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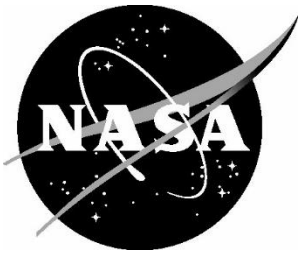

Calibration Results of a Newly Developed Low Liquid Water Content Cloud Using Mod2 Nozzles in the NASA Glenn Icing Research Tunnel

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November 2026

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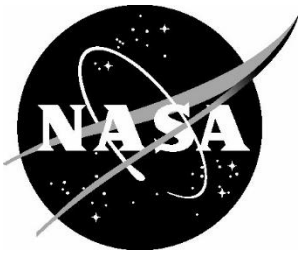

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Abstract

The NASA Glenn Icing Research Tunnel (IRT) has historically used Standard (Std) and Mod1 spray nozzles to generate icing clouds for aircraft certification and research. The IRT recently investigated Mod2 nozzles, which have the smallest hypodermic-needle inner diameter and lowest flow rate of the available nozzle configurations. These characteristics enable the generation of substantially lower liquid water content (LWC) clouds than were previously achievable in the facility.

This effort was motivated by increasing customer demand for low-water-content icing environments representative of FAA Appendix O freezing-drizzle and freezing-rain conditions. Previously, customers often relied on scaling methods to approximate desired ice-accretion characteristics when target low-LWC conditions could not be reproduced directly in the tunnel. A robust low-LWC cloud can reduce reliance on scaling and enable more direct simulation of certification icing environments.

This paper describes the methodology, instrumentation, and results of the Mod2 cloud calibration at the NASA Glenn Icing Research Tunnel. The investigation included cloud-uniformity measurements, drop-size characterization, LWC measurements, and preliminary ice-shape comparison tests. The calibration demonstrated that the Mod2 cloud can produce LWC values ranging from approximately 0.2 to 5.0 g/m³ and can support Appendix C conditions and portions of Appendix O conditions. The work also established a foundation for future bimodal-cloud development at the IRT.

Nomenclature

ARP	Aerospace Recommended Practice
CDP	Cloud Droplet Probe, drop sizer, 2 to 50 μm
$\mathbf{D_{v0.}}_{\boldsymbol{n}}$	Drop diameter at which *n* percent of the total volume of water is contained in smaller drops
FAA	Federal Aviation Administration
FZDZ	Freezing Drizzle
FZRA	Freezing Rain
IRT	Icing Research Tunnel
$\boldsymbol{K}$	Empirical function used in LWC curvefit
$\mathbf{K_v}$	Function of velocity, used in LWC curvefit
$\mathbf{K_a}$	Function of nozzle air pressure, used in LWC curvefit
LD	Large-Drop conditions in the IRT: Mod1 nozzles, $2 \le P_{air} \le 8$ psig, Mod2 nozzles $2 \le P_{air} \le 6$ psig
LWC	Liquid Water Content, g/m^3
MVD	Median Volumetric Diameter, μm
Mod1	Mod1 nozzles
Mod2	Mod2 nozzles
OAP–230X	Optical Array Probe, drop sizer, 15 to 450 μm
OAP–230Y	Optical Array Probe, drop sizer, 50 to 1,500 μm
$\boldsymbol{P_{air}}$	Spray nozzle atomizing air pressure, psig
$\boldsymbol{P_{water}}$	Spray nozzle water pressure, psig
$\boldsymbol{\Delta P}$	Spray nozzle $P_{water} - P_{air}$, psid
RTD	Resistance Temperature Detector
SEA, Inc.	Science Engineering Associates, Inc.
SLD	Supercooled Large Drop
Std	Standard nozzles
TWC	Total Water Content, g/m^3
$\boldsymbol{V}$	Calibrated true airspeed (velocity) in the test section, kn

Introduction

The NASA Glenn Icing Research Tunnel (IRT) is designed to simulate atmospheric icing conditions for aircraft certification and icing physics research. The facility has historically utilized Standard and Mod1 spray nozzles to generate icing clouds meeting FAA Appendix C certification requirements (Ref. 1).

The primary differences between the Standard and Mod1 nozzles are their water flow rates and the inner diameters of the hypodermic needles in the nozzle assemblies. The third nozzle type, Mod2, has the smallest hypodermic needle diameter and the lowest water flow rate of the three configurations. These characteristics suggested that Mod2 nozzles could generate clouds with substantially lower LWC.

Achieving low-LWC conditions has historically been a challenge for icing facilities worldwide, particularly for environments associated with FAA Appendix O freezing drizzle and freezing rain certification conditions (Ref. 2). External customers conducting icing research and certification testing at the IRT have increasingly requested lower water content conditions to better reproduce desired ice accretion characteristics. In many cases, customers previously relied on scaling methodologies to approximate the desired icing environment (Ref. 3 & 4).

The development of a robust low-LWC cloud offers the potential to reduce reliance on scaling methods and provide more representative icing environments directly within the tunnel. Although the IRT has had the Mod2 nozzles available for some time, earlier facility configurations were not well suited to support the low flow rates and small needle diameters associated with these nozzles. Since then, upgrades to the spray-bar system and supporting facility infrastructure enabled renewed investigation into Mod2 cloud capability.

This paper summarizes the calibration process, instrumentation, and resulting cloud characteristics associated with calibration of the newly developed Mod2 cloud at the NASA Glenn Icing Research Tunnel. Further details about the development process and considerations with the Mod2 cloud can be found in a follow-on publication.

Facility Description

The IRT is a sea-level, closed-loop refrigerated wind tunnel that simulates flight through an icing cloud. Figure 1 shows a general schematic of the facility. A 5,000 hp (3,728.5-kW) motor drives the 25 ft- (7.6-m-) diameter fan with blades made of wood from Sitka spruce. The fan drives air through expanding turning vanes in C-corner (see Figure 1) and into the face of the staggered 26 ft- (7.9-m-) high, 50 ft- (15.2-m-) wide heat exchanger. There, the air is chilled or warmed within a temperature range of 5 °C (41 °F) total to –40 °C (–40 °F) static. Twenty-four resistance temperature detectors, RTDs, are distributed on the D-corner contracting turning vanes and measure the total temperature in the settling chamber.

Downstream of the D-corner contracting turning vanes are ten spray bars with two different air atomizing nozzle types. Since the IRT now has three nozzles available for use: Mod1, Mod2, and Std nozzles, the Mod1 nozzles remain installed in the spray bars while the Mod2 and Std nozzles are alternatively installed in the second operationally-available nozzle positions, dependent upon scheduled test requirements. The nozzle housings are connected to an air manifold and two water manifolds. The cloud (spray) is turned on using remotely controlled solenoid valves. The water manifolds can be individually turned on to spray only the Mod1 nozzles, only the Mod2/Std nozzles, or both (with the same atomizing air pressure). Each bar has 55 nozzle positions that contain either a Mod1 nozzle, a Mod2/Std nozzle, or a plug. The Mod2 nozzles have the lowest-available water flow rate of the nozzles and the Std nozzles have the highest-available water flow rate, with Mod1 nozzles in the middle.

In 2006, vertically mounted struts were added to the spray bars. These struts were installed to improve the cloud uniformity and are still part of the system (Ref. 5). The contraction area ratio into the test section is 14:1. The test section itself is 20 ft (6.1 m) long (axial) by 6 ft (1.8 m) high by 9 ft (2.7 m) wide. The center of the test section is 44 ft (13.4 m) from the spray bars. From the test section, the cloud flows into the diffuser toward A corner, into B corner, and into the fan. The calibrated speed range in the test section is from 50 to 300 kn (Ref. 6).

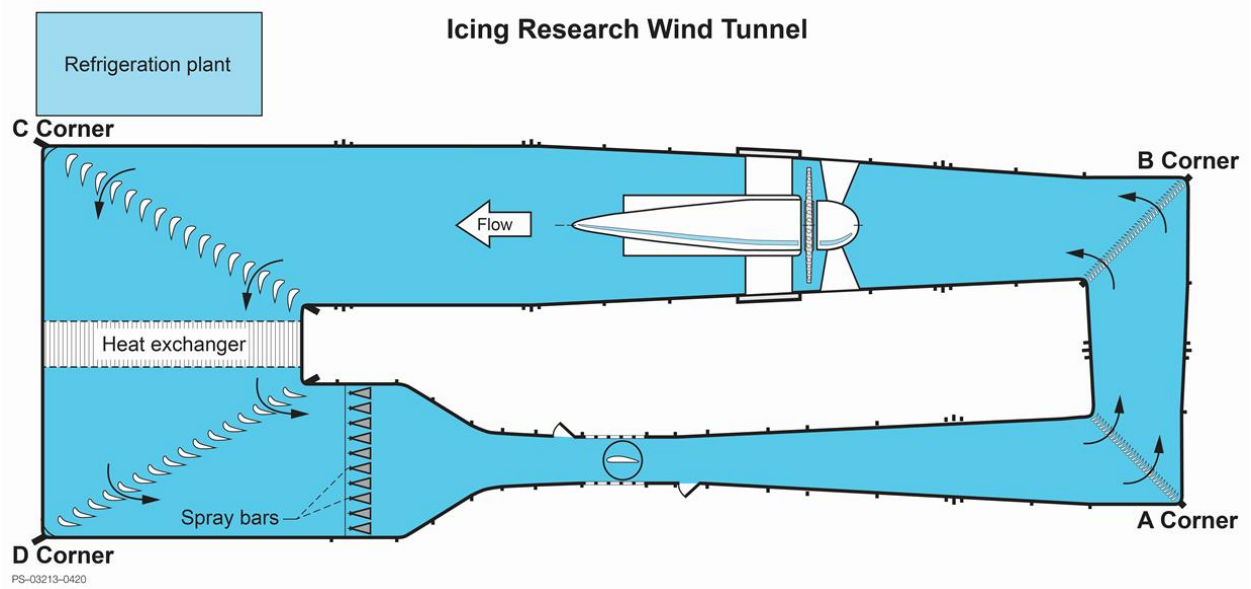


Figure 1. NASA Glenn Research Center Icing Research Tunnel

IRT Cloud Calibration Practices

The IRT cloud-calibration process follows SAE International's Aerospace Recommended Practice (ARP) 5905, which provides guidance for icing-wind-tunnel calibration. The manuscript states that ARP 5905 recommends a full cloud calibration every five years, an interim calibration one year later to verify stability, and check calibrations every six months thereafter.

The Mod2 cloud-development effort initially focused on producing a cloud that met the uniformity guidance in ARP 5905. The cited criterion states that local LWC should remain within ±20 percent of the centerline/reference LWC over the defined test-section reference area (Ref. 7). After acceptable uniformity was established, the calibration proceeded to drop-size characterization and LWC measurements.

Icing Cloud Uniformity

The first step in the calibration was to establish cloud uniformity. Figure 2(a) shows the grid used for these measurements. The grid is 6 ft (1.8 m) high by 6 ft (1.8 m) wide and extends from the floor to the ceiling of the test section. The mesh elements are 2 in. (5.08 cm) deep and have a flat, 0.125-in. (0.3175-cm) face for ice accretion. Ice accretes on the grid, and the thickness is measured at the center of each vertical element, which are spaced 6 in. (15.24 cm) apart. Digital calipers are used to measure the ice thickness. The measured values are plotted as ratios to the average of the central 12 measurements. Examples are shown in Figure 3. The light-beige regions indicate LWC uniformity within ±10 percent across most of the mapped area.

(a)



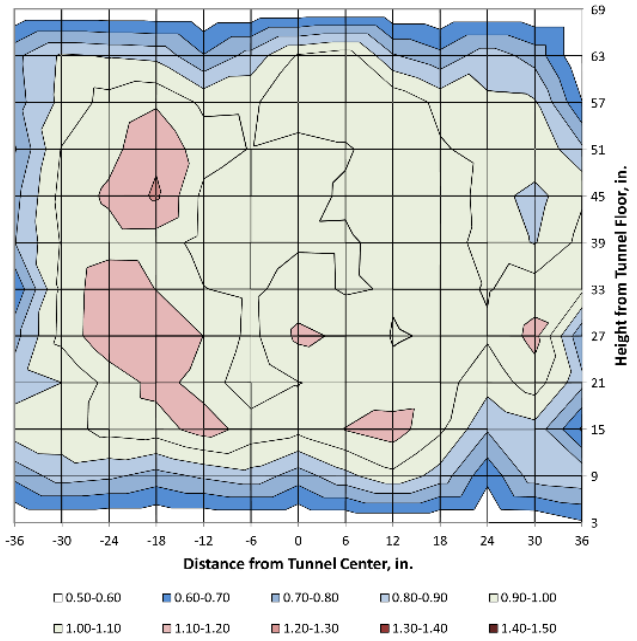
(b)



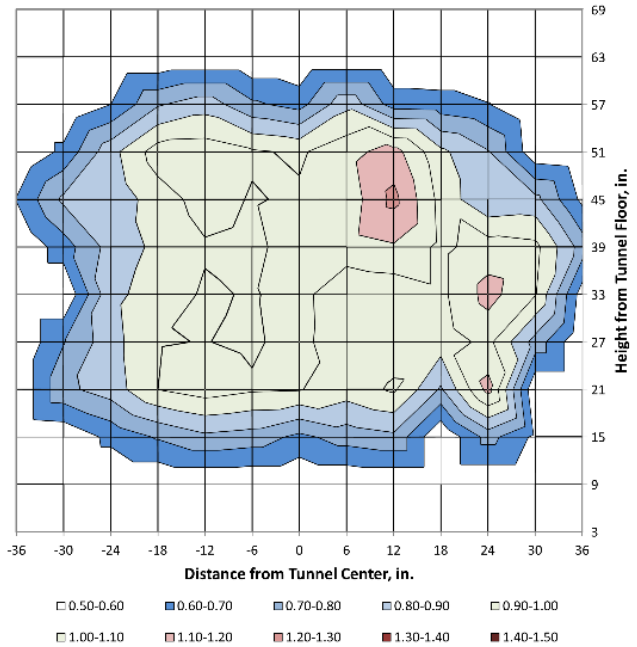
Figure 2. Cloud uniformity grid. (a) Grid mounted in center of test section in Icing Research Tunnel. (b) Ice accretion on grid elements.

Achieving acceptable uniformity requires iterative adjustment of nozzle operation. Regions exhibiting excessive ice accumulation or insufficient ice accumulation were corrected through selective activation or deactivation of nozzles. At the beginning of the investigation, the drop size and water content characteristics of the Mod2 cloud were unknown. Consequently, spray times were estimated using expected flow rate reductions relative to Mod1 nozzles. Despite these uncertainties, the team successfully developed a cloud meeting acceptable exploratory uniformity requirements.

The resulting cloud uniformity maps are shown in Figure 3(a) and (b) for the Mod2 nozzles: Appendix C and Large Drop, respectively. These plots are viewed facing downstream.



(a)



(b)

Figure 3. Cloud uniformity viewed facing downstream, plotted as ratios to average accretion thickness from center 12 elements. (a) Mod2 nozzle cloud uniformity, 14-μm median volumetric diameter (MVD) at an airspeed of 150 kn. (b) Mod2 nozzle large-drop cloud uniformity, 130-μm median volumetric diameter (MVD) at an airspeed of 250 kn.

Drop-Size Calibration

Following cloud uniformity development, drop-size characterization was conducted using three optical measurement instruments. The instruments used were the Cloud Droplet Probe (CDP) made by ENVEA (formerly Droplet Measurement Technologies, Inc.) and two Optical Array Probes (OAP-230X and OAP-230Y) made by Particle Measuring Systems. Figure 4 shows these probes mounted in the IRT test section.

(a)  (b)  (c) 

Figure 4. Three drop sizing instruments used for drop-size calibration mounted in Icing Research Tunnel test section. (a) Cloud Droplet Probe (CDP), 2 to 50 µm. (b) Optical Array Probe (OAP–230X), 15 to 450 µm and (c) Optical Array Probe (OAP–230Y), 50 to 1,500 µm

Initially, only Appendix C conditions were investigated using the CDP and OAP-230X. As the investigation progressed and large-drop potential became evident, the OAP-230Y was incorporated into the measurement campaign.

The CDP measures drop diameters from 2 to 50 µm using forward-scattered light intensity. The OAP–230X measures diameters from 15 to 450 µm, and the OAP–230Y measures diameters from 50 to 1,500 µm. Both optical array probes determine drop size using diode shadowing. The investigation confirmed that Mod2 nozzles produced substantially smaller droplets than Mod1 nozzles and that increasing atomizing-air pressure reduced droplet size. At pressures above approximately 25 psig, the droplets were considered too small for meaningful certification or research testing. Therefore, the maximum calibrated atomizing-air pressure for the Mod2 cloud was limited to 20 psig. Atomizing-air pressures below 10 psig were also investigated for Appendix C conditions.

Since the CDP measures the smallest drop sizes of the three probes, and because all IRT spray conditions contain small drops, CDP data were collected and used over the full range of spray conditions. The spray conditions covered the following nozzle atomizing air pressure, P_{air}, and differential pressure, ΔP, ranges (ΔP is defined as the water pressure, P_{water}, minus the air pressure, or $\Delta P = P_{water} - P_{air}$). For the Appendix C conditions, the range was $7 \leq P_{air} \leq 20$ psig and $5 \leq \Delta P \leq 250$ psid. Development of the large-drop Mod2 cloud followed procedures similar to those used for Appendix C conditions. Because the IRT atomizing air pressure system is limited to a minimum operating pressure of approximately 2 psig, the team initiated large-drop testing at this condition and incrementally increased atomizing air pressure until the resulting cloud transitioned into Appendix C-type conditions. For the Large-Drop conditions, the range was at $2 \leq P_{air} \leq 6$ psig, with the allowable ΔP range dependent on the corresponding P_{air} range. Specifically, $\Delta P \geq 25$ psid for $2 \leq P_{air} \leq 3$ psig, $\Delta P \geq 40$ psid for $3 < P_{air} \leq 4$ psig, $\Delta P \geq 60$ psid for $4 < P_{air} \leq 5$ psig, and $\Delta P \geq 85$ psid for $5 < P_{air} \leq 6$ psig. The maximum differential pressure for the Large-Drop conditions is similar to Appendix C differential pressure range, 250 psid.

Data Processing of Drop-Size Distributions

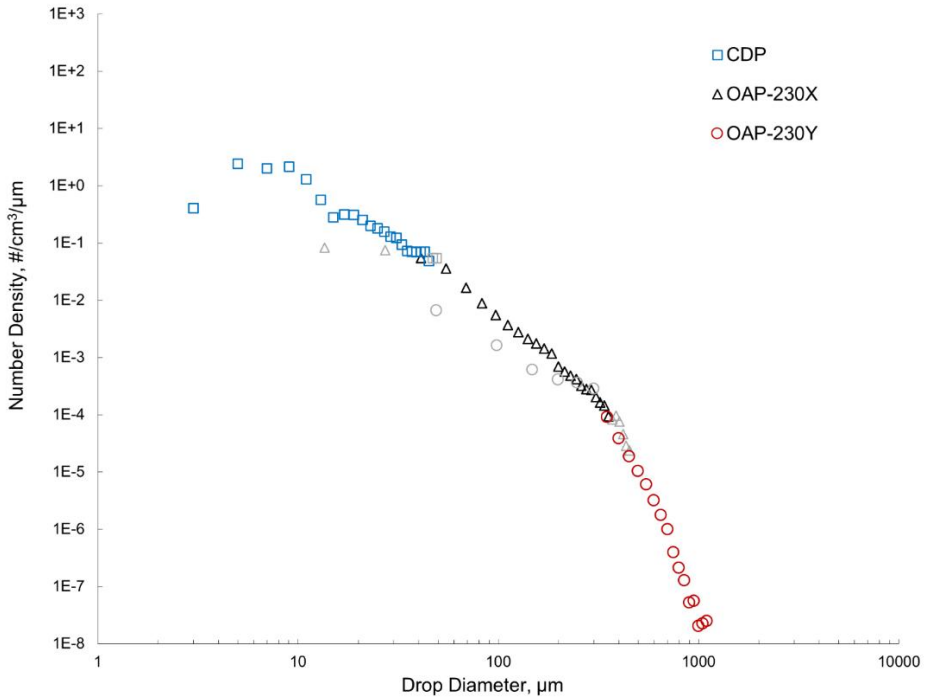
Drop-Size Distributions

An example drop-size distribution is shown in Figure 5 combining all three probes for a large-drop spray condition. The number density is the number of drops that are recorded in each bin normalized by the sample

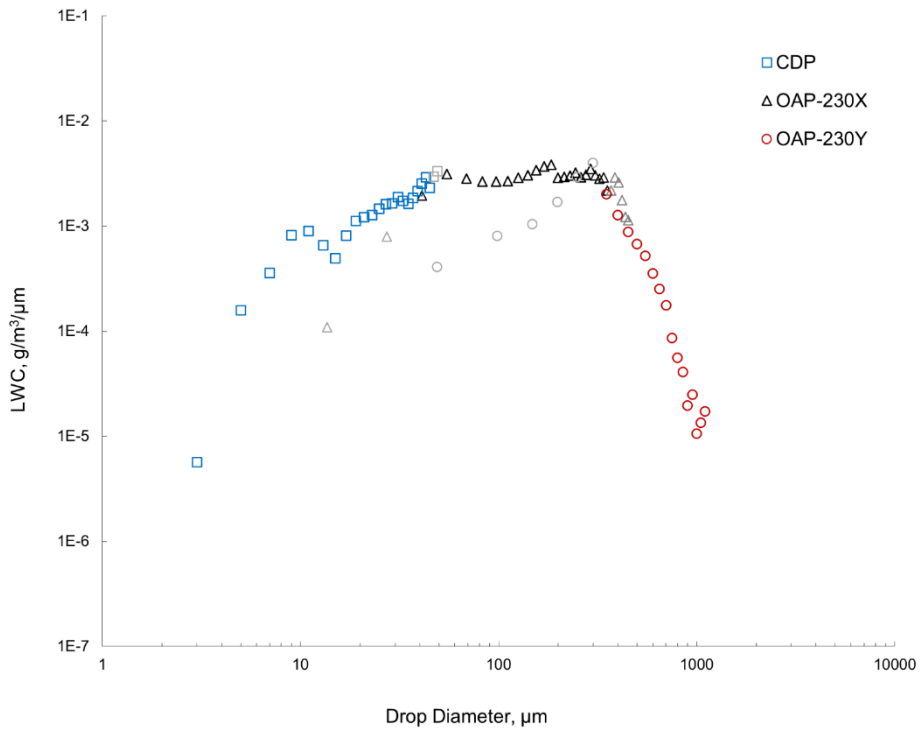
volume for that drop size and the bin width. For Figure 5(a) and (b), the squares show the size distribution as measured by the CDP, the triangles by the OAP–230X, and the circles by the OAP–230Y. The gray data points represent measurements from the respective probes that were not used in MVD calculation. The volume is calculated using the median bin diameter size multiplied by the number of recorded counts, which then results in the LWC for each bin. Figure 5(b) shows an example LWC distribution for a case with an MVD of 233 μm where values are normalized by their respective bin widths. The MVD can then be determined by plotting the normalized cumulative water content versus drop diameter, as seen in Figure 5(c).

Drop-size distributions are characterized by the MVD. This is the value at which half of the water volume is contained in smaller (or larger) drops. MVD can also be referred to as "$D_{v0.50}$". Correspondingly, $D_{v0.90}$ is the diameter at which 90 percent of the volume is contained in smaller drops. Normalized cumulative volume distributions for the IRT are shown in Figure 6. Bin volumes are plotted cumulatively, such that each data point represents the amount of water contained in all smaller diameters normalized by the total volume contained in all bins. Figure 6(a) shows cumulative volume distributions for MVD values less than or equal to 50 μm, and Figure 6(b) shows cumulative volume distributions for MVD greater than 50 μm.

As noted, the CDP, OAP–230X, and OAP–230Y each contribute measurements to the overall particle size distribution based on their sizing ranges. Their size ranges overlap, and efforts were made to determine how to address the overlaps. More information can be found in Ref. 2 to support the crossovers of the three probes.



(a)



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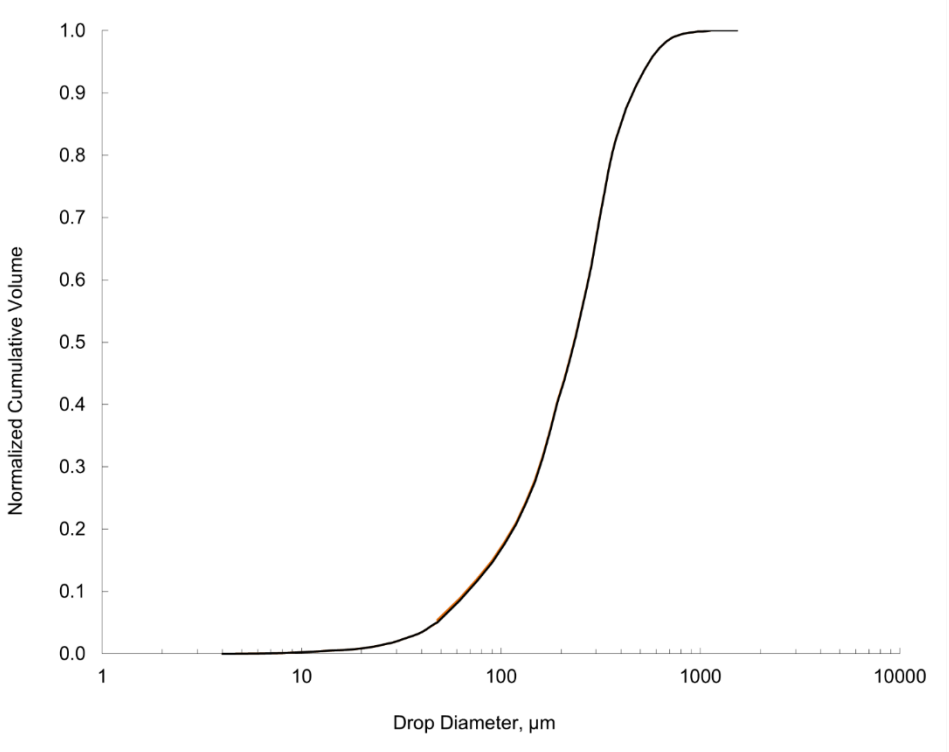
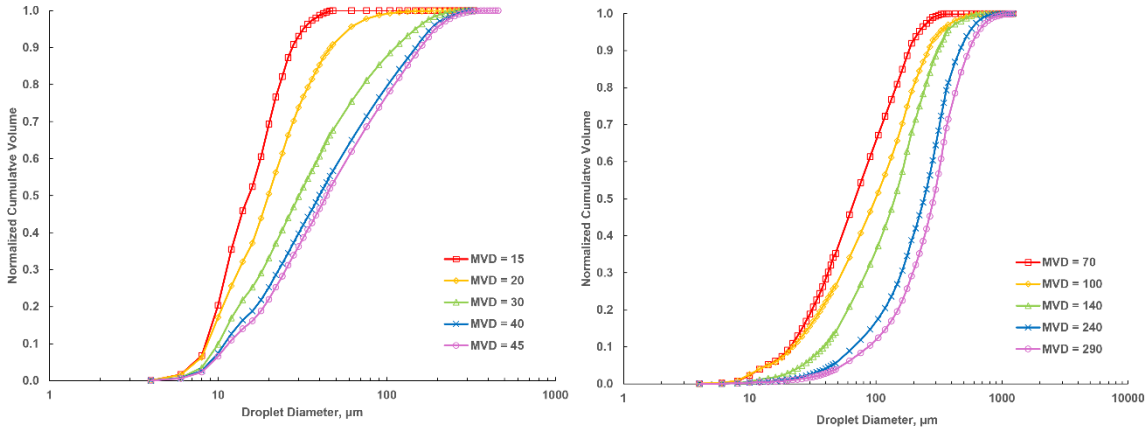


(c)

Figure 5. Drop-size distribution combining all three probes for median volumetric diameter (MVD) = 233 µm including the number density distribution, cumulative volume distribution, and the liquid water content (LWC) distribution. All go into calculations for MVD. Gray data points represent measurements from respective probes that

were not used in MVD calculation. (a) Number density distribution. (b) LWC distribution. (c) Cumulative volume distribution.



(a) (b)

Figure 6. Normalized cumulative volume plots for the Icing Research Tunnel drop-size regimes produced by the Mod2 nozzles. (a) Size range 15 to 50 µm. (b) Size range >50 µm up to maximum calibrated Median volumetric diameter (MVD).

Drop-size Equations

The drop-size calibration was used to characterize drop-size distributions and develop curve-fit equations relating measured atomizing-air pressure P_{air} and ΔP ($P_{water} - P_{air}$) to MVD. The curve fit generator, TableCurve (Systat Software, Inc.) was used to generate equation that fit the majority of the data within ±10 percent.
The Mod2 Appendix C MVD curve fit equation is

$$MVD = \frac{1}{a + \left[\frac{b * \ln(P_{air})}{P_{air}}\right] + \left[c * \sqrt{\Delta P}\right]} \quad (1)$$

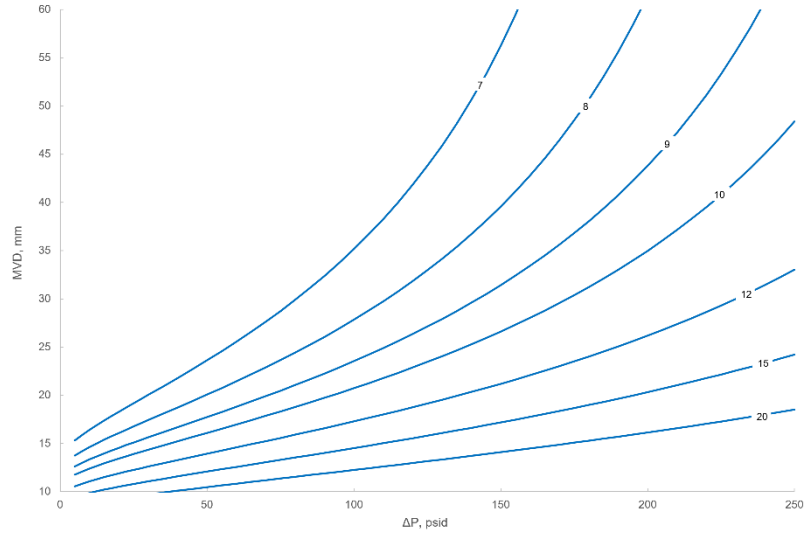
where a = 0.191202474, b = -0.41479073, and c = -0.00474511.

And the Mod2 Large-Drop MVD curve fit equation is

$$MVD_{\mathrm{LD}} = a + (b * P_{air}) + [c * \ln(\Delta P)] + [d * (P_{air})^2] + \{e * [\ln(\Delta P)]^2\} + [f * P_{air} * \ln(\Delta P)] + [g * (P_{air})^3] + \{h * [\ln(\Delta P)]^3\} + \{i * P_{air} * [\ln(\Delta P)]^2\} + [j * (P_{air})^2 * \ln(\Delta P)] \quad (2)$$

where a = 27.83322361, b = 223.0741437, c = -150.732265, d = 41.57086146, e = 102.918281, f = -182.61894, g = -0.34549238, h = -10.7735579, i = 21.80795885, and j = -5.45097233.

Figure 7(a) and (b) summarize the Mod2 MVD curve fits for Appendix C and Large Drop conditions, respectively. The fitted curves are plotted as functions of ΔP for each calibrated atomizing-air pressure (P_{air}). Figure 8 compares MVD values calculated from the fitted equations with measured values. The plotted data indicate agreement within ±10 percent for both Appendix C and Large Drop conditions.



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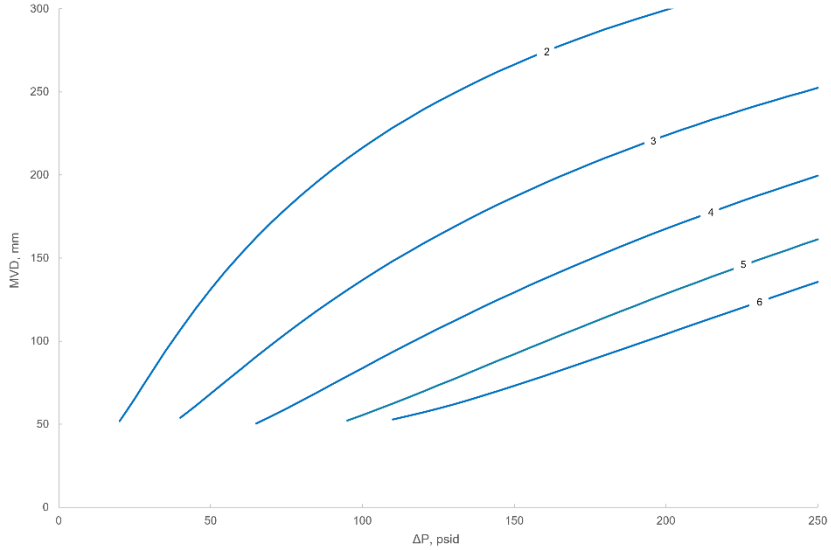
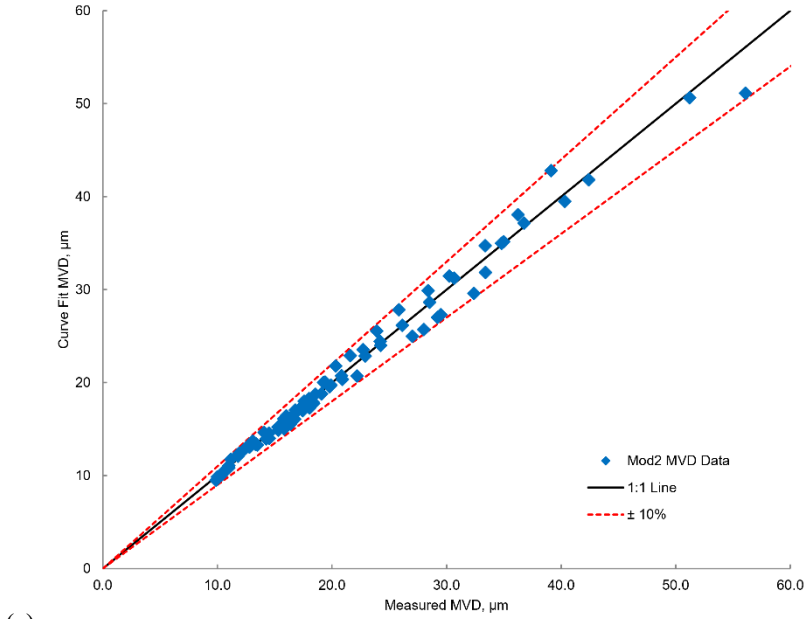
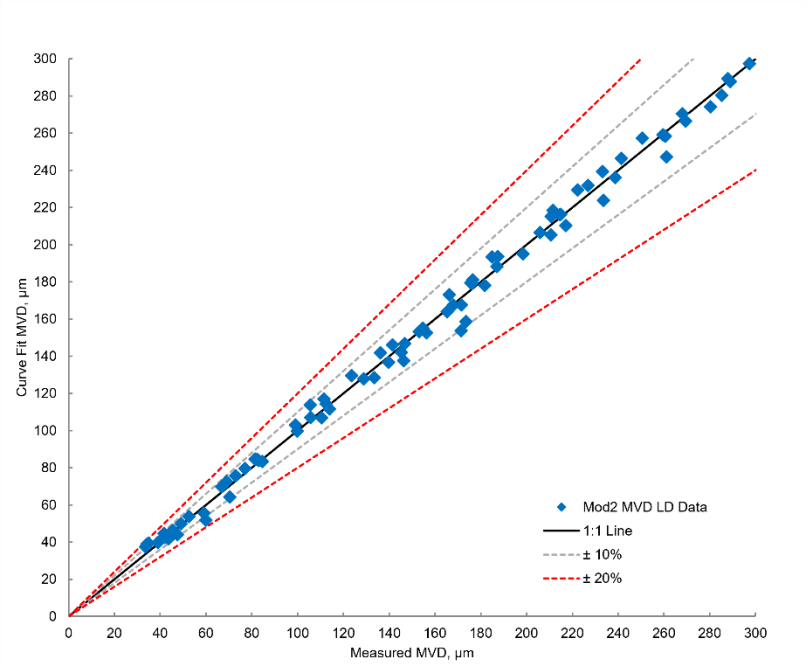


(b)

Figure 7. Median volumetric diameter (MVD) curve-fits as function of ΔP for each atomizing air pressure (P_{air}) for the Mod2 nozzles. (a) Appendix C (b) Large Drop.



(a)



(b)

Figure 8. Curve-fit Median Volumetric Diameter (MVD) values from generated equations compared to measured MVD values for Federal Aviation Administration (FAA) 14 CFR Parts 25 and 29 (a) Mod2 nozzles, Appendix C (b) Mod2 nozzles, Appendix O.

Using the calibration data, the team compared Mod2 cloud characteristics with FAA Appendix O drop-size distributions and LWC requirements. The investigation demonstrated that the Mod2 cloud matched LWC requirements for freezing drizzle (FZDZ) with MVD below and above 40 µm and for freezing rain (FZRA) with MVD below 40 µm. Spray conditions matching FZRA conditions with MVD above 40 µm remain challenging and require further development.

Measured IRT droplet distributions showed promising agreement with FAA Appendix O distributions, particularly for freezing-drizzle conditions with MVD below 40 µm (Figure 9). The FZRA distribution with MVD below 40 µm in Figure 9(c) includes two IRT spray conditions: one that closely matches the smaller-drop portion through $D_{v0.60}$ and another that closely matches the larger-drop portion of the distribution from $D_{v0.80}$ to $D_{v1.0}$.

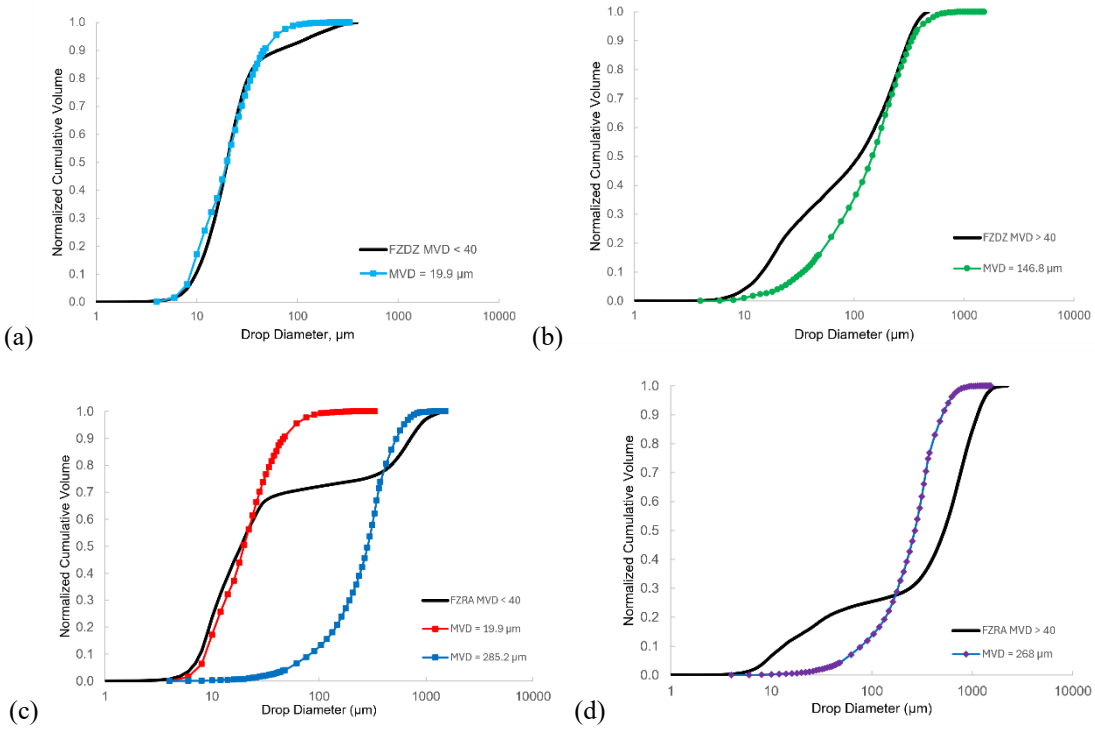


Figure 9. Icing Research Tunnel (IRT) distributions to Federal Aviation Administration (FAA) 14 CFR Parts 25 and 29, Appendix O requirements for both Freezing Drizzle (FZDZ) and Freezing Rain (FZRA) conditions. (a) FZDZ, median volumetric diameter (MVD) <40 µm. (b) FZDZ, MVD >40 µm. (c) FZRA, MVD <40 µm. (d) FZRA, MVD >40 µm.

Liquid Water Content Calibration

Following characterization of drop-size distributions, the team proceeded with liquid water content measurements. Because the Mod2 cloud characteristics were initially unknown, the icing blade was used first for the water content measurements due to its simplicity and reduced susceptibility to electronic failure compared to electronic probes such as the multi-element sensor.

The blade is an accretion-based instrument with dimensions of 0.125 in. (3.18 mm) wide by 6.06 in. (154-mm) long by 0.75 in. (19.05 mm) thick. It is mounted in such a way that it is located at the horizontal centerline and the vertical center of the test section. It is run at a tunnel total air temperature between –0.4 and –4 °F (–18 and –20 °C) in an attempt to ensure that rime ice is accreted on the 0.125-in. (3.18-mm) flat face in most cases. After select icing blade measurements were completed, further water content data was collected with the multi-element sensor.

The IRT uses SEA Inc.'s M300 Data Acquisition System along with their WCM–2000 system to collect data from the multi-element sensor. The M300 records the power output of each of the sensing elements and receives the facility conditions from the facility control system, including total temperature, static temperature, airspeed, static air pressure, spray-bar nozzle pressures, and whether the spray is on or off. All necessary calibration values and sensing element dimensions are received from the probe, and these are used along with the received facility conditions such that the data system can correlate the power of each sensing element to a calculated LWC. All the recorded values are output as 1-second averages into a CSV file. Once the data has been retrieved from the M300, it

is postprocessed using a MATLAB® (The MathWorks, Inc.) code that was developed in-house. This code averages the data system outputs for each spray, starting 20 s after the spray begins and ending 2 s before the spray ends. A plot is generated for each spray so that the user may view the profile of the data and decide if the data seem reasonable. Further details can be found in Ref. 9.

Water-content measurements from the multi-element sensor were compared with icing-blade results and showed close agreement. The team used the data to develop LWC calibration relationships as functions of drop size, airspeed, atomizing-air pressure, and atomizing differential pressure. These relationships were used to develop calibration curves for Mod2 Appendix C and Large Drop conditions.

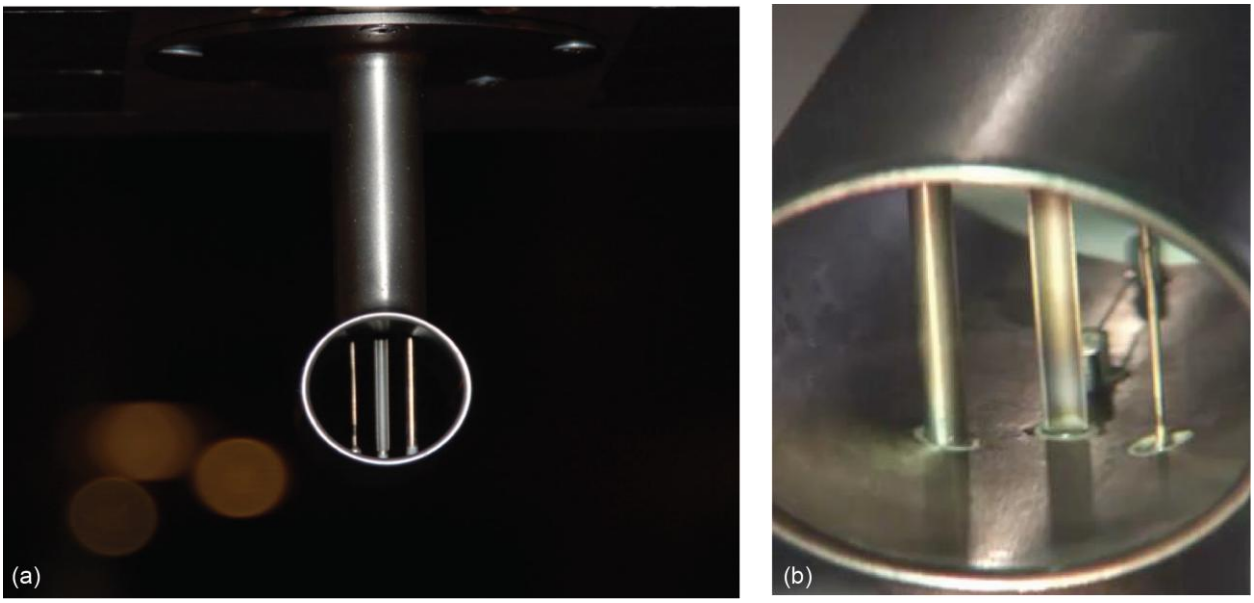


Figure 10. Science Engineering Associates, Inc., Multi-Element Sensor. (a) Closeup view. (b) View of elements rotated 180° from (a).

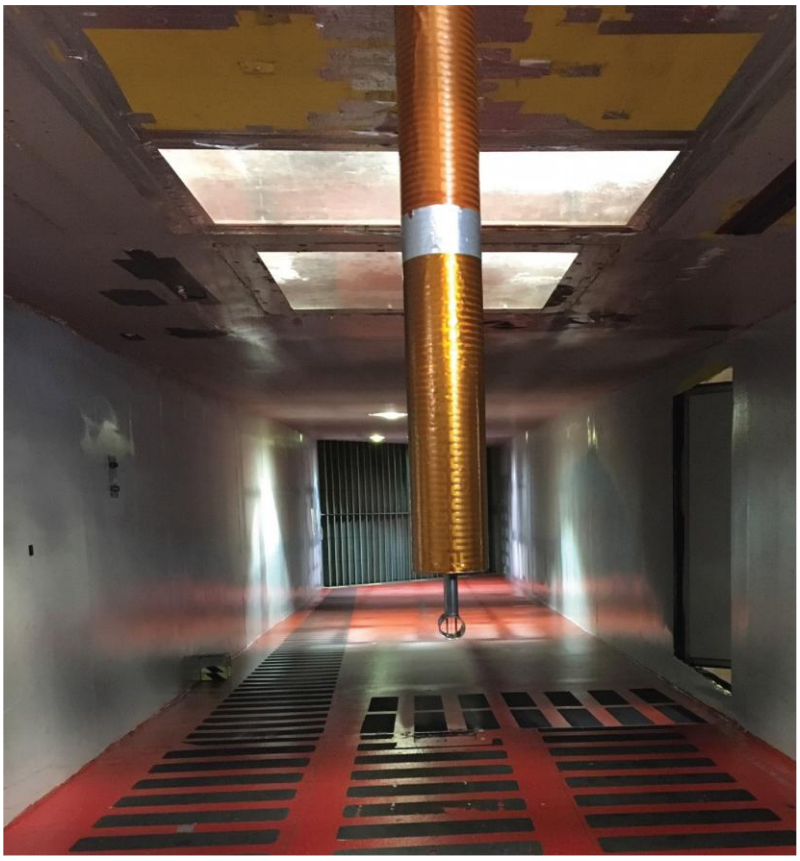


Figure 11. Multi-Element Sensor (Science Engineering Associates, Inc.) mounted in Icing Research Tunnel test section.

The data from the TWC or half-pipe element of the multiwire were corrected for collision efficiency according to the test point's particle size distribution and then compiled to build the LWC curve-fits, correlating LWC to P_{air}, ΔP, and V. As described in the 2006 IRT calibration report (Ref. 5), the LWC calibration is a function of the form:

$$LWC = K(V, P_{air})\frac{\sqrt{\Delta P}}{V} \tag{3}$$

where K is a function of V and P_{air}. Fitting the LWC curve involves determining the function K for both parameters, Ka and Kv. To define Kv, measurements were made from V = 50 to 300 kn while P_{air} and ΔP (and MVD) are held constant. Similarly, to determine Ka, V and MVD were held constant while making measurements from P_{air} = 7 to 20 psig. K is calculated for each of the measured values by rearranging Equation 4: $K = LWC * \frac{V}{\sqrt{\Delta P}}$. Once relationships are found, they are combined to determine the surface function, K, which is unique for the Mod2-Appendix C and Mod2 Large-Drop conditions. Equations 5 and 6 are the respective equations for each.

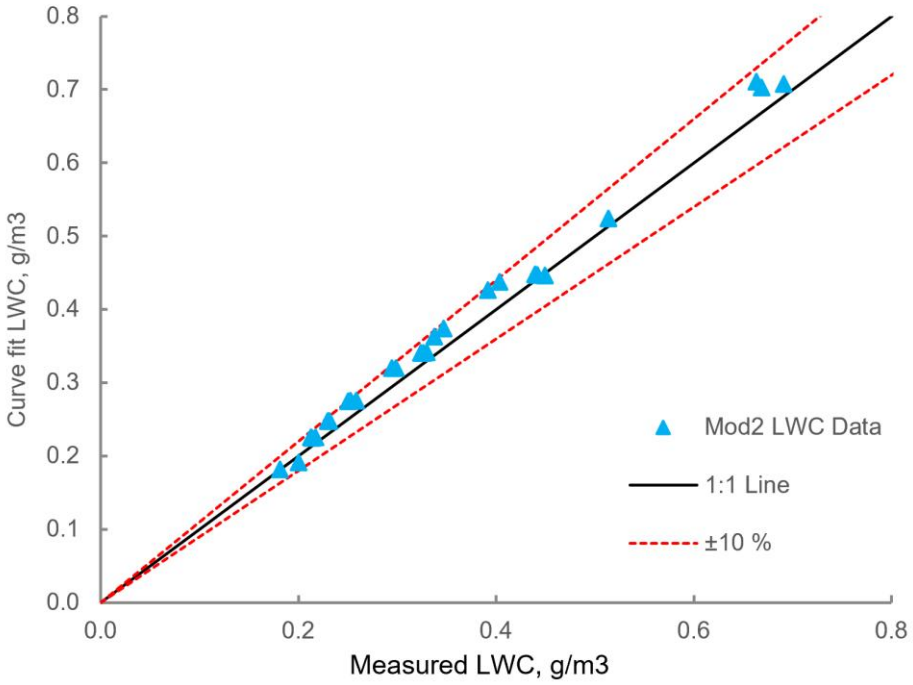
$$LWC_{Mod2} = \left[a + (b * V^2) + (c * V) + \left(d * {P_{air}}^2\right) + (e * P_{air})\right] * \left[\frac{\left(\sqrt{\Delta P - f}\right)^g}{V}\right] * \left[\left(\frac{MVD - h}{i}\right)^j\right] \tag{4}$$

where a = 2.23181643015433, b = -0.0000546672829758082, c = 0.0269740970496195, d = 0, e = 0.0182638979910018, f = 0, g = 1.08, h = 7, i = 100, and j = 0.1025.

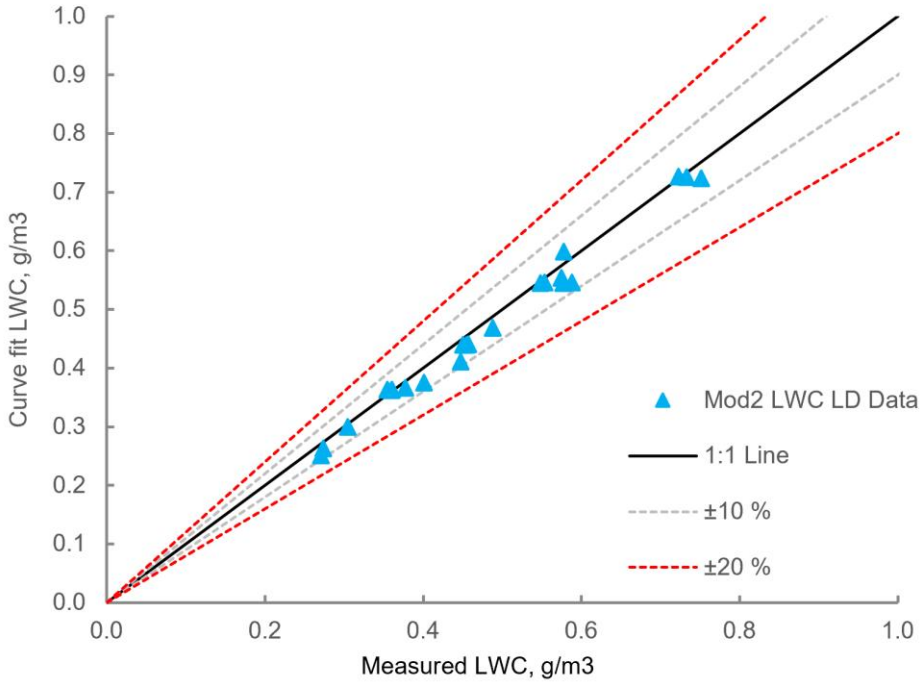
$$LWC_{Mod2LD} = \left[a + (b * V^2) + (c * V) + \left(d * {P_{\text{air}}}^2\right) + (e * P_{\text{air}})\right] * \left[\frac{\left(\sqrt{\Delta P - f}\right)^g}{V}\right] * \left[\left(\frac{MVD - h}{i}\right)^j\right] \quad (5)$$

where a = 3.21500224037992, b = -0.00005, c = 0.0265, d = 0, e = 0.00727691721742185, f = 0.97, g = 1, h = 11, i = 100, and j = 0.15.

Figure 12(a) illustrates the fit of the Mod2 Appendix C LWC equation relative to the IRT target accuracy of ±10 percent. Figure 12(b) shows that the LD data fit within the specified target accuracy of ±20 percent, with the majority of the data also falling within the tighter ±10 percent range.



(a)

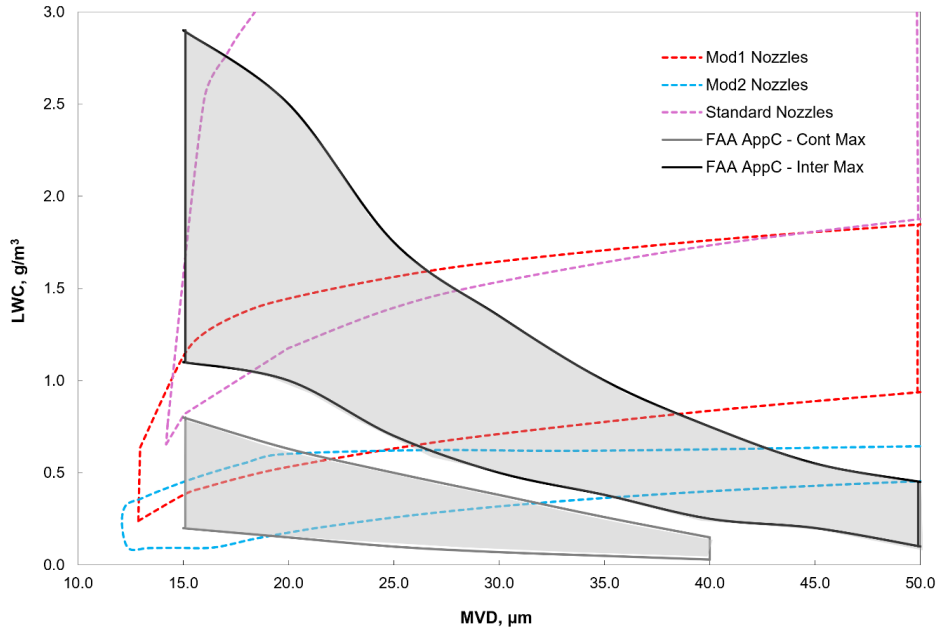


(b)

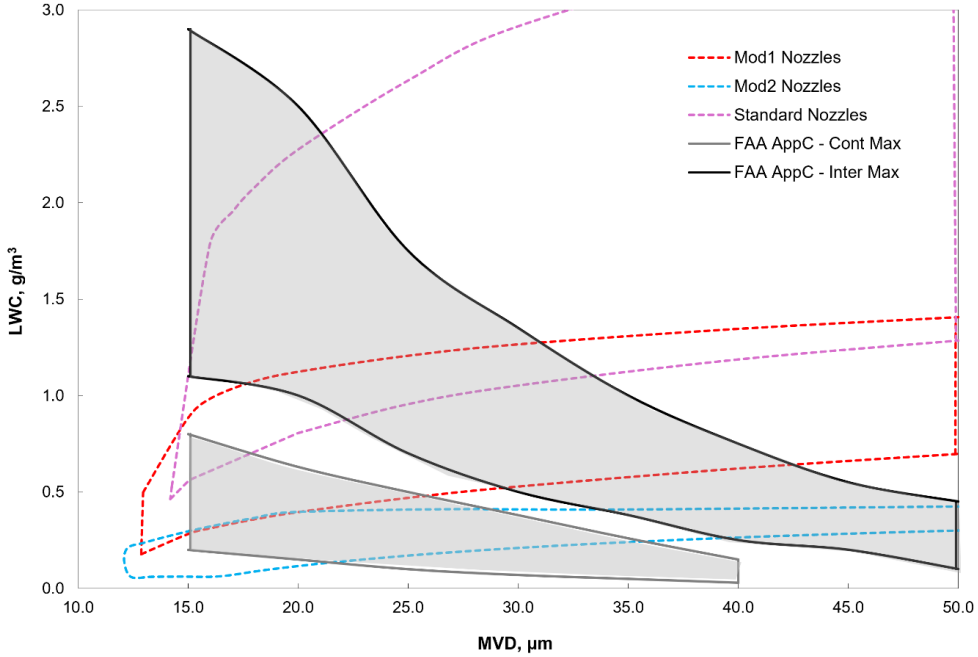
Figure 12. Curve fit values from generated equations compared to measured values for the Mod2 nozzle set. (a) Appendix C. (b) Large-drop conditions. Liquid water content (LWC).

Icing Cloud Operating Envelopes

Figure 13 compares the IRT operating envelopes for the Standard, Mod1, and Mod2 nozzle sets with the FAA Appendix C icing criteria (Ref. 3) at different airspeeds. Figure 14 shows the operating envelopes for Large Drop (LD) conditions. LWC depends on airspeed: higher airspeeds permit lower LWC values, whereas lower airspeeds permit higher values, as shown in Figure 14(a) and (b). Large Drop conditions are calibrated only for airspeeds from 100 to 250 kn; Appendix C conditions are calibrated from 50 to 300 kn. The stated MVD and LWC uncertainties for Large Drop conditions are ±20 percent, compared with ±10 percent for Appendix C. The cloud also tends to be smaller, and uniformity may be reduced depending on the test condition, as illustrated by the uniformity maps in Figure 3.



(a)

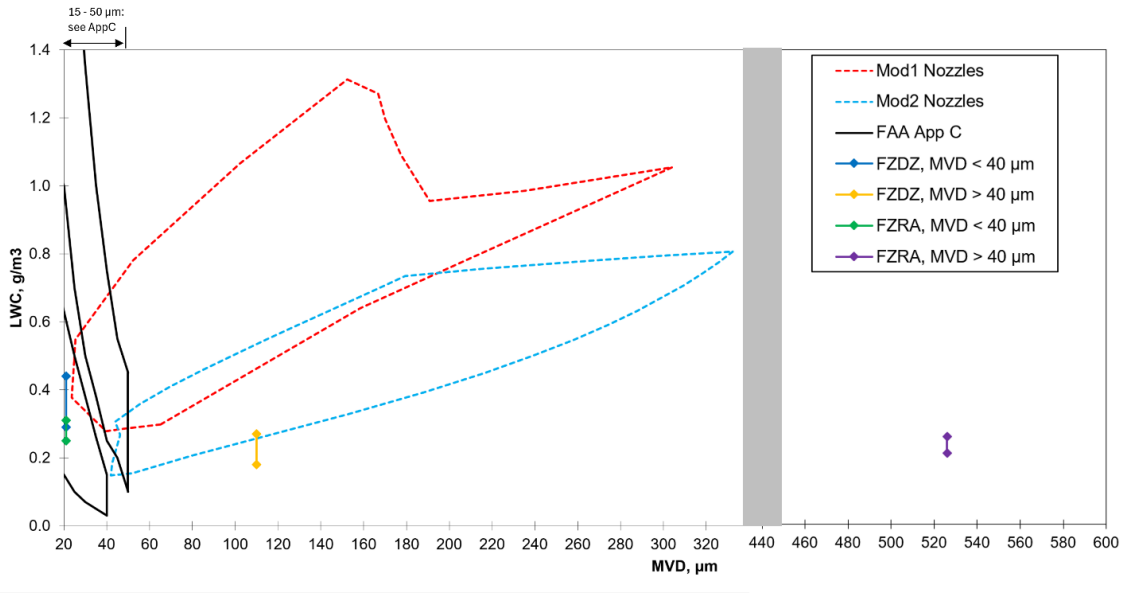


(b)

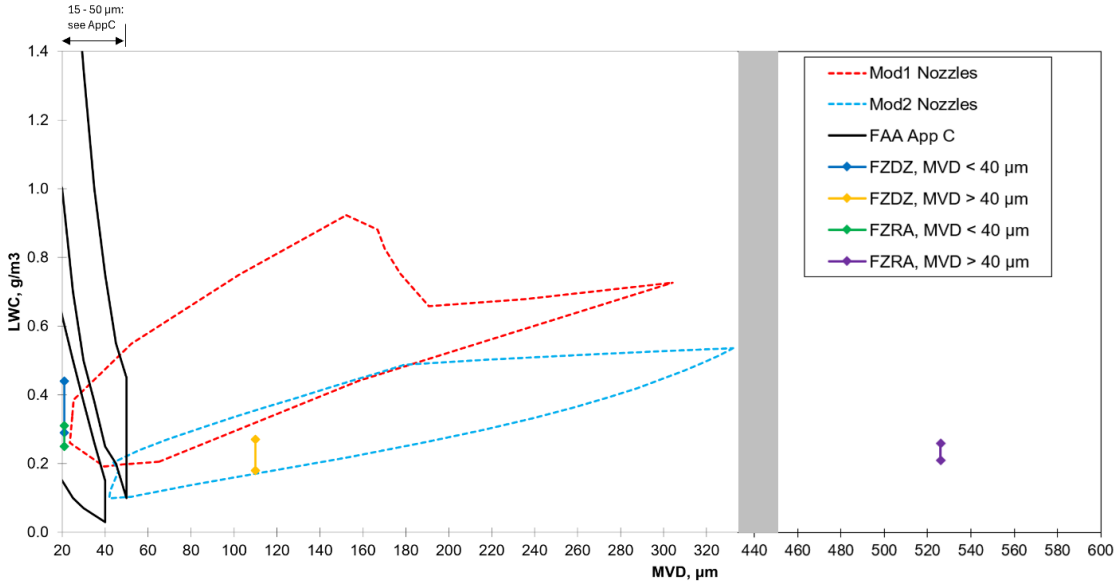
Figure 13. Icing Research Tunnel operating envelopes for Appendix C with median volumetric diameter (MVD)<50 µm at different airspeeds compared to Federal Aviation Administration (FAA) 14 CFR Parts 25 and 29, Appendix C. (a) 150 kn. (b) 250 kn.

The operating envelopes for the large-drop conditions are shown in Figure 14(a) and (b), which also show the inversely proportional airspeed and LWC relationship. These two plots also indicate the FZDZ and FZRA

conditions as specified by the FAA in Reference 4, according to their MVD values and LWC ranges. Those who wish to test FAA Appendix O conditions in the IRT may contact any of the authors of this report to discuss options.



(a)



(b)

Figure 14. Icing Research Tunnel operating envelopes for large-drop conditions at different airspeeds compared to Federal Aviation Administration (FAA) 14 CFR Parts 25 and 29, Appendix O. (a) 150 kn. (b) 250 kn. Freezing Drizzle (FZDZ). Freezing Rain (FZRA). Liquid water content (LWC).

Conclusion

The NASA Glenn Icing Research Tunnel successfully developed and calibrated a low-LWC cloud using Mod2 spray nozzles. The Mod2 cloud provides substantially lower water contents than were previously achievable with Standard and Mod1 nozzles and supports Appendix C conditions and portions of Appendix O conditions. The investigation established cloud-uniformity results, drop-size calibration relationships, LWC calibration curves, and preliminary capability for Appendix O simulation.

The calibrated cloud enables researchers and external customers to perform testing in more representative low-water-content icing environments while reducing dependence on scaling methodologies.

Future work will focus on developing bimodal Appendix O spray distributions, improving small-droplet data collection, and expanding freezing-rain capability for MVD values above 40 μm. The Mod2 cloud calibration expands the IRT's capability to support aircraft icing certification and icing-physics research.

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