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VALIDATION OF A NONINTRUSIVE OPTICAL TECHNIQUE FOR THE MEASUREMENT OF LIQUID MASS DISTRIBUTION IN A TWO-PHASE SPRAY

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Introduction

The work presented herein is the continuation of an optical technique development program initiated as part of the 1992 Summer Faculty Fellowship Program. The 1992 work consisted of the formulation and implementation of a technique involving the spatial deconvolution of fluorescence data from a uniformly illuminated, seeded dense spray to obtain quantitative measurements of the liquid density profiles. This measurement approach largely overcomes substantial scattering problems associated with other optical approaches for two-phase flows.[1] However, to apply this measurement approach with confidence to unknown flows, the technique must be validated. Consequently, technique validation using classical grid patternator techniques has been the focus of the current work. This work has included the design and construction of a patternator rig and the implementation of a test program designed for the comparison of patternator data with the deconvolved optical data. The flow field used for the validation is the plume of an axisymetric swirl coaxial LOX injector being considered for use in the Space Transportation System Main Engine. The flow facility is an improved version of the test rig which was constructed in 1992 for the initial technique development. This report includes a brief description of the optical measurement technique and the patternator rig and a presentation of the data comparisons.

Optical Technique and Patternator Rig

Several optical techniques for quantitatively investigating specific liquid spray plumes have been developed.[2,3,4] A phase/Doppler interferometer has been used to determine drop-size and velocity components in a plume similar to the plume investigated herein.[5] However, these previously-developed techniques are primarily applicable to spray plumes in which the droplet distribution is sparse and the signal from one drop is not substantially interfered with by the presence of the remainder of the spray. The optical measurement approach employed herein involves the uniform illumination of the axisymetric plume and a subsequent inversion of the measured fluorescence from R6-G dye seeded into the water used for the LOX simulate. By illuminating the plume uniformly, scattering, which inherently limits the quantitative applicability of planar imaging and interferometric schemes, is made more uniform and nonuniform contributions associated with scattering are minimized. Uniform illumination, however, does not provide a direct measure of the mass distribution in a particular plane. The radial distribution of the signal collected using uniform illumination may be determined using any of a variety of deconvolution techniques provided the distribution is known to be axisymetric. For this work, the Abel inversion procedure was chosen. For the problem at hand, it may be shown that the Abel integral equation to be solved can be reduced to

$$\epsilon(r) = -\frac{1}{\pi}\int_r^R \frac{I'(y)}{\sqrt{y^2 - r^2}}\,dy$$

where $\epsilon(r)$ is the radial signal distribution, R is the maximum plume diameter at the deconvolution height, y is the distance from the center of the plume measured on the raw data and $I'(y)$ is the derivative of the measured signal at location y.[6] Deconvolution techniques such as this are inherently dependent on the derivative of the measured distribution. This makes the determination of the distribution sensitive to noise in the data. To minimize this effect, an even-ordered polynomial curve fit is applied to the data. Equation 1 is then applied numerically to the curve fit using FORTRAN. The data for the deconvolutions is collected using a RCA video camera and an EPIX frame grabber card installed in an IBM compatible 386 personal computer.

The mechanical patternator is composed of the head, which is a linear array of twenty-three square 1/8" brass tubes, and the collector, which is a bank of 1/2" glass tubes connected by a low pressure manifold. The head, shown in the photograph in Fig. 1, is fitted with a hinged flap which can cover or uncover all of the tubes in the array simultaneously. The collector, shown in Fig.2, is fitted with individual scales for each tube and flapper doors on the bottom of each tube allow the patternator to be quickly reset after each run. The patternator is operated by establishing the flow to be probed with the head covered, lowering the pressure in the collector manifold (to insure that droplets falling on the patternator head are captured), uncovering the head until at least one collector tube is nearly full, re-covering the head and then stopping the flow.

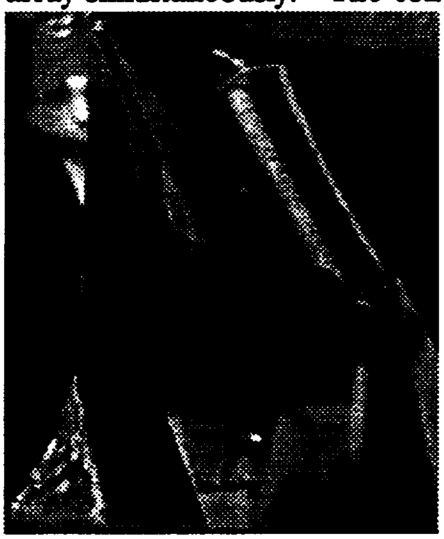

Figure 1: Patternator head.

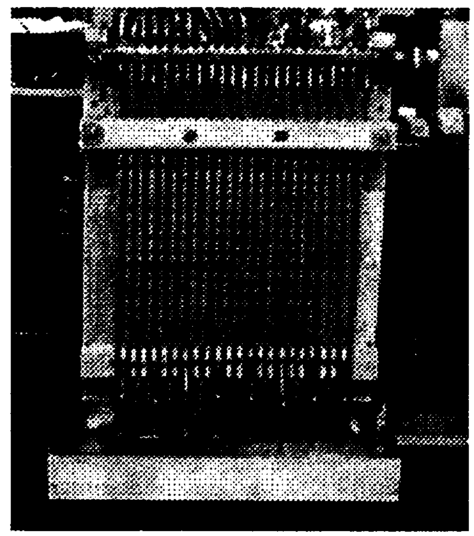

Figure 2: Patternator collector

Measurements

An image of the fluorescence signal in the swirl spray with a drive pressure of 50 psi resulting from uniform illumination is presented in Fig. 3. Note that, although the mass density is known to be nearly zero at the plume center, a substantial signal is present near the center of the image. This signal comes from the near and far edges of the plume. Several radial sections of this fluorescence data were inverted and a representative inversion compared with patternator data is shown in Fig. 4. The peaks of the data have been artificially forced to match and

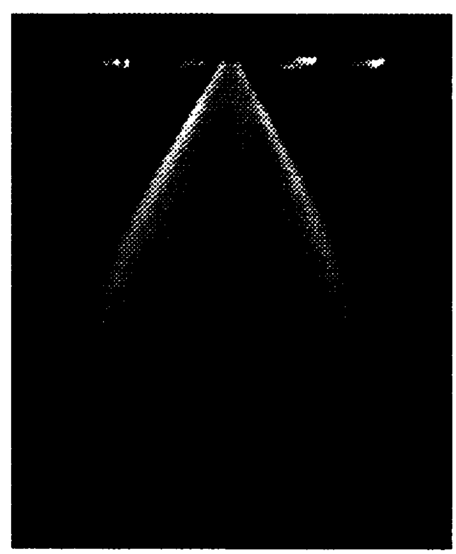

Figure 3: Fluorescence Signal.

the agreement in profiles is reasonably good; however, it was believed that a lack of atomization in the plume and problems with low signal and background correction were degrading the quality of the data. To address this issue, 1 μs shadowgraphs were taken at the 50 psi drive pressure and at 300 psi drive pressure (which is closer to projected operating conditions). These shadowgraphs are shown in Figs. 5 and 6 respectively. Clearly, at 50 psi, the injectant plume has atomized very little in the near field of the injector; however at 300 psi, atomization has progressed much closer to the injector exit. For this reason, additional fluorescence data and patternator data were obtained at the higher operating pressure. In addition to increasing the atomization, some adjustments were made in the optical arrangement. The laser power was increased to obtain better signal to noise ratios and the background was substantially reduced. The comparison between the data at 300 psi is shown in Fig. 7. With the improved signal levels, no need for background correction, and the improved atomization, the deconvolved signal, which is a measure of the mass density profile, agrees functionally quite well with the mass flux distribution measured using the patternator.

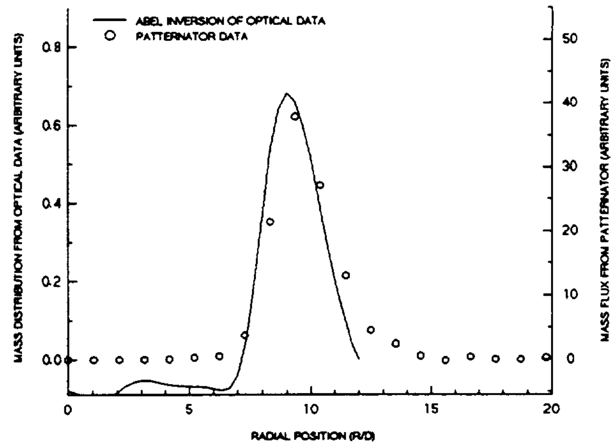

Figure 4: Comparison of Data at Z/D = 20.

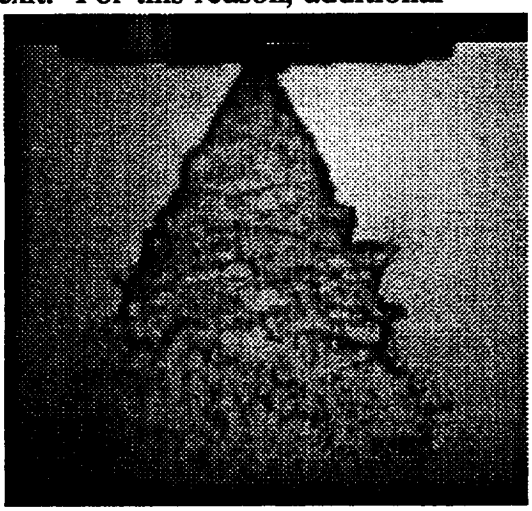

Figure 5: 1 μs shadowgraph at 50 psi.

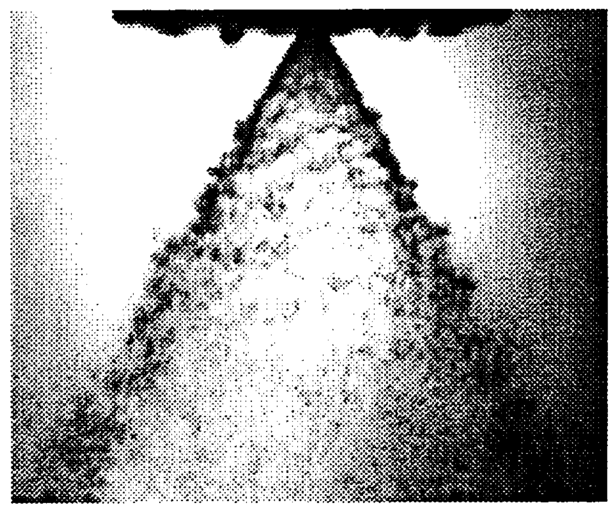

Figure 6: 1 μs shadowgraph at 300 psi.

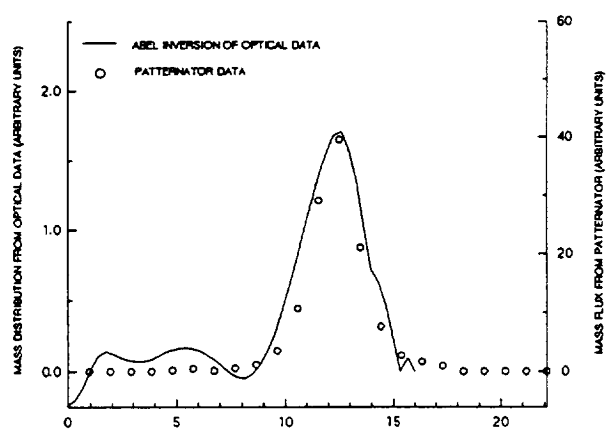

Figure 7: Comparison of data at Z/D = 20 for 300 psi drive pressure.

Summary and Future Work

Developmental work for a nonintrusive LIF measurement technique for mass distribution in dense sprays has been conducted. A grid patternator has been designed, constructed and operated as part of an effort to validate the optical measurement approach. Good agreement between the profiles of mass flux obtained using the patternator and the mass density distribution obtained using the optical measurements was obtained in a high pressure spray.

Planned future work includes additional optical technique development including the extension of the technique to multiangular imaging for use with non-symmetric flows. Additional improvements in the technique may include the use of a higher quality detector and improvements in the deconvolution algorithm. The investigation and potential development of additional nonintrusive techniques, including X-RAY absorption, nuclear magnetic resonance and neutron beam absorption is also planned.

Acknowledgements

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