NASA Glenn Icing Research Tunnel: 2014 Cloud Calibration

Jan-Feb 2014 tests

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Overview

This presentation is meant to (briefly) cover the contents of the newly published paper:

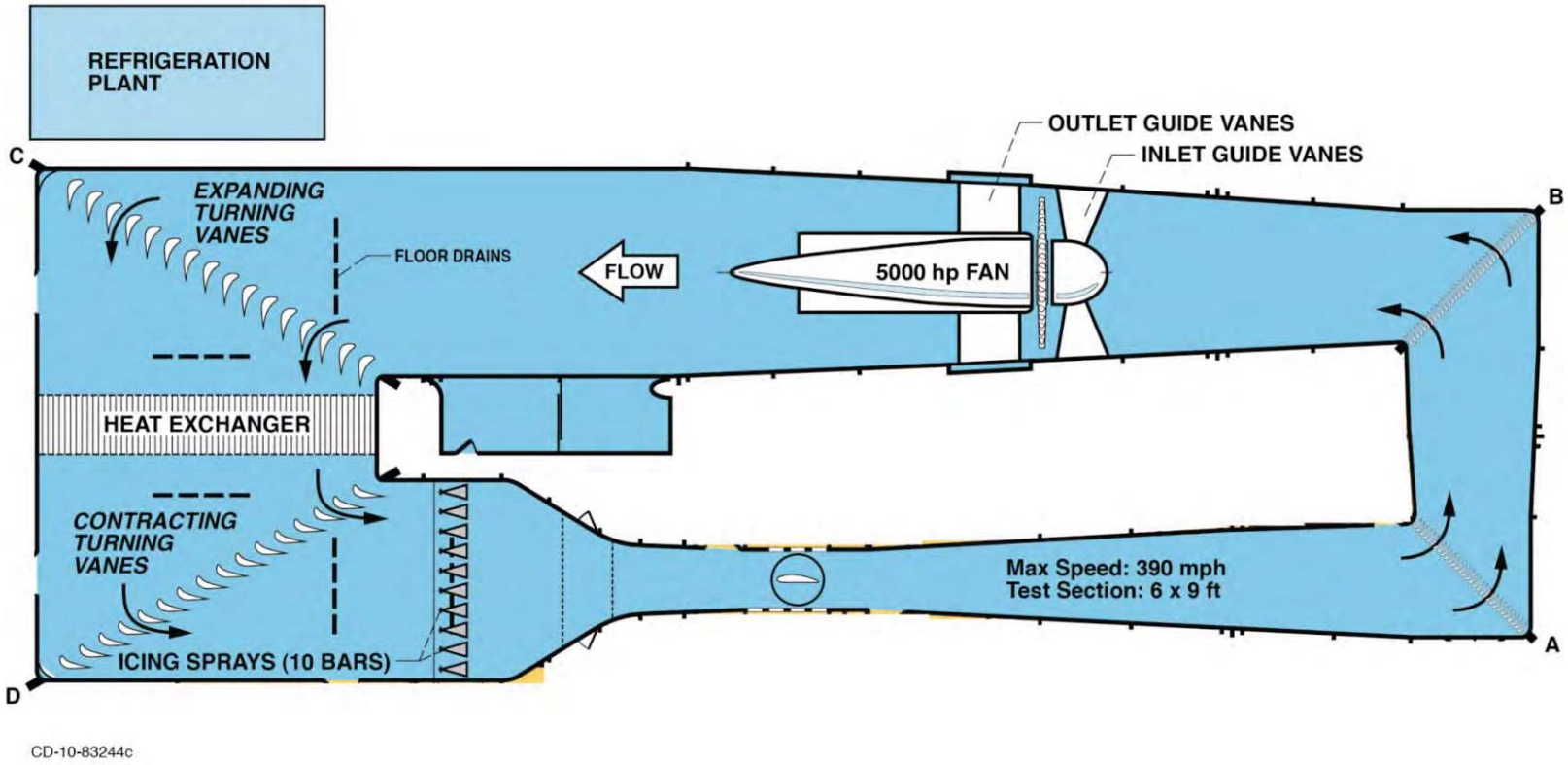
NASA/TM—2014-218392: "NASA Glenn Icing Research Tunnel: 2014 Cloud Calibration Procedure and Results"

by Van Zante, Ide, Steen, and Acosta

Outline:

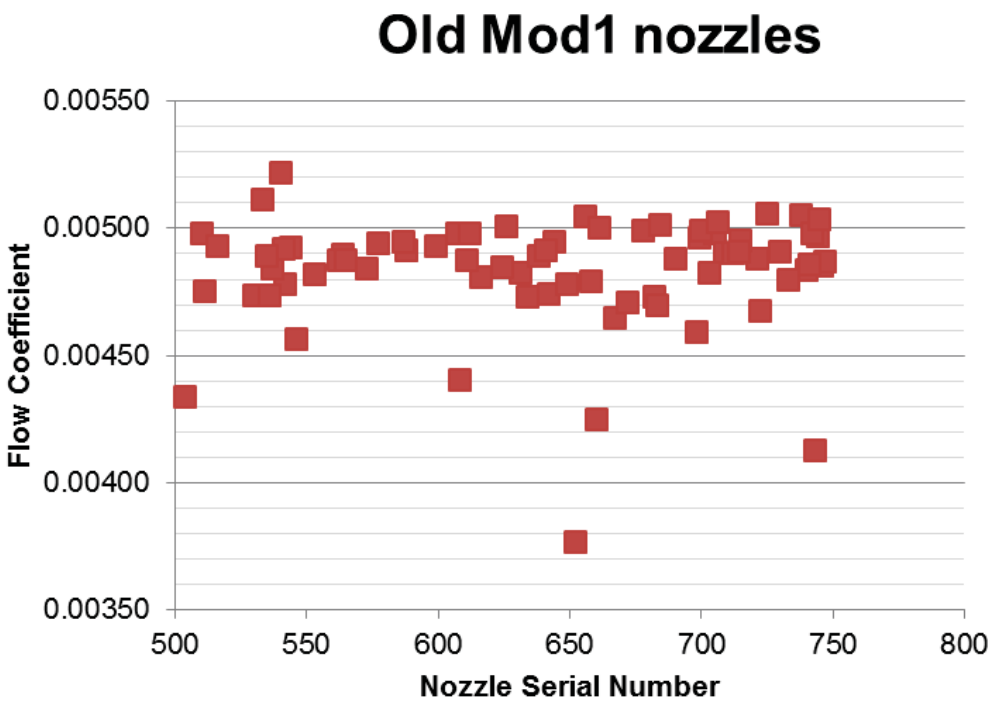
- *Brief description of the Icing Research Tunnel (IRT)*
- *What changed:*
  - *New Mod1 nozzles with tighter flow coefficients*
- *Procedure and Results:*
  - *Cloud Uniformity*
  - *Drop Size (Median Volumetric Diameter: MVD)*
  - *Liquid Water Content (LWC)*
- *IRT Operating Envelopes*

NASA GRC Icing Research Tunnel



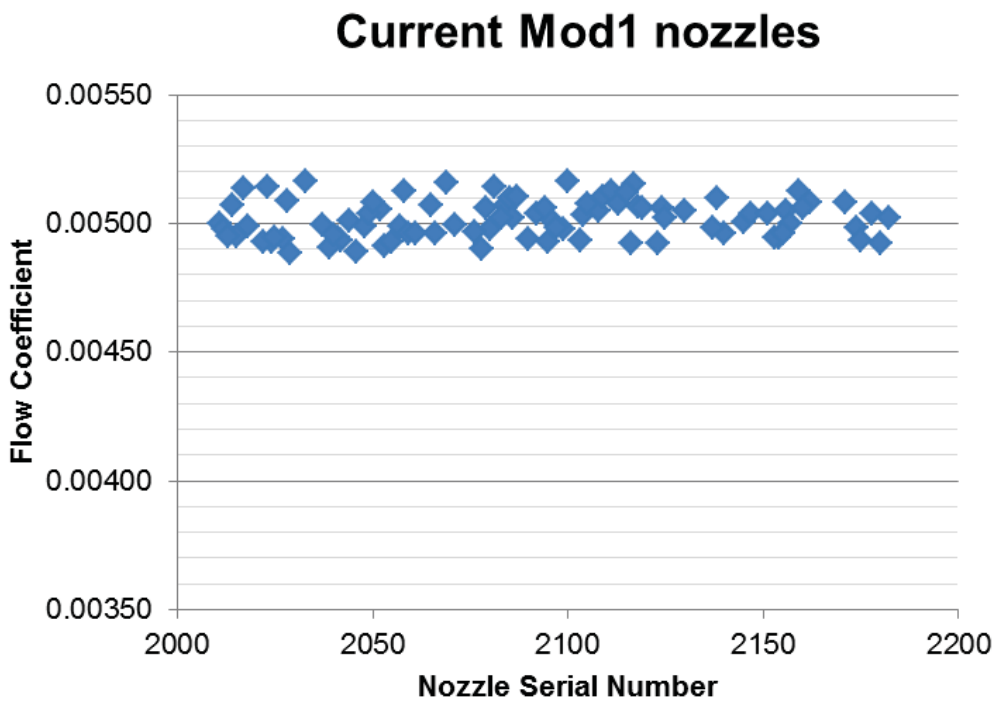
- Atmospheric, closed-loop tunnel
- Test section: 6 ft. x 9 ft. x 20 ft.
- Calibrated test section speed: 50 – 325 kts
- Temperature range:
  +20 degC total temp to -40 degC static temp

Improved Mod1 Nozzle Flow Coefficients



Average: 0.00484

Std. Dev: 0.000223



Average: 0.00501

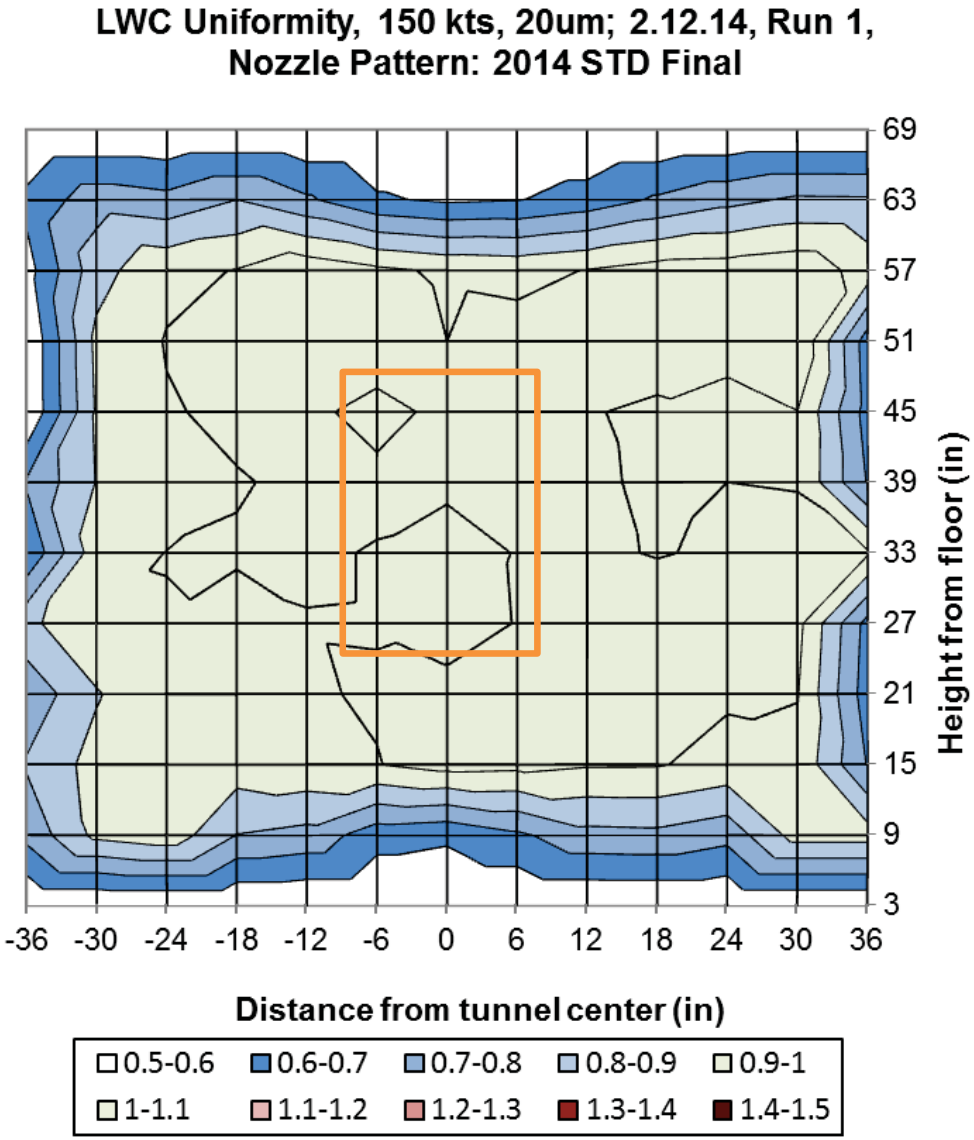
Std. Dev: 0.000073

- We replaced the water tubes in the Mod1 nozzles to improve the flow coefficients
- All plotted measurements were made using an in-house flow-calibration rig in Dec. 2013
- We only used new nozzles with Cf's that deviated less than 3% from the mean value
- Standard nozzles were not changed: the new water tubes had an higher average Cf. This would have had a negative impact on our operating envelopes.
- Also increased the total number of nozzles that were spraying from 73 to 88

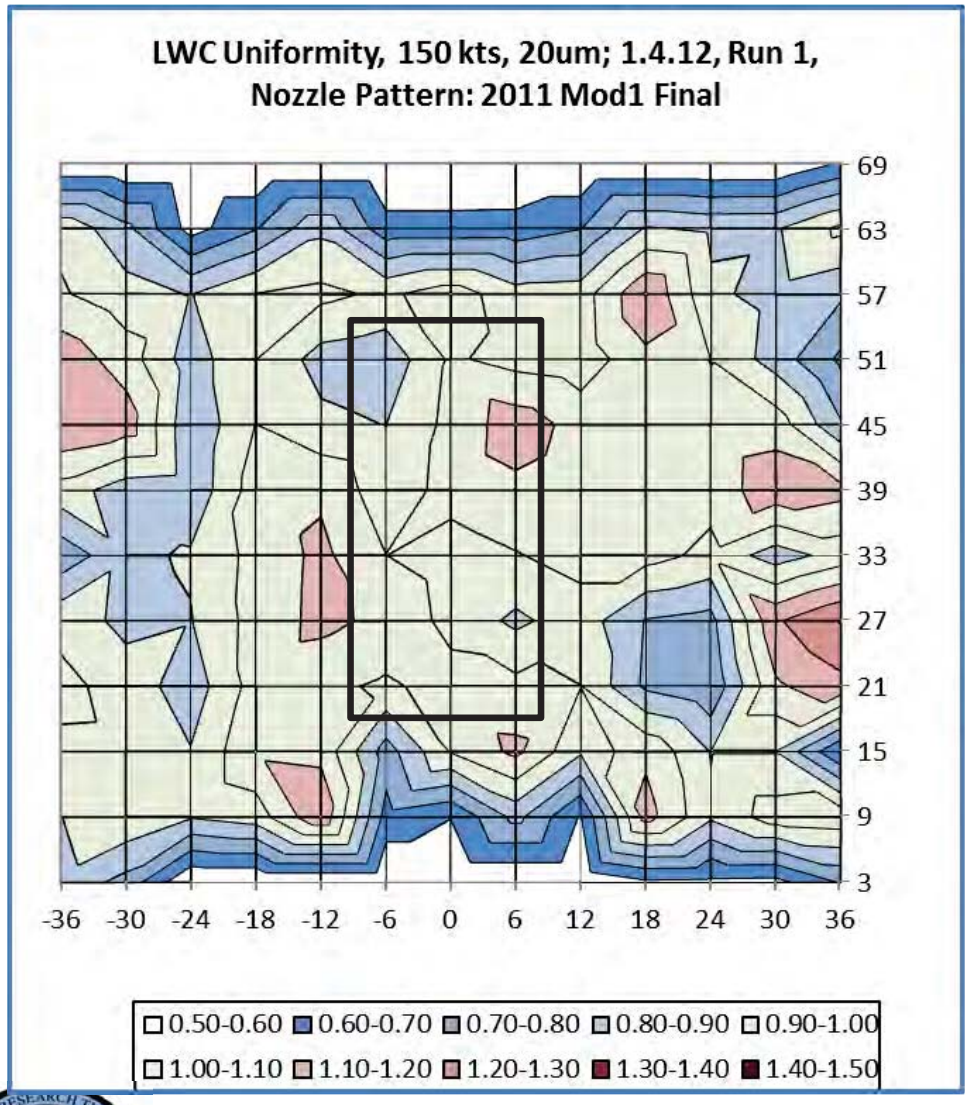
Test Facilities Operation, Maintenance & Engineering

Cloud Uniformity

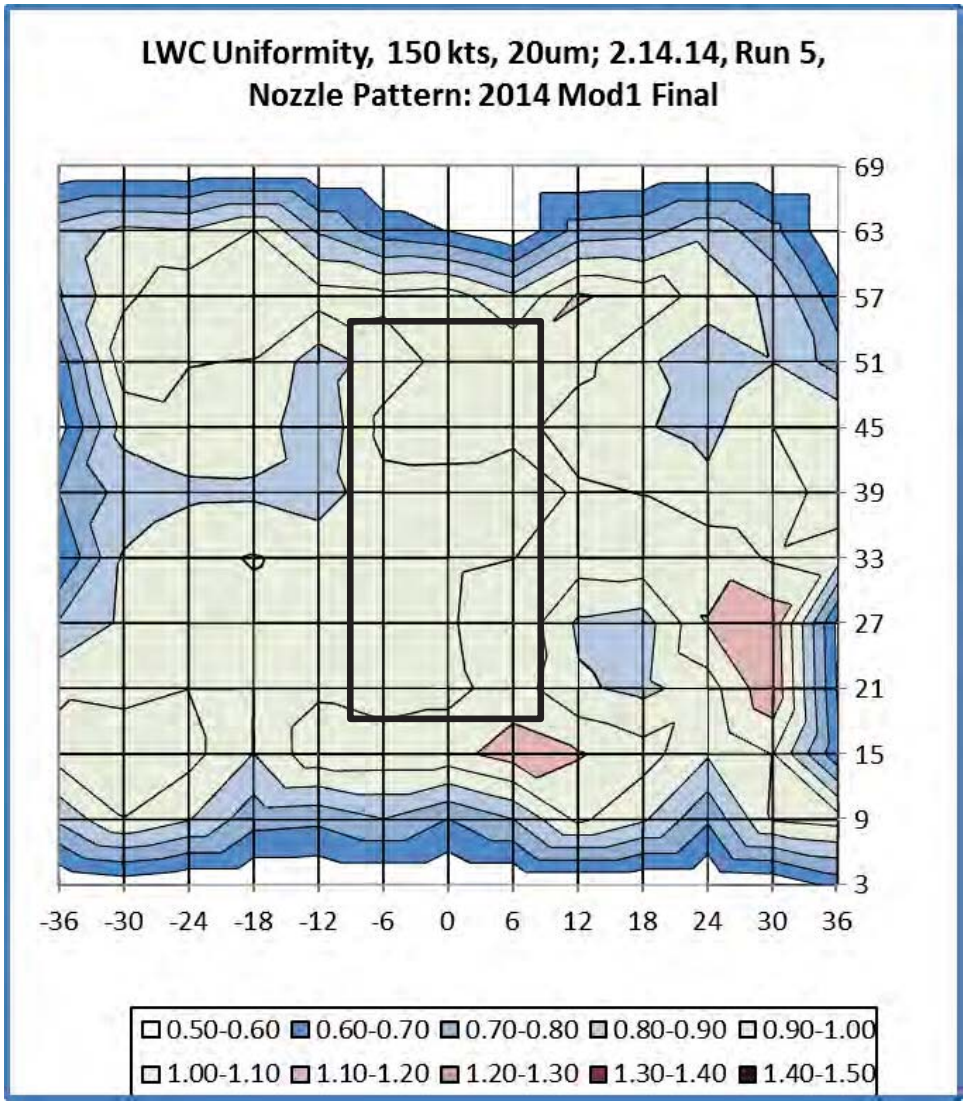
- Measured with a 6 ft. x 6 ft. grid
  - Mesh is 6 in. x 6 in.
  - Measurements are made at 6-inch vertical intervals, starting 3 inches from the tunnel ceiling
- Uniformity is established by turning nozzles on & off and iterating measurements until a uniform map is established
- Values are plotted as a ratio of the average of the center-12 points



Mod1 Nozzle Uniformity



January 2012

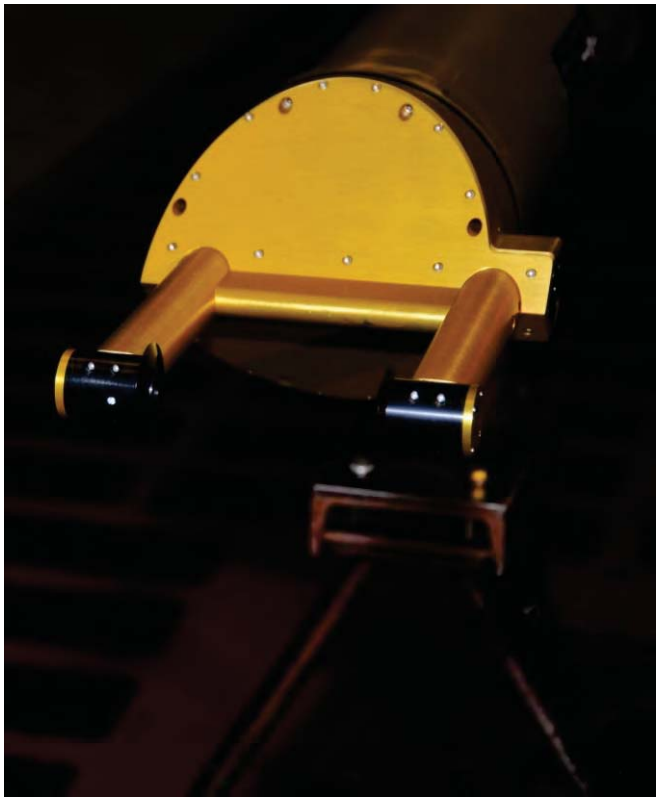


February 2014

Drop Size Calibration: Probes

Cloud Droplet Probe
CDP
2 – 50 μm

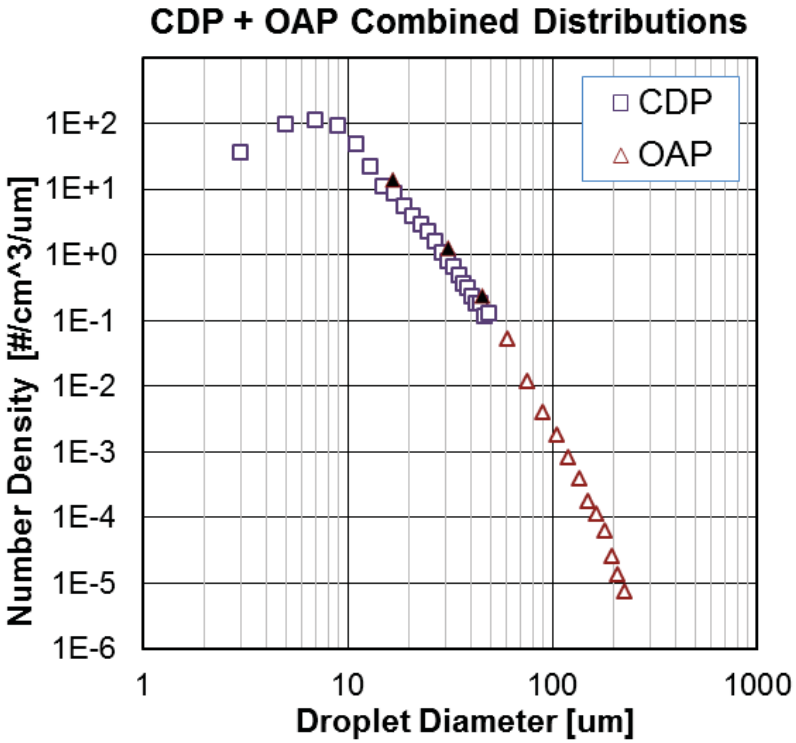
Optical Array Probe
OAP-230X
15 – 450 μm



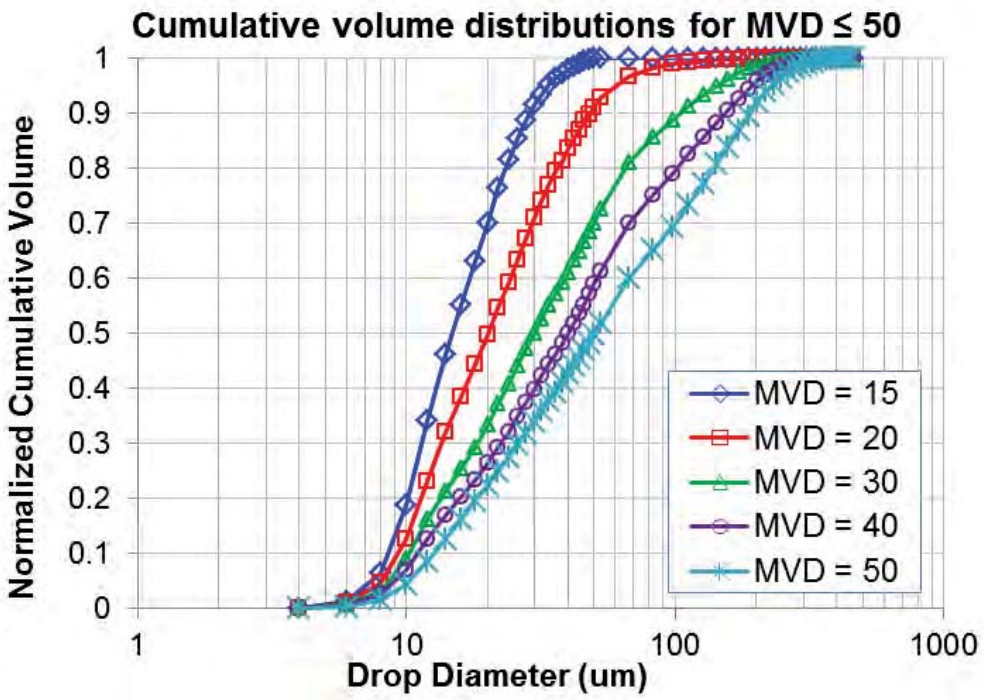
Cloud Imaging Probe
CIP-GS
15 – 930 μm

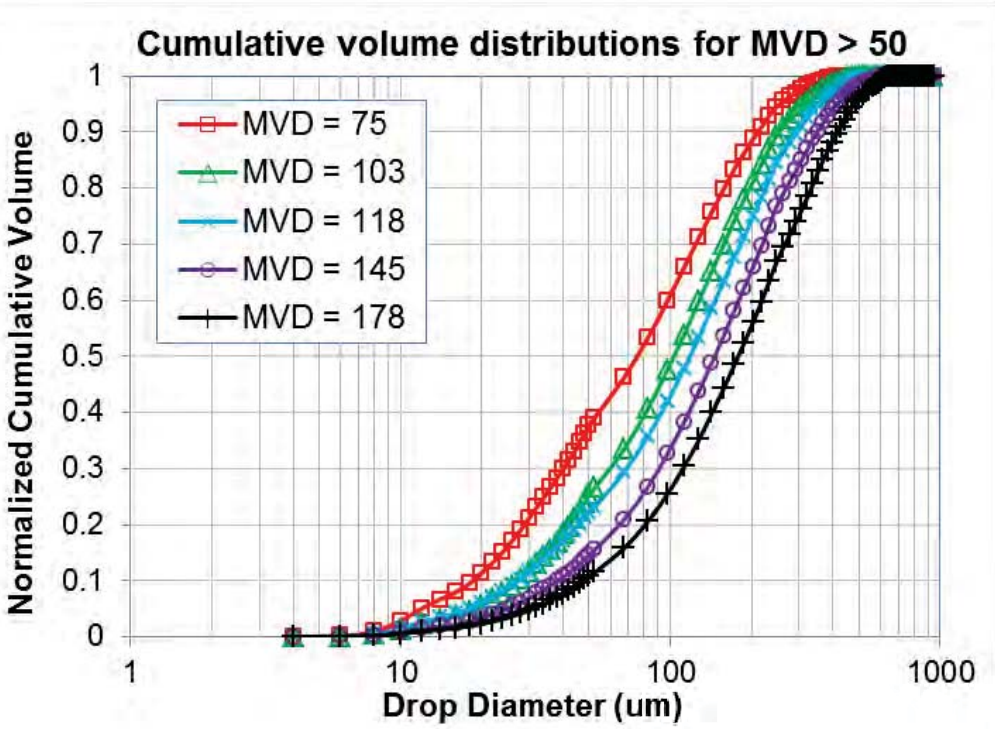
- Dropsize distributions from the CDP are combined with either the OAP-230X or the CIP-GS to determine Median Volumetric Diameter (MVD)

Drop Size Distributions



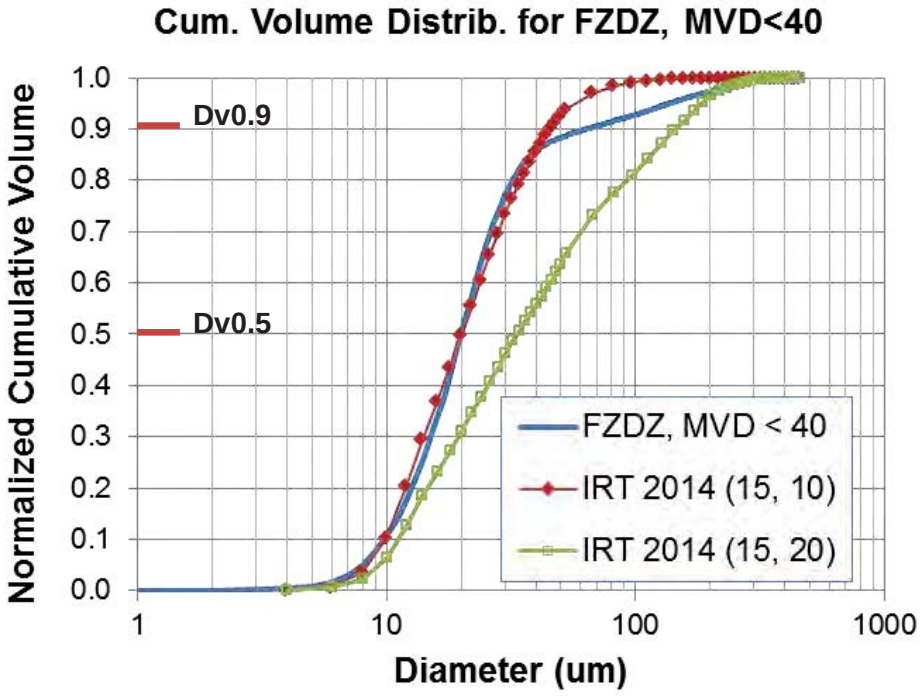
- For MVD's 14-50 μm, combined CDP + OAP-230X
- For SLD conditions
  - Nozzle air pressure <10 psig
  - MVD's between ~30 - 175 μm
  - Measured with CDP, OAP-230X, and CIP-GS

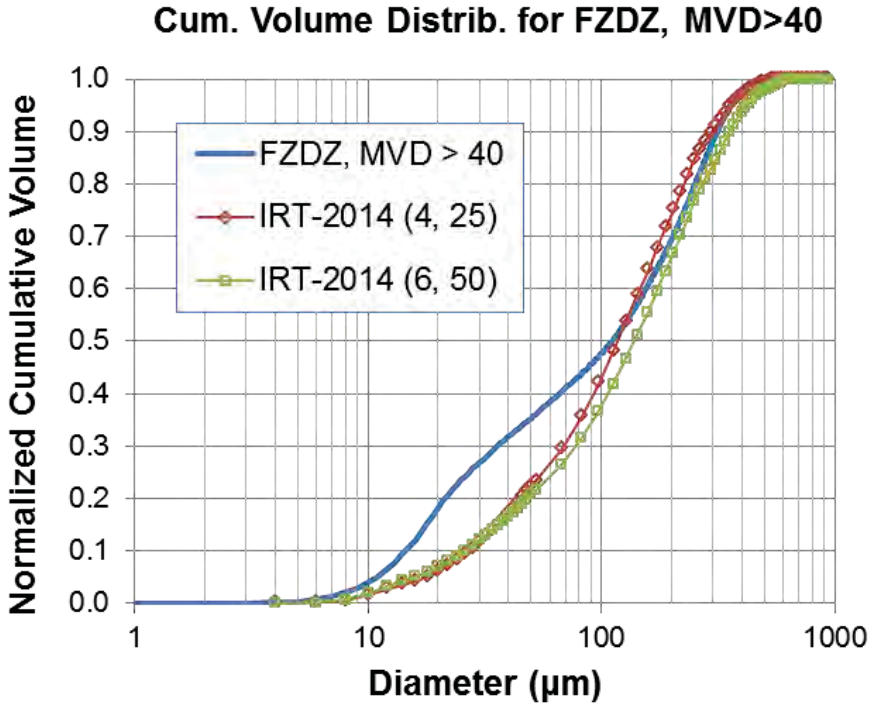




Super-Cooled Large Drops

- Matching IRT measured volume distributions to Appendix O volume distributions for Freezing Drizzle (FZDZ)

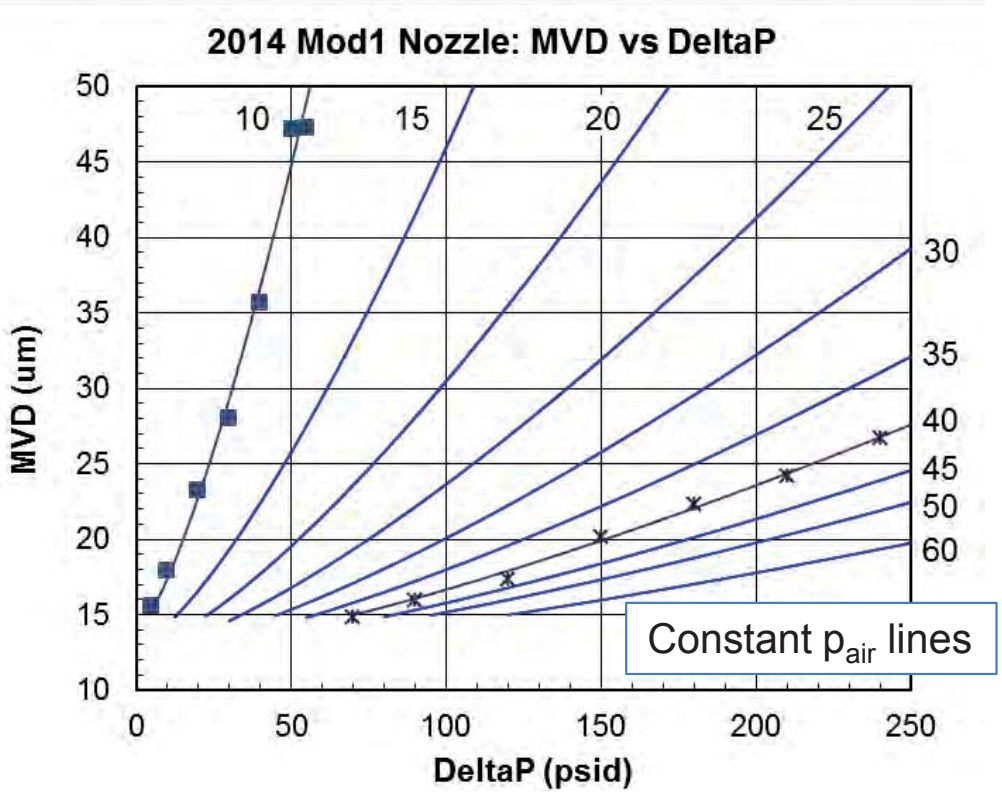


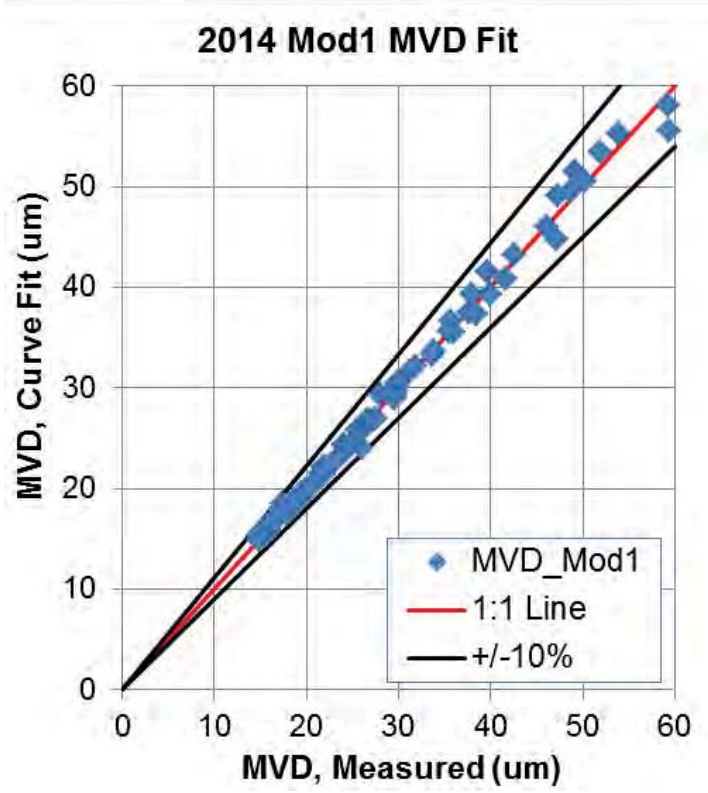


FZDZ Distributions taken from reference:

FAA FAR 14 CFR Parts 25 and 33, "*Airplane and Engine Certification Requirements in Supercooled Large Drop, Mixed Phase, and Ice Crystal Icing Conditions*", Federal Register / Vol. 75, No. 124 /Tuesday, June 29, 2010 / Proposed Rules.

Drop-Size Curve Fits (Mod1)

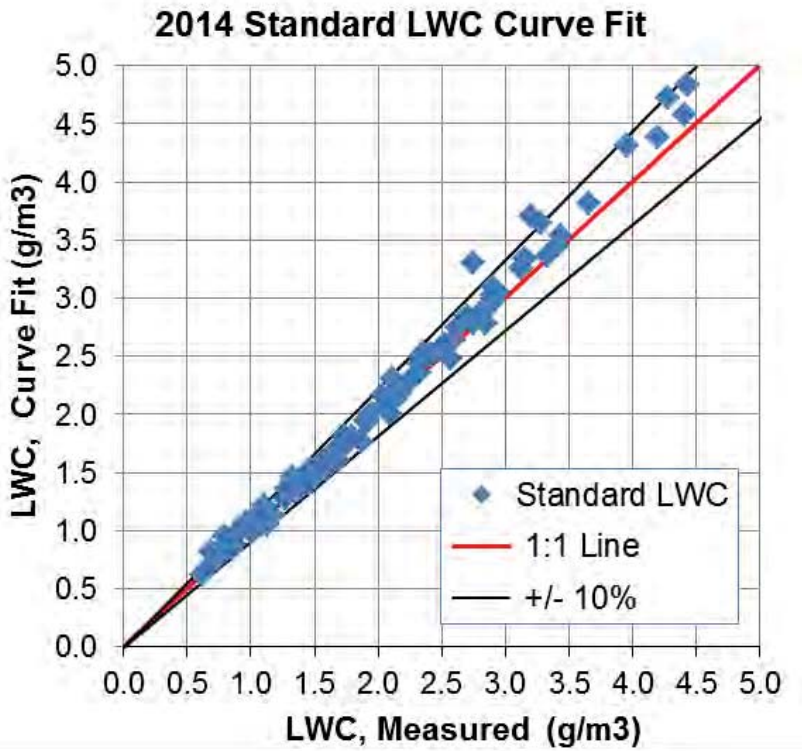


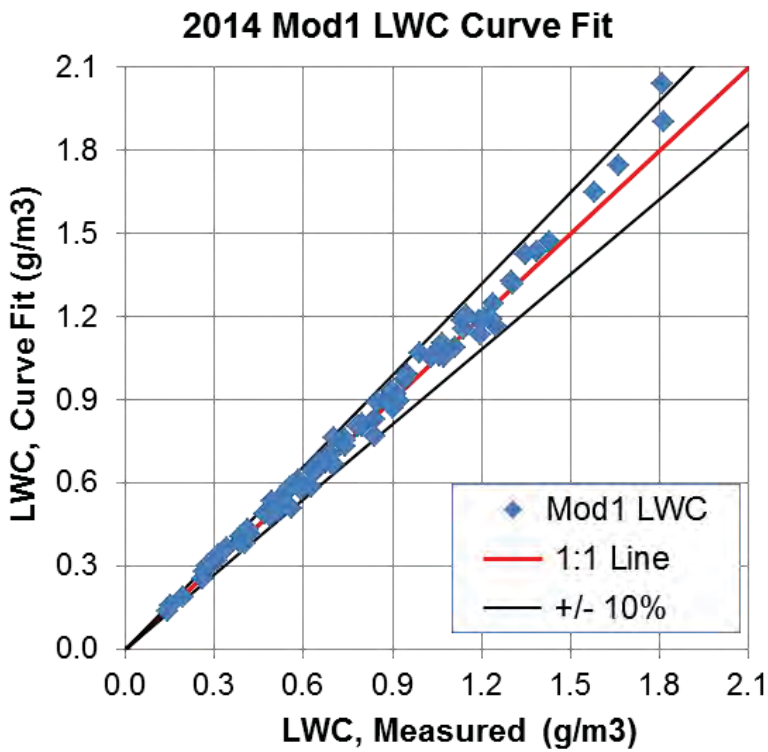


- MVD = f(p_{air}, Δp)
- Curve fits for Standard nozzles, Mod1 nozzles, and SLD conditions agree with measured MVD to within +/- 10%

Liquid Water Content (LWC) Curve Fit

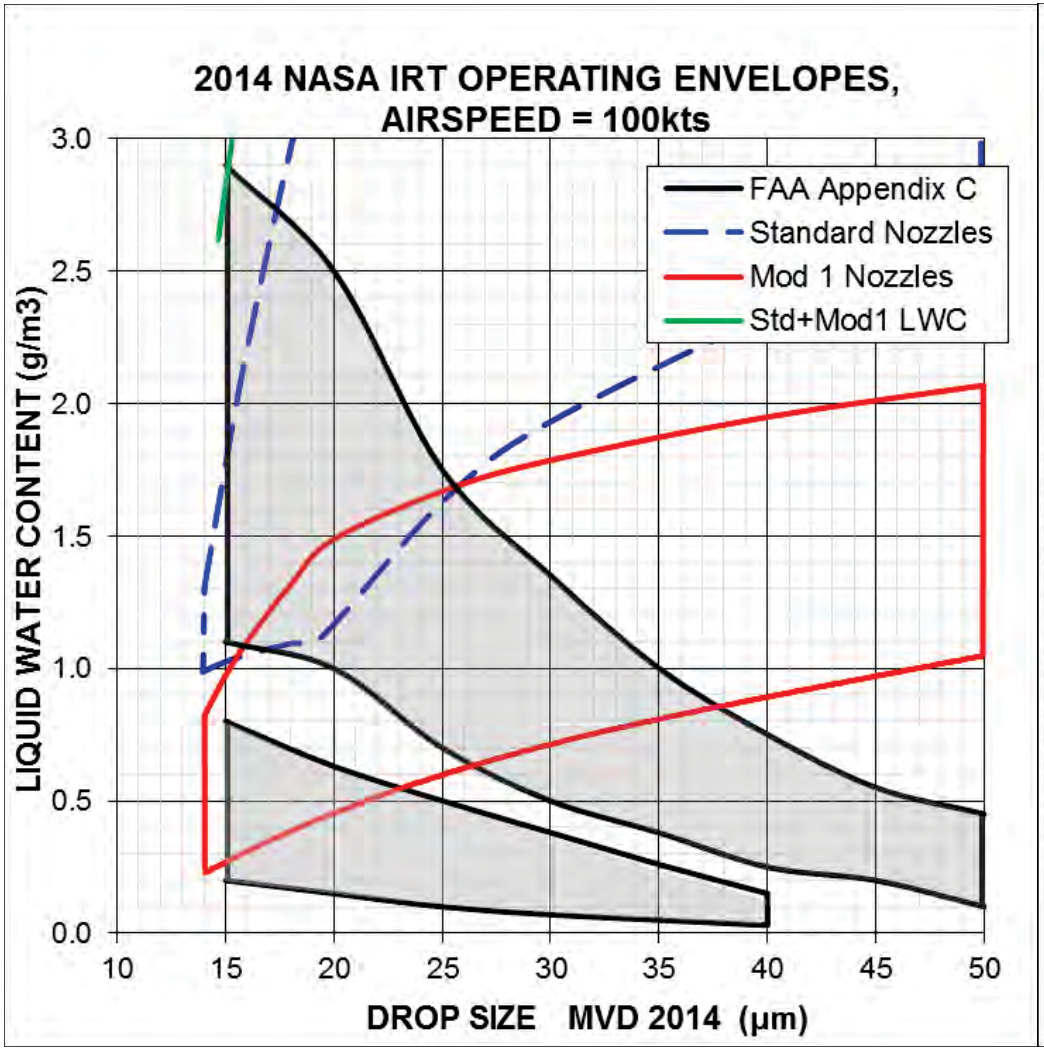
SEA
Multi-Wire Probe

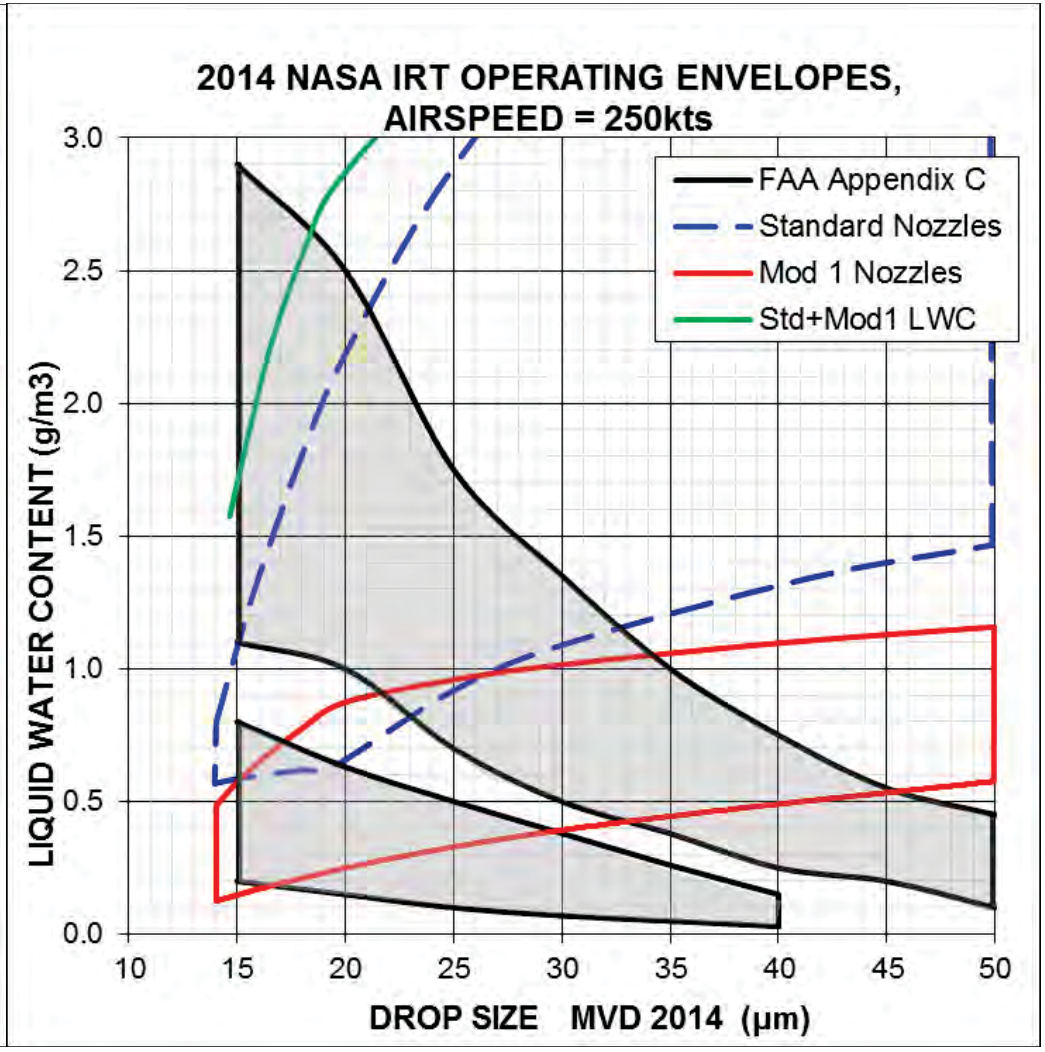




- LWC = f(velocity, p_{air}, Δp, mvd)
- Curve fits for Standard nozzles, Mod1 nozzles and SLD conditions agree with measured LWC to within +/- 10%

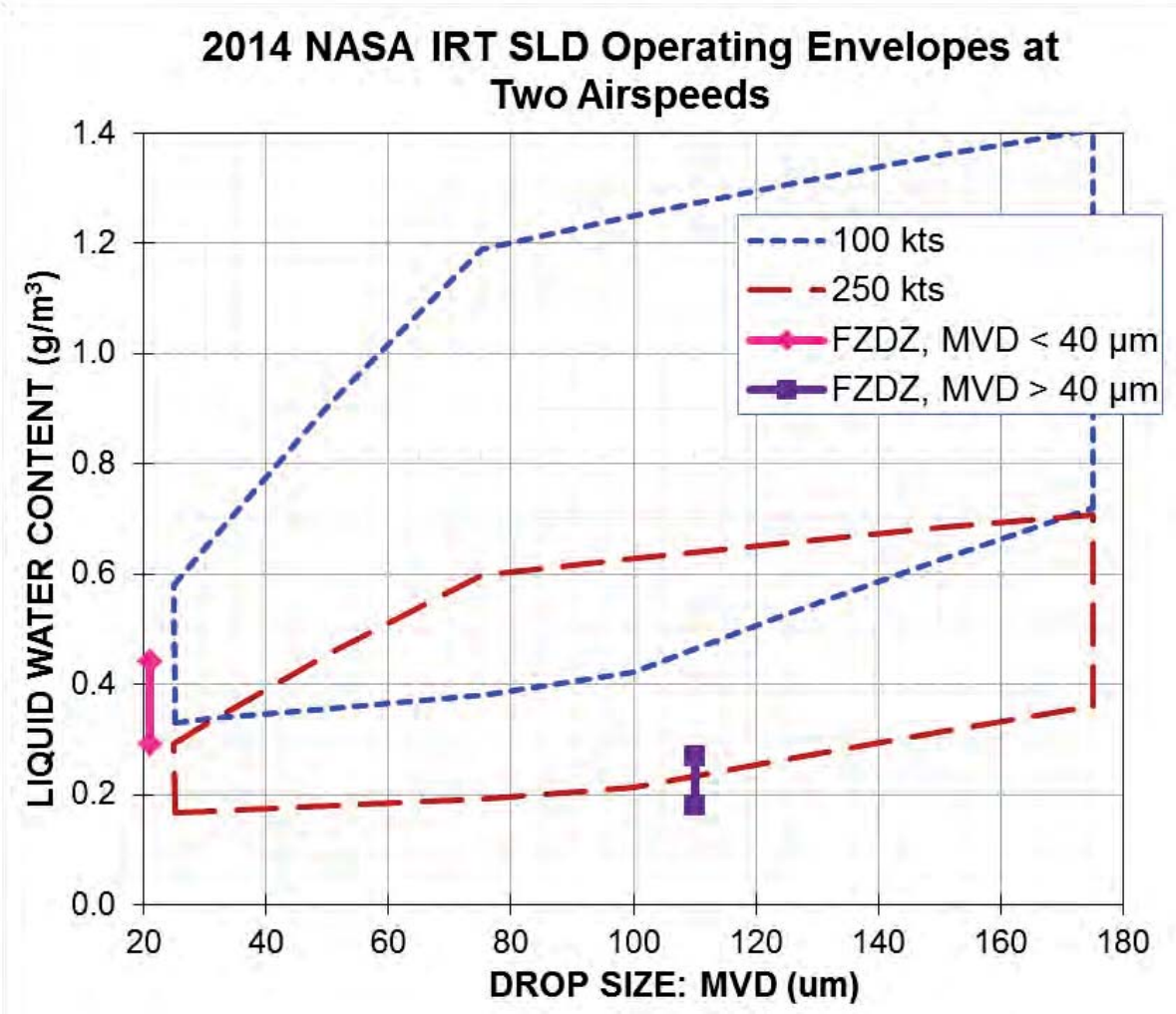
2014 Operating Envelopes: Appendix C





Appendix C conditions taken from:
Jeck, Richard K., "Icing Design Envelopes (14 CFR Parts 25 and 29, Appendix C) Converted to a Distance-Based Format", DOT/FAA/AR-00/30, Apr 2002.

2014 Operating Envelopes: Appendix O



IRT SLD conditions = nozzle air pressure p_{air} <10 psig

FZDZ conditions taken from reference: (Fig. 1)
Cober, S. Bernstein, B., Jeck, R., Hill, E., Isaac, G., Riley, J., and Shah, A., "Data and Analysis for the Development of an Engineering Standard for Supercooled Large Drop Conditions", DOT/FAA/AR-09/10, Mar 2009.

Concluding Remarks

- Tunnel occupancy time: approx. 2 months
  - Total test time: 28 days
- Calibration was successful within acceptance criteria of ARP 5905 “Calibration and Acceptance of Icing Wind Tunnels”

Short time for questions…

and then on to PSL