

# Extinction Tomography for Spray

## An Overview



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# Outline

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- **Optical patternator (visible light)**
- **X-Ray patternator (soft X-Rays)**



# Optical patternator



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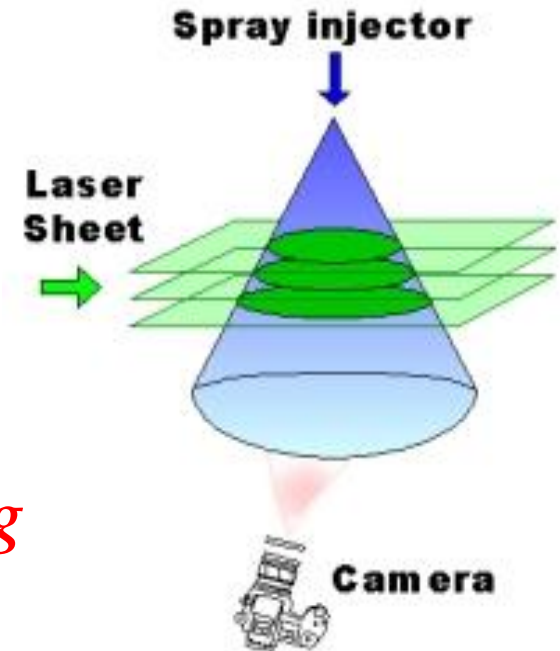
# Advantages of optical patternator

- **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**

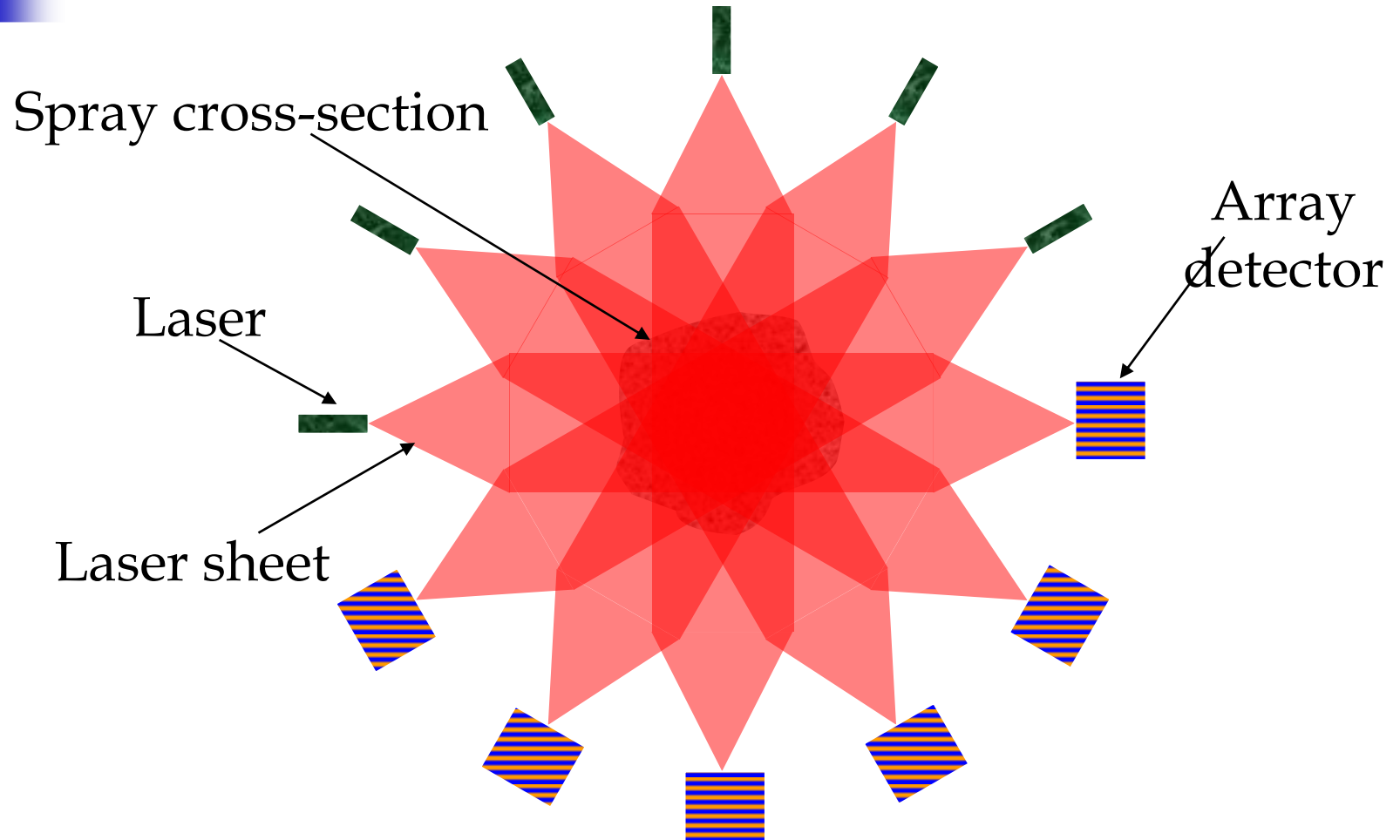
# Principal Types of Optical Patternators

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

*First two methods have errors arising from laser extinction, signal attenuation, and secondary emission  
Not used for quantitative patterning*



# The SETScan Patternator

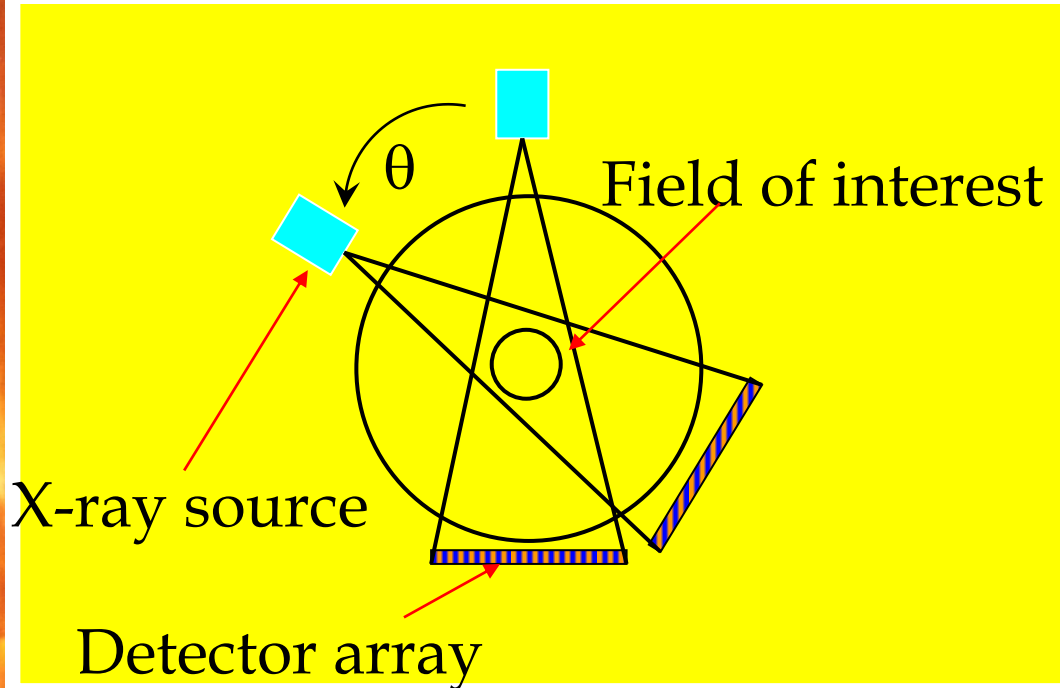




# Principle of Operation

- **Path integrated extinction of laser sheets**
- **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 coefficients is equal to the drop surface areas per unit volume**

# Primer on Tomography



*Most successful medical diagnostic tool!*



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# Performance Highlights

- **Fast** ⇒ Up to 10 KHz, transient patterning of fuel injector sprays
- **Extinction** ⇒ Well developed technique
- **MLE Deconvolution** ⇒ Accurate (+/- 2%)
- **High repeatability** (+/- 2% on patterning number)
- **Six-axis** ⇒ Angular resolution up to 5 degrees
- **512 element array** ⇒ Spatial resolution up to 0.2 mm

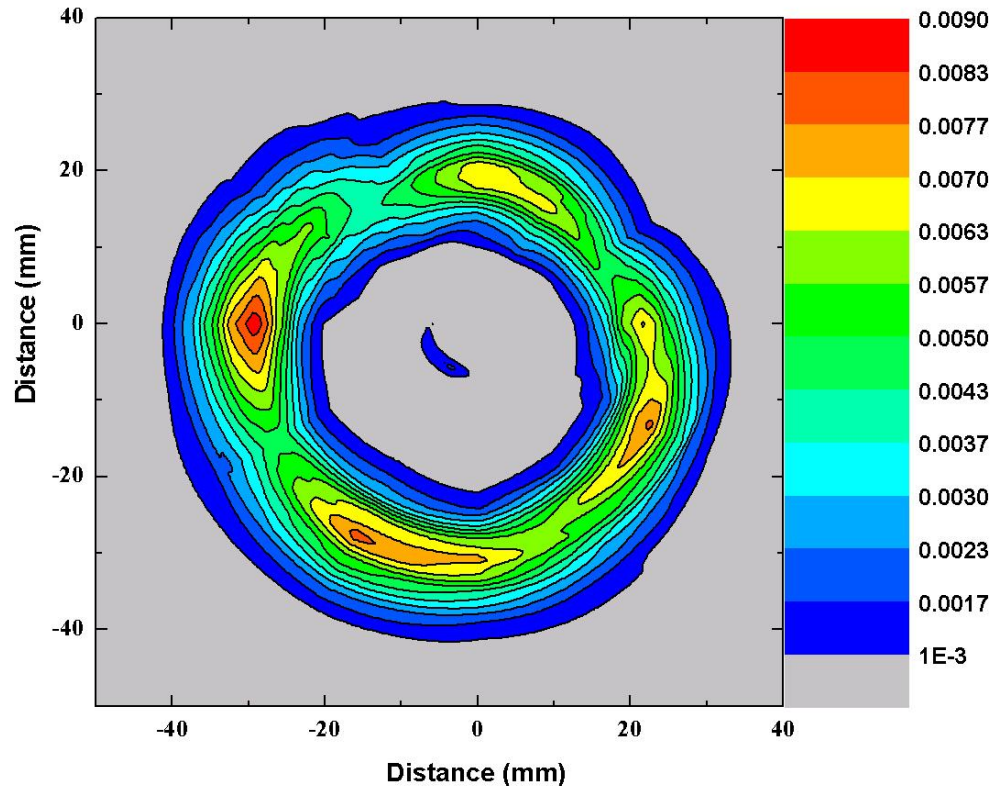
# Comparison with Competitive Technology

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

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

# Sample: Aircraft Engine Nozzle

- Struts signature seen in drop surface area map
- Hollow cone seen as hollow
- Drip from nozzle seen at the center
- High flow rate ~ 200 kg/hr



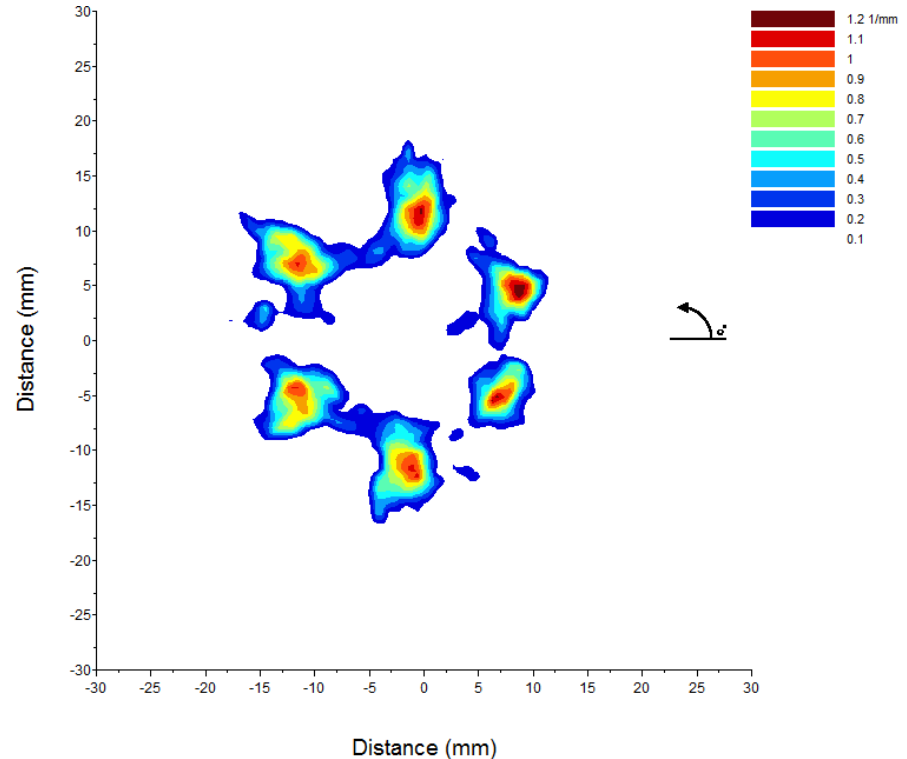


# Interpretation of Data

- **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*



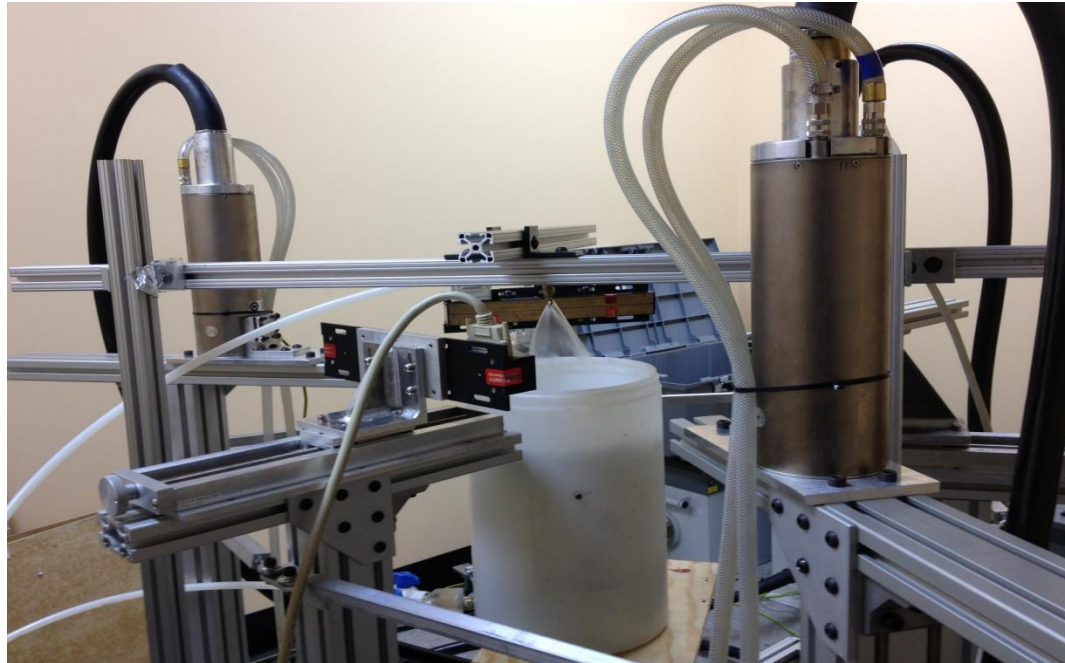
# X-Ray Patternator



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# Open source design



*Three sources in fan beam configuration within a 12 ft x 12 ft x 6 ft lead lined chamber*

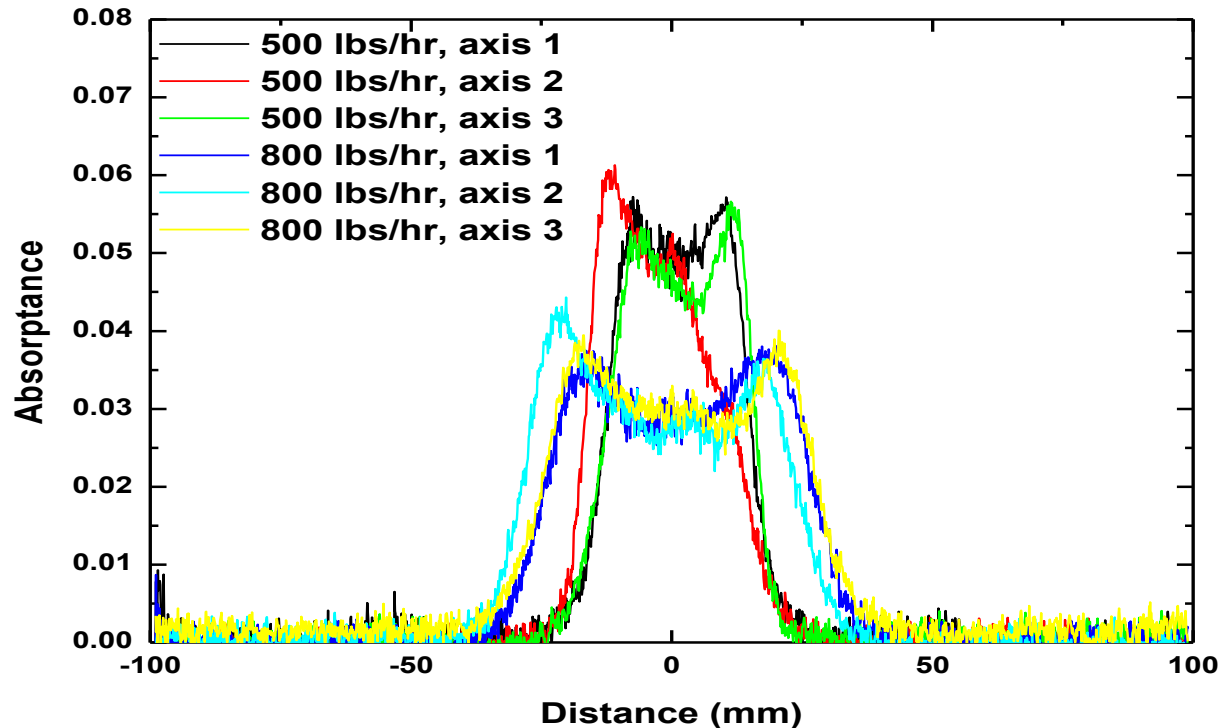


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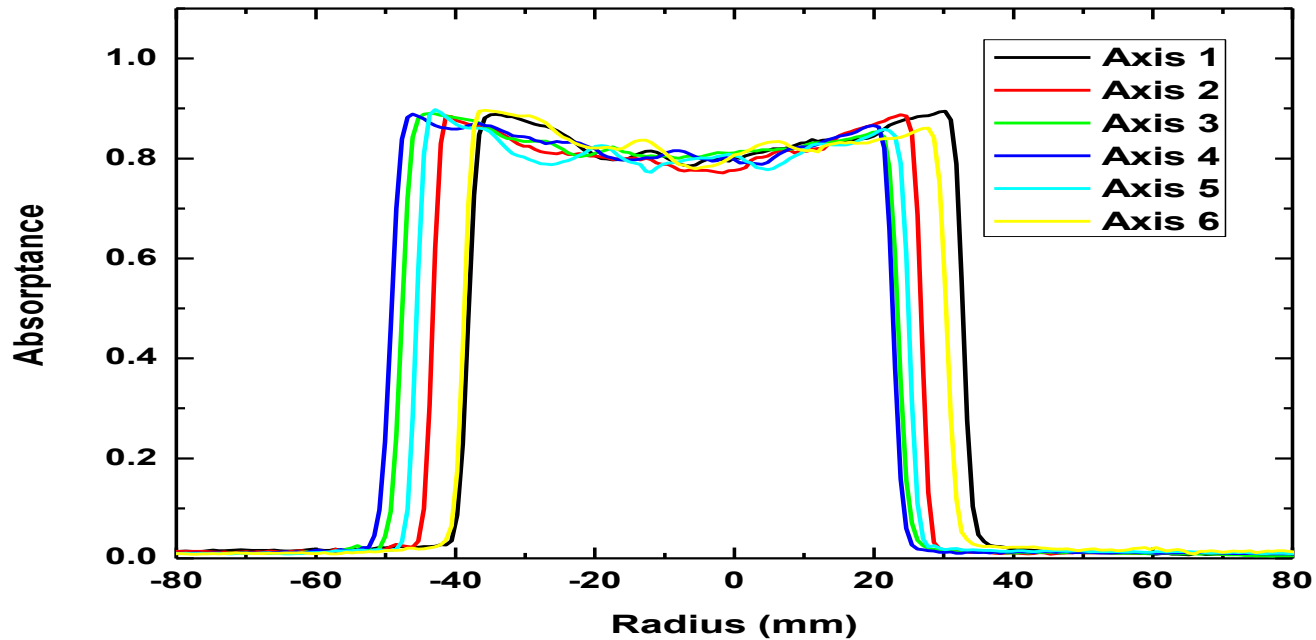
# Absorptance Measurements in Sprays



- Peak absorptance < 10% implies can look at tons/hr
- Larger flow rate has wider spread

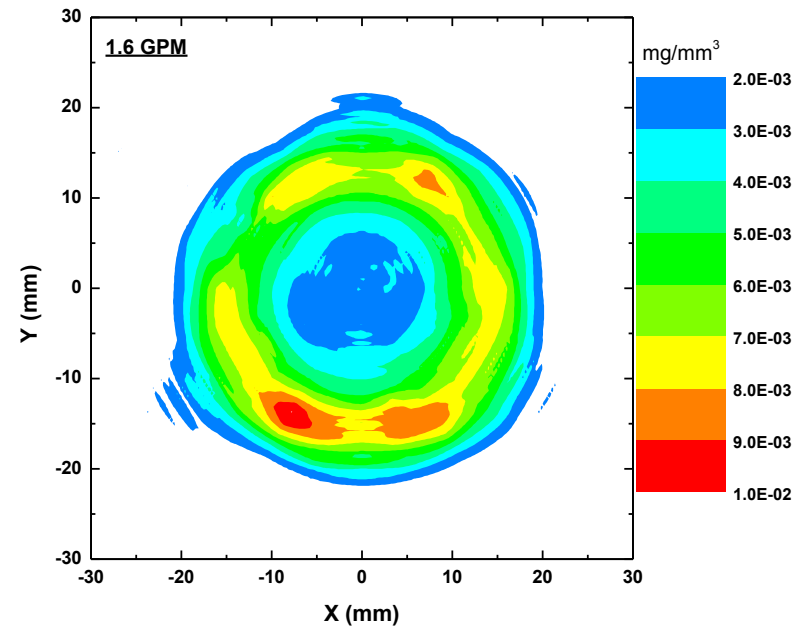
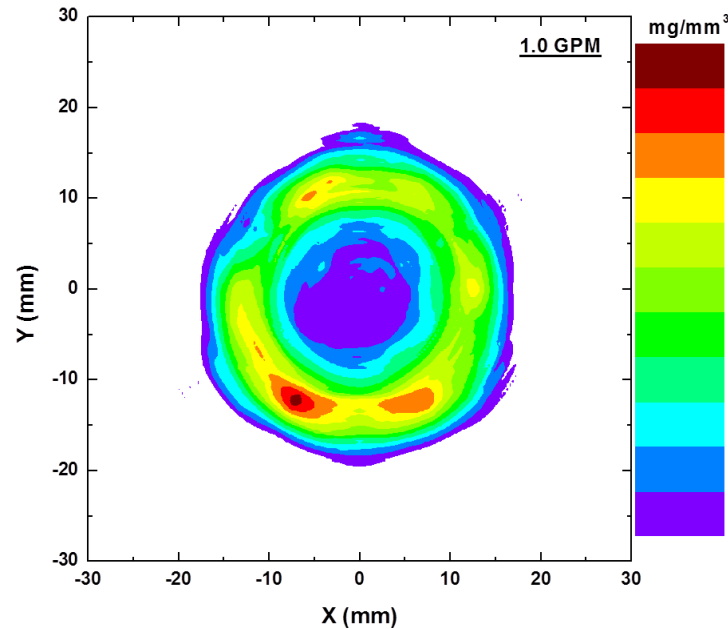


# Comparison with optical patternator



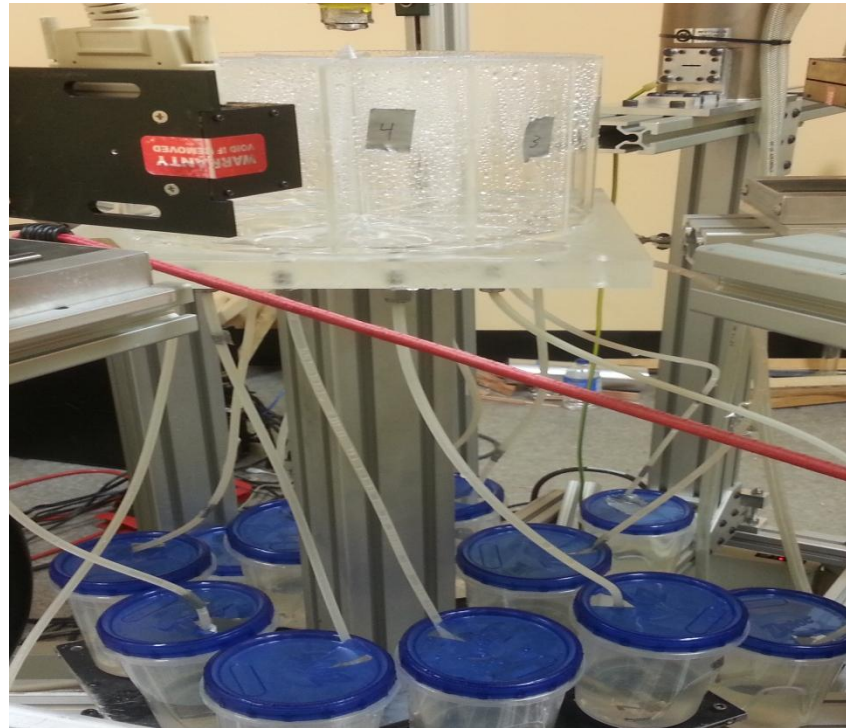
- 500 lbs/hr
- Mean peak value at 0.92
- Instantaneous value exceeds 0.99 occasionally
- If drops are smaller, even this flow rate is not feasible

# Mass Concentration Maps



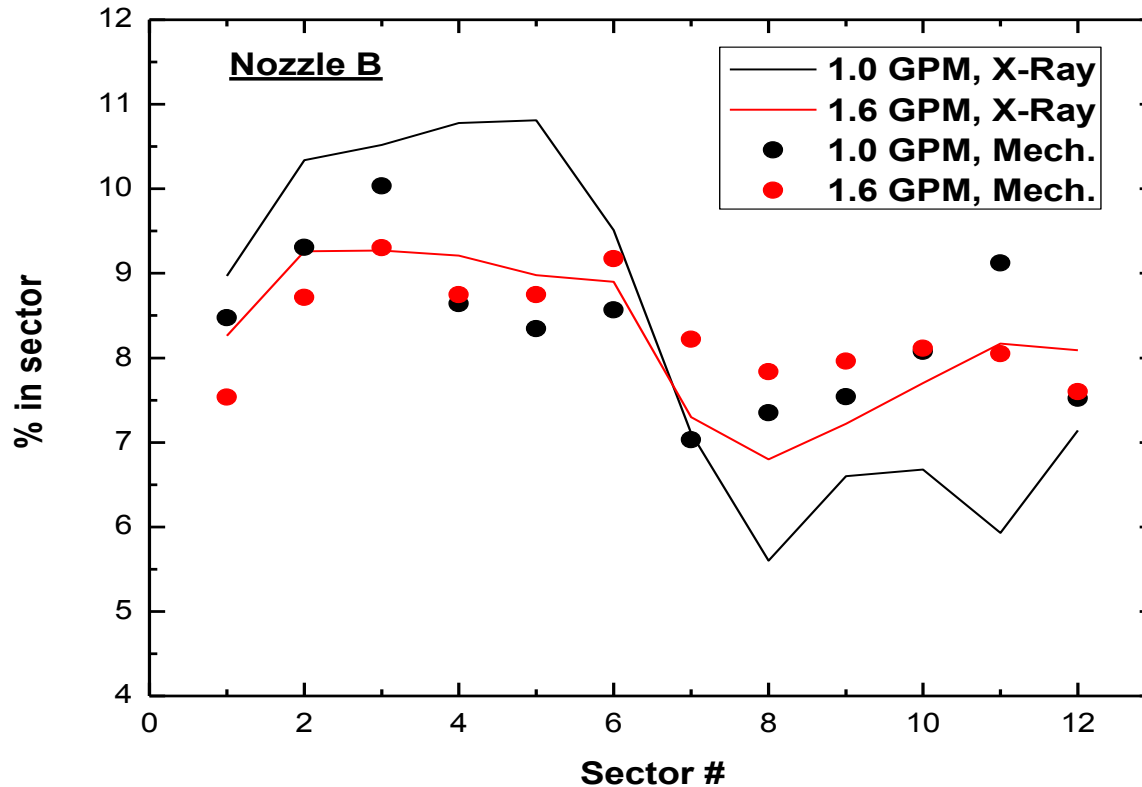
- Deconvoluted results of mass fraction of water
- Lower flow rate has higher local concentration
- High flow rate had larger footprint

# Mechanical Patternator for Validation



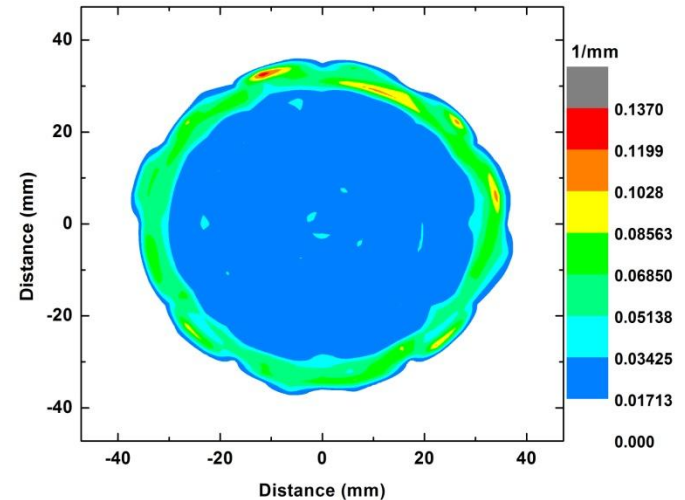
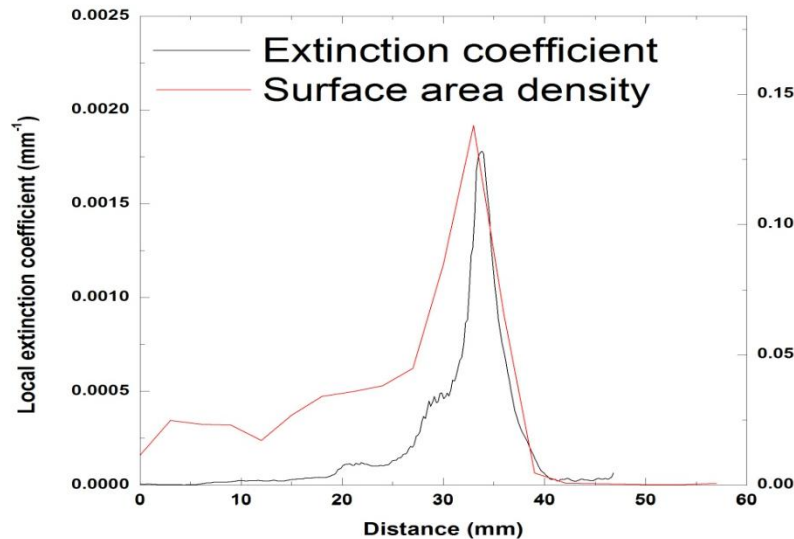
*Twelve sector patternator commonly used by the aircraft industry*

# Validation (Mechanical Patternation)



- Similar trends with flow rates and angle
- Results agree with uncertainty of mechanical patternator

# Validation (Optical patternator)

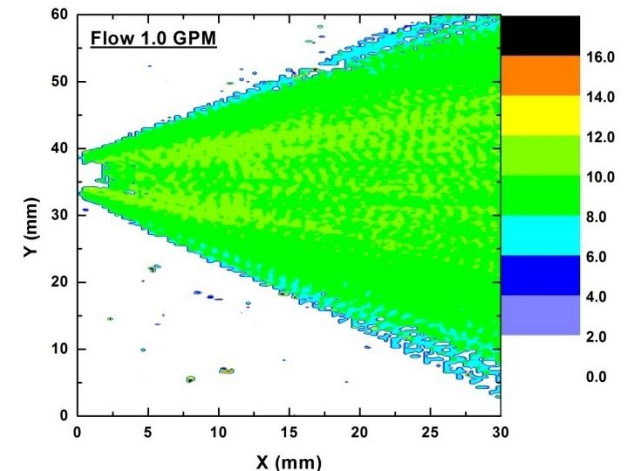


- Radial peak location very similar (only one condition)
- SMD (from mass concentration/surface area) is 141  $\mu\text{m}$  (nozzle specification is 125  $\mu\text{m}$ )

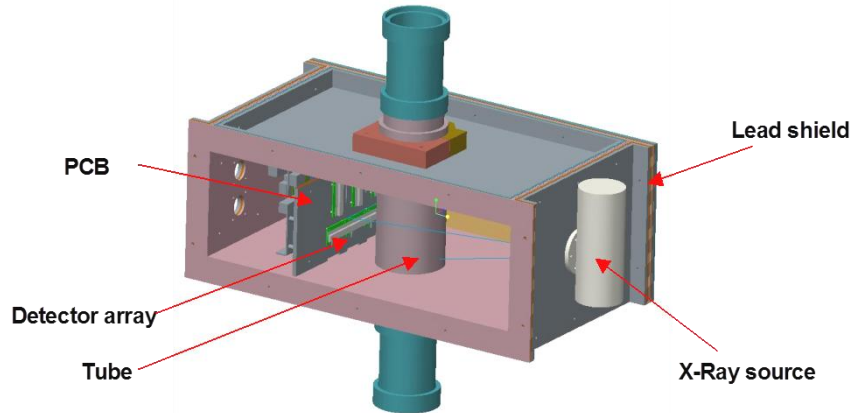
# Validation (Total flow)

Nozzle	Input Flow (kg/hr)	Total planar mass (mg/mm)	Mean velocity (m/s)	Planar mass flux (kg/hr)
A	227	10.2	5.72	211
A	363	11.1	8.86	353
B	227	7.20	9.44	245
B	363	7.52	14.5	392

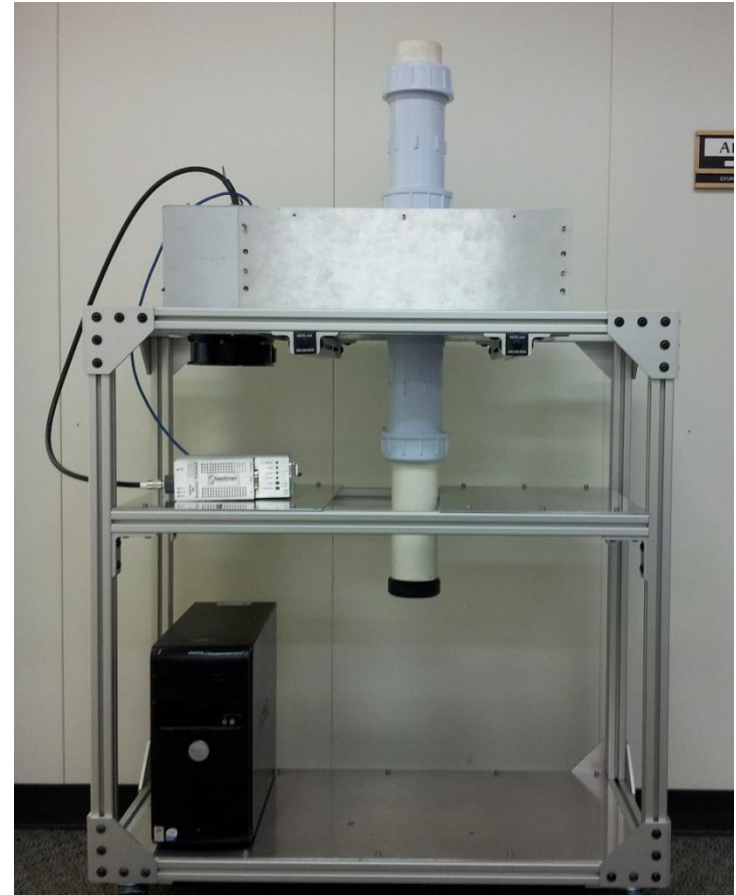
- Velocity measured using Statistical Pattern Imaging velocimeter
- Nozzle A results match flow meter to within 5%
- Nozzle B results match flow meter to within 10%
- Results validate X-Ray measurements within the uncertainty of flow meter and velocimeter



# Single Axis System



- **Nozzle rotate six times to get planar information**
- **Transient information not available**
- **Smaller size sprays**



# Selected Patternator Customers

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