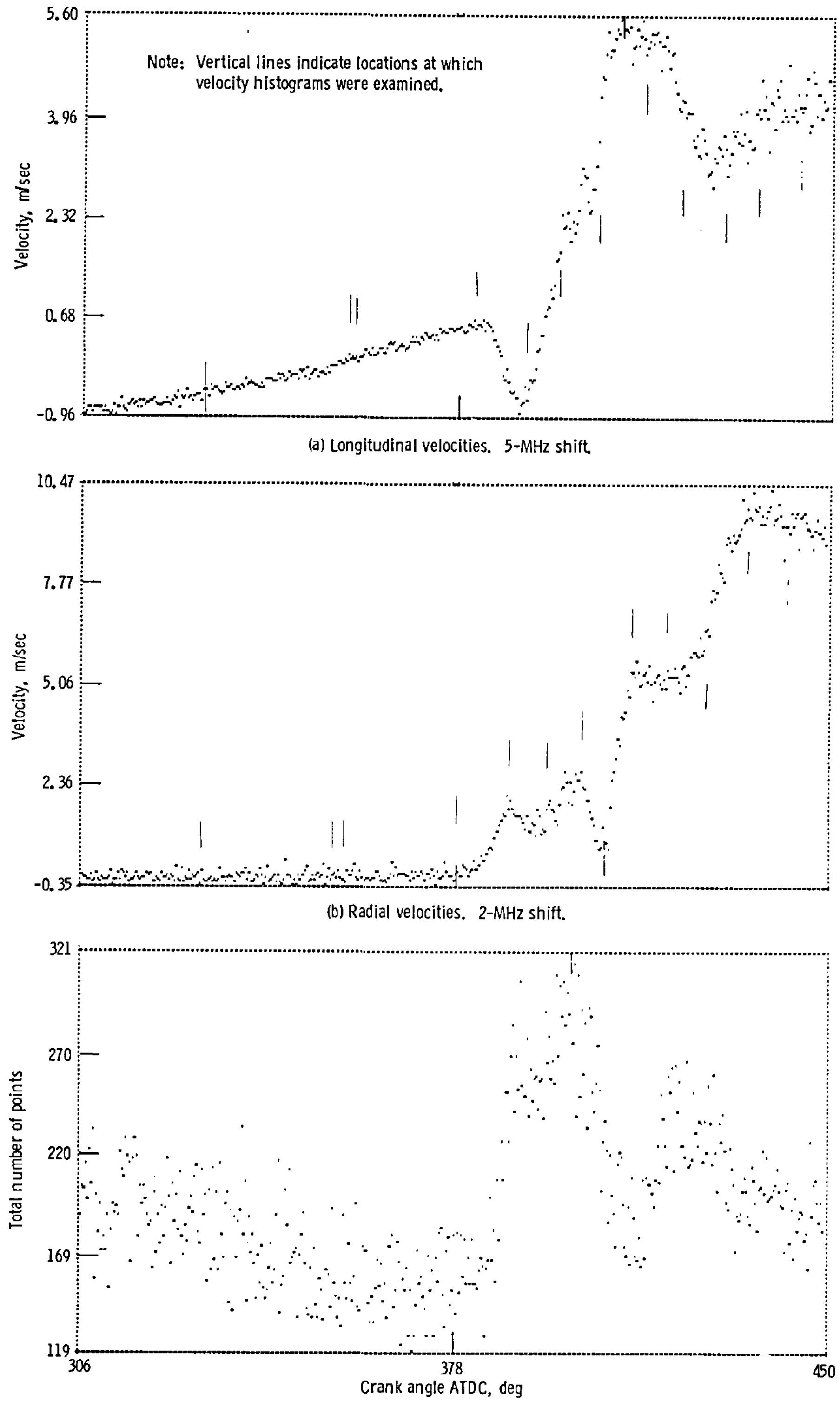


Figure 6. - Longitudinal and radial velocities and total number of validated points.

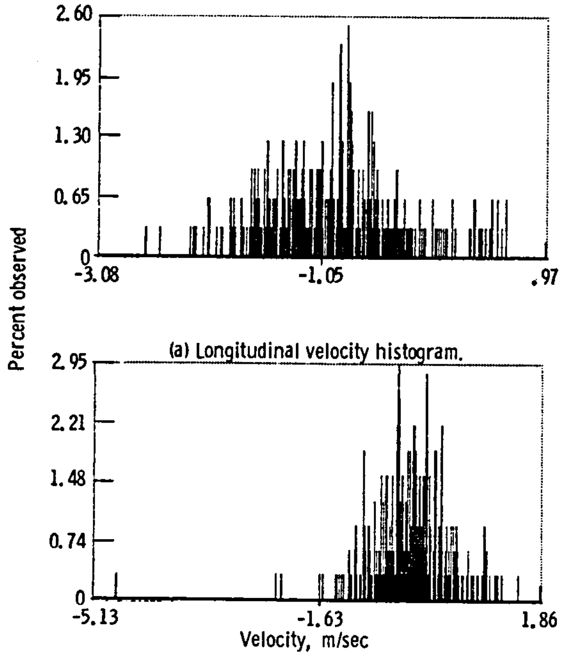


(a) Longitudinal velocities. 5-MHz shift.

(b) Radial velocities. 2-MHz shift.

(c) Validated points.

Figure 7. - Longitudinal and radial velocities and total number of validated points.



(b) Radial velocity histogram.

Figure 8. - Longitudinal and radial velocity histograms at 310^0.

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM-83534		

4. Title and Subtitle	
Multicomponent Velocity Measurement in a Piston-Cylinder Configuration Using Laser Velocimetry	5. Report Date December 1983
	6. Performing Organization Code 505-40-62
7. Author(s) Harold J. Schock, Carolyn A. Regan, William J. Rice, and Richard A. Chlebecek	8. Performing Organization Report No. E-1835
	10. Work Unit No.
9. Performing Organization Name and Address National Aeronautics and Space Administration Lewis Research Center Cleveland, Ohio 44135	11. Contract or Grant No.
	13. Type of Report and Period Covered Technical Memorandum
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546	14. Sponsoring Agency Code

15. Supplementary Notes

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16. Abstract

Because of its nonintrusive nature, Laser Doppler Velocimetry (LDV) has become a popular tool for velocity measurements in internal combustion engines. This work shows how one can use an on-axis measurement technique, in conjunction with the standard two channel LDV technique, to make simultaneous three-component measurements using a single focusing lens. Simultaneous measurement of two of these three components in a piston-cylinder configuration is demonstrated.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Laser velocimetry I.C. engine Piston-cylinder configuration Airflow	Unclassified - unlimited STAR Category 02

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of pages	22. Price*
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