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AEROSPACE RECOMMENDED PRACTICE

ARP5945

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Endurance Time Tests for Aircraft Deicing/Anti-icing Fluids SAE Type I

RATIONALE

The purpose of ARP5945 is to provide the sample selection and endurance time test procedures for SAE Type I 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. The document was previously balloted and comments were received from the SAE G-12 Holdover Time Subcommittee. This document consists of the revised ARP5945.

FOREWORD

This document describes the procedures to be employed in the conduct of endurance time testing of aircraft deicing/anti-icing fluids certified under requirements of AMS 1424.

Endurance time is defined as the time that a fluid can endure controlled and defined temperature and freezing precipitation conditions before attaining visual failure. These temperature and precipitation conditions were developed taking into consideration meteorological data. The resulting endurance time data are presented to the SAE G-12 Holdover Time Subcommittee for examination and validation. If found to be of acceptable quality, these data are used to update the holdover time (HOT) guidelines, which are used by many of the world's airlines in assessing the time of effectiveness of aircraft anti-icing fluids. HOT guidelines are published in regulatory documents such as the U.S. Federal Aviation Administration's Flight Standards Information Bulletin for Air Transportation (FSAT) and Transport Canada HOT Guidelines. Other organizations, including the Association of European Airlines (AEA), publish HOT guidelines derived from endurance time data.

In prior years, fluids were tested in a laboratory environment that was similar to outdoor natural conditions in order to generate the data from which HOT guidelines were formulated. These laboratory methods evolved over several years and had been tacitly accepted. This Aerospace Recommended Practice (ARP) provides written documentation of the procedures to be employed for laboratory endurance time testing in freezing fog, freezing drizzle, light freezing rain, and rain on a cold-soaked wing conditions.

Frost holdover times are currently based on the high humidity endurance test described in AS5901. A frost test is being developed and will be included in future versions of this document.

Prior to the year 2000, the Type I fluid HOT range used by operators worldwide in snow conditions was 6 to 15 min, based on early substantiation tests carried out by several organizations. During the 1999-2000 winter, a series of Type I fluid endurance time tests in natural snow were performed using a natural snow test protocol similar to that included within ARP5485, which was developed for testing SAE Type II, Type III, and Type IV fluids. These Type I fluid endurance time data suggested that the snow HOT range for Type I fluid was lower than the 6 to 15 min HOT range. Subsequently, at the SAE G-12 Holdover Time Subcommittee meeting in Toulouse, France in May 2000, the SAE Type I HOT range for snow was reduced to values significantly shorter than 6 to 15 min. The reduction in fluid endurance times coincided with the general realization that the test protocol for Type I endurance times required further verification.

As a result, a new test protocol was developed for measuring endurance times for SAE Type I fluids that more closely reflects real field operations. The new protocol simulates the full nature of actual deicing/anti-icing operations on real wings in the natural environment. This new protocol employs a new test surface that provides a thermal equivalent to an aircraft wing leading edge. This test surface produces a more accurate representation of the temperature decay rate demonstrated by wings following application of heated Type I fluids in natural outdoor conditions.

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This ARP contains the natural snow endurance time test protocol that was developed for use in the time subsequent to the May 2000 Toulouse SAE G-12 meetings, as described in the above paragraph. A future version of this ARP will contain the laboratory snow test methods that have been developed and are being incorporated into ARP5485.

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1. SCOPE

1.1 Purpose

The purpose of this ARP is to provide the sample selection criteria and test procedures for SAE Type I 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.

A significant body of previous research and testing has indicated that all Type I fluids formulated with glycol perform in a similar manner from an endurance time perspective. This applies to Type I deicing/anti-icing fluids formulated with propylene glycol, ethylene glycol, and diethylene glycol only. Type I deicing/anti-icing fluids containing these glycol bases no longer require testing for endurance times. The methods described in this ARP shall be employed, however, if endurance time testing of a glycol-based Type I deicing/anti-icing fluid is desired or requested by a fluid manufacturer, operator or other organization. Fluids formulated with glycol bases other than those listed herein, and all non-glycol Type I deicing/anti-icing fluids, must be tested for endurance times using the methods described in this ARP (as appropriate).

1.2 Examination of Endurance Time Data

Periodically, the SAE G-12 Holdover Time Subcommittee examines endurance time test data of SAE Type I aircraft deicing/anti-icing fluids and validates, based on the endurance time data, if such fluids can be used in conjunction with generic Type I HOT 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 HOT guidelines.

1.3 Limits

This ARP provides criteria for the laboratory simulation of freezing fog, freezing drizzle, light freezing rain, and rain on a cold-soaked wing. It also describes test conditions for outdoor natural snow tests. Other forms of freezing/frozen precipitation are not addressed in this ARP.

1.4 Testing Agent(s)

1.4.1 Independence of the Testing Agent

The testing agent shall be independent of the fluid manufacturer or 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) and, as required, the testing agent may conduct endurance time testing at a suitable facility on the selected fluid.

1.4.3 Sending Samples

Fluid samples for testing shall be sent to a designated 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 Facility/Site

1.5.1 Independence of the Test Facility/Site

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

1.5.2 Role of the 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 International System (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
ARP5485	Endurance Time Tests for Aircraft Deicing/Anti-Icing Fluids SAE Type II, III, and IV
AS5900	Standard Test Method for Aerodynamic Acceptance of SAE AMS 1424 and SAE AMS 1428 Aircraft Deicing/Anti-Icing Fluids
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 4037	Aluminum Alloy, Sheet and Plate, 4.4Cu - 1.5Mg - 0.6Mn (2024; -T3 Flat Sheet, -T351 Plate) Solution Heat Treated
AMS 4041	Aluminum Alloy, Alclad Sheet and Plate, 4.4Cu - 1.5Mg - 0.60Mn Alclad 2024 and 1-1/2% Alclad 2024, -T3 Flat Sheet; 1-1/2% Alclad 2024-T351 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.

TP 12899E Validation of Methodology for Simulating a Cold-Soaked Wing

TP 13827E SAE Type I Fluid Endurance Time Test Protocol

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

TP 13994E Generation of Holdover Times Using the New Type I Fluid Test Protocol

2.5 U.S. Federal Aviation Administration Documents

Flight Standards Information Bulletin for Air Transportation, FAA Approved Deicing Program Updates, Winter 2004-2005, FAA Bulletin number FSAT 04-05 (this document is updated in October of each year).

2.6 Other Applicable References

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. (English translation: Procedure for the Determination of Fog and Cloud Droplet Dimensions).

Godard, S. (1960), Mesure des gouttelettes de nuage avec un film de collargol. Bulletin de l'observation du Puy de Dôme, pp. 41-46. (English translation: Measurement of Cloud Droplets using a Colloidal Film).

Mason, B.J. (1971), *Physics of Clouds,* 2nd edition. Oxford University Press, pp. 607.

Guide to Meteorological Instruments and Methods of Observation, World Meteorological Organization (1983).

3. SAE TYPE I FLUID SAMPLES ELIGIBLE FOR ENDURANCE TIME TESTING

3.1 Requirements

3.1.1 Normal Batch

The sample shall be fluid taken from a production batch in a form normally supplied by the vendor.

3.1.2 Ready-to-Use Fluid

If the fluid is intended for use undiluted (ready-to-use), the water spray endurance time (WSET) test results of the sheared sample must not be less than 3 min. (In the normal qualification process, the WSET is performed on fluids that have been sheared in accordance with the methods outlined in paragraph 3.3.4 of AMS 1424 for anti-icing performance tests. To ensure the candidate fluid fulfills the normal requirement of qualification, its WSET must be conducted on a sheared sample.)

3.1.3 Fluid Concentrate

If the fluid is intended for use as a dilution of a concentrate, the WSET result (as defined in AS5901) of a sheared 50/50 volume ratio of fluid and hard water (see 3.1.4) must not be less than 3 min.

3.1.4 Composition of Hard Water

To make hard water, the following procedure shall be used: Dissolve 400 mg ± 5 calcium acetate dihydrate $Ca(C_2H_3O_2)_2.2H_2O$ and 280 mg ± 5 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).

3.1.5 Manufacturer's Documentation

The fluid manufacturer shall send or make available the following documentation to the designated testing agent:

a. The AMS 1424 certificates of conformance of the fluid (to ensure that the fluid is fully qualified).

b. The volume dilution versus freezing point data for the fluid (data needed to prepare the dilutions).

c. The freezing point versus refraction at 20 °C data for the fluid (to check the correctness of dilutions).

d. A manufacturer’s safety data sheet (MSDS) and/or other safety related documentation as deemed appropriate.

3.2 Testing Agent Duties

3.2.1 Conduct WSET and Report WSET Results for Ready-to-Use-Fluid

If the fluid is intended for use undiluted, the designated testing agent shall:

a. Perform a WSET on the sheared sample.

b. Report the results to the manufacturer prior to conducting any endurance time testing.

3.2.2 Conduct WSET and Report WSET Results on Fluid Concentrate

If the fluid is intended for use diluted, the designated testing agent shall:

a. Dilute the sample 50/50 by volume with hard water (see 3.1.4).

b. Conduct the WSET on the sheared, diluted fluid sample.

c. Report the results to the manufacturer prior to running any endurance time testing.

3.2.3 Check Documentation

The designated testing agent shall make sure that it has on hand the manufacturer's documentation described in 3.1.5.

3.2.4 Check WSET

The designated testing agent shall ensure that only fluids with WSET results no less than three minutes are passed on for endurance time testing.

3.3 Authorization to Proceed with Endurance Time Testing

3.3.1 Manufacturer's Authorization to Proceed

After reviewing the results of 3.2.1 or 3.2.2, the fluid manufacturer (if desirous of proceeding with endurance time tests) shall send to the designated testing agent authorization to proceed.

3.3.2 Final Check

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

3.4 Condition of the Sample to be Tested for Endurance Times

3.4.1 Freezing Point

The sample shall be tested at dilutions where the freezing point is 10 °C below the air temperature. The dilutions shall be prepared by the designated testing facility using hard water (see 3.1.4).

3.4.2 Lowest Test Temperature

The test temperature shall not be lower than the lowest temperature associated with acceptable aerodynamic performance in accordance with AS5900, as reported in the certificate of conformance provided to the designated testing agent as part of the manufacturer's documentation. There is no reason to test below the lowest aerodynamic acceptance temperature of the fluid. Testing may be conducted below the lowest temperature with acceptable aerodynamic performance, but the fluid can't be used below this temperature.

3.4.3 Shear Level of Fluids Employed in Endurance Time Testing

Fluids whose sheared samples have met the WSET requirements of 3.1.2 or 3.1.3 may be tested for endurance times. The fluid shall be sheared in accordance with the methods outlined in paragraph 3.3.4 of AMS 1424 for use in endurance time testing.

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 endurance time tests of aircraft deicing/anti-icing fluids under conditions of freezing fog, freezing drizzle, light freezing rain, and rain on a 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 I fluids.

This section does not apply to natural snow testing (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, snow, freezing drizzle, light freezing rain, and rain on a cold-soaked wing conditions. 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 many or all conditions (except where otherwise noted). Sections 5 to 10 establish the specific requirements for each precipitation condition.

4.4 Facility/Site Qualification

Substantiation that the 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 a temperature control system such as a solid state temperature sensor with 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 6 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 (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 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 is given in this ARP for each of the conditions listed (Sections 6 to 11). This one example for each condition is called Method A to differentiate it from other icing intensity methods.

4.6.2.2 Icing Intensity Measurement Method 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, called Method B, 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 icing intensity using regression analysis are described in Sections 6, 8, 9, and 10.

4.6.2.3 Other Icing Intensity Measurement Methods

Icing intensity measurement methods may differ from methods described in 4.6.2.1 or 4.6.2.2 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 Measurement 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) across each test plate can be established by periodically replacing the test plates with a specified number of pre-weighed 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 6 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 the test plate support 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 differently 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 Table 1 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 graticule 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 graticule or from enlarged photographs of the slide.

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.

TABLE 1 - EXAMPLES OF WATER DROPLET SIZE MEASURING METHODS

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

X denotes a recommended method

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 rinse 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 area 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 the treated 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 I) and dilution tested (e.g., received SAE Type I concentrate; tested diluted 1:1 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 9.

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

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

n. For natural 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	20 °C ± 5 °C
† Ice-catch Plates	
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	
Ice-catch pans	277 mm x 540 mm
Number of ice-catch pans	1 per test location
Spray Equipment	
Water supply temperature	Adjusted to produce supercooled water droplets
Water droplet median volume diameter	22 µm ± 5 µm

† Method A
‡ Method B

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 set up 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 plate 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 plate is 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.

6.1.3.2 The equipment used to provide the water spray comprises a low flow nozzle supplied with water of quality and condition 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.

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:

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

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

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 (R1) is calculated per Equation 3.

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

where:

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

W_{a1} = weight 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:

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

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 ice-catch pan is used for continuous rate monitoring when conducting 1 to 6 fluid tests, and two ice-catch pans are used for continuous rate monitoring continuous when conducting 7 to 12 tests. For this purpose, ice collection 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 with “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-S	FOG-T	FOG-C	FOG-D	FOG-E	FOG-F
Air temperature, °C	-3 ± 0.5	-3 ± 0.5	-6 ± 0.5	-6 ± 0.5	-10 ± 0.5	-10 ± 0.5	-25 ± 1	-25 ± 1
Air temperature standard deviation	0.3	0.3	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	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	2.0 ± 0.3	5.0 ± 0.4
‡ Icing intensity standard deviation	<0.3	<0.4	<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	≤ 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	≤ 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 1 L of fluid onto each test plate. As soon the fluid has spread over the plates (almost instantaneous for Type I 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.

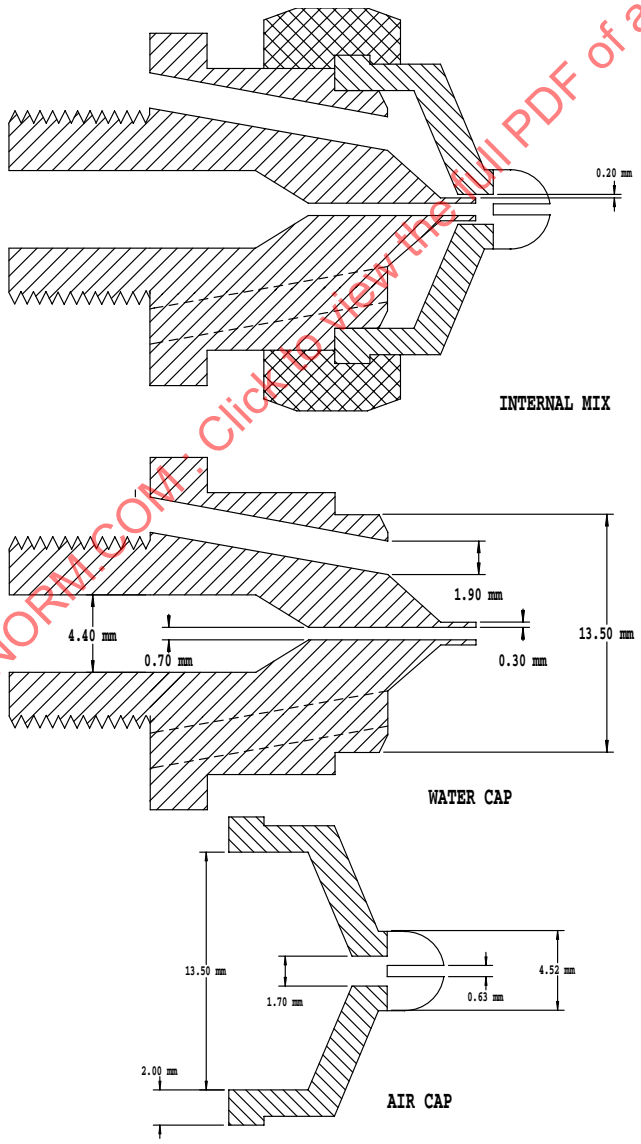

FIGURE 1 - EXAMPLE OF SPRAY NOZZLE FOR FREEZING FOG

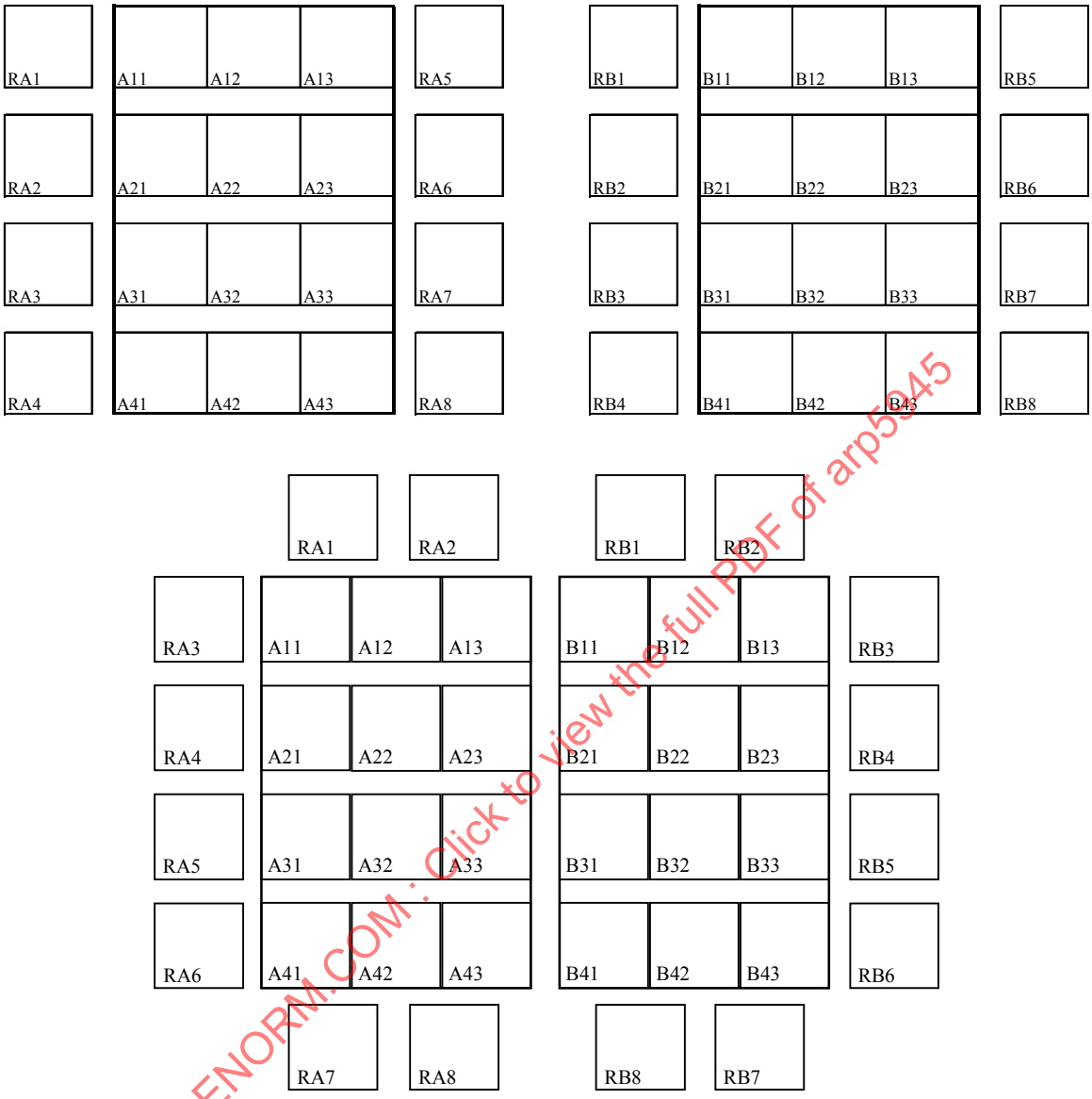

FIGURE 2 - ARRANGEMENT OF ICE-CATCH PLATES AND REFERENCE ICE-CATCH PLATES

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).

7. ENDURANCE TIME TEST - LABORATORY SNOW

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

8. ENDURANCE TIME TEST - FREEZING DRIZZLE

8.1 Freezing Drizzle 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 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 °C 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	20 °C ± 5 °C
† 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
‡ Ice-catch Pans	
Ice-catch pans	277 mm x 540 mm
Number of ice-catch pans	1 per test location
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
‡ Method B

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 Method A

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 as to minimize the contact between the test surface and the support.

8.1.2.4 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 4. The test plate is 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 for Method A are described in Figure 3.

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 that freeze on impact. This is verified by observation of an ice-catch plate.

8.1.4.2 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 Tables 4 and 5 are met.

8.1.5 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.

8.2 Freezing Drizzle 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 5 throughout.

8.2.2 Measurement Methods for Icing Intensity Variability Across Test Plate

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.

8.3 Freezing Drizzle Test Conditions

Test conditions for freezing drizzle are in Table 5.

TABLE 5 - FREEZING DRIZZLE TEST CONDITIONS

Test Condition	ZL-A	ZL-B	ZL-S	ZL-T	ZL-C	ZL-D
Air temperature, °C	-3 ± 0.5	-3 ± 0.5	-6 ± 0.5	-6 ± 0.5	-10 ± 0.5	-10 ± 0.5
Air temperature standard deviation, °C	0.3	0.3	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	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	5 ± 0.4	13 ± 0.5
‡ Icing intensity standard deviation	< 0.4	< 0.7	< 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	≤ 0.6	≤ 1.4
‡ Icing intensity range across all test plates, g/dm^2/h	≤ 1.4	≤ 2.2	≤ 1.4	≤ 2.2	≤ 1.4	≤ 2.2

† Method A
‡ Method B

8.4 Freezing Drizzle 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 except that failure is defined in 8.4.6.

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 plate; using a method such as described in 8.2.1, 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.

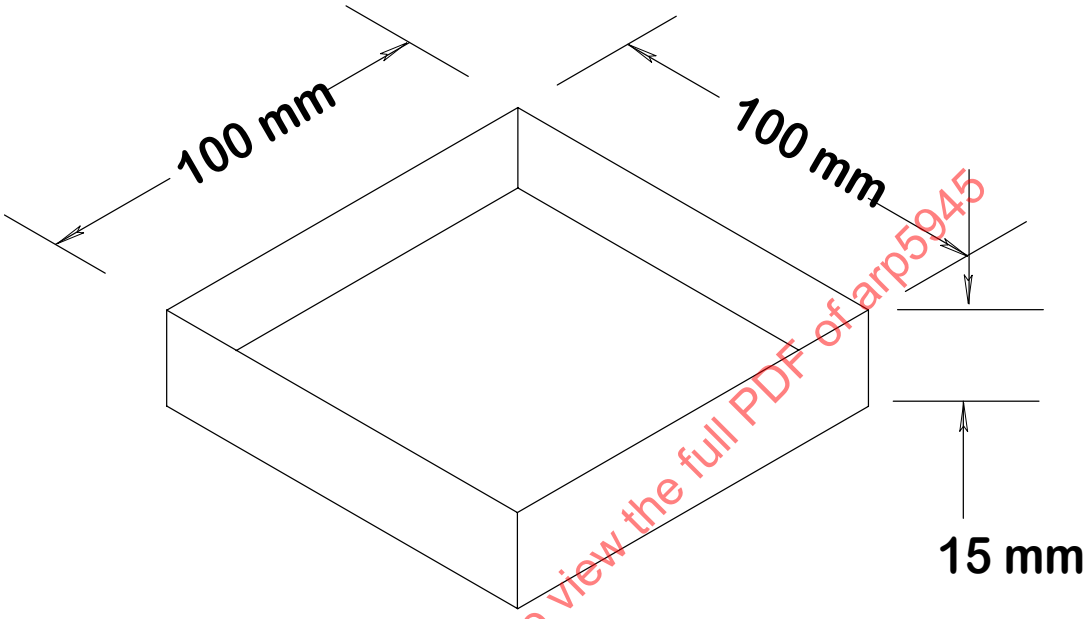

FIGURE 3 - ICE-CATCH PANS

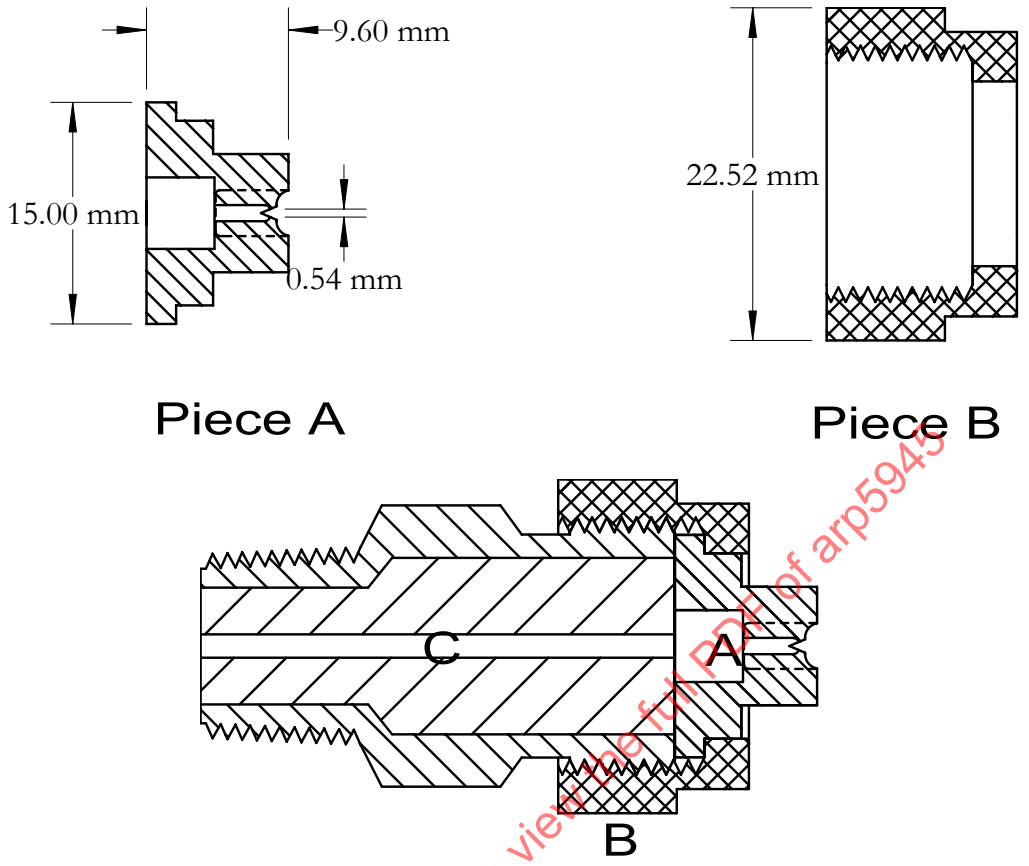

FIGURE 4 - EXAMPLE OF A HYDRAULIC NOZZLE FOR FREEZING DRIZZLE

9. ENDURANCE TIME TEST - LIGHT FREEZING RAIN

9.1 Light Freezing Rain 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 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 °C 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	20 °C ± 5 °C
† 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
‡ Ice-catch Pans	
Ice-catch pans	277 mm x 540 mm
Number of ice-catch pans	1 per test location
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
‡ Method B

9.1.2 Test Plates

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

9.1.2.2 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.

9.1.2.3 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 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.

9.1.3 Ice-catch Pans

The ice-catch pans, described in Table 6 and Figure 3, are used to evaluate the ice-catch.

9.1.4 Spray Equipment

9.1.4.1 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 plate.

9.1.4.2 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 Tables 6 and 7 are met.

9.1.5 Example of Spray Equipment

See 8.1.5.

9.2 Light Freezing Rain Measurement Methods

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 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.

TABLE 7 - LIGHT FREEZING RAIN TEST CONDITIONS

Test Condition	LZR-A	LZR-B	LZR-S	LZR-T	LZR-C	LZR-D
Air temperature, °C	-3 ± 0.5	-3 ± 0.5	-6 ± 0.5	-6 ± 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

* Type I fluids are not tested in freezing rain at -3 °C because the latent heat of freezing in calm test conditions produces artificially long endurance times. Use results from testing at -6 °C.
† Method A
‡ Method B

9.3 Light Freezing Rain Test Conditions

Test conditions for light freezing rain are in Table 7.

9.4 Light Freezing Rain Test Procedure

9.4.1 Test Plate Cleanliness

Clean test plates according to 4.7.1.

9.4.2 Temperature Verification

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

9.4.3 Failure Time

See 6.4.3 except that failure is defined in 9.4.6.

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 plate; using a method such as described in 8.2.1, 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.

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 - RAIN ON A COLD-SOAKED WING

10.1 Rain on a Cold-Soaked Wing 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 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 A 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	20 °C ± 5 °C
† 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
‡ Ice-catch Pans	
Ice-catch pans	277 mm x 540 mm
Number of ice-catch pans	1 per test location
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

† Method A, ‡ Method B

10.1.2 Test Plates

The test plate represents the upper surface of the cold-soak box (Figure 5).

10.1.3 Cold-Soak Box

Before starting the test, the cold-soak 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-soak box shall be insulated (except for the test surface) with a 25 mm polystyrene jacket (RSI = 0.88). 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-soak 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.

10.1.4 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 Tables 8 and 9 are met.

10.1.5 Example of Spray Equipment

See 8.1.5.

10.2 Measurement Methods for Rain on a Cold-Soaked Wing

10.2.1 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 9 throughout.

10.2.2 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 9.

10.3 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 A COLD-SOAKED WING TEST CONDITION

Test Condition	RCSW-A	RCSW-B
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 µm	1400 µm ± 150 µm
† 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

10.4 Rain on a Cold-Soaked Wing Test Procedure

10.4.1 Test Plate Cleanliness

Clean test plates according to 4.7.1.

10.4.2 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 plates to prevent any accumulation of ice.

10.4.3 Failure Time

Wait for the temperature of the test plate (or, if no test plate is used, the upper surface of the cold-soak box) to be at the start temperature. When the start temperature is reached, remove the paper towels and cover. Continue as in 6.4.3 except that failure is defined in 10.4.6.

10.4.4 Icing Intensity

After all the plates have failed, turn off the water spray, and weigh the ice-catch on each ice-catch plate; using a method such as described in 8.2.1, 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.

10.4.5 Delayed Crystallization

See 4.7.3.

10.4.6 Failure Criterion

See 6.4.6.

10.4.7 Reproducibility/Precision

See 6.4.7.

10.4.8 Report

See 4.7.4.

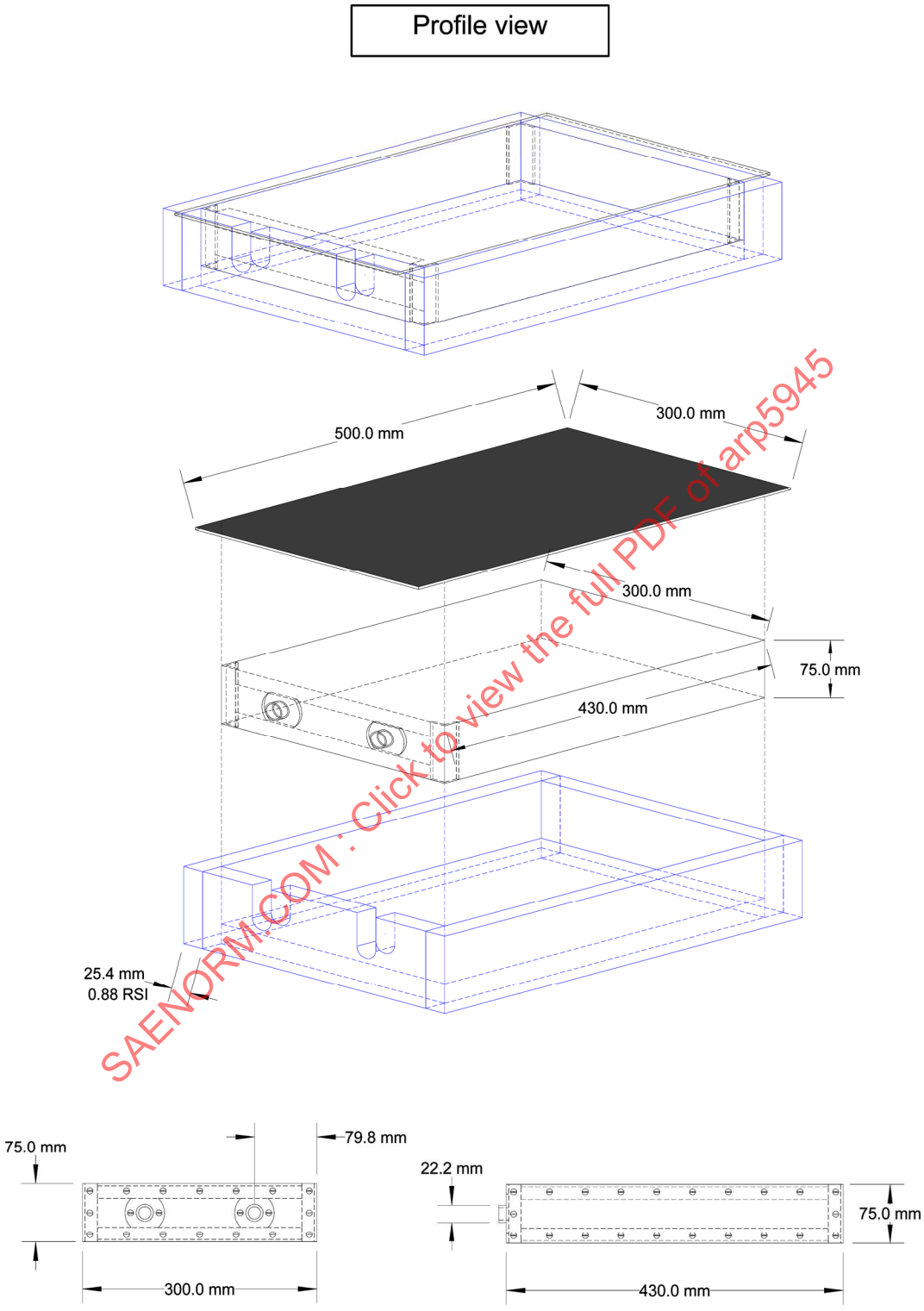

FIGURE 5 - COLD-SOAK BOX