SAE Aerospace
An SAE International Group

AEROSPACE RECOMMENDED PRACTICE

ARP5485 REV. A

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Superseding ARP5485

Endurance Time Tests for Aircraft Deicing/Anti-icing Fluids SAE Type II, III, and IV

RATIONALE

This document has been revised to include indoor laboratory snow testing methods.

FOREWORD

Aircraft deicing/anti-icing fluids certified under AMS 1428 (Types II, III, and IV fluids) must be tested for endurance time as described in this Aerospace Recommended Practice (ARP). Endurance time can be defined as the time that a fluid can endure controlled and defined temperature and precipitation conditions before failure. These temperature and precipitation conditions were developed taking into consideration meteorological data. The endurance time data are presented to the SAE G-12 Holdover Time Subcommittee for examination and validation. If of acceptable quality, these data are used to update holdover time guidelines for the appropriate fluid type, taking into consideration the effects of natural variability of precipitation both in time and space. Holdover time guidelines are published in documents issued by regulatory bodies such as the US Federal Aviation Administration 8000 Series Notices and Transport Canada Holdover Time (HOT) Guidelines. Additional testing on the fluid may be required by the FAA or Transport Canada for inclusion in their guidelines

This ARP provides peer reviewed written documentation for laboratory endurance time testing for freezing fog, freezing drizzle, light freezing rain, snow and rain on a cold-soaked wing. Frost holdover times are currently based on the high humidity endurance test described in AS5901. A new frost test is being developed and will be included in future versions of ARP5485.

In the past, snow tests were conducted outdoors, predominantly in Canada. This presented the obvious problem of awaiting for suitable weather conditions. Additionally, relying on outside weather conditions, forces holdover time to be reviewed and issued after the northern hemisphere winter (deicing season). This version of the ARP includes two indoor laboratory snow procedures in addition to the outdoor snow procedure. Either of the three methods can be used to produce endurance time data for review by the SAE G-12 Holdover Time Subcommittee.

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1. SCOPE

1.1 Purpose

The purpose of this SAE Aerospace Recommended Practice (ARP) is to provide the sample selection and endurance time test procedures, for SAE Type II, III, and IV aircraft deicing/anti-icing fluids, required for the generation of endurance time data of acceptable quality for review by the SAE G-12 Holdover Time Subcommittee.

1.2 Examination of Endurance Time Data

Periodically, the SAE G-12 Holdover Time Subcommittee examines endurance time test data of SAE Type II, III, and IV aircraft deicing/anti-icing fluids and validates, based on the endurance time data, if such fluids can be used in conjunction with SAE Type II, III, or IV fluid holdover time guidelines. As the SAE G-12 Holdover Time Subcommittee examines endurance time data, it will take into consideration the effects of natural variability of precipitation both in time and space to generate or adjust holdover time guidelines.

1.3 Limits

This ARP provides laboratory simulation of freezing fog, freezing drizzle, light freezing rain, snow and rain on cold soaked wing. Other forms of freezing/frozen precipitation are not addressed in this ARP.

1.4 Testing Agent(s)

1.4.1 Independence of the Testing Agents

A testing agent shall be independent of the fluid manufacturer and fluid vendor.

1.4.2 Role of the Testing Agent

The testing agent shall coordinate activities related to the sample selection procedures (see Section 3).

1.4.3 Sending Samples

Fluid samples for testing shall be sent to a testing agent for verification under the sample selection procedures. In turn the testing agent, if the requirements of the applicable sample selection procedure are fulfilled, shall send the samples to the facility/site for endurance time testing.

1.5 Test Facility/Site

1.5.1 Independence of the Test Facility/Site

The test facility/site shall be independent of the fluid manufacturer and fluid vendor.

1.5.2 Role of the Test Facility/Site

The test facility/site shall be responsible for performing the endurance time tests (see Sections 4 to 11).

1.6 Units

The values stated in SI units are to be regarded as the standard.

1.7 Safety

While the materials, methods, applications, and processes described or referenced in this ARP may involve the use of hazardous materials, this ARP does not address the hazards that may be involved in such use. It is the sole responsibility of the user to ensure familiarity with the safe and proper use of any hazardous materials and processes and to take necessary precautionary measures to ensure the health and safety of all personnel involved.

2. 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 SAE Publications

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

ARP4737 Aircraft Deicing/Anti-icing Methods

AS5901 Water Spray and High Humidity Endurance Test Methods for SAE AMS 1424 and SAE AMS 1428 Aircraft Deicing/Anti-icing Fluids

AIR9968 Viscosity Test of Thickened Aircraft Deicing/Anti-icing Fluids

AMS 1424 Deicing/Anti-Icing Fluid, Aircraft, SAE Type I

AMS 1428 Fluid, Aircraft Deicing/Anti-Icing, Non-Newtonian, (Pseudoplastic), SAE Types II, III, and IV

AMS 4037 Aluminum Alloy, Sheet and Plate, 4.4Cu - 1.5Mg - 0.60Mn (2024; -T3 Flat Sheet, -T351 Plate) Solution Heat Treated

AMS 4041 Aluminum Alloy, Alclad Sheet Plate 4.4Cu - 1.5Mg - 0.60Mn Alclad 2024 and 1-1/2% Alclad 2024 -T3 Flat Sheet; 1-1/2% Alclad 2024-351 Plate

2.2 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.

ASTM D 1193 Reagent Water

2.3 ISO Publications

Available from International Organization for Standardization, 1, rue de Varembe, Case postale 56, CH-1211 Geneva 20, Switzerland, Tel: +41-22-749-01-11, www.iso.org.

ISO 10012 Quality assurance requirements for measuring equipment

2.4 Transport Canada Publications

Available from Transportation Development Center, Transport Canada, 800, boul. René-Lévesque Ouest, 6th Floor, Montréal QC H3B 1X9, Canada.

Validation of Methodology for Simulating a Cold Soaked Wing. Transport Canada Document TP 12899E.

Aircraft Ground De/Anti-icing Fluid Holdover Time and Endurance Time Testing Program for the 2001–2002 Winter. Transport Canada Document TP 13991E.

2.5 Other Documents

Godard, L. (1959), Procédé pour déterminer les dimensions des gouttelettes de brouillard ou de nuages, Bulletin de l'observation du Puy de Dôme, pp.11-13. Translated title : Procedure to determine fog and cloud water droplet size

Godard, S. (1960), Mesure des gouttelettes de nuage avec un film de collargol. Bulletin de l'observation du Puy de Dôme, pp. 41-46. Translated title : Measurement of cloud water droplet size using collargol film

3. SAE TYPE II, III, AND IV FLUID SAMPLES ELIGIBLE FOR ENDURANCE TIME TESTING

3.1 Requirements

3.1.1 Normal Batch and Viscosity Reduction

The sample shall be fluid taken from a production batch and its viscosity may be reduced by the manufacturer by some process subsequent to manufacturing.

3.1.2 Water Spray Endurance Time (WSET)

The WSET (measured according to AS5901 but without shearing) of the sample must be (a) equal to (within experimental error, approximately ±10%) or less than the WSET of the neat sample (100/0, neat fluid/water) on which qualification WSET in 4.2.3.1.1 of AMS 1428 was done and (b) must not be less than 30 min for Type II fluids, not less than 20 min for Type III fluids, and not less than 80 min for Type IV fluids, as required by AMS 1428.

3.1.3 Viscosity

The sample’s 0.3 rpm 20 °C viscosity must be equal to (within experimental error, approximately ±10%) or less than the 0.3 rpm 20 °C viscosity of the neat sample (100/0, neat fluid/water) as measured by AIR9968 on which the certification water spray endurance time (WSET) in 4.2.3.1.1 of AMS 1428 was done.

3.1.4 Fluid Manufacturer's Documentation

The fluid manufacturer shall send the AMS 1428 certificates of conformance of the fluid to the testing agent.

3.2 Testing Agent Duties

3.2.1 Run and Report WSET

The testing agent shall run WSET (without shearing) and report to the manufacturer prior to running any endurance time testing.

3.2.2 Run and Report Viscosity

The testing agent shall run the viscosity of the unsheared sample at 0.3 rpm 20 °C according to AIR9968 and report to the manufacturer prior to running any endurance time testing.

3.2.3 Check Certificates of Conformance

The testing agent shall ensure that it has on hand the AMS 1428 certificates of conformance for the fluid (to make sure it is fully certified).

3.2.4 Check WSET

The testing agent shall ensure that the requirements of 3.1.2 are evaluated.

3.2.5 Check Viscosity

The testing agent shall ensure that the requirements of 3.1.3 are evaluated.

3.3 Authorization to Proceed with Endurance Time Testing

3.3.1 Manufacturer's Authorization to Proceed

After reviewing the reports sent by the testing agent, the fluid manufacturer (if desirous of proceeding with endurance tests) shall send to the testing agent authorization to proceed.

3.3.2 Final Check

The testing agent shall proceed with endurance time testing upon successful completion of 3.2.3, 3.2.4, 3.2.5, and 3.3.1 by sending the sample to the testing facility/site.

3.4 Condition of the Sample to be Tested for Endurance Time

3.4.1 The neat sample shall be tested without shearing.

3.4.2 The 75/25 and 50/50 volume/volume dilutions of the sample shall be made with hard water and shall be tested without shearing.

3.4.3 Composition of Hard Water

The hard water use for dilution shall be made according to the following procedure: Dissolve 400 mg ± 5 mg calcium acetate dihydrate $Ca(C_2H_3O_2)_2.2H_2O$ and 280 mg ± 5 mg magnesium sulfate heptahydrate $MgSO_4.7H_2O$, both of analytical reagent quality, in 1 L of ASTM D 1193 Type IV water. If calcium acetate dihydrate is not readily available, use calcium acetate monohydrate or anhydrous calcium acetate of analytical reagent quality and ensure the hard water has 82.6 mg/L Ca^{++} by atomic absorption (or equivalent method).

3.5 Recertification

If a fluid manufacturer submits a sample which has a 0.3 rpm 20 °C viscosity or WSET that does not meet the requirements of 3.2.4 and 3.2.5, the sample may be submitted for endurance time testing provided that prior to testing, the manufacturer submits new certificates of conformance under 4.2.3.1.1 (including all subparagraphs a, b and c) of AMS 1428 demonstrating that the sample meets the requirements of 3.2.4 and 3.2.5.

3.6 Viscosity Measurements

Viscosity in this section shall be determined on the neat, 75/25 and 50/50 dilutions with hard water according to 3.4.2 using the same procedure and instrumentation (spindle/sample size combination) as used for the AMS 1428 certification (most current).

4. ENDURANCE TIME TEST - GENERAL

4.1 Purpose

This section of the ARP establishes the general minimum requirements for test equipment and test procedures used to carry out laboratory endurance time tests of aircraft deicing/anti-icing fluids under conditions of freezing fog, freezing drizzle, light freezing rain, snow and rain on cold soaked wing. The primary purpose for such a test method is to determine endurance time for these conditions under controlled laboratory conditions for SAE Type II, III, and IV fluids.

This section does not apply to natural snow testing performed outside (Section 11) except where noted otherwise.

4.2 Summary of the Tests

Fluids to be evaluated are applied to test plates exposed to freezing fog, freezing drizzle, light freezing rain, snow and rain on a cold-soaked (simulated) wing. Endurance times are evaluated by measuring the minimum exposure time before a specified degree of freezing occurs.

4.3 General Versus Specific Requirements

This general section (Section 4) covers requirements that are common to laboratory conditions (except where otherwise noted). Sections 5 to 10 establish the specific requirements for each precipitation condition.

4.4 Test Facility/Site Documentation

Substantiation that the testing facility and associated staff and resources satisfy the requirements of this endurance time test method including calibration and measurement methods, shall be documented. Such documentation shall be kept for 3 years.

This requirement (4.4) is applicable to Section 11.

4.5 General Environmental Chamber Equipment

4.5.1 Air Temperature Sensor

The air temperature sensor shall be in proximity to the test plate, typically within 1.5 m of the side of the test plate, but outside the spray area (if any). The distance and position of the sensing device shall be reported.

4.5.2 Lighting

The test chamber shall be equipped with artificial lighting facilitating ice formation observation but positioned such that it does not interfere with air, fluid and plate temperatures.

4.5.3 Data Acquisition System

The air temperature, plate temperature and humidity sensors shall be linked to an electronic data acquisition system as a means of checking and recording the environmental characteristics of the test chamber and test plates throughout the course of a test run.

4.5.4 Temperature Control Equipment

The air temperature (for all conditions) and test plate temperature, if required by the test protocol, shall be maintained at the required level using heat exchangers connected to temperature control equipment comprising solid state temperature sensor such as a platinum resistance probe (100 Ω at 0 °C), coupled to a proportional temperature controller having a minimum resolution of 0.5 °C.

4.5.5 Air Distribution System

The air distribution system shall be comprised of a fan or fans to provide air recirculation through the main body of the test chamber and to the heat exchanger. Ducting for the passage of air at both the inlet and the outlet of the heat exchanger shall have entry and exit ports positioned to provide good air recirculation throughout the test chamber. The heat exchanger shall be capable of cooling the air and maintaining it at the specified temperature level. Airflow shall be measured using a suitable anemometer or velocity meter (see also 4.6.4).

4.5.6 Water Supply for Nozzles

Water supplied to nozzles shall conform to ASTM D 1193 Type IV water or a hardness of less than 300 ppm reported as $CaCO_3$.

4.6 Calibration and Measurement Methods

4.6.1 Calibration of Standard Measuring Devices

All temperature sensors, humidity sensors, electronic balances, anemometers, velocity meters, and timing devices shall be maintained in a known state of calibration in accordance with recognized international standards, such as ISO 10012, by calibrating each instrument at least once every six months or whenever a piece of equipment is repaired, replaced, moved, or otherwise suspect. A written record of the calibrations shall be kept available.

4.6.2 Icing Intensity Measurement Methods

The following methods are intended to produce the same results.

4.6.2.1 Icing Intensity Measurement Methods Using Reference Ice-catch Plates or Pans (Method A)

In most cases the icing intensity on a test plate with fluid cannot be measured directly as the fluid and some of the precipitation will flow off of the test plate, preventing the weighing of the total precipitation for the duration of the test. Icing intensity is generally established by catching the precipitation with a specified number of so-called reference ice-catch plates or pans placed adjacent to the test plate and weighing the amount of precipitation for the duration of the test period. At least one example of an appropriate icing intensity measurement method using reference ice-catch plates or pans is given in this ARP for each of the conditions listed (Sections 6 to 12). This one example for each condition is called method A to differentiate it from other icing intensity methods.

4.6.2.2 Icing Intensity Using Regression Analysis (Method B)

An alternative way of measuring icing intensity is to catch the precipitation a number of times at the very position of the test plate before and after the test and average the results. For this method, at least two tests with fluid are performed and endurance times determined at each of the targeted rates. The results are analyzed using regression analysis to determine the endurance time at the targeted rates of precipitation. Examples of the icing intensity using regression analysis (method B) are described in Sections 6, 7, and 9.

4.6.2.3 Other Icing Intensity Measurement Methods

Icing intensity measurement methods may differ from methods described in 4.6.3.1 or 4.6.3.2 depending on the specific configuration of the equipment (e.g., number of ice-catch plates or their geometry) used to create the various precipitation conditions.

4.6.2.4 Documentation

Each facility/site performing endurance time tests shall develop and document appropriate icing intensity measurement methods for each precipitation condition to ensure that the test conditions are within the specified limits. Reports issued by the facility/site shall describe the icing intensity measurement methods and their results.

4.6.3 Measurements Methods for Icing Intensity Variability Across Test Plates

4.6.3.1 Measurement Method for Intensity Variability Across a Test Plate (Used with Method A)

It is important to establish that icing intensity across each test plate is uniform and within specified limits. The icing intensity variability (uniformity or lack of uniformity) across each test plate can be established by periodically replacing the test plates with a specified number of preweighed ice-catch plates, weighing the precipitation, and calculating the range. The range is simply the highest value minus the lowest value and is a quantitative representation of the variability of precipitation data across each plate. This range must not exceed limits that are specified for each test condition. The measurement of the icing intensity variability across a test plate shall be run at least every six months or whenever a piece of equipment is repaired, replaced, moved or otherwise suspect.

4.6.3.2 Measurement Method for Intensity Variability Across All Test Plates (Used with Method B)

This method is described in 6.2.2.3. The measurement of the icing intensity variability across all test plates shall be run every time tests are performed.

4.6.3.3 Other Methods for Measuring Icing Intensity Variability Across Test Plates

A facility/site may have specific equipment that requires a method for estimating the icing intensity variability across test plates other than in 4.6.3.1 or 4.6.3.2. Such other methods are acceptable if they are shown to be equivalent or more conservative.

4.6.4 Horizontal Air Velocity Measurement

Horizontal air velocity shall be measured 50 mm above the surface of the test plate using a velocity meter or anemometer.

4.6.5 Water Droplet Size Measurement

Several methods are available to determine the water droplet size (median volume diameter). Table 1 lists several acceptable methods as a function of droplet size. A description of the methods of follows:

a. Slide Impact Method with Oil: A sample of the water droplets from the precipitation is collected on an oil coated microscope slide. An oil having a viscosity of 5000 mPa.s at 20 °C, spread to an appropriate thickness will be suitable for certain droplet sizes (see Table 1 for appropriate thickness). The oil may be either a mineral oil or silicone oil. The droplet size is determined by direct observation under a microscope using an eyepiece with the appropriate graticle, or from enlarged photographs of the slide.

b. Slide Impact Method with Colloidal Silver: A sample of the water droplets from the precipitation is collected on a microscope slide coated with a colloidal silver solution. A thin film of 95% water and 5% colloidal silver is brushed over a microscope slide. Once the film is dry (about 30 s) it is exposed to the water spray, where it becomes permanently marked with the droplet imprints. The droplet diameter is one third of the print diameter measured under a microscope using an eyepiece with the appropriate graticle or from enlarged photographs of the slide.

TABLE 1 - EXAMPLES OF WATER DROPLET SIZE MEASURING METHODS

Droplet Size	Slide Impact with Oil (Required Oil Thickness)	Slide Impact with Colloidal Silver	Laser Diffraction	Dye Stain
5 µm		recommended		
20 µm	recommended (500 µm)	recommended	recommended	
200 µm	recommended (1000 µm)			recommended
1000 µm	recommended (2000 µm)			recommended

c. Laser Diffraction Method: Using a laser diffraction particle analyzer, incorporating a low power laser transmitter and photo detector, the size of the droplets can be measured as they fall towards the surface of the test plate. Analysis of the diffraction patterns gives the size and the distribution of the droplets. Some equipment is capable of achieving this in real time.

d. Dye Stain Method. Prepare discs by dusting filter paper discs with a water-activated very finely divided powder form of methylene blue dye. The prepared discs are manually positioned under precipitation for a fixed time in order to acquire a droplet size pattern. A calibration curve is then used to convert from the measured diameter of the droplets on the pattern to the experimental median volume diameter.

4.7 General Test Procedures

4.7.1 Test Plate Cleanliness

The test plates shall be free of all visible contamination, smears, or stains, except for markings used to estimate ice coverage. Between test runs, any contamination shall be removed by washing with hot water immediately followed by an ethanol rinse. If the same fluid is tested on the same plate for two or more consecutive tests, it is not necessary to clean the plates with ethanol before the second test; a hot water rinse is sufficient. Allow the plates to dry after rinsing and ensure they are at the appropriate temperature before use.

4.7.2 Appearance of Frozen Contamination

Failure is called when 30% of the plate is covered with frozen contamination. Appearance of this frozen contamination includes, but is not limited to:

a. An ice front

b. An ice sheet

c. Slush, in clusters or as a front

d. Disseminated fine ice crystals

e. Frost on fluid surface

f. Clear ice pieces partially or totally imbedded in fluid

g. Snow bridges on top of the fluid

4.7.3 Delayed Crystallization

Delayed crystallization may occur during the course of a test run (for all precipitation conditions except for snow, which is already crystalline), and is defined as a sudden (within 30 s) appearance of frozen contamination covering a large surface area of a test plate. If this sudden coverage exceeds the percentage of the test plate area that is considered to be a failure, the test is invalid and must be repeated. In the case of suspected delayed crystallization, if the test has been invalidated three times, the plate may be seeded at the center top edge of the plate with an ice crystal to initiate crystallization. Seeding consists of putting an ice crystal in contact with the fluid by means of a chilled metal rod (below 0 °C). If upon seeding, the frozen contamination area suddenly exceeds the percentage of the plate area that is considered to be a failure, the test is invalid.

4.7.4 Report

The report shall include:

a. Name and address of the facility conducting the tests.

b. Statement confirming that the test facility is autonomous of the manufacturer and vendor of the fluid.

c. Date(s) the tests were conducted.

d. Manufacturer’s or vendor's name and address.

e. Name or reference number and lot number of the fluid tested.

f. Type of fluid (SAE Type II, III, or IV) and concentration of the fluid as received and as tested (e.g., received SAE Type IV neat; tested neat; tested diluted 75:25 and 50:50 with hard water).

g. Quantity of fluid applied to test plates, if different from the norm.

h. Summary of test results and the icing intensity results for each test.

i. Icing intensity measurement method including ice-catch raw data.

j. Method of estimation of failure area.

k. Description of appearance of frozen contamination. For natural snow report the form of the snow according to Figure 14.

l. Measurement Method for icing intensity variability across test plates, its results (range), and date performed.

m. Distance from test plates and location of air temperature sensor.

n. For natural outdoor snow tests, orientation of the test stand and direction of the wind.

5. ENDURANCE TIME TEST - FROST

This section is being developed for future versions of this ARP.

6. ENDURANCE TIME TEST - FREEZING FOG

6.1 Freezing Fog Test Equipment and Test Parameters

6.1.1 Environmental Chamber Equipment and Plates

In addition to the requirements given in 4.5, environmental chamber and associated equipment requirements for freezing fog endurance time testing are given in Table 2 and in the following paragraphs.

TABLE 2 - REQUIREMENTS FOR FREEZING FOG TEST EQUIPMENT

Test Parameters	Requirements
Environmental Chamber	
Minimum volume	7 m³ for each 300 mm x 500 mm test plate
Air temperature range	0 °C to at least -25 °C
Minimum temperature sampling rate	1 datum per minute
Horizontal air velocity	≤ 0.4 m/s
Relative humidity	> 40%
Test Plates	
Material	Aluminum alloy AMS 4037 or 4041
Test plate dimensions	500 mm long x 300 mm wide x 3.2 mm thick
Angle	10.0° ± 0.2°
Surface finish	Average surface roughness: Ra ≤ 0.5 µm
Temperature at start of test	Within 0.5 °C of air temperature
Number of test plates	2 per fluid tested
Fluid application temperature	Within 3 °C of the air temperature
Ice-catch Plates (Method A)	
Ice-catch plates	100 mm x 100 mm x 1.6 mm thick
Number of reference ice-catch plates	8 surrounding each test plate
Number of ice-catch plates for measuring icing intensity variability across test plates	12 per test plate
Ice-catch Pans (Method B)	277 mm x 540 mm
Spray Equipment	
Water supply temperature	Adjusted to produce supercooled water droplets
Water droplet median volume diameter	22 µm ± 5 µm

6.1.2 Test Plates

6.1.2.1 Each test plate is removable and placed on a support that is housed within the environmental chamber.

6.1.2.2 Each test plate shall be equipped with a temperature sensor located on the underside of or embedded within the plate. This sensor shall be capable of measuring to an accuracy of ±0.5 °C and shall be linked to an electronic data acquisition system.

6.1.2.3 Method A

The test plate support is setup in such a way that it can accommodate eight ice-catch plates per test plate. The ice-catch plates shall be adjacent to, but not in contact with, each test plate. The test plate support face shall be inclined from the horizontal as specified in Table 2. The test plates shall be placed on the support such that the fluid can freely flow off all edges of the plate. The test stand should be designed as to minimize the contact between the test surface and the support.

6.1.2.4 Method B

The test plate support is set up in such a way that it can accommodate six test plates. The test plate support face shall be inclined from the horizontal as specified in Table 2. The test plates are placed on the support such that the fluid can freely flow off all edges of the plate. The test stand should be designed to minimize the contact between the test surface and the support.

6.1.3 Spray Equipment

6.1.3.1 It is a fundamental requirement of this test that the spray impinges onto the surface of the test plate as supercooled water droplets that freeze on impact. This is verified by observation of an ice-catch plate.

The equipment used to provide the water spray comprises a low flow nozzle supplied with water of quality described in 4.5.6. This equipment is housed in the upper region of the test chamber above the test plate. The exact type and geometry of the spray system used to generate the water spray for the test is left to the discretion of the testing facility, provided the requirements of Table 2 and Table 3 are met.

6.1.4 Example of Spray Equipment

An example of a suitable spray system is as follows: the nozzle comprises two sections, outer and inner units for the respective passage of water and compressed air (Figure 1). The nozzle reciprocates to provide even and reproducible coverage of the test plate at the specified water spray intensity.

6.2 Freezing Fog Measurement Methods

6.2.1 Icing Intensity Measurement Methods

6.2.1.1 For general requirements see 4.6.2.

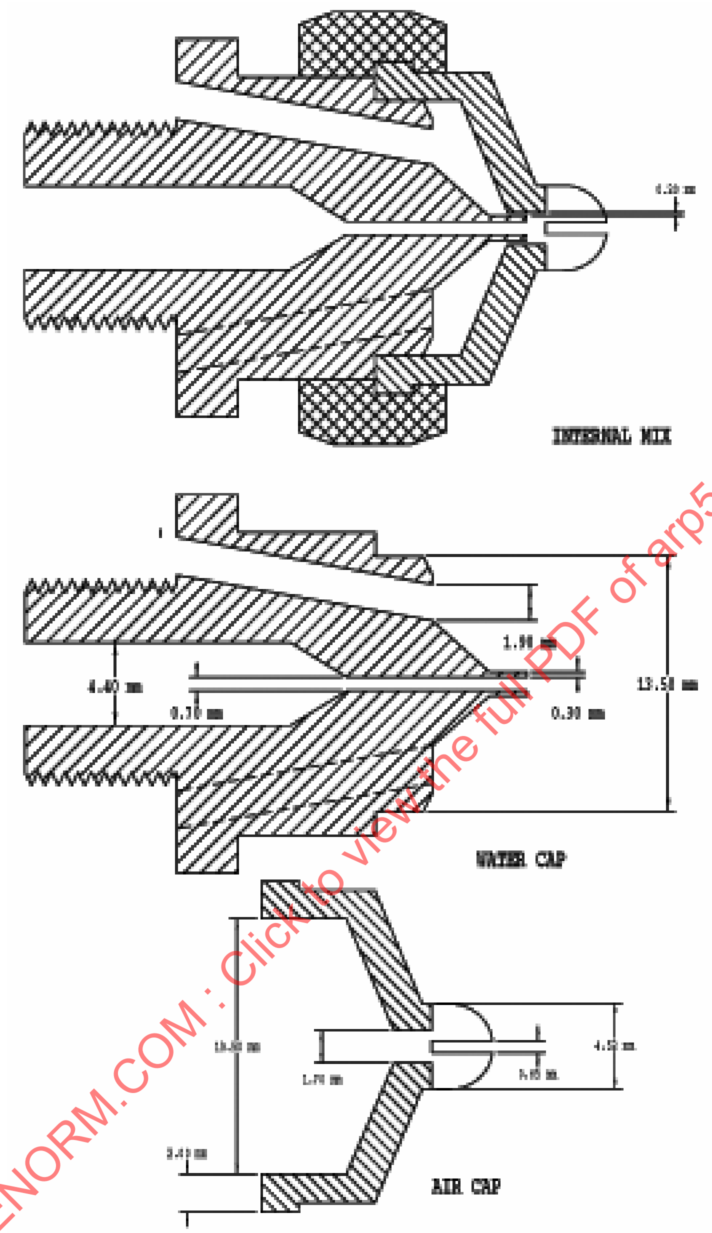

FIGURE 1 - EXAMPLE OF SPRAY NOZZLE FOR FREEZING FOG

6.2.1.2 Method A

Each test plate is replaced with 12 ice-catch plates which in turn are surrounded by eight additional reference ice-catch plates (examples, see Figure 2). All plates are weighed before and after a run made without fluid (so-called calibration run). The ice-catch is recorded for each plate. The average ice-catch of the 12 ice-catch plates replacing a test plate and the average ice-catch of the reference plates are calculated. The ratio of these two averages is calculated using Equation 1.

For a run without fluid (calibration run):

$$\text{Ratio} = I_{plate}/I_{ref} \qquad \text{(Eq. 1)}$$

where:

Ratio = ratio of the ice-catch over the plates replacing the test plate with respect to the ice-catch on the reference plates

I_{plate} = average ice-catch on the ice-catch plates replacing the test plate

I_{ref} = average ice-catch on the reference ice-catch plates surrounding the test plate

The ratio is used to estimate the ice-catch intensity during a test run with fluid when only the reference plates are available. The ice-catch is measured on the reference plates and averaged. This average is multiplied by the ratio calculated above based on the test performed without fluid. The resulting value is reported as the icing intensity over the test plate.

For a run with fluid:

$$I_{plate} = \text{Ratio} \times I_{ref} \qquad \text{(Eq. 2)}$$

where:

I_{plate} = reported intensity of that plate

I_{ref} = average ice-catch on the reference plate surrounding the test plate during the run with fluid

Ratio = see above

Two examples of dispositions of reference ice-catch plates (denoted RA1 to RA8 for plate A and RB1 to RB8 for plate B) each surrounding the 12 ice-catch plates replacing the test plates (A11 to A43 for test plate A and B11 to B43 for test plate B).

FIGURE 2 - ARRANGEMENT OF ICE-CATCH PLATES AND REFERENCE ICE-CATCH PLATES

6.2.1.3 Method B

Icing Intensity Measurement: Initially, place ice-catch pans (27.7 cm x 54 cm) on the test plate support at each test location (typically 12 locations). Each pan is marked with a number identifying the collection location on the test plate support. The individual pans are weighed prior to exposure to precipitation and the weights are recorded. At the start of the ice-catch period, the exact time (hh:mm:ss) is recorded. The pans are then placed on the test plate support for a period of at least 10 min. The pans are re-weighed following this period and the ice-catch rate for each pan (R1) is calculated per Equation 3.

$$R\#=(W_{a1}-W_{b1})/\text{Area-of-pan}*(T_{a1}-T_{b1}) \qquad \text{(Eq. 3)}$$

where:

\# = numerical indicator for ice-catch rate collection period

W_{a1} = eight after of the 1st measurement

W_{b1} = weight before of the 1st measurement

T_{a1} = time at the end of the 1st measurement

T_{b1} = time at the beginning of the 1st measurement

The pans are then weighed and placed on the test plate support for a second collection period and the second ice-catch rate calculated (R2). A fluid test begins following the second ice-catch rate collection period. Following the failure of a test plate, an ice-catch pan placed at the plate location for at least 10 min and the third ice-catch rate is calculated (R3). Another ice-catch is done to get a fourth ice-catch rate (R4). More ice-catch runs before or after a fluid test may be performed at the discretion of the testing agent.

The rate of precipitation (icing intensity) for any location on the stand is calculated by averaging at least two rates measured immediately prior to the test (more than two rates may be run) and at least two rates measured immediately following the test (more than two rates may be run). In order for the test to be valid, the average rate and the standard deviation must be within the limits shown in Table 3.

At a given temperature, two tests are conducted at the lower icing intensity (e.g., FOG -A) and two tests are conducted at the upper icing intensity (e.g., FOG-B). If the endurance time at one of the icing intensities lies outside ±10% from the average, then two additional tests are run, for a total of four data points at that icing intensity. All of the data points are used for the regression analysis - no data points shall be rejected.

The endurance times are obtained by producing a best-fit regression curve using a power law transformation based on all of the data collected at the lower and upper rates. A minimum of four data points are required to generate the regression curve for any fluid, with at least two at each icing intensity.

The equation used to treat the data is as follows:

$$t = cR^a \qquad \text{(Eq. 4)}$$

where:

t = time (minutes)

R = rate of precipitation ($g/dm^2/h$)

a, c = coefficients determined from the regression

The upper and lower fluid endurance time values are determined from the points at which the best-fit curve intersects the lower (e.g., at 2.0 $g/dm^2/h$ for FOG-A) and upper icing intensity (e.g., at 5.0 $g/dm^2/h$ for FOG-B).

Continuous Rate Monitoring: During a test, rates are continuously monitored to ensure that icing intensity remains within specification. One continuous monitoring pan is required when conducting 1 to 6 fluid tests, and two continuous monitoring pans are required for 7 to 12 tests. For this purpose, ice-catch pans are weighed and placed on each designated location. The ice-catch pans are re-weighed at 15 min intervals during the test and the icing intensity calculated using Equation 3 (but with the “R” replaced by “RC”; e.g., RC1 for the first 15 min interval, RC2 for the second 15 min interval, etc.). For any given test to be valid, the continuous rates of the selected monitoring position (including R1, R2, all the RCs, R3 and R4 at this position) must be within 1.5 times the standard deviation limits in Table 3.

6.2.2 Icing Intensity Variability Measurement Methods

6.2.2.1 For general requirements see 4.6.3.

6.2.2.2 Measurement Method for Variability Across a Test Plate (Used with Method A)

The icing intensity variability across a test plate shall be the range of the icing intensities measured for the 12 ice-catch plates in 6.2.1.2 and shall conform to the value of the ”Icing intensity range across a test plate” in Table 3. It shall be done for all test plates.

6.2.2.3 Measurement Method for Variability Across All Test Plates (Used with Method B)

With method B the variability is not measured for a single (divided) plate as it is with method A; rather, it is measured across all of the (undivided) plates for a given period of time. The icing intensity variability across all test plates shall be the range of icing intensities for all R1s (R1 for position 1, R1 for position 2, etc., for all positions) defined in 6.2.1.3. The range of all R1s shall conform to the value of the ”Icing intensity range across test plates” in Table 3. Furthermore, the range of R2s, R3s, and R4s shall also conform to the value of the ”Icing intensity range across test plates” in Table 3. Results from positions not fulfilling this requirement shall not be used.

6.3 Freezing Fog Test Conditions

Test conditions for freezing fog are in Table 3.

TABLE 3 - FREEZING FOG TEST CONDITIONS

Test Condition	FOG-A	FOG-B	FOG-C	FOG-D	FOG-E	FOG-F
Type II, III and IV, neat Types II and IV, 75/25 (neat fluid/hard water) Types II and IV, 50/50 (neat fluid/hard water)	Yes Yes Yes	Yes Yes Yes	Yes Yes No	Yes Yes No	Yes No No	Yes No No
Air temperature, °C	-3 ± 0.5	-3 ± 0.5	-14 ± 0.5	-14 ± 0.5	-25 ± 1	-25 ± 1
Air temperature standard deviation	± 0.3	± 0.3	± 0.3	± 0.3	± 0.5	± 0.5
† Icing intensity, $g/dm^2/h$	2.0 ± 0.2	5.0 ± 0.2	2.0 ± 0.2	5.0 ± 0.2	2.0 ± 0.2	5.0 ± 0.2
‡ Average icing intensity, $g/dm^2/h$	2.0 ± 0.3	5.0 ± 0.4	2.0 ± 0.3	5.0 ± 0.4	2.0 ± 0.3	5.0 ± 0.4
‡ Icing intensity standard deviation	<0.3	<0.4	<0.3	<0.4	<0.3	<0.4
† Icing intensity range across a test plate, $g/dm^2/h$	≤ 0.4	≤ 0.6	≤ 0.4	≤ 0.6	≤ 0.4	≤ 0.6
‡ Icing intensity range across all test plates, $g/dm^2/h$	≤ 1.2	≤ 1.7	≤ 1.2	≤ 1.7	≤ 1.2	≤ 1.7

† Method A
‡ Method B

6.4 Freezing Fog Test Procedure

6.4.1 Test Plate Cleanliness

Clean test plates according to 4.7.1.

6.4.2 Temperature Verification

Ensure the test chamber, fluid and test plates are at the required temperature.

6.4.3 Failure Time

Pour 500 mL of fluid onto each test plate (if more fluid is required, record the quantity of fluid actually used). As soon the fluid has spread over the plates (up to 30 s for Type II, III, and IV fluids), expose to precipitation and start the timing device. Observe the plates and, when the failure occurs (defined in 6.4.6), record the time as the endurance time.

6.4.4 Icing Intensity

After all of the plates have failed, shield the ice-catch plates from precipitation, and weigh the ice-catch on each ice-catch plate; using a method such as described in 6.2.1, estimate the icing intensity for each test plate. If the icing intensity is not within the specified limits Table 3 for the test being conducted, the time recorded is not valid.

6.4.5 Delayed Crystallization

See 4.7.3.

6.4.6 Failure Criterion

Failure is called when 30% of the plate is covered with frozen contamination. Frozen contamination is described in 4.7.2. Pen marks on the plate can be used to estimate the area of failure. For instance, a line drawn across the plate at 150 mm from the top edge will delineate an area corresponding to 30% of the plate.

6.4.7 Reproducibility/Precision

6.4.7.1 Reproducibility/Precision for Method A

The test is dynamic by nature, and small variations can be expected. If the range (highest value minus lowest value) of the endurance time is less than 10% of the average anti-icing endurance time, report the average as the endurance time for that condition. If not, repeat testing on two additional plates, for a total of four data points. The highest and lowest points shall be discarded, and the average of the two remaining points shall be the endurance time for that condition.

6.4.7.2 Reproducibility/Precision for Method B

With this method, data is not rejected but incorporated using regression analysis. See 6.2.1.3.

6.4.8 Report

See 4.7.4.

7. ENDURANCE TIME TEST - FREEZING DRIZZLE

7.1 Freezing Drizzle Test Equipment and Test Parameters

7.1.1 Environmental Chamber Equipment and Plates

In addition to the requirements given in 4.5, environmental chamber and associated equipment requirements for freezing drizzle endurance time testing are given in Table 4 and in the following paragraphs.

TABLE 4 - REQUIREMENTS FOR FREEZING DRIZZLE TEST EQUIPMENT

Test Parameters	Requirements
Environmental Chamber	
Air temperature range	0 to -10 °C
Minimum temperature sampling rate	1 datum per minute
Horizontal air velocity	≤ 1.0 m/s
Relative humidity	> 40%
Test Plates	
Material	Aluminum alloy AMS 4037 or 4041
Test plate dimensions	500 mm long x 300 mm wide x 3.2 mm thick
Angle	10° ± 0.2°
Surface finish	Average surface roughness: Ra = ≤ 0.5 µm
Temperature at start of test	Within ± 0.5 °C of air temperature
Number of test plates	2 per fluid tested
Fluid application temperature	Within 3 °C of the air temperature
† Ice-catch Pans	
Ice-catch pan dimensions	100 mm x 100 mm x 0.8 mm thick with all around rim 15 mm high
Number of reference ice-catch pans	8 surrounding each test plate
Number of ice-catch pans for measuring icing intensity variability across test plates	12 per test plate
Spray Equipment	
Distance between nozzle and test plate	7 m ± 0.5 m
Water supply temperature	≤ 2 °C just before the nozzle
Water droplet median volume diameter	300 µm ± 100 µm

† Method A

7.1.2 Test Plates

7.1.2.1 Each test plate is removable and placed on a support that is housed within the environmental chamber.

7.1.2.2 Each test plate shall be equipped with a temperature sensor located on the underside of, or embedded, within the plate. This sensor shall be capable of measuring to an accuracy of ±0.5 °C and shall be linked to an electronic data acquisition system.

7.1.2.3 The test plate support is set-up in such a way that it can accommodate eight 100 mm x 100 mm ice-catch pans surrounding, but not in contact with, each test plate. The test plate support face shall be inclined from the horizontal (see Table 4 for the angle). The test plates are placed on the support such that the fluid can freely flow off all edges of the plate. The test stand should be designed to minimize the contact between the test surface and the support.

7.1.3 Ice-catch Pans

The ice-catch pans are described in and Figure 3.

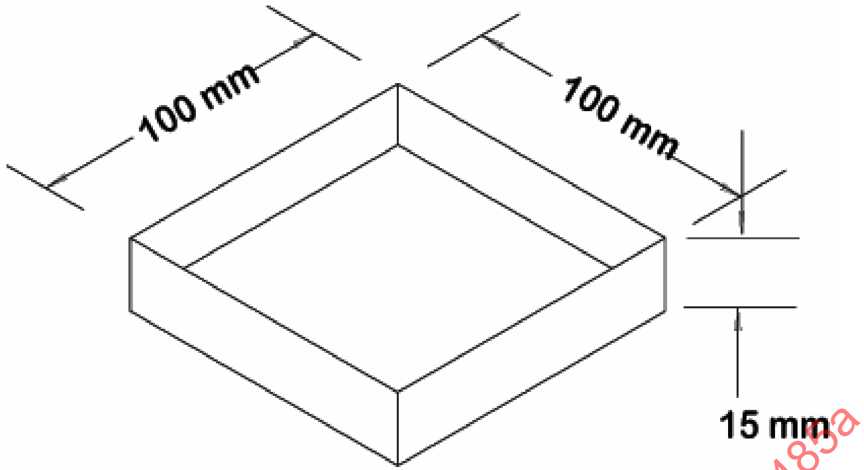

FIGURE 3 - ICE-CATCH PANS

7.1.4 Spray Equipment

7.1.4.1 It is a fundamental requirement of this test that the spray impinges onto the surface of the test plate as supercooled water droplets which freeze on impact. This is verified by observation of an ice-catch pan.

7.1.4.2 The equipment used to provide the water spray comprises a low-flow nozzle supplied with water of quality described in Table 5. This equipment is housed in the upper region of the test chamber above the test plate. The exact type and geometry of the spray system used to generate the water spray for the test is left to the discretion of the testing facility/site, provided the requirements of Table 5 are met.

TABLE 5 - FREEZING DRIZZLE TEST CONDITIONS

Test Condition	ZL-A	ZL-B	ZL-C	ZL-D
Types II III, and IV, neat	Yes	Yes	Yes	Yes
Types II and IV, 75/25 (neat fluid/water)	Yes	Yes	Yes	Yes
Types II and IV, 50/50 (neat fluid/water)	Yes	Yes	No	No
Air temperature, °C	-3 ± 0.5	-3 ± 0.5	-10 ± 0.5	-10 ± 0.5
Air temperature standard deviation, °C	± 0.3	± 0.3	± 0.3	± 0.3
† Icing intensity, $g/dm^2/h$	5 ± 0.2	13 ± 0.5	5 ± 0.2	13 ± 0.5
‡ Average icing intensity, $g/dm^2/h$	5 ± 0.4	13 ± 0.5	5 ± 0.4	13 ± 0.5
‡ Icing intensity standard deviation	< 0.4	< 0.7	< 0.4	< 0.7
† Icing intensity range across a test plate, $g/dm^2/h$	≤ 0.6	≤ 1.4	≤ 0.6	≤ 1.4
‡ Icing intensity range across all test plates, $g/dm^2/h$	≤ 1.4	≤ 2.2	≤ 1.4	≤ 2.2

† Method A
‡ Method B

7.1.5 Example of Spray Equipment

The hydraulic nozzle shown in Figure 4 comprises three sections, an outer unit holding two inner units. Water is stored in a pressurized tank and provides the flow to the nozzle. The water droplet size depends on the nozzle used and the settings on a pulse system which controls the flow of water to the nozzle. The icing intensity is controlled by selecting the opening and closing times (on/off) of the pulse system. An even distribution over the test plate is achieved by a controlled oscillation of the nozzle.

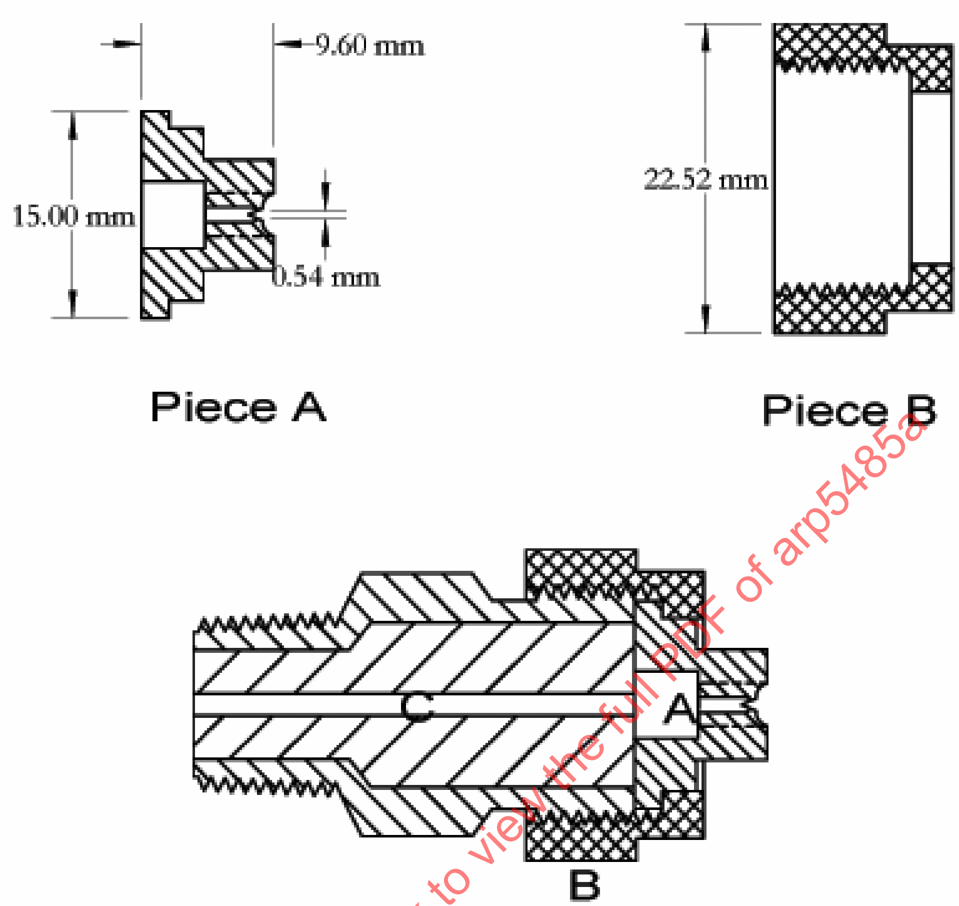

FIGURE 4 - EXAMPLE OF A HYDRAULIC NOZZLE FOR FREEZING DRIZZLE

7.2 Freezing Drizzle Measurement Methods

7.2.1 Measurement Methods for Icing Intensity

The methods are the same as in 6.2.1 except that the ice-catch plates are replaced by ice-catch pans in 6.2.1.2 and that Table 3 is replaced by Table 5 throughout.

7.2.2 Measurement Methods for Icing Intensity Variability Across Test Plates

The methods are the same as in 6.2.2 except that (a) the ice-catch plates are replaced by ice-catch pans in 6.2.2.2 and (b) Table 3 is replaced by Table 5 throughout.

7.3 Freezing Drizzle Test Conditions

Test conditions for freezing drizzle are in Table 5.

7.4 Freezing Drizzle Test Procedure

7.4.1 Test Plate Cleanliness

Clean test plates according to 4.7.1.

7.4.2 Temperature Verification

Ensure the test chamber, fluid and test plates are at the required temperature.

7.4.3 Failure Time

See 6.4.3 except that failure is defined in 7.4.6.

7.4.4 Icing Intensity

After all of the plates have failed, turn off the water spray, and weigh the ice-catch on each ice-catch pan; using a method such as described in 7.2.1, estimate the icing intensity for each test plate. If the icing intensity is not within the specified limits for the test being conducted, the time recorded is not valid.

7.4.5 Delayed Crystallization

See 4.7.3.

7.4.6 Failure Criterion

See 6.4.6.

7.4.7 Reproducibility/Precision

See 6.4.7.

7.4.8 Report

See 4.7.4.

8. ENDURANCE TIME TEST - LIGHT FREEZING RAIN

8.1 Light Freezing Rain Test Equipment and Test Parameters

8.1.1 Environmental Chamber Equipment and Plates

In addition to the requirements given in 4.5, environmental chamber and associated equipment requirements for light freezing rain endurance time testing are given in Table 6 and in the following paragraphs.

TABLE 6 - REQUIREMENTS FOR LIGHT FREEZING RAIN TEST EQUIPMENT

Test Parameters	Requirements
Environmental Chamber	
Air temperature range	0 to -10 °C
Minimum temperature sampling rate	1 datum per minute
Horizontal air velocity	≤ 1.0 m/s
Relative humidity	> 40%
Test Plates	
Material	Aluminum alloy AMS 4037 or 4041
Test plate dimensions	500 mm long x 300 mm wide x 3.2 mm thick
Angle	10° ± 0.2°
Surface finish	Average surface roughness: Ra ≤ 0.5 µm
Temperature at start of test	Within ± 0.5 °C of air temperature
Number of test plates	2 per fluid tested
Fluid application temperature	Within 3 °C of the air temperature
† Ice-catch Pans	
Ice-catch pan dimensions	100 mm x 100 mm x 0.8 mm thick with all around rim 15 mm high
Number of ice-catch pans	8 surrounding each test plate
Number of ice-catch pans for measuring icing intensity variability across test plates	12 per test plate
Spray Equipment	
Distance between nozzle and test plate	7 m ± 0.5 m
Water supply temperature	≤ 2 °C just before the nozzle
Water droplet median volume diameter	1000 µm ± 100 µm

† Method A

8.1.2 Test Plates

8.1.2.1 Each test plate is removable and placed on a support that is housed within the environmental chamber.

8.1.2.2 Each test plate shall be equipped with a temperature sensor located on the underside of, or embedded within, the plate. This sensor shall be capable of measuring to an accuracy of ±0.5 °C and shall be linked to an electronic data acquisition system.

8.1.2.3 The test plate support is set-up in such a way that it can accommodate eight 100 mm x 100 mm ice-catch pans surrounding, but not in contact with, each test plate for Method A. The test plate support face shall be inclined from the horizontal (see Table 6 for the angle). The test plates are placed on the support such that the fluid can freely flow off all edges of the plate. The test stand should be designed to minimize the contact between the test surface and the support.

8.1.3 Ice-catch Pans

The ice-catch pans, described in Table 6 and Figure 3 (for Method A) or Table 2 for Method B, are used to evaluate the ice-catch.

8.1.4 Spray Equipment

8.1.4.1 It is a fundamental requirement of this test that the spray impinges onto the surface of the test plate as supercooled water droplets which freeze on impact. This is verified by observation of an ice-catch pan.

8.1.4.2 The equipment used to provide the water spray comprises a low flow nozzle supplied with water of quality described in 4.5.6. This equipment is housed in the upper region of the test chamber above the test plate. The exact type and geometry of the spray system used to generate the water spray for the test is left to the discretion of the testing facility/site, provided the requirements of Table 6 and Table 7 are met.

8.1.5 Example of Spray Equipment

See 7.1.5.

8.2 Light Freezing Rain Measurement Methods

8.2.1 Measurement Methods for Icing Intensity

The methods are the same as in 6.2.1 except that the ice-catch plates are replaced by ice-catch pans in 6.2.1.2 and that Table 3 is replaced by Table 7 throughout.

8.2.2 Measurement Methods for Icing Intensity Variability Across Test Plates

The method is the same as in 6.2.2 except that (a) the ice-catch plates are replaced by ice-catch pans and (b) Table 3 in 6.2.2.2 is replaced by Table 7.

8.3 Light Freezing Rain Test Conditions

Test conditions for light freezing rain are in Table 7.

TABLE 7 - LIGHT FREEZING RAIN TEST CONDITIONS

Test Condition	LZR-A	LZR-B	LZR-C	LZR-D
Types II III, and IV, neat	Yes	Yes	Yes	Yes
Types II and IV, 75/25 (neat fluid/hard water)	Yes	Yes	Yes	Yes
Types II and IV, 50/50 (neat fluid/hard water)	Yes	Yes	No	No
Air temperature, °C	-3 ± 0.5	-3 ± 0.5	-10 ± 0.5	-10 ± 0.5
Air temperature standard deviation, °C	± 0.3	± 0.3	± 0.3	± 0.3
† Icing intensity, g/dm^2/h	13 ± 0.5	25 ± 1.0	13 ± 0.5	25 ± 1.0
‡ Average icing intensity, g/dm^2/h	13 ± 0.5	25 ± 1.0	13 ± 0.5	25 ± 1.0
‡ Icing intensity standard deviation	< 0.7	< 1.5	< 0.7	<1.5
† Icing intensity range across a test plate, g/dm^2/h	≤ 1.4	≤ 3.0	≤ 1.4	≤ 3.0
‡ Icing intensity range across all test plates, g/dm^2/h	≤ 2.0	≤ 4.0	≤ 2.0	≤ 4.0

† Method A
‡ Method B

8.4 Light Freezing Rain Test Procedure

8.4.1 Test Plate Cleanliness

Clean test plates according to 4.7.1.

8.4.2 Temperature Verification

Ensure the test chamber, fluid, and test plates are at the required temperature.

8.4.3 Failure Time

See 6.4.3.

8.4.4 Icing Intensity

After all the plates have failed, turn off the water spray and weigh the ice-catch on each ice-catch pan; using a method such as described in 7.2.1, estimate the icing intensity for each test plate. If the icing intensity is not within the specified limits for the test being conducted, the time recorded is not valid.

8.4.5 Delayed Crystallization

See 4.7.3.

8.4.6 Failure Criterion

See 6.4.6.

8.4.7 Reproducibility/Precision

See 6.4.7.

8.4.8 Report

See 4.7.4.

9. ENDURANCE TIME TEST - RAIN ON COLD SOAKED WING

9.1 Rain on a Cold-Soaked Wing Test Equipment and Test Parameters

9.1.1 Environmental Chamber Equipment and Plates

In addition to the requirements given in 4.5, environmental chamber and associated equipment requirements for rain on a cold-soaked wing endurance time testing are given in Table 8 and in the following paragraphs.

TABLE 8 - REQUIREMENTS FOR RAIN ON COLD SOAKED WING TEST EQUIPMENT

Test Parameters	Requirements
Environmental Chamber	
Air temperature range	1 °C
Minimum temperature sampling rate	1 datum per minute
Horizontal air velocity	≤ 1.0 m/s
Relative humidity	> 40%
Test Plates	
Material	Aluminum alloy AMS 4037 or 4041
Test plate dimensions	500 mm long x 300 mm wide x 3.2 mm thick
Angle	10° ± 0.2°
Surface finish	Average surface roughness: Ra ≤ 0.5 µm
Number of test plates	2 per fluid tested
Fluid application temperature	Within 3 °C of the air temperature
Ice-catch Pans (Method A)	
Ice-catch pan dimensions	100 mm x 100 mm x 0.8 mm thick with all around rim 15 mm high
Number of reference ice-catch pans	8 surrounding each test plate
Cold Soak Box	
Material	Aluminum alloy AMS 4037 or 4041
Material Thickness	1.6 mm
Dimensions	430 mm x 300 mm x 75 mm
Coolant in box	65% propylene glycol, 35% water
Spray Equipment	
Distance between nozzle and test plate	7 m ± 0.5 m
Water supply temperature	≤ 2 °C just before the nozzle

9.1.2 Test Plates

Each test area is either the upper surface of the cold-soak box or a removable test plate centered on the face of the cold soak box (Figure 5). If a removable test plate is used, a 65/35 propylene glycol/water solution is spread between the cold soak box and the test plate to improve thermal conductivity between the cold soak box and the test plate. During the course of a test run, the test plate is surrounded by eight reference ice-catch pans (Method A). Both the test plate and the cold soak box are housed within the test chamber.

9.1.3 Cold Soak Box

Before starting the test, the cold soaked box (Figure 5) must be filled with coolant and both the box and its coolant must be at the pre-start temperature (see Table 9). It is acceptable to either refrigerate the box and its (static) coolant or circulate refrigerated coolant at an appropriate temperature to achieve the pre-start temperature. The cold box shall be insulated (except for the test surface) with a 25 mm polystyrene jacket (RSI = 0.88(R value of Thermal Resistance Système International)). The box shall be equipped with a temperature sensing device capable of measuring the temperature of the test plate with an accuracy of ±0.5 °C and situated within the test plate, 150 mm from the top and 150 mm from the side of the plate. This temperature sensor shall be linked to a data acquisition system to check and record the test plate temperature throughout the course of a test run. The cold soaked box face shall be inclined from horizontal (see Table 8 for the angle). The test plate is positioned on the box so that fluid can freely flow off all edges of the plate.

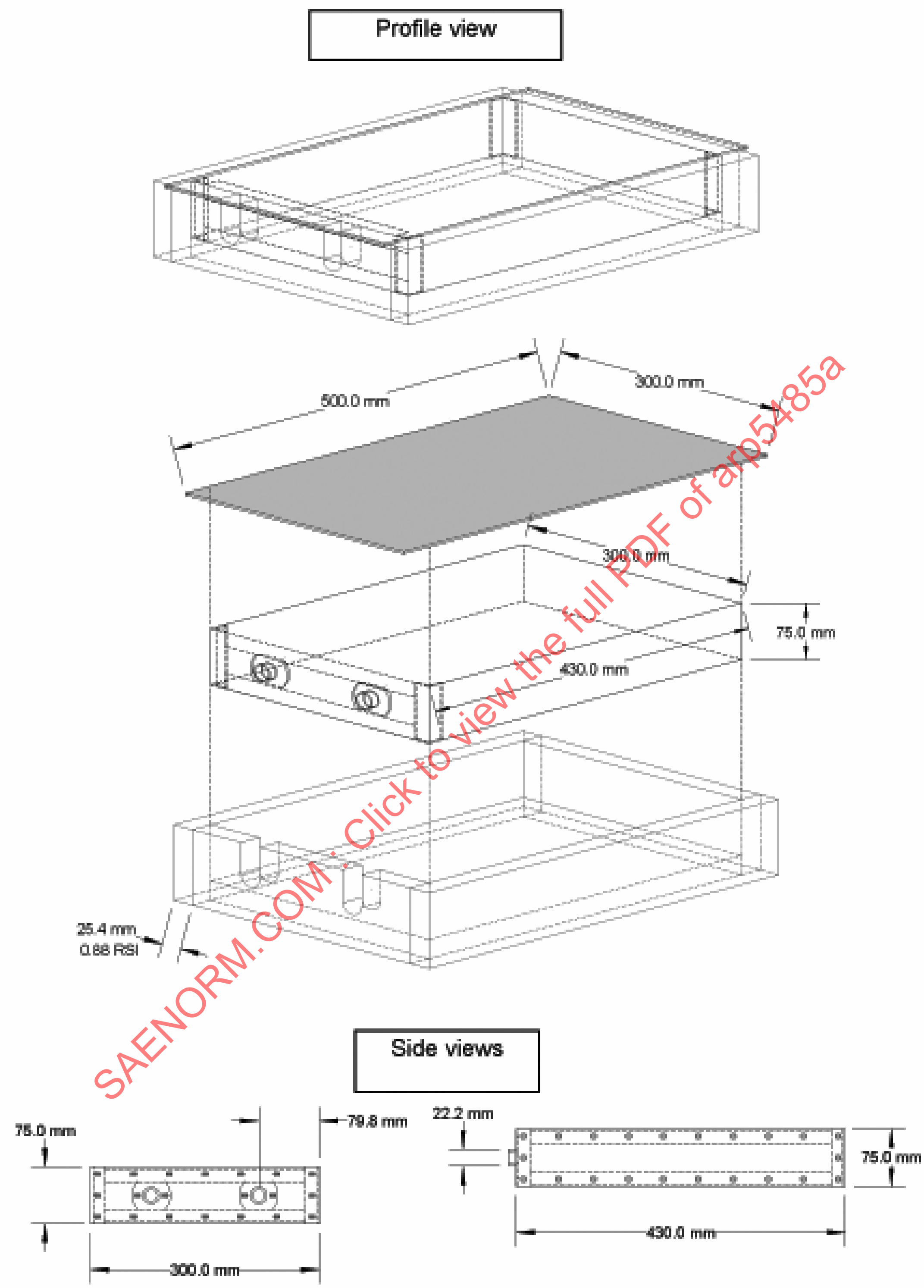

FIGURE 5 - COLD SOAK BOX

9.1.4 Spray Equipment

The equipment used to provide the water spray comprises a low flow nozzle supplied with water of quality described in Table 8. This equipment is housed in the upper region of the test chamber above the test plate. The exact type and geometry of the spray system used to generate the water spray for the test is left to the discretion of the testing facility/site, provided the requirements of Table 8 and Table 9 are met.

9.1.5 Example of Spray Equipment

See 7.1.5.

9.2 Measurement Methods for Rain on a Cold-Soaked Wing

9.2.1 Measurement Methods for Icing Intensity

The methods are the same as in 6.2.1 except that the ice-catch plates are replaced by ice-catch pans in 6.2.1.2 and that Table 3 is replaced by Table 7 throughout.

9.2.2 Measurement Method for Icing Intensity Variability Across Test Plates

The method is the same as in 6.2.2 except that: (a) the ice-catch plates are replaced by ice-catch pans, and (b) Table 3 in 6.2.2.2 is replaced by Table 9.

9.3 Rain on a Cold-Soaked Wing Test Conditions

Test conditions for rain on a cold-soaked wing are in Table 9.

TABLE 9 - RAIN ON COLD SOAKED WING TEST CONDITIONS

Test Condition	RCSW-A	RCSW-B
Types II III, and IV, neat	Yes	Yes
Types II and IV, 75/25 (neat fluid/hard water)	Yes	Yes
Types II and IV, 50/50 (neat fluid/hard water)	No	No
Air temperature, °C	1 ± 0.5	1 ± 0.5
Air temperature standard deviation, °C	± 0.3	± 0.3
Test plate temperature at start, °C	-10 ± 1	-10 ± 1
Pre-start coolant temperature, °C	-12 ± 1	-12 ± 1
Water droplet median volume diameter	300 μm ± 100	1400 μm ± 150
† Icing intensity, $g/dm^2/h$	5.0 ± 0.2	75.0 ± 3.0
‡ Average icing intensity, $g/dm^2/h$	5.0 ± 0.4	75.0 ± 3.0
‡ Icing intensity standard deviation	< 0.4	< 4.5
† Icing intensity range across a test plate, $g/dm^2/h$	≤ 0.6	≤ 9.0
‡ Icing intensity range across all test plates, $g/dm^2/h$	≤ 1.2	≤ 15

† Method A
‡ Method B

9.4 Rain on Cold Soaked Wing Test Procedure

9.4.1 Test Plate Cleanliness

Clean test plates according to 4.7.1.

9.4.2 Temperature Verification

Prior to the start of a test, ensure that the test chamber and fluid are at the required temperatures. Ensure that the cold soak box and its coolant are at the pre-start temperature. Place both paper towels and a cover over the test plate and the ice-catch pan to prevent any accumulation of ice.

9.4.3 Failure Time

Wait for the temperature of the test plate (or, if no test plate is used, the cold box upper surface) to be at the start temperature. When the start temperature is reached, remove the paper towels and cover. Continue as in 6.4.3.

9.4.4 Icing Intensity

After all the plates have failed, turn off the water spray, and weigh the ice-catch on each ice-catch pan; using a method such as described in 7.2.1, estimate the icing intensity for each test plate. If the icing intensity is not within the specified limits for the test being conducted, the time recorded not valid.

9.4.5 Delayed Crystallization

See 4.7.3.

9.4.6 Failure Criterion

See 6.4.6.

9.4.7 Reproducibility/Precision

See 6.4.7.

9.4.8 Report

See 4.7.4.

10. ENDURANCE TIME TEST - INDOOR LABORATORY SNOW

10.1 Inside Snow Test Equipment and Test Parameters

10.1.1 Environmental Chamber Equipment and Plates

In addition to the requirements given in 4.5, environmental chamber and associated equipment requirements for laboratory snow endurance time testing are given in Table 10 and in the following paragraphs.

TABLE 10 - REQUIREMENTS FOR INDOOR SNOW TEST EQUIPMENT

Test Parameters	Requirements	
Environmental Chamber		
Air temperature range	-25 to 0 °C	
Minimum temperature sampling rate	1 datum per minute	
Horizontal air velocity	≤ 1 m/s	
Relative humidity	Rh ¨> 40 % (For Example 1: 40 % < Rh < 75%)	
Test Plates		
Material	Aluminum alloy AMS 4037 or 4041	
Test plate dimensions	500 mm long x 300 mm wide x 3.2 mm thick	
Angle	10.0° ± 0.2°	
Surface finish	Average surface roughness: Ra ≤ 0.5 µm	
Number of test plates	2 per fluid per test condition	
Fluid application temperature	Within 3 °C of air	
Snow Catch Pans	**Example 1**	**Example 2**
Snow catch pan dimensions	100 mm x 150 mm x 0.8 mm thick with all around rim 15 mm high	150 mm x 167 mm x 0.8 mm thick with all round rim of 15 mm high
Number of snow catch pans for measuring snow intensity variability across test plates	10 per test plate	6 per test plate

10.1.2 Test Plates and Test Stand

10.1.2.1 Each test plate is removable and placed on a support that is housed within the environmental chamber.

10.1.2.2 Each test plate shall be equipped with a temperature sensor located on the underside of, or embedded within, the plate in the center, 1/3 of the way down. This sensor shall be capable of measuring to an accuracy of ±0.5 °C and shall be linked to an electronic data acquisition system. Each test plate shall be equipped with temperature control equipment that is capable of meeting the requirements of Table 11. Typically, this consists of a silicon rubber flexible heating sheet pad that covers most of the underside of the test plate.

10.1.2.3 The test plate support face shall be inclined from the horizontal (see Table 10 for the angle). The test plates are placed on the support such that the fluid can freely flow off all edges of the plate and be collected, along with the incoming precipitation, into a pan (Figure 6). The pan rests on a balance capable of recording the weight of the fluid and incoming snow throughout the test. The balance is then used to measure, and, along with a computer control program, control the rate of snow falling to meet the prescribed rates of Table 11.

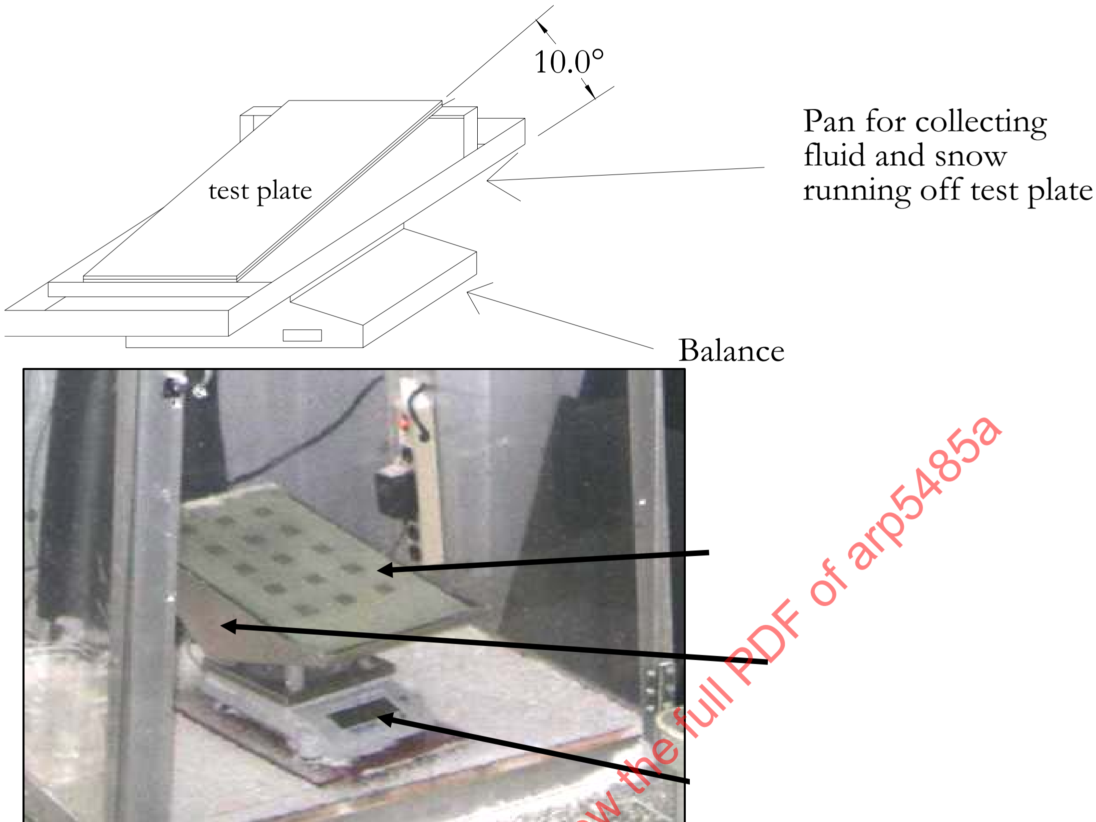

FIGURE 6 - EXAMPLES OF TEST PLATE SUPPORT WITH CATCH PAN AND BALANCE

10.1.3 Test Plate Temperature

Several years of testing have indicated that in order to get a reasonable correlation between indoor and outdoor endurance times, the temperature of the test plate needs to be controlled. Research has shown that the best correlation between indoor and outdoor results is achieved when the plate temperature is set according to the following equation:

$$P_T = T_T - 0.065 * I_I - 0.5 \quad \text{(Eq. 5)}$$

where:

P_T = plate temperature in °C

T_T = test condition temperature in °C

I_I = icing intensity (g/dm²/h)

The test values indicated in Table 11 are calculated using the above equation.

10.1.3.1 Testing Above 0 °C

Theoretically, testing above 0 °C cannot be performed in an indoor laboratory setting since the snow would melt before falling onto the test plate. Such a condition occurs in the real world since the air above may be colder and the fluid will fail since the surface on which the snow falls may be, or become, colder as a result of Equation 5. Therefore, to simulate this condition in a cold room (SNW-A and SNW-B in Table 11) the cold room is set at its warmest without melting the snow (-5 °C) and the plate temperature is set according to Equation 5 for a test condition temperature of 0 °C, around -1 °C, the warmest possible that will allow the fluid to eventually fail.

10.1.4 Snow Sources

10.1.4.1 The precipitation may be natural or laboratory-made simulated snow. Laboratory-made snow shall be made with deionized water. The snow shall be in the form of solid crystals and have a density of less than 0.25 g/cm^2 measured according to 10.2. It shall show no signs of sintering, agglomeration or recrystallization (if stored, sintering may occur within seven days depending on the form of the snow crystals and storage conditions).

10.1.4.2 The method for collecting natural snow or the method for making laboratory snow is left to the discretion of the facility/site as long as the requirements of 10.1.4.1 are met. Examples of such snowmaking, and snow distribution, can be found below.

10.1.5 Snow Distribution System

10.1.5.1 Configuration Requirements

For tests on Type, II, III, and IV fluids, the configuration of the snow distribution system is left to the discretion of the facility/site as long as all the parameters shown in Table 11 are satisfied.

10.1.6 Example 1: Snow Making, Storage and Distribution System

10.1.6.1 General

For this method, the system can be divided into three parts: snow making, snow storage, and systematic distribution of the snow onto the test plates.

10.1.6.2 The artificial snow is made using a fine water spray which freezes in the air to produce an artificial soft rime. The exact type and geometry used to generate the water spray is left to the discretion of the testing facility/site, provided the artificial snow made has a density of less than 0.25 g/cm^3 when measured according to 10.2.1.

10.1.6.3 Example of an Artificial Snow Making Method

The artificial snow is made in a cold chamber by means of two pneumatic water spray nozzles supplied with water and compressed air. The nozzles produce a spray of very fine water droplets which become supercooled in cold air and freeze to form solid ice crystals on a collection plate on the chamber floor.

10.1.6.4 Typical parameters are:

a. Air temperature: -20 °C ± 5 °C

b. Water droplet size: Median volumetric diameter, MVD = 22 µm ± 3 µm

c. Water flow rate to nozzle: 70 mL/min

d. Air pressure to nozzle: 260 kPa

10.1.6.5 Artificial Snow Storage

The laboratory-made snow shall be stored in an insulating container kept in a freezer at a temperature below -10 °C for no longer than 2 weeks prior to testing. The snow quality shall be verified prior to each test by means of a density measurement described in 10.2. If the artificial snow shows any evidence of sintering, agglomeration or crystallization, it shall not be used.

10.1.6.6 Artificial Snow Distribution

Once the snow has been made and stored it must be evenly distributed over the test plates. The exact method used is left to the discretion of the test facility, but must meet the allowed variations presented in Table 11.

10.1.6.7 Example of an Artificial Snow Distribution System

For the snow tests, the snow is distributed as ice particles in the form of clusters to obtain the desired range. The snow is placed in a U-shaped aluminum box, 320 mm long, 253 mm high and 132 mm wide at the top, with a 65 mm high drawer at the top with a sliding base which allows the addition of snow in between and during tests (Figure 8). The box is suspended from a track around 336 mm above the bottom of the test plate (Figure 7). The track is attached to a motor which provides the lateral movement of the snow box. The lateral displacement speed depends on the desired snow intensity. The snow is continually stirred inside the box by a rotating system consisting of three blades disposed at 120 degree angles from each other (Figure 8). Each blade measures 50 mm x 300 mm and consists of a frame housing a wire mesh. The continued rotation of the blades prevents clumping of the snow prior to dispensing. The box contains an opening at the base, 10 mm wide along the length of the box. This opening houses a 32 mm diameter cylinder to transfer snow from the box to the test plate, which contains cavities arranged in 6 rows at 60 degree spacing (Figure 9). The cylinder turns after a given time interval thus dispensing snow clusters onto the test plate. The rotation speed of the cylinder is adjusted by the computer control to obtain the desired snow intensity.

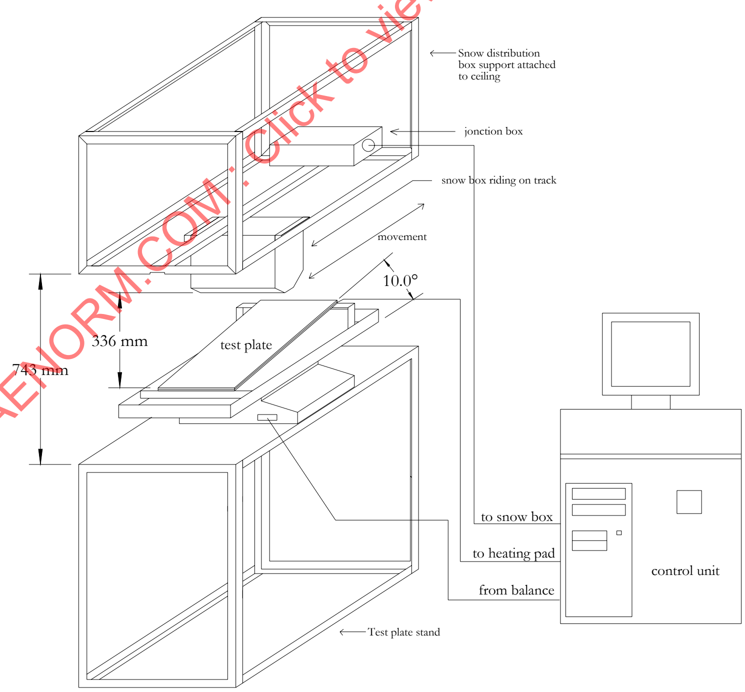

FIGURE 7 - SNOW BOX DISTRIBUTION SYSTEM

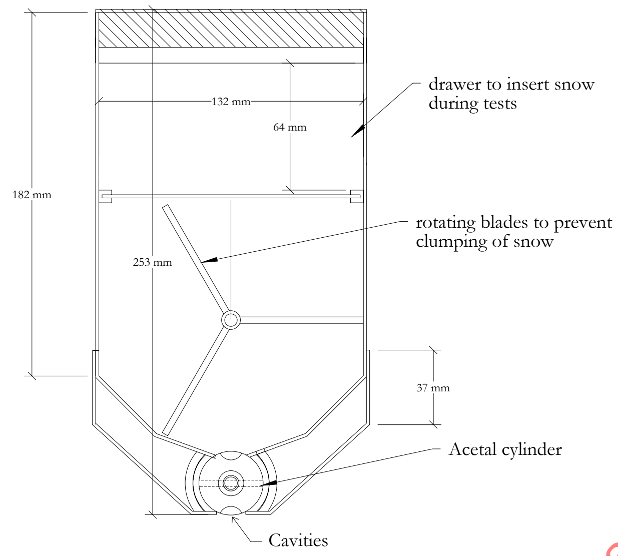

FIGURE 8 - CROSS-SECTION OF SNOW BOX

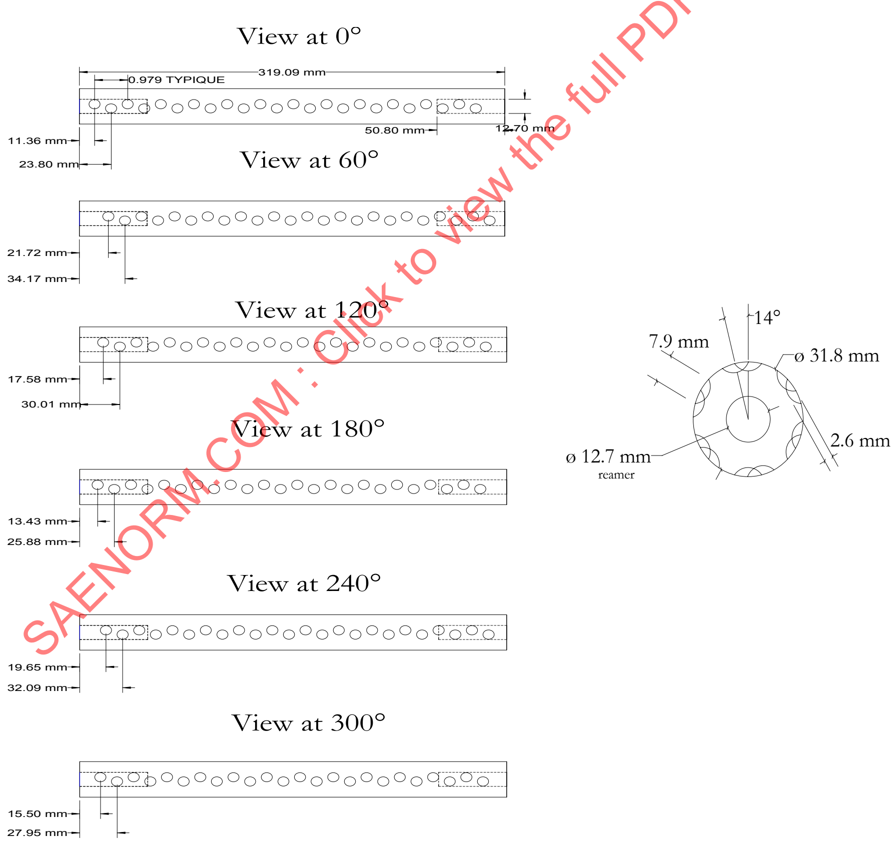

FIGURE 9 - SIDE VIEWS AND CROSS SECTION OF ACETAL CYLINDER WITH 6 ROWS OF 24 CAVITIES WHICH TRANSFER SNOW FROM THE BOX TO THE TEST PLATE

10.1.7 Example 2: Simultaneous Artificial Snow Making and Fluid Testing System

10.1.7.1 General

The artificial snow generating system described here generates artificial snow at the same time as the fluid test by mechanically shaving a deionized water ice core inside an enclosure measuring approximately 3 m tall (Figure 10). The length and width are trapezoidal with the top of the machine being smaller in dimension than the bottom of the machine. The shaving is accomplished with a 7.5 cm diameter drill bit (or potentially larger) rotating between 620 and 3100 rpm. The drill bit is wider than the typically 6 cm diameter ice core. The ice core is fed with a horizontally oriented constant speed translator into the rotating drill bit. Ice shavings are produced with a snow density less than 0.10 g/cm³. The snow density is measured by allowing the snow to build up on the plate to about 1 cm, and then measuring the depth at various locations and weighing the mass (method of 10.2.2). The size of the ice shavings should be between 0.5 and 10 mm in order to simulate natural snow. The distance between the ice core and the test plates must be greater than 1.5 meters in order to achieve a more even snowfall distribution across the test plate. Icing intensity (snowfall rates) up to 50 g/dm^2/h can be generated controlling the speed of the ice core translator with a digitally controlled stepper motor. Only one test plate can be tested at a time with this system due to the limited dispersion of the snow. Snow is concentrated onto the test plate by hollow semi-cylindrical panels positioned above and perpendicular to the spread of ice core shavings produce by the drill bit. The lower portion of the hollow panels is perforated, and a positive air flow is maintained out of the perforations through the use of two fans contained within either side of the panels. The positive air flow is maintained to prevent the build up of snow on the panels. A wiper blade assembly is also used to clean the lower portion of the panels every few seconds. This latter system is needed to prevent snow buildup for the -3 °C tests. Typical horizontal distance of the deflector panels from the snow generation point is 10 cm. To aid in the production of a uniform snow distribution, the snow could be dispersed with air from air jets placed throughout the enclosure or other methods.

FIGURE 10 - EXAMPLE OF A SIMULTANEOUS ARTIFICIAL SNOW MACHINE AND FLUID TESTING SYSTEM