Fire Protection Products

Droplet Characterization Using Direct Imaging Techniques

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Suppression Detection Conference

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Co-authors and acknowledgements

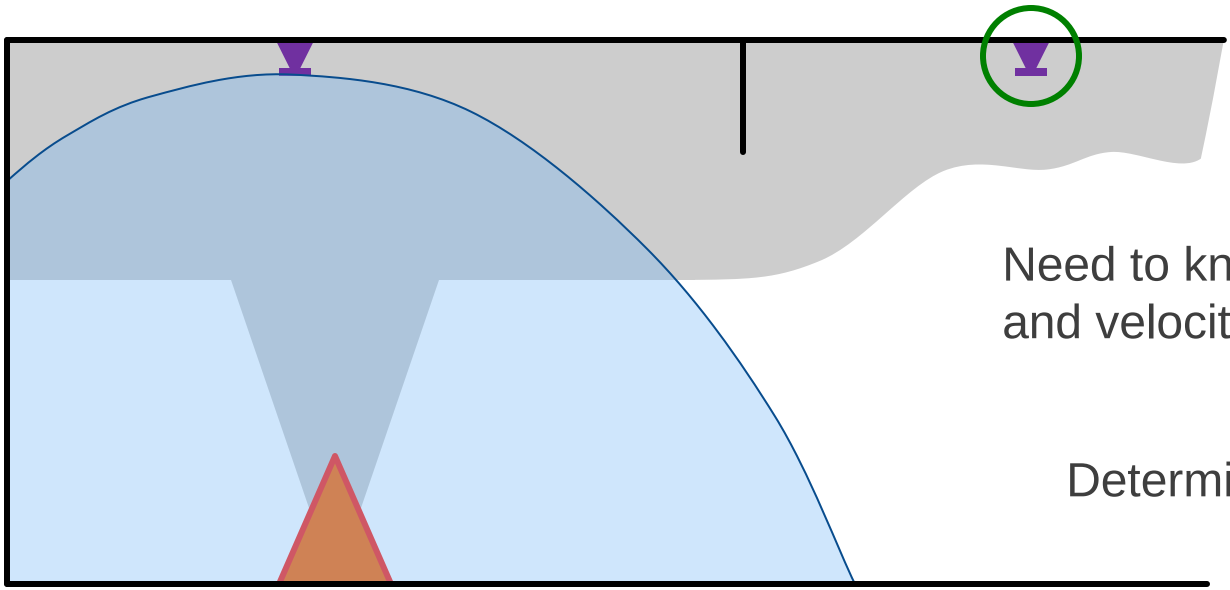
- Zachary Magnone, Tyco Fire Protection Products
- Cooperation with Shanghai Jiao Tong University (SJTU) and Worcester Polytechnic Institute (WPI)
  - Hao “Jonathan” Bohan, SJTU, mechanical engineering
  - Chu “Stella” Yueshan, SJTU, mechanical engineering
  - Nicholas Fast, WPI, mechanical engineering
  - Rachel Winsten, WPI, civil engineering
  - Professor Nick Dembsey, WPI, fire protection engineering
- Chad Goyette, Tyco Fire Protection Products
- Dr. Patricia Beaulieu

Background

- Sprinkler Design
  - Can streamline development with more in-depth knowledge of sprays
- Approval Agencies
  - Similar testing is starting to be used for sprinkler approvals
- Work by others in the field
  - Marshall, Sheppard, Drysdale, Brenton, Grant, etc.
- Fire Modeling
  - Fire models are only as accurate as the information you provide them
  - Characterization means more precise models in FDS

Background – Research Need

- How do sprinkler sprays really work?



e.g. Will additional sprinklers activate?

Need to know local temperature and velocity information

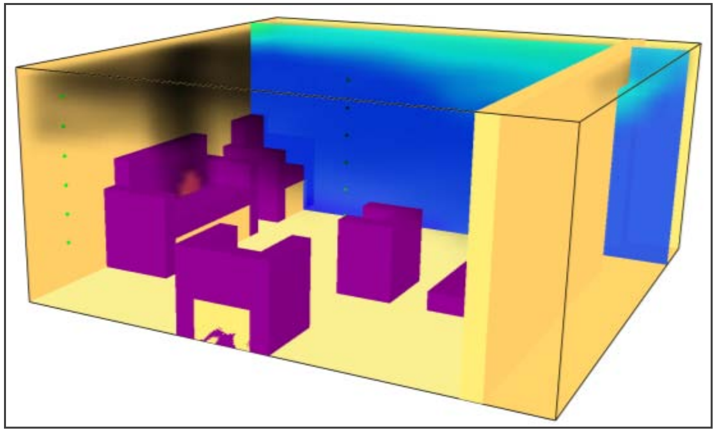
Determine using CFD

- Need critical spray characteristics (relate to CFD inputs)
  - Spray geometry: 3D spatial distribution of water droplets
  - Energy transfer: droplet size, velocity, temperature, total flow rate, etc.

Our research questions

- How is sprinkler spray droplet size affected by:
  - K-factor?
  - Pressure?
  - Spray angle?
  - Measurement location in spray?

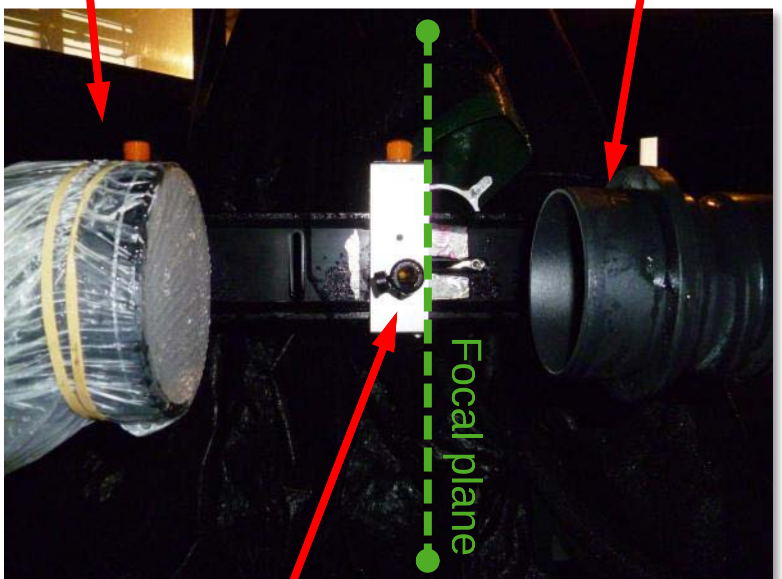
- What implications do our results have on how specific spray patterns are:
  - Developed?
  - Studied?
  - Simulated?



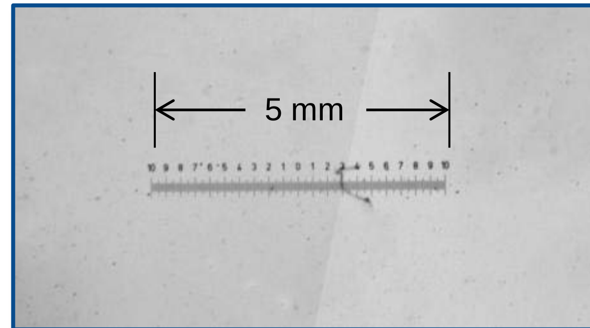
Setup – Imaging System

Backlight diffuser

High-speed camera in waterproof housing with microscope lens

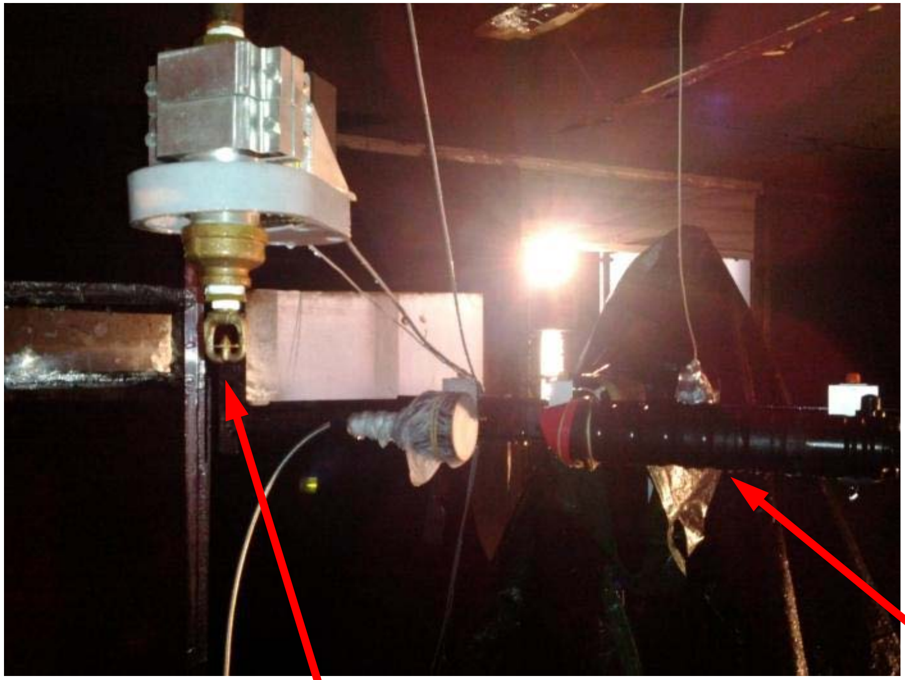


Calibration reticle mounting location



Calibration reticle used for image scaling

Setup – Translation Stage, Nozzle Rotation



- Nozzle mounted in automatic rotational indexer
- Can set rotation angle within 1° accuracy

- Camera assembly mounted on 3-axis linear translation stage
- Can set measurement coordinate to 1 mm accuracy within 1 m^3 space

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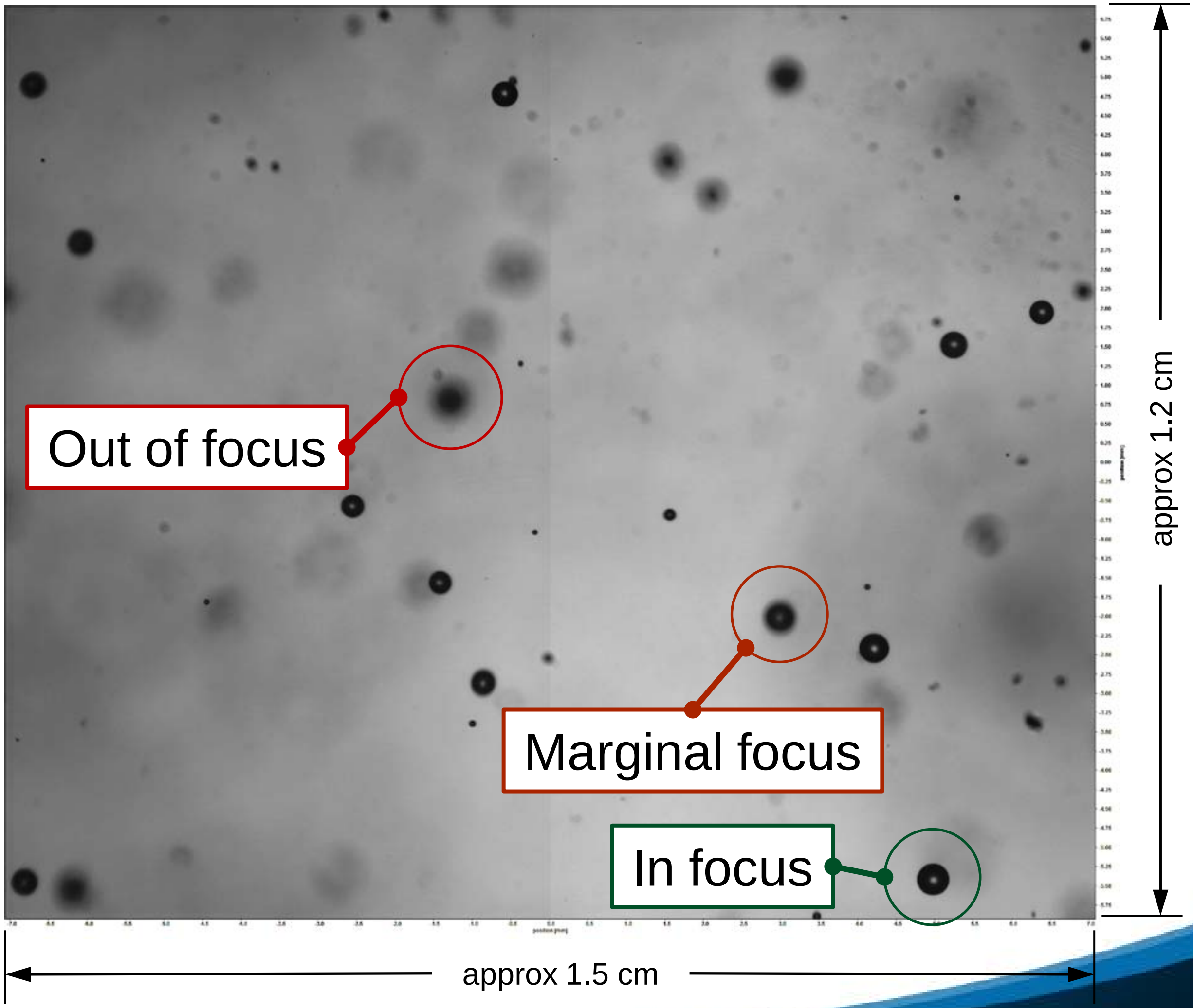
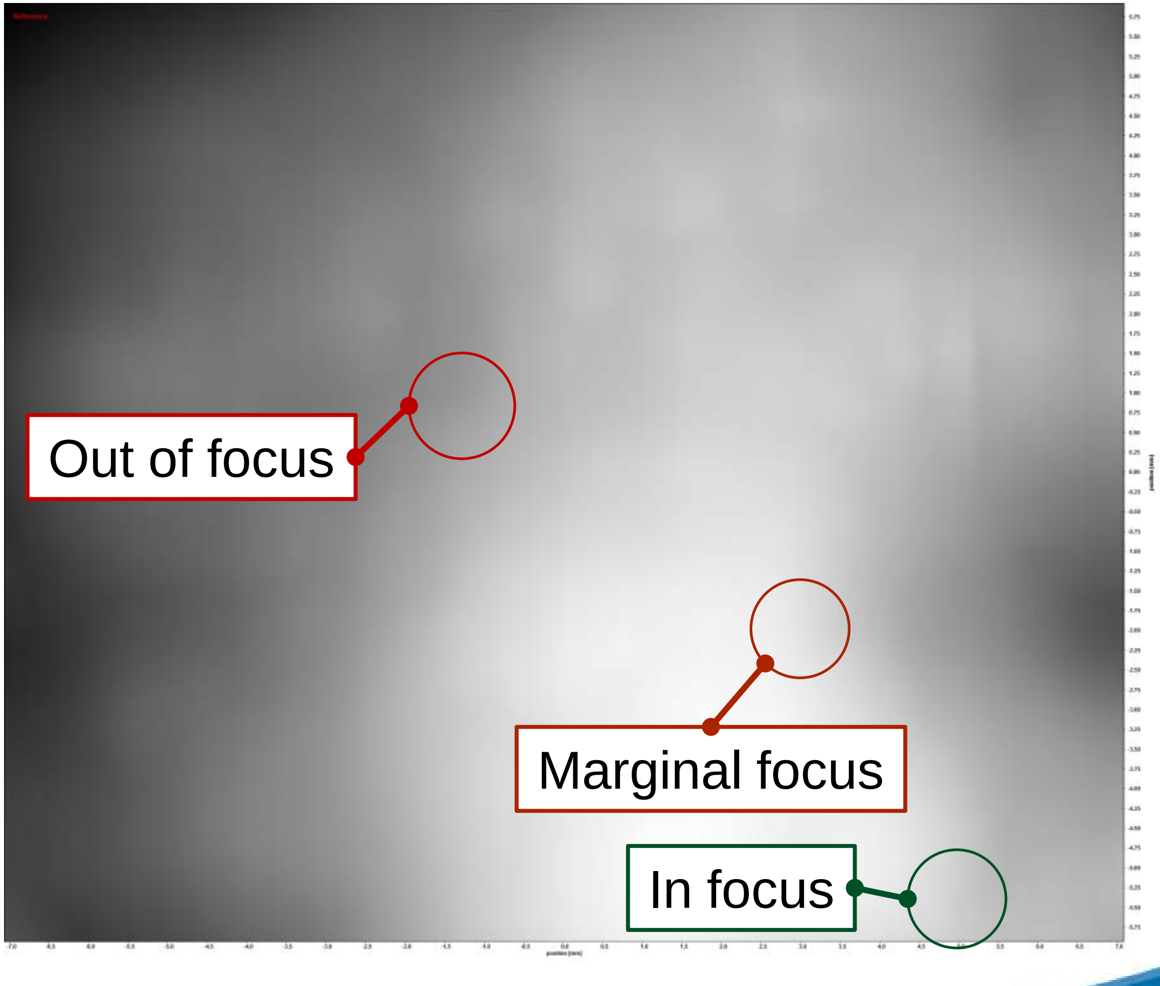
Setup – software and processing

- Raw shadow image
  - Backlight causes bright background
  - Droplets show up as dark shadows



Setup – software and processing

- **Step 1:** Apply smoothing filter
  - Only inconsistencies in background brightness remain
  - “Small” in-focus objects washed out



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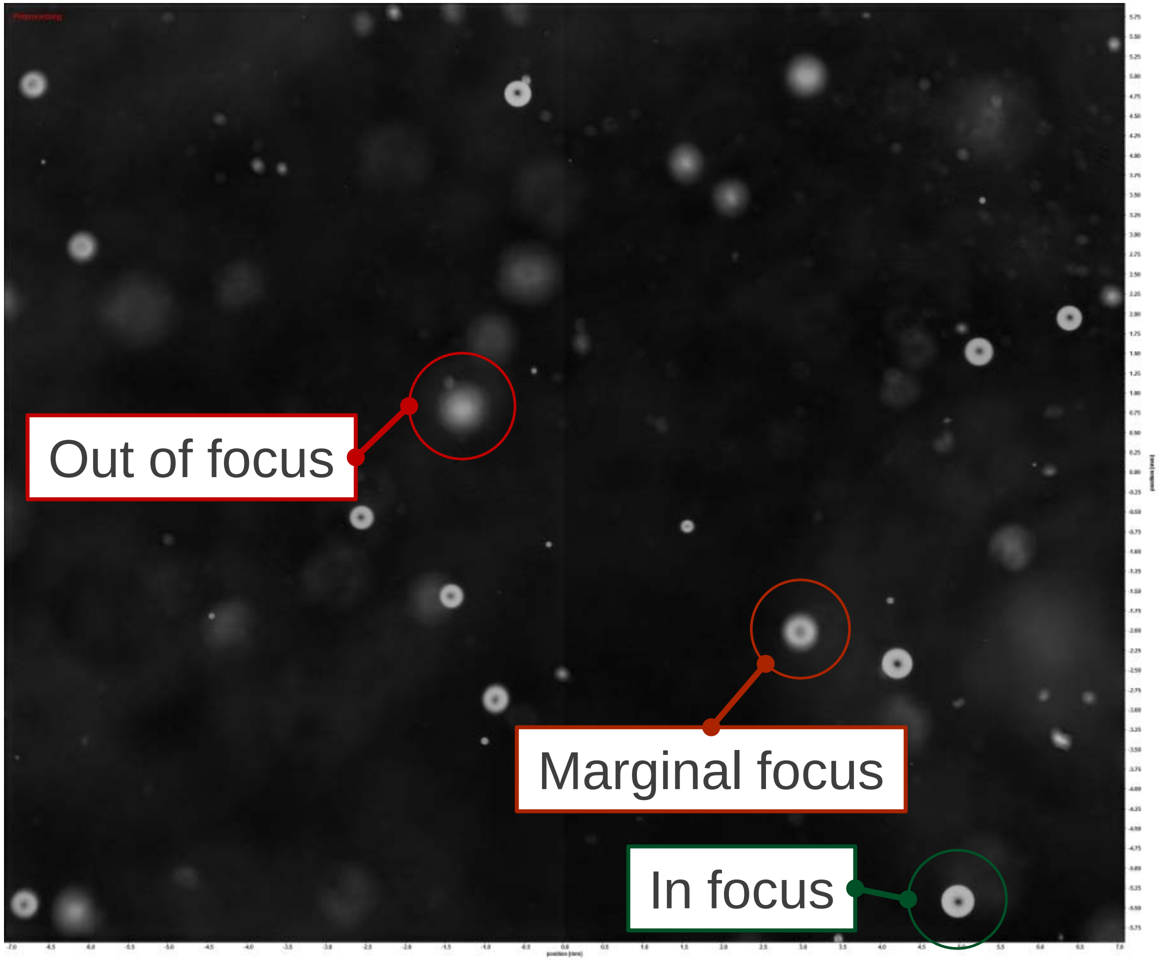
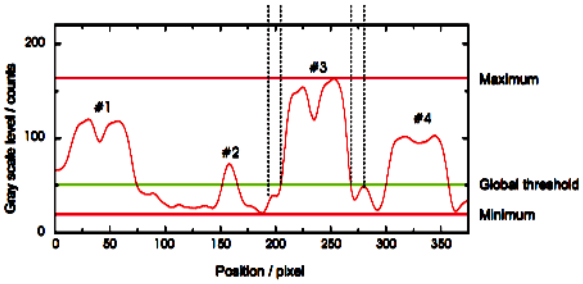
Setup – software and processing

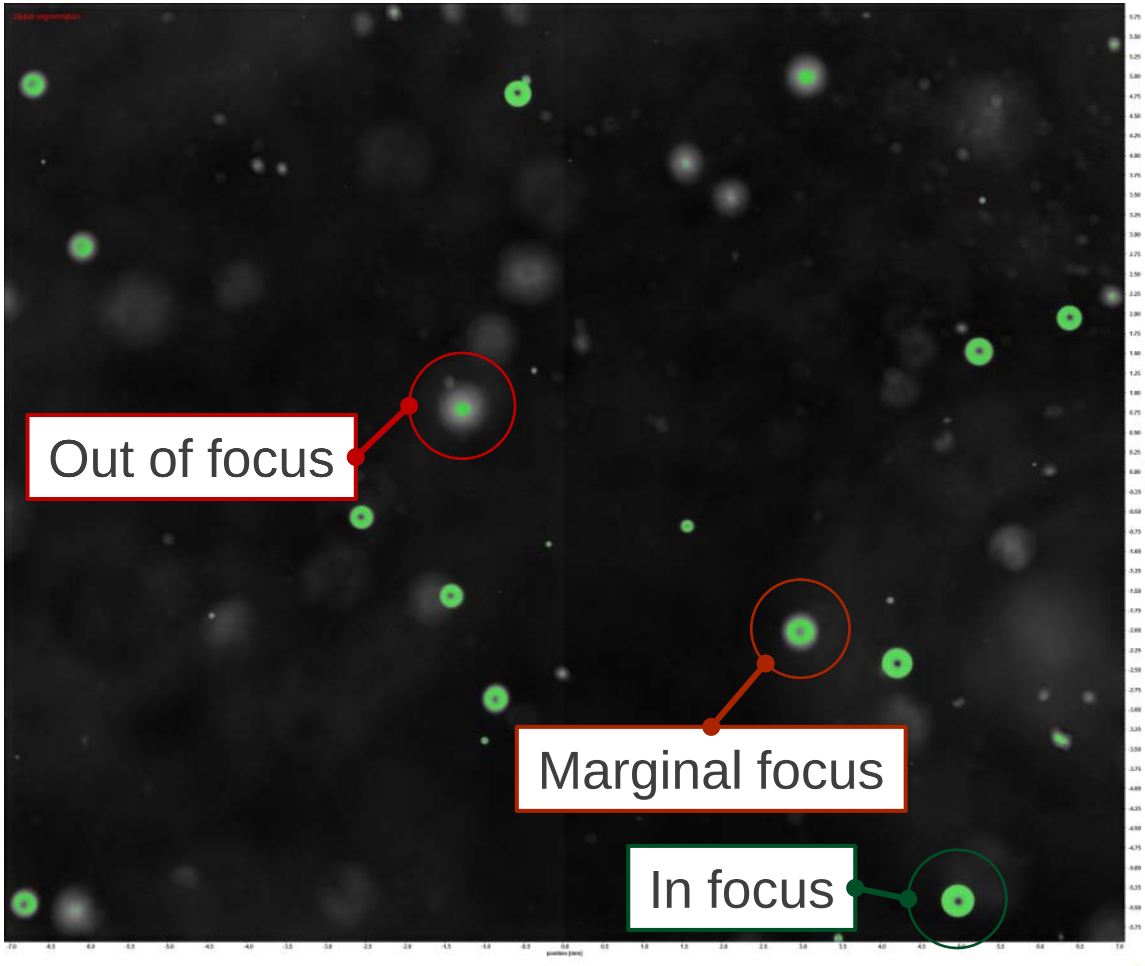
- **Step 2:** Even out image intensity
  - Subtract smooth image from original to normalize
    - ❑ Brightest = 100%
    - ❑ Darkest = 0%
  - Droplets now show up as bright spots



Setup – software and processing

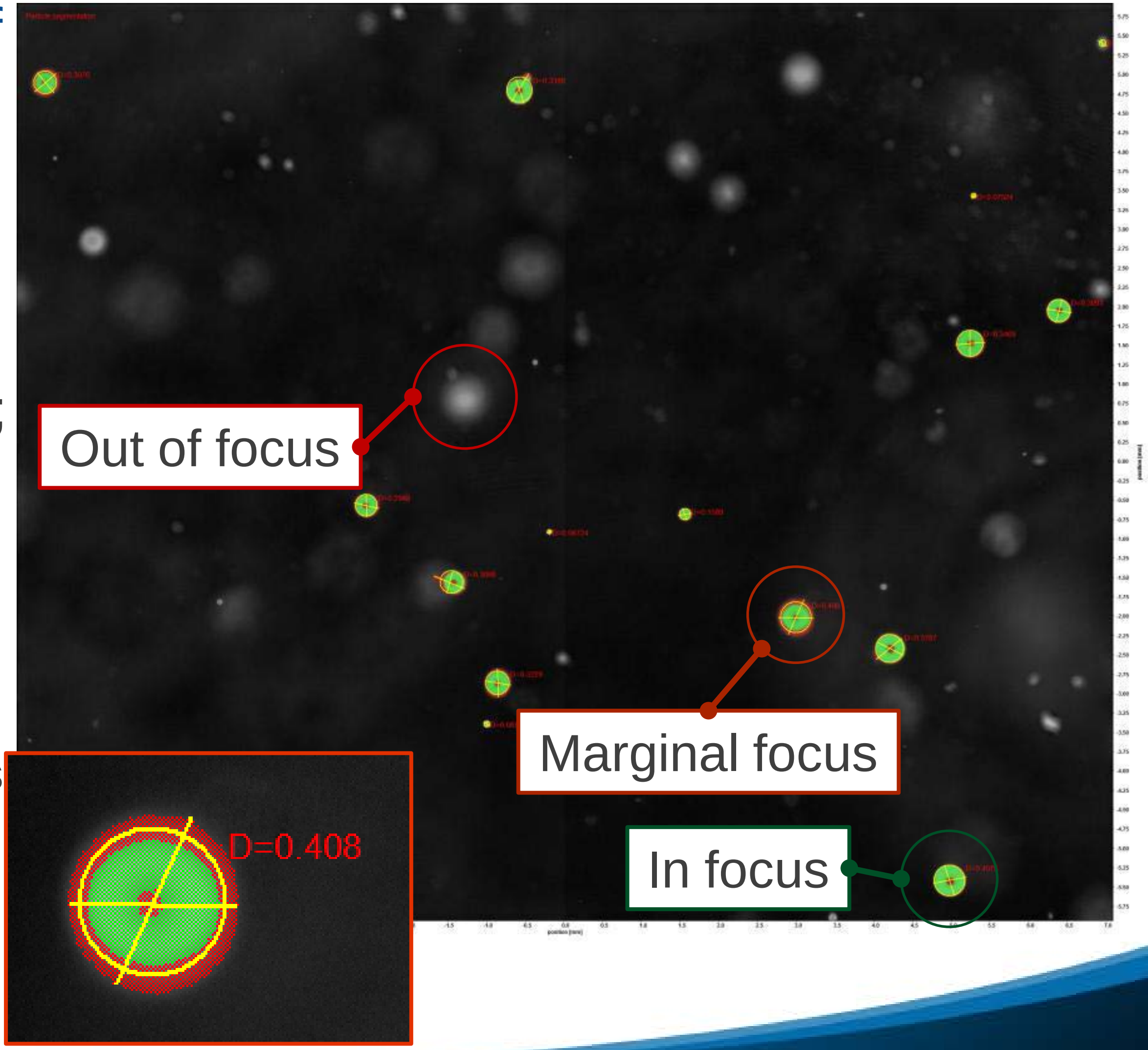
- **Step 3:** Find possible droplets
  - Scan for areas brighter than a certain "global" threshold
    - ❑ e.g. brighter than 40% total intensity range





Setup – software and processing

- **Step 4:** Filter out of focus droplets, measure size
  - Review droplets using brightness thresholds (low 30%; high 70%)
  - Compare relative areas
    - ❑ low area < 200% high area = in focus
  - Avg intensity = diameter

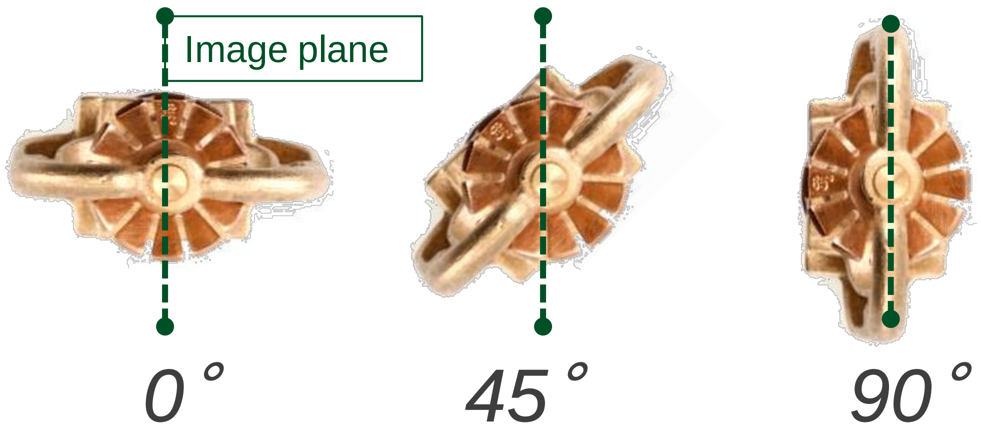


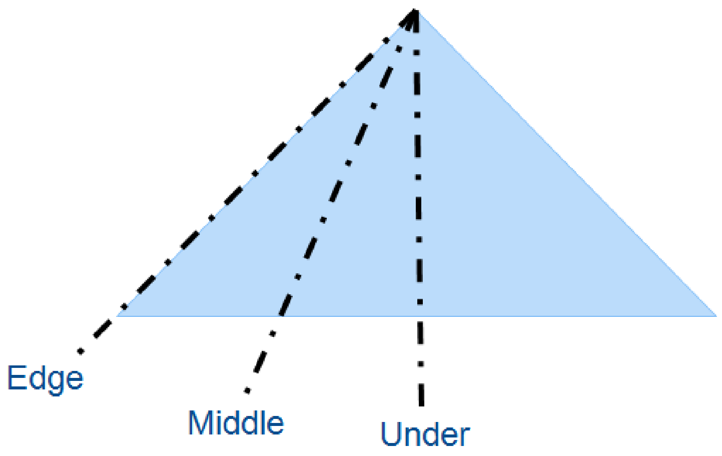
Testing – nozzle parameters

- Tyco D3 nozzle
- 132 tests in total
  - Every sensible combination of given parameters tested
  - Some repeated multiple times
- K-factor
  - 1.2K (K17.3)
  - 3.0K (K43.2)
- Spray angle
  - 65°
  - 180°

Testing – location parameters

- Nozzle rotation
  - 0° (tine)
  - 45° (slot)
  - 90° (frame arms)
- Location in spray
  - Under
  - Middle
  - Edge
- Distance from nozzle
  - 1 ft (0.3m)
  - 3 ft (0.9m)





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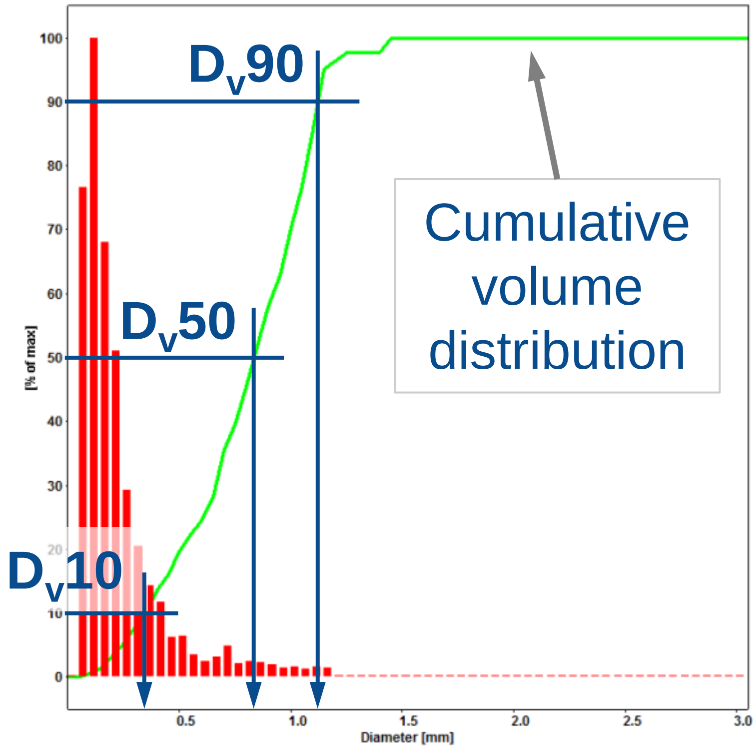
Analysis – statistics definition

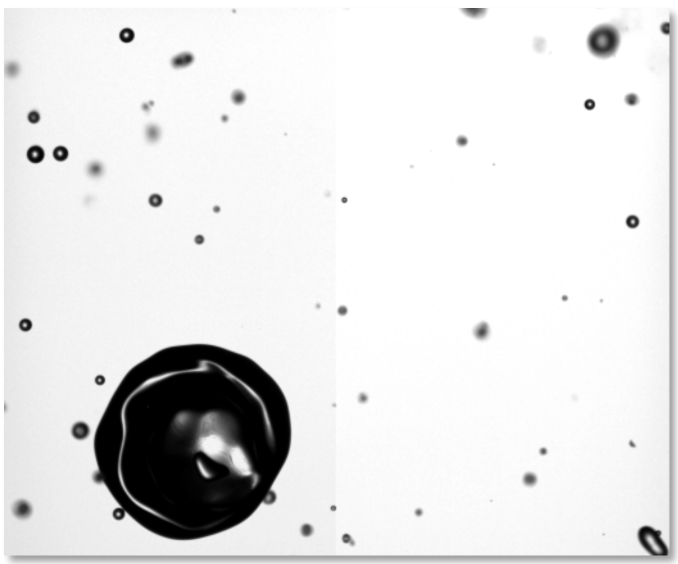
- **D10:** Mean diameter
- **D32**: Sauter Mean Diameter
  - Droplet with same surface area to volume ratio as total distribution
  - Useful when interested in evaporative cooling processes
- **D_VXX** (e.g. D_V10, **D_V50**, D_V90): Volumetric Mean Diameter
  - The diameter below which the distribution contains XX percentage of the total flow
  - D_V50 commonly used in CFD

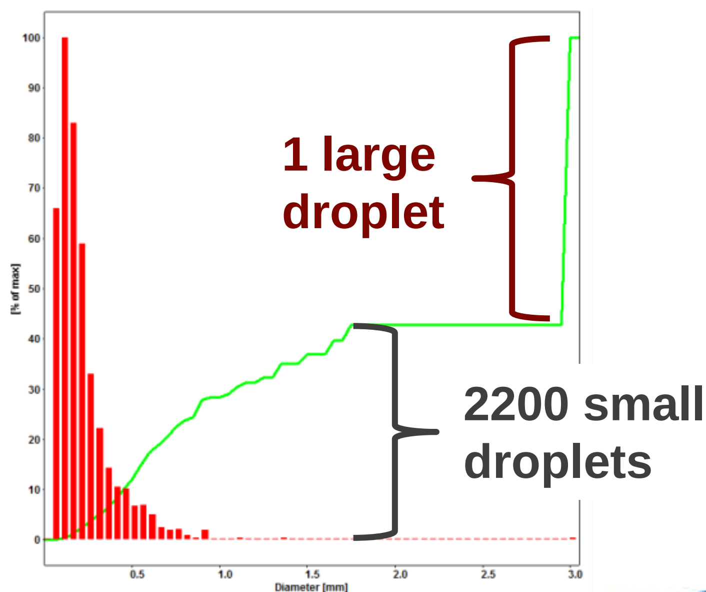
Volumetric Mean Diameter



Analysis – D_VXX sensitivity

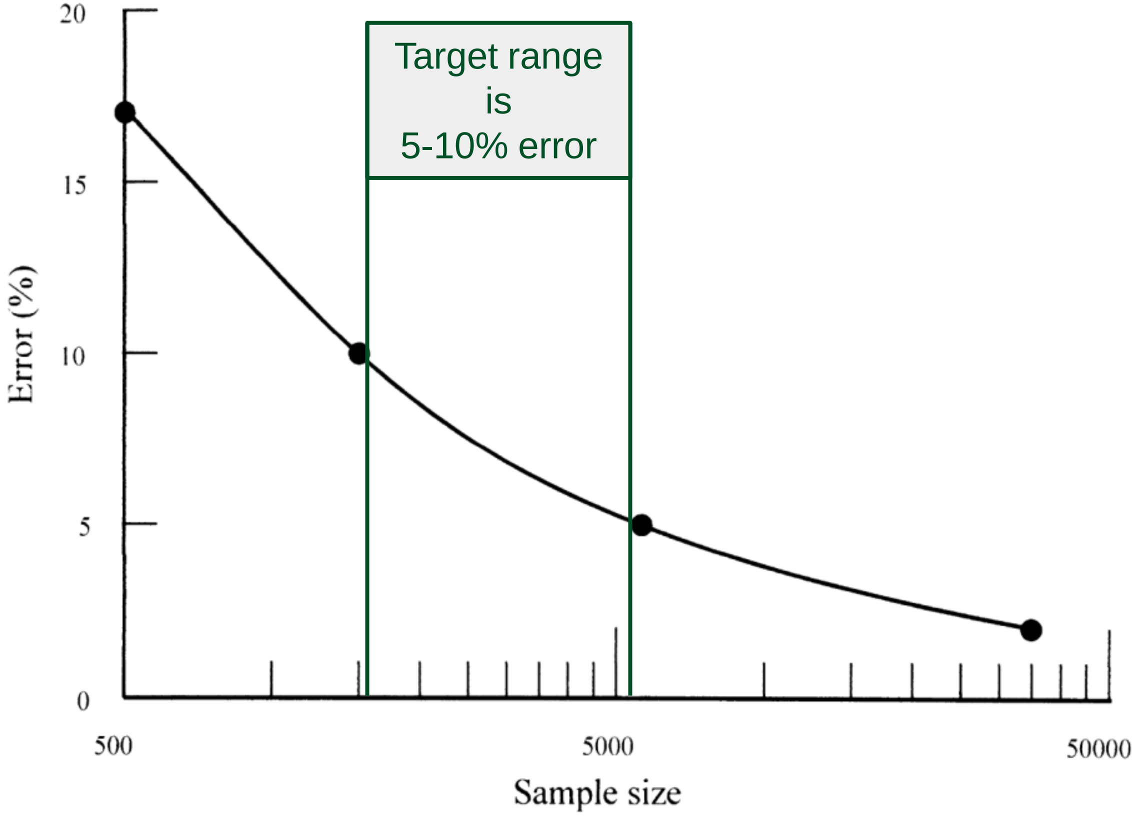
- **The cumulative volume distribution is very sensitive to droplet size.**
  - Droplet volume ~ diameter^3
  - One big droplet in image set can greatly skew D_VXX results





Analysis - statistical confidence

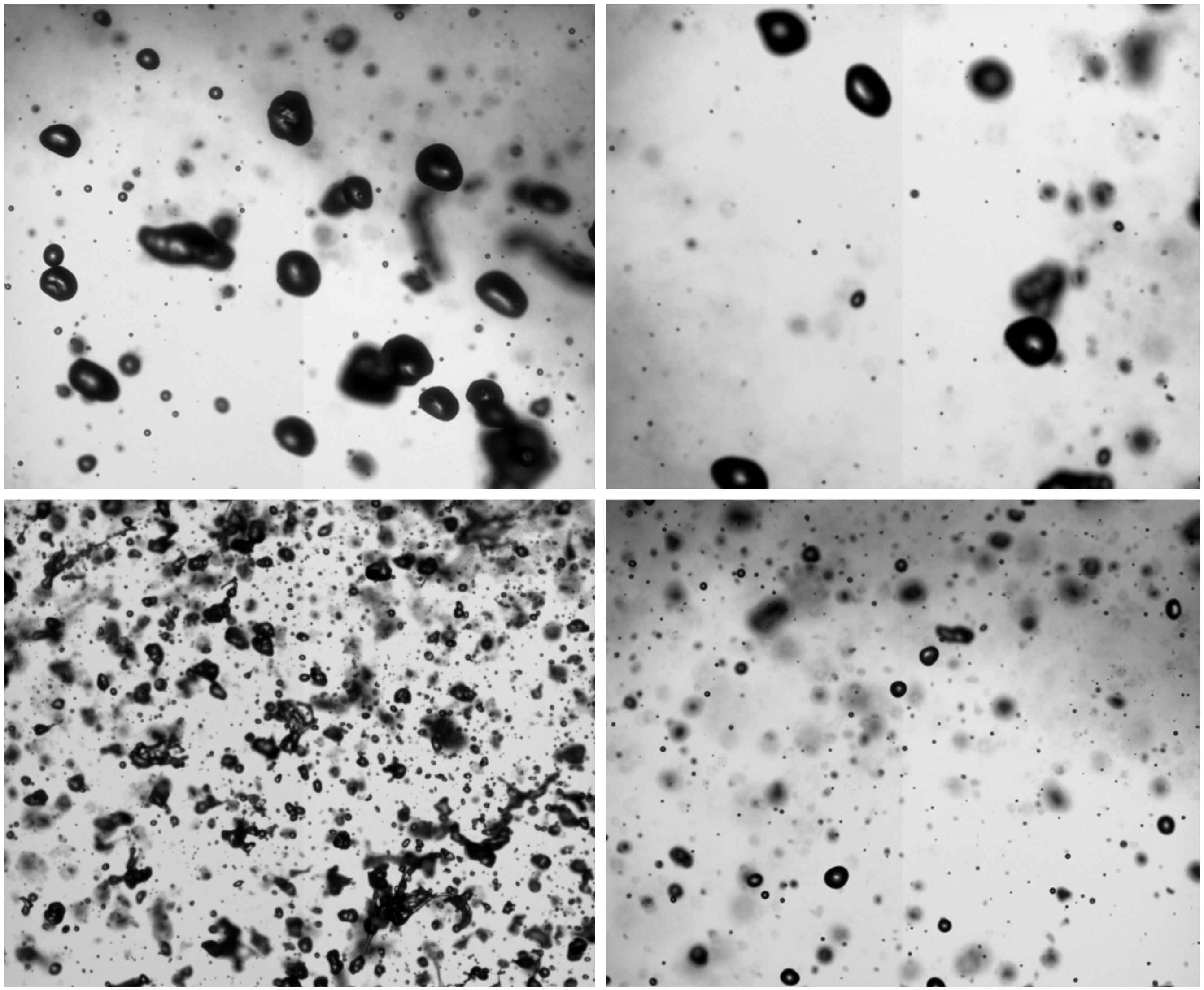
Accuracy of mean droplet diameter as a function of sample size



- Sample size is related to several parameters
  - Number of images
  - Density of measurable droplets per image
- In areas where the spray is disperse, more images are needed for proper statistical confidence

Figure Reference: Grant, G., Brenton, J., & Drysdale, D. (2000). Fire suppression by water sprays. *Progress in Energy and Combustion Science , 26*, pp. 79-130.

Results – Tine *(3.0K, 65^o nozzle)*



20 PSI (1.4 Bar)

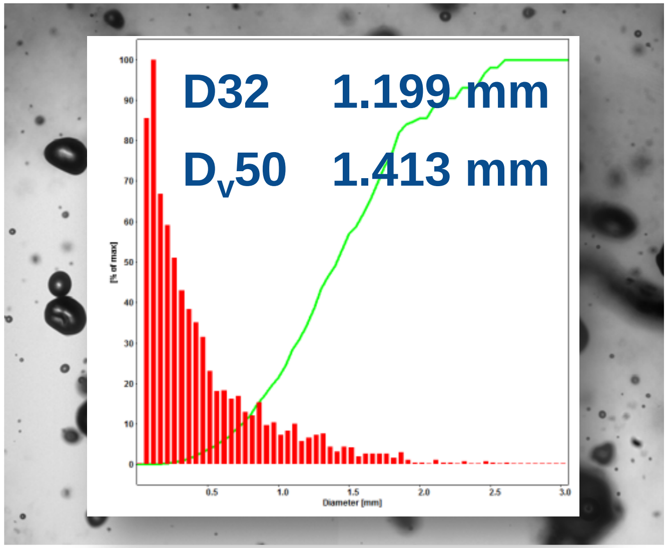
100 PSI (6.9 Bar)

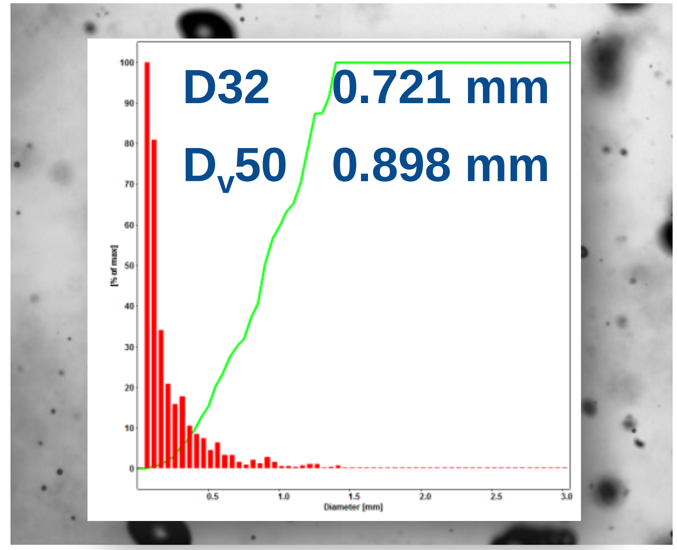
1 ft (30.5 cm) radius

3 ft (91.5 cm) radius

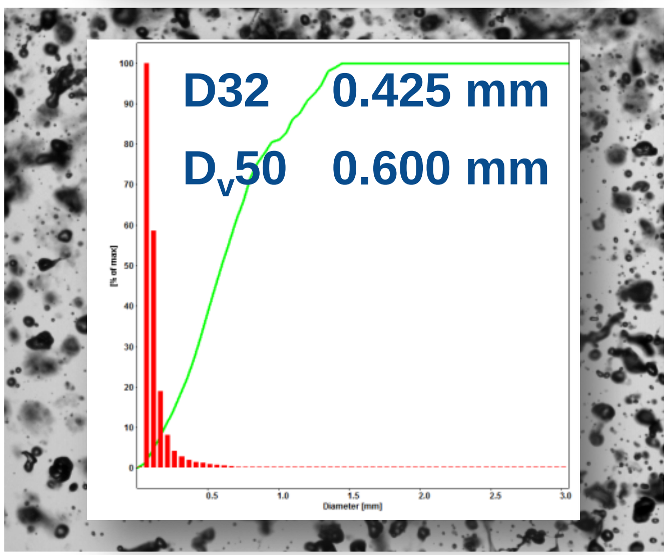
Results – Tine *(3.0K, 65º nozzle)*

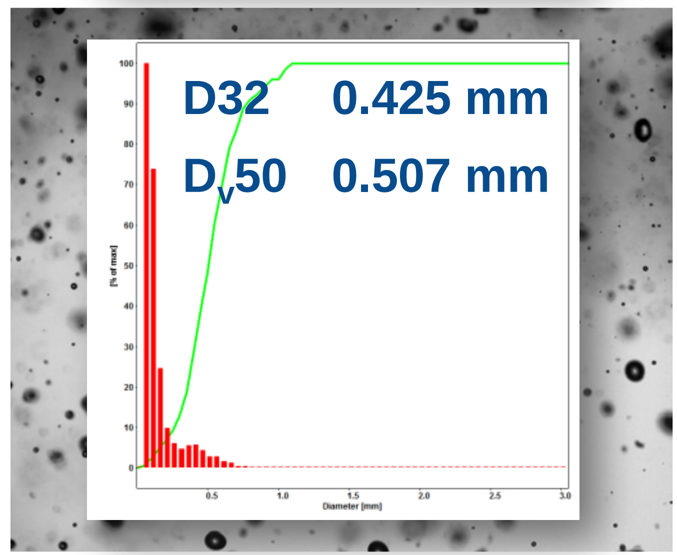
20 PSI (1.4 Bar)





100 PSI (6.9 Bar)





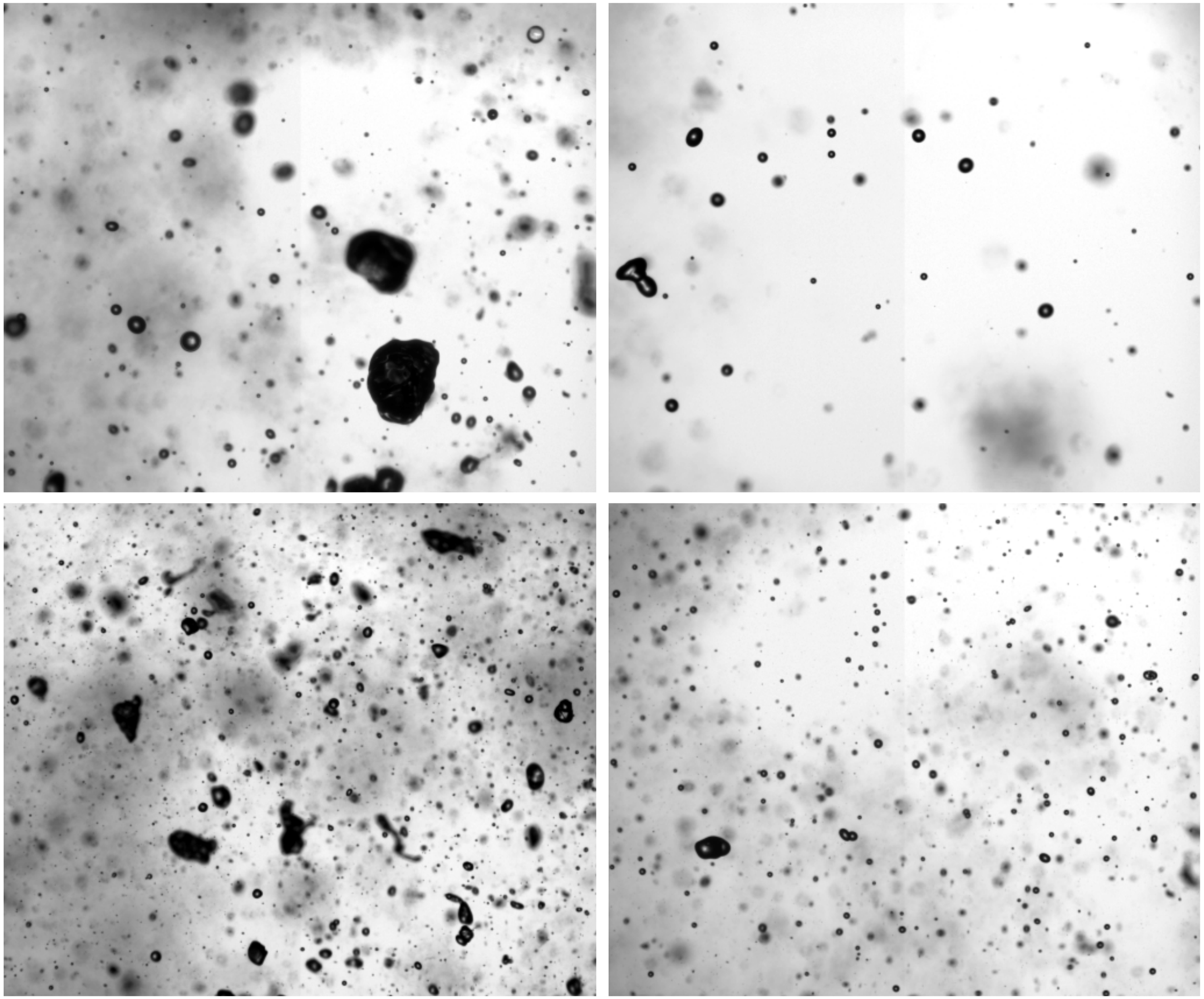
1 ft (30.5 cm) radius

3 ft (91.5 cm) radius

Results – Slot *(3.0K, 65° nozzle)*

20 PSI (1.4 Bar)

100 PSI (6.9 Bar)



1 ft (30.5 cm) radius

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Results – Slot *(3.0K, 65^o nozzle)*

20 PSI (1.4 Bar)

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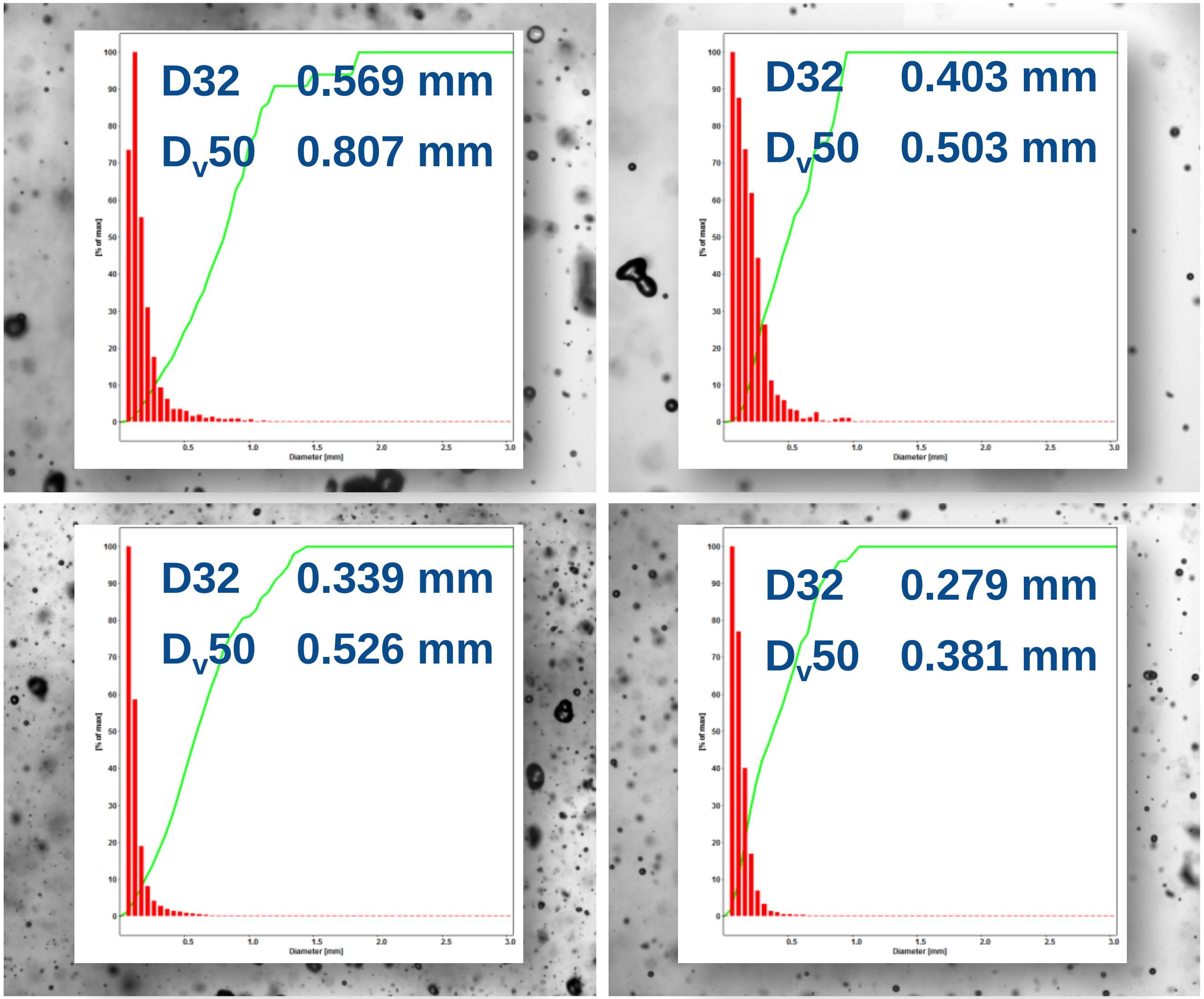


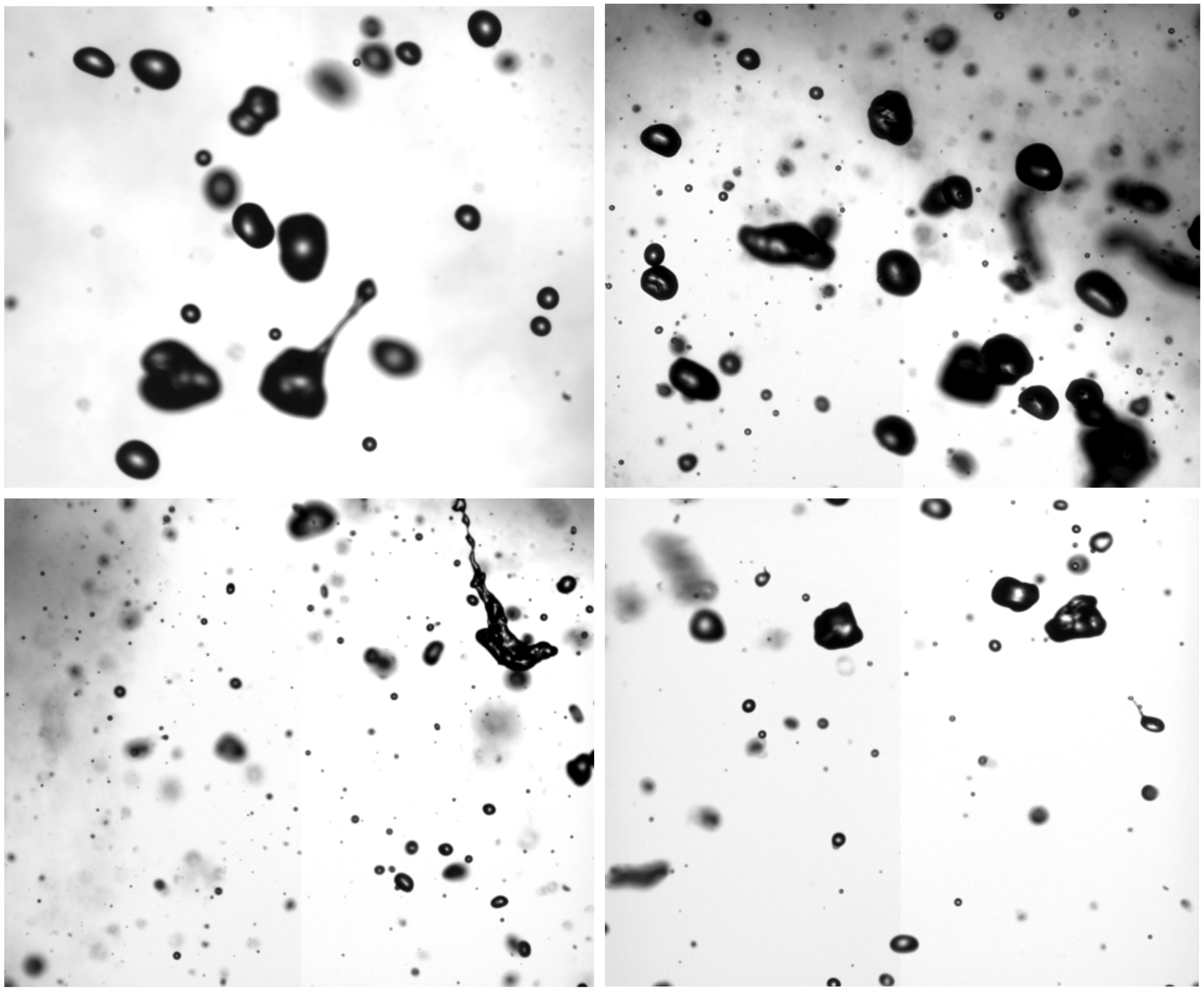
1 ft (30.5 cm) radius

3 ft (91.5 cm) radius

Results – orifice and spray angle *(20 psi, tine, 1 ft)*

65° Spray

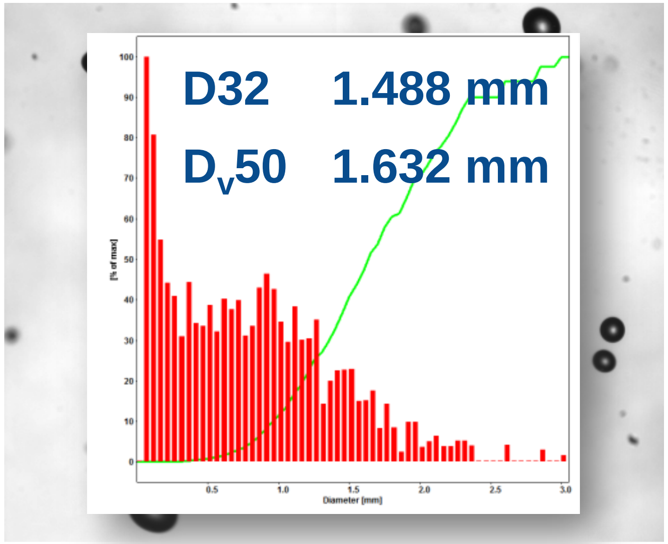
180° Spray

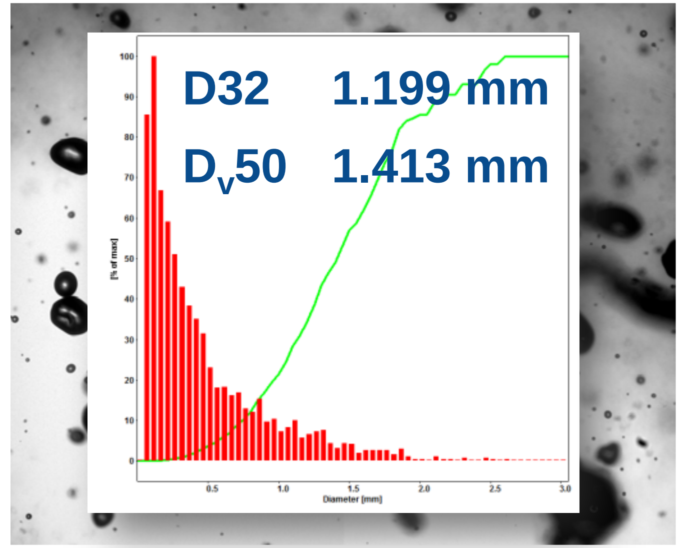


K = 1.2 gpm/psi$^{0.5}$ | K = 3.0 gpm/psi$^{0.5}$

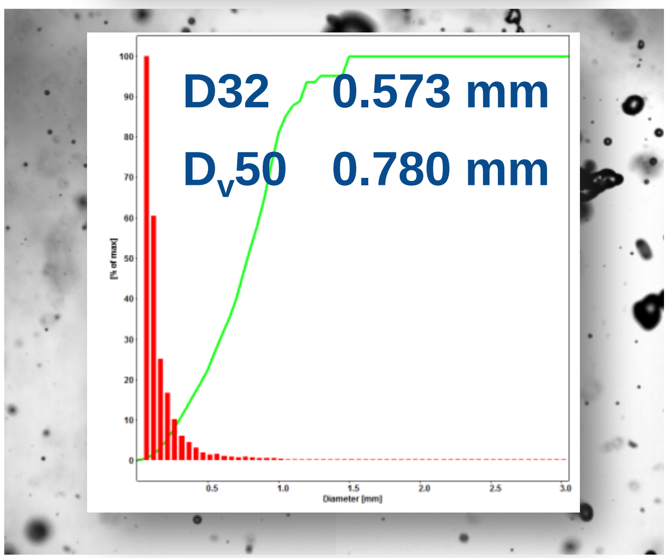
Results – orifice and spray angle *(20 psi, tine, 1 ft)*

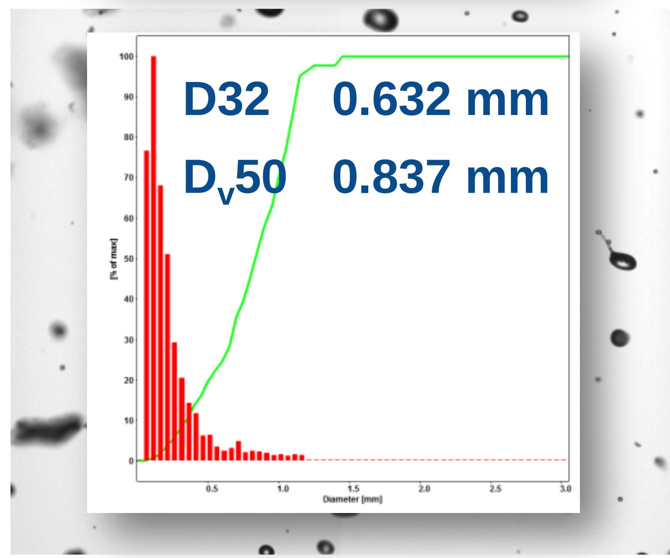
65° Spray





180° Spray





$K = 1.2\ gpm/psi^{0.5}$

$K = 3.0\ gpm/psi^{0.5}$

Conclusions

- Interactions with the frame arms cause relatively unpredictable results
  - Frame arm shadow at 90^{o} spray angle
  - Directly underneath the nozzle
- Big drops tend to maintain trajectory, small droplets fill in gaps
  - Leads to full conical spray pattern of D3
- An increase in orifice size causes an increase in droplet size
  - Exception: frame shadow region
  - On the “edge” of the pattern (subjective definition)

Conclusions

- A wider spray angle produces smaller droplets
  - Thinner water sheet or more turbulence in spray? Or combination?
- There is a significant reduction in droplet size with an increase in pressure
  - Most significant reduction on tines
- Trends tend to match what is generally expected for variations in the chosen parameters
- Research is first step in continuation of spray characterization
  - Leads to streamlined development and better modeling capabilities

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Thank You