



# AEROSPACE RECOMMENDED PRACTICE

**ARP5905™****REV. A**

Issued 2003-09  
Reaffirmed 2015-09  
Revised 2025-01

Superseding ARP5905

## Calibration and Acceptance of Icing Wind Tunnels

### RATIONALE

This document has been revised to address areas where the committee determined it needed improvement. The original document did not specify the necessity of a test section centerline temperature calibration, and this has been added. Also, the document now contains recommendations with regard to icing wind tunnels that have altitude capability. The spray durations and recommended test matrix in 7.2.1 (previously 8.2.2) have been reworded to more accurately reflect common ice accretion test practices. Performance targets and accompanying text have been added with regard to test section calibrations (not just measurement targets). Recommendations have been added regarding the possible effects of humidity on LWC and MVD, including recommendations for facility humidity instrumentation. The original document's Appendix A (LWC instrumentation) was removed in favor of AIR6977, and its Appendix C (Guideline to Determining Derived Aerodynamic Parameters) was removed in favor of other publications that better describe wind tunnel aero-thermal calibration. A new Appendix D was added with information regarding particle size distributions.

### FOREWORD

The U.S. Federal Aviation Administration established an icing plan in 1997 to respond to a need for a comprehensive program to create an awareness of in-flight icing issues and to establish documents to provide training and guidance for regulatory authorities, aircraft operators, research organizations, and aircraft manufacturers. The FAA published a 14-task plan, titled the "FAA In-flight Aircraft Icing Plan," and identified groups of people within the U.S. government and throughout the aircraft industry to address the action items contained in this plan. Task 11 of this plan called for the development of "validation criteria and data for simulation methods used to determine ice shapes on aircraft." It also indicated that this task was to include data on "wind tunnel(s), ice accretion computer codes, and icing tankers." The FAA suggested "a coordinated effort among research organizations, industry, and regulatory authorities," and individuals were asked to participate in this work. Task 11 was divided into three subtasks, and the people that participated in Subtask A were tasked with addressing criteria for the use of tankers, tunnels, and codes. Three documents were developed by the members of the Task 11.A Working Group, and these three documents were published as SAE Aerospace Recommended Practices. While each document follows a format that is appropriate to the topic, the three documents provide guidance for the application of codes (refer to ARP5903), tankers (refer to ARP5904), and tunnels (refer to ARP5905) to the icing certification or qualification process.

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## 1. SCOPE

This SAE Aerospace Recommended Practice (ARP) provides recommended practices for the calibration and acceptance of icing wind tunnels to be used in testing of aircraft components and systems and for the development of simulated ice shapes. This document is not directly applicable to air-breathing propulsion test facilities configured for the purposes of engine icing tests, which are covered in AIR6189. This document also does not provide recommended practices for creating Supercooled Large Drop (SLD) or ice crystal conditions, since information on these conditions is not sufficiently mature for a recommended practice document at the time of publication of ARP5905A. Use of facilities as part of an aircraft's ice protection Certification Plan should be reviewed and accepted by the applicable regulatory agency prior to testing. Following acceptance of a test plan, data generated in these facilities may be submitted to regulatory agencies for use in the certification of aircraft ice protection systems and components. Certain types of tests may be appropriate in facilities with capabilities that are not as rigorously characterized by the practices defined herein, and the acceptability of these tests should be coordinated with the applicable regulatory agency.

### 1.1 Purpose

The purpose of this ARP is to compile, in one definitive source, commonly accepted calibration and acceptance criteria and procedures for icing wind tunnels. Wind tunnels that meet these criteria will have known icing conditions simulation capability. Each manufacturer is responsible for obtaining regulatory agency approval for using a specific facility to generate certification data in their specific certification program.

The reader is directed to the following: DTIS ADA276499, AC 20-73A, AC 29-2C, and AC 23.2010-1; and the standards for icing certification of airplanes (refer to ASTM F3120/F3120M-20 and AC 25-28) for the myriad of considerations that are inherent in defining and conducting test programs for the purpose of obtaining certification for flight into known icing conditions. This ARP provides recommended practices for the calibration of icing wind tunnels. It is not intended to substitute for the regulatory agency's latitude in selecting the combination of tests or inspections required to demonstrate compliance with regulations as described in the Aircraft Icing Handbook.

An icing facility that conforms to the recommended practices in this document provides an artificial icing test volume consistent with the capability provided by current wind tunnel technology. If results produced in a test facility are to be used in the certification process of aircraft components or ice protection systems, it should be substantiated that the facility calibration and supporting resources conform to this ARP. Also, a comparison between the facility icing condition envelopes that can be simulated and those defined by the regulatory authorities should be presented.

## 2. REFERENCES

### 2.1 Applicable Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

#### 2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), [www.sae.org](http://www.sae.org).

|         |                                                                                |
|---------|--------------------------------------------------------------------------------|
| AIR4906 | Droplet Sizing Instrumentation Used in Icing Facilities                        |
| AIR5320 | Summary of Icing Simulation Test Facilities                                    |
| AIR6189 | Design, Calibration, and Test Methods for Turbine Engine Icing Test Facilities |
| AIR6977 | Water Content Instrumentation for Icing Cloud Characterization                 |
| ARP5624 | Aircraft Inflight Icing Terminology                                            |

ARP5903 Droplet Impingement and Ice Accretion Computer Codes

ARP5904 Airborne Icing Tankers

ARP5905 Calibration and Acceptance of Icing Wind Tunnels

Agui, J., Struk, P., and Bartkus, T., "Total Temperature Measurements in Icing Cloud Flows Using a Rearward Facing Probe," SAE Technical Paper 2019-01-1923, 2019, <https://doi.org/10.4271/2019-01-1923>.

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## 2.1.2 AIAA Publications

Available from American Institute of Aeronautics and Astronautics, 1801 Alexander Bell Drive, Suite 500, Reston, VA 20191-4344, Tel: 703-264-7500, [www.aiaa.org](http://www.aiaa.org).

AIAA G-045-2003 Guide to Assessing Experimental Uncertainty – Supplement to S-071A-1999

AIAA R-093-2003 Calibration of Subsonic and Transonic Wind Tunnels

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### 2.1.3 ASTM Publications

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, [www.astm.org](http://www.astm.org).

ASTM F3120/F3120M-20 Standard Specification for Ice Protection for General Aviation Aircraft

### 2.1.4 Code of Federal Regulations (CFR) Publications

Available from United States Government Publishing Office, 732 North Capitol Street, NW, Washington, DC 20401, Tel: 202-512-1800, [www.gpo.gov](http://www.gpo.gov).

14 CFR Part 25 Airworthiness Standards: Transport Category Airplanes"

14 CFR Part 29 Airworthiness Standards: Transport Category Rotorcraft"

### 2.1.5 Department of Defense Technical Publications

Available from Defense Technical Information Center (DTIC), 8725 John J. Kingman Road, Fort Belvoir, Virginia 22060-6218, Tel: 800.225.3842, <https://Discover.DTIC.mil>.

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Willbanks, C. and Schulz, R. (1973). *Analytical Study of Icing Simulation for Turbine Engines in Altitude Test Cells*. AEDC-TR-73-144.

### 2.1.6 FAA Publications

Available from Federal Aviation Administration, 800 Independence Avenue, SW, Washington, DC 20591, Tel: 866-835-5322, [www.faa.gov](http://www.faa.gov).

AC 20-73A Aircraft Ice Protection

AC 23.2010-1 FAA Accepted Means of Compliance Process for 14 CFR Part 23

AC 25-28 Compliance of Transport Category Airplanes with Certification Requirements for Flight in Icing Conditions

AC 29-2C Certification of Transport Category Rotorcraft

### 2.1.7 NACA Publications

Available from National Technical Information Service, 5301 Shawnee Road, Alexandria, VA 22312, Tel: 1-888-584-8332 or 703-605-6050, [www.ntis.gov](http://www.ntis.gov).

DTIS ADA276499 Aircraft Icing Handbook (Update), Volume 2, Chapter V, Section 4.0, Testing to Demonstrate Compliance

NACA Report No. 1135 (1953). *Equations, Tables and Charts for Compressible Flow*. NASA Ames Research Center.

### 2.1.8 NASA Publications

Available from NASA Technical Services, NASA STI Program STI Support Services, Mail Stop 148, NASA Langley Research Center, Hampton, VA 23681-2199, Tel: 757-864-9658, Fax: 757-864-6500, <http://ntrs.nasa.gov/>.

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Langmuir, I. and Blodgett, K.B. (1946). *A Mathematical Investigation of Water Droplet Trajectories* (U.S. AAF Technical Report 5418).

## 2.2 Related Publications

The following publications are provided for information purposes only and are not a required part of this SAE Technical Report.

### 2.2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), [www.sae.org](http://www.sae.org).

Cain, G., Yurczyk, R., Belter, D., and Chintamani, S., "Boeing Research Aerodynamic/Icing Tunnel Capabilities and Calibration," SAE Technical Paper 940114, 1994, <https://doi.org/10.4271/940114>.

### 2.2.2 AIAA Publications

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Steen, L., Ide, R., and Van Zante, J. (June 2016). *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. Available at <https://doi.org/10.2514/6.2016-4051>.

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## 2.3 Symbols

|                |                                                   |
|----------------|---------------------------------------------------|
| $\gamma$       | Ratio of specific heats                           |
| $\rho_{ice}$   | Density of ice                                    |
| $\rho_w$       | Density of water                                  |
| $\tau_C$       | Thickness of the iced grid at the center location |
| $\tau_{grid}$  | Thickness of grid in the uniced condition         |
| $\tau_{ice}$   | Thickness of ice                                  |
| $\tau_{ice R}$ | Relative thickness of ice                         |
| $\tau_{(x,y)}$ | Thickness of the iced grid at each (x,y) location |
| $\omega_a$     | Air mass flow rate                                |
| $\omega_w$     | Water flow rate                                   |
| $\omega_{wB}$  | Bulk water flow rate                              |
| $A$            | Flow area                                         |
| $a$            | Speed of sound                                    |

|                  |                                                                               |
|------------------|-------------------------------------------------------------------------------|
| $C_{d\ a}$       | Air discharge coefficient                                                     |
| $C_{d\ w}$       | Water discharge coefficient                                                   |
| $C_{d\ w/a}$     | Discharge coefficient based on difference of water and air pressures          |
| $C_f$            | Water flow coefficient                                                        |
| $C_0$            | Intercept constant                                                            |
| $D$              | Nozzle approach diameter                                                      |
| $d_o$            | Nozzle orifice diameter                                                       |
| $H_1, H_2, H_3$  | Icing grid locations (horizontal)                                             |
| $K$              | Unit conversion factor                                                        |
| $K_A$            | Liquid water content calibration constant for constant tunnel velocity        |
| $K_e$            | Calculated nozzle correlation parameter                                       |
| $K_v$            | Liquid water content calibration constant for constant spray bar air pressure |
| $LWC$            | Liquid water content                                                          |
| $LWC_B$          | Bulk liquid water content                                                     |
| $LWC_b$          | Icing blade liquid water content                                              |
| $LWC_c$          | Tunnel centerline liquid water content                                        |
| $LWC_e$          | Facility calibration predicted liquid water content                           |
| $LWC_{(x,y)}$    | Liquid water content calculated at icing grid location (x,y)                  |
| $M$              | Freestream Mach number                                                        |
| $MVD$            | Median volumetric diameter                                                    |
| $P_a$            | Spray bar air pressure                                                        |
| $PSD$            | Particle size distribution                                                    |
| $P_s$            | Freestream static pressure                                                    |
| $P_{s\ down}$    | Static pressure downstream of orifice                                         |
| $P_{s\ up}$      | Static pressure upstream of orifice                                           |
| $P_T$            | Freestream total pressure                                                     |
| $P_w$            | Spray bar water header pressure                                               |
| $\Delta P_{w-a}$ | Spray bar water to air differential pressure                                  |

|                 |                                                        |
|-----------------|--------------------------------------------------------|
| R               | Gas constant                                           |
| RTD             | Resistance temperature detector                        |
| $T_s$           | Absolute freestream static air temperature             |
| $T_T$           | Absolute freestream total air temperature              |
| $T_{Ta}$        | Nozzle total air temperature                           |
| t               | Time                                                   |
| V               | Freestream velocity (i.e., true airspeed)              |
| $V_{TS}$        | Test section freestream velocity (i.e., true airspeed) |
| $V_1, V_2, V_3$ | Icing grid locations (vertical)                        |

### 3. FACILITY DESCRIPTION

This ARP is intended to cover a variety of icing wind tunnel types from refrigerated closed-circuit facilities to open air freejet facilities. AIR5320 also presents information on icing test facilities.

#### 3.1 Example Closed-Circuit Facility

An example facility consists of a closed-circuit, refrigerated wind tunnel with a constant area test section. A variable speed fan motor provides for a variation in the test section air velocity. Refrigeration is obtained via a heat exchanger placed upstream of the settling chamber, adequately sized to provide the required test section temperature setting. The facility has a settling chamber that may be fitted with honeycomb flow straighteners and screens and a contraction section with sufficient area ratio to provide for good airflow quality in the test section. Water spray bars located in the settling chamber and their associated controls provide the water droplet spectrum and liquid water content (LWC) required for the test conditions. The water used in the spray bar system is normally heated and treated (e.g., deionized) in order to avoid freeze-out and fouling of the water spray atomizing nozzles, respectively. An example of a typical closed-circuit refrigerated facility is shown in Figure 1.

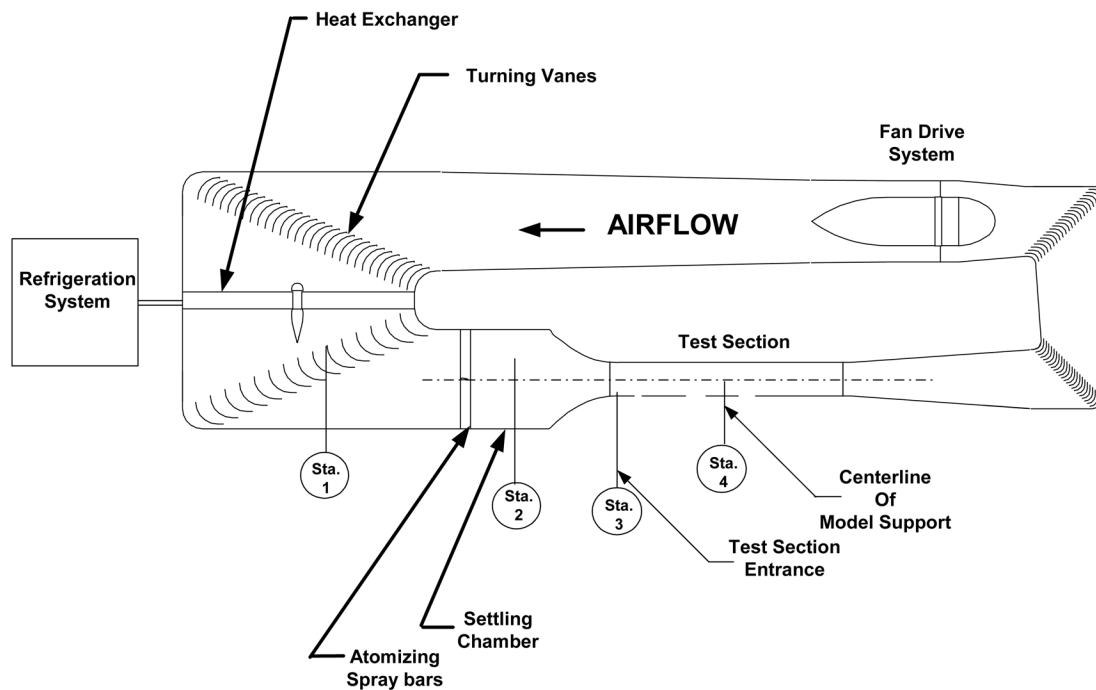


**Figure 1 - Example of typical closed-circuit, refrigerated icing tunnel**

### 3.2 Considerations for Open-Circuit Wind Tunnels and Facilities with Alternate Configurations

Another example facility is an open-circuit refrigerated wind tunnel, typically used for engine testing. Such facilities are briefly addressed here but are described in greater detail in AIR6189. The NRC Canada 3 m x 6 m icing wind tunnel is an example of this type of facility and is shown schematically in Figure 2. In this facility, cold air is supplied at the inlet and driven by a fan through a series of flow conditioning screens in the settling chamber to straighten the flow and improve the velocity distribution. The flow is accelerated as it passes through a bell mouth or other contraction device and is conducted via a straight duct to the test section, where the test article is typically placed. The icing water spray is injected upstream of the test section. The flow then discharges through the diffuser along with any engine combustion products. Generally, the flow in such (engine test) facilities does not meet the detailed flow angle and turbulence criteria cited in Section 4.

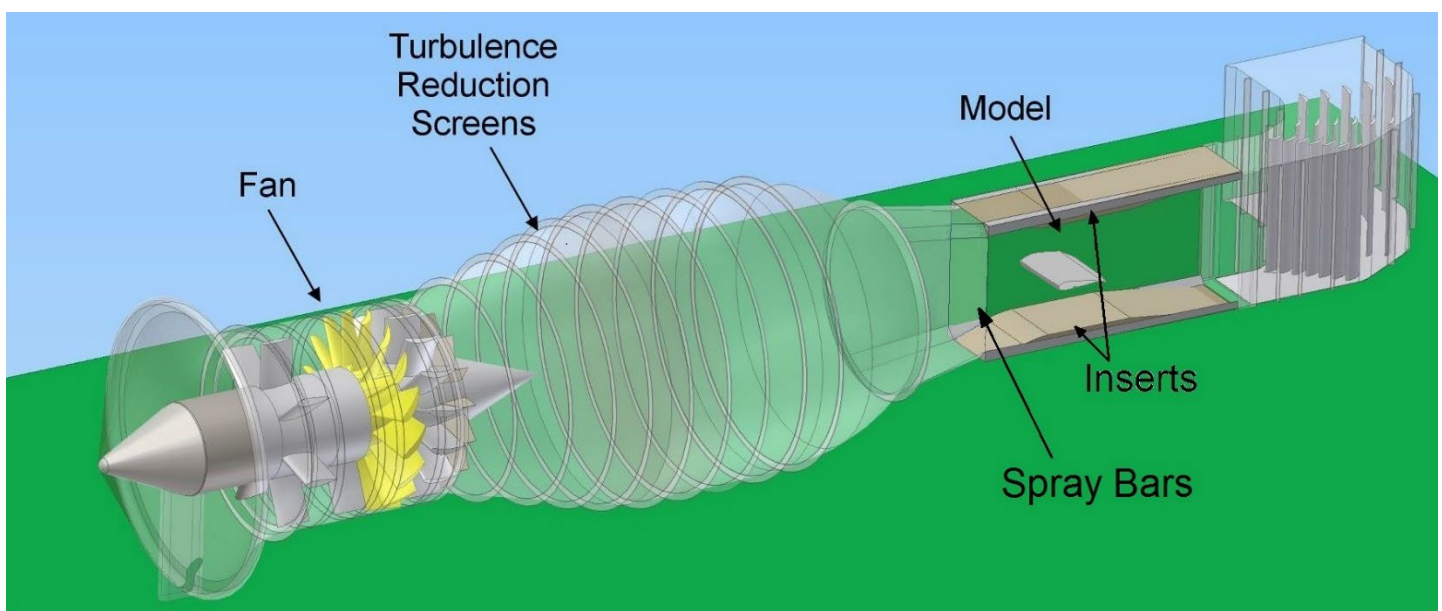


**Figure 2 - Example of a non-recirculating icing wind tunnel**

It should be pointed out that in some instances an open-circuit facility is adapted to specific tests and does not have a static configuration (i.e., is not permanently configured as an icing facility). This is also the case for other icing facilities (e.g., climatic chambers and tunnels with removable contractions or test sections), which have alternate facility configurations that make a full calibration unfeasible. Consequently, these facilities are not consistently configured for the routine calibrations cited below and generally do not have the same characterized flow quality as a closed-circuit facility. Typically, spray nozzles are flow calibrated and characterized for droplet size, but they are installed in an adaptable array for generation of a specific cloud. To overcome these facility constraints, these facilities typically calibrate the flow and cloud either prior to a specific test or during the test. These calibrations are then adequate only for the specific test and do not constitute a general facility calibration. However, these calibrations should use the practices established in this document.

#### 4. FACILITY PERFORMANCE TARGETS

Icing testing should be performed in facilities having measured, defined, and documented aerothermodynamic flow qualities, icing cloud qualities, and calibrated instrumentation. The facility should be calibrated in accordance with the time frames in Section 6 and the procedures in Section 7. The test section aerothermodynamics and icing cloud characteristics should be within the range of performance targets listed in Table 1 over the area of the uniform icing cloud. The uniform icing cloud is defined as the area of the test section over which the LWC does not vary by more than  $\pm 20\%$  from the test section centerline LWC value for a given airspeed and water droplet size MVD.

**Table 1 - Test section performance targets<sup>(1)</sup>**

|                                                            | Measurement Instrumentation Maximum Uncertainty | Tunnel Centerline Temporal Stability <sup>(2)</sup> | Spatial Uniformity <sup>(3)</sup> | Limit Value <sup>(4)</sup> | Test Section Calibrations (see Section 7) <sup>(5)</sup> |
|------------------------------------------------------------|-------------------------------------------------|-----------------------------------------------------|-----------------------------------|----------------------------|----------------------------------------------------------|
| <b>Aerothermodynamic Parameters</b>                        |                                                 |                                                     |                                   |                            |                                                          |
| True Airspeed <sup>(6)(7)</sup>                            | ±1%                                             | ±2%                                                 | ±2%                               | N/A                        | ±1%                                                      |
| Total Air Temperature below -30 °C <sup>(8)</sup>          | ±2 °C                                           | ±2 °C                                               | ±2 °C                             | N/A                        | ±2 °C                                                    |
| Total Air Temperature Between -30 and +5 °C <sup>(8)</sup> | ±0.5 °C                                         | ±0.5 °C                                             | ±1 °C                             | N/A                        | ±0.5 °C                                                  |
| Flow Angularity                                            | ±1.0°                                           | N/A                                                 | ±2°                               | ±3°                        | N/A                                                      |
| Pressure Altitude                                          | ±50 m                                           | ±50 m                                               | N/A                               | N/A                        | ±50 m                                                    |
| <b>Flow Turbulence</b>                                     |                                                 |                                                     |                                   |                            |                                                          |
| (P <sub>a</sub> -Off or minimum) <sup>(9)</sup>            | ±0.25%                                          | N/A                                                 | <2%                               | 2% <sup>(11)</sup>         | N/A                                                      |
| (P <sub>a</sub> -On at maximum) <sup>(10)</sup>            | ±0.25%                                          | N/A                                                 | <2%                               | 5% <sup>(11)</sup>         | N/A                                                      |
| <b>Cloud Parameters</b>                                    |                                                 |                                                     |                                   |                            |                                                          |
| Liquid Water Content <sup>(12)</sup>                       | ±10%                                            | ±20%                                                | ±20%                              | N/A                        | ±10%                                                     |
| Median Volume Diameter <sup>(13)</sup>                     | ±20%                                            | ±10% <sup>(14)</sup>                                | N/A                               | N/A                        | ±20%                                                     |
| Relative Humidity                                          | ±3%                                             | N/A                                                 | N/A                               | N/A                        | (15)                                                     |

- (1) These performance targets are for an empty test section and apply for otherwise uncorrected parameters (i.e., deviations from above may be allowed if the flow quality is sufficiently known to locally correct the conditions and/or results).
- (2) Temporal stability is the time variation of the measurement over the duration of the test point (e.g., cloud exposure per 14 CFR Parts 25 and 29, Appendix C conditions) for each parameter. Temporal stability should be assessed at the geometric center (x,y,z) of the test section. The minimum time interval for establishing temporal stability is 30 seconds.
- (3) Spatial uniformity is the recommended maximum allowable deviation of a temporal average at any point within the uniform icing cloud area relative to the temporal average at the centerline.
- (4) Limit is the recommended maximum allowable value of any single measurement at any point within the uniform icing cloud area.
- (5) Test section calibration relationships are required to relate facility instrument data to test section parameters measured at centerline during facility calibration (see Section 7). It is recommended that the calibration relationships align with the measured test section values within the limits specified in this column. This applies to airspeed, air temperature, altitude, liquid water content, and median volumetric diameter.
- (6) In this document, airspeed is understood to be true airspeed, not indicated airspeed.
- (7) For airspeed less than 40 m/s, instead of ±1% use ±0.4 m/s.
- (8) Table 1 recommends total temperature performance targets rather than static temperature performance targets. This is because total temperature is a measured value, and most ground testing facilities control to total temperature. Static temperature, however, is a calculated value (refer to AIAA R-093-2003) and thus has greater potential for error. Further discussion can be found in the notes following Table 2.
- (9) (P<sub>a</sub>-Off) designates the spray nozzle atomization air is not flowing. If the operations are such that the facility never collects test data with air pressure completely off, they may instead run this test at the minimum air pressure at which the facility collects data.
- (10) (P<sub>a</sub>-On) designates the spray nozzle atomization air is set at the maximum pressure that may be used during regular facility testing. If hydraulic atomization nozzles are used, ignore this entry. Further information on measured effect of nozzle air pressure on turbulence intensity can be found in Henze and Bragg (1999).
- (11) The flow turbulence intensity is defined in Chapter 10 of Jørgensen (2005).
- (12) For LWC less than 0.2 g/m<sup>3</sup>, use uncertainty of 0.02 g/m<sup>3</sup> instead of ±10%.
- (13) For MVD less than 15 µm, use uncertainty of ±3 µm instead of ±20%.
- (14) See 7.2.3 on time intervals for MVD measurements.
- (15) This document gives no specified recommendation to measure the humidity values in the test section and correlate/calibrate it to the sensor measurement(s) that exist elsewhere within the facility (see 5.1.3). However, changes in humidity values can affect MVD and LWC values and may also have an effect on cloud uniformity. Facilities should either ensure that their humidity levels are consistent enough to not greatly impact these values or should be able to account for differences in their calibration that may be caused by the changes in humidity to maintain the parameter accuracy values specified in Table 1.

Accuracy and uncertainty are determined by a statistical process whereby measured data is analyzed by acceptable means. Wind-tunnel-specific assessment of data uncertainty is discussed in AIAA S-071A-1999 and AIAA G-045-2003. A textbook treatment on the topic of statistical method for the assessment of data uncertainty can be found in Coleman and Steele (1989). Temporal stability is defined as the variation of the parameter over the run. Uniformity is the spatial variation of the parameter over the cross-sectional area of the uniform icing cloud. The limits in the spatial uniformity column of Table 1 are applicable for parameters that are characteristics of a facility design and generally are not controlled.

In addition to the non-controlled performance parameters found in Table 1, the facility operator should also document the time to achieve spray bar system (both air and water pressure) stability. This performance feature of an icing wind tunnel does not lend itself to definition in Table 1. However, it is an important performance characteristic to document, as the operator has the responsibility to ensure that time to achieve a stable icing cloud is consistent with (generally much less than) the icing spray duration for a given test point. The spray can be considered “stabilized” when the temporal variations in air and water pressure values are small enough that the temporal variances in LWC and MVD are less than  $\pm 20\%$  and  $\pm 10\%$ , respectively, of their mean values (see Table 1). The operator should know the time required to stabilize the spray bar system to within  $\pm 2$  seconds. If a test point requires a very short spray duration (i.e., less than 10 seconds), the spray stabilization time may comprise a substantial portion of the test time. In such cases, the facility operator may need to work with the test conductor to determine possible accommodations and/or corrections as needed. One example accommodation is to have a retractable shield over the test article that can be removed quickly after the spray is stabilized or, conversely, to insert the test article into the cloud after spray is stabilized.

## 5. INSTRUMENTATION

All instrumentation (sensors, transducers, and data acquisition systems) used in the facility for monitoring facility operation and for determining the aerothermodynamic and icing cloud properties should be traceable to the applicable national standards setting agency (National Institute of Standards and Testing, United States; National Research Council, Canada; Servizio di Taratura, Italy; etc.) and should be calibrated at least annually or in accordance with each facility-operator organization’s processes and procedures.

Standard instruments should be used for pressure and temperature measurements in the facility as well as the test section. This will enable the tunnel operator to vary the fan and heat exchanger controls to maintain the velocity and temperature in the test section within the set tolerance limits. Calibration relationships are generally built by relating test section measurements (see 5.2) to measurements from the facility-mounted instrumentation (see 5.1) using procedures described in Section 7.

### 5.1 Facility Instrumentation

The following sections provide information on the minimum instrumentation set for measuring tunnel total pressure, static pressure, total temperature, and humidity. Special care should be used in the selection of the instrumentation for an icing tunnel due to the icing conditions that will exist. Typically, heated probes are used to avoid measurement contamination due to ice buildup. Additionally, this section gives recommendations for the spray bars that create the liquid water spray.

#### 5.1.1 Tunnel Temperatures

Two types of temperatures are commonly used to define the air temperature. Total temperatures are generally measured and used along with Mach number,  $M$  (determined from the measured total and static pressure that are described in 5.1.2), to determine the static temperatures, which are used as the defining temperature for icing conditions. Static temperature is also used to calculate the velocity of the tunnel. The equations used to determine static temperatures are described in NACA Report No. 1135, Equations 44 and 43, which are also given in Equations 1 and 2:

$$\frac{P_S}{P_T} = \left(1 + \frac{\gamma-1}{2} M^2\right)^{-\frac{\gamma}{\gamma-1}} \quad (\text{Eq. 1})$$

$$\frac{T_S}{T_T} = \left(1 + \frac{\gamma-1}{2} M^2\right)^{-1} \quad (\text{Eq. 2})$$

where:

$\gamma$  = ratio of specific heats

$M$  = freestream Mach number

$P_S$  = freestream static pressure

$P_T$  = freestream total pressure

$T_S$  = absolute freestream static temperature

$T_T$  = absolute freestream total temperature

#### 5.1.1.1 Total Temperature Probe

A total temperature probe is commonly located in the settling chamber near Station 1 of Figure 1; that is, downstream of the heat exchanger but upstream of the spray bars. It is recommended to install the total temperature probe upstream of the spray bars so that it does not need to be heated. A flow-through temperature probe that allows airflow to pass over the sensing element is recommended. In the settling chamber, since airspeed is generally low, recovery error corrections are generally not needed but can be performed. Temperature measurements inside a cloud in the test section are not generally part of the recommended practice of this document, but if a facility wants to attempt this (see 5.1.3.1), they will need to use a self-heated probe like that shown in Figure 3, and they will need to be familiar with the manufacturer's recommendations regarding the necessary temperature corrections, which may include recovery error, deicing heater error, and self-heating error.



**Figure 3 - Example of total temperature probe**