NASA Glenn Icing Research Tunnel: 2019 Cloud Calibration

February – September 2019 Tests

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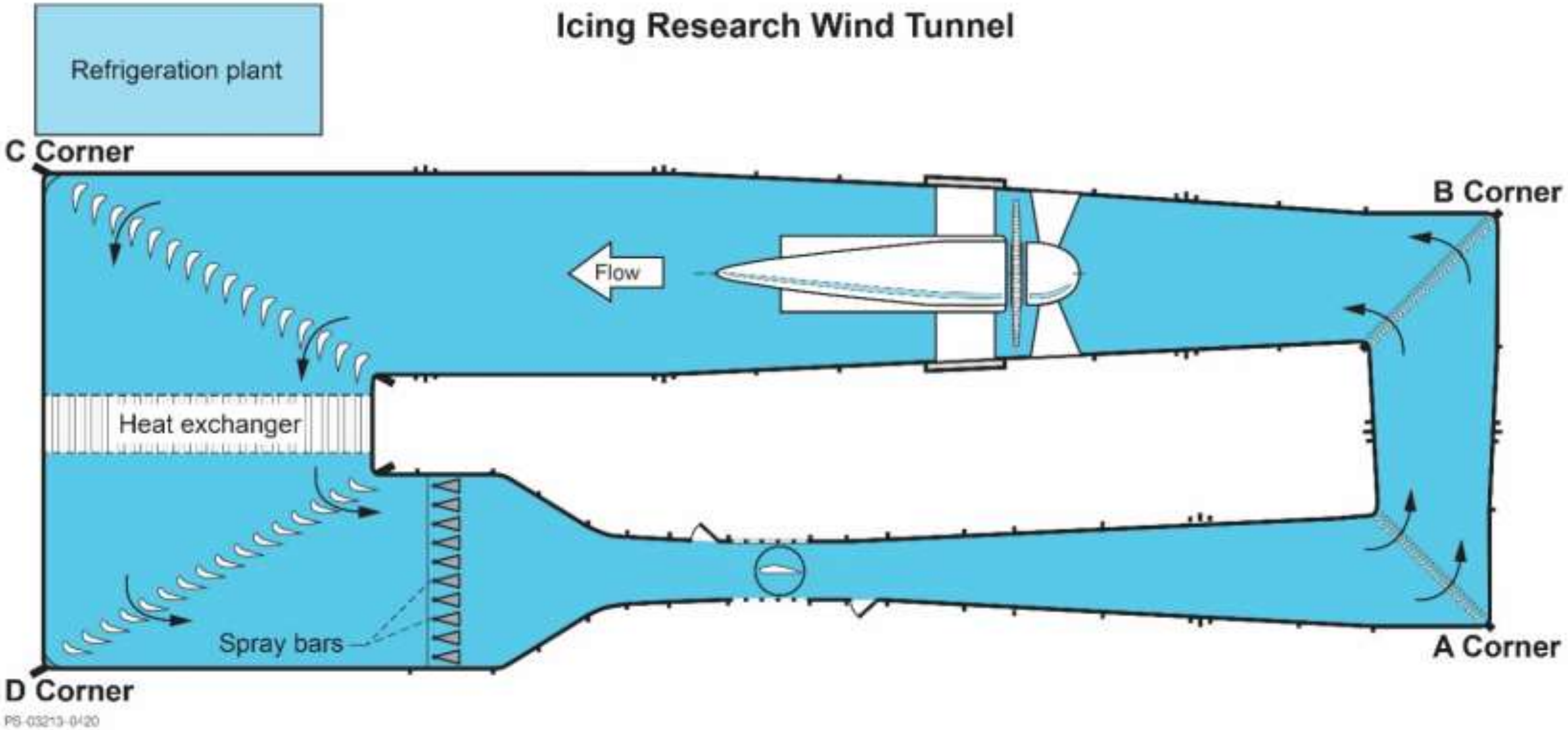
Overview

- Motivation and changes made from 2014 calibration
- Brief description of Icing Research Tunnel (IRT)
- Procedure and results
  - Cloud uniformity
    - Nozzle map changes
  - Drop size (Median Volumetric Diameter: MVD)
  - Liquid Water Content (LWC)
- IRT operating envelopes

Motivation and Changes Made from 2014 Calibration

- 5 year calibration interval
  - ARP5905, "Calibration and Acceptance of Icing Wind Tunnels"
- By July 2018, Mod1 cloud had become less uniform
- Increased the number of Mod1 spraying nozzles in an effort to make overall uniformity more robust
- Added 15 spraying nozzles for the 2019 Mod1 nozzle map
  - updating from **88** spraying nozzles and 2 air-only nozzles to **103** spraying nozzles and 2 air-only nozzles
- 2019 Standard nozzle map remained the same with **165** spraying nozzles

NASA GRC Icing Research Tunnel

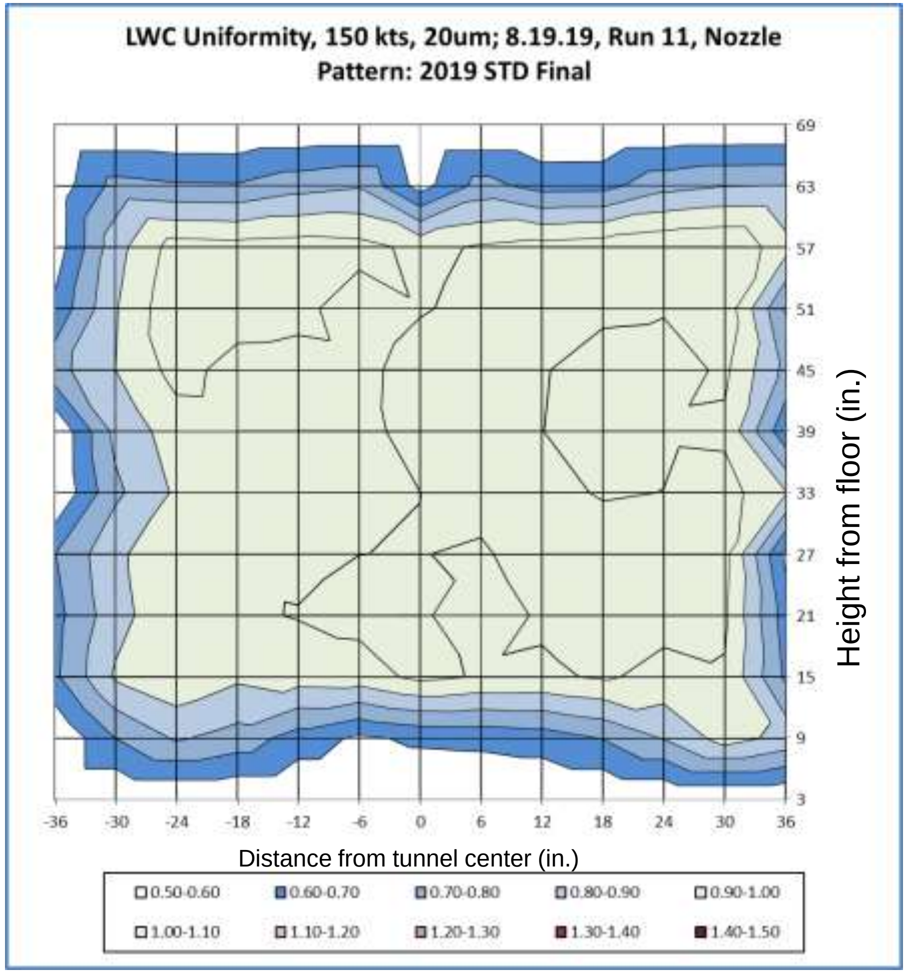


- Test section size: 6 ft. x 9 ft. (1.8 m x 2.7 m)
- LWC & MVD calibration measurements are made in the center of the test section
- LWC uniformity: ±10% for central 4 ft x 6 ft
- Calibrated test section airspeed: 50 –300 kts
- Air temperature: -35ºC static to +15ºC total
- Calibrated MVD range: 14 –270 μm
- Calibrated LWC range: 0.17 –4.0 g/m^3 (function of airspeed)
- Two types of spray nozzles:
  - Standards = higher water flow rate
  - Mod1 = lower water flow rate

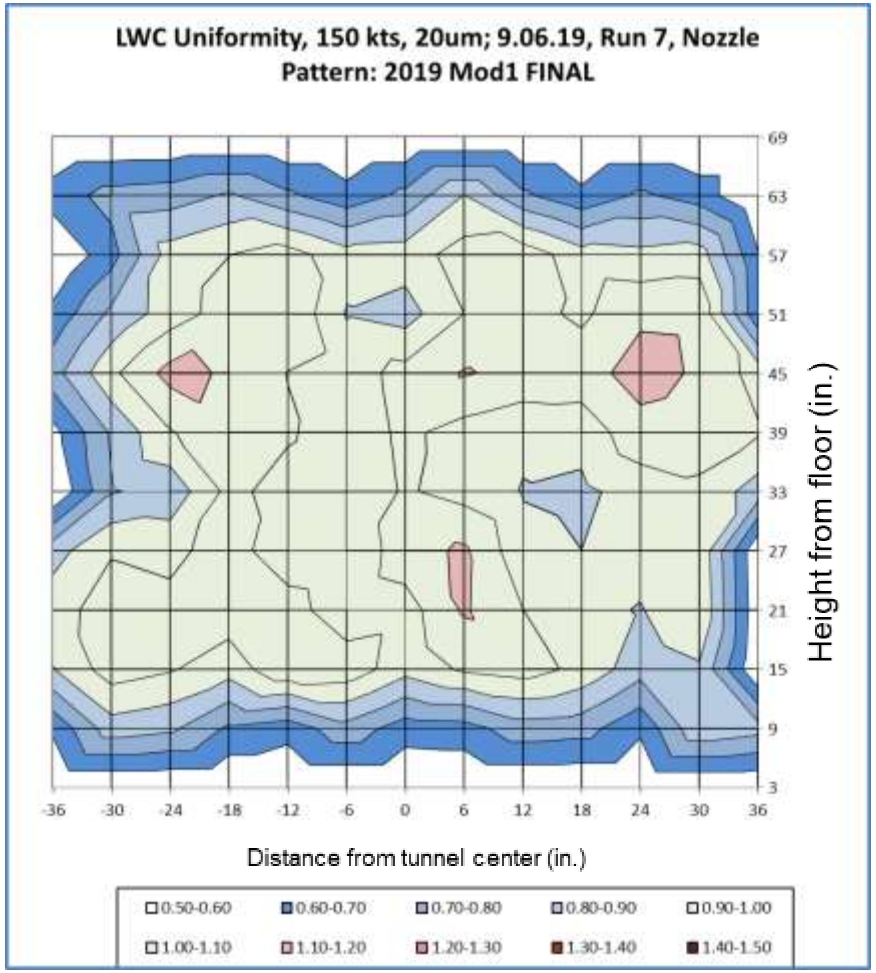
Cloud Uniformity

- Measured with a 6 ft. x 6 ft. grid
  - Grid extends floor to ceiling
  - Mesh elements are spaced every 6 in.
  - Measurements made on vertical elements at 6-inch intervals, starting 3 inches from the tunnel ceiling
- Digital calipers used to measure ice thickness accreted at center mesh points of vertical elements
- Uniformity is established by turning nozzles on & off and iterating measurements until a uniform map is established
- Values are plotted as a ratio of the average of the center-12 points

Cloud Uniformity

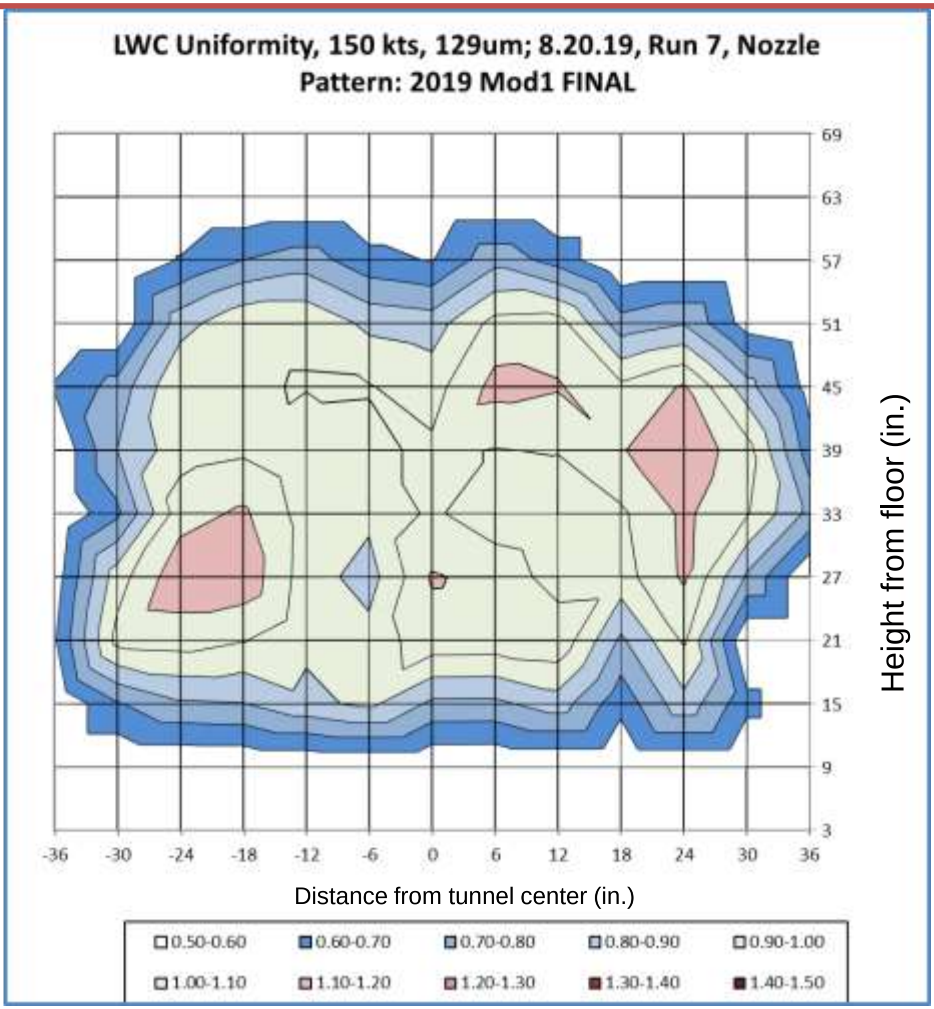


Standard Nozzles



Mod1 Nozzles

Cloud Uniformity



Mod1 nozzles between 2 ≤ P_{air} ≤ 8 psig (SLD) conditions

Drop Size Calibration: Probes

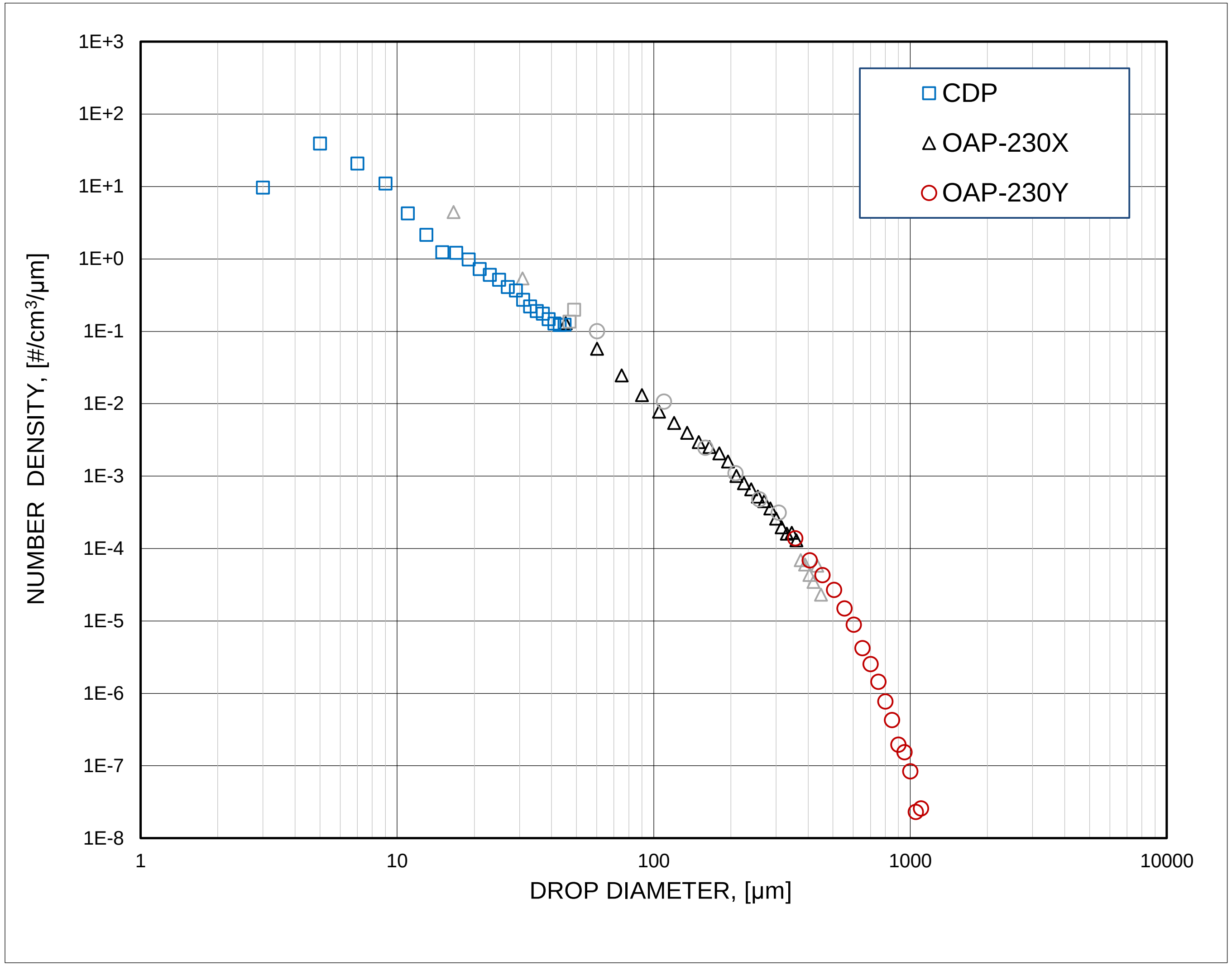
Cloud Droplet Probe
CDP
2 – 50 μm

Optical Array Probe
OAP-230X
15 – 450 μm

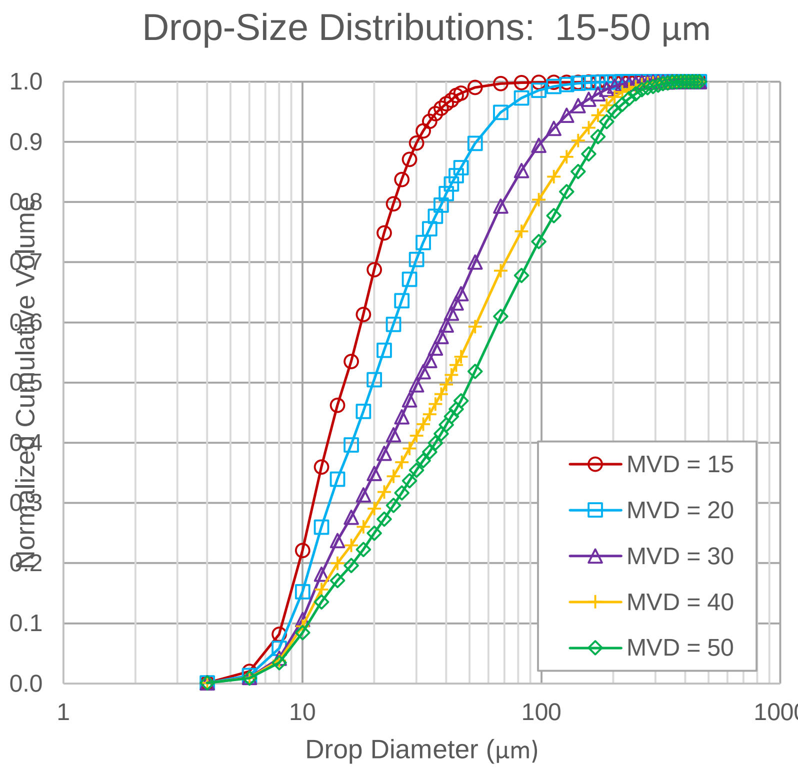
Optical Array Probe
OAP-230Y
50 – 1525 μm

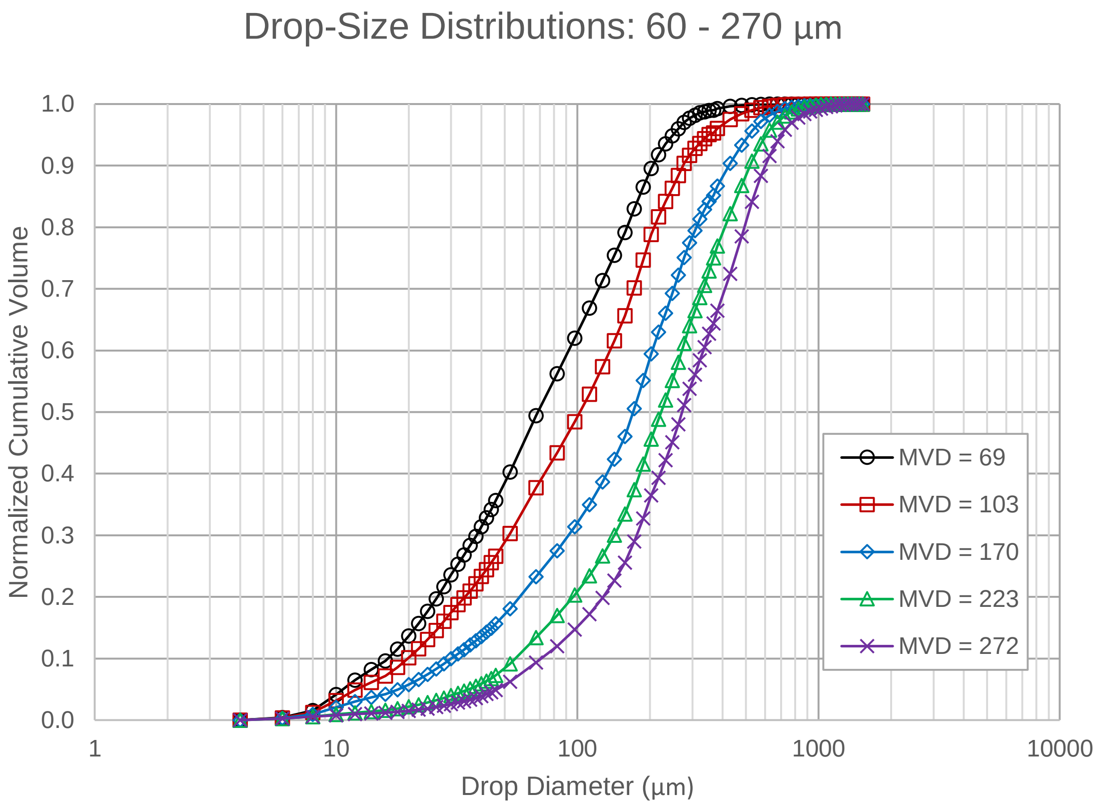
- Drop size distributions from the CDP are combined with the OAP-230X and OAP-230Y to calculate Median Volumetric Diameter (MVD)

Number Density Plot

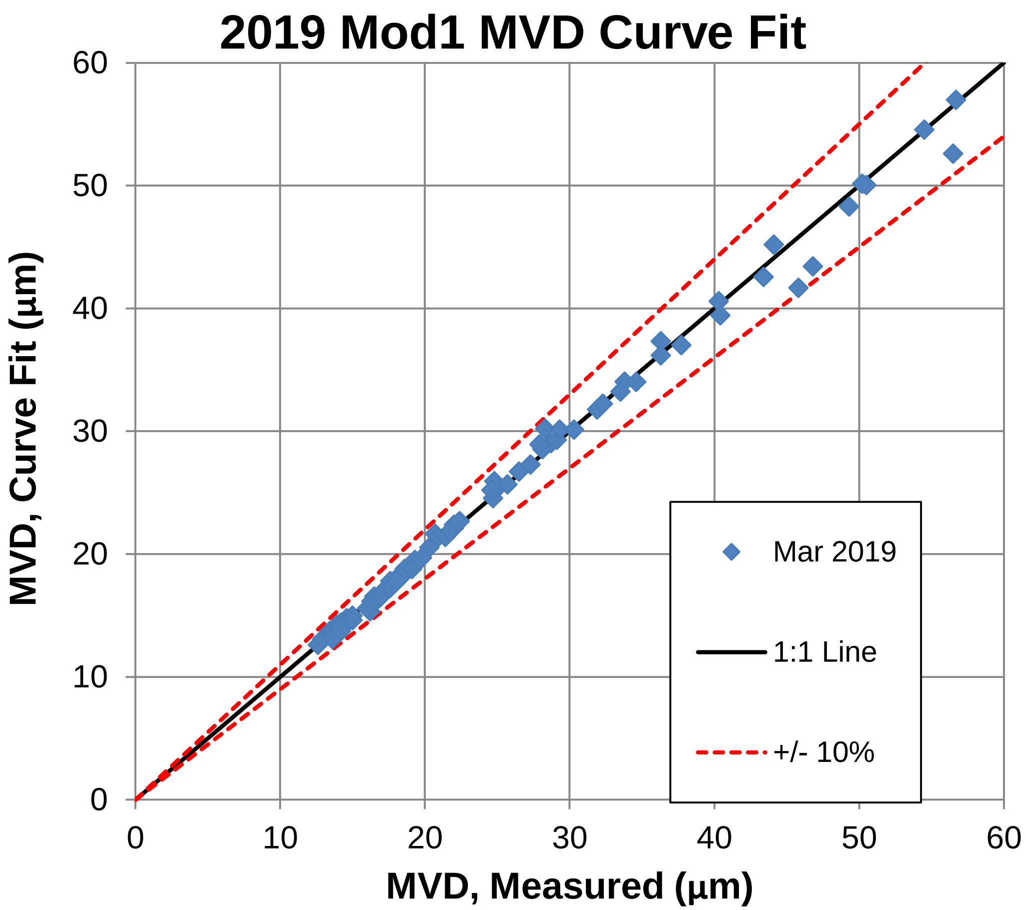


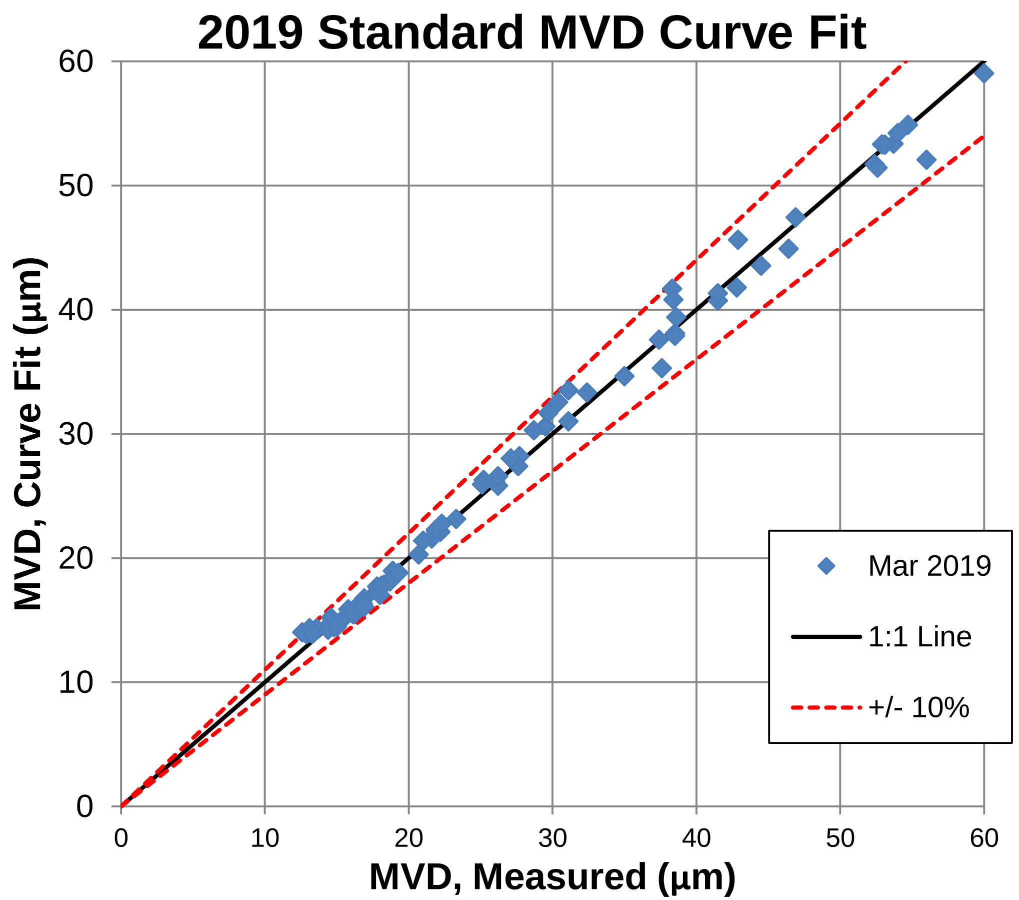
Drop-size Distributions





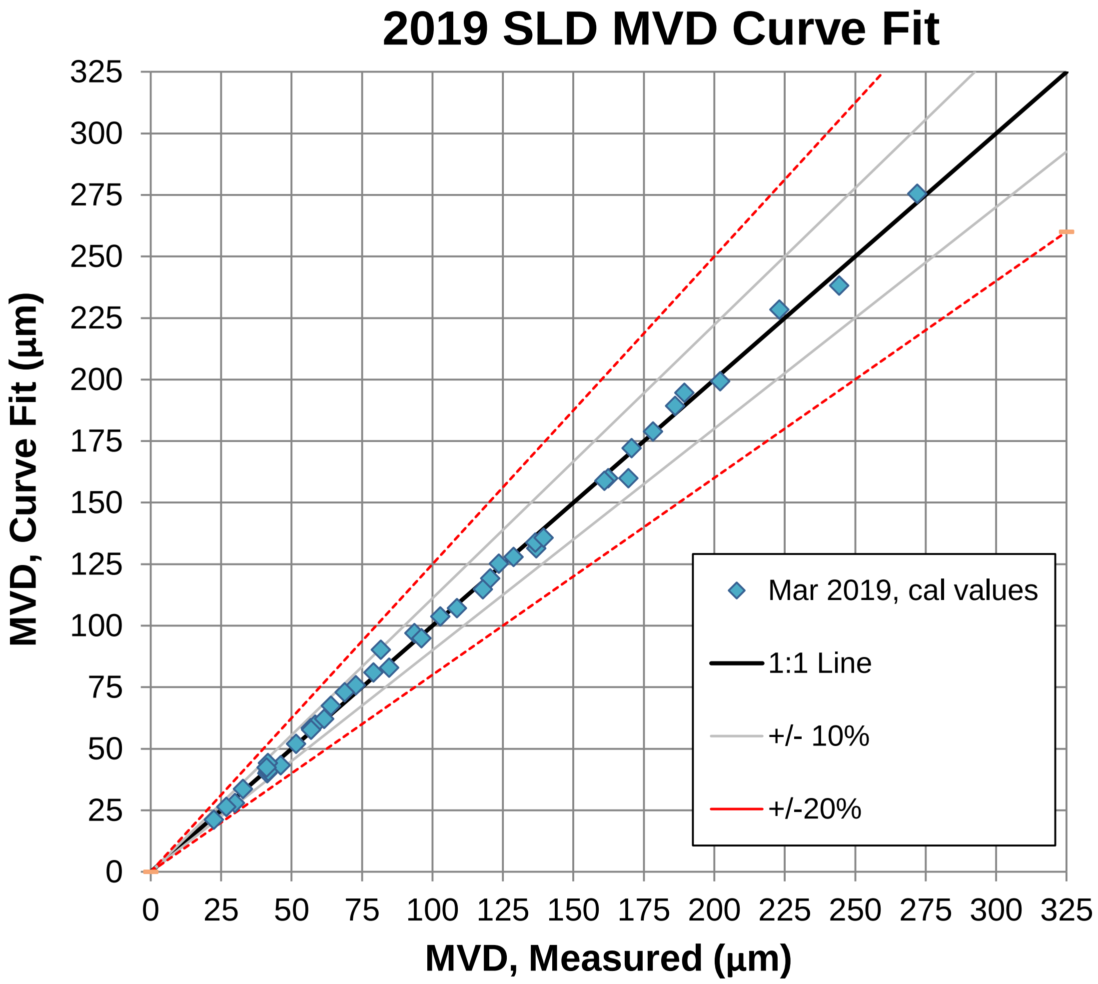
Drop-Size 1:1 Reference Lines





- Curve fits for Standard nozzles and Mod1 nozzles agree with measured MVD to within +/- 10%

Drop-Size 1:1 Reference Lines (Supercooled Large Drops)



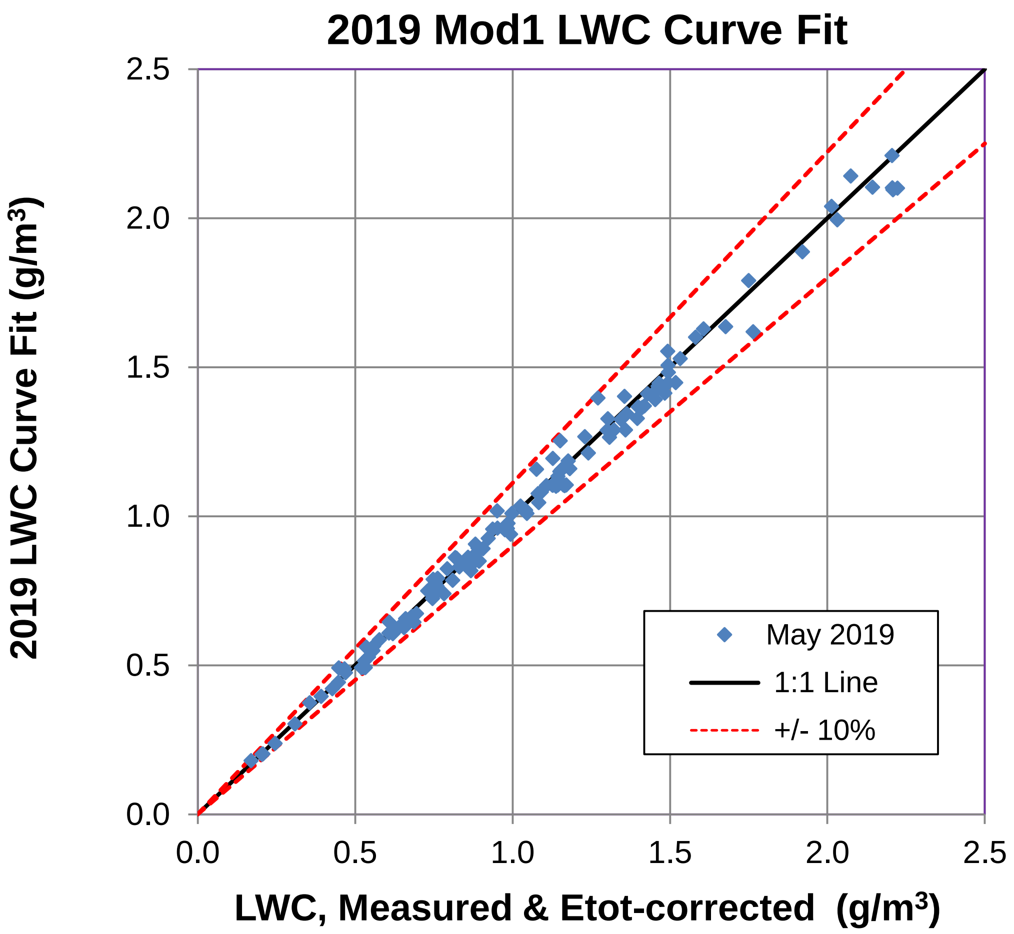
- MVD = f(P_{air}, ΔP)
- Curve fits for supercooled large drop conditions agree with measured MVD to within +/- 20%

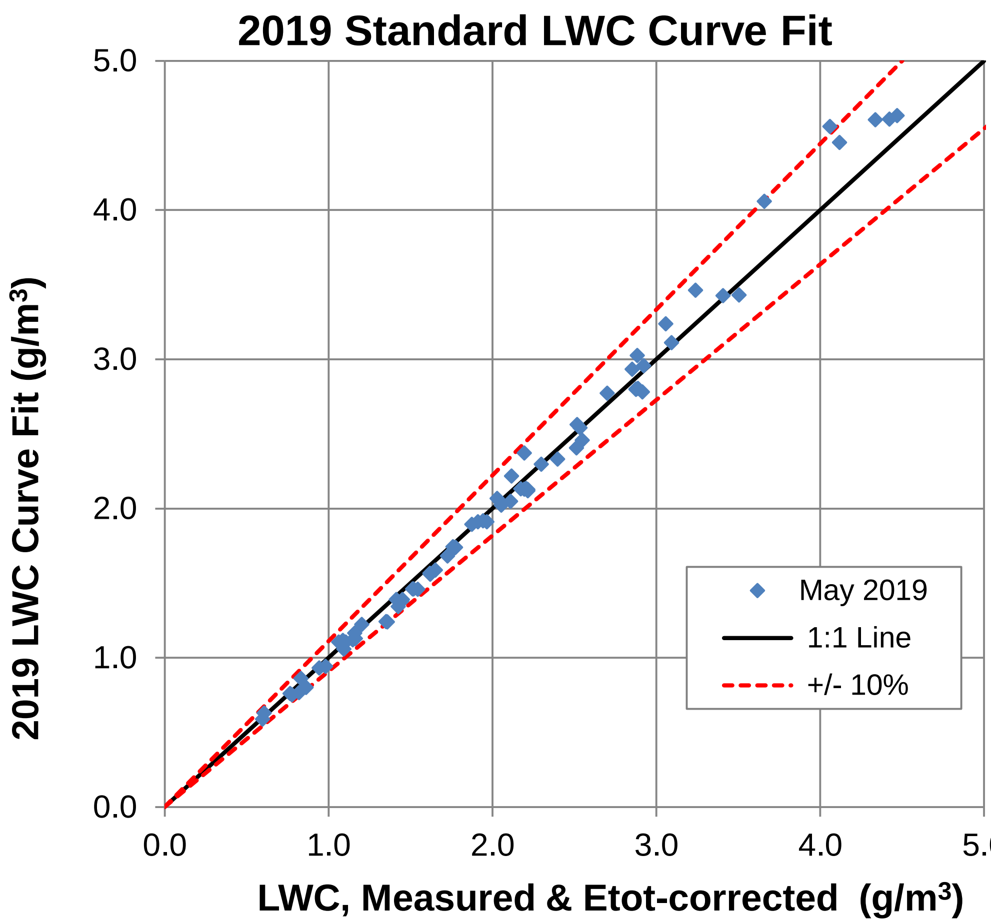
Liquid Water Content (LWC): Instrumentation

- Multi-Element Sensor ("Multi-Wire")
  - Science Engineering Associates, Inc.
  - 3 sensing elements of different size, designed for response of varying conditions
    - IRT uses the TWC element for LWC calibration
  - Change in instrument setup: removed the splitter plate previously used

- Icing Blade
  - Stainless Steel
  - 1/8" x 6" x 3/4"
    - 3.175mm x 154.2mm x 19.05mm
  - Was the standard LWC measurement for IRT from 1980-2011
  - Measured enough data points to confirm accuracy of MW

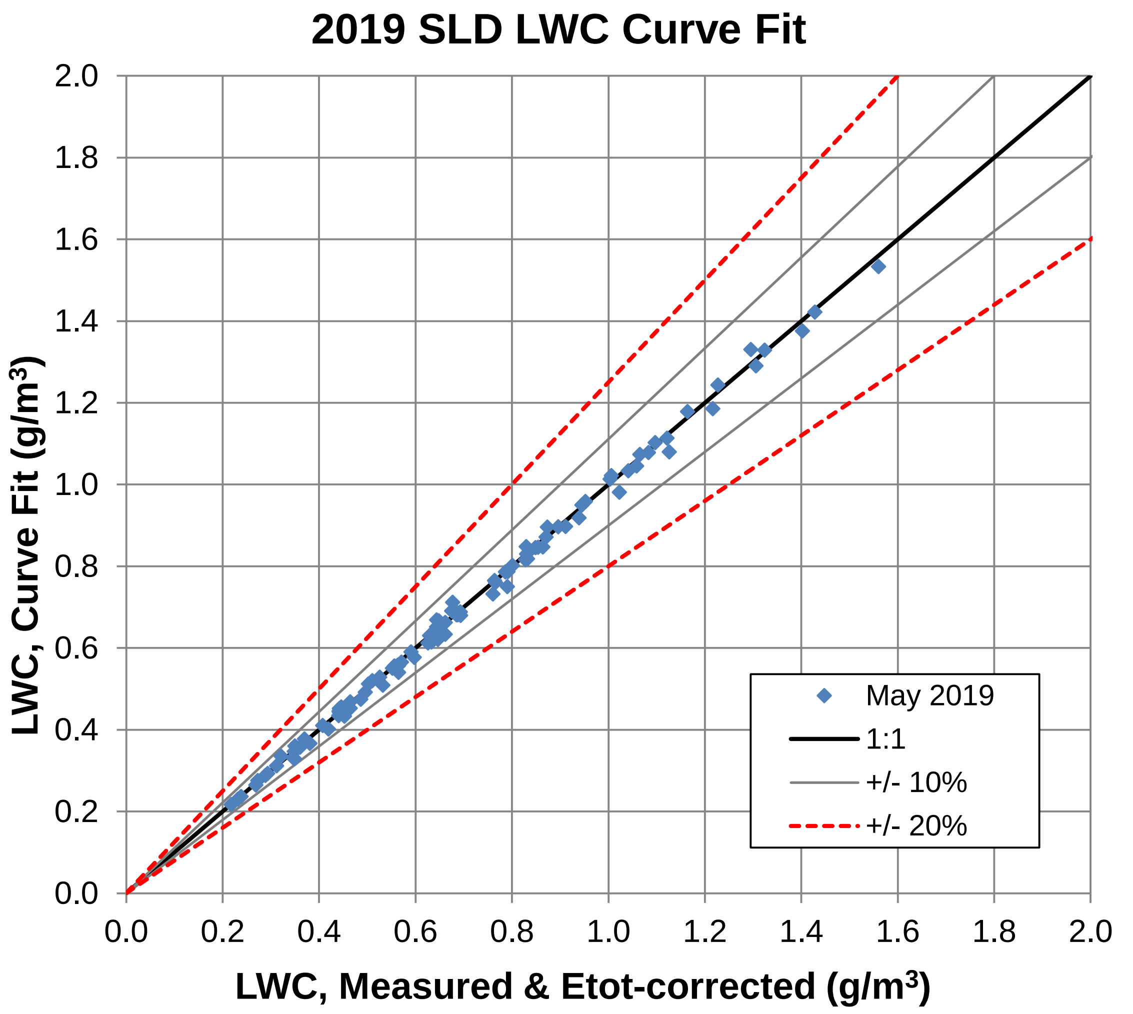
Liquid Water Content (LWC) MVD Curve Fit vs Measured





- LWC = f(velocity, P_{air}, ΔP, MVD)
- Curve fits for Standard and Mod1 nozzle conditions agree with measured LWC to within +/- 10%

Liquid Water Content MVD Curve Fit vs Measured (Supercooled Large Drops)



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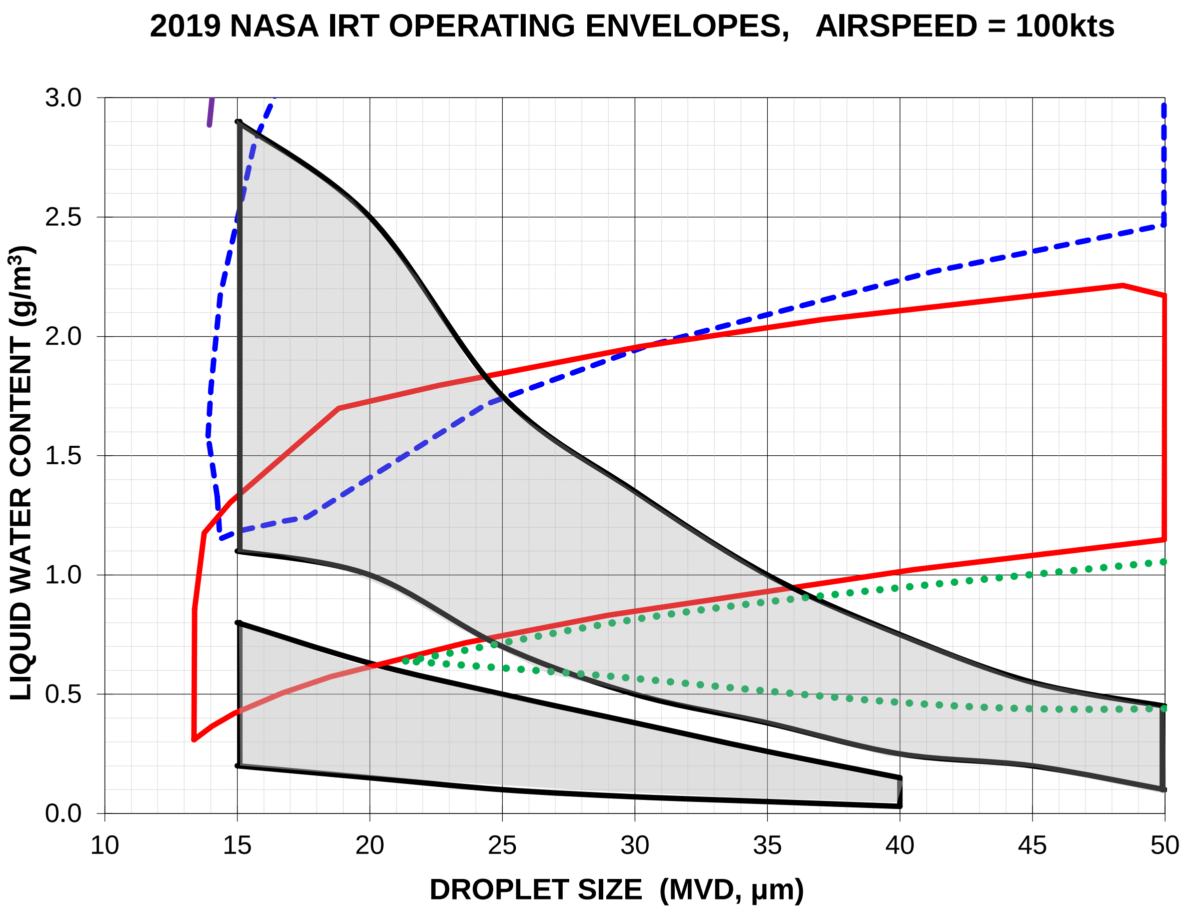
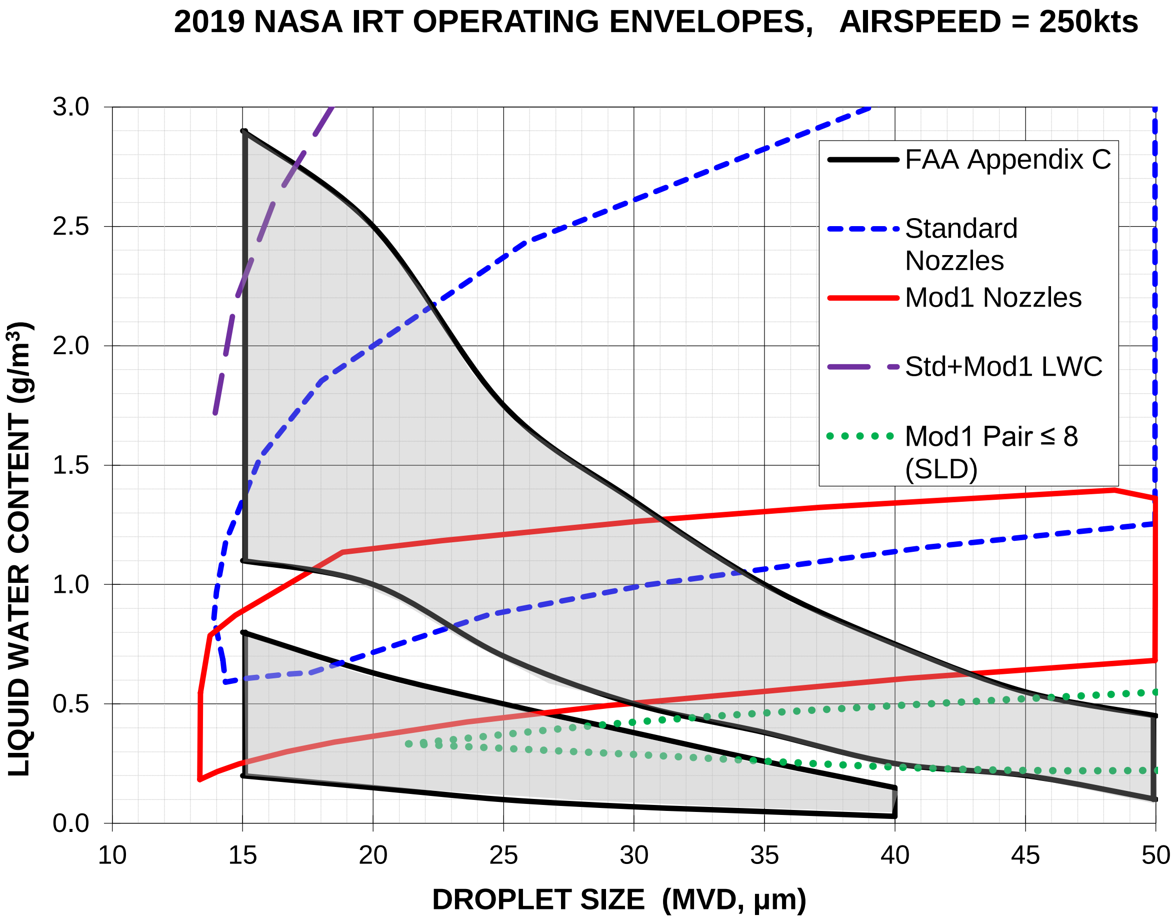
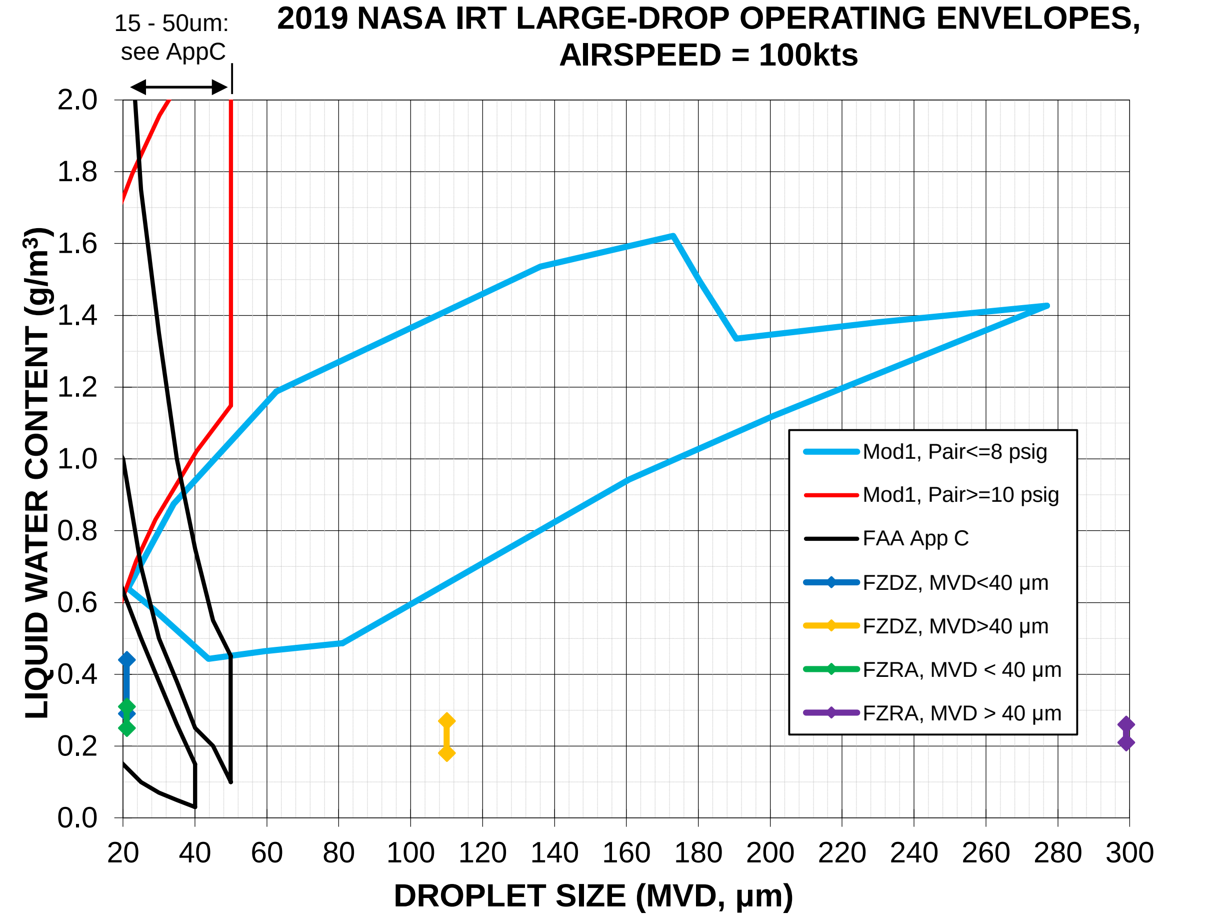
2019 Operating Envelopes: Appendix C

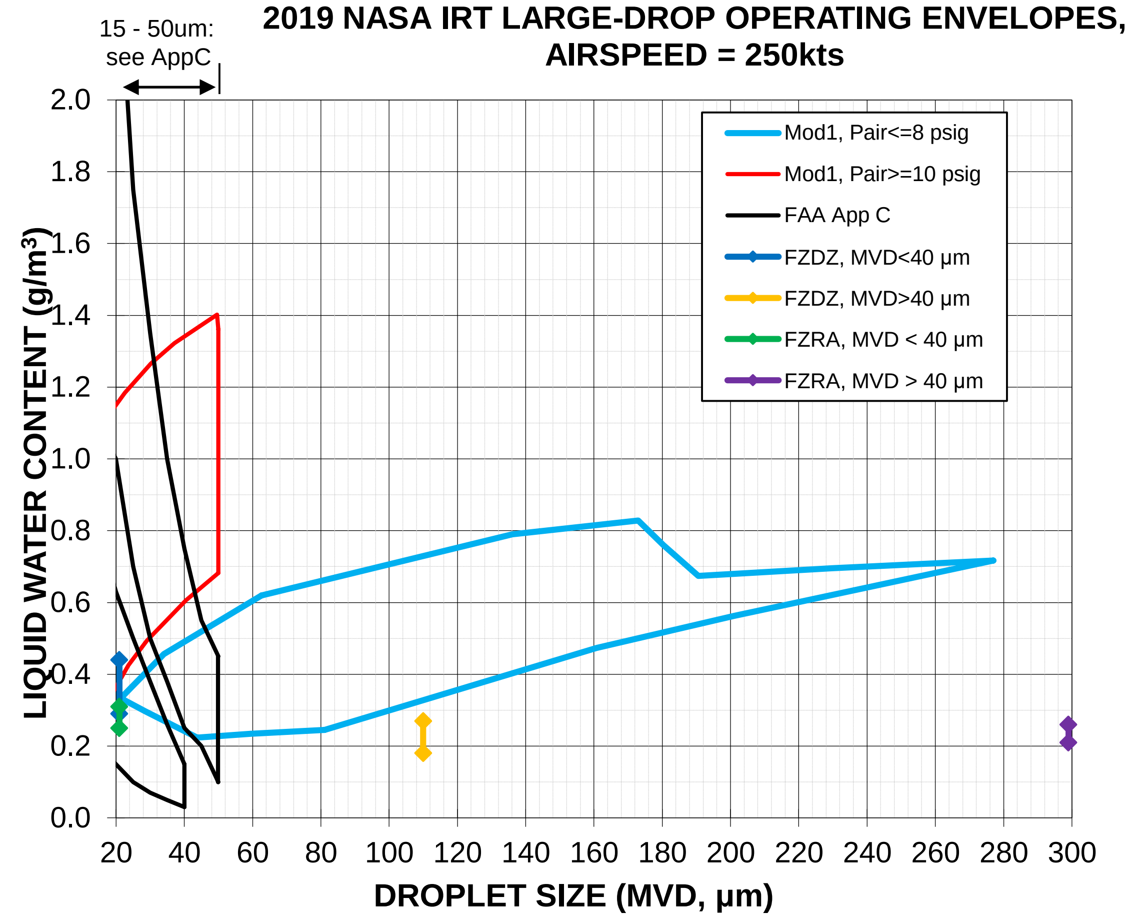




Federal Aviation Administration: Atmospheric Icing Conditions. U.S. Code of Federal Regulations, Title 14, Part 25, Appendix C, 2015.

2019 Operating Envelopes: Appendix O





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- Federal Aviation Administration: Supercooled Large Drop Icing Conditions. U.S. Code of Federal Regulations, Title 14, Part 25, Appendix), 2015.
- Steen, L.E., Ide, R.F., Van Zante, J.F., and Acosta, W.J., "NASA Glenn Icing Research Tunnel: 2014 and 2015 Cloud Calibration Procedure and Results," NASA/TM—2015-21878
- Ide, Robert F., Sheldon, David W., "2006 Icing Cloud Calibration of the NASA Glenn Icing Research Tunnel," NASA/TM—2008-215177.
- Society of Automotive Engineers: ARP5905, "Calibration and Acceptance of Icing Wind Tunnels."
- Steen, L.E., Ide, R.F., and Van Zante, J.F., "An Assessment of the Icing Blade and the SEA Multi-Element Sensor for Liquid Water Content Calibration of the NASA GRC Icing Research Tunnel." 8th AIAA Atmospheric and Space Environments Conference. June 2016.
- Rigby, D.L., Struk, P.M., and Bidwell, C., "Simulation of Fluid Flow and Collection Efficiency for an SEA Multi-Element Probe," 6th AIAA Atmospheric and Space Environments Conference, AIAA 2014-2752, 2014.
- *To Be Published: Timko, E.N., King-Steen, L.E., Acosta, W.J., and Van Zante, J.F., "NASA Glenn Icing Research Tunnel: 2019 Cloud Calibration Procedure and Results," NASA/TM*

Questions?