The SETScan Patternator

An Overview

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Innovations in Quality Control

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Outline

- Background on patternation
- Sample applications
- Quality assurance using the SETscan optical patternator

Background on Patternation

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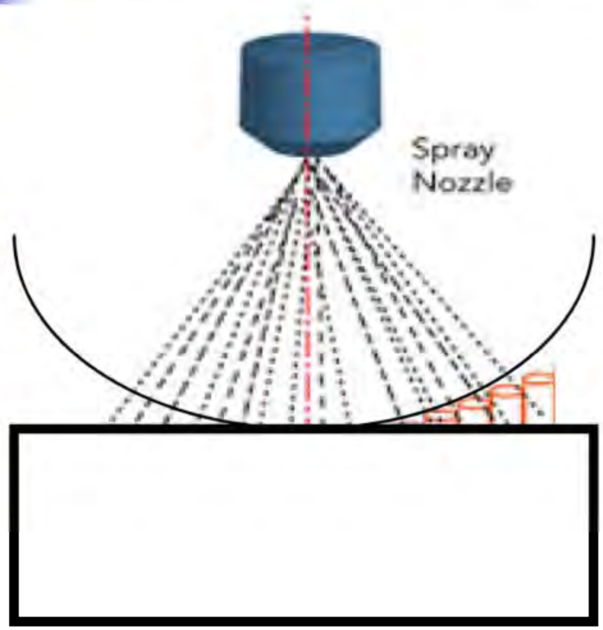
Principal Types of Patternators

- Mechanical patternators
- Laser sheet imaging (optical)
- Planar Laser Induced Fluorescence (optical)
- Extinction based systems (optical)

Mechanical Patternator



Stagnation plane leads to very low accuracy (~ 30%) Worse for high speed sprays from fuel injectors

- Mechanical patternators are placed in the path of the spray with collection tubes
- In the radial patternators, a set of tubes are arranged in a hemispherical pattern.
- In the circumferential patternators, a set radial lines to delineate the sectors
- In general purposed patternator, an array of tubes used to get mass flux pattern

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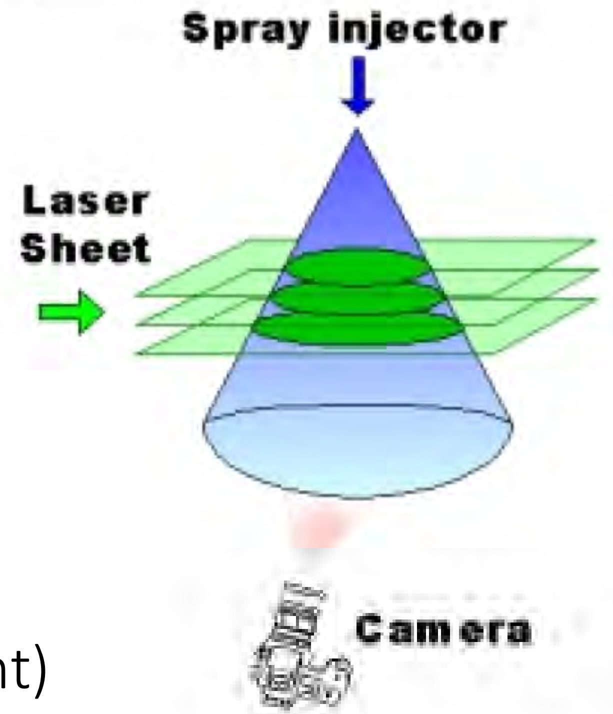
Why Optical Patternation

- Fast, capable of obtaining transient data
- Greater reproducibility than mechanical devices
- Does not interfere with the spray
- Greater spatial resolution
- Low maintenance and operational cost
- Ideal for quality audit
- No spray interference or material wastage

Laser Sheet Imaging

- Laser sheet to illuminate spray
- Image taken using a CCD camera at an oblique angle
- Intensity proportional to drop surface area per unit volume



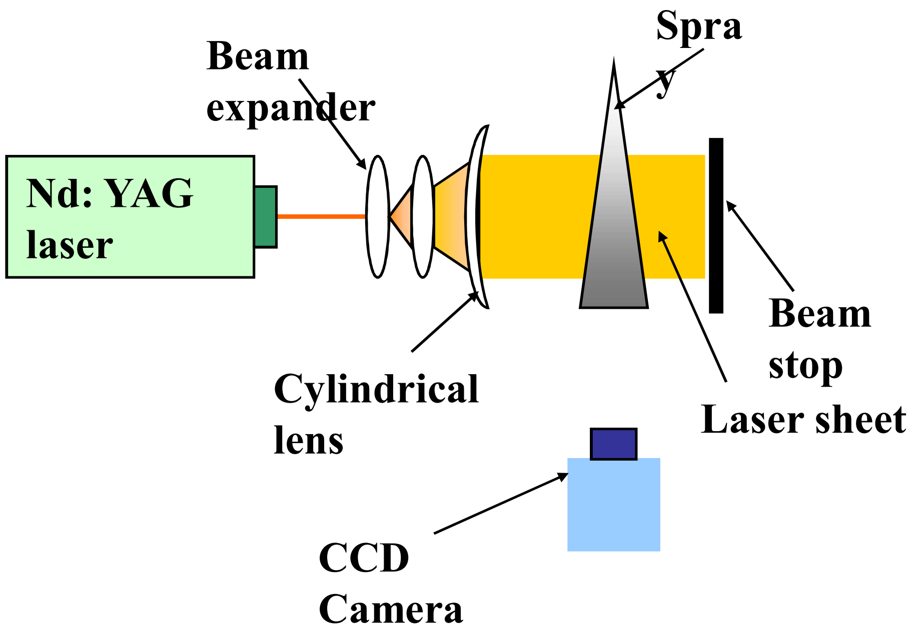
Potential Errors

- Laser extinction (less bright on the right)
- Signal attenuation (less light from the back end)
- Secondary emission (multiple scattering from large aperture)

Implication: Difficult to get for quantitative patternation

Planar Laser Induced Fluorescence

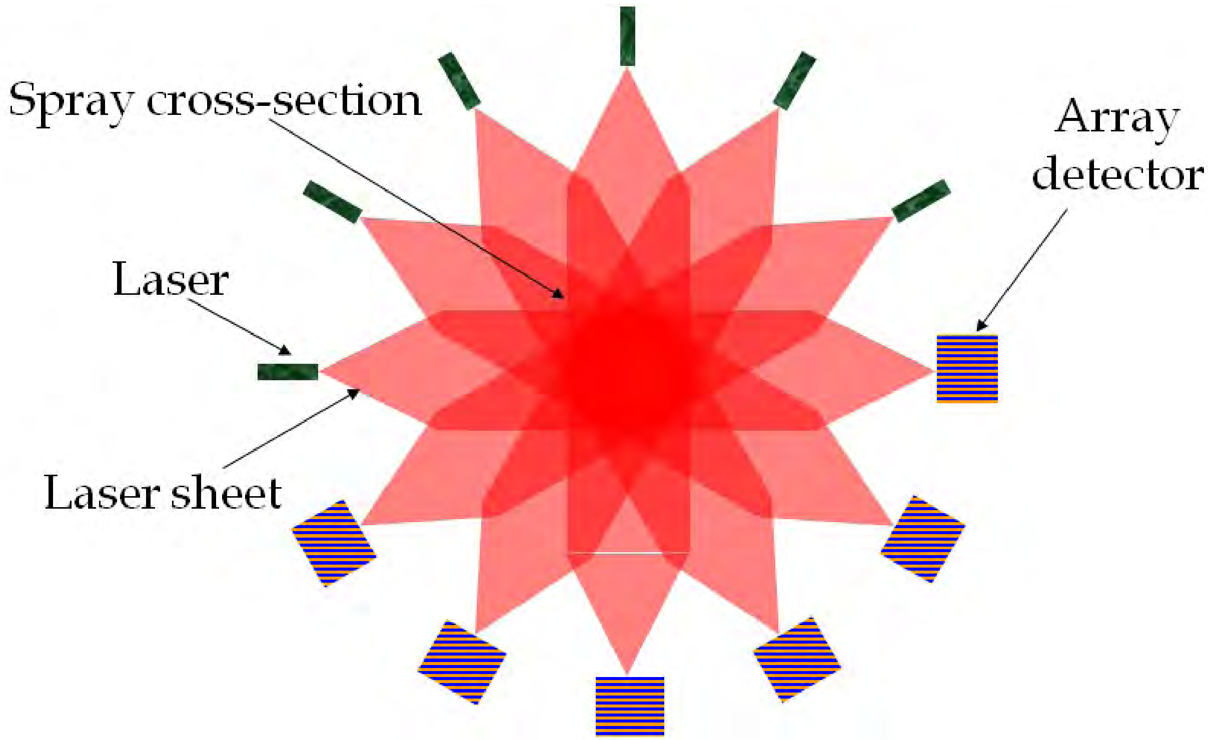
- Excited with laser sheet
- Fluorescence observed with CCD array
- Intensity proportional to fuel volume fraction
- Needs fluorophore (dye)



Potential Errors

- Laser extinction
- Signal attenuation
- Shot-to-shot variation
- Not used for quality audit

The SETScan Patternator



Only quantitative optical patternator in the market

US Patent No. 6,184,989

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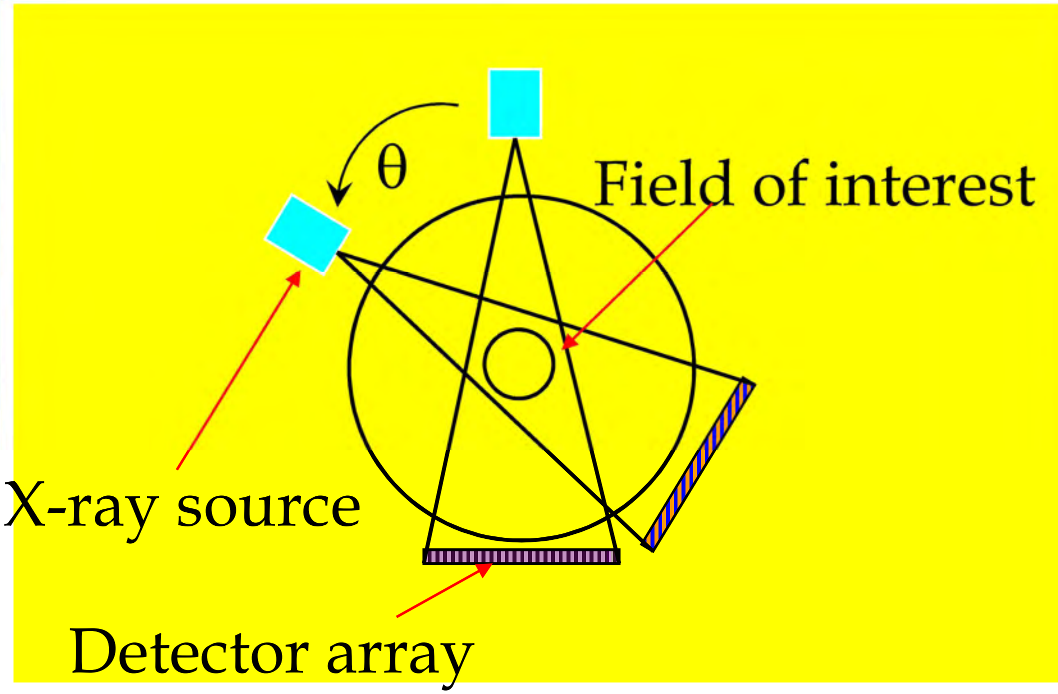
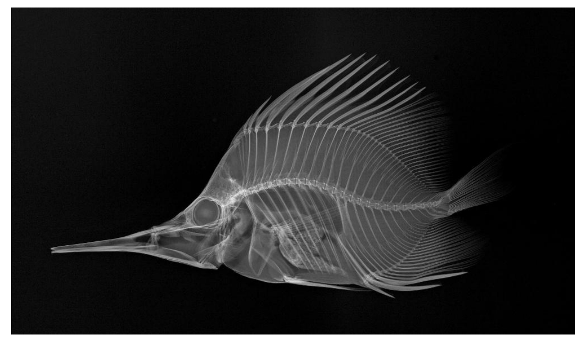
Principle of Operation

- Path integrated extinction of laser sheets
- Multiple view angles for non-axisymmetric turbulent flows
- Multiple slices to obtain high spatial resolution
- High speed (10 KHz) for transient patternation
- Local extinction coefficients obtained by statistical tomography (MLE method)
- For liquid sprays, the local extinction coefficients is equal to the drop surface areas per unit volume

Primer on Tomography



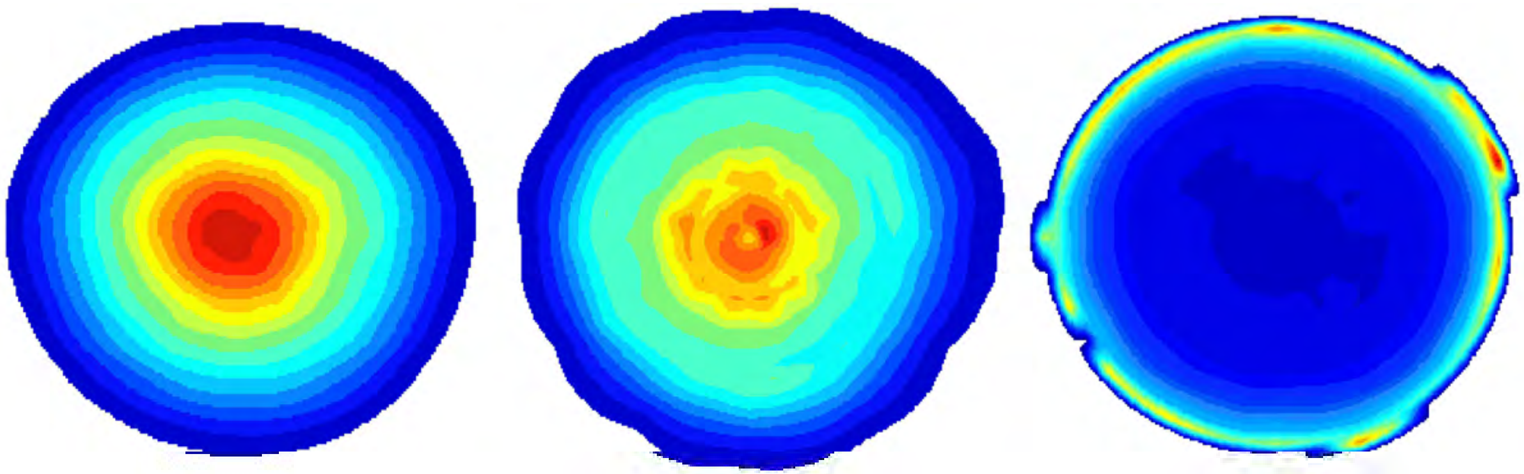


Most successful medical diagnostic tool!

Performance Highlights

- Fast ⇒ 10,000 Hz, transient patternation of fuel injector and high speed sprays
- Extinction ⇒ Well developed technique
- MLE Deconvolution ⇒ Accurate (+/- 2%)
- High repeatability (+/- 2% on patternation number and +/- 0.5 % on drop surface areas and plume angles)
- Six-axis ⇒ Angular resolution up to 5 degrees
- 512 element array ⇒ Spatial resolution up to 0.2 mm
- Immune to factory floor lighting

Basic Information for Quality Control



Mean, RMS, and RMS/Mean of drop surface areas to look at different aspects (uniformity, steadiness, drop size variations, presence of streaks and voids) of the spray

Why surface area density

- Total amount of fuel or liquid evaporated is proportional to heat release rate in combustion and solid mass fraction in spray drying.
- Correlation coefficient (R) of different parameters with total fuel evaporated
- Mass flux R = 0.903   Velocity R = -0.239
- Diameter = 0.681 *Surface area density = 0.961*

For combustion, spray drying, and urea dosing applications, surface area density is optimal method of comparing different nozzles or checking uniformity

Comparison with Competitive Technology

- Extinction ⇒ Immune to environmental lighting
- Diode lasers ⇒ Class II, no safety issues
- Monolithic ⇒ Out-of-box factory floor deployment
- Adaptive grids ⇒ Alignment of nozzle not critical
- Advanced GUI ⇒ Easily operated by technician
- Low power ⇒ Extended life in continuous operation
- Service contracts ⇒ Very short downtime in production
- Reliable ⇒ 100% quality assurance of nozzles

Only quantitative (+/- 2% on absolute values, +/- .5% repeatability) patternator on the market

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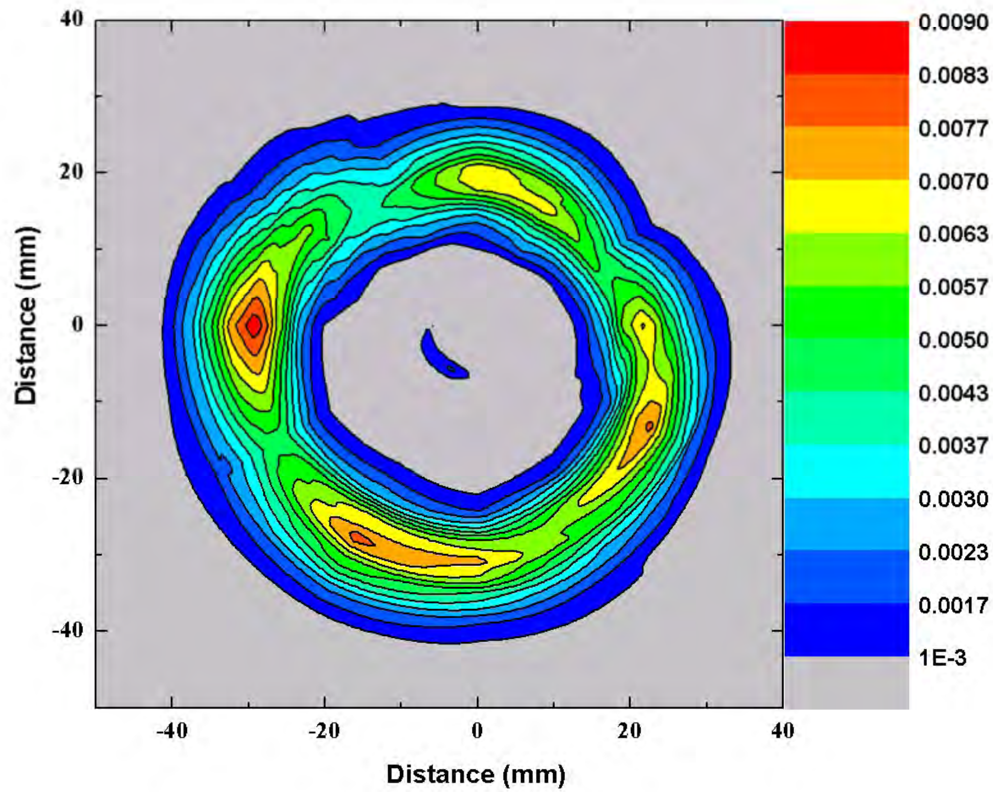
Sample Applications

Aircraft Engine Nozzle

- Struts signature seen in the drop surface area map
- Hollow cone spray seen as hollow
- Drip from nozzle seen at the center
- Good for high flow rate nozzles (greater than 300 kg/hr)



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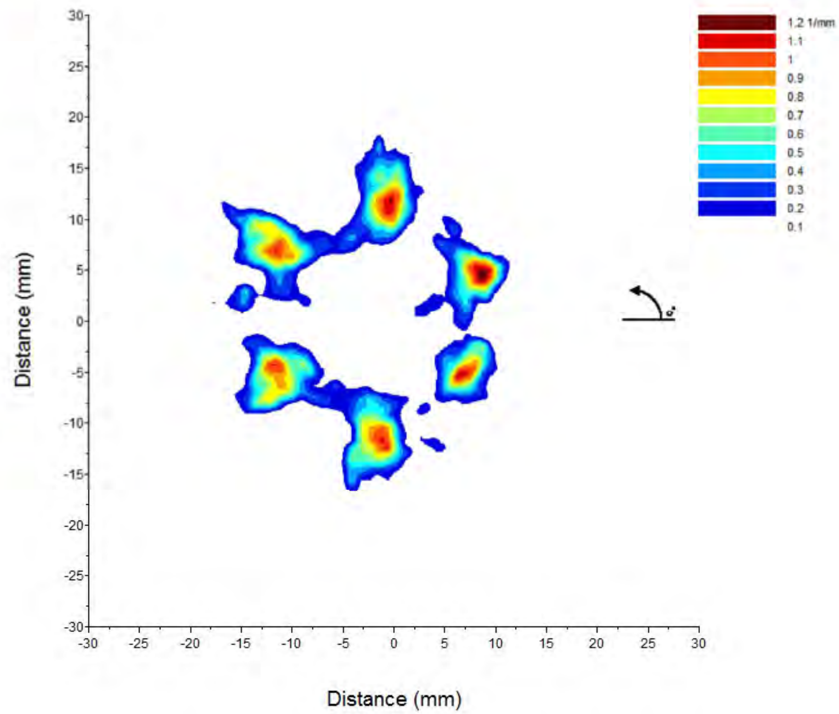
Interpretation of Data

- The data is the ensemble average of drop surface area per unit volume
- Differs from mechanical patternator (which is time average of mass flux)
- High surface area indicates streaks
- Low surface area indicates voids
- 50 to 95% of total enclosed surface areas typically used for defining spray angles
- Both inner and outer cone angles as well as deviation angles used for quality audit of hollow cone nozzles

Automotive Injector

Mean plume angles (deg.)	% area in plume
10.89	19.32
5.73	4.69
11.53	21.71
10.48	17.91
11.51	23.06
9.35	12.93

Mean centroid (x, mm)	Mean centroid (y, mm)
3.26	-5.69
-4.84	14.28
-22.13	1.97
-29.04	-10.75
-15.37	-18.49
0.10	-20.01



Reliable data with multiple plume injectors (GDI, shower heads, diesel, agricultural, etc.)

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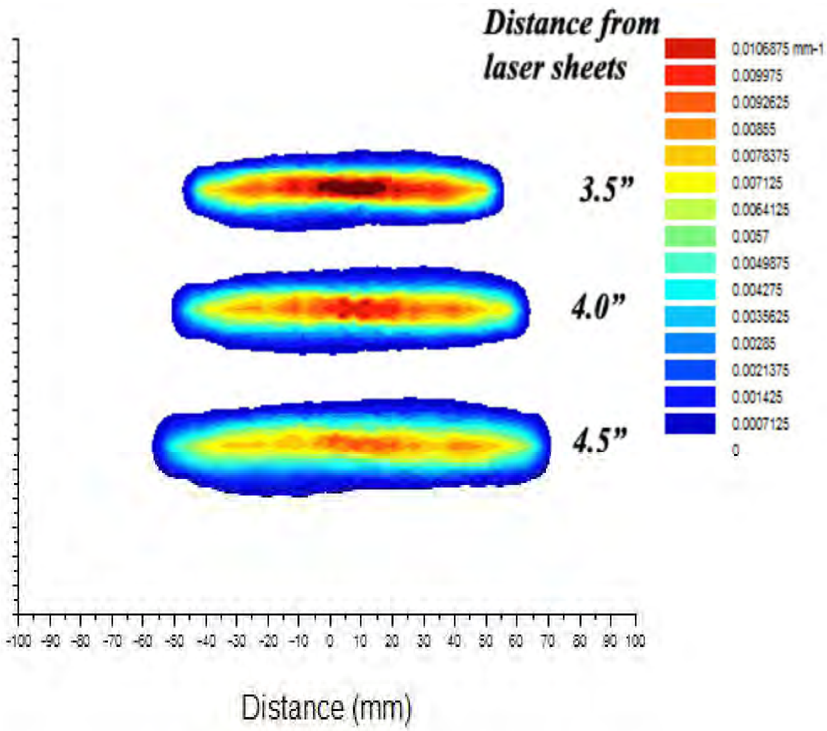
Flat Fan Paint Nozzle



Summary report

Major and minor angles

Deviation from center

Unsteadiness

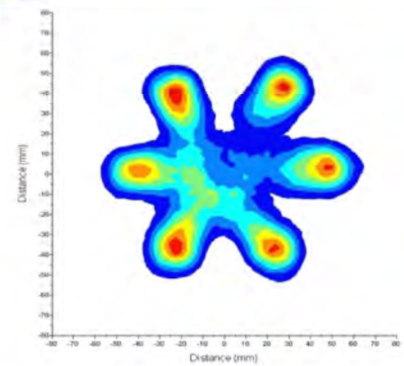
Y-Integral

Roll, Yaw, Pitch, Aim, and Fan angles

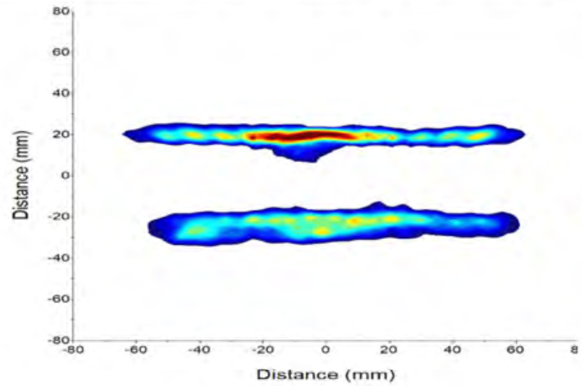
Spray thickness

Used for quantifying wear on nozzles

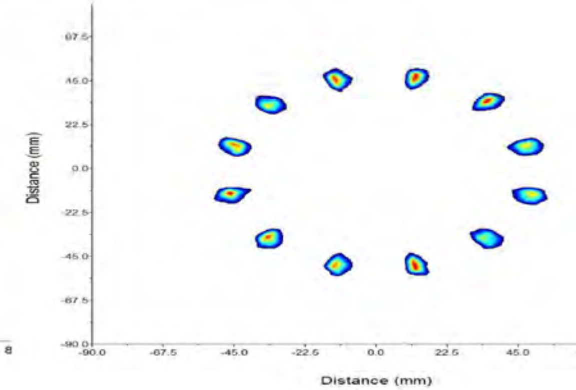
Sample spray patterns



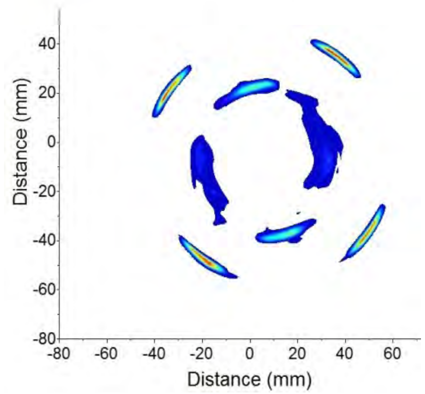
Agriculture



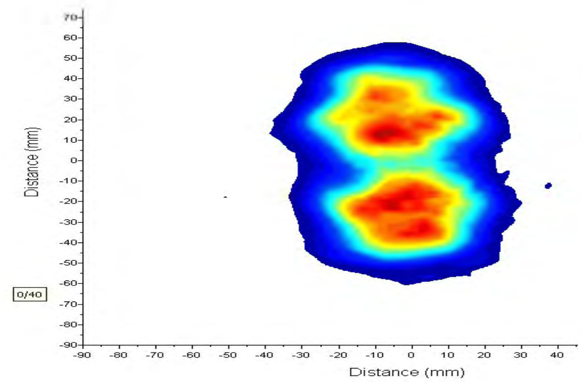
Pesticide



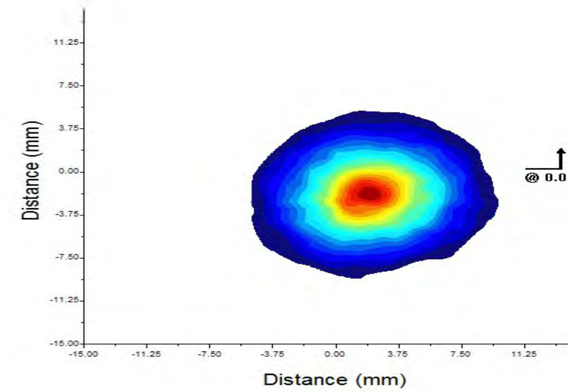
GDI



Showerhead



PFI



Consumer

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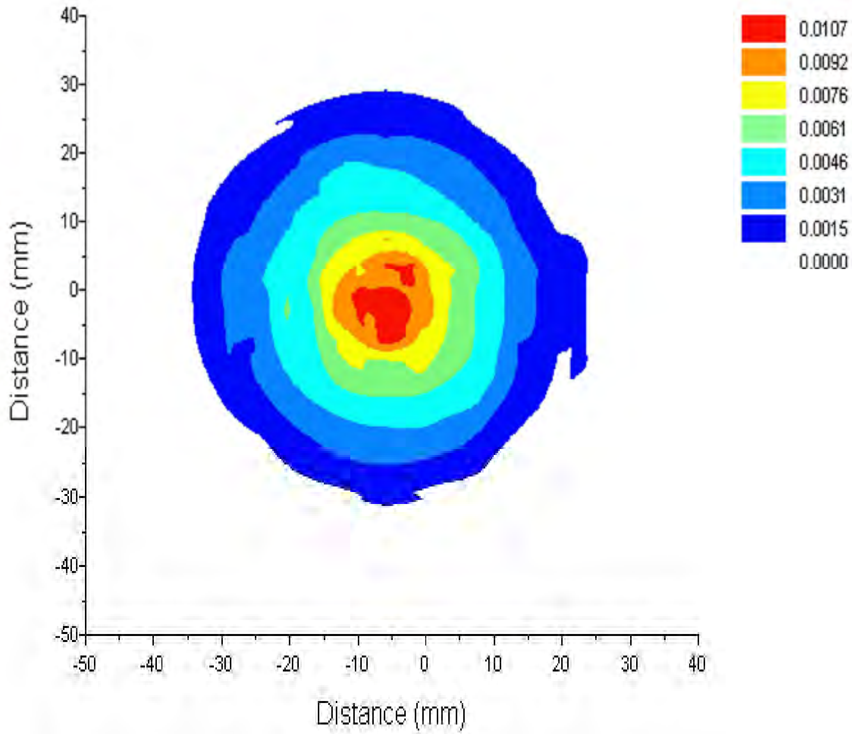
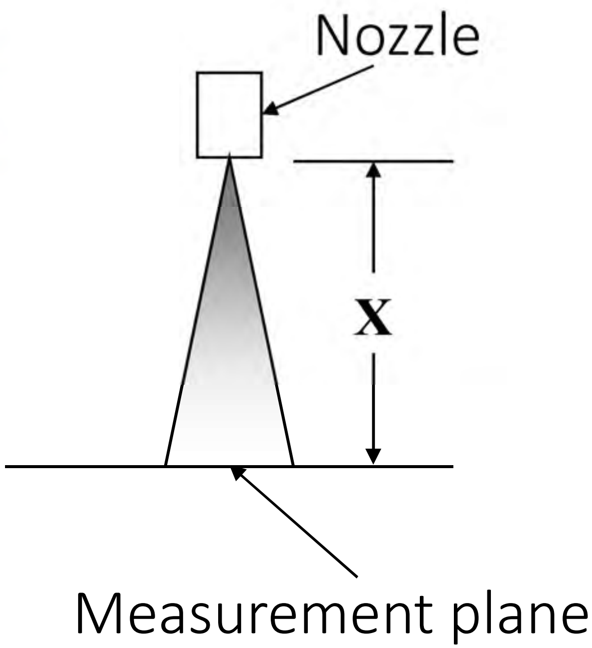
Quality Assurance of Nozzles

Quality Control Objectives

- Define QC parameters
- Set tolerance limits
- Generate master template
- Compare each nozzle with master template
- Accept/reject nozzle based on patternation result
- Typical data collection time of 5 second and analysis time of 3 second with the SETscan optical patternator
- Complete thousands of nozzles per 8 hour shift

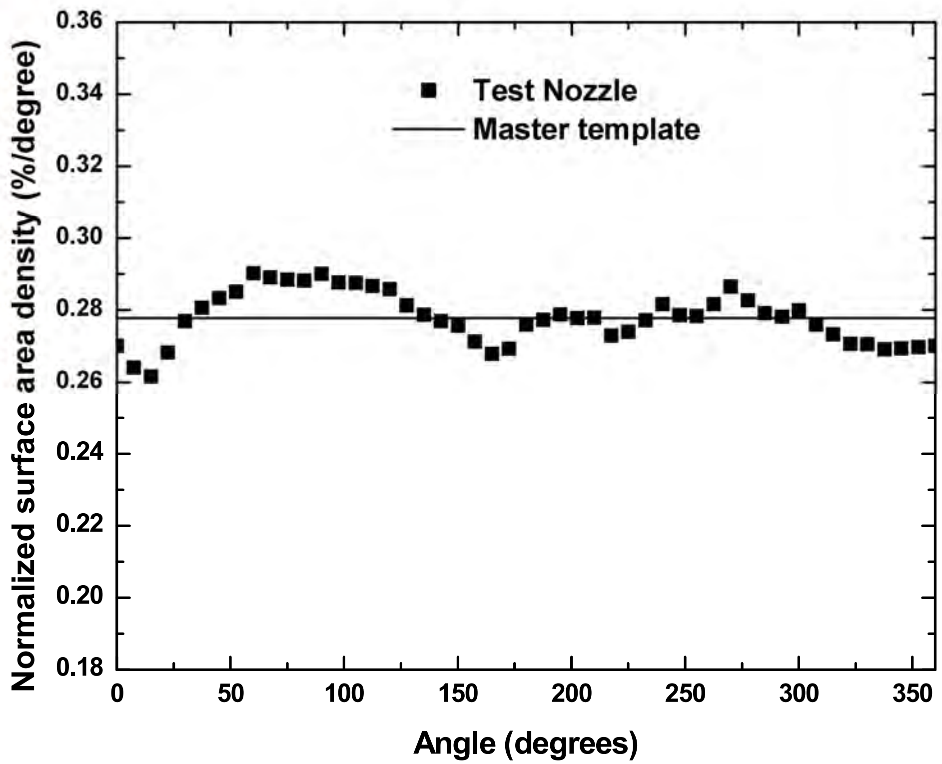
Sample QC parameter: Spray Angle (s)





Major, Minor, Inner, Outer, Roll, Yaw, Pitch, Aim, and Fan angles

Sample QC parameter: Angular Distribution



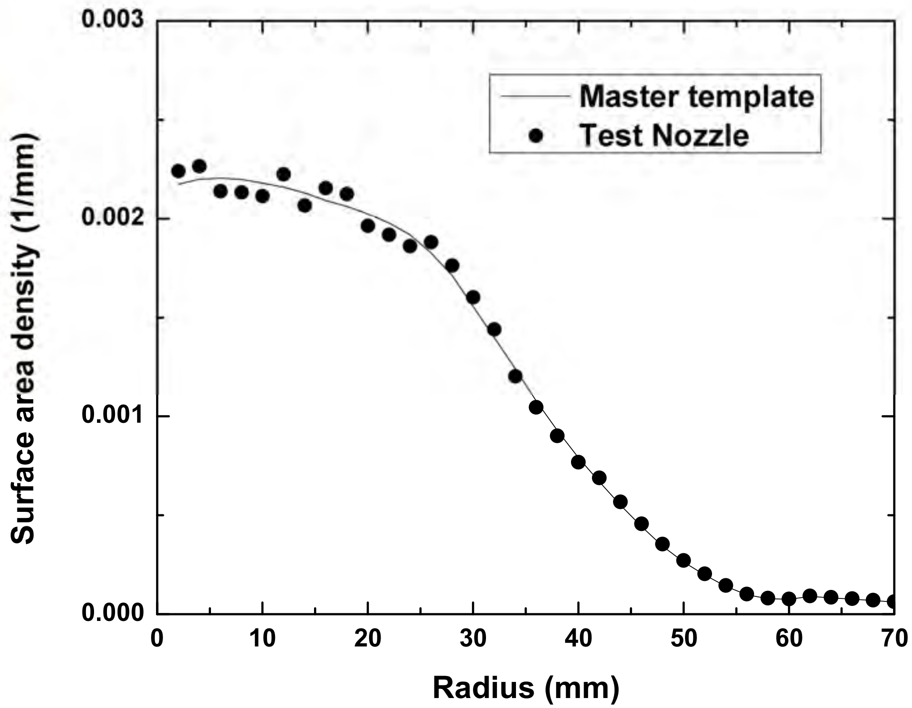
- **Maximum distance**

$$\Delta\Gamma_{Max} = \left|S_t^i - S_m^i\right|$$

- **L2 Norm**

$$L_2 = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(S_t^i - S_m^i)^2}$$

Sample QC Parameter Radial Uniformity



➢ **Maximum distance**

$$\Delta X_{Max} = \left| S_t^i - S_m^i \right|$$

➢ **L2 Norm**

$$L_2 = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (S_t^i - S_m^i)^2}$$

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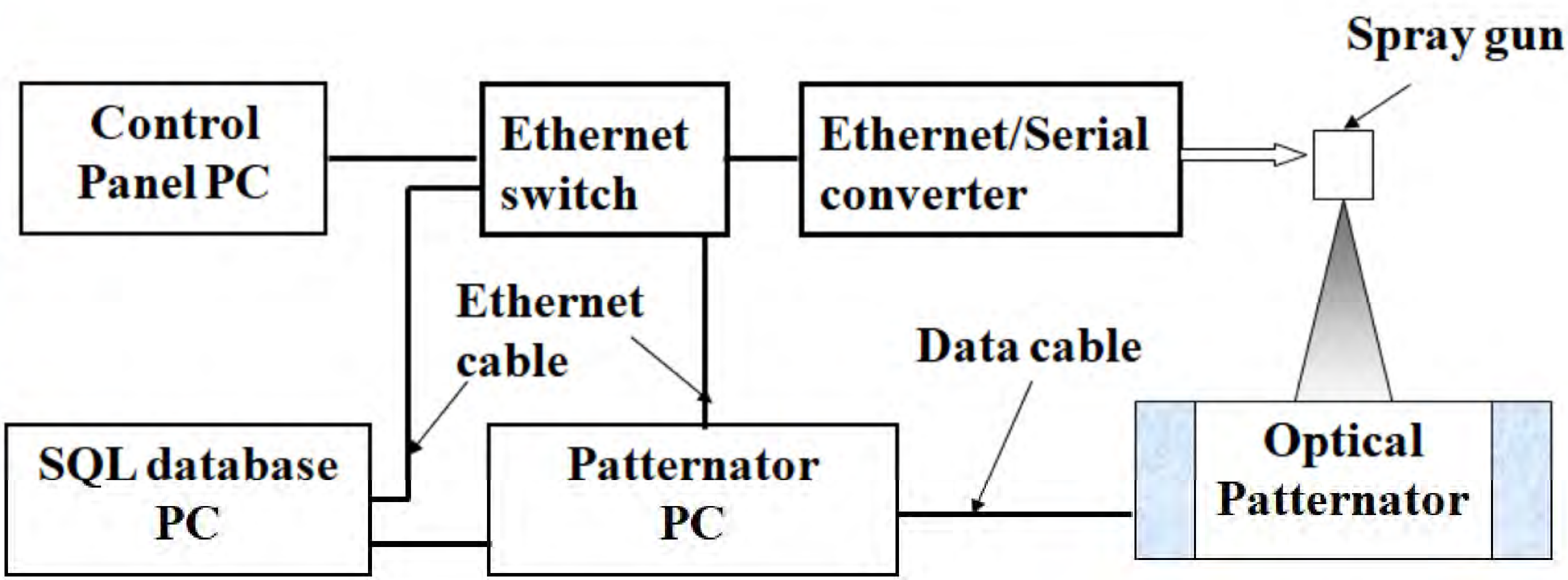
Quality audit configuration



Example configuration with three computers. All functions performed by the three computers can also be implement on a single computer

Sample Report Generated by SETscan

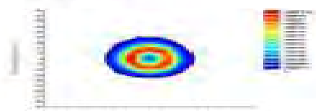
Customer Logo

Optical Patternation Report

Patternation Plot

Radial distribution plot

Contour Plot



Angular distribution plot

Master template limits

1. Angle: A1 – A2
2. L2 Norm Radial: B1 – B2
3. L2 Norm Axial: C1 – C2
4. Deviation angle: D1 – D2
5. Max. radial distance: E1 – E2
6. Max. axial distance: F1 – F2
7. Total surface area: G1 – G2

Measured values

1. Angle: A
2. L2 Norm Radial: B
3. L2 Norm Axial: C
4. Deviation angle: D
5. Max. radial distance: E
6. Max. axial distance: F
7. Total surface area: G

Standard nozzle report

Code No:
Operator No.
Nozzle No:
Date:

SETScan OP-600 patternator

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Sample Installation (OP-600)

- 2 computer QA system
- Automatic nozzle mounts
- Booth by Alsmatik
- QA software by En'Urga
- Multiple types of nozzles
- Typical output: 1000/day

Photograph: Courtesy Danfoss S/A

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Product Quality Implications

- On-line 100% inspection of nozzles enabled
- Traceable and warehoused data
- Quick design verification tool
- Sorting of already manufactured nozzles
- Customer see proactive quality conscious vendor
- Eliminates tedious manual testing of nozzles
- Less quality errors than manual testing

Selected Patternator Customers

Abbott	General Motors	Hitachi
Bend Research	Cummins	AVL
Pfizer	Emcom Technologies	FEV
S.C. Johnson & Son	Faurecia	Nordson
Catalytica Energy	Donaldson	Delavan
Delphi	Proctor & Gamble	Woodward
Ricardo	Honeywell	Tenneco
Continental	Bombardier	Synerject
Eaton	Rolls Royce	Danfoss
Columbian Chemical	General Electric	Boston Scientific
United Technologies Aerosapce System	Dow Agrosciences Laboratories	Vertex Pharmaceuticals
Toyota	Bosch LLC.	3M

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Selected Customer Comments

"We purchased the patternator and in six months we approached our customer with a request to tighten tolerances on the nozzles we produce"

"The SETscan patternator has given us an order of magnitude return on investment within one year after purchase"

"The first time I saw the patternation results obtained with our nozzles on the SETscan, I was amazed. I did not realize what was possible with current technology"

"Our department will most probably win the improved productivity award of our company, thanks in a large measure to the SETscan patternator"