# Characterization of Multiple Plume Fuel Injectors Using Extinction Tomography


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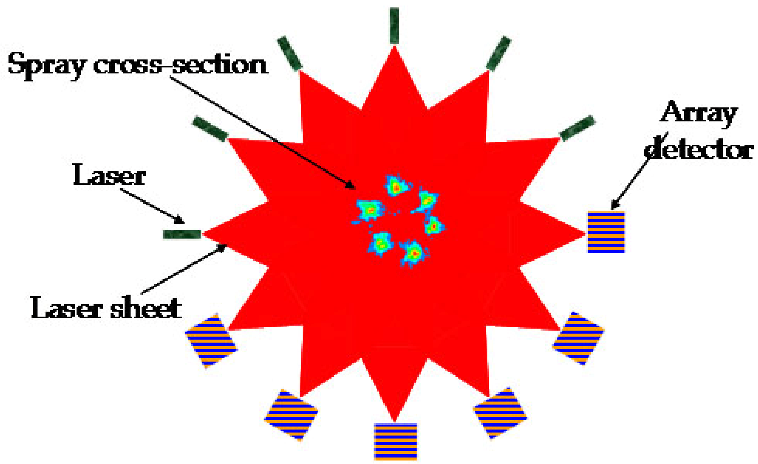
# Motivation

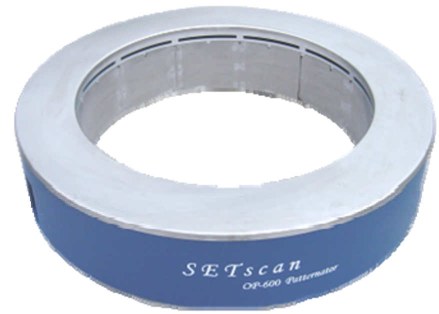
- Multiple plume fuel injectors are increasing used in GDI systems, diesel engines, and urea dosers
- Wide variation in injector performance, even from the same manufacturer
- Several methods exist to characterize single plume or even two plume fuel injectors
- There is no SAE or other standards for characterization of multiple plume injectors

# Objective

- Develop a reliable and accurate method to characterize multiple plume injectors.
- Capability to analyze injectors in < 5 seconds
- Propose key spray parameters that can be used for developing quality audit parameters
- Implementation on production floor

# Statistical Extinction Tomography




**Several sizes for sprays ranging from 25 mm to 250 mm footprint**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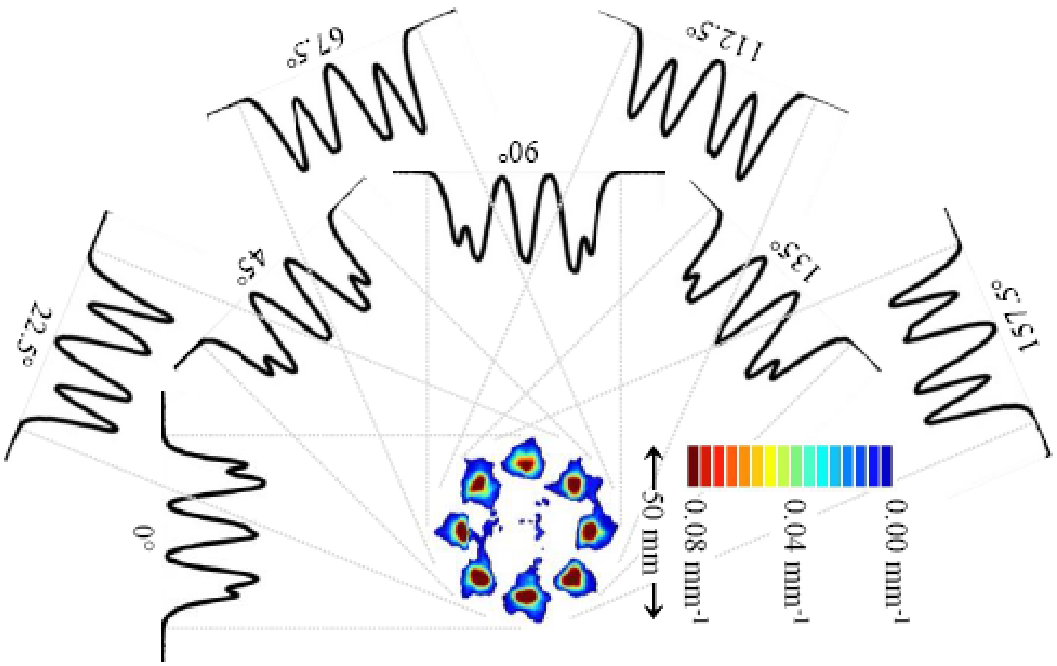
# Principle of Operation of Patternator




- Tomography of extinction data with a sampling frequency of 10 KHz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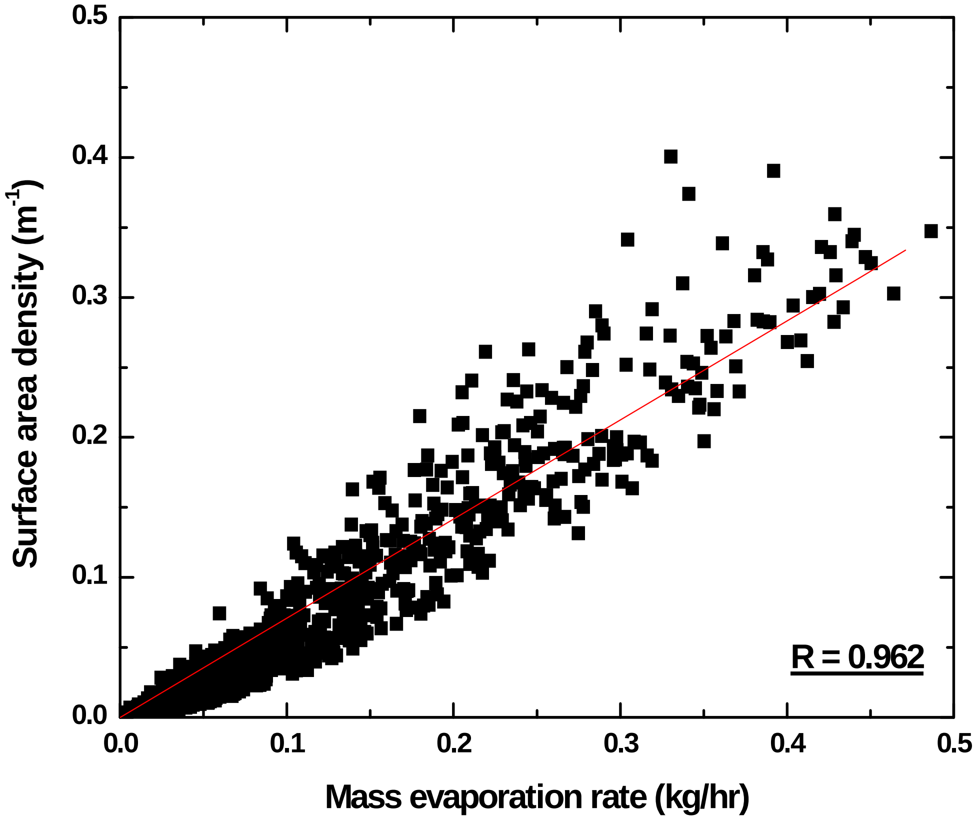
# Characteristics of Data

- The data can be either transient or ensemble average of drop surface area per unit volume
- Differs from mechanical patternator (which is time average of mass flux)
- Spatially and temporally resolved
- Triggered with injection pulse to study pulse to pulse variation
- Injection time of ~ 1 to 2 ms (10 to 20 frames)

# Importance of surface areas

Correlation of fuel evaporation with parameters




Drop size = 0.681
Velocity = - 0.239
Mass flux = 0.903
Surface area density = 0.962

**Surface area density is the most important parameter to measure if you are interested in obtaining the amount of fuel evaporated at any location in a spray**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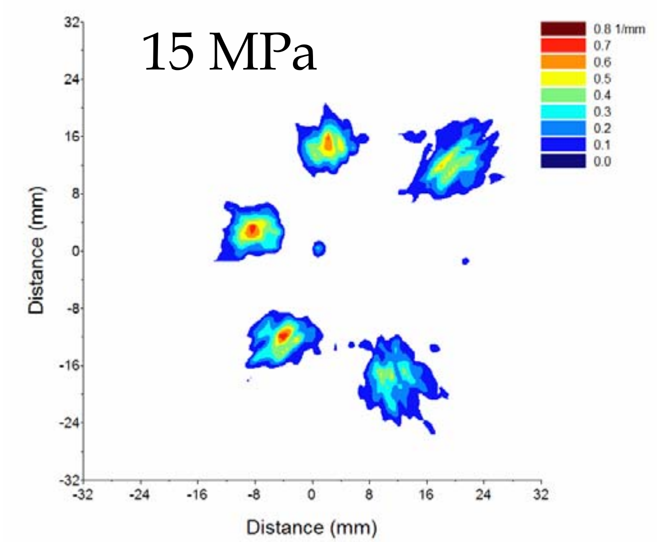
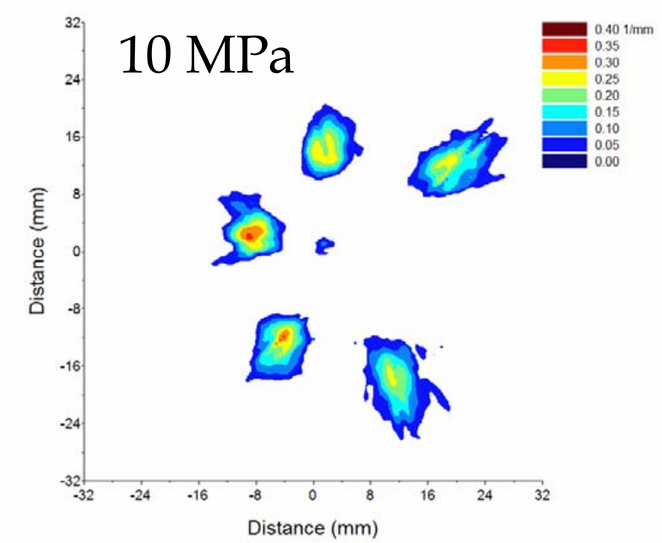
# Sample Results

# Test Details

- Two injectors (5 orifice and 6 orifice)
- Ambient pressure of 101 KPa
- Fuel temperature of 20 $^{O}$C
- Baseline E-10 gasoline fuel
- Injection pressures of 10 and 15 MPa
- All data based on 5 injection events lasting 1. 5 ms each

# Surface area distribution (5 holes)



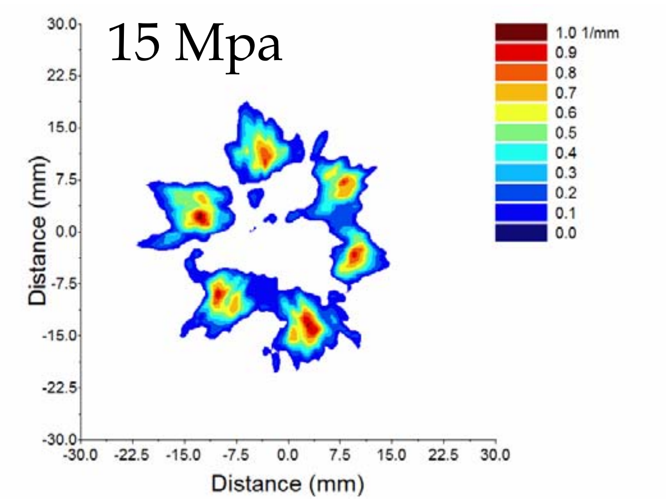

- **Quantitative values of surface areas (+/- 2%)**
- **Drop surface areas greater at 15 MPa (smaller drops)**
- **Very similar for both pressures**

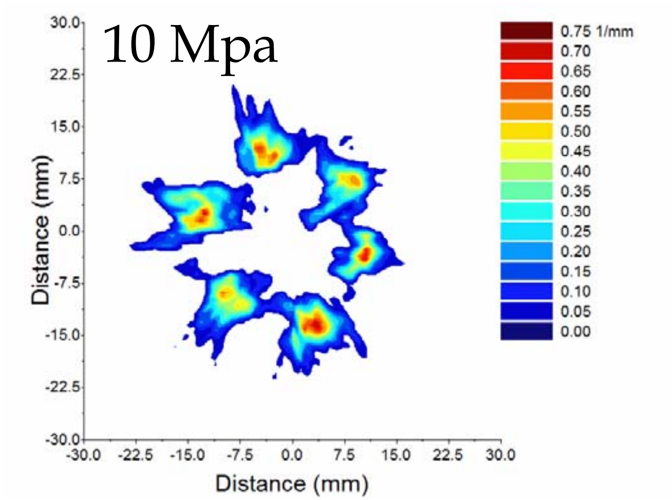
# Plume Analysis (5 holes)

| Plume ID | Center R (mm) | Center q (deg) | Center X (mm) | Center Y (mm) | Plume Angle (deg) | Total Area (mm2) | % in Plume |
|---|---|---|---|---|---|---|---|
| 1 | 22.9 | 35.9 | 18.5 | 13.4 | 29.2 | 24.2 | 23.8 |
| 2 | 15 | 85.1 | 1.3 | 15 | 21.4 | 17.7 | 17.4 |
| 3 | 9 | 164.3 | -8.6 | 2.4 | 23.1 | 19.3 | 19 |
| 4 | 13.2 | 254 | -3.7 | -12.7 | 23.4 | 18.9 | 18.6 |
| 5 | 21.2 | 305.8 | 12.4 | -17.2 | 123.8 | 21 | 20.7 |
| Total (plume separation at 7.0%) | | | | | | 101.2 | 99.4 |

- **Centroids within 200 microns**
- **Plume angles within 1/2 degree**
- **% distribution in plumes within 1%**
- **Improves with more samples**

# Surface area distribution (6 holes)



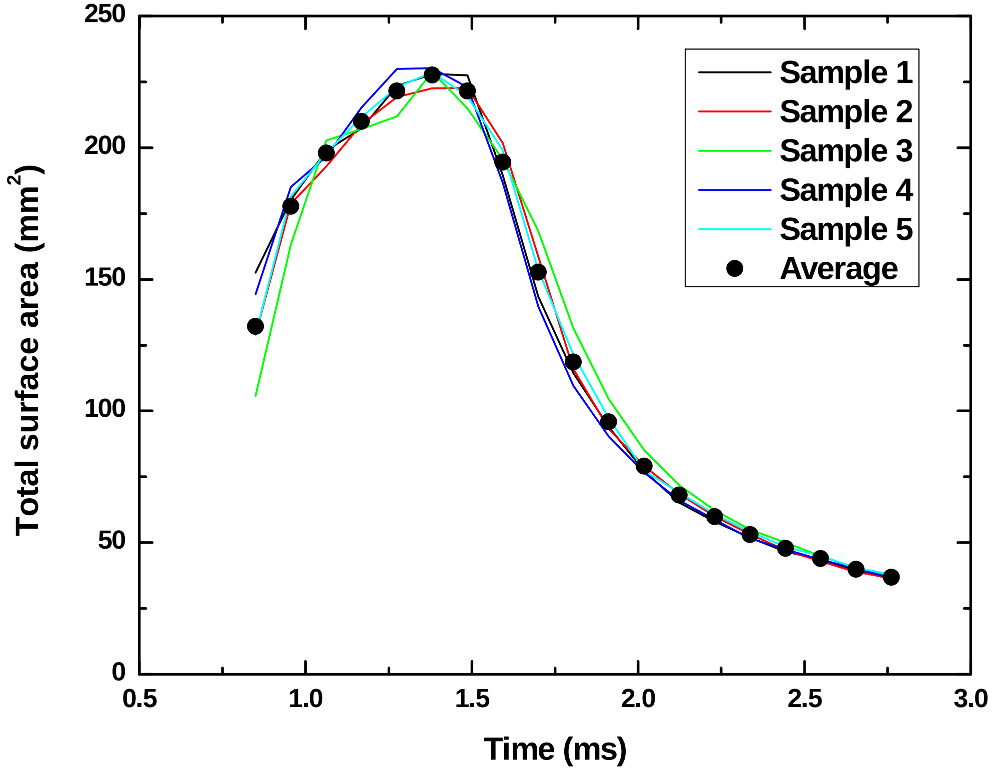

- Slightly smaller footprint
- Higher surface areas than 5 hole injector
- Similar trends with pressure

# Plume Analysis (6 holes)

| Plume ID | Center R (mm) | Center θ (deg) | Center X (mm) | Center Y (mm) | Plume Angle (deg) | Total Area (mm2) | % in Plume |
|---|---|---|---|---|---|---|---|
| 1 | 12.2 | 18.3 | 8.3 | 4.8 | 7.2 | 18.4 | 13.4 |
| 2 | 11.4 | 76.8 | -0.7 | 12.1 | 8.8 | 26.7 | 19.4 |
| 3 | 10.7 | 141.6 | -11.7 | 7.6 | 8.6 | 25.3 | 18.4 |
| 4 | 10.3 | 217.7 | -11.4 | -5.3 | 8.4 | 24.4 | 17.7 |
| 5 | 12.5 | 277.1 | -1.8 | -11.5 | 8.4 | 25 | 18.2 |
| 6 | 11.8 | 331.6 | 7.1 | -4.7 | 6.6 | 15.1 | 11 |
| Total (plume separation at 15.9%) | | | | | | 135 | 98.2 |

- **All analysis is automated**
- **Only input required is number of plumes**
- **Any of the above can be used for quality audit**

# Sample Repeatability




- Total surface area of all the drops within a 1 mm height in the plane
- Standard deviation in all cases (other than the first sample) is <5%
- If total surface area over entire injection period is taken, standard deviation is less than 0.5%

**Ideal variable for quality audit of different nozzles**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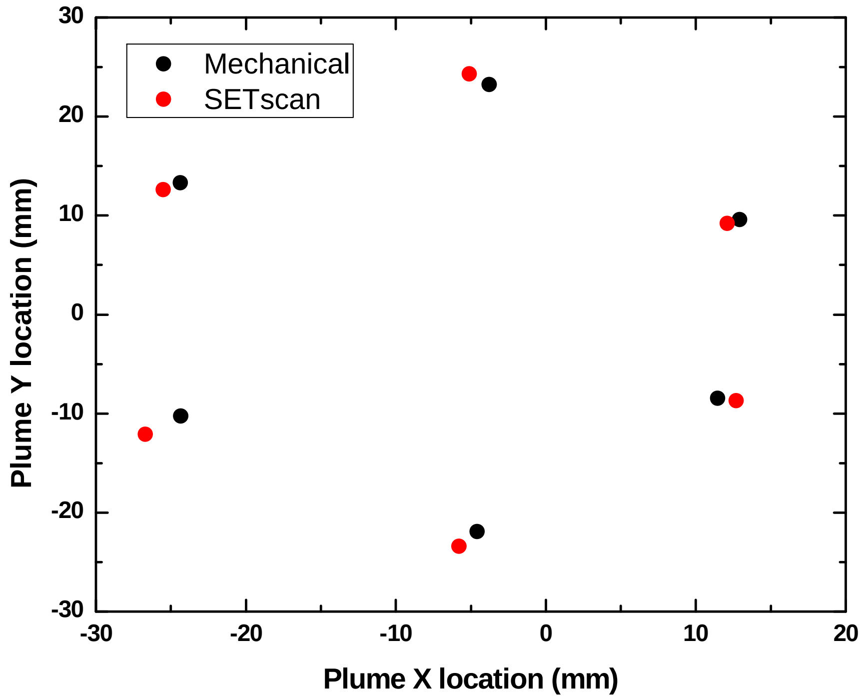
# Comparison with Mechanical Patternator




- Mechanical patternator has stagnation planes
- Requires extensive time and effort
- Spatial resolution not very high for mechanical patternator
- Results show that mass flux centers correlate well with surface area centers

*Fully automated plume analysis for quality audit*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# Comparison with Conventional methods

- Diffraction based drop sizing methods have large errors (+/- 20%) due to beam wandering
- Shadowgraph based videos do not provide for the analysis of individual plumes
- Phase doppler based methods are time consuming and inaccurate (+/- 10%) for mapping entire sprays
- Mie scattering based imaging not useful

# Conclusions

- Extinction based measurements show higher consistency that diffraction or scattering based measurements under real operating conditions
- Planar extinction tomography has been shown to be the only method available for ranking multiple orifice nozzles or for quality audit purposes
- The SETscan patternator is the only patternator that provides quantitative information in fuel injectors.

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