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ANALYSIS AND TESTING OF A NEW METHOD FOR DROP SIZE AND VELOCITY MEASUREMENTS USING LASER LIGHT SCATTER INTERFEROMETRY

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Research was conducted on a laser light scatter detection method for measuring the size and velocity distributions of spray drops. The work was motivated by the need for accurate fuel spray data in a variety of research and development activities related to combustion applications. Presently, there is considerable interest in obtaining measurements of the fuel drop and air motions within the spray combustor. It is known that the turbulent motions influence the reactions by increasing the oxygen supply to the burning fuel. Thus, the droplet size and velocity distributions are important data to be obtained when characterizing the combustion process. The need for simultaneous size and velocity measurements has been recognized for even general characterizations of sprays. This is especially true when the nozzles are operating in turbulent flow environments or when the nozzles generate drops that are moving at relatively high velocities and subsequently relax to the ambient flow speed in accord with their initial momentum.

The requirement for simultaneous measurements of drop size and velocity has led to the combination of the laser Doppler velocimeter (LDV) with various particle sizing methods[1,2,3]. However, experience has shown that the available methods are adversely affected by the measurement environment. The conditions include high drop number densities, beam attenuation by the surrounding drops and optical access ports, and the presence of small combustion generated particulate. Many of these measurement limitations have been eliminated by deriving a method that performs the measurements independent of the beam intensity.

The method consists of an optical system which is the same as a LDV except that three detectors are located at selected spacings behind the receiver aperture. Drops passing through the intersection of the two beams scatter light which produces an interference fringe pattern. The temporal frequency of the fringe pattern is the Doppler difference frequency which is linearly proportional to the drop velocity while the spatial frequency is linearly related to the drop diameter. The spacing of the fringes is also dependent upon the light wavelength, beam intersection angle, drop refractive index (unless reflected light is measured), and the location of the receiver. Measurement of the spacing of the fringe pattern produced by the scattered light may be achieved by placing pairs of detectors at selected spacings in the fringe pattern or its image. As the fringes move past the detector at the Doppler difference frequency, the detectors produce identical signals but with a phase shift proportional to the fringe spacing. The utilization of three detectors ensures that phase ambiguity does not occur, provides redundant measurements for signal validation and allows an expanded operating range while maintaining good sensitivity.

An experimental effort was conducted to verify the theoretical analysis, evaluate signal phase processing methods, and investigate the effects of signal quality upon the measurements. The optical system was arranged to provide the flexibility needed in evaluating the parameters that influence the measurements. Only two detectors were used in the present investigations. After investigating several signal processing concepts, a breadboard processor was developed and interfaced to an IBM microcomputer. Simultaneous phase and Doppler period measurements were made and transmitted to the computer to form size and velocity distributions.

Several drop sources were used to establish the test conditions. A Berglund-Liu generator was used to produce monodisperse drop streams. The monodisperse stream could be directed through various parts of the measurement volume. Several spray nozzles were also used including pressure atomizers of moderate flow rates, high volume nozzles that produced large drops and spinning disk atomizers that produced small drops in a narrow distribution.

Initially, tests were performed using the monodisperse drops to verify the theoretical analysis. The results obtained were in complete agreement with the theory for all of the optical parameters tested. The parameters included the laser beam intersection angle, the detector spacing, and light scatter detection angle. Off-axis backscatter was also evaluated. These tests showed that the light scattered internally was measured when the drops were transparent. Dye was used to produce opaque drops which then resulted in the measurement of reflected light. Measurements based on reflected light can be made independent of the drop index of refraction.

Spray interference effects were evaluated by passing the laser beams through the spray and measuring the monodisperse drop stream. This had an insignificant effect on the measurements. The small differences observed were in most part a result of the spray interference with the monodisperse droplet stream. The effect of the attenuation of the individual laser beams was tested by attenuating one of the beams by 90%. Such attenuations can occur, for example, when large drops pass through the beams outside of the measurement volume. As expected, this had no effect on the measurements.

Sprays were measured to assess the performance of the basic system in real environments. In the first case, the spinning disk atomizer was used to generate drops in the small size range. Measurements were obtained at three size range settings and the results compared to determine the consistency of the data. The agreement was good and the mean size agreed with the results obtained with other methods. Direct comparisons were also made of the measurements obtained in a spray generated by a pressure atomizer. The data obtained by Delavan Inc. and our method showed good agreement of both the mean size and the distribution.

In summary, the recognized characteristics of the method are:

- linear relationship between the measured phase angle and drop size
- size range of approximately 100 at a single optical setting
- simultaneous size and velocity measurement
- relative insensitivity to beam or light scatter attenuation
- high spatial resolution
- operation is similar to an LDV

- adaptable to existing LDV systems

- can perform measurements independent of refractive index

An instrument is currently being developed for delivery to NASA Lewis. Development work is continuing on the refinement of the analysis, sample volume characterization, and the mass flow measurement capability. Further evaluations of the method will be made in combustion environments. The development of the technology for performing two-component velocity measurements in two-phase flows is required.

REFERENCES

1. W. M. Farmer, "Measurement of Particle Size, Number Density, and Velocity Using a Laser Interferometer," *Appl. Opt.*, rm Vol. 11, 1972, p. 2603.

2. A. J. Yule, N. A. Chigier, S. Atakan, and A. Ungut, "Particle Size and Velocity Measurement by Laser Anemometry," *AIAA 15th Aerospace Sciences Meeting*, Los Angeles, Paper no. 77-214, 1977.

3. W. D. Bachalo, "Method for Measuring the Size and Velocity of Spheres by Dual-Beam Light-Scatter Interferometry," Appl. Opt., Vol. 19, No. 3, 1980.

DEVELOPMENT GOALS

PRODUCE AN INSTRUMENT TO ACCURATELY MEASURE DROP SIZE AND VELOCITY DISTRIBUTIONS TO ADDRESS THE FOLLOWING:

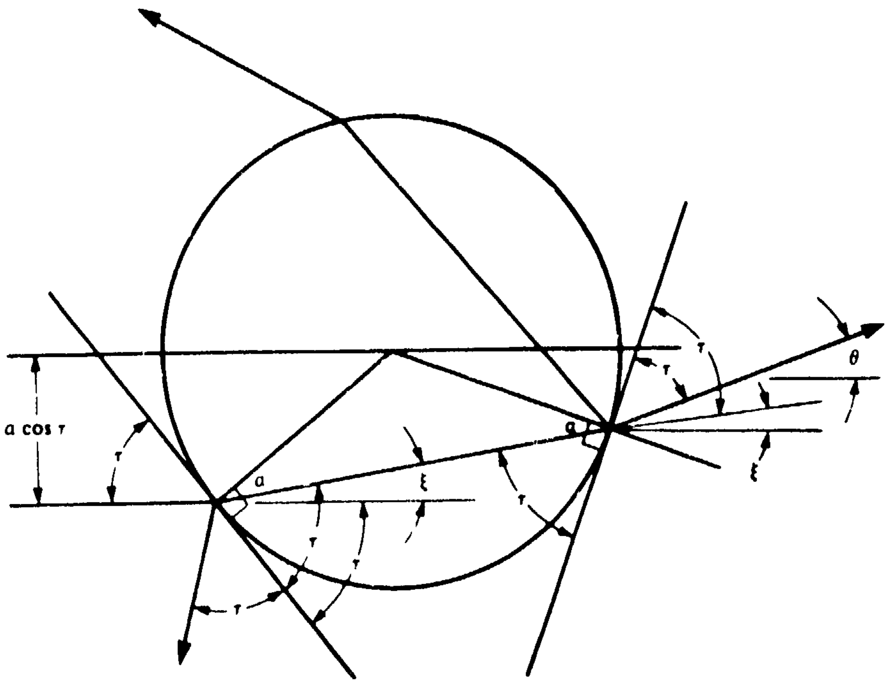
- SPRAY CHARACTERIZATIONS
- SPRAY CHARACTERIZATIONS IN COMPLEX TURBULENT FLOWS
- TWO-PHASE TURBULENT FLOW MEASUREMENTS
- SPRAY DROP MEASUREMENTS IN COMBUSTION

PHASE/DOPPLER SPRAY ANALYZER

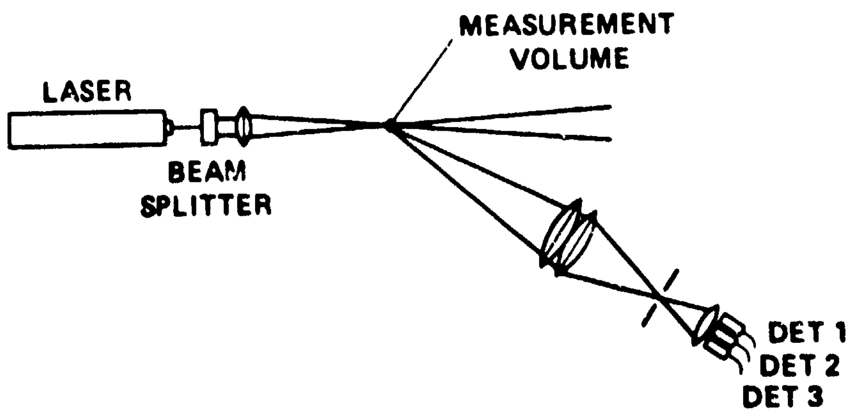
OBJECTIVE: INVESTIGATE THE CHARACTERISTICS OF A NEW METHOD FOR MEASURING THE DROP SIZE AND VELOCITY DISTRIBUTIONS IN SPRAYS

TASKS:

- PRODUCE THEORETICAL DESCRIPTIONS OF THE LIGHT SCATTERED BY SPHERES AT THE INTERSECTION OF TWO LASER BEAMS
- GENERATE THE THEORETICAL RELATIONSHIP BETWEEN THE MEASURED INTERFERENCE FRINGE PATTERN AND THE DROP SIZE
- EXPERIMENTALLY VERIFY THE THEORETICAL ANALYSIS USING MONODISPERSE DROPS
- EVALUATE SIGNAL PROCESSING METHODS
- TEST THE SELECTED PROCESSING METHOD



GEOMETRICAL DIAGRAM OF LIGHT RAYS SCATTERED BY A SPHERE.



SCHEMATIC OF THE OPTICAL SYSTEM FOR AN LDV AND THE DROPLET SIZING SYSTEM.

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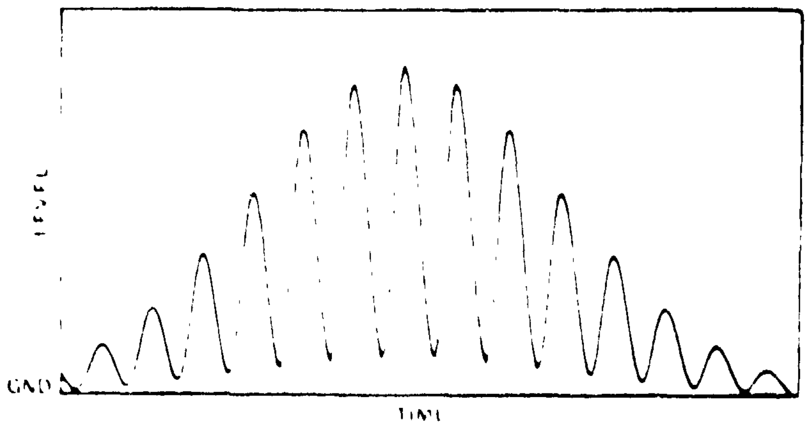
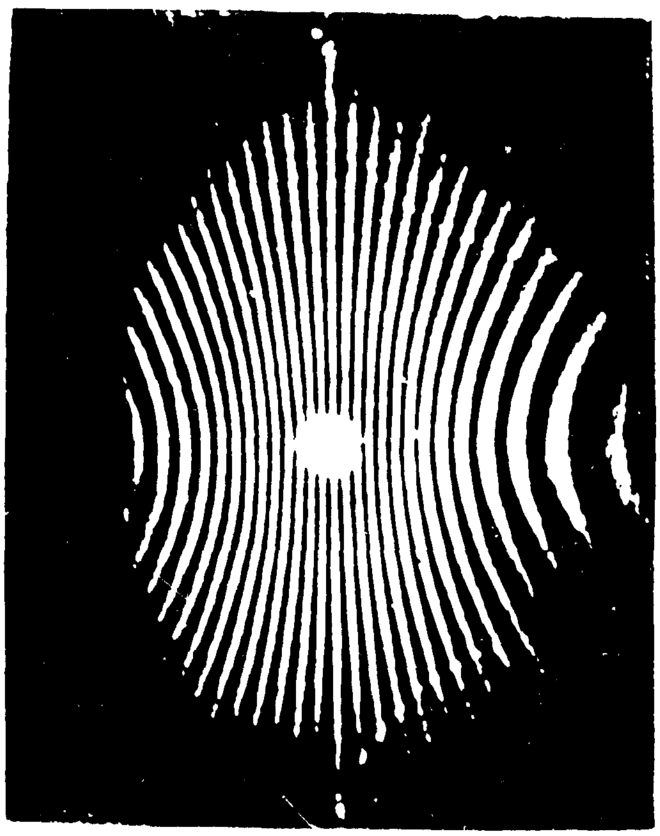
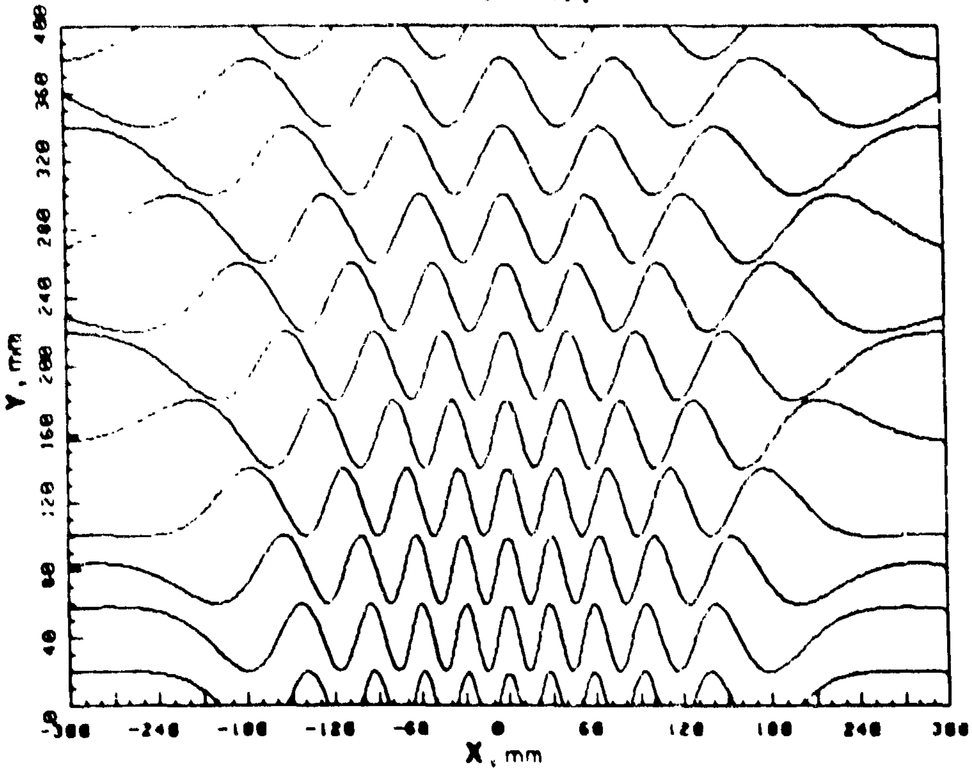


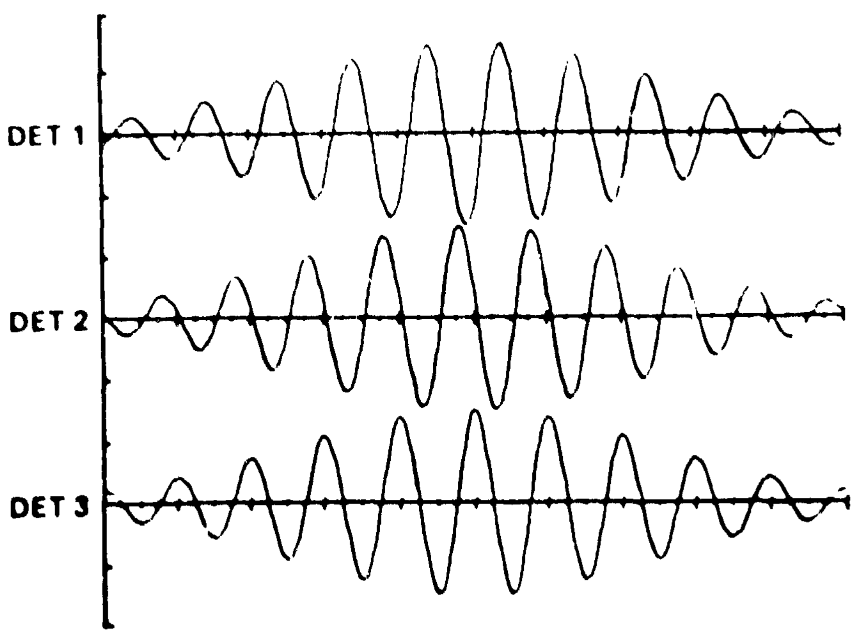
LASER DOPPLER BURST SIGNAL.



SCATTERED LIGHT INTERFERENCE FRINGE PATTERN PRODUCED BY A DROPLET.



COMPUTED INTERFERENCE FRINGE PATTERN PRODUCED BY A DROPLET.



HIGH PASS FILTERED DOPPLER BURST SIGNALS ILLUSTRATING THE PHASE SHIFT BETWEEN DETECTORS.

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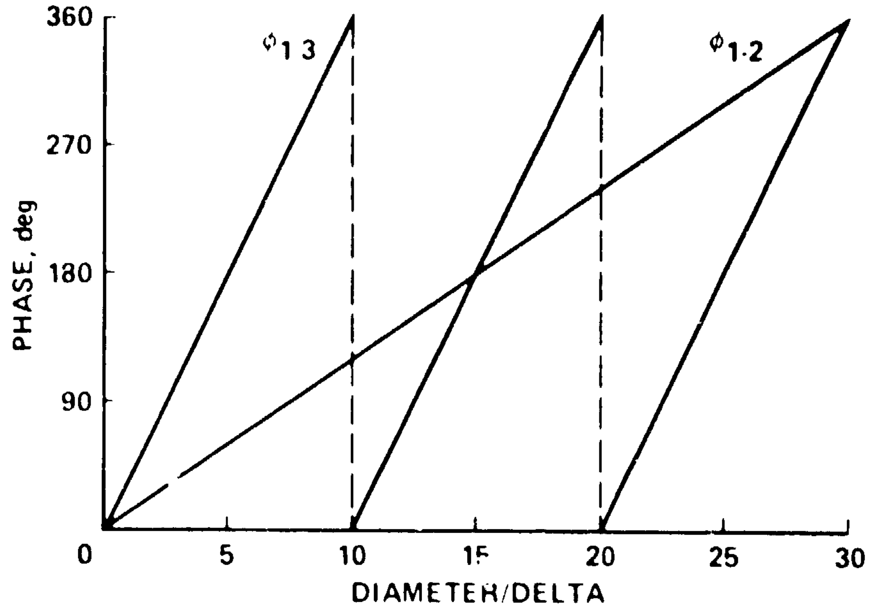
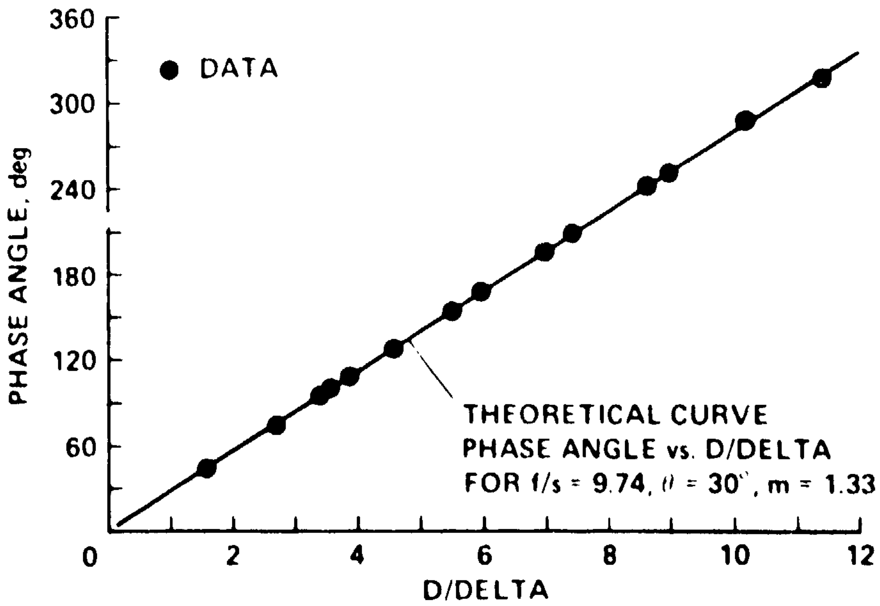
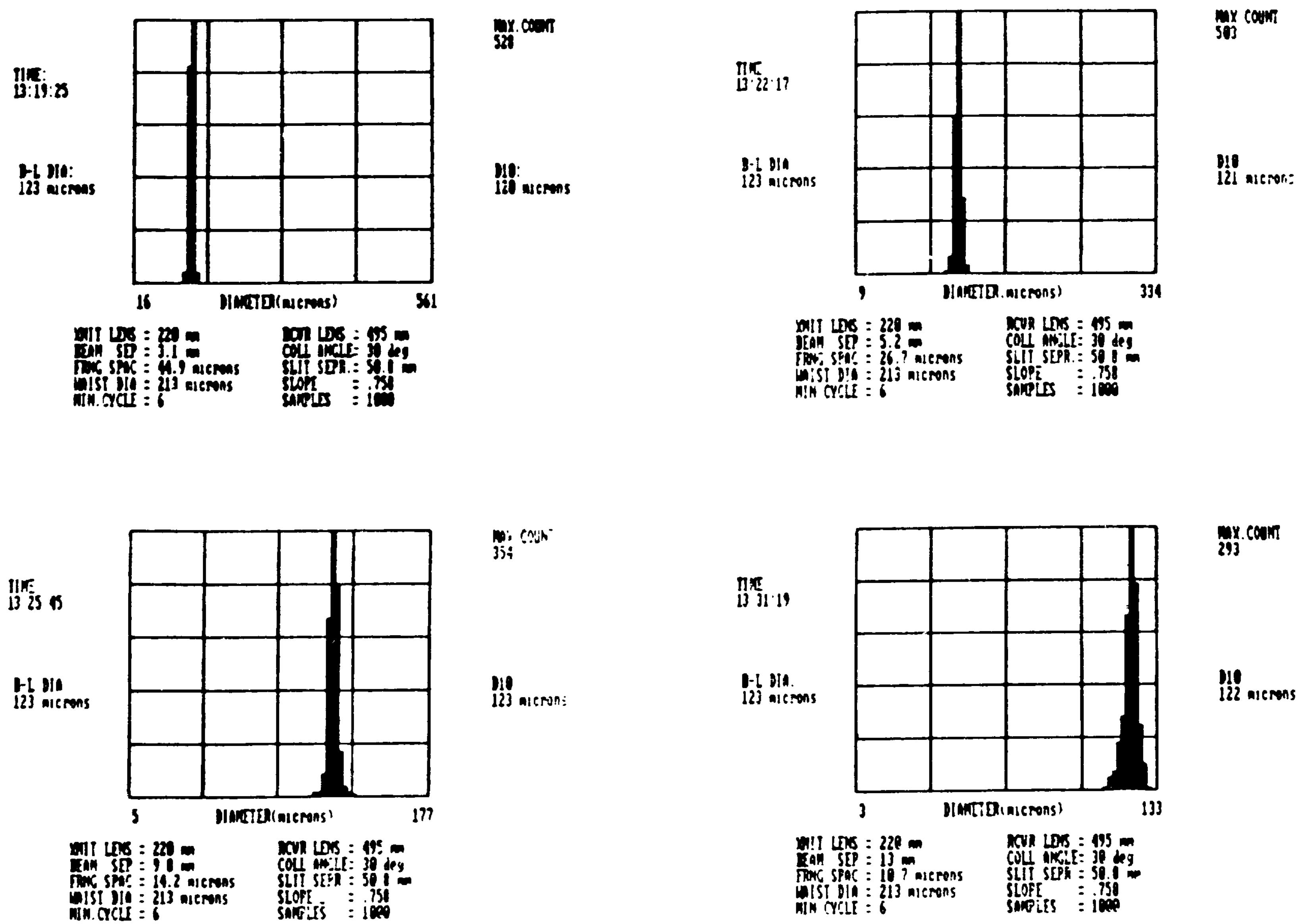


RELATIONSHIP FOR THREE DETECTORS.



COMPARISONS WITH EXPERIMENT.

THEORETICAL PREDICTION SHOWING THE PHASE VARIATION WITH THE DIMENSIONLESS DROP SIZE



FRINGE SPACING VARIATIONS.

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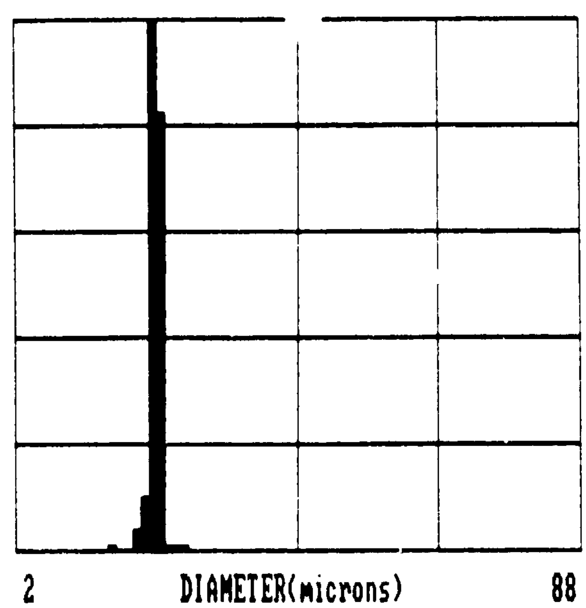
TIME:
15:26:25



MAX.
504

D10:
23 microns

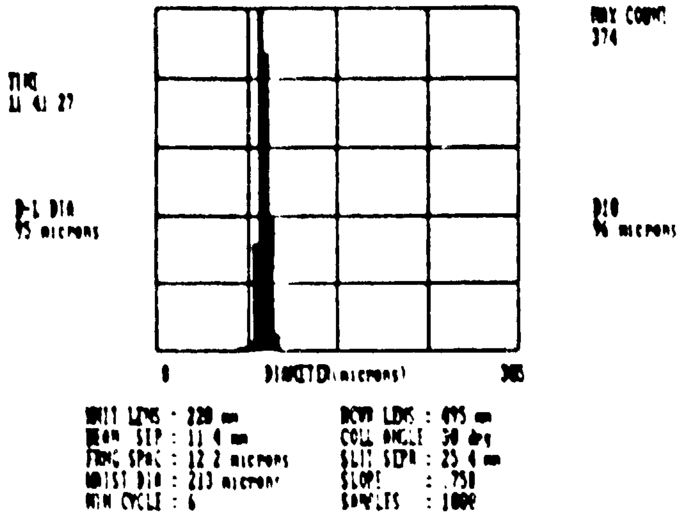
24 microns

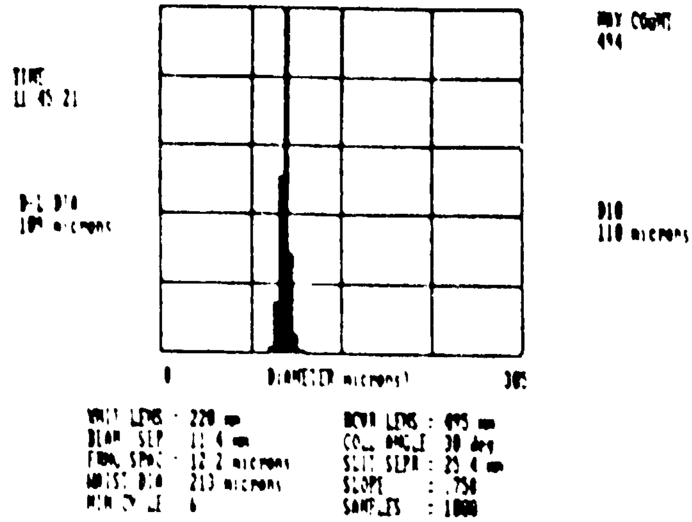
XMIT LENS = 90 mm
BEAM SEP = 8 mm
FRNG SPAC = 7.1 microns
WAIST DIA = 87 microns
MIN.CYCLE = 3

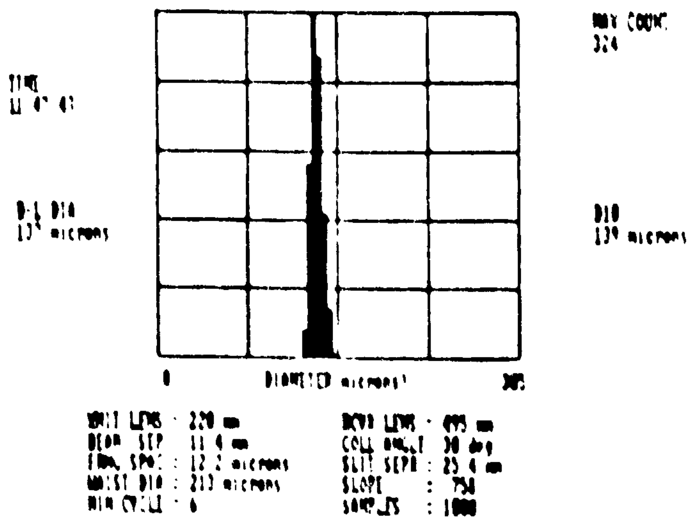
RCVR LENS = 495 mm
COLL.ANGLE= 30 deg
SLIT SEPR.= 50.8 mm
SLOPE = .758
SAMPLES = 1000

1-NEW PARAMETERS 2-REPEAT RUN 3-LIST RESULTS 4-END ?

MONODISPERSE DROP SIZE VARIATIONS.







MONODISPERSE DROP SIZE VARIATIONS.

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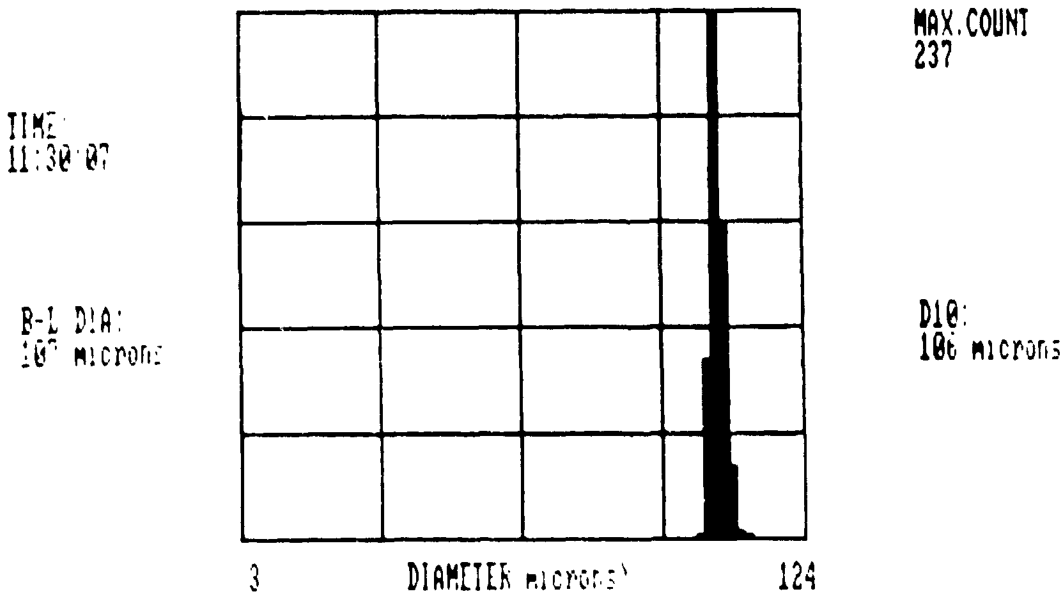
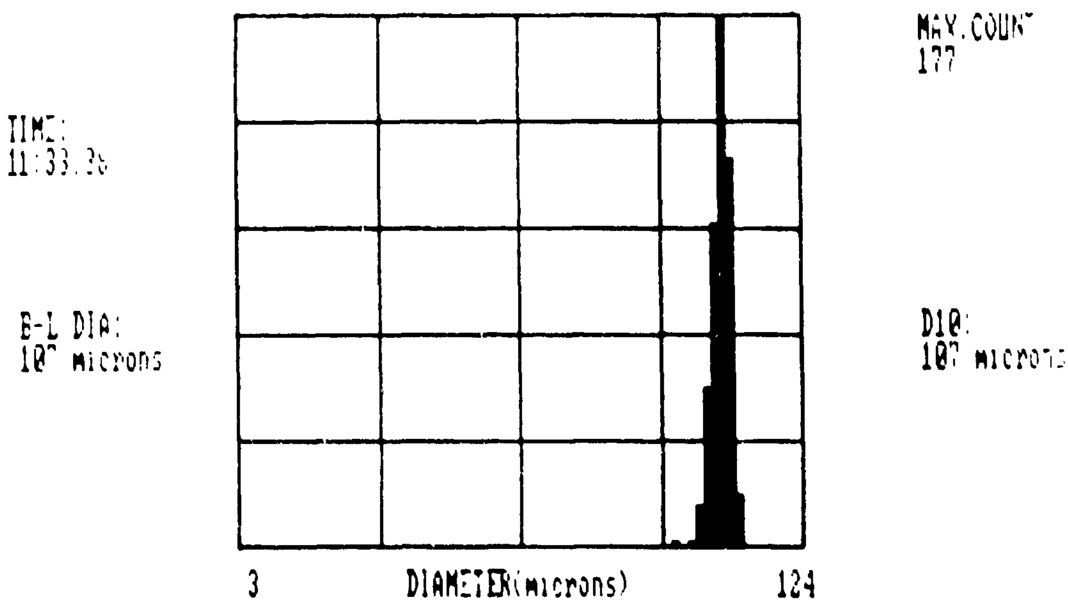


XMIT LENS = 220 mm
BEAM SEP = 14 mm
FRNG SPAC = 9.9 microns
WAIST DIA = 213 microns
MIN.CYCLE = 8

RCVR LENS = 495 mm
COLL ANGLE= 30 deg
SLIT SEPR.= 50.8 mm
SLOPE = .758
SAMPLES = 500

BEAM ATTENUATION TESTS - EQUAL BEAM INTENSITIES.



XMIT LENS = 220 mm
BEAM SEP = 14 mm
FRNG SPAC = 9.9 microns
WAIST DIA = 213 microns
MIN.CYCLE = 8

RCVR LENS = 495 mm
COLL.ANGLE= 30 deg
SLIT SEPR.= 50.8 mm
SLOPE = .758
SAMPLES = 500

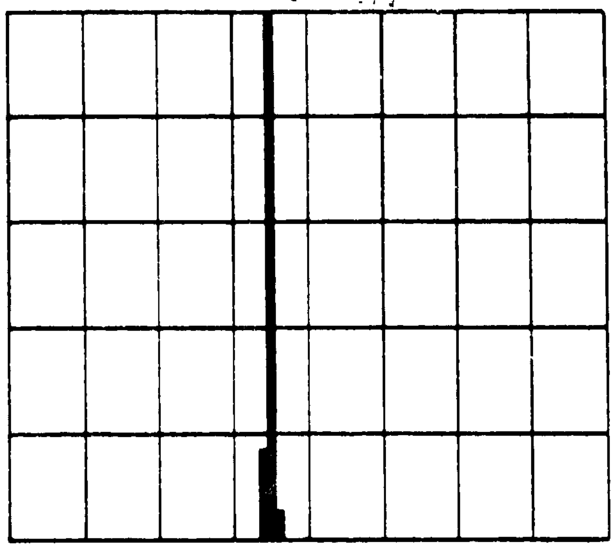
BEAM ATTENUATION TESTS - ONE BEAM ATTENUATED.

(90:10 RATIO)

DATE:
10-11-1983

TIME:
11:34:38

MAX.COUNT
6714



B-L SIZE:
123 microns

MEAN SIZE:
124 microns

0 DIAMETER(microns) 280

XMIT LENS = 220 mm
BEAM SEP = 18.6 mm
FRNG SPAC = 7.4 microns
WAIST DIA = 213 microns
MIN.CYCLE = 10

RCVR LENS = 495 mm
COLL.ANGLE= 150 deg
SLIT SEPR.= 50.8 mm
MAX. DIA. = 280 microns
SAMPLES = 8237

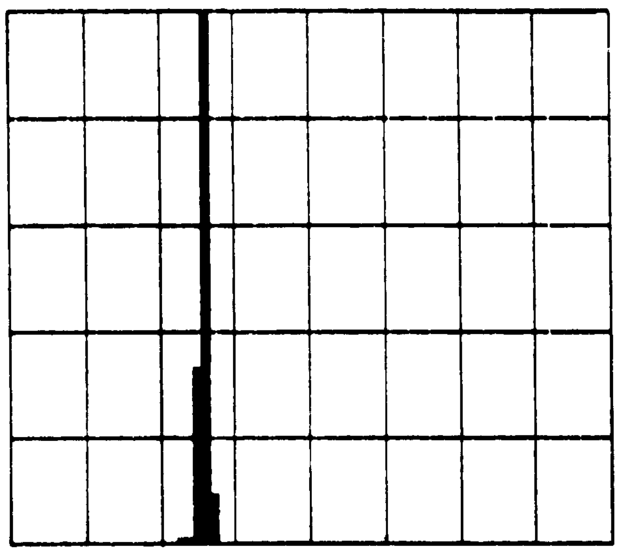
BACKSCATTER TEST - OPAQUE DROPS.

FIRST SURFACE REFLECTION.

DATE:
10-11-1983

TIME:
10:23:31

MAX.COUNT
700



B-L SIZE:
123 microns

MEAN SIZE:
118 microns

0 DIAMETER(microns) 357

XMIT LENS = 220 mm
BEAM SEP = 5 mm
FRNG SPAC = 27.8 microns
WAIST DIA = 213 microns
MIN.CYCLE = 3

RCVR LENS = 495 mm
COLL.ANGLE= 150 deg
SLIT SEPR.= 50.8 mm
MAX. DIA. = 357 microns
SAMPLES = 1005

BACKSCATTER TEST - TRANSPARENT DROPS,

PREDICTION FOR INTERNAL REFLECTION.

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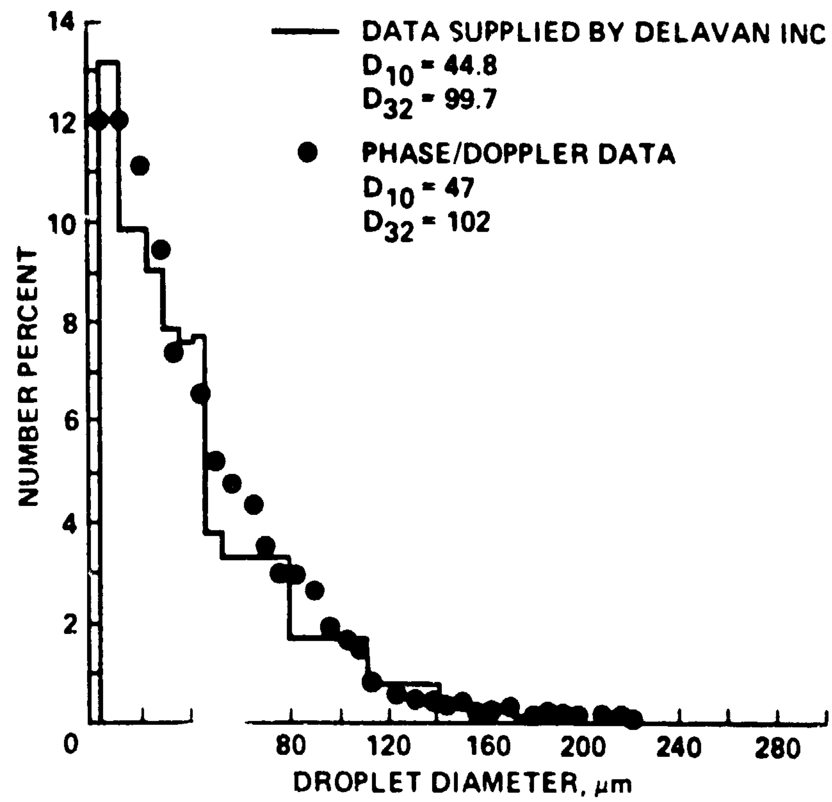
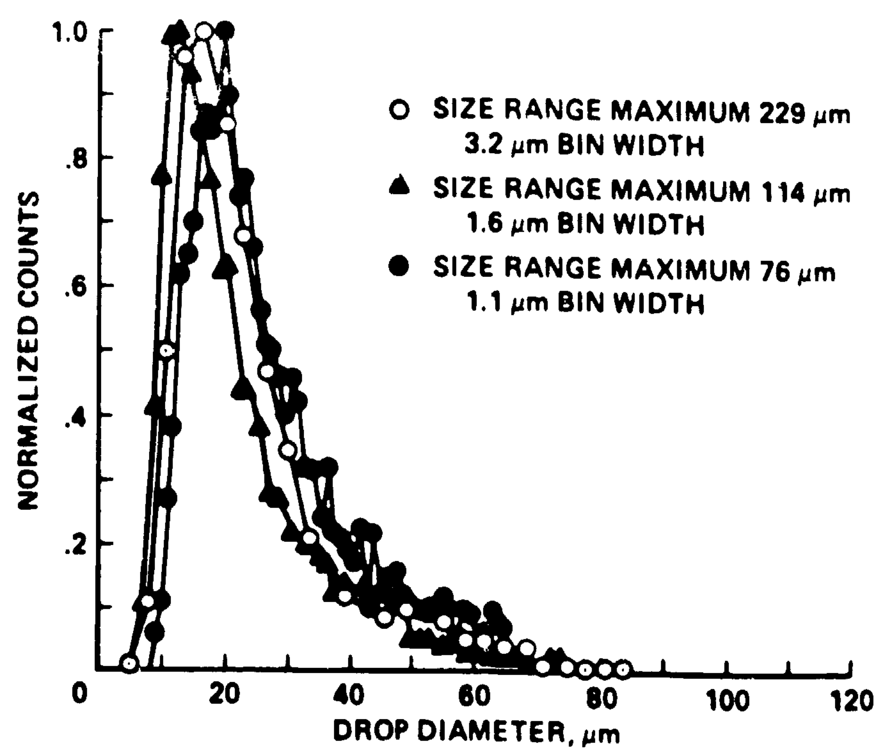


COMPARISON OF DROP SIZE DISTRIBUTIONS MEASURED WITH OTHER MEANS.



COMPARISONS OF DROP SIZE DISTRIBUTIONS MEASURED AT THREE SIZE RANGE SELECTIONS.

POTENTIAL CHARACTERISTICS OF THE METHOD

- LINEAR RELATIONSHIP BETWEEN THE MEASURED PHASE ANGLE AND DROP SIZE
- SIZE RANGE OF 30 OR GREATER AT A SINGLE OPTICAL SETTING
- OVERALL SIZE RANGE OF 3 TO 2000 MICRONS
- SIMULTANEOUS SIZE AND VELOCITY MEASUREMENTS
- RELATIVE INSENSITIVITY TO BEAM OR LIGHT SCATTER ATTENUATION
- HIGH SPATIAL RESOLUTION
- OPERATION IS SIMILAR TO AN LDV
- ADAPTABLE TO EXISTING LDV SYSTEMS
- CAN DISTINGUISH BETWEEN GAS PHASE AND DROPLETS
- REDUCED SENSITIVITY TO MISALIGNMENT
- CAN PERFORM MEASUREMENTS INDEPENDENT OF REFRACTIVE INDEX

SUMMARY

EVALUATIONS WERE CONDUCTED ON A NEW SPRAY DROP SIZE AND VELOCITY MEASUREMENT METHOD

- THEORETICAL ANALYSES OF THE LIGHT SCATTERING PHENOMENA WERE DEVELOPED
- EXPERIMENTAL TESTING VERIFIED THE ANALYSES
- MEASUREMENTS UNDER SIMULATED SPRAY CONDITIONS WERE CONDUCTED
- COMPARISONS OF SPRAY MEASUREMENTS WITH OTHER METHODS SHOWED GOOD AGREEMENT
- SIGNAL PROCESSING METHODS WERE DEFINED AND TESTED