The SETScan Patternator

An Overview

En'Urga Inc.

1201 Cumberland Avenue, Suite R, West Lafayette, IN 47906

765-497-3269 ***http://www.enurga.com***

En'Urga Inc.

innovations in quality control

SETscan®

Outline

- Background on optical tomography
- Sample applications such as spray diagnostics
- Quality assurance using optical patternator

Background on Optical Patternation

Why Optical Patternation?

Purpose: Obtain a cross-section profile of materials

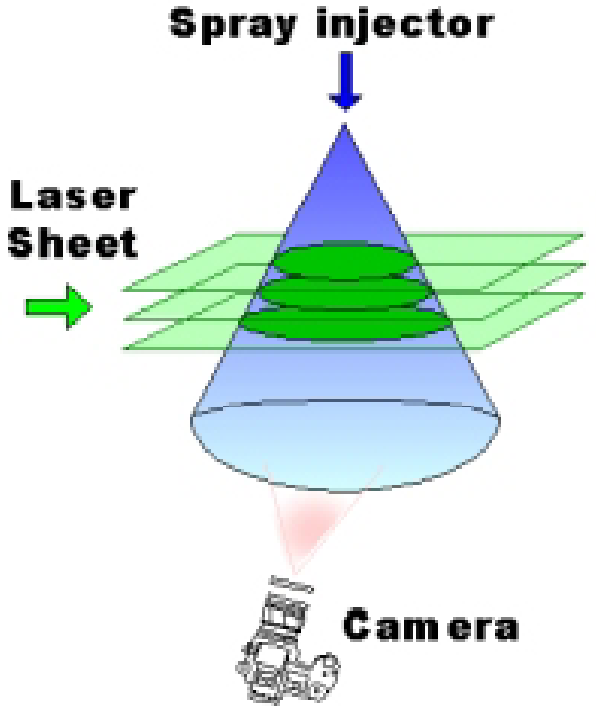
- **Fast, capable of obtaining transient data**
- **Greater reproducibility than mechanical devices because no moving parts**
- **No interference with the spray**
- **Greater spatial resolution**
- **Low maintenance and operational cost**

Principal Types of Optical Patternators

- Laser sheet imaging
- Planar Laser Induced Fluorescence
- Extinction based systems (SETscan)

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

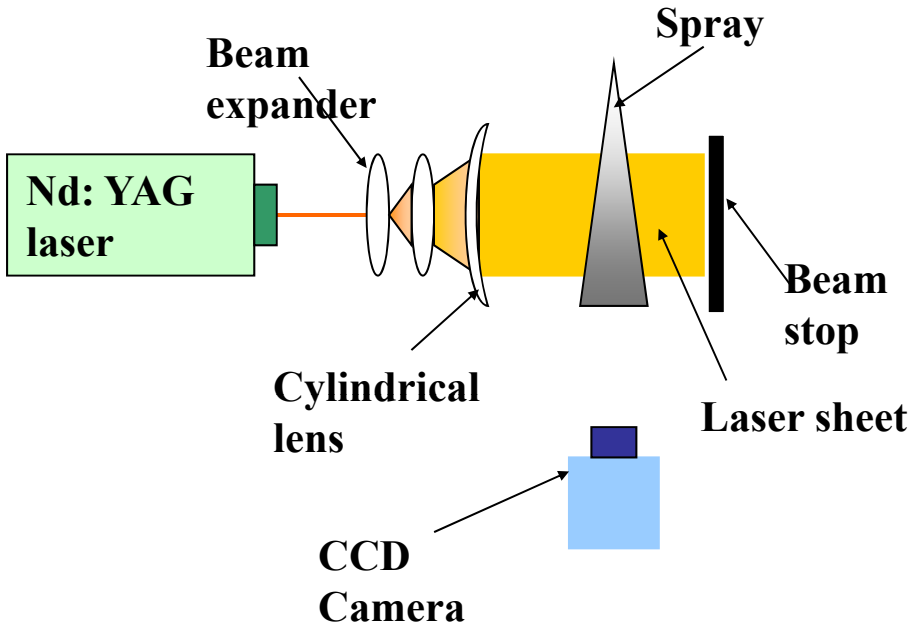
- Laser extinction
- Signal attenuation
- Secondary emission

Source: Brown et al., ILASS - 2003

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

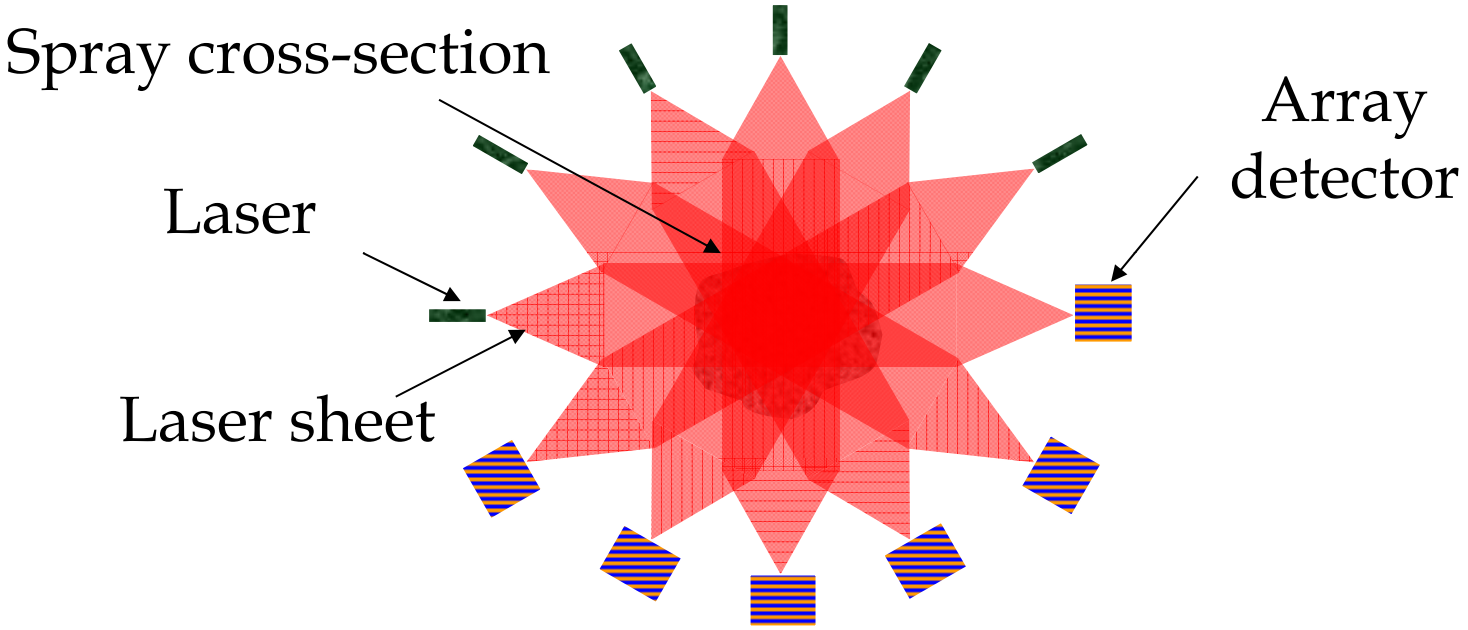


Potential Errors

- Laser extinction
- Signal attenuation
- Shot-to-shot variation

Source: Pastor et al., Opt. Express, 2002

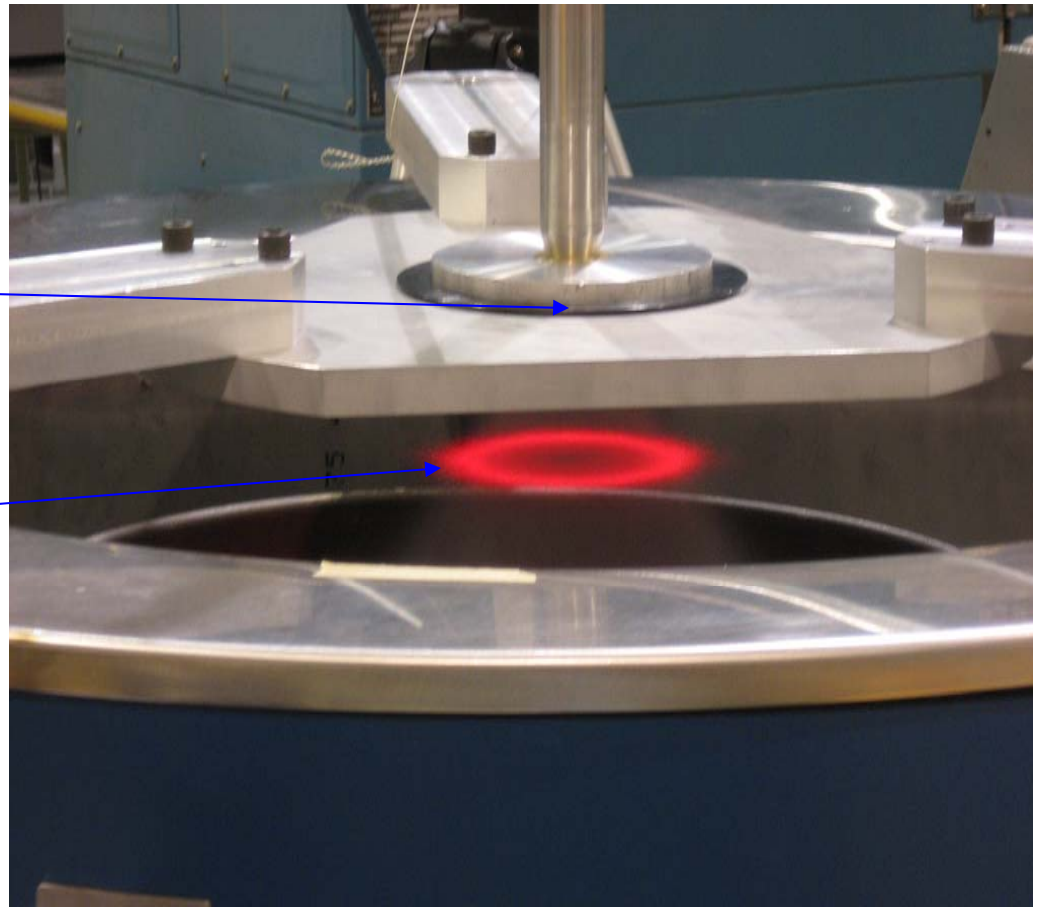
The SETscan Patternator (Extinction Based)



Example Spray in Laser Sheet

Hollow Cone Aircraft Engine Nozzle

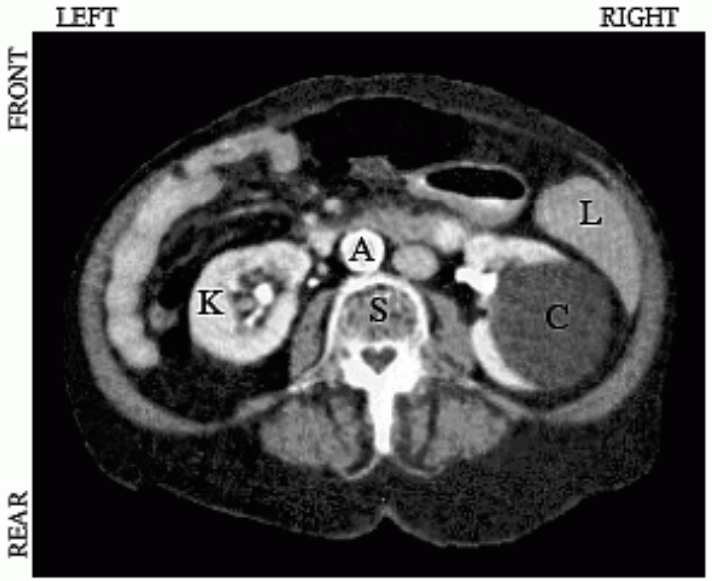
Laser Sheet



What is Tomography?

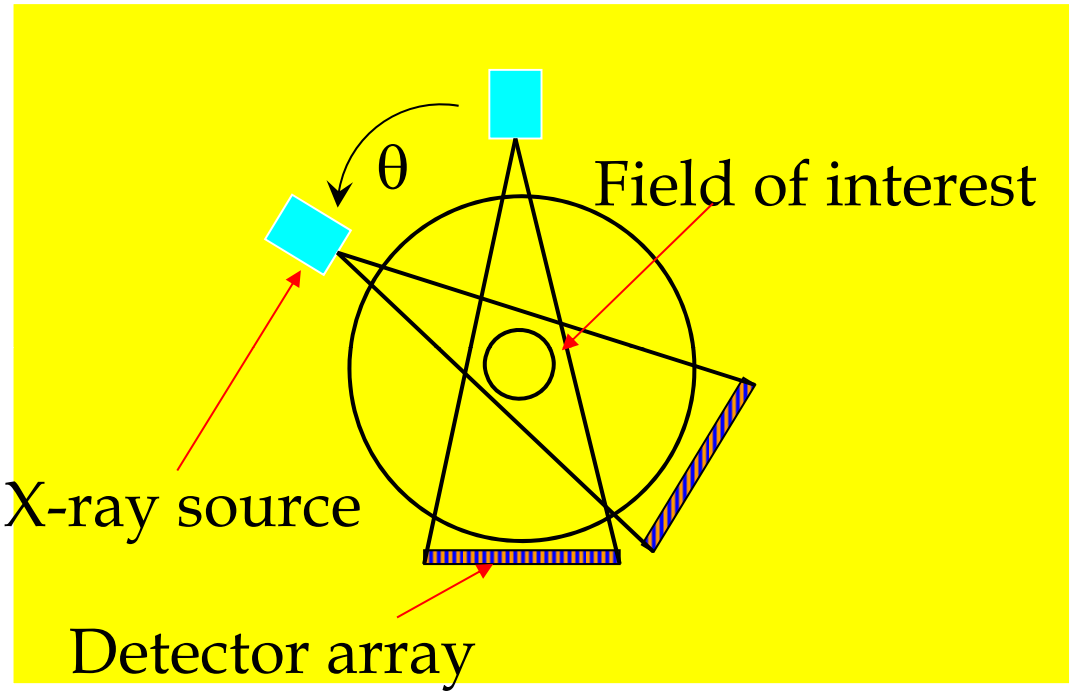
- Tomography means “a picture of a plane.”

FIGURE 25-13
Computed tomography image. This CT slice is of a human abdomen, at the level of the navel. Many organs are visible, such as the (L) Liver, (K) Kidney, (A) Aorta, (S) Spine, and (C) Cyst covering the right kidney. CT can visualize internal anatomy far better than conventional medical x-rays.



Cross-section plane
of a human abdomen

Primer on Tomography



Most successful medical diagnostic tool!

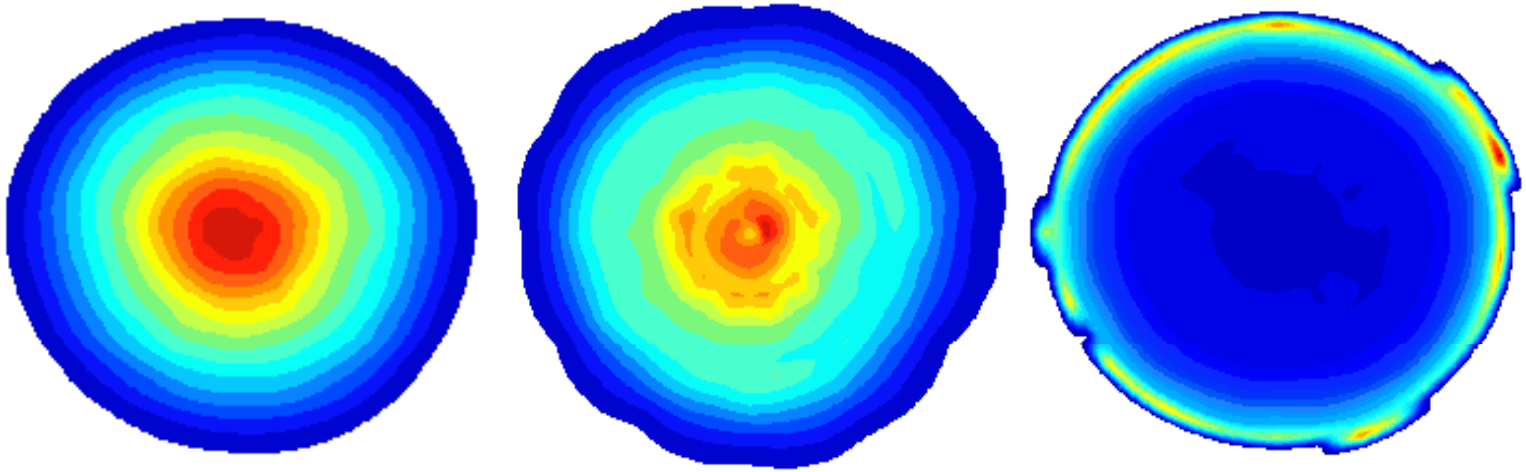
Principle of SETscan Operation

- Path integrated extinction of laser sheets
- Minimal noise from scattering due to line detectors
- Multiple view angles for non-axisymmetric turbulent flows
- Multiple slices to obtain high spatial resolution
- Local extinction coefficients obtained by statistical tomography (MLE method)
- For liquid sprays, the local extinction coefficient is equal to the drop surface areas per unit volume

Performance Highlights

- **Fast Data Acquisition ⇒ Up to 10,000 Hz, transient patternation of fuel injector sprays**
- **Extinction ⇒ Well developed technique**
- **Maximum Likelihood Extinction MLE Deconvolution ⇒ Accurate (+/- 2%), Fast (~2 seconds)**
- **High repeatability (+/- 2% on patternation number)**
- **Six-axis ⇒ Angular resolution up to 5 degrees**
- **512 element array ⇒ Spatial resolution up to 0.2 mm**

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.
- Statistical Correlation coefficient (R) of different parameters with total fuel evaporated
  - Mass flux R = 0.903
  - Diameter = 0.681
  - Velocity R = -0.239
  - ***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

SETscan Advantages:

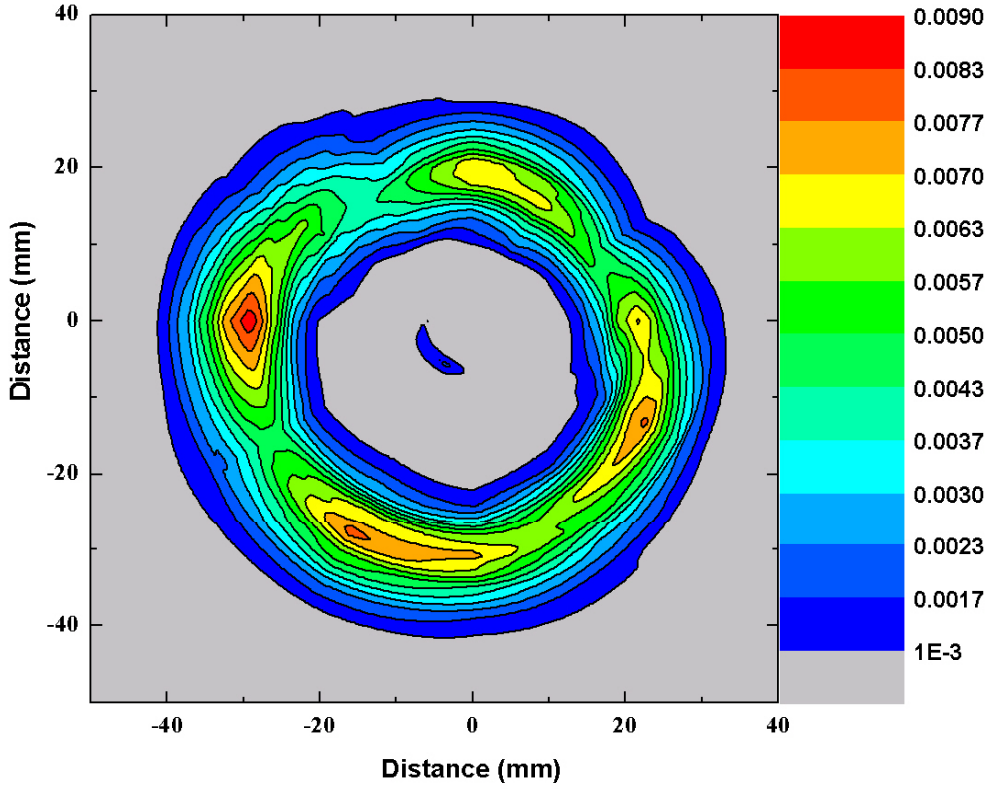
- Extinction ⇒ Immune to environmental lighting
- Diode lasers ⇒ Class II, No safety issues
- Monolithic ⇒ Out-of-box factory floor deployment
- Adaptive grids ⇒ Alignment of nozzle not critical
- Advanced GUI ⇒ Easily operated by technician
- Reliable ⇒ 100% quality assurance of nozzles

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

Sample Applications

Aircraft Engine Nozzle

- Struts signature seen in drop surface area map
- Hollow cone seen as hollow
- Drip from nozzle seen at the center

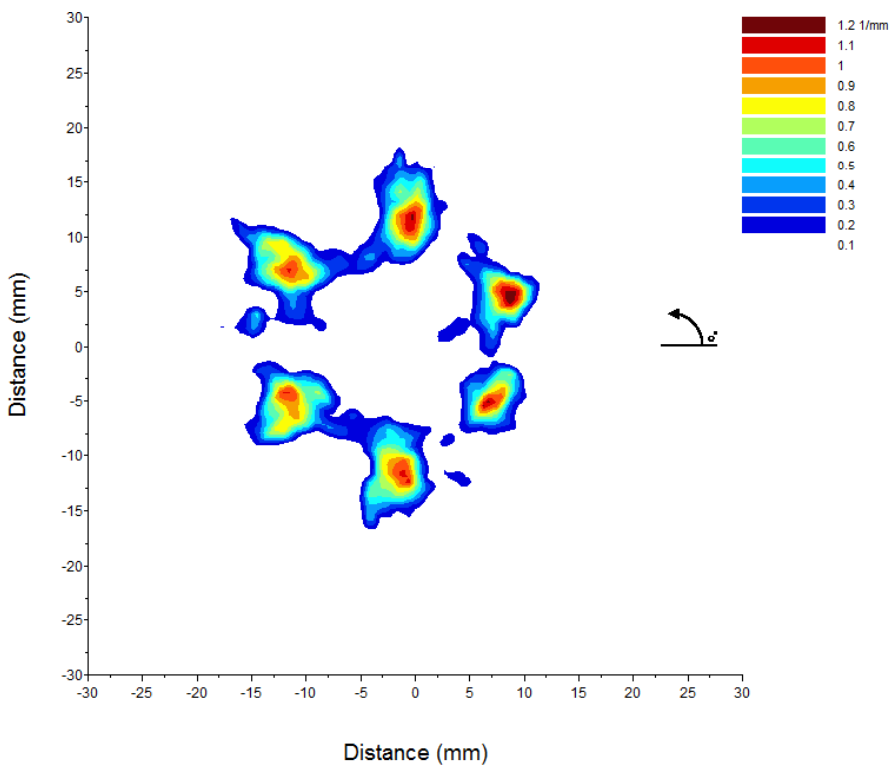


Interpretation of Data

- 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
- 95% ring typically used for spray angle

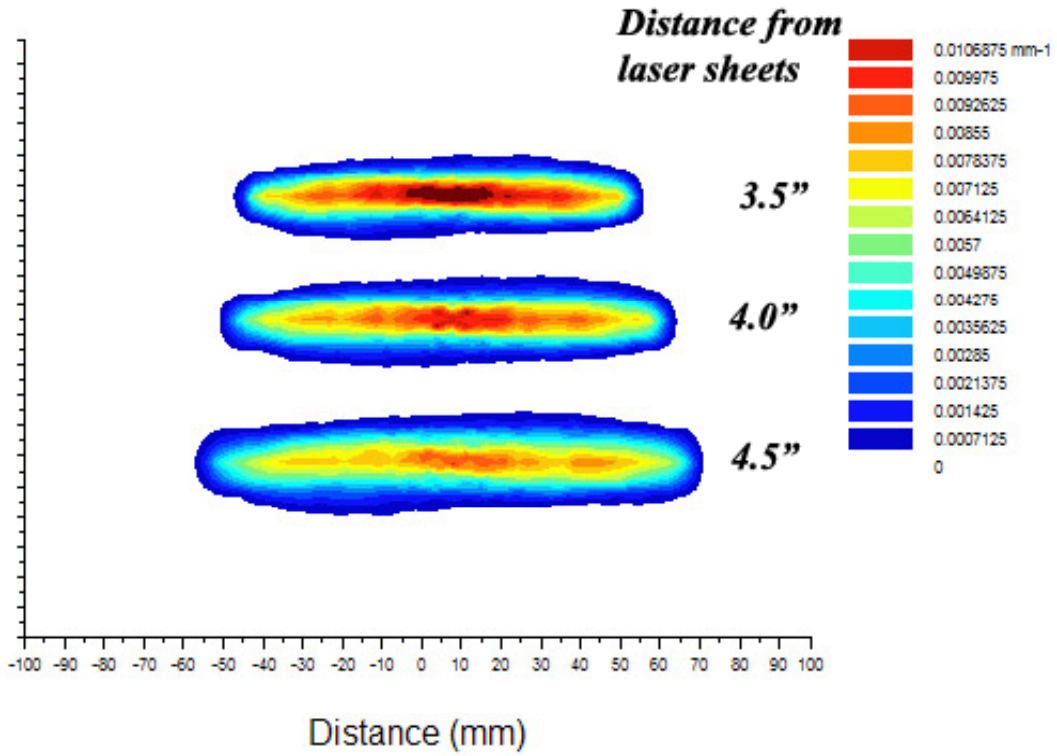
Automotive Injector

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 orifice injectors

Flat Fan Paint Nozzle



Quality Assurance of Nozzles

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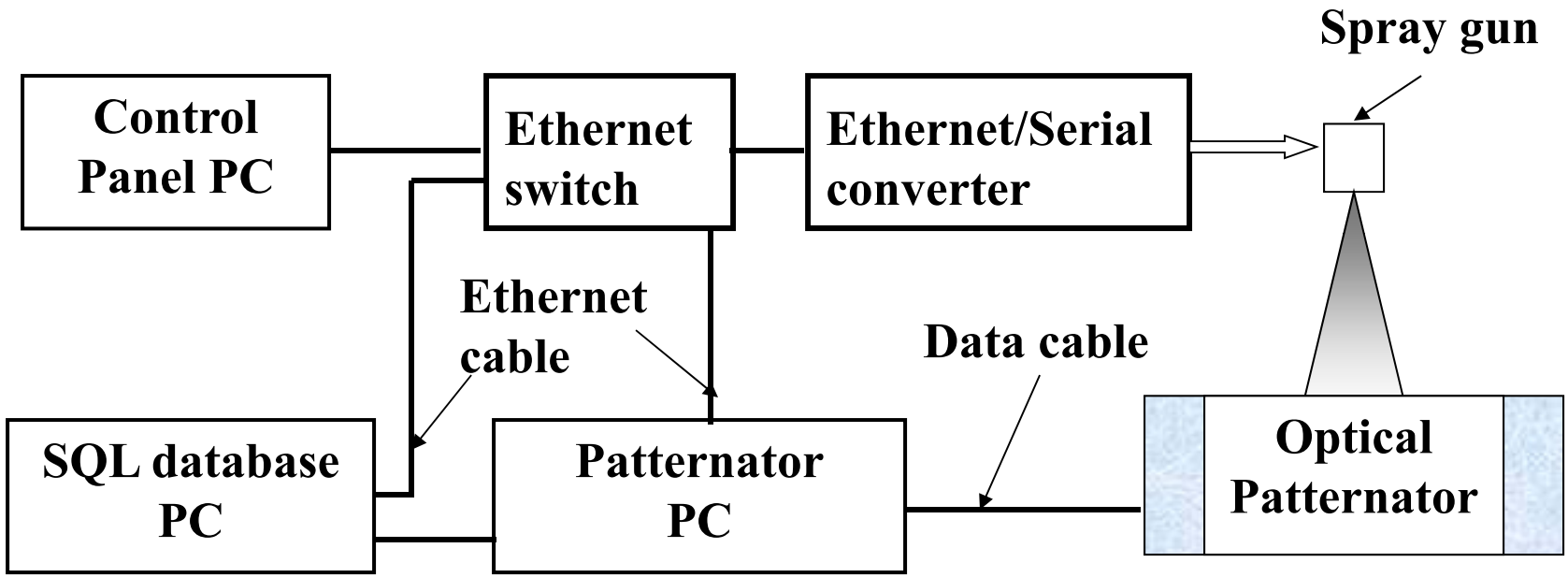
Quality Control Objectives

- Define QC parameters
- Set tolerance limits
- Generate master template
- Compare each nozzle with master template
- Accept/reject nozzle based on patternation result

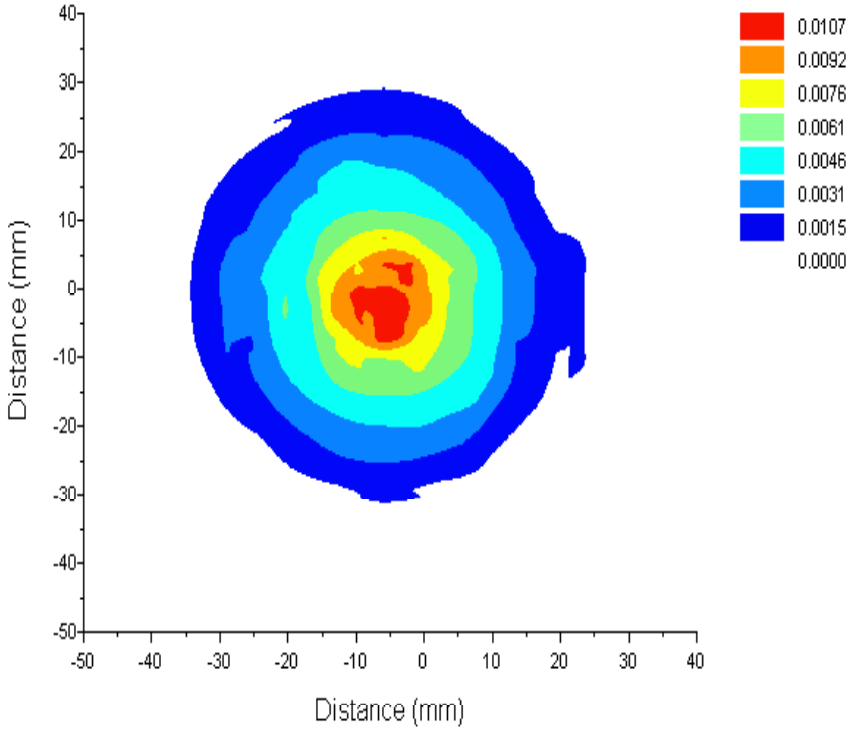
Quality audit configuration

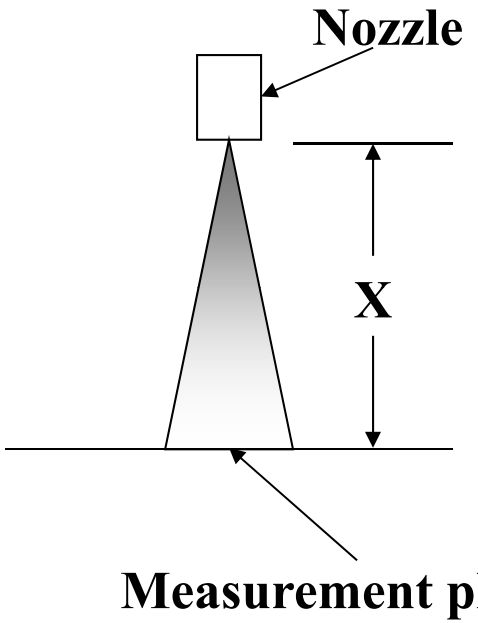


Product Quality Implications

- On-line 100% inspection of nozzles enabled
- Traceable and warehoused data
- Quick design verification tool
- Sorting of already manufactured nozzles
- Can provide Summary Report which includes Major Angle, deviation from center, unsteadiness, Y-integral, Custom parameters

Sample QC parameter (1): Spray Angle





Angle = $2*(\tan^{-1}(R/X))$

Integrate in concentric circles, each of larger radius, until 95% of Spray Surface Area Density is found.

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

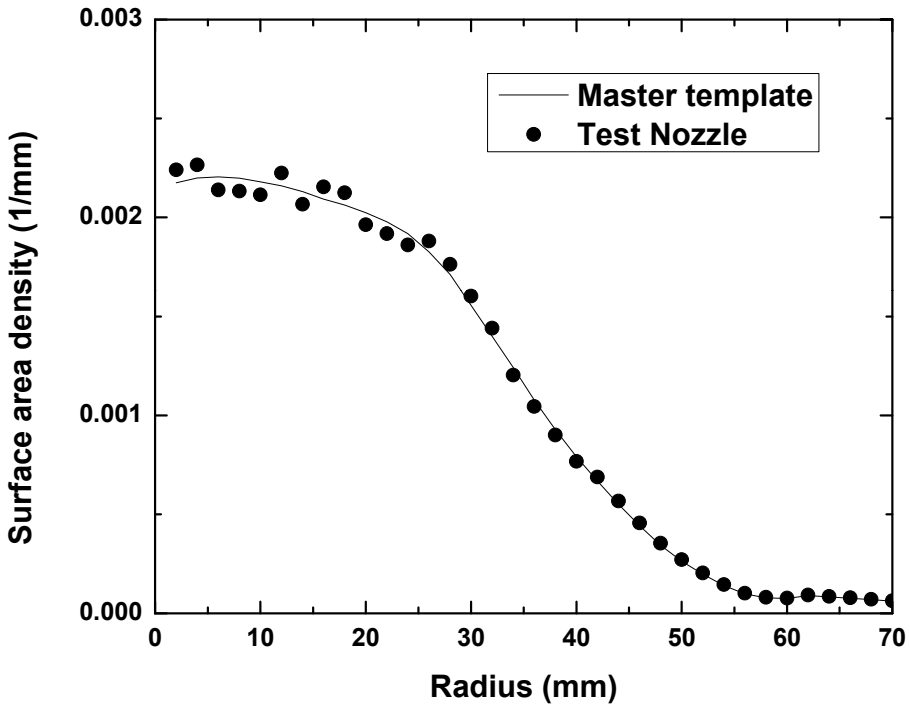
Selected Patternator Customers

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

Any Questions?

Extra Slides

Sample QC Parameter (3): Radial Uniformity



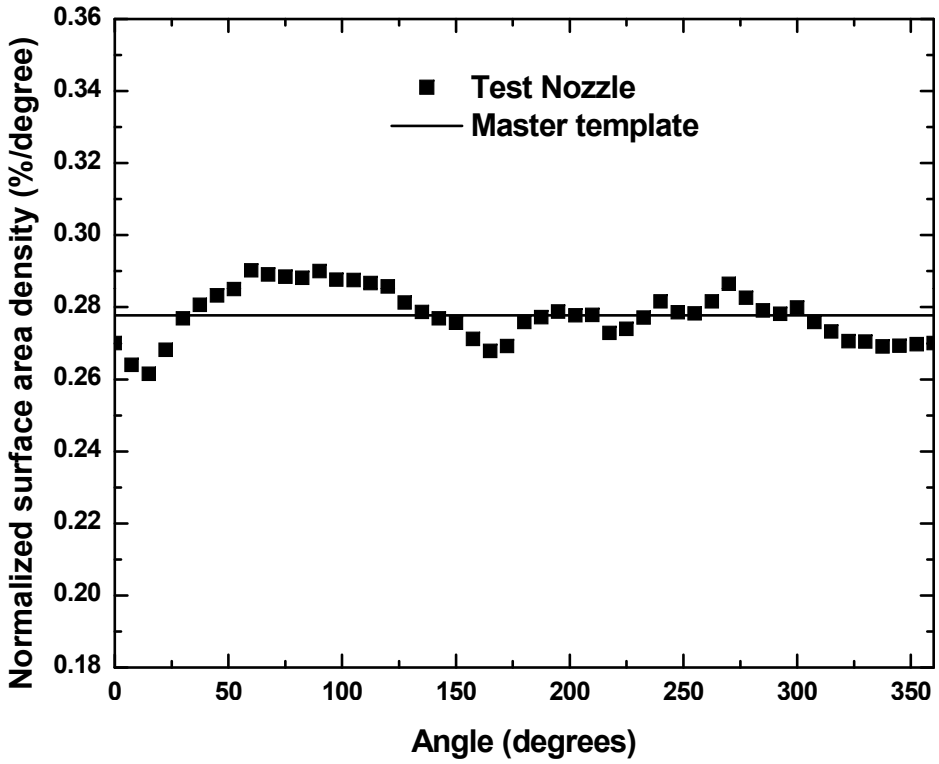
➢ **Maximum distance**

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

➢ **L2 Norm**

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

Sample QC parameter (2): Angular Distribution



➢ **Maximum distance**

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

➢ **L2 Norm**

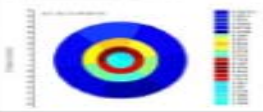
$$L_2 = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(S_t^i - S_m^i)^2}$$

Sample Report Generated by SETscan

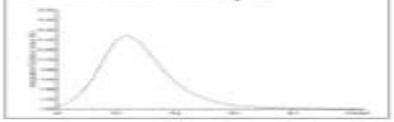
Customer Logo

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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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 we purchased it"

"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"