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AUTOMATIC HOLOGRAPHIC DROPLET ANALYSIS FOR LIQUID FUEL SPRAYS*

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Substantial attention has been directed toward both modeling and experimental characterization of liquid fuel sprays in order to develop a fundamental understanding of the fluid mechanical and chemical interactions which govern the combustion process in these two-phase flows (ref. 1). Two critical parameters needed to characterize spray combustion are the size and velocity distributions of the fuel spray droplets. Several laser-based optical techniques, including scattered intensity, laser interferometry, and laser velocimetry, have been applied in recent years to measurements in fuel sprays (ref. 2). An alternative approach is holographic analysis of sprays, in which the three dimensional spatial distribution of droplets is recorded in a hologram for subsequent analysis (ref. 3). For such an approach to be practical, however, an automated system for analysis of the holograms is required. The goal of the present research program is to demonstrate an automated approach for droplet hologram analysis and to identify critical requirements for adaptation of this technique to measurements in spray combustion systems.

The basic scheme for automated holographic analysis involves an optical system for reconstruction of the three-dimensional real image of the droplet field, a spatial scanning system to transport a digitizing x-y image sensor through the real image, and processing algorithms for droplet recognition which establish the droplet sizes and positions. The hardware for this system is straightforward. In the present demonstration experiment, we are utilizing the expanded and collimated beam from a 5 mW helium-neon laser for hologram reconstruction, an imaging lens for magnification of the real image field, and a video camera and digitizer providing 512-by-512 pixel resolution with 8-bit digitization. A mechanical stage is used to scan the hologram in three-dimensional space, maintaining constant image magnification. A test droplet hologram provided by Dr. Michael Farmer of the University of Tennessee Space Institute is used for development and testing of the image processing algorithms.

For the case of fuel sprays, where the liquid droplets may be assumed spherical, the image processing problem is simplified in that there is no rotational degree of freedom, and special edge-tracking algorithms for tracing the boundary of complicated shapes are not required. The problem reduces to one of recognizing droplets by comparing pixel intensities against a threshold level which is selected on the basis of the average droplet and background intensities. The droplet location in three dimensional space is then established by finding the position of best focus in the image field. We are studying two approaches for finding the best focus. In the simpler approach, the droplet image areas are

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determined at successive image planes by counting the number of pixels above threshold. The plane with the smallest image area is the best focal plane. The second approach, which is expected to be more sensitive, analyzes intensity gradients by examining intensity differences between adjacent pixels at the image boundary. The image plane with the sharpest intensity gradients is chosen as the plane of best focus.

An extension of this technique, which we anticipate will be explored in a future phase of the program, is the determination of droplet velocities and trajectories by the use of multiple exposure holograms (ref. 4). In this approach, a pulsed laser is used to create a hologram by two or more exposures at well-known intervals. The droplet image locations in the reconstructed hologram are determined using the boundary-defining algorithms described above. Finally, statistical pattern recognition techniques would be used to associate droplet image locations at later times with their locations at earlier times.

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DROPLET MEASUREMENT TECHNIQUES FOR SPRAY COMBUSTION

GOAL: CHARACTERIZATION OF DROPLET SIZE AND VELOCITY DISTRIBUTIONS IN FUEL SPRAYS

APPROACHES:

- IN-SITU LASER MEASUREMENTS
  - SCATTERED INTENSITY
  - "INTERFEROMETRY"
  - LASER DOPPLER VELOCIMETRY
- HOLOGRAPHY
  - 3-D RECORDING MEDIUM: DROPLET SIZE AND POSITIONS
  - AUTOMATED ANALYSIS SYSTEM REQUIRED FOR TECHNIQUE TO BE PRACTICAL

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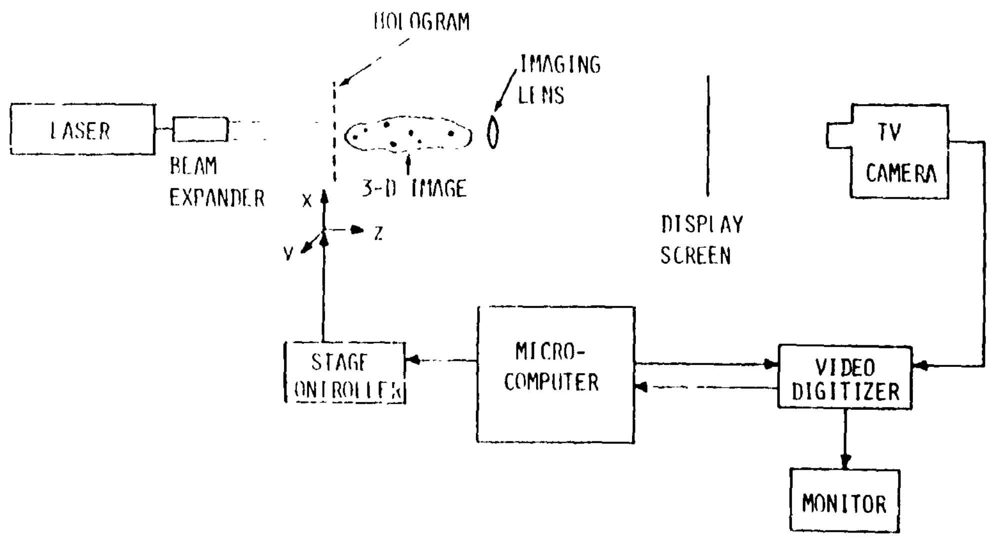
AUTOMATED DROPLET HOLOGRAM ANALYSIS

1. RECONSTRUCT HOLOGRAM TO OBTAIN REAL IMAGE OF 3-D DROPLET FIELD
2. USE VIDEO CAMERA AND DIGITIZER AND COMPUTER-CONTROLLED MECHANICAL STAGES TO DIGITIZE X-Y IMAGE PLANES ALONG Z DIMENSION
3. USE IMAGE PROCESSING ALGORITHMS FOR DROPLET RECOGNITION AND LOCATION

APPARATUS FOR AUTOMATED ANALYSIS OF DROPLET HOLOGRAMS



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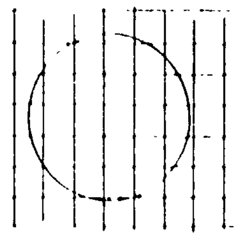
DROPLET BOUNDARY RECOGNITION ALGORITHMS



INTENSITY SCANNING

- COMPARE PIXEL INTENSITIES AGAINST THRESHOLD LEVEL FOR DROPLET RECOGNITION
- OBTAIN DROPLET AREAS BY COUNTING NUMBER OF PIXELS ABOVE THRESHOLD
- BEST FOCAL PLANE IS PLANE OF MINIMUM AREA

EDGE GRADIENTS

- DEFINE DROPLET EDGES BY COMPARISON OF INTENSITIES OF ADJACENT PIXELS
- BEST FOCAL PLANE IS PLANE WITH SHARPEST EDGE GRADIENTS

MULTIPLE EXPOSURE HOLOGRAPHY

- MULTIPLE EXPOSURE HOLOGRAMS MAP DROPLET DISPLACEMENTS IN 3-D SPACE
- APPLY DROPLET RECOGNITION ALGORITHMS TO FIND DROPLET LOCATIONS
- USE STATISTICAL PATTERN RECOGNITION TECHNIQUES TO ASSOCIATE DROPLET IMAGES AT EARLIER AND LATER TIMES
- OBTAIN DROPLET VELOCITIES FROM MEASURED DISPLACEMENTS AND KNOWN TIME INTERVALS