FTA4000 Epson Ink Jetting

14 August 2007

The FTA4000 is now equipped with a dual-mode dispenser. This can operate with traditional pendant drop and spherical cap touch-off, or it can function as a true piezoelectric Epson-style jetting device. The jetting device has a Luer-hub fitting and connects in place of the ordinary Luer-hub needle. It can be thought of as a "super-needle."

Piezoelectric Jetting Background

The jetter is a glass capillary tube, with outside diameter of about ½ millimeter, that is surrounded by a ceramic piezoelectric element. The glass capillary is drawn down to a point with a specified diameter orifice opening. The diameter of the jetter used in this work was 50 microns. A voltage pulse is applied to the piezoelectric to cause a small droplet to emit from the orifice. This pulse is of the order of 50V and lasts for about 25 microseconds. Interestingly, it works in a non-obvious way: The voltage pulse causes the element to *expand*, thus causing liquid to be drawn back into the glass from the tip. When the pulse ends, the element relaxes, the glass capillary contracts, and liquid rushes back towards the tip. Basically a small amount keeps on going and ejects from the liquid on the tip. The volume that ejects is predictable and depends on several factors, listed in order of importance:

1. Orifice diameter. The droplet volume is basically that of a sphere with diameter equal to the orifice diameter. For reference,

   50 microns → 65.5 picoliters
   40 microns → 33.5 picoliters
   30 microns → 14.1 picoliters

2. Liquid surface tension and viscosity. Higher surface tension raises the dispensed volume as does higher viscosity. Higher values require higher drive voltages which then tend towards larger droplets. The interactions are complex – basically any liquid, with its density, surface tension, and viscosity, will have a region of voltage amplitudes and durations that result in emission. Some combinations are quite broad and most anything will causes ejection and other combinations are narrow and specific.

3. Voltage amplitude. Within the region of successful emission, higher amplitudes result in larger volumes, but the overall range is only of the order of ±50% from the nominal volume. To get grossly larger volumes, you emit two or more droplets closely spaced together so they pile up into a single droplet on the specimen. To get grossly smaller volumes, you must go to a smaller orifice.

Contact Angles Made From a Jetter

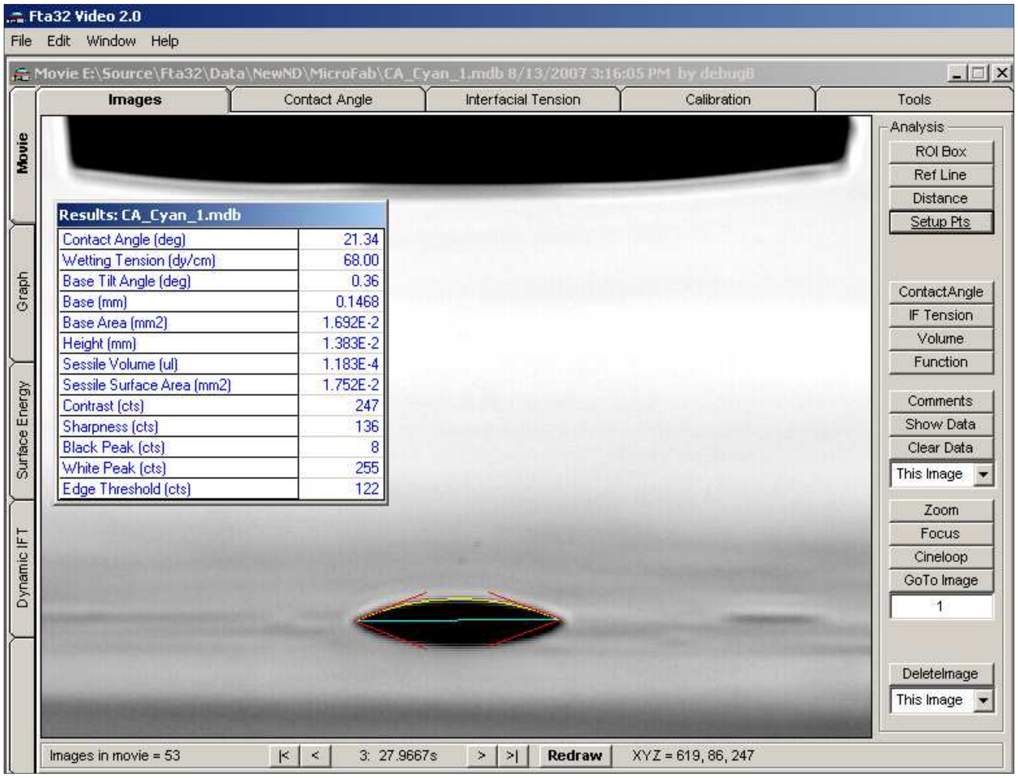
The velocity of the incoming droplet can be large enough to distort the droplet upon landing on the surface. The ejection velocity is typically 1 to 2 meters per second and the spacing of the dispense tip above the specimen is a couple of millimeters. Fortunately the droplet slows quickly from air resistance, so raising the tip will lower the impact velocity and make contact angles true. For guidance:

1. Volumes above 100 picoliters are subject to impact distortion. Smaller volumes have lower mass and momentum and much lower surface area, resulting in a “stronger” drop.

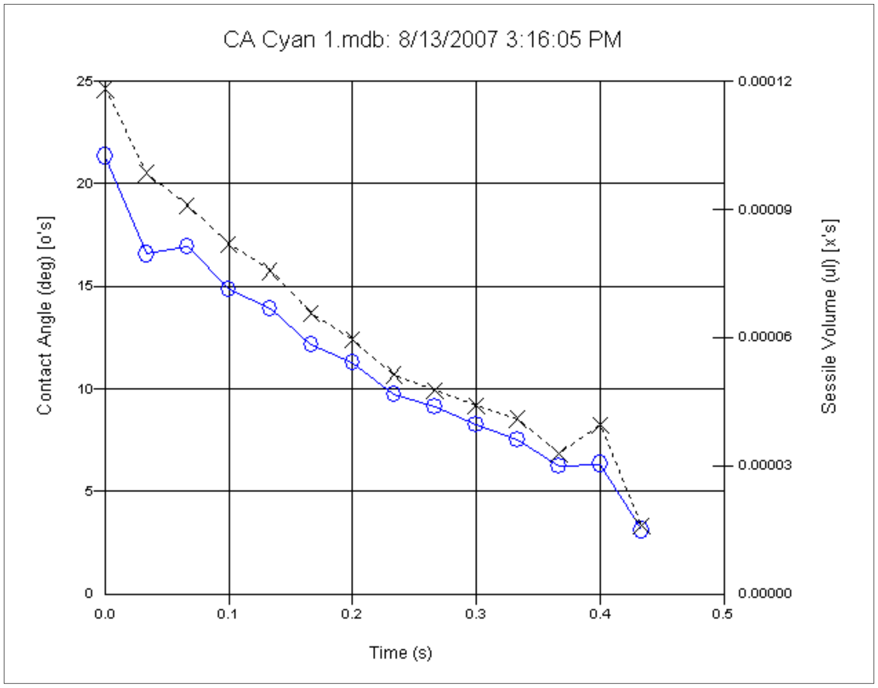
2. High contact angles are subject to impact distortion. Angles above 90° are much more likely to be corrupted by spreading upon impact.

3. High density liquids are subject to impact distortion. These have higher kinetic energy that must be dissipated upon impact.

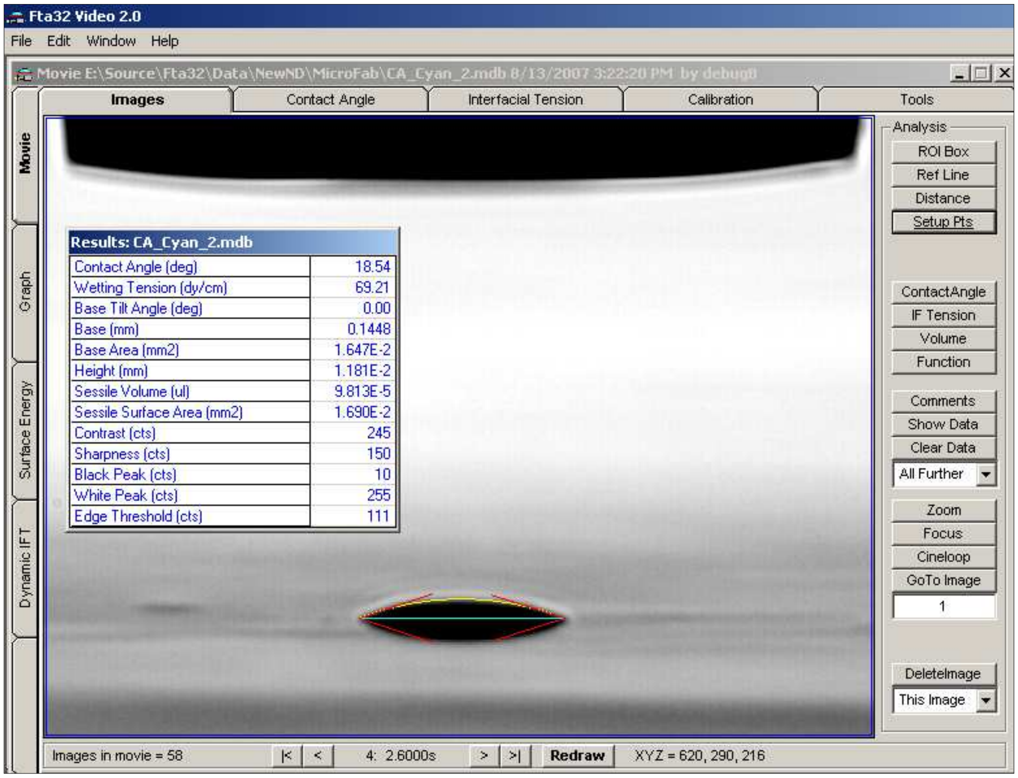
We now show some representative contact angle droplets made with commercial Epson cyan ink on gloss paper. Five tests were run using the same ink and paper. We present an overview of the results and then discuss the method further. All relevant data taken are shown. Analysis was automatic spherical mode. Graphs are unsmoothed.



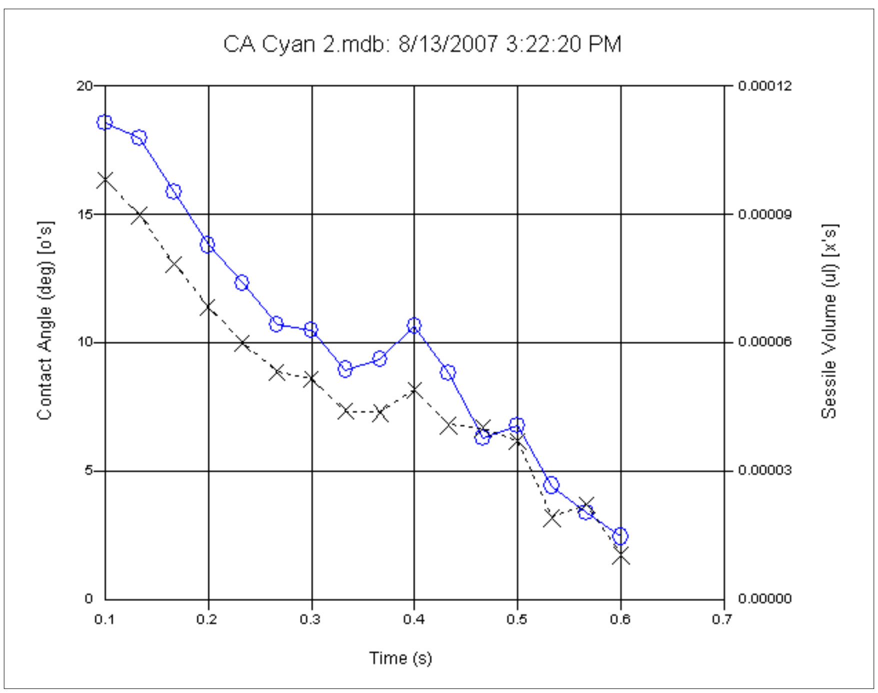
Large object at top is bottom of 1/2mm glass capillary jetter. This is first image showing droplet (30 frames per second rate). Initial contact angle 21.3° and sessile volume 118 picoliters.



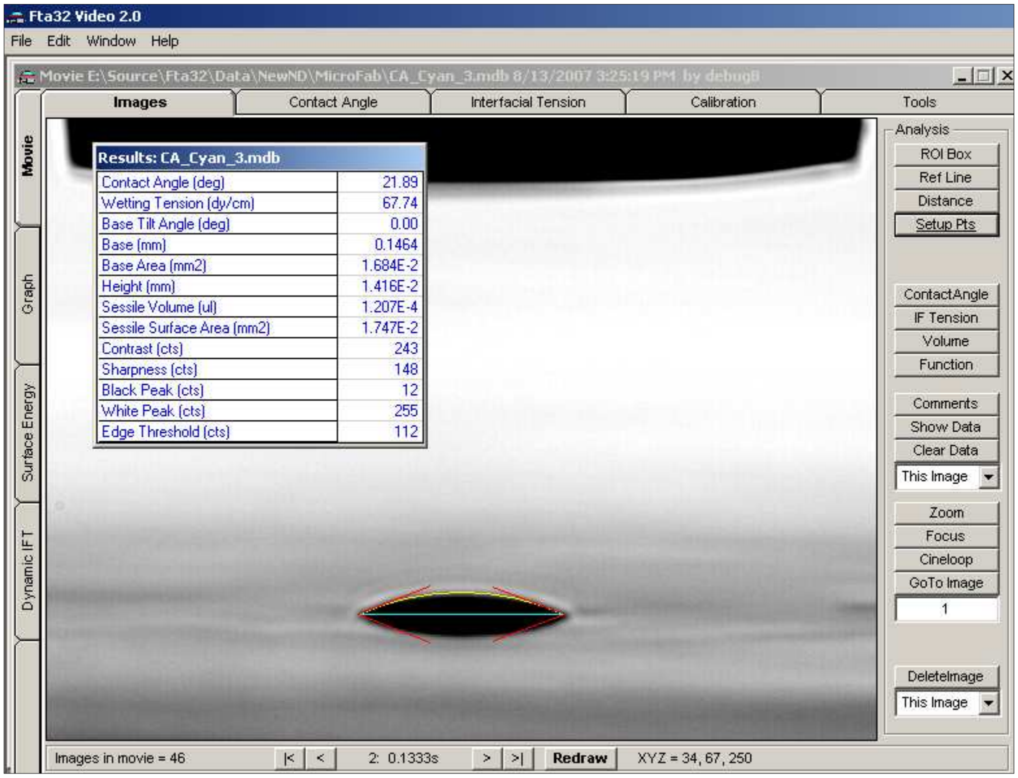
Time response. Blue circles denote contact angles (left axis). Black crosses denote volume (right axis). Time between experiments can be determined by time stamp in heading.



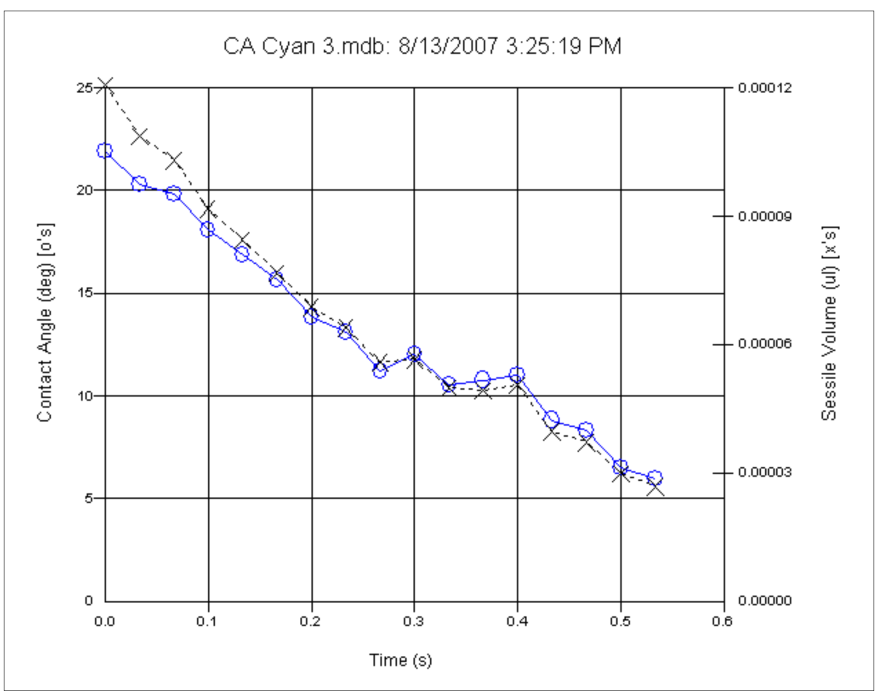
Next run. Initial contact angle 18.5° and sessile volume 98 picoliters.



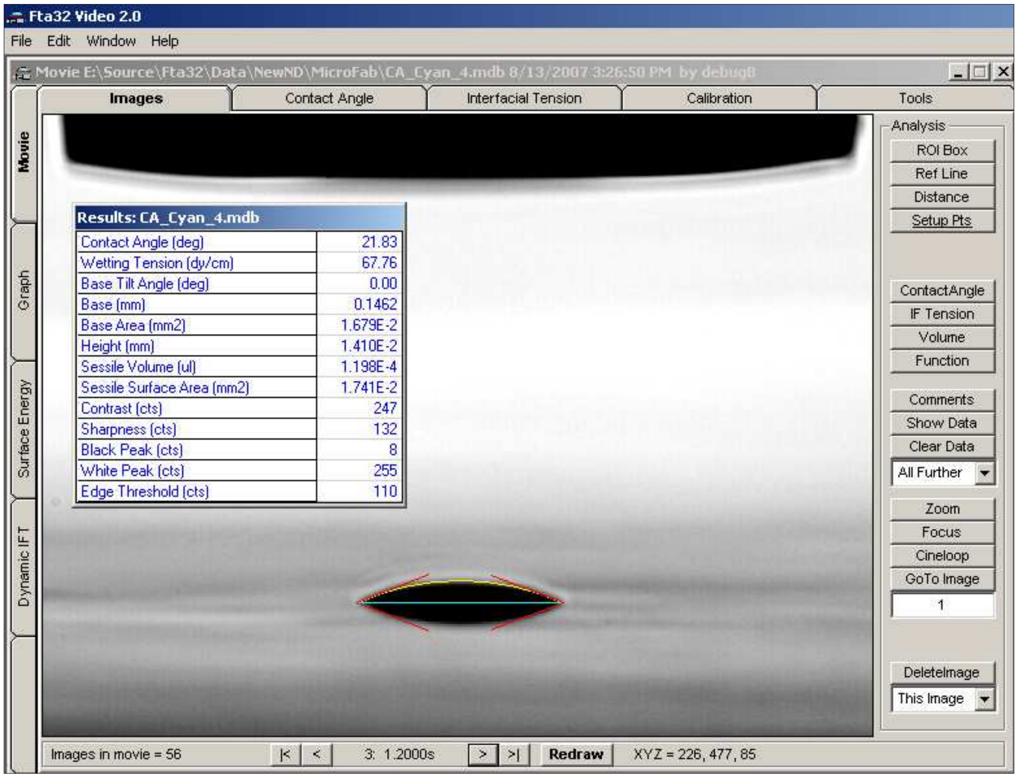
Contact angle (o's) and sessile volume (x's) in time. About 6 minutes after first run.



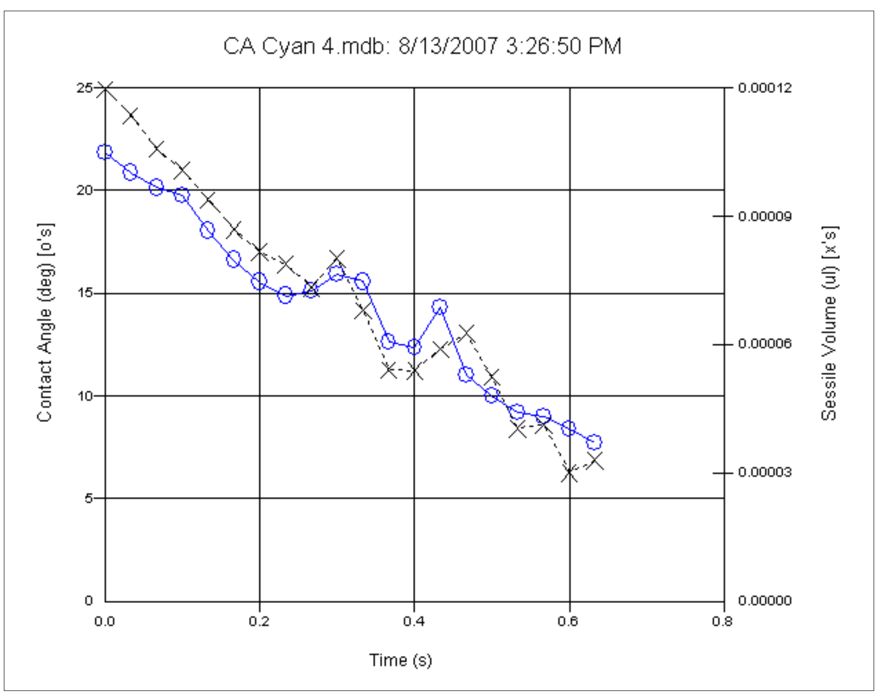
Third run. Initial contact angle 21.9° and sessile volume 121 picoliters.



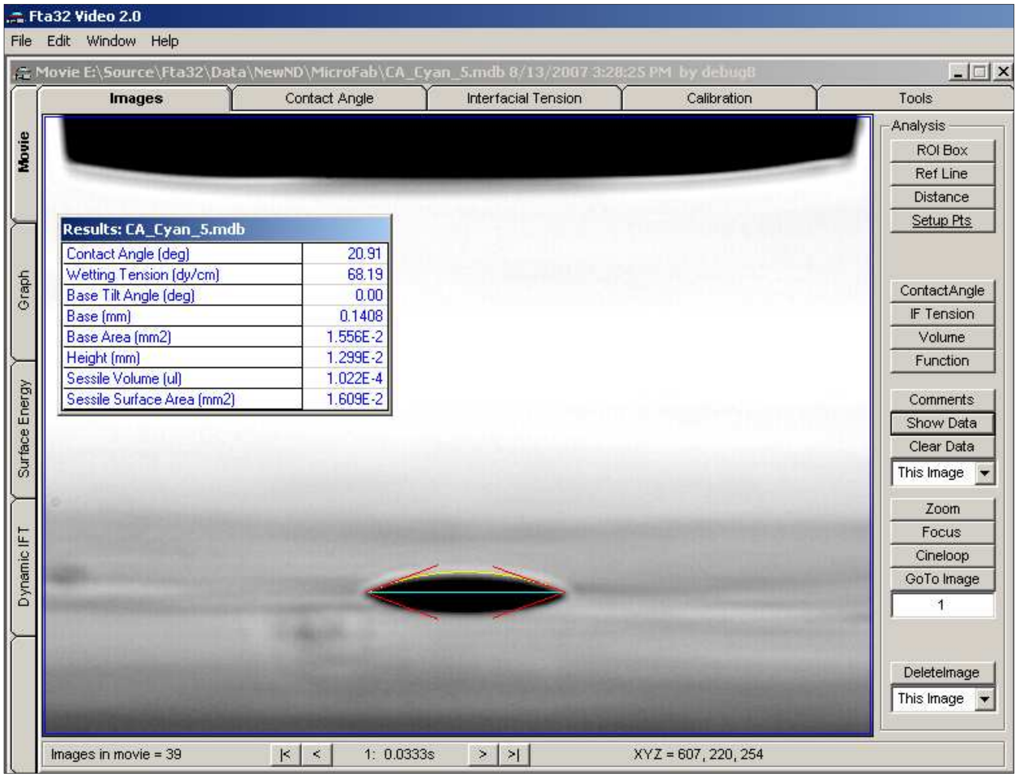
Contact angle (o's) and sessile volume (x's) in time. About 3 minutes after previous run.



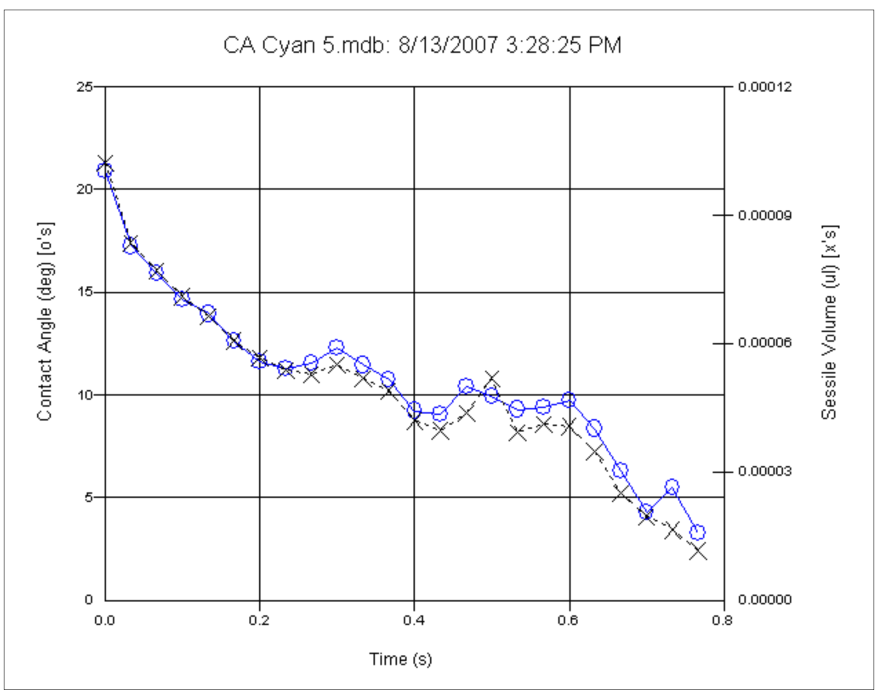
Fourth run. Initial contact angle 21.9° and sessil e volume 120 picoliters.



Contact angle (o's) and sessile volume (x's) in time. About 1.5 minutes after previous run.



Fifth run. Initial contact angle 20.9° and sessile volume 102 picoliters.



Contact angle (o's) and sessile volume (x's) in time. About 2 minutes after previous run.

The times between runs are noted because the jetter received no priming or attention between dispensing these five drops. Each time, it was asked to dispense a *single* drop, each time it did, and these are shown here. We can summarize the uniformity in the following table.

Parameter	Mean (μ, average)	Standard Deviation (σ)	Min Value	Max Value
Sessile Volume (pl)	112	11	98	121
Contact Angle (°)	20.9	1.4	18.5	21.9

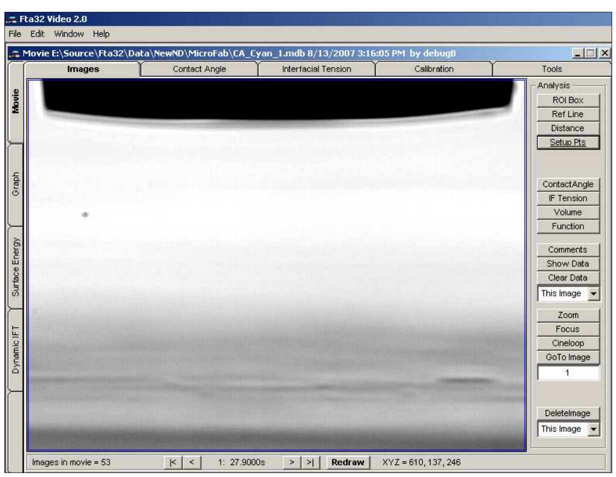
The quality of these results, particularly at this scale, speak for themselves.

Contact Angle Analysis Method

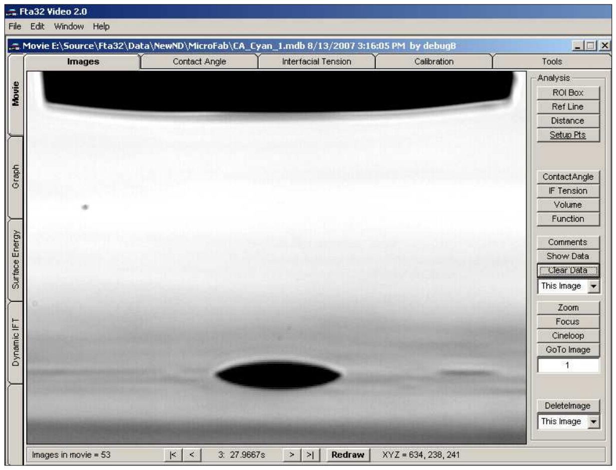
The optics used for this work were not optimized for small drop image quality because they were being used to analyze the jetting device itself at the same time. Nevertheless, the results were quite usable. The image analysis proceeded down the following path:

- obtain a *reference* image before the drop appeared
- subtract the reference image from the image with the drop
- smooth/sharpen the subtracted image, as needed
- perform desired drop shape analysis

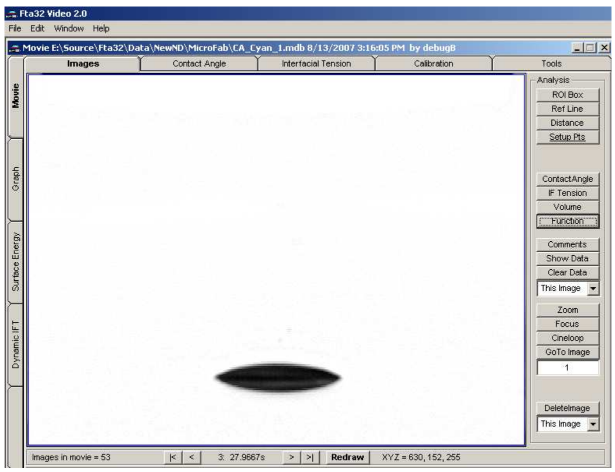
The next four images show this applied to the first droplet. You can combine this with the ROI (region of interest) function to solve many measurement problems and obtain automatic contact angle analysis.



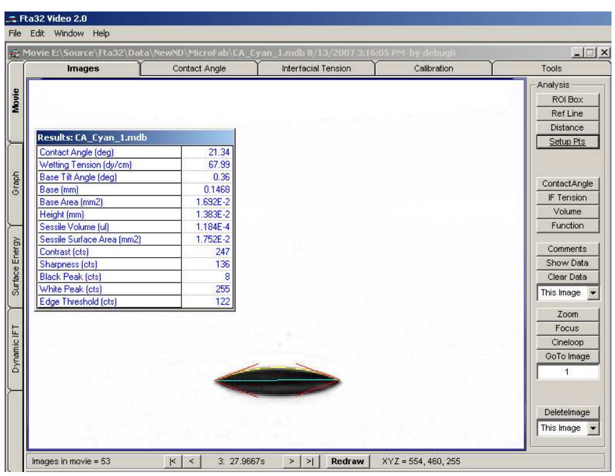
Reference image.



Unprocessed droplet image.



Drop image with background (reference image) subtracted.



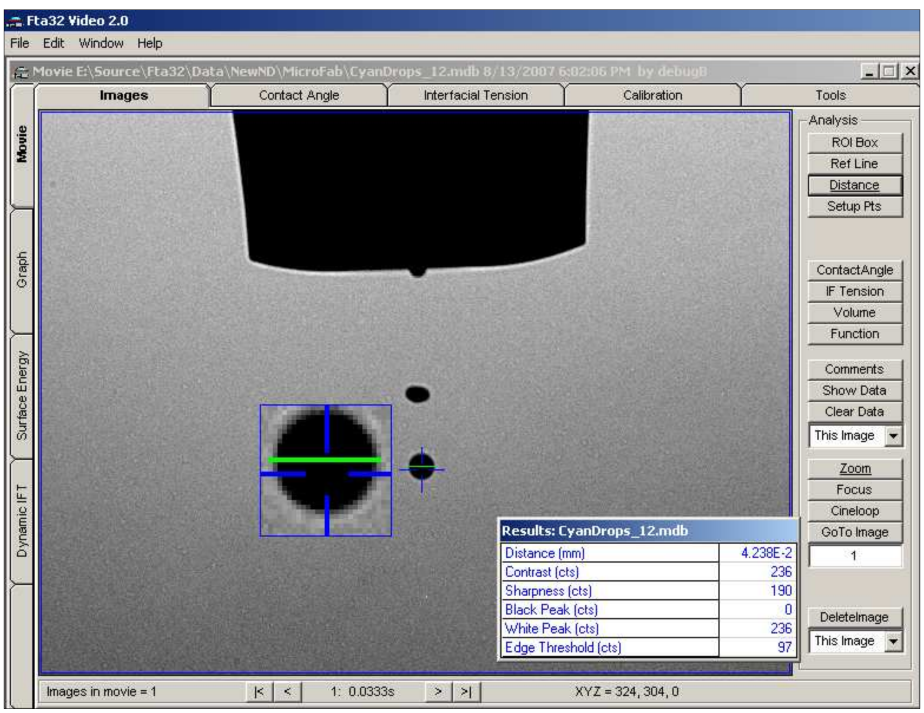
Analyze image. By applying **Redraw**, the original image is restored while retaining the drop shape analysis. This is the image shown at the beginning of this report.

Jetter Setup

The jetter requires a recipe for each liquid you wish to dispense. The recipe is the waveform, with its voltages and timing, that is applied to the piezoelectric element. The recipe is reasonably constant from one particular element to another of the same orifice size (i.e., the jetters themselves are reasonably constant), but varies from liquid to liquid. These factors affect the recipe, in order of importance:

- orifice diameter
- liquid viscosity (strongly affected by temperature)
- liquid surface tension
- liquid density

Recipes can be stored and recalled, but must be initially determined manually. A *strobed* lighting system is used for this purpose. The strobe emits a brief pulse of light after some delay from the waveform application. The jetter is operated in a repetitive mode and the result is a "stop-action" image of the emitted droplets (assuming there are some!). The image below shows Epson ink being emitted in this fashion. Note the camera is operated in a normal, slow (30 fps) mode and, during its exposure of a *single* image, there can be *multiple* strobe flashes (3 in this case).



Jetting of Epson cyan ink. The jetter tip appears in the top of the image and is nominally ½ millimeter in diameter. Three drops appear as the consequence of 3 strobes. The bottom one is the oldest and is now traveling the slowest. We measure its diameter as 43 microns (42pl) in the blue-box zoom window using the green Distance tool. The middle droplet is still distorted as it is still moving fast – it will slow and assume a spherical shape. The top one has not yet extracted itself from the liquid in the orifice.

The FTA4000 includes an LED strobed light source in order to analyze jetter performance and setup new recipes.

Jetter Maintenance

Dispensing "ordinary" pure liquids such as water and isopropanol (IPA) is straightforward and cleaning the jetter is merely a case of flushing the appropriate solvent through the system. Complex liquids, and this includes ink jet ink, are a different matter. These can dry and leave a deposit, or film, on the orifice and perhaps clog it completely. Since the jetting element is expensive, you do not want this to happen. More to the point, you want the device to function and emit *single* droplets when you demand them. The inconvenience of having it not function may be more costly than replacing the element.

When we discussed the five contact angle experiments, we noted they were made over a period of almost 15 minutes without any intervention with the tip. This was accomplished by driving the piezoelectric with higher voltage than usual. A consequence of this higher voltage was larger drops. We had an average volume of 112 picoliters rather than the nominal 65. On the other hand, the droplet volume in the strobed example, just previous, was 42 picoliters but we were driving the piezoelectric element at the low end of the voltage range for this liquid. This range is representative of the effects of varying the recipe. To cope with liquids such as this ink, FTA has devised a cleaning station to maintain the tip between uses. This resembles that provided in high-end ink jet printers.

FTA4000 Features and Benefits

Feature	Benefits
Dual mode: touch-off + jetting	Can perform pendant drop, microliter volume sessile drop, and picoliter measurements
Syringe backing pump	Reliable priming (filling) of jetter
Dip-and-sip liquid pickup	Use only small volumes of high-value samples
Luer hub connection	Easily switch between classic needles and jetter: jetter is approximately size of needles
Image processing	Subtraction and silhouetting make drops visible
Liquid filter	Special filter protects small orifices against particles
Strobe illumination mode	Setup and test recipes; measure incoming droplet volume and speed
Cleaning station	Automatically prepares tip for use
Retrofittable to all FTA4000's	Upgrade previous instruments to new technology

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