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Picosecond Imaging of Sprays

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Summary

Preliminary results from applying a Kerr-Fourier imaging system to a water/air spray produced by a shear coaxial element are presented. The physics behind ultrafast time-gated optical techniques is discussed briefly. A typical setup of a Kerr-Fourier time gating system is presented.

Discussion

In attempts to characterize the spray of a simulated coaxial rocket engine injector¹ it became clear that it was not possible to make drop size measurements any closer than 2 in. downstream of the injector face. The applicability of dropsize correlations developed from cold flow measurements 2 in. downstream of the injector face is debatable. The details of the evolution from jet to spray (critical to modeling) are lost. Ultrafast optical imaging provides the possibility of making diagnostic measurements in dense sprays.

Various ultrafast time-gated optical imaging techniques²⁻⁶ such as Kerr-gate, holography, streak camera, etc., have been used in attempts to identify hidden objects in turbid media for use in medical diagnosis. Recently, a collaborative effort was established between researchers at Lewis Research Center and the Institute for Ultrafast Spectroscopy and Lasers (NASA/IRA) at the City College of New York to see if these techniques might be applicable to making diagnostic measurements in the dense sprays encountered in liquid rocket engines.

When ultrashort laser pulses are incident upon a slab of scattering medium the transmitted pulses consist of a ballistic component, a diffuse component, and a snake component. The intensity of the ballistic component (consisting of photons traveling along a straight line path) is attenuated exponentially with the thickness of the material they are traversing. This attenuation puts a severe limitation on the use of ballistic photons in imaging applications. The diffuse component consists of photons that have been scattered randomly in all directions and have different path histories through the material. The snake component consists of early-

arriving photons that have undergone only a few scatterings along an almost straight path through the material. The snake photons form the early component of the diffuse photons and carry information about the optical characteristics of the material they have traversed. Time resolved detection techniques separate these snake photons from the rest of the diffuse component and use them to construct images of objects in the material with different optical characteristics.

As part of the collaborative effort between Lewis and CCNY, a spray rig (Figure 1.) has been installed at the Mediphotonics Laboratory at CCNY. The spray rig consists of a single, water/air coaxial element spraying into a plexiglass test section. The inner diameter of the water tube is .078" and the inner and outer diameters of the air annulus .125" are .219" and respectively. The dimensions are similar to those used in the test program of reference 1. The test section is approximately high and 3.75 by 8 inches. Provisions have been made for optical access through two windows at the top of the test section near the injector face.

In the first phase of this effort a Kerr-Fourier picosecond imaging system developed by CCNY will be used to image the water jet through the dense spray of the coaxial element. The Kerr-Fourier imaging system is shown in Figure 2. The imaging system consists of three main parts: a laser source, an optical Kerr gate (which acts as an ultrafast shutter) , and a detector. A picosecond mode locked Nd⁺ glass laser laser system which emits a 1054 nm 10 ps laser pulse is used as an illumination source. Its second harmonic (527 nm) is used as the gating source. The Kerr gate consists of a pair of calcite crossed polarizers and a 1cm CS₂ Kerr cell. A cooled CCD camera system was used to detect the gated image.

Figures 3 and 4 show the preliminary results obtained with the ultrafast imaging system. All flowrates quoted are approximate due to unsteadiness in the supply system. Figure 3 shows an image of a water jet at approximately 1.5 cm downstream of the injector face. The water and air flowrates were 10 g/s and .8 g/s respectively. The image system configuration used to produce Figure 3 did not include a Kerr gate. The circular border corresponds to the 1 cm diameter region illuminated. At this relatively low air flowrate, the jet remains largely intact and its sinuous, helical structure is evident. The contrast obtained is at least as good as that obtained with laser sheet imaging. A result obtained with the Kerr-Fourier imaging system is displayed in Figure 4. The water and air flowrates were 5 g/s and 1.1 g/s respectively. In Figure 4, the imaging region is at the injector face. The tip of the water tube is visible as it

protruded several millimeters from the injector face. The tube was extended from the injector face so that the imaging system would not encounter liquid hanging from from the injector face due to recirculated drops. At this higher air flowrate, the stripping of liquid ligaments and drops is evident. However, a contiguous liquid jet remains. Image contrast remains relatively sharp but it is apparent that better resolution is required in imaging individual drops or ligaments. CCNY is currently at work on a lens arrangement for increased resolution. Further work will include attempts to image regions of the spray donstream of the jet at this higher resolution.

References

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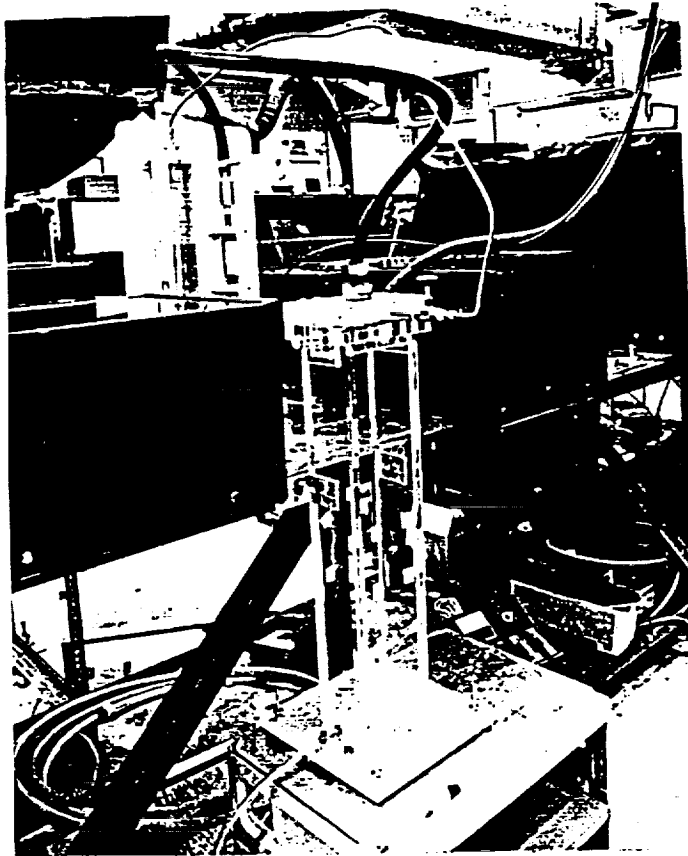
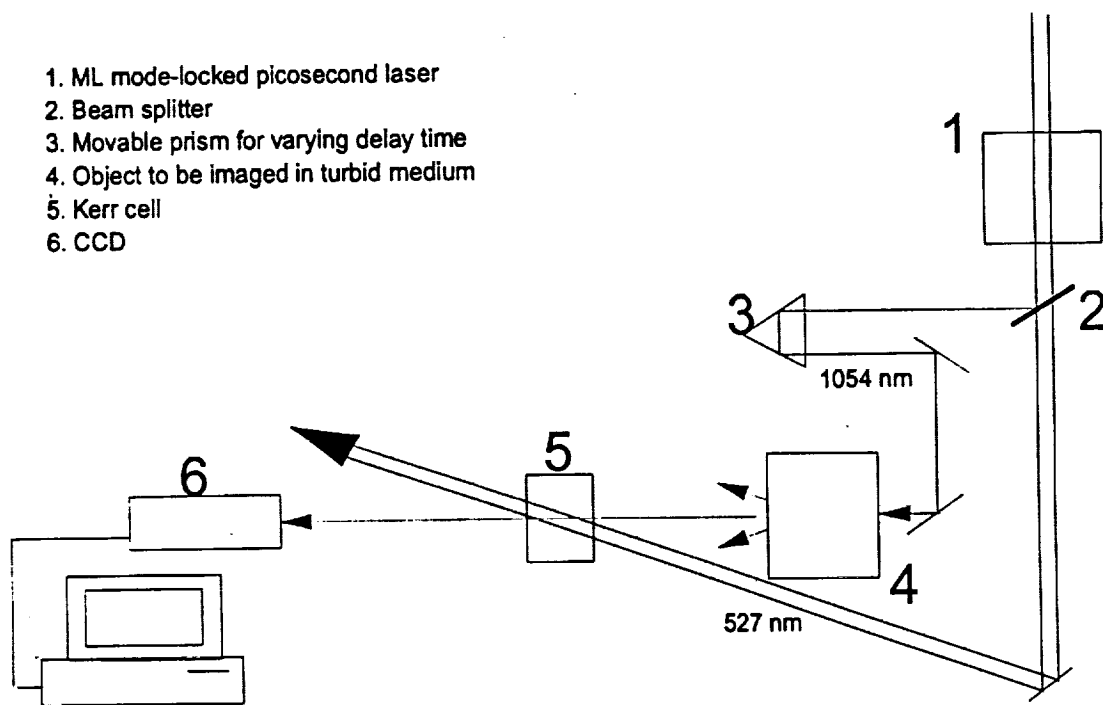


Figure 1. - Water / Air Spray Rig



- 1. ML mode-locked picosecond laser
- 2. Beam splitter
- 3. Movable prism for varying delay time
- 4. Object to be imaged in turbid medium
- 5. Kerr cell
- 6. CCD

Figure 2. - Kerr - Fourier Imaging Setup (CCNY)

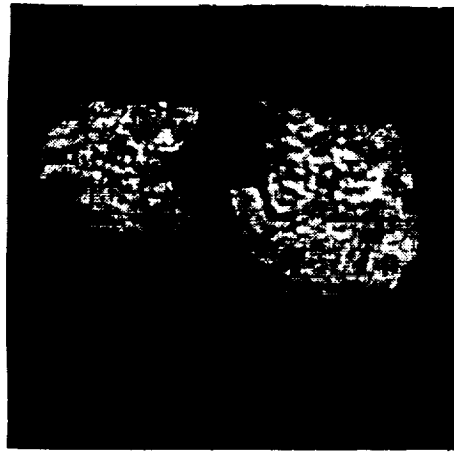


Figure 3. - Non - Kerr gated image

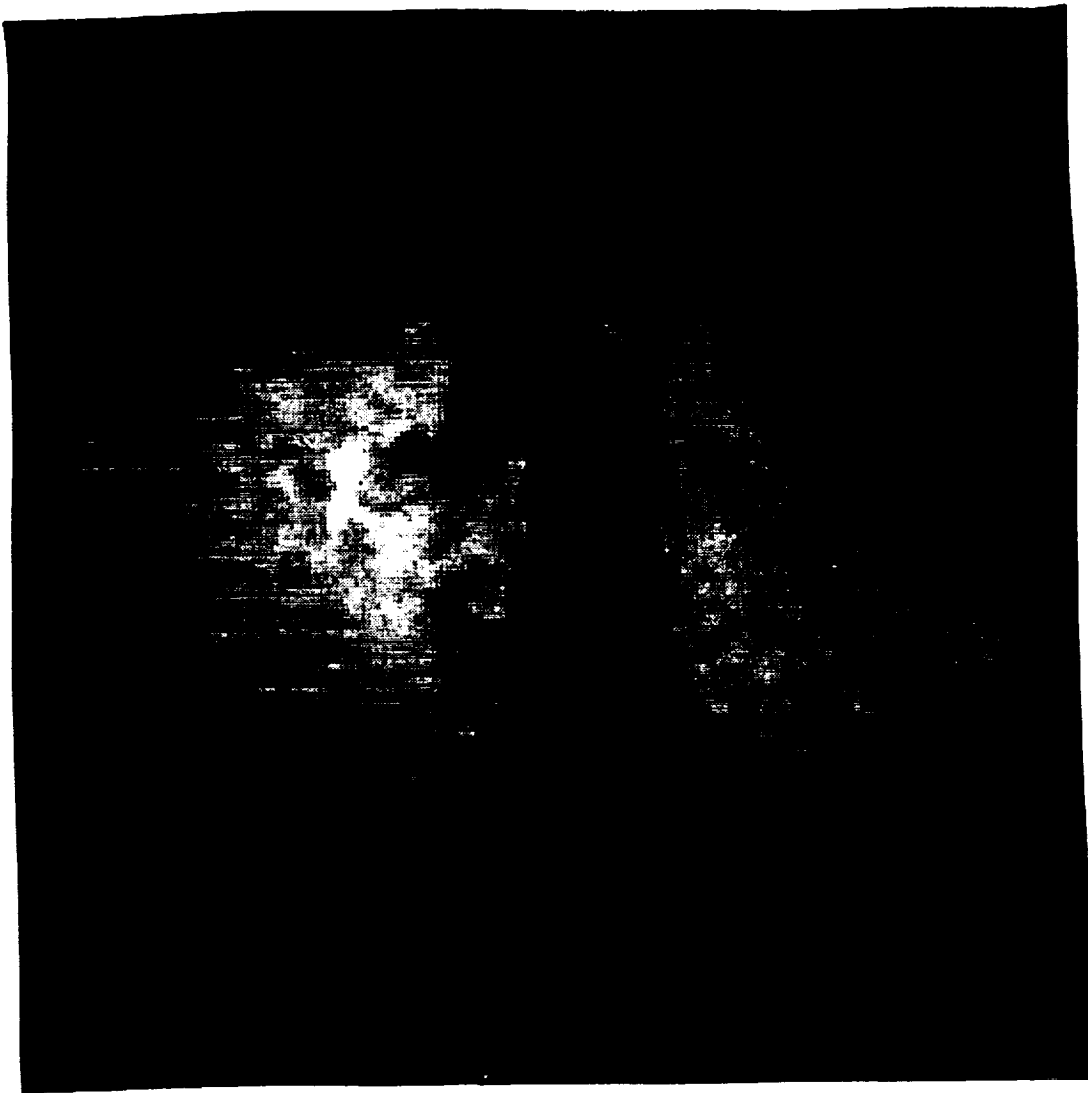


Figure 4. - Kerr gated jet image

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