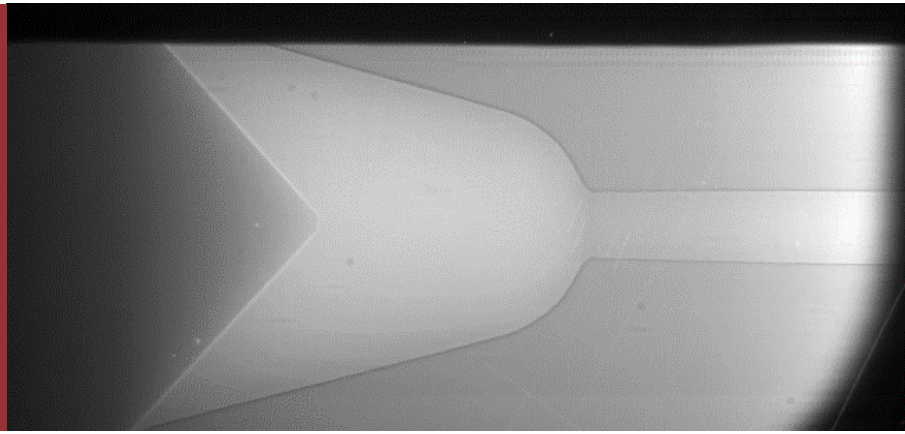
SEPTEMBER 10, 2018

TOPICS 1 & 2: DIESEL INTERNAL AND NEAR NOZZLE FLOW



MATHIS BODE
RWTH Aachen University

BRANDON SFORZO
Argonne National Laboratory

MICHELE BATTISTONI
University of Perugia

ECN 6 Workshop, Valencia, Spain

ENGINE COMBUSTION NETWORK

SEPTEMBER 10, 2018

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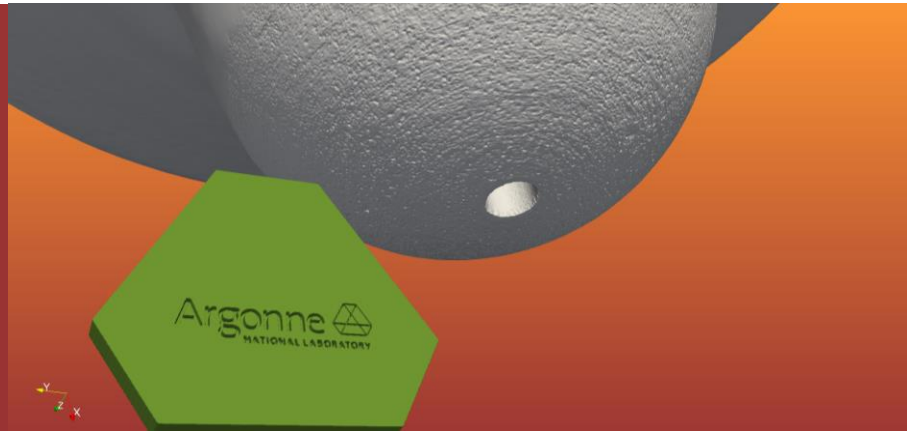
1. X-RAY DIAGNOSTICS OF ECN SPRAY C & D



CHRISTOPHER POWELL
Principal Scientist
Energy Systems Division

BRANDON SFORZO
Mechanical Engineer
Energy Systems Division

ALAN KASTENGREN
Physicist
X-Ray Science Division

KATARZYNA MATUSIK
Assistant Physicist
X-Ray Science Division

ECN 6 Workshop, Valencia, Spain

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ACKNOWLEDGMENTS

- Use of APS 7-BM, 9-ID, and 32-ID beamlines supported by **U.S. Department of Energy** (DOE)
  - Contract No. DE-AC0206CH11357
- X-ray fuel spray sponsored by **DOE Vehicle Technologies Program**
  - Gurpreet Singh & Michael Weismiller

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ECN 6: TOPICS 1 & 2
NEW EXPERIMENTAL CONTRIBUTIONS

Diagnostic	Injector	Inj P (MPa)	Amb P (MPa)	Inj Dur (ms)	Notes
Nozzle Tomo	C #37				
Imaging – cav.	C #37	150	**0.1**	2.5	
	D #134	150	**0.2**	2.5	
Needle Motion	C #37	150	**0.1**	**2.5***	***modified available**
Spray Tomo	C #37	150	2	1.5	
	D #134	150	2	1.5	
Radiography	C #37	150	2	2.5	
	D #133	150	2	2.5	
USAXS	C #37	150	2	ss	*SMD
	D #133	150	2	ss	*SMD

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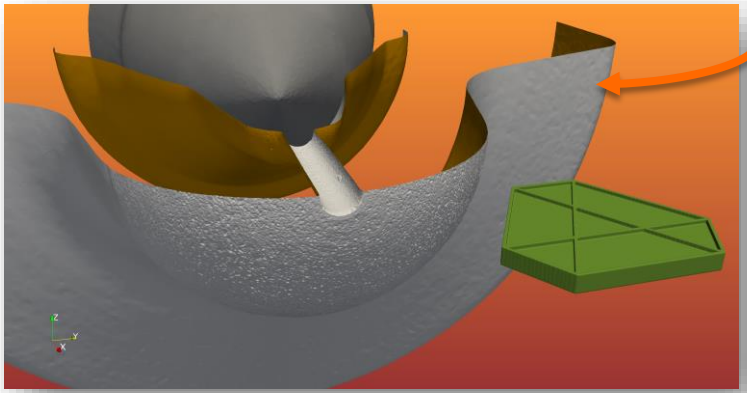
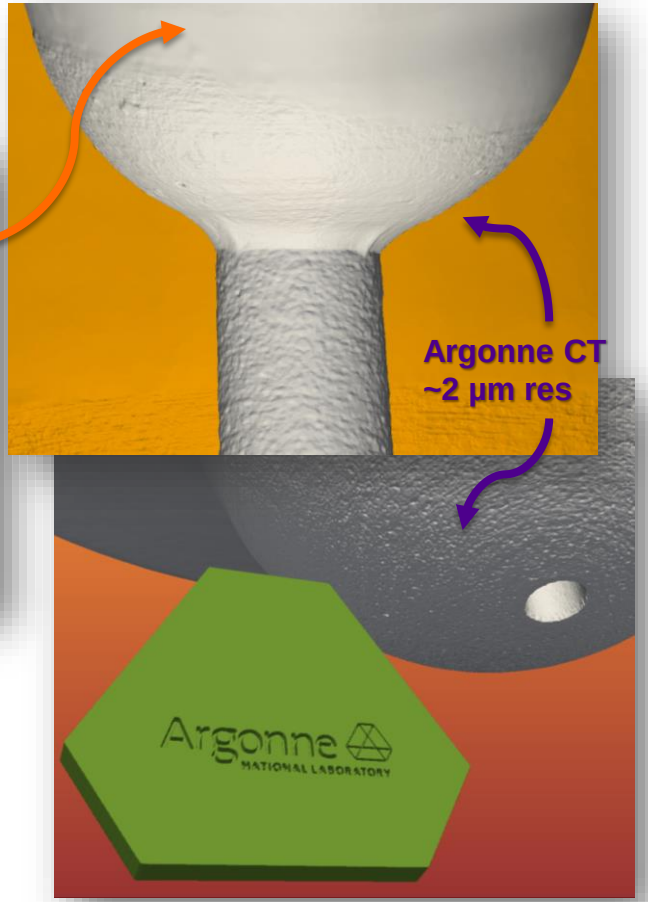
REFINED ISOSURFACE

Spray C #37





- Merged Commercial “upper” to Argonne detailed geometry
- Segregated regions for direct implementation
- Includes needle region and outer domain
  - Can be truncated and reconfigured
- “New” Spray C #37 available!

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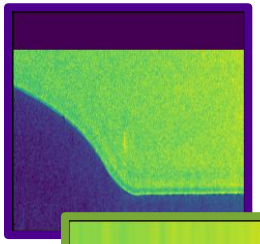
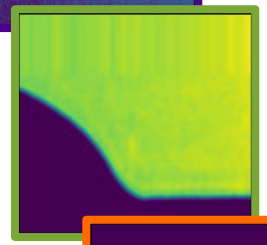
DETAILED GEOMETRY ANALYSIS

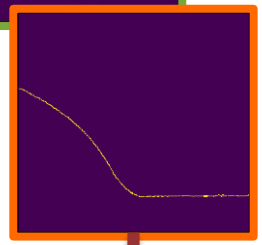
Inlet radius of curvature quantified



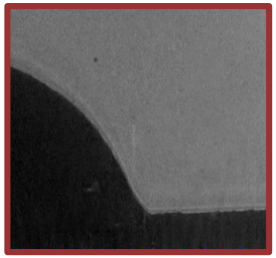
- thresholding
- cropping
- filtering

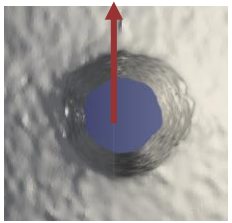


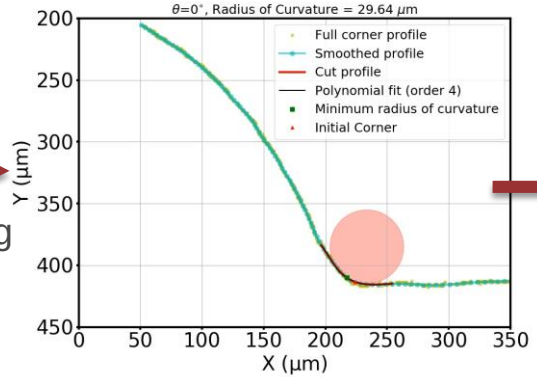
- edge detection

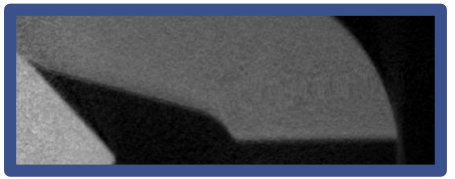


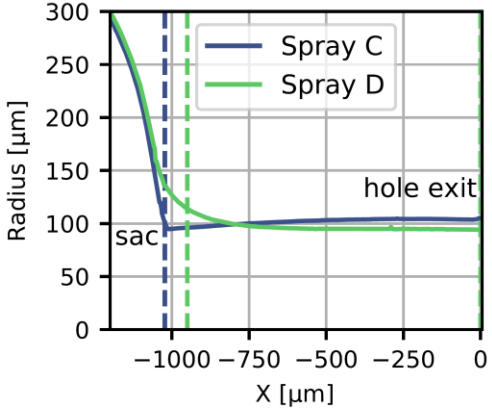
- smoothing
- poly. fit
- curvature search

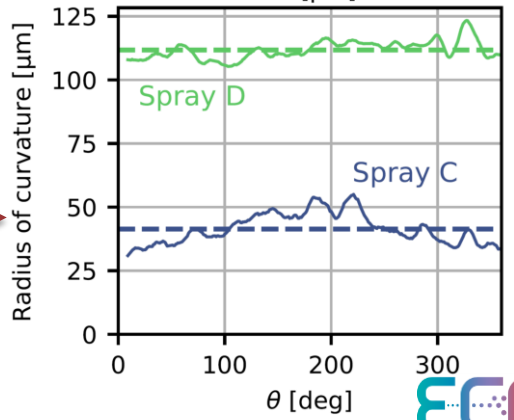












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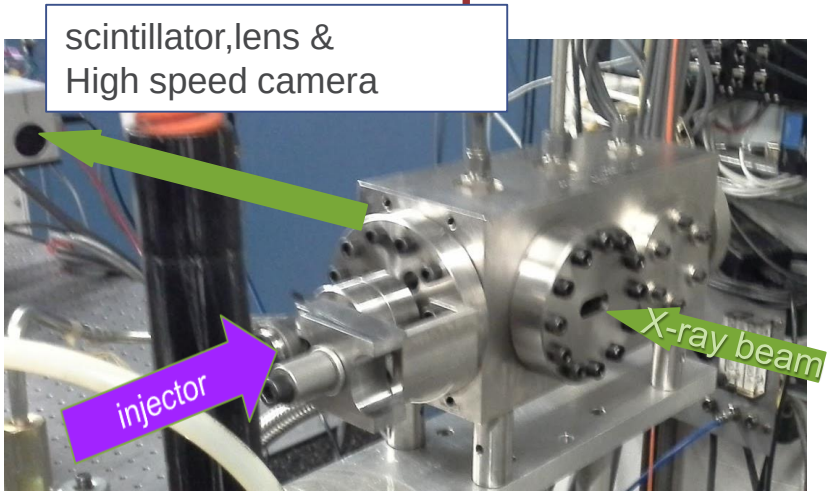
X-RAY PHASE CONTRAST IMAGING

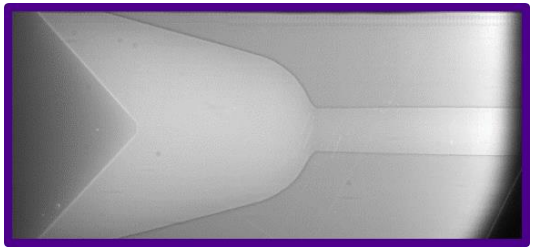
Conditions of experiments



Parameter	Imaging	Radiography/ USAXS	Spray Tomography
$T_{ambient}$ (K)	298	298	298
$p_{ambient}$ (MPa)	0.1, 0.2	2.0	
fuel	n-dodecane	n-dodecane	
$P_{injection}$ (MPa)	150	150	
T_{fuel_nozzle} (K)	298	298	
Hyd. Injection duration (ms)	2.5	2.5	1.5

- Collected 40 injection events at 50,000 fps
- Different image processing algorithms to extract needle motion or gas/liquid interface

✓ No contrast solution used



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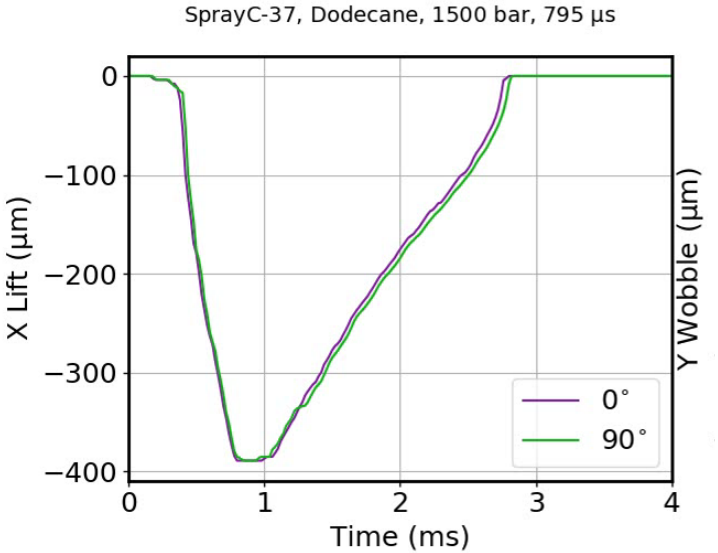
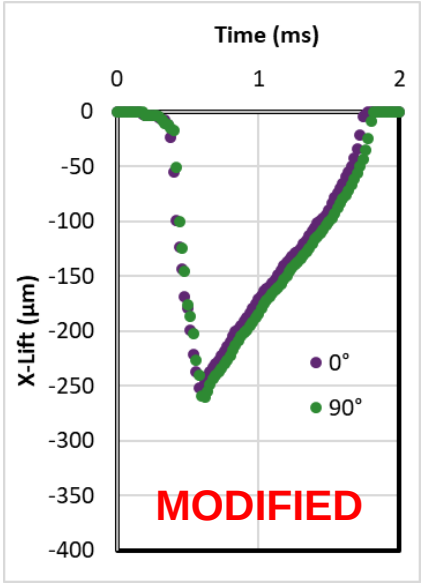
NEEDLE MOTION

Original: 795 µs command





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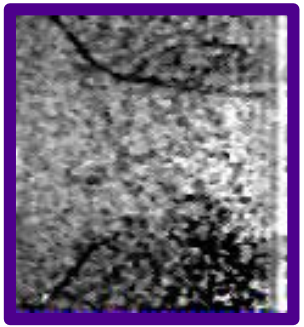
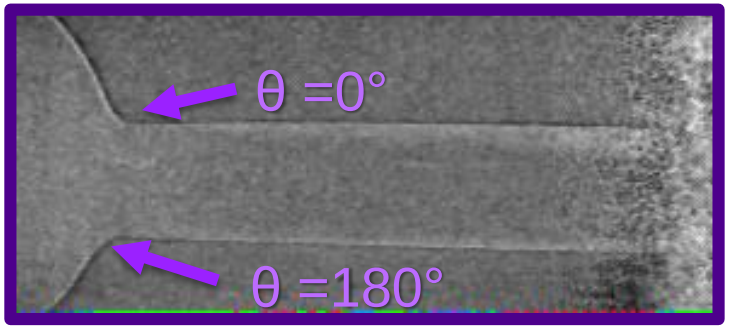
SPRAY C CAVITATION

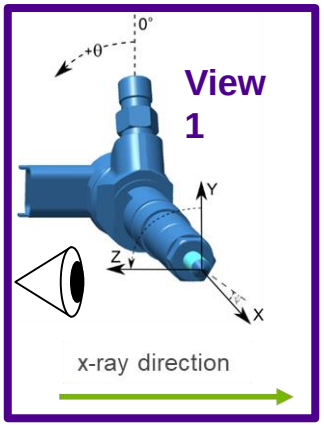
Visualization of vapor interface

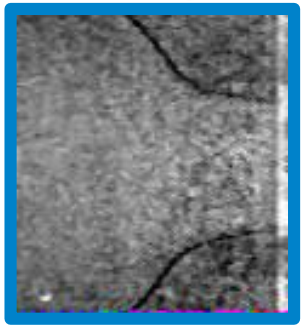


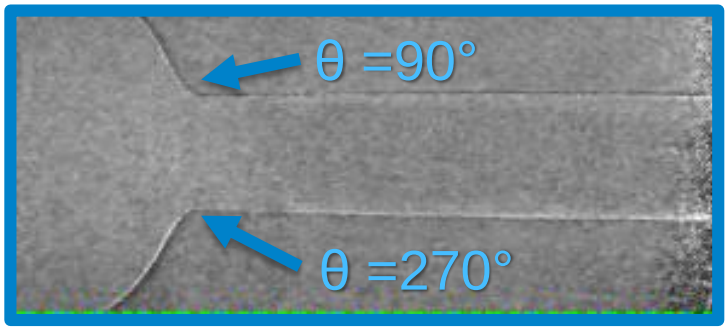
Spray D

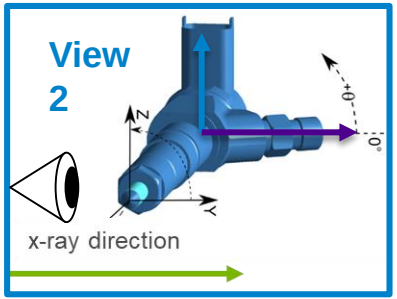


Spray C









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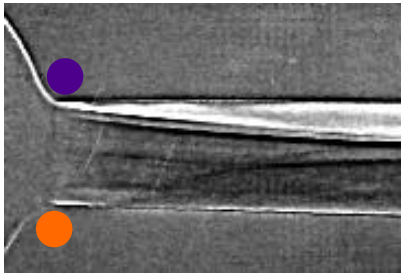
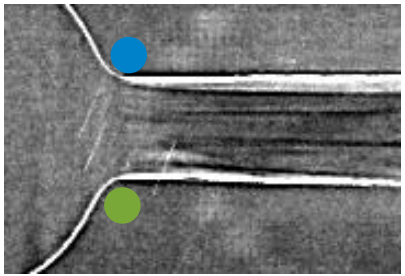
SPRAY C CAVITATION SOURCES

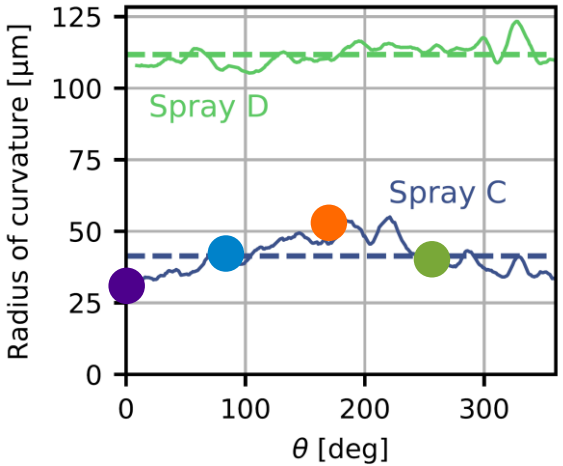
Vapor blockage, possibly significant



38%



26% max



- Vapor sheath grows along θ = 0° corner
  - Blocks 38% of diameter by 425 µm upstream of orifice exit
- View 2 has a max of 26% diameter blockage
- Hole “blockage” up to 32% of area

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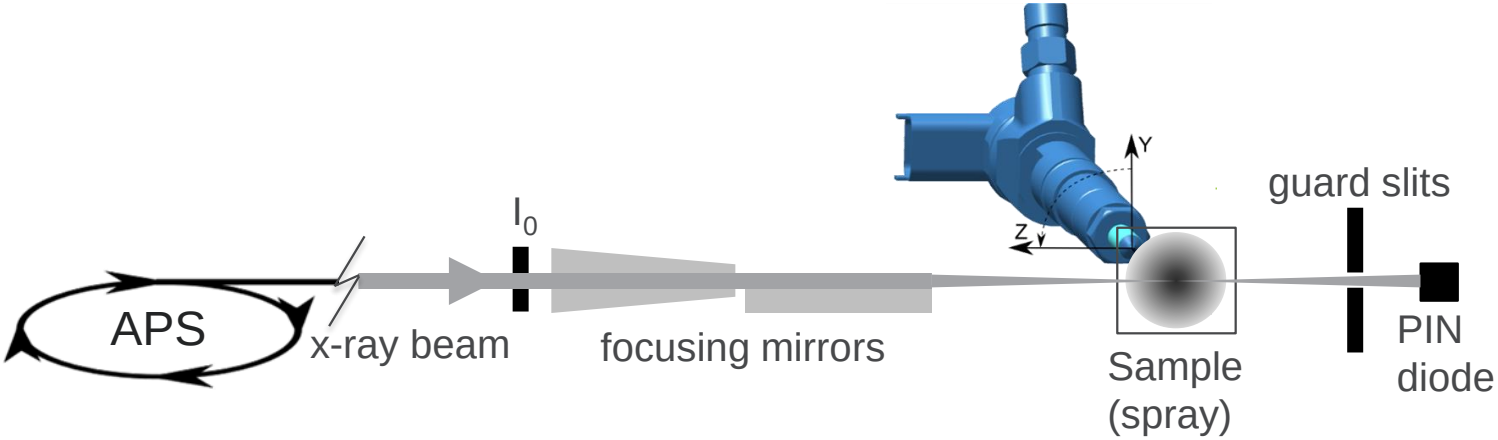
SPRAY C & D RADIOGRAPHY

Projected density or spray density (via tomography)



- Monochromatic beam at 8 keV
- 4 μm x 6 μm (V x H) footprint
- Line-of-sight measurement

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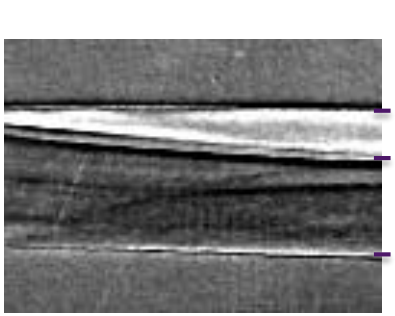
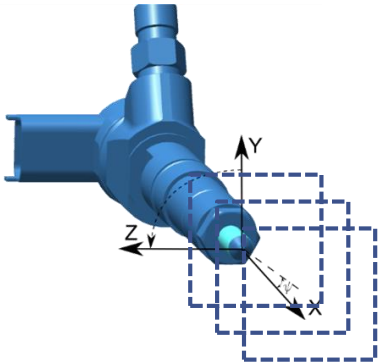
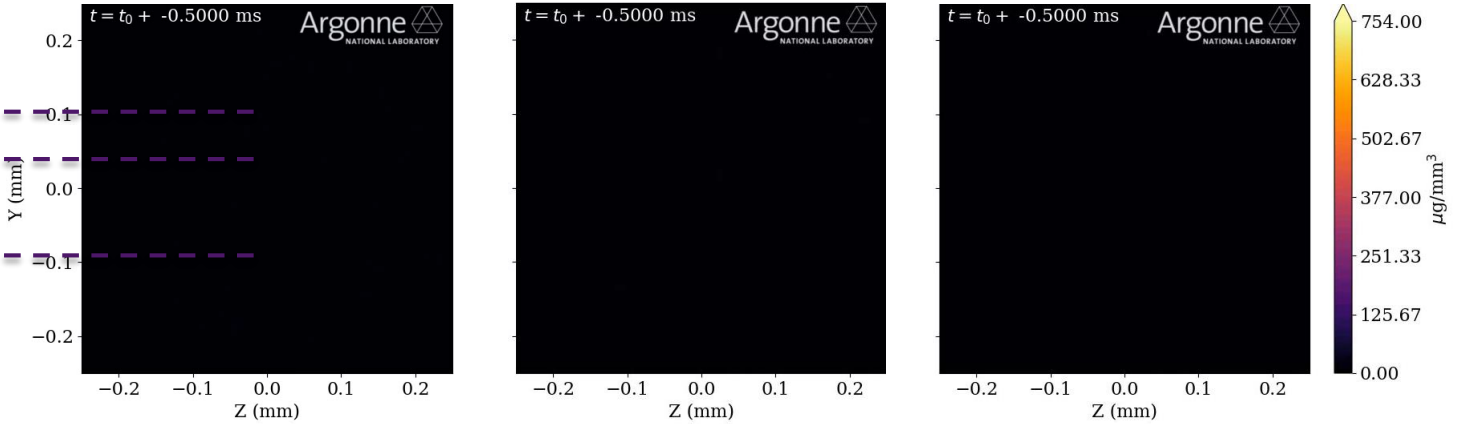
SPRAY TOMOGRAPHY OF SPRAY C







X = 0.1 **X = 2.0** **X = 5.0 [mm]**

- 20 bar ambient, 55 °C injector
- Hole exit (0.1mm) illustrates vapor void
- Mass distribution highly transient
- Subtle cavitation changes highly influence downstream distribution

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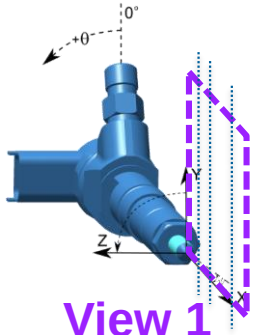
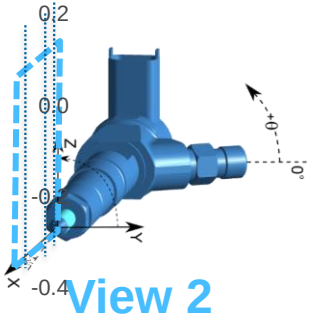
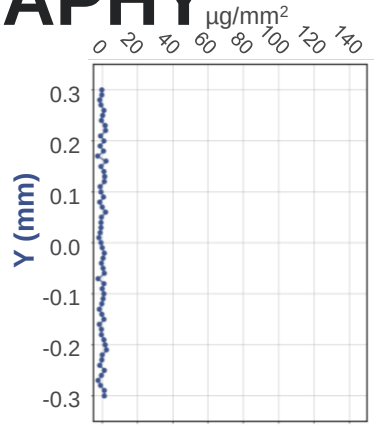
ENGINE COMBUSTION NETWORK

SPRAY C #037
VISUAL SUMMARY

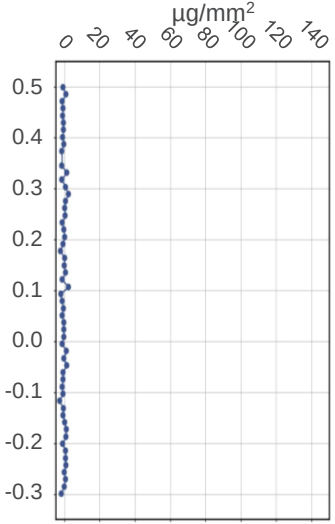
SPRAY C ASYMMETRY RADIOGRAPHY



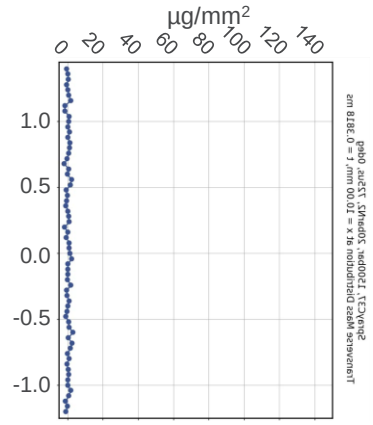




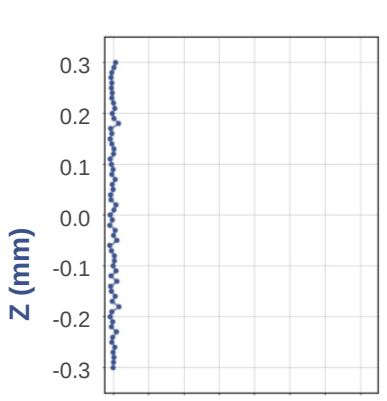
X = 0.1

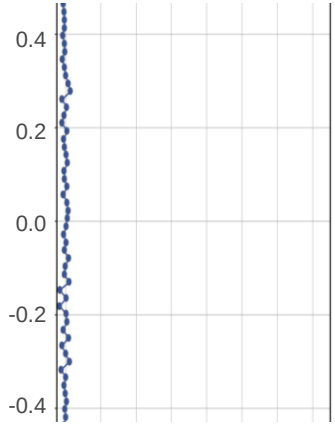


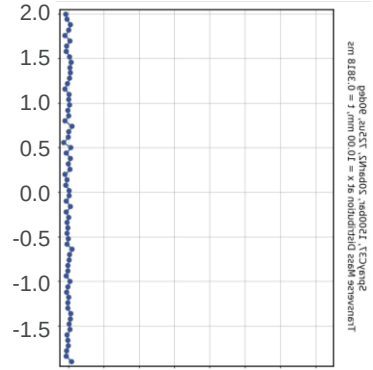
X = 2.0



X = 10.0







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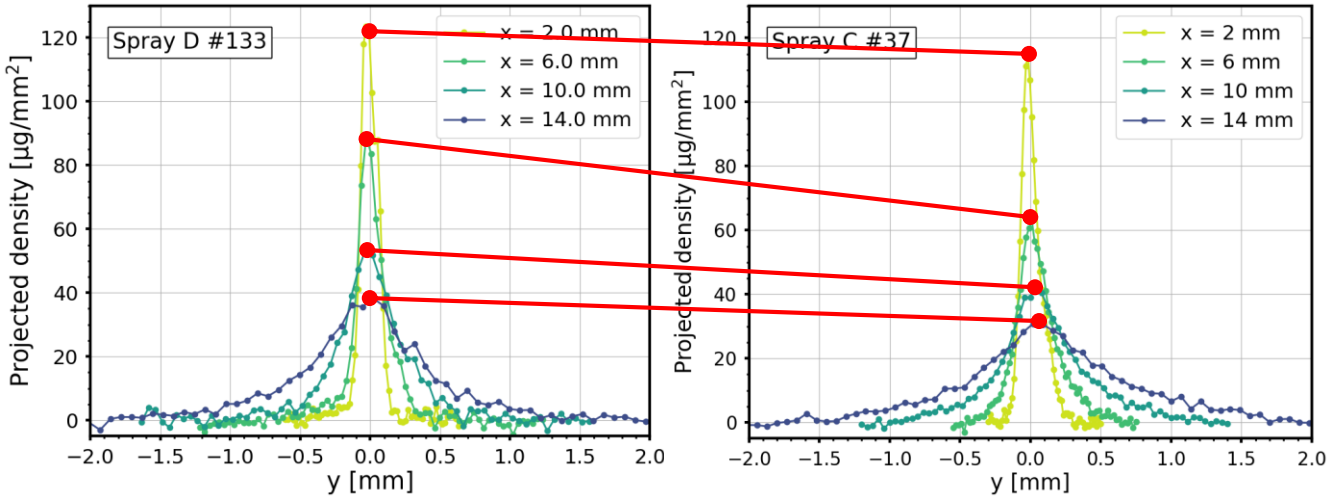
TRANSVERSE PROJECTED DENSITY PROFILES

Spray D #133 & Spray C #37 at 1500 bar inj P, 20 bar amb



- Spray C #37 consistently exhibits lower projected density values at each axial location

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"X-Ray Measurements of Fuel Spray Specific Surface Area and Sauter Mean Diameter for Cavitating and Non-Cavitating Diesel Sprays", Katarzyna E. Matusik, Brandon A. Sforzo, Hee Je Seong, Alan L. Kastengren, Jan Ilavsky, and Christopher F. Powell. 14th International Conference on Liquid Atomization and Spray Systems, Chicago, IL, July 2018.

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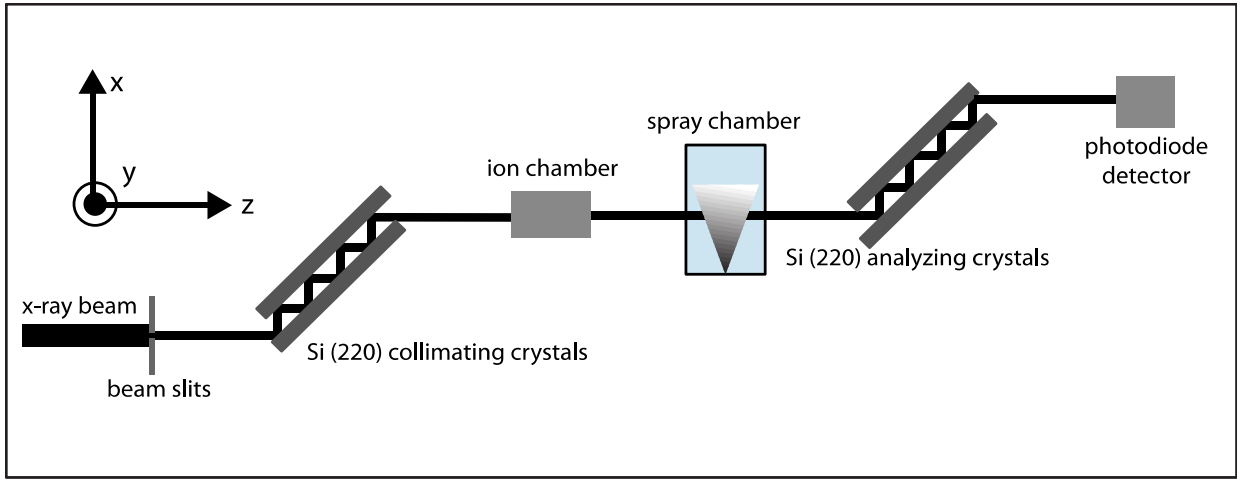
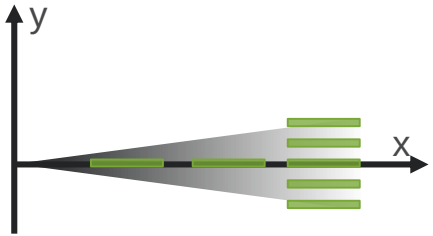
MEASURING THE SPECIFIC SURFACE AREA

Ultra-small-angle x-ray scattering (USAXS)



- Monochromatic beam at 21 keV
- 500 μm x 50 μm (H x V) footprint
- Line-of-sight measurement



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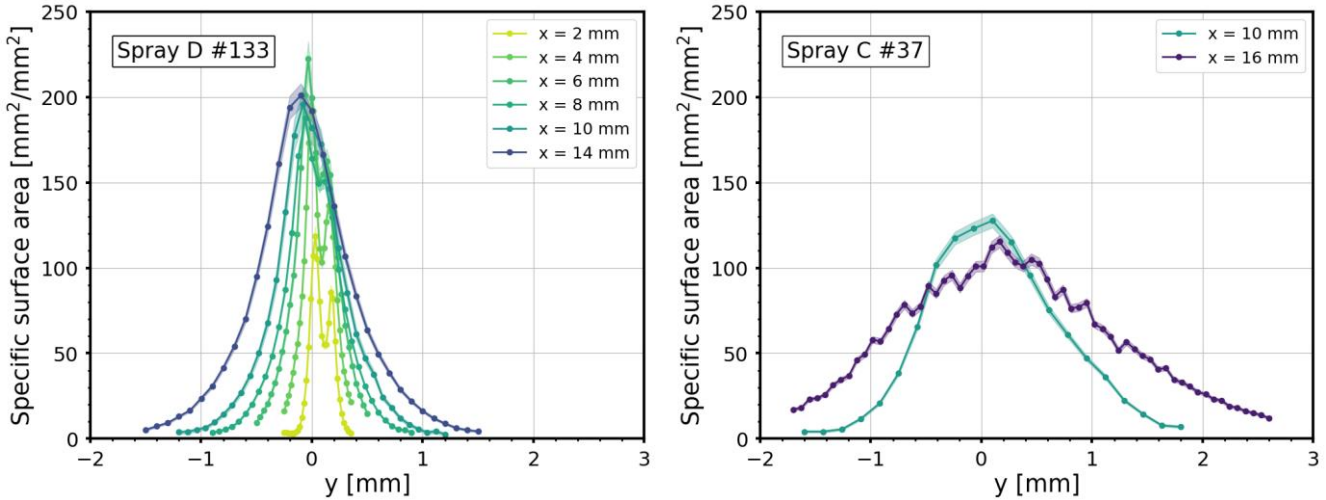
TRANSVERSE SURFACE AREA PROFILES

Spray D #133 & Spray C #37 at 1500 bar injection P, 20 bar ambient P



- Local region of “poor atomization” disappears around x = 10 mm for Spray D

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"X-Ray Measurements of Fuel Spray Specific Surface Area and Sauter Mean Diameter for Cavitating and Non-Cavitating Diesel Sprays", Katarzyna E. Matusik, Brandon A. Sforzo, Hee Je Seong, Alan L. Kastengren, Jan Ilavsky, and Christopher F. Powell. 14th International Conference on Liquid Atomization and Spray Systems, Chicago, IL, July 2018.

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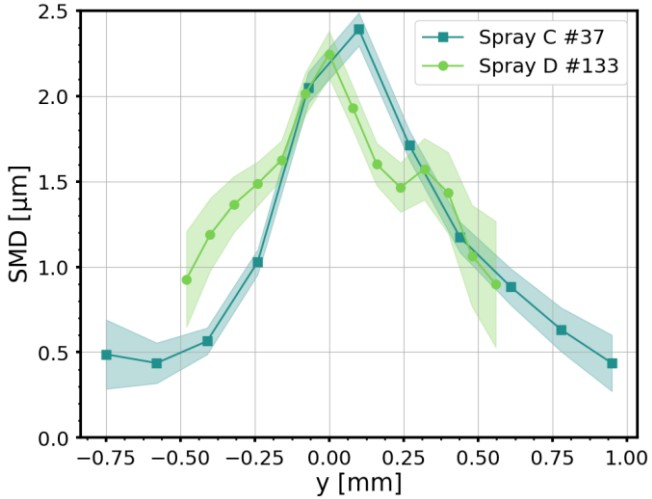
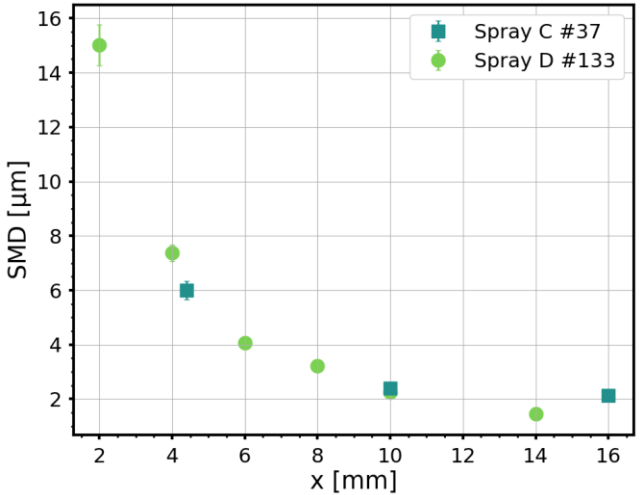
CAVITATING VS. NON-CAVITATING NOZZLE SMD

Spray D #133 & Spray C #37 at 1500 bar injection P, 20 bar ambient P





SMD: $d_{32} = 6\frac{V_p}{S_p}$

Transverse profiles at x = 10 mm

Peak SMD as a function of axial distance

"X-Ray Measurements of Fuel Spray Specific Surface Area and Sauter Mean Diameter for Cavitating and Non-Cavitating Diesel Sprays", Katarzyna E. Matusik, Brandon A. Sforzo, Hee Je Seong, Alan L. Kastengren, Jan Ilavsky, and Christopher F. Powell. 14th International Conference on Liquid Atomization and Spray Systems, Chicago, IL, July 2018.

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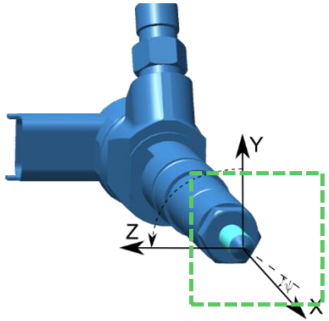
OBSERVATIONS FOR DISCUSSION

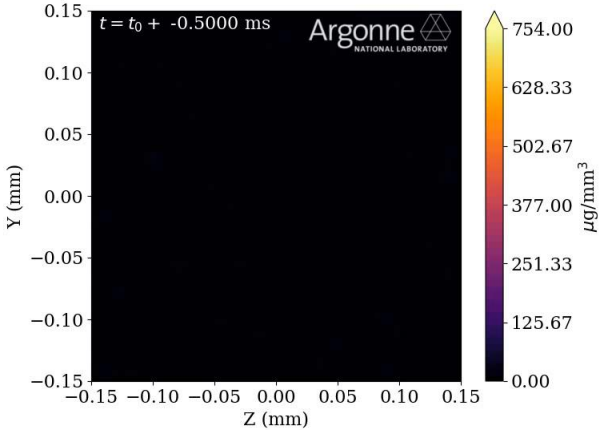
- Sharp and irregular geometric features lead to asymmetric flow in nozzle
- Cavitation blockage leads to redistribution of bulk mass at near nozzle
  - Transient cavitation results in moving mass distribution
- Atomization influenced at cavitation regions
- Peak SMD trends are similar for cavitation vs. non cavitating

QUESTIONS?

BACKUP

SPRAY TOMOGRAPHY OF SPRAY D





X = 0.1 mm

- 20 bar ambient, 55 °C injector
- Hole exit (0.1mm)

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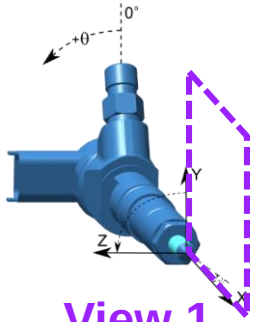
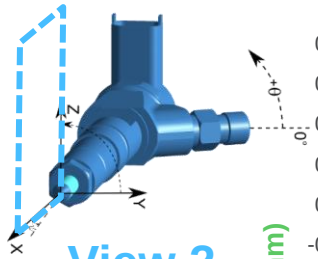
ENGINE COMBUSTION NETWORK

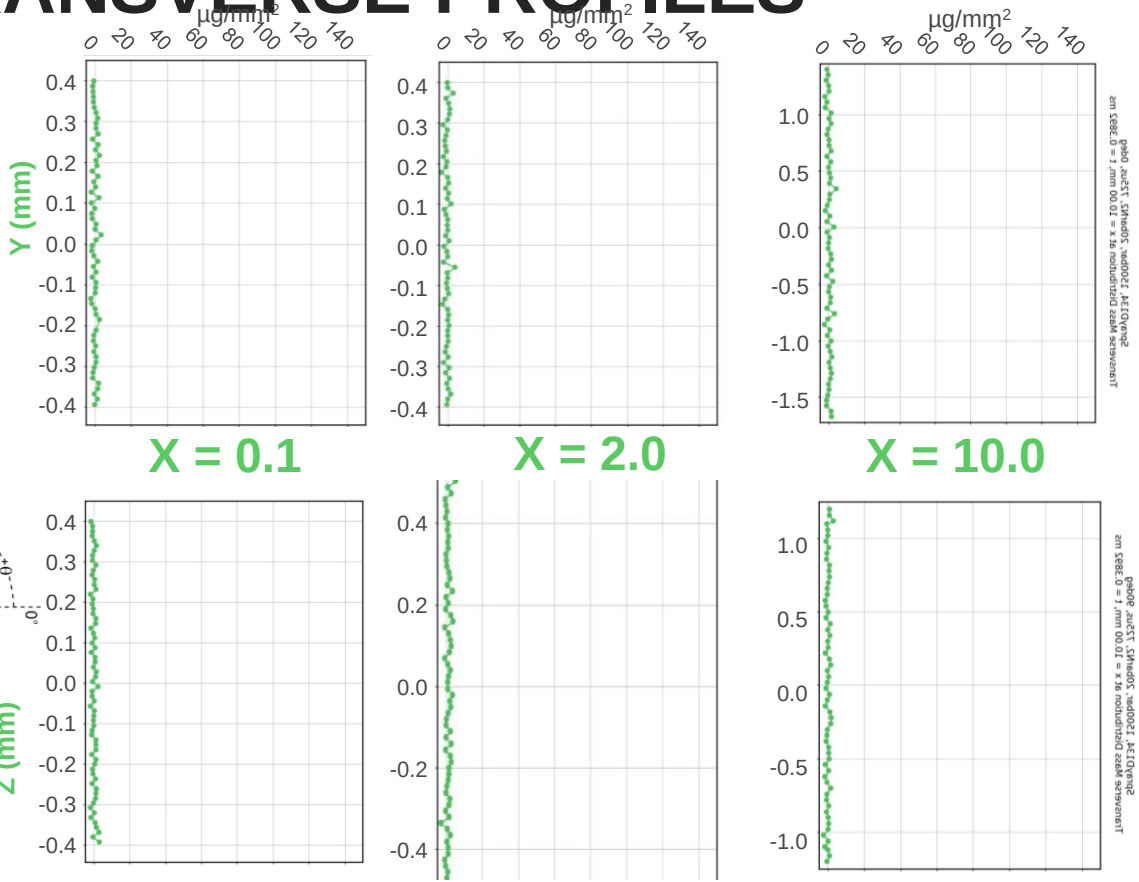
SPRAY D TRANSVERSE PROFILES



View 1



View 2



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