IMAGING AND CHARACTERIZATION OF HIGH SPEED PHENOMENA

S. Desai, R. Gukan, D. Pai and J. Sankar
Center for Advanced Materials and Smart Structures
North Carolina A&T State University
Greensboro, NC 27411

Keywords
High speed phenomena, droplet digital imaging, and stroboscopic photography

Prerequisite Knowledge
Basic physics and computer knowledge

Objective
To use digital photography and the stroboscopic technique to measure high speed droplet size and velocity

Equipment and Materials
1. Food dye to identify droplets (we used carbon particles from a water pitcher)
2. Burette with control valve/knob, ruler with millimeter scale graduations
3. Digital SLR camera with zoom len
4. Computer with imaging software (we used a PC with Image–J software - NIH freeware)

Introduction

Modern engineering and scientific applications involve enabling technologies that occur at high speeds. Typical applications include high speed assembly lines, conveyor systems, bottling operations, printing process, turbine operations and other research setups. Moreover, cutting-edge research fields such as nano, micro and bio technology involve processes that operate at extremely high speeds such as micro/nano droplet formation, propagation and deposition. Visualization of high-speed phenomena is an integral part of understanding the behavior of systems under investigation. It can potentially lead to new discoveries and interpretations. In addition, scientific visualization plays a major role in research for validating computational modeling results, thus matching theory with practice. However, the infrastructure support needed to observe such phenomena requires exorbitant investments that are beyond the reach of conventional high-school and undergraduate education institutions. We have developed a simple experiment setup that simulates high speed phenomena such as droplet flow through an orifice. A stroboscope and digital SLR camera is employed to capture flow behavior of the droplet stream. Image analysis is carried out using freeware software called ImageJ (NIH) to capture droplet size and calculate the droplet in-flight velocity. This setup is benchmarked with an ultra-high speed micro droplet experimental setup at the authors' laboratory.

Procedure
This experiment demonstrates high speed phenomena using droplets being ejected at different rates from an orifice. The setup is shown in Figure 1. It included a 100 ml burette with control valve/knob that was held in a vertical stand. We mixed red color food dye in water to obtain a

better contrast for digital photography. Approximately 100 ml of red-colored water solution was added to the glass burette. A 200 ml beaker was positioned below the burette to collect the droplets being released from the burette. The control knob of the burette was manipulated to release a stream of droplets at different drop rates. A digital SLR camera (Canon EOS Digital REBEL) was used to capture the droplets in-flight from the burette orifice to the beaker. In order to avoid shaking due to hand motion, the camera was mounted on a tripod in the timer mode for image capture. The camera settings are shown in Table 1. A handheld stroboscope (Pocket-Strobe Model PK2) [1] was used with flash rates ranging from 30-12000 flashes per minute (fpm). The flash rate for the experiment was set at 3000 flashes per minute, which is equivalent to a flash every 20 milliseconds.

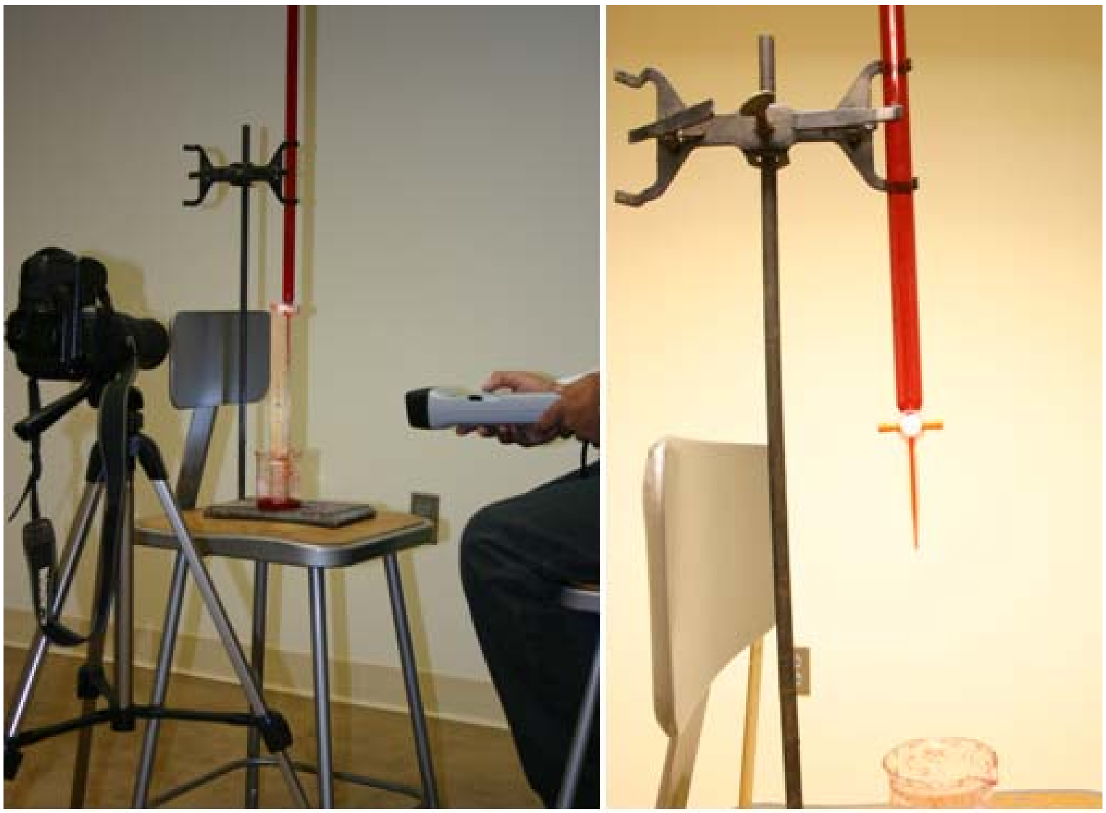

Figure 1: Experimental setup for recording high speed droplet photography

Table 1: Camera settings for digital photographs of in-flight droplets

Camera properties	**Values**
Camera model	Canon EOS Digital REBEL
Shutter speed	1/3 sec
Lens Aperture	F/5.6
Focal length	49 mm
Exposure Time	1/3 sec
F-Number	F/5.6
ISO Speed	ISO-1600

The experiments were conducted in a dark, windowless room. The stroboscope was started at 3000 fpm. Digital images were taken using at different drop rates. A standard ruler with millimeter scale graduations was placed adjacent to the droplets path of flight to provide a calibration scale for the image analysis.

<u>Image Analysis</u>

We used Image – J which an image analysis software from NIH [2]. This is a freeware that can be downloaded from NIH website. Image-J accepts images in .jpeg, .tiff and other formats. The image was manipulated using contrast and edge sharpening tools to obtain a sharper edge boundary. Further, the ruler scale was used to relate ruler graduation distance on the image to equivalent pixel counts.

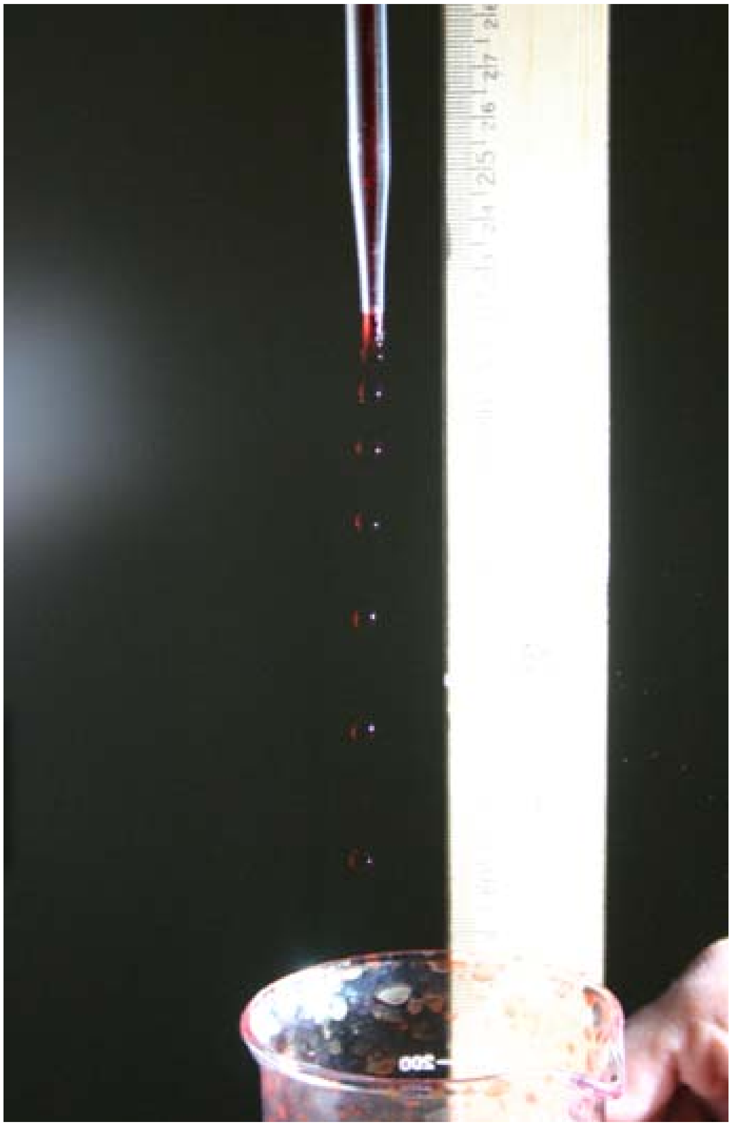

Figure 2: In-flight droplet capture using digital SLR camera and stroboscope

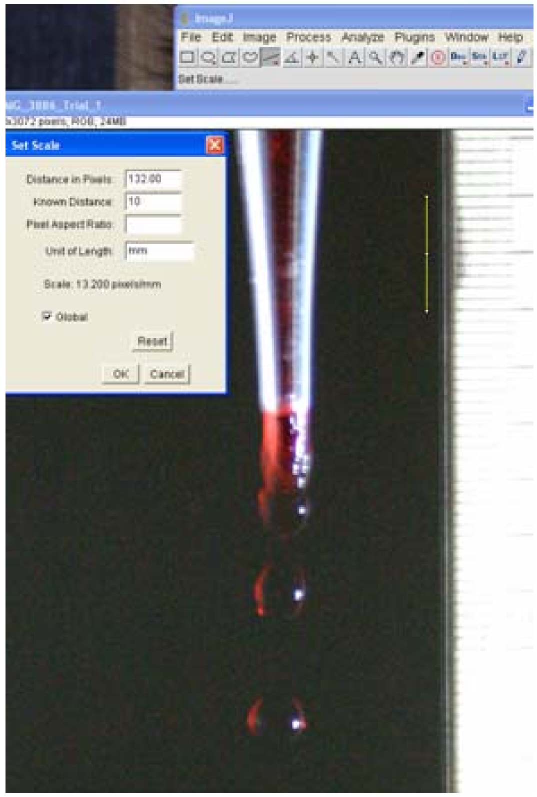

Figure 3: Calibration of image pixels to millimeter ruler scale

Figure 3 shows the calibration of image pixels to the millimeter ruler scale. The set scale tool was used to assign global scaling to all measurements in this image. An elliptical and straight line tool was used to measure the diameter and distance between droplets as shown in Figure 4. Average velocities of droplets were calculated at different locations in their path of flight. Figure 5 shows the measurements taken for calculation of distances between successive droplets for average velocity calculations. The drop velocities increased as the drop moved further away from the burette tip towards the beaker. Droplet diameters varied based on the rate of drop formations. High rate of drop formations resulted in smaller drop diameters and vice versa. Average drop diameter for the image shown in Figure 2 was around 5.12 mms.

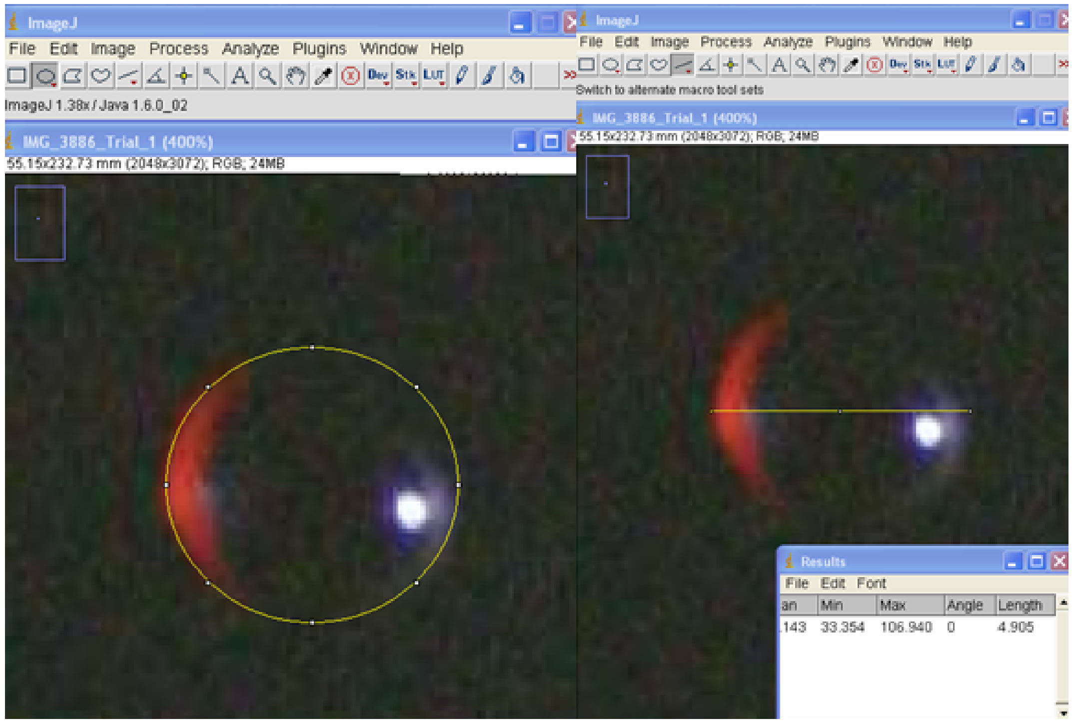

Figure 4: Use of elliptical and straight line measurement tool for droplet diameter calculation

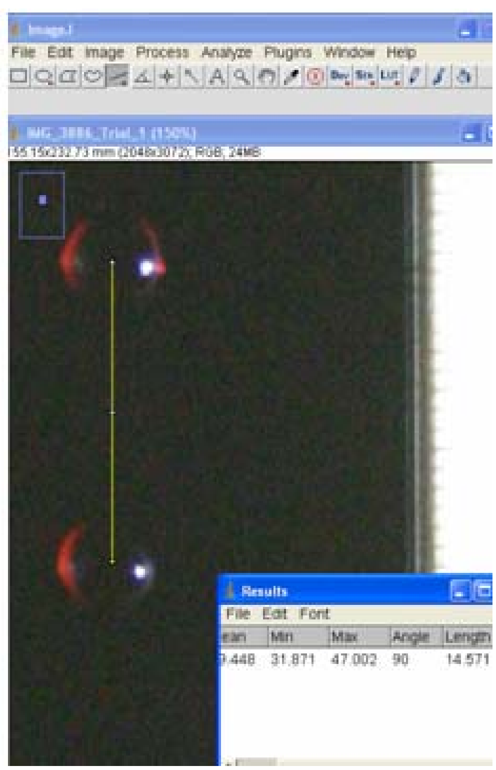

Figure 5: Measurement of distance between two successive droplets for velocity calculations

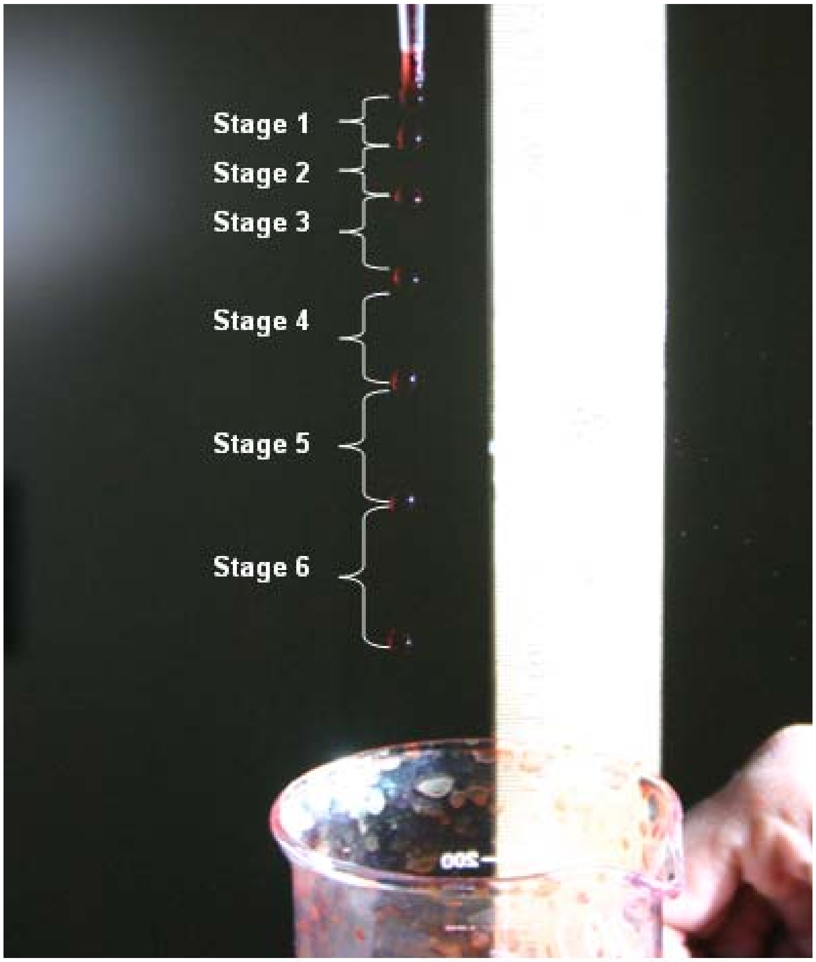

Figure 6: Drop formation stages for average drop velocity calculations

The calculations for average velocity between successive droplets were performed for different stages of drop progression as shown in Figure 6. Table 2 shows these calculations.

Table 2: Calculations for drop velocity at different stages in-flight

Drop Stage	Distance traveled (mm)	Elapsed time (secs)	Velocity = Distance/Time (m/s)
1	6.68	0.02	0.33
2	11.07	0.02	0.55
3	14.57	0.02	0.73
4	19.29	0.02	0.96
5	22.57	0.02	1.13
6	25.91	0.02	1.29

Ultra-high speed photography of micro droplets

In this section we demonstrate image capture of high speed phenomena using sophisticated research equipment. Image capture equipment include ultra-high speed gated intensified camera system, trigger based xenon light source, microscopic zoon lens and frame grabbing software. Our experimental setup as shown in Figure 7 includes a customized inkjet system that generates micro droplets (20-40 µm) at high rates (400 Hz to 10,000 Hz). Figure 8 shows image capture at exposure time of 10 µs for a 50 µm droplet being ejected by the inkjet system.

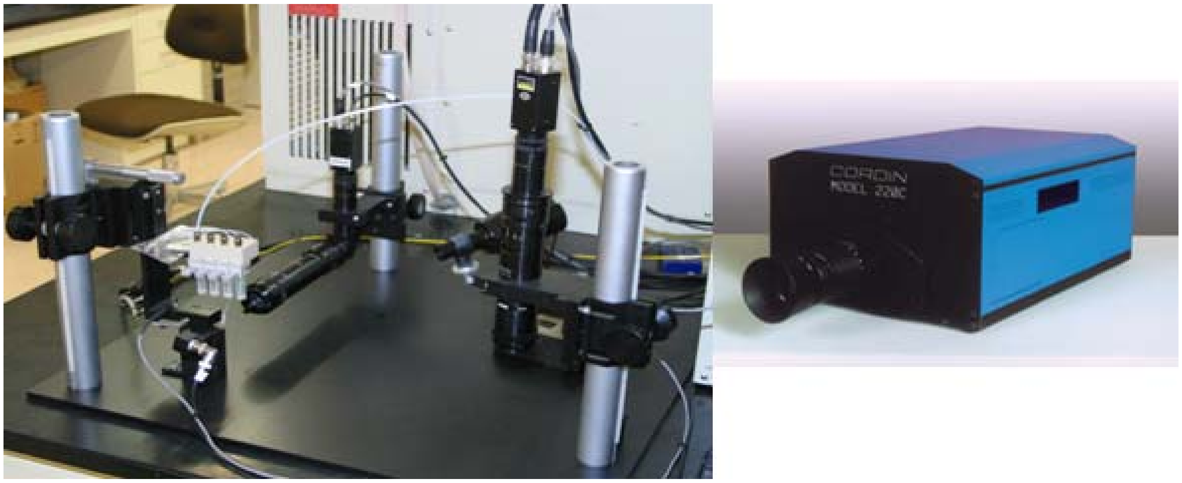

Figure 7: Customized inkjet system (left) and ultra-high speed camera (right)

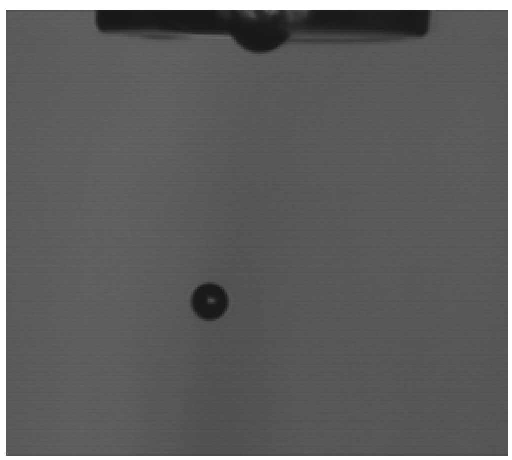

Figure 8: Ultra high-speed photography of droplet formation phenomena
(exposure: 10 µs, drop dia. ~ 5 µm) [3]

Comments

This tutorial demonstrates the use of basic photography, image analysis and laboratory instrumentation to simulate analogous conditions for high speed phenomena such as microdroplet generation from inkjet systems.

Acknowledgement

The authors wish to acknowledge the NC A&T State University Center for Advanced Materials and Smart Structures (including NSF NUE 0634218 and NSF NSEC 0328162) for the equipment and computing facilities used for this work.

References:

1. Pocket-Strobe, Portable Digital Stroboscope (Model PK2), Electromatic Equipment Co. Inc, NY 11516.
2. http://rsb.info.nih.gov/ij/download.html (Image J - freeware from NIH)
3. Desai S., Lovell M., "Coupled Field Analysis of a Piezoelectric Bimorph Disc within a CIJ Microfabrication process," *Industrial Engineers Research Conference (IERC*), Orlando, FL, May 2006.

Biographies

Salil Desai is an Assistant Professor of Industrial & Systems Engineering at North Carolina A&T State University. Dr. Desai's expertise is in the area of micro/nano fabrication, multiphysics modeling, and nano-structured material characterization. He is currently working on transport phenomena of nanoparticles within high aspect ratio conduits. His other research interests include Product Design, Manufacturing Systems and Statistical Optimization.

Gukan Rajaram, a post-doctoral researcher within the Center for Advanced Materials and Smart Structures (CAMSS) at North Carolina A&T State University, received his Ph.D from NC A&T State University. His research is in the area of electrode and electrolyte synthesis and characterization for solid oxide fuel cells. He teaches sophomore level mechanical engineering tools lab.

Devdas M. Pai, Professor of Mechanical Engineering at North Carolina A&T State University, is Associate Director of CAMSS. He teaches manufacturing processes and tribology related courses. A registered Professional Engineer in North Carolina, he serves on the Mechanical PE Exam Committee of the National Council of Examiners for Engineers and Surveyors and is active in several divisions of ASEE and in ASME.

Jagannathan Sankar, Distinguished University Professor and HBCU White House Millennium Researcher at North Carolina A&T State University, is Director of CAMSS. His expertise is in advanced materials synthesis and characterization. Dr. Sankar is closely involved in organizing materials research and education related symposia and session and several international conferences including ASME, MRS, ICCE and NEW.