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APPLICATION OF ADVANCED DIAGNOSTICS TO AIRBLAST INJECTOR FLOWS*

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The achievement of a predictable and satisfactory distribution of finely atomized fuel is of importance to the design of well-performing gas turbine engine combustion chambers. The development of non-intrusive laser diagnostics has offered the possibility of acquiring detailed point-resolved information on the gas and liquid-phase flow fields and on the droplet size distribution produced by fuel injectors. This effort is concerned with the application of both conventional laser velocimetry and phase-Doppler anemometry to the flow produced by an airblast nozzle. The emphasis is placed on the acquisition of data using actual engine injector/swirler components at (noncombusting) conditions simulating those encountered in an engine. The objective of the effort was to test the applicability of the instrumentation to real injector flows, to develop information on the behavior of injectors at high flow; and to provide data useful in the development of physical models of injector flows.

APPROACH

The airblast fuel nozzle employed in this study is typical of the designs employed in high-thrust advanced engines. Atomization is accomplished by concentric swirling airstreams which shear fluid from a filming lip. The nozzle selected was a model nozzle manufactured to within special tolerances in order to produce a closely-axisymmetric flow (Figs. 1 & 2).

The instrumentation employed includes a two-component TSI Model 9700-2 laser velocimeter (Fig. 3) used for measurement of the gas-phase flow velocity and a single-component Aerometrics Phase Doppler Particle Analyzer (Fig. 4) used for measurement of particle size and velocity. Also employed was a high-resolution fuel spray patternator which employs a physical probe array to acquire information on the spray mass flux distribution and a Malvern ST1800 spray analyzer used for determination of a path-mean droplet size.

For purposes of this study, the fuel nozzle was operated at a single atmospheric pressure condition. The simulation procedure used is to operate

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with a pressure drop across the injector/swirler assembly which produces the same air velocity as would be achieved under high power engine conditions, and with an injectant mass flow rate such that the liquid/gas momentum ratio present at engine conditions is preserved. For these tests, the peak gas velocities exceed 100 mps while the liquid flow rate is 70 Kg/hr.

RESULTS

The general characteristics of the flow produced by the nozzle are illustrated by the spray patternator results. Profiles illustrating the mass flux contours at stations 2.54, 3.81, 5.08, and 6.35 cm downstream of the nozzle exit are illustrated in Fig. 5. Water was used as the injectant in this test. Measures of the circumferential uniformity are provided by the patternation index (PI) and the Min/ Max ratio. These parameters are based on the mass flow passing through each of eight sectors shown superimposed on the contours and are the parameters generally used in the industry for acceptance testing of fuel nozzles. For an ideal nozzle, the value of PI (which is the sum of the [absolute] differences between the sector flow and that produced by a circumferentially uniform spray) would be zero. Real airblast fuel nozzles rarely exhibit values less than 10. The range of measured values from 5.5 to 7.4 indicate that this nozzle flow is highly uniform. This will permit the assumption of axisymmetry to be made with a high level of confidence when modelling this flow. The included angle (Alpha) formed by the spray boundary (defined by the radius of the cross section capturing 90% of flow) is shown to vary from 85 to 64 degrees. The measured magnitudes and manner of variation are typical of airblast nozzles. The Sauter mean diameter (SMD) measured using the Malvern ST1800 (a path measurement along a diameter) shows the indicated mean droplet size to range from 85 to 57 microns. This value is typical of values measured when airblast nozzles designed to operate with jet fuel are operated using water as the working fluid.

The results of tests performed using Jet A fuel are shown in Fig. 6. Again the circumferential uniformity is quite good. The spray angle is slightly smaller than the values measured using water. The SMD is substantially smaller and is in the 20-25 micron range generally indicated by the Malvern instruments for similar nozzles operating with jet fuel. Also shown on both figures is the collection efficiency of the patternation system which represents the ratio of the flow obtained by integration of the measured values and the metered flow rate. The collection efficiency is close to unity when operating with water but falls to 0.88 with Jet A indicating that there is some loss of mass captured in the case of the smaller diameter, more-volatile Jet A spray.

The character of the airflow produced by by the airblast nozzle is illustrated by the plots of axial velocity shown in Fig. 7. The diametral variation of velocity is shown for stations located from 0.11 to 10 cm downstream of the nozzle discharge plane. It is evident that the strongly swirled flow produces a central vortex having a centerline time mean velocity of 10 m/s or less (compared to a peak axial velocity of 70 m/s) for a distance up to five cm from the nozzle face. The strength of this vortical flow is moderate in nature--some nozzle designs show no evidence of vortex breakdown when operated in an unconfined environment while others show a high, negative, time-mean centerline velocity.

Measurements of the radial distribution of the three components of velocity were performed at the nozzle discharge plane and of the axial variations of the three velocities at specified outer radii in order to provide boundary condition information for the modeling of the flow.

Typical results of the spatially-resolved measurements of spray droplet characteristics performed using a phase-doppler particle analyzer are shown in Fig. 8. Measurements of both the mean droplet velocity and the mean gas-phase velocity are shown. The designation "gas-phase" velocity pertains to the gas phase in the presence of the spray while the designation "gas-only" pertains to the axial velocity measurement obtained using the velocimeter and in the case when no spray was present. It is apparent that two flow regimes can be identified: a core region where the gas and liquid phase velocities are similar; and an outer region where the droplet velocity is significantly higher than the nearly-zero gas phase velocity.

Results of the droplet size measurements are shown in Fig. 2 where it is evident that the larger diameter droplets have been centrifuged to the outer region of the flow, as expected.

Information on the local mass flux is available and will be used to establish the relationship between metered liquid flow rate and that obtained by integration of the local flux.

These diametral surveys were successfully performed at downstream stations of 2.54, 3.81, 5.08 and 10.16 cm from the nozzle exit plane. Attempts to acquire data at a distance of 1.28 cm were unsuccessful due to the high density of the spray. It was entirely expected that the instrumentation would not yield valid data in these very dense upstream regions and certainly not at the exit plane where the atomization is not yet complete.

CONCLUDING REMARKS

The data obtained in this program provide information on the development of the two-phase flow field downstream of an air-blast nozzle. These data can be used to test the capability of existing fluid mechanic analyses for predicting the distribution of fuel within a combustion chamber. Determination of the adequacy of the several analyses being used by the technical community is important to establishing cost-effective design tools to be used in specifying the fuel nozzle characteristics which should lead to the tailored combustor exit temperature distributions required in high durability engines.

SCHEMATIC DIAGRAM OF MODEL NOZZLE

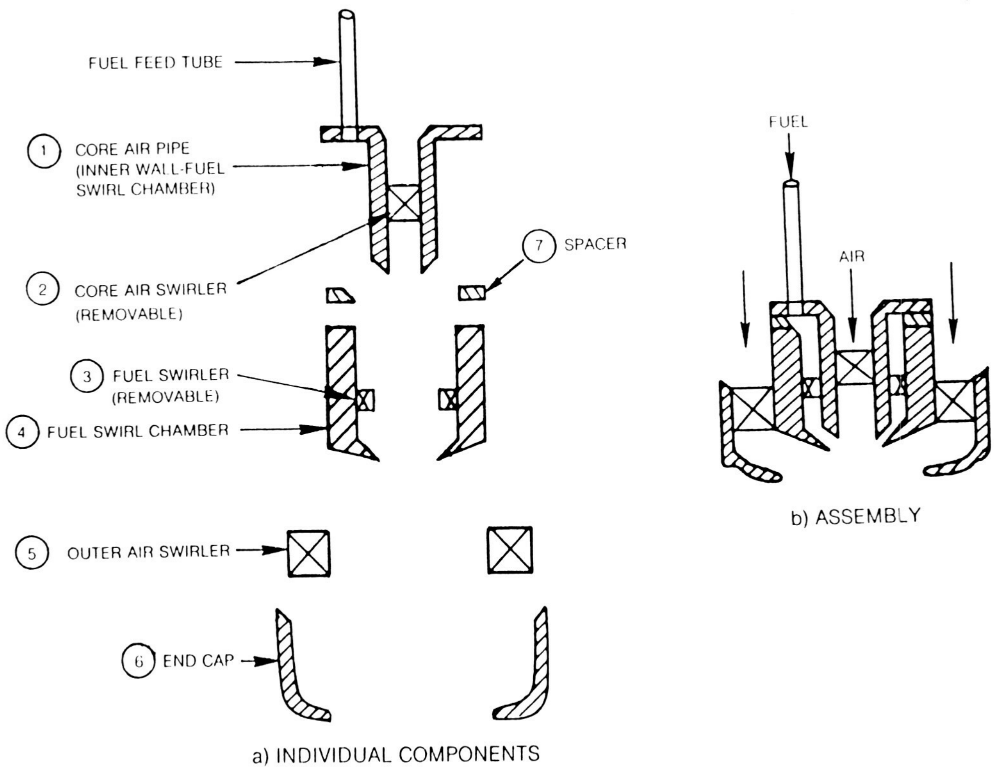

Figure 1

MODEL NOZZLE ASSEMBLY

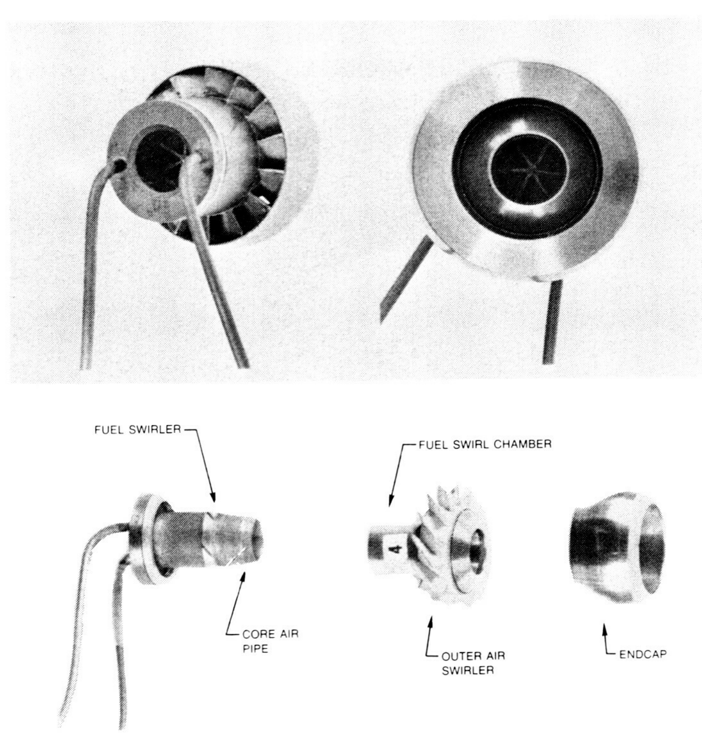

Figure 2

LASER VELOCIMETER SYSTEM

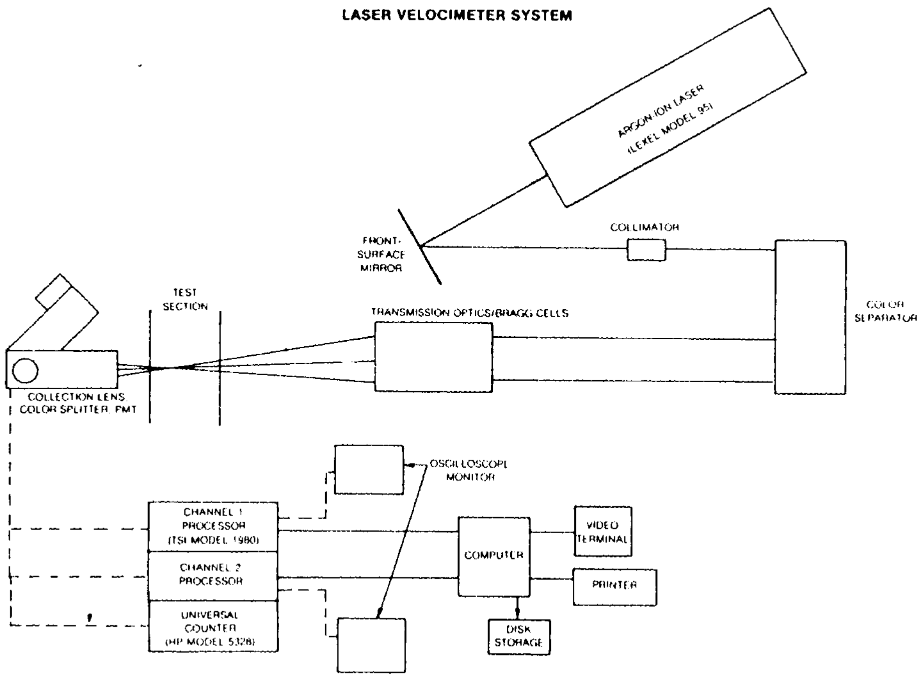

Figure 3

PHASE/DOPPLER PARTICLE ANALYZER

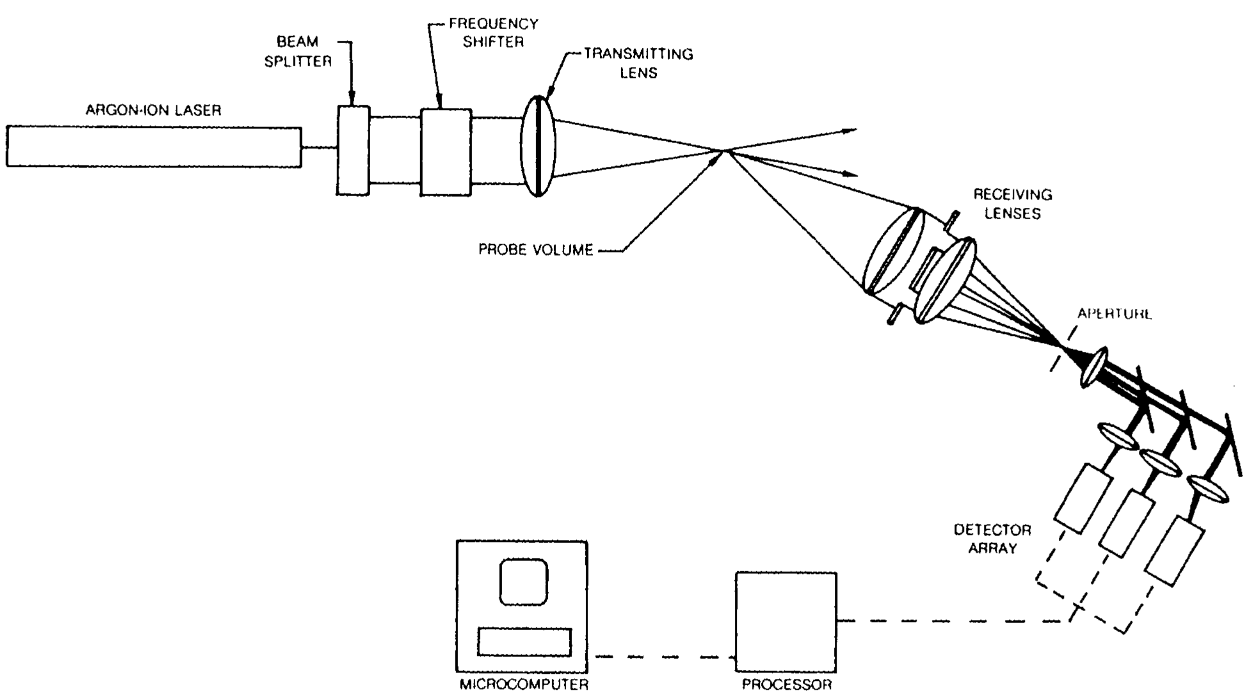

Figure 4

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MASS FLUX DISTRIBUTION - WATER

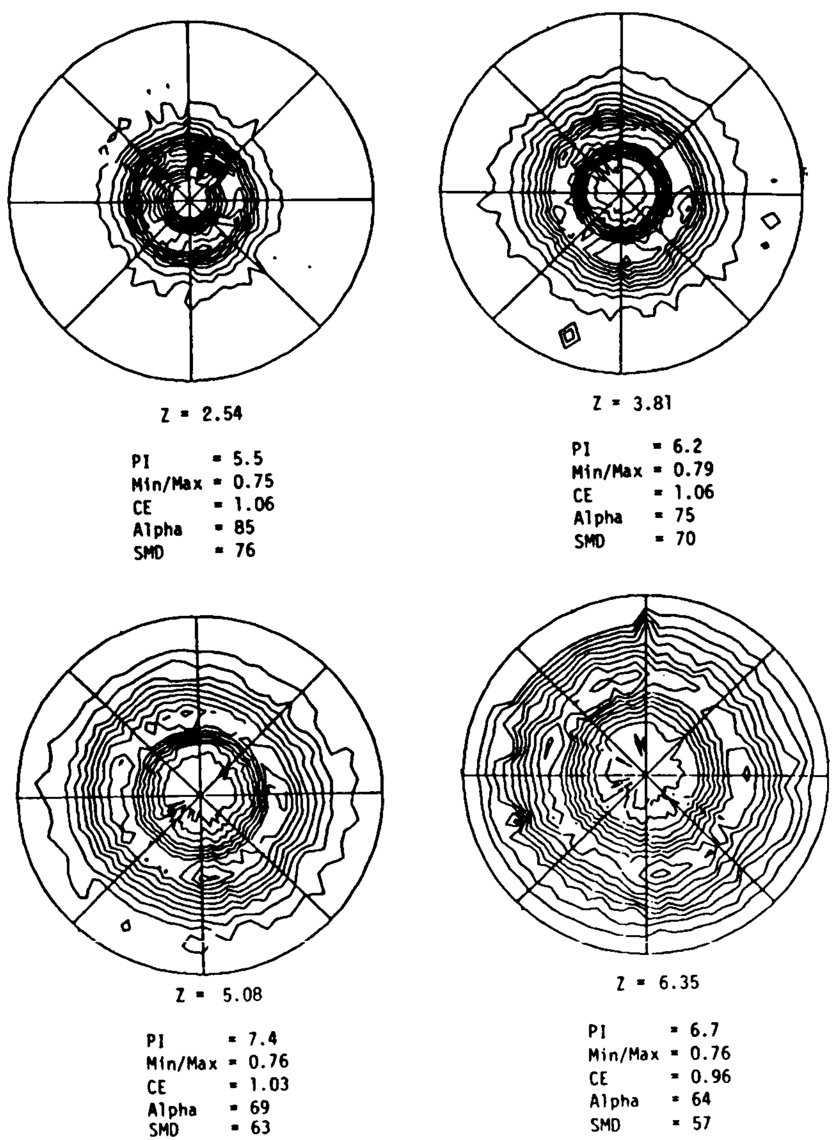

Figure 5

MASS FLUX DISTRIBUTION - JET A

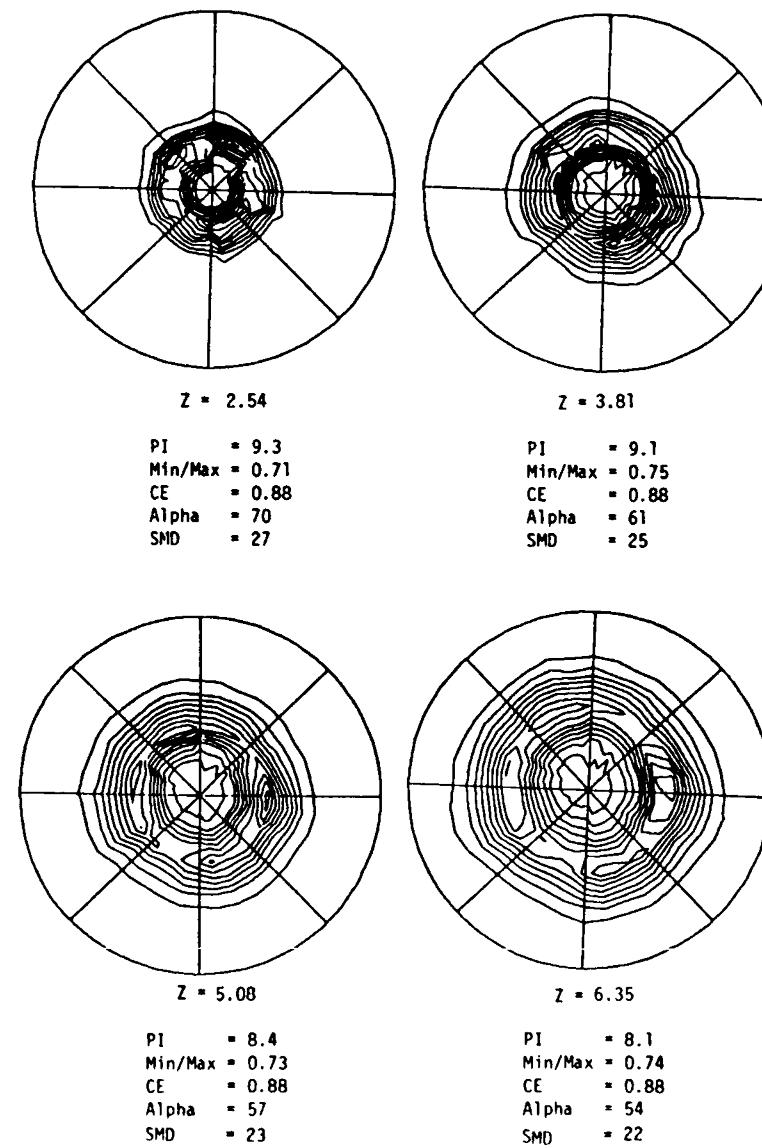

Figure 6

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Mean Axial Velocity - Gas Phase Only

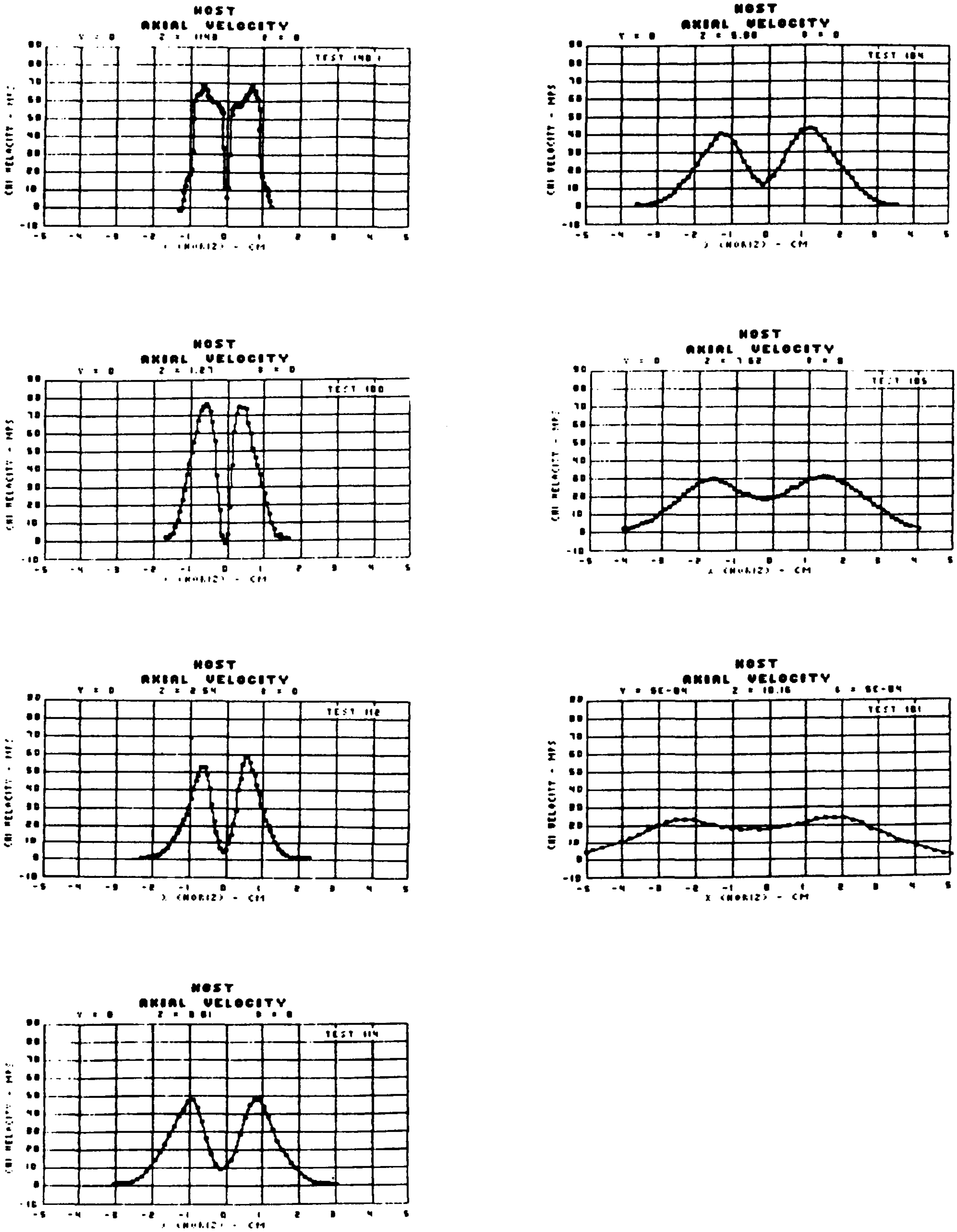

Figure 7

SPRAY AXIAL VELOCITY CHARACTERISTICS

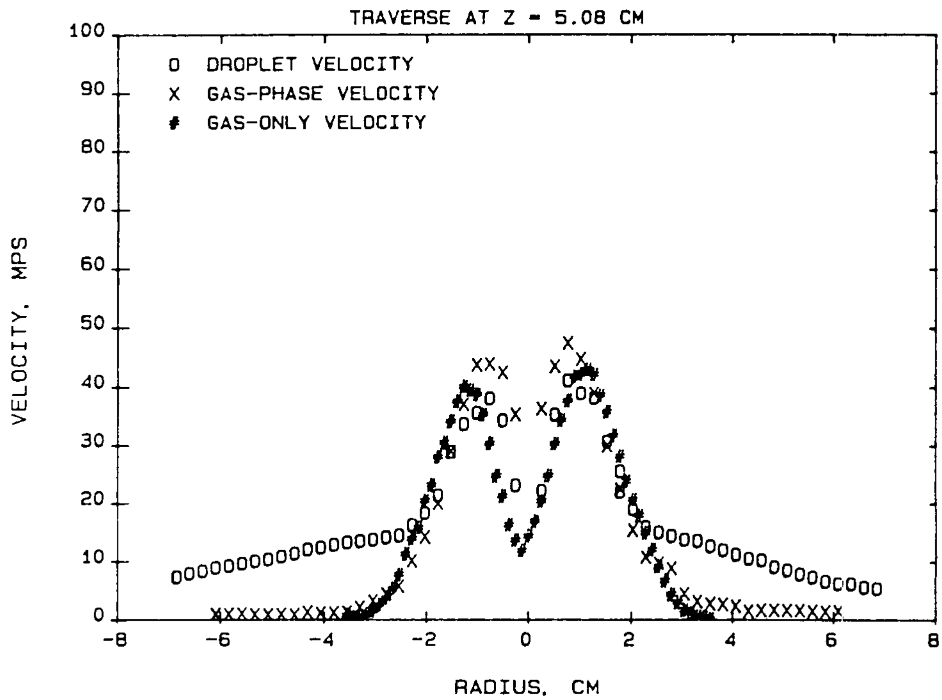

Figure 8

DROPLET SIZE CHARACTERISTICS

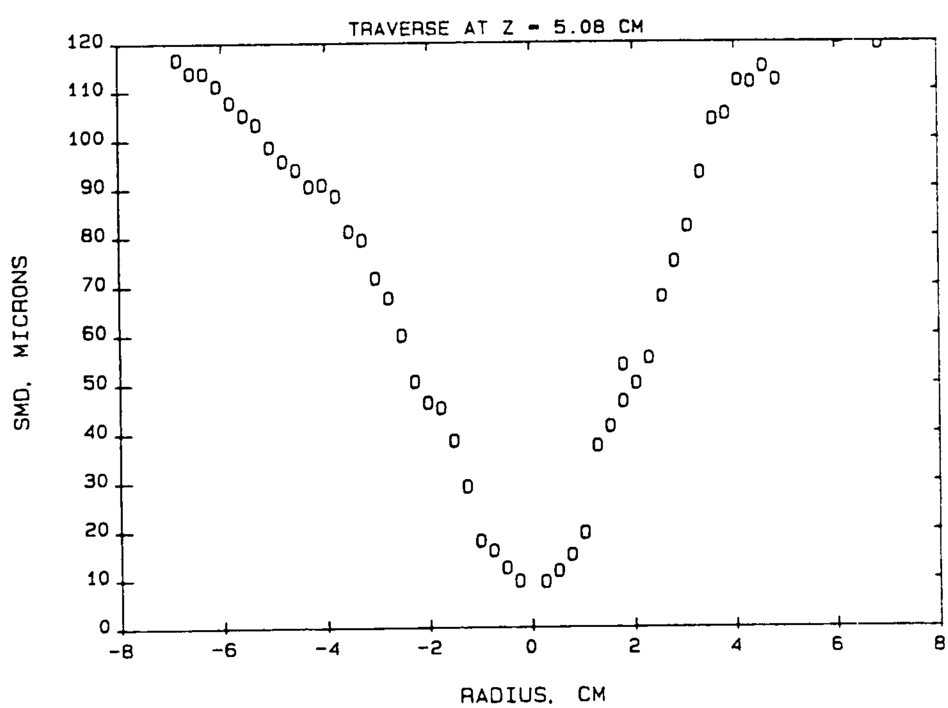

Figure 9