TP 13828E

Endurance Time Testing in Snow: Reconciliation of Indoor and Outdoor Data Winter 2000-01

Prepared for

Transportation Development Centre
On behalf of
Civil Aviation
Transport Canada

and

The Federal Aviation Administration
William J. Hughes Technical Centre

APS AVIATION INC.

October 2001

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by
Michael Chaput
and
Richard Campbell

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Un sommaire français se trouve avant la table des matières.

PREFACE

Under contract to the Transportation Development Centre, co-sponsored by the U.S. Federal Aviation Administration, of Transport Canada, APS Aviation Inc. (APS) undertook a research program co-sponsored by the U.S. Federal Aviation Administrantion to advance aircraft ground de/anti-icing technology. The specific objectives of the APS test program are the following:

- To develop holdover time data for all newly qualified de/anti-icing fluids;
- To conduct endurance time frost tests for each temperature to substantiate the values in the current SAE holdover time guidelines for Type IV, Type II, and Type I fluids;
- To evaluate weather data from previous winters to establish a range of snow precipitation suitable for the evaluation of holdover time limits;
- To develop a protocol for Type I fluid testing;
- To examine the change in viscosity during the application of Type IV fluids;
- To compare holdover times in natural snow with those in NCAR's artificial snow;
- To prepare the JetStar and Canadair RJ wing for thermodynamic tests;
- To further evaluate the flow of contaminated fluid from the wing of a Falcon 20D aircraft during simulated take-off runs;
- To further evaluate hot water deicing;
- To provide support for tactile tests at Toronto Central Deicing Facility; and
- To apply ice sensors to the pre-take-off contamination check.

The research activities during the winter of 2000-01 are documented in six reports. The last four objectives listed above have not yet been finalized and are not included in this series of reports. Results will be reported upon study completion. The titles of the documented reports are as follows:

- TP 13826E Aircraft Ground De/Anti-icing Fluid Holdover Time Development Program for the 2000-01 Winter;
- TP 13827E SAE Type I Fluid Endurance Time Test Protocol;
- TP 13828E Endurance Time Testing in Snow: Reconciliation of Indoor and Outdoor Data Winter 2000-01;
- TP 13829E Modification of Test Wing to Accommodate Fuel Load Effects for Deicing Research: 2001;
- TP 13830E Winter Weather Data Evaluation (1995-2001); and
- TP 13831E Endurance Time Tests in Simulated Frost Conditions: 2001.

In addition, an interim report entitled *Viscosity Measurement of Type IV Fluids on Wing Surfaces* will be written.

This report, TP 13828E, has the following objective:

- To compare holdover times in natural snow with those in artificial snow.

This objective was met by conducting a series of natural snow trials and comparing these results to artificial snow trials conducted in a cold chamber. Test parameters included ambient temperature, precipitation rate, and test fluid. The trial results recorded were: fluid failure times, snow appearance, and snowmaker functionality.

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Research reports produced on behalf of Transport Canada for testing during previous winters are available from the Transportation Development Centre (TDC). Seven reports (including this one) were produced as part of this winter's research program. Their subject matter is outlined in the preface. Partial funding was provided courtesy of the FAA.

16. Abstract

The objective of this report was to compare endurance times for natural and artificial snow, and to continue the evaluation of the general functionality of an artificial snowmaking system that was developed by National Centre for Atmospheric Research (NCAR) under contract with the Federal Aviation Administration (FAA).

Outdoor natural snow tests were conducted by APS Aviation and the Anti-Icing Materials Laboratory (AMIL) using three Type IV fluids. 177 tests were conducted in natural snow using common procedures and fluids from the same production batches. In addition, 18 tests were conducted by APS on the NCAR bucket assembly in natural snow.

Thirty-five rate distribution trials were conducted with the NCAR system. The snow intensity range observed in these simulated snow trails was on average 3 times greater than the values proposed in Aerospace Standard AS 5485.

A total of 36 Type IV tests were conducted with the NCAR machine at the National Research Council Climatic Engineering Facility in Ottawa. NCAR personnel in Boulder, Colorado conducted an additional 8 tests. The indoor results were significantly inferior to those obtained in natural snow for propylene glycol-based fluids. In some cases, the indoor results were only 40 percent of the natural snow times. For ethylene glycol-based fluids the results of indoor and outdoor tests were similar.

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15. Remarques additionnelles (programmes de financement, titres de publications connexes, etc.)
Les comptes rendus de recherches produits pour le compte de Transports Canada sur les essais des hivers antérieurs peuvent être obtenus du Centre de développement des transports (CDT). Sept comptes rendus (y compris celui-ci) ont été produits dans le cadre du programme de recherches de cet hiver. Les grandes lignes de cette matière sont dans l'introduction. La FAA a fourni une partie des ressources financières.

16. Résumé

Le présent compte rendu avait pour but de comparer l'endurance de la neige naturelle et artificielle et de poursuivre l'évaluation de la fonctionnalité générale d'un système de fabrication de neige artificielle mis au point par le National Center for Atmospheric Research (NCAR), en vertu d'un contrat avec la FAA.

Des essais à l'extérieur sur la neige naturelle ont été faits par APS Aviation et le Laboratoire international des matériaux antigivre (LIMA) avec trois liquides de type IV. 177 essais ont été faits dans la neige naturelle avec des procédures communes et des liquides du même lot de production. De plus, 18 essais ont été faits par APS sur l'ensemble de godets du NCAR avec la neige naturelle.

Trente cinq essais de répartition de neige artificielle ont été faits avec le système du NCAR. Les marges d'intensité observées lors de ces pistes de neige simulées étaient en moyenne 3 fois plus grandes que les valeurs spécifiées dans la Norme aérospatiale (AS) 5485 proposée.

En tout, 36 essais de liquides de type IV ont été faits avec l'appareil du NCAR à l'installation d'ingénierie climatique du Conseil national de recherches (CNRC) à Ottawa. Le personnel du NCAR à Boulder, Colorado a mené huit essais additionnels. Les résultats à l'intérieur étaient nettement inférieurs aux résultats dans la neige naturelle pour les liquides propylènes à base de glycol. Dans certains cas, les résultats à l'intérieur n'atteignaient que 40 pourcent de l'endurance dans la neige naturelle. Les résultats des liquides éthylènes à base de glycol étaient semblables dans les essais intérieurs et extérieurs.

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Neige artificielle, appareil de fabrication de neige de troisième génération, dégivrage, antigivrage

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EXECUTIVE SUMMARY

Introduction

Under contract to the Transportation Development Centre (TDC) of Transport Canada and the U.S. Federal Aviation Administration (FAA), APS Aviation Inc. (APS) undertook a research program to compare holdover times for natural and artificial snow, and to continue the evaluation of the general functionality of an artificial snowmaking system that was developed by the National Center for Atmospheric Research (NCAR) under contract with the FAA.

Other laboratory snowmakers are also in development. These systems would allow a testing agency to evaluate the snow endurance times of de/anti-icing fluid at any time of year. The specifications for the use of such machines are outlined in the draft SAE Aerospace Standard AS 5485, dated October 3, 2000. This standard will ultimately contain the test procedures for use in the determination of aircraft deicing and anti-icing fluid endurance times.

Procedures and Data Processing

Outdoor natural snow tests using three Type IV fluids – Kilfrost ABC-S, SPCA AD-480, and Dow/UCAR Ultra+ – were conducted during the winter of 2000-01 by APS, AMIL, and NCAR. All tests were performed using common procedures and fluids from the same production batches. In total, 177 outdoor tests were conducted. The results of these tests were compared to data produced by the artificial snowmakers.

The bucket assembly used for the NCAR indoor tests was positioned outdoors for natural snow testing at the Dorval Airport test site. Eighteen fluid endurance time tests were conducted on the bucket assembly in natural snow events. The 18 data points collected outdoors were then duplicated indoors by NCAR personnel using the newly designed *variable autorate* function, which uses the electronic rate profile of the outdoor test as a template to run the indoor artificial snow test.

Thirty-five artificial snow distribution trials were performed with the NCAR system in April and June 2001.

Trials were performed to obtain fluid failure times in artificial snow using the NCAR snowmaking machine. Type IV fluids were tested in 100/0, 75/25, and 50/50 concentrations. The NCAR snowmaking machine was operated according to the guidelines set forth by NCAR in the operation manual supplied with the system. A total of 36 tests with Type IV fluids were conducted in artificial snow on several occasions at the National Research Council (NRC) Climatic Engineering Facility in Ottawa.

Twenty-three additional indoor tests were performed at the Centre de Recherche Industrielle du Quebec (CRIQ) with a certified Type IV fluid. The results of these tests were compared to results obtained from outdoor testing with the same fluid at the APS Dorval site.

Conclusions

The results from distribution trials conducted in April and June 2001 indicated that the snowfall distribution over the test plate was not uniform. The snow intensity range observed in the distribution trials was approximately 3 times greater than the values specified in the Proposed Aerospace Standard (AS) 5485.

A brief examination of the snowflake diameters produced by the NCAR machine lends support to visual observations indicating that the flakes produced by the NCAR snowmaker were, on average, larger than those found in nature. This seemed to be especially true at colder temperatures. It is also suspected that these larger flakes lead to snow bridging failures, which contribute to the occurrence of reduced endurance times in artificial snow.

The endurance times of Type IV fluids in artificial snow exhibited significant differences from natural snow. For propylene fluids, the indoor values were inferior to the outdoor values in all cases, ranging from 40% to 85% of the outdoor numbers, depending on fluid and dilution. The indoor failure times observed in trials with ethylene Type IV were within experimental error of the outdoor results.

Recommendations

The differences between natural and artificial snow should be further evaluated, and the modified snowmaking system requires further testing.

SOMMAIRE

Introduction

En vertu d'un contrat avec le Centre de développement des transports (CDT) de Transports Canada et la Federal Aviation Administration (FAA) des États-Unis, la société APS Aviation Inc. (APS) a entrepris un programme de recherches visant à comparer les durées d'efficacité applicables à la neige naturelle et à la neige artificielle, ainsi qu'à poursuivre l'évaluation de la fonctionnalité générale d'un système de fabrication de neige artificielle mis au point par le National Center for Atmospheric Research (NCAR), en vertu d'un contrat avec la FAA.

D'autres systèmes de fabrication de neige sont également en cours de développement. Ces systèmes permettraient à un organisme d'essais d'évaluer l'endurance à la neige de liquides d'antigivrage ou de dégivrage durant toute l'année. Les spécifications d'utilisation de tels appareils sont exposées dans l'ébauche du document provisoire AS 5485 de la SAE – Norme aérospatiale, du 3 octobre 2000. À terme, cette norme énoncera les procédures d'essais visant à établir l'endurance des liquides d'antigivrage et de dégivrage d'aéronefs.

Procédures et traitement des données

Durant l'hiver de 2000-01, des essais sur la neige naturelle à l'extérieur avec les liquides de type IV Kilfrost ABC-S, SPCA AD-480, et Dow/UCAR Ultra+ ont été faits par APS, le LIMA et le NCAR. Tous les essais ont été faits avec des procédures communes et des liquides du même lot de production. En tout, 177 essais ont été faits à l'extérieur. Les résultats de ces essais ont été comparés aux données produites par les systèmes de fabrication de neige artificielle.

L'ensemble de godets utilisé par NCAR pour les essais à l'intérieur avait été placé à l'extérieur pour des essais de neige naturelle à l'emplacement d'essai de l'Aéroport de Dorval. Dix-huit essais d'endurance de liquides ont été faits avec l'ensemble de godets au cours de chutes de neige naturelle. Les 18 points de données pris à l'extérieur ont ensuite été reproduits à l'intérieur par le personnel du NCAR, à l'aide de la fonction *autorate variable* nouvellement conçue, qui utilise le profil électronique du taux de l'essai extérieur en guise de modèle pour l'essai à l'intérieur avec la neige artificielle.

Trente cinq essais de répartition de neige artificielle ont été faits avec le système du NCAR en avril et juin 2001.

Des essais visant à obtenir les temps de défaillance des liquides en présence de neige artificielle ont été faits à l'aide de l'appareil de fabrication de neige du

NCAR. Des liquides de type IV ont été évalués dans des concentrations de 100/0, 75/25 et 50/50. L'appareil de fabrication de neige du NCAR a été utilisé en conformité avec les lignes directrices du NCAR dans le mode d'emploi fourni avec le système. En tout, 36 essais de liquides de type IV ont été faits dans la neige artificielle en plusieurs occasions à l'installation d'ingénierie climatique du Conseil national de recherches (CNRC) à Ottawa.

Vingt trois essais additionnels à l'intérieur ont été faits au Centre de Recherche Industrielle du Québec (CRIQ) sur un liquide certifié de type IV. Les résultats de ces essais ont été comparés à ceux des essais extérieurs sur le même liquide à l'emplacement d'APS à Dorval.

Conclusions

Les résultats des essais de répartition d'avril et de juin 2001 démontraient que la répartition des chutes de neiges n'était pas uniforme sur la plaque d'essai. Les marges d'intensité de neige observées lors des essais de répartition étaient environ 3 fois plus grandes que les valeurs spécifiées dans la Norme aérospatiale (AS) 5485 proposée.

Un court examen par l'appareil du NCAR du diamètre des flocons de neige confirme les observations visuelles qui démontrent que les flocons produits par l'appareil du NCAR étaient en général plus grands que ceux de la neige naturelle. Cela semblait être particulièrement le cas à des températures plus basses. On soupçonne également que ces flocons plus grands causent des défaillances de ponts de neige, qui contribuent à des temps réduits d'endurance dans la neige artificielle.

L'endurance des liquides de type IV dans la neige artificielle présente d'importantes différences avec l'endurance dans la neige naturelle. Dans tous les cas des liquides propylènes, les valeurs intérieures étaient inférieures aux valeurs extérieures, allant de 40% à 85% des valeurs extérieures, selon le liquide et la dilution. Les temps de défaillance observés aux essais d'éthylène de type IV se situaient dans la marge d'erreur expérimentale des résultats extérieurs.

Recommendations

Les différences entre la neige naturelle et artificielle devraient être évaluées davantage et le système modifié de fabrication de neige exige également d'autres essais.

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GLOSSARY

AMIL	Anti-Icing Materials Laboratory
APS	APS Aviation Inc.
AS	Aerospace Standard
CEF	Climatic Engineering Facility
CRIQ	Centre de Recherche Industrielle du Quebec
FAA	Federal Aviation Administration (U.S.)
MSC	Meteorological Service of Canada (formerly known as Atmospheric Environment Services or AES)
NCAR	National Center for Atmospheric Research
NRC	National Research Council Canada
RTD	Resistance Temperature Detector
SAE	Society of Automotive Engineers
TDC	Transport Development Centre
UCAR	Union Carbide

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1. INTRODUCTION

Under contract to the Transportation Development Centre (TDC) of Transport Canada and the Federal Aviation Administration (FAA), APS Aviation Inc. (APS) undertook a research program to compare aircraft de/anti-icing fluid endurance times in natural and artificial snow. This report covers the indoor and natural snow reconciliation work that was conducted by APS during the 2000-01 test season.

An artificial snow generation system was developed by the National Centre for Atmospheric Research (NCAR) in Boulder, Colorado, for the conduct of snow endurance time testing in a controlled laboratory environment. This system has been used in all indoor snow tests conducted by APS since 1998.

During the 1998-99 test season, APS undertook a research program to evaluate the prototype, or first generation, snowmaking system developed by NCAR. The results of this study, along with several recommendations for system improvement, were published in the Transport Canada report, TP 13488E, *A Snow Generation System - Prototype Testing*, (1).

Indoor artificial snow tests were also conducted during the 1999-2000 test season. In addition to determining the fluid failure times and failure patterns resulting from indoor artificial snow precipitation, this body of tests was designed to investigate overall snowmaker functionality, and to evaluate the improvements that were made to the original prototype. Specific fluid failure times were compared to the holdover time tables generated from natural precipitation tests. The results of tests with the second-generation snowmaker were published in the Transport Canada report, TP 13661E, *A Second Generation Snowmaking System - Prototype Testing*, (2).

Other laboratory snowmakers are also in development. These systems would allow a testing agency to evaluate the snow endurance times of de/anti-icing fluid at any time of year. The specifications for the use of such machines are outlined in the Proposed SAE Aerospace Standard AS 5485, dated October 3, 2000 (3).

An excerpt from the TDC work statement is given in Appendix A and includes a description of the snow reconciliation trials.

The APS 2000-01 snow reconciliation test program had the following objectives:

- Evaluate the performance of the third generation NCAR system for the conduct of future endurance time tests, and to ensure that the icing intensity and the icing intensity distribution range over the test plate produced by the NCAR machine are within the specifications defined in the Proposed SAE Aerospace Standard AS 5485;

- Evaluate and compare the endurance times obtained by APS, Anti-Icing Materials International Laboratory (AMIL), and NCAR in natural and artificial snow;
- Determine the reasons for differences in the endurance times obtained in natural snow tests and those conducted under artificial snow with the NCAR system; and
- Evaluate and compare the endurance times of a certified Type IV fluid in natural and artificial snow.

Each of the objectives is further described in Subsections 1.1 to 1.4.

1.1 Conformance of the NCAR Artificial Snow Generation System with the Test Parameters Outlined in the Proposed SAE Aerospace Standard AS 5485

The purpose of these tests was to evaluate the performance of the third generation NCAR system for the conduct of future endurance time tests, and to ensure that the icing intensity and icing intensity distribution range over the test plate produced by the NCAR machine are within the specifications defined in the Proposed SAE Aerospace Standard AS 5485 (October 2000).

Several modifications were made to the NCAR system during the 2000-01 test season, including the installation of an snow distribution plenum above the ice core and drill, and the removal of fans used to circulate the snow within the machine. These modifications will be discussed further in Section 2.

The modifications made to the NCAR machine and their impact on the icing intensity distribution range were evaluated through a series of calibration trials with the improved snowmaking machine. Distribution trials with the third generation machine were conducted at the National Research Council (NRC) Climatic Engineering Facility (CEF) in Ottawa at several ambient temperatures. The type of snow produced at each temperature was also examined and documented.

The calibration trials provided a means of determining the efficiency and usefulness of the NCAR artificial snow machine for evaluating fluid endurance times while highlighting any of its shortcomings related to the test specifications outlined in the Proposed Aerospace Standard 5485.

1.2 Intra-Laboratory Snow Reconciliation

The purpose of these tests was to evaluate and compare the endurance times obtained by APS, AMIL, and NCAR in natural and artificial snow.

1.2.1 APS, AMIL, and NCAR Outdoor Natural Snow Data

The three testing agencies, APS, AMIL, and NCAR, performed outdoor endurance time testing using common test procedures and fluid samples. Following completion of the outdoor testing, the test data compiled by the laboratories were combined and endurance times for the various fluids were determined using a power law regression analysis.

1.2.2 Indoor versus Natural snow Data

Indoor artificial snow testing was conducted by each of the three laboratories using the same fluids tested in outdoor conditions. The APS indoor tests were run at the most restrictive temperature in each cell of the holdover time table using the snow precipitation rate limits of 10 and 25 g/dm^2/h, which are used in the holdover time evaluation of de/anti-icing fluids. A comparison of the indoor snow data recorded and the outdoor fluid holdover times determined from the regression curves was then performed.

1.3 NCAR Snow Reconciliation

The purpose of these tests was to determine the reasons for differences between the endurance times obtained in natural snow tests and those obtained under artificial snow with the NCAR system.

To accomplish this goal, the NCAR bucket assembly was positioned outdoors on a test stand during natural snow events, and fluid endurance time tests with several Type IV fluids were performed on the bucket assembly. Precipitation rate over time, plate temperature, and ambient air temperature, were recorded.

The test conditions reported during outdoor trials using the NCAR bucket assembly were reproduced in laboratory trials with the NCAR artificial snow generation system. Electronic snow rate files collected during outdoor trials were then used as templates for indoor NCAR artificial snow tests to mimic the fluctuating snowfall rates observed during the outdoor tests.

This methodology allowed for the direct comparison between tests performed under natural snow conditions and duplicate tests performed under artificial conditions with the NCAR system.

1.4 Comparison of Indoor and Outdoor Endurance Times for a Certified Type IV Fluid

The purpose of these tests was to evaluate and compare the endurance times of a certified Type IV fluid in natural and artificial snow. Outdoor tests were conducted at the Dorval test facility using current fluid endurance time test procedures. The indoor tests were run with the NCAR system at the most restrictive temperature given in each cell of the holdover time table and using the snow precipitation rate limits of 10 and 25 $g/dm^2/h$. A comparison of the indoor snow endurance time data and the outdoor fluid holdover times determined from the regression analysis was then performed.

2. METHODOLOGY

This section describes the methodology used to perform indoor trials with the NCAR snowmaking system and outdoor tests in natural snow for each of the four elements of the 2000-01 test program.

2.1 Conformance of the NCAR Artificial Snow Generation System with the Test Parameters Outlined in the Proposed Aerospace Standard AS 5485

2.1.1 Test Sites

Snow intensity distribution trials were conducted on three occasions during the 2000-01 test season at the National Research Council Climatic Engineering Facility (CEF) in Ottawa:

- April 2 to 5, 2001;
- June 4 to 7, 2001; and
- June 26 to 28, 2001.

The CEF is partitioned into two sections separated by an insulating door. Each partition can be separately controlled, permitting different tests to be conducted simultaneously. Photo 2.1 gives an exterior view of the facility. Photos 2.2 and 2.3 provide interior images of the small and large ends of the facility. The size of the chamber is 30 m by 5.4 m, with a height of 8 m. The lowest temperature attainable in the chamber is -46°C.

2.1.2 Description of Test Procedures

The test procedure established by APS to assess the performance of the NCAR artificial snow generation system is included in Appendix B. The operation manual for the NCAR system has also been included in Appendix B.

According to the procedures in the Proposed Aerospace Standard 5485, the snow intensity distribution across a test plate is assessed by replacing the test plate with ten ice-catch pans. The dimensions of the pans are 150 mm by 100 mm, 0.8 mm thick, and have a rim 15 mm high all around. The pre-weighed pans are weighed upon completion of each calibration test and the difference in the recorded weights together with the area of the pans and the exposed time interval is used to compute the icing intensity (snow catch) for that pan. The AS 5485 proposes that the average and range of the icing intensity of the ten pans should fall within the limits in each test condition, as listed in Table 2.1.

The holdover time range for any deicing or anti-icing fluid is obtained by conducting endurance time tests at the temperatures and icing intensities listed in Table 2.1. Tests conducted at the high icing intensity (25g/dm^2/h) determine the lower holdover time, while tests conducted at the low icing intensity (10 g/dm^2/h) determine the upper holdover time.

Prior to the start of snow distribution trials, the snow distribution pattern on the NCAR plate was examined visually, as suggested in the NCAR operation manual, and the collection bucket and weigh scale were positioned accordingly in the NCAR snow machine enclosure. For snow distribution trials, the placement of the NCAR system is shown in Figure 2.1.

The APS snow intensity distribution procedure varied slightly from the procedures outlined in the Proposed AS 5485, and was not included in the test procedure in Appendix B. The APS procedure used 15 ice catch pans, 100 mm x 100mm in dimension, instead of the 10 ice catch pans, 150 mm x 100 mm in dimension, outlined in the Proposed AS 5485.

The APS snow distribution procedure is summarized below:

- Set up the NCAR *Labview* software;
- Install the ice core;
- Prepare and number 15 ice-catch pans (100 mm x 100 mm x 15 mm);
- Weigh the individual ice-catch pans;
- Secure the ice catch pans with Velcro to a standard test plate;
- Ensure the snow machine and software are functioning satisfactorily;
- Ensure that the linear *autorate* function is on and input the desired icing intensity;
- Position the plate containing the ice catch pans onto the bucket in the snow maker enclosure;
- Start the snow machine by pressing the *start experiment* button;
- Expose the ice catch pans to snow for 30 minutes;
- Press *end experiment* button at the end of the exposure period;
- Remove the plate and ice catch pans and reweigh; and
- Calculate the icing intensities.

Photo 2.4 shows the snow distribution test set-up prior to the onset of a snow distribution test at NRC. Photo 2.5 displays the accumulated snow in each of the 15 pans following a snow distribution trial.

TABLE 2.1
Proposed AS 5485 Criteria

Test Condition Temperature °C	Snow -3°C	Snow -3°C	Snow -10°C	Snow -10°C	Snow -14°C	Snow -14°C	Snow -25°C	Snow -25°C	Snow <-25°C
Icing Intensity $g/dm^2/h$	10±0.5	25±1.0	10±0.5	25±1.0	10±0.5	25±1.0	10±0.5	25±1.0	5±0.2
Icing intensity range across a test plate, $g/dm^2/h$	≤1.5	≤4.0	≤1.5	≤4.0	≤1.5	≤4.0	≤1.5	≤4.0	≤0.8

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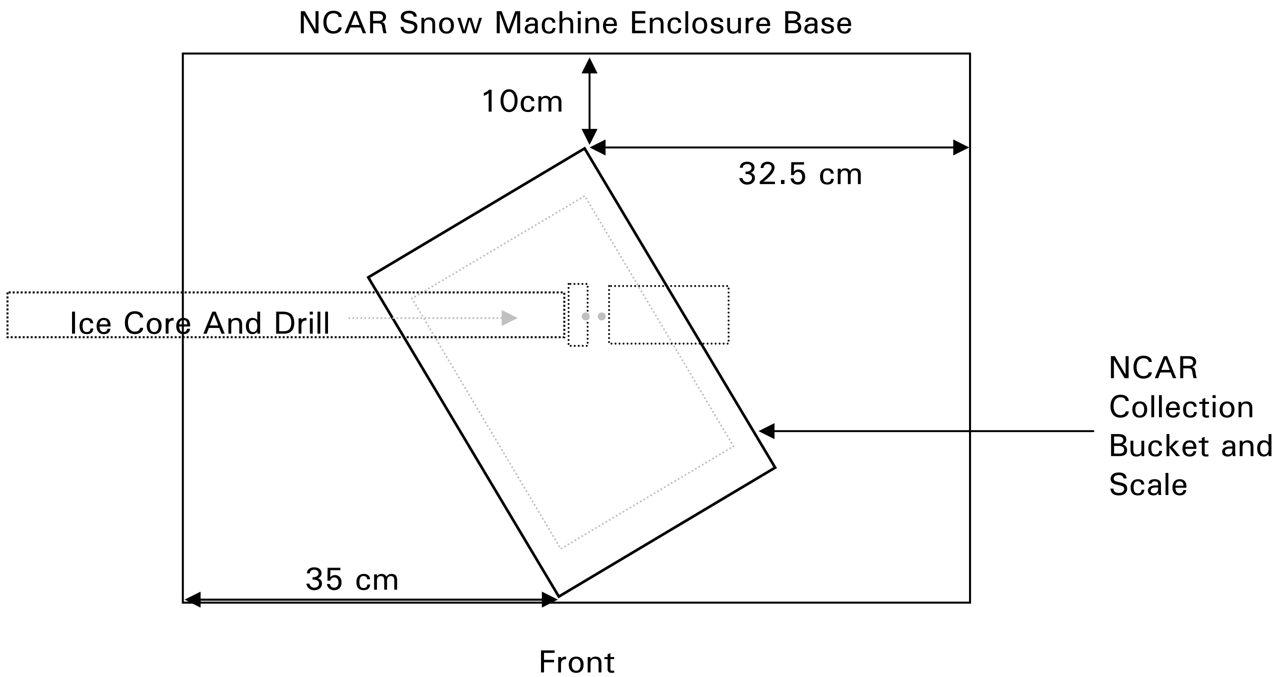

FIGURE 2.1

Snow Collection Bucket Placement within NCAR Enclosure Top View

To compare the distribution values obtained in the trials with 15 pans to the specification requirements in the Proposed AS 5485 (based on 10 pans), the 15-pan values were mathematically converted to 10 pans.

Figure 2.2 depicts how this conversion was accomplished. For example, in the *10 catch pans from 15* schematic in Figure 2.2, the newly-created larger pan 1 contains the entire smaller pan 1 catch as well as half the smaller pan 2 catch.

2.1.3 Equipment

The NCAR snow system (see Photo 2.6) is a complex assembly of components. It operates by feeding a 7-cm diameter ice core made from distilled water into a carbide-tipped Fostner bit, which shreds the ice into smaller flakes at a controlled rate. The feed rate of the ice core is determined by a series of high-frequency pulses generated by a desktop computer and outputted to a stepper motor control circuit and to the stepper motor. The ice flakes are then distributed randomly by an air circulation system that consists of two large fans (with approximate diameter of 30 cm) that were installed above the ice core in the *snow distribution plenum* (see Photo 2.7). The snow distribution plenum is a sheet of metal with holes drilled in it such that air can be blown through and form a boundary layer that inhibits the snow coming off the ice core. The ice flakes fall 2.5 m onto a standard aluminium plate supported by a fluid trap. The plate and fluid trap assembly, with a dead weight of 4 300 g, rests on a 0.1 g resolution 12-kg capacity analytical balance. In this configuration, the total mass and snowfall rate can be measured in real-time. A high-resolution (Analog Devices) temperature transmitter monitors a temperature channel. The temperature sensor uses a 1.5 mm diameter, 100 ohm platinum resistance temperature detector (RTD) that is embedded into the aluminium test plate at the 15-cm (6″) line. A second identical temperature sensor will be positioned above the test plate to monitor the air temperature within the NCAR enclosure, although this has yet to be installed.

The NCAR machine gathers data from various sensors and stores the acquired information in a date and time coded text file. This data is displayed to the user during the test. The following information is recorded in this file:

- Time;
- Date;
- Command snowfall rate;

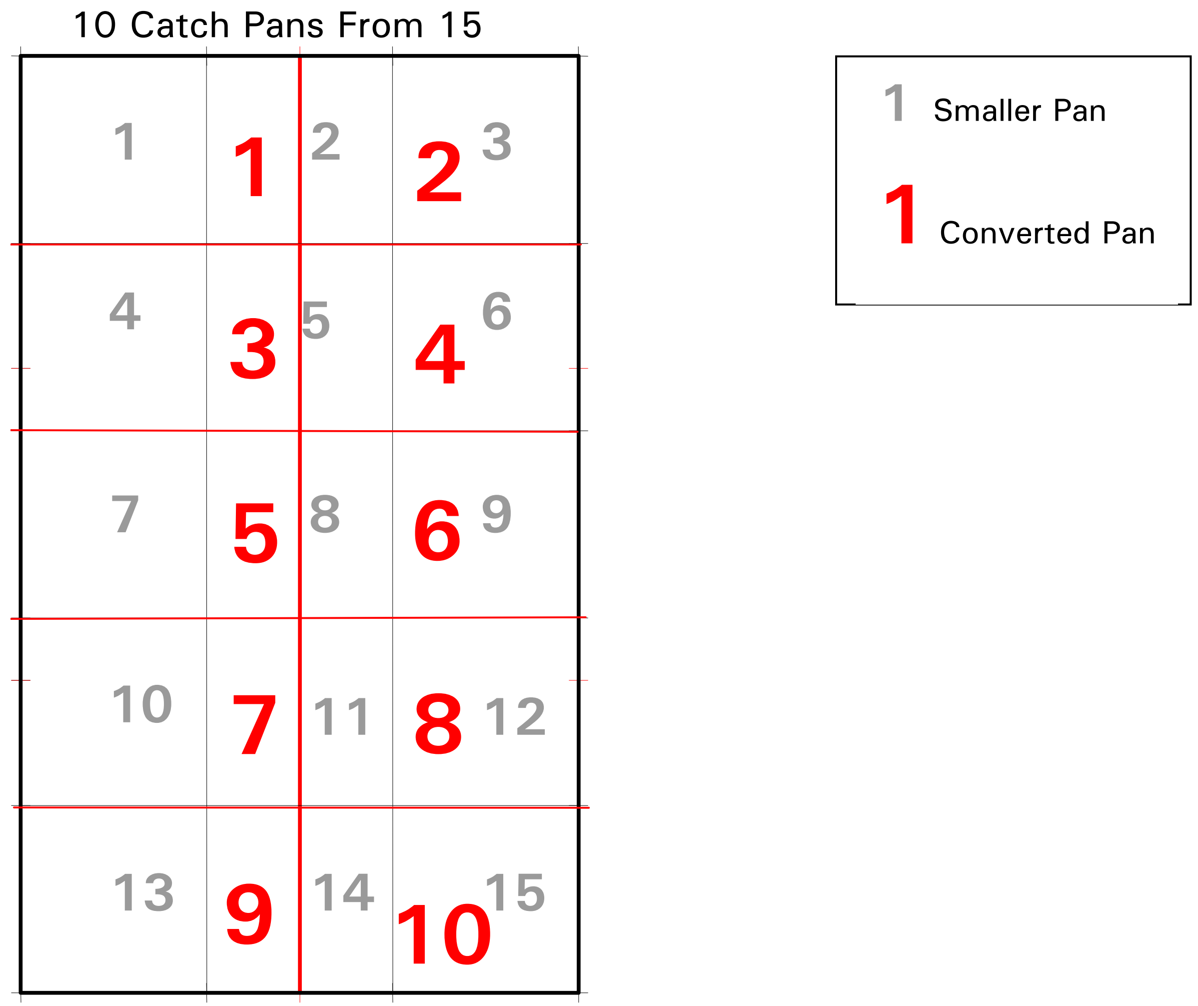

FIGURE 2.2

Icing Intensity Distribution Conversion

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- Overall snowfall rate;
- Snow mass;
- Plate temperature; and
- Comments input by the operator.

A complete list of equipment required for all tests with the NCAR snow system is included in the test procedure shown in Appendix B.

2.1.4 Modifications to Snow Machine System

Initial calibration testing was conducted in April 2001 using the second-generation NCAR machine from 1999-2000 tests, despite the fact that several modifications and improvements had been made to the machine design since that time.

For the first test session in June 2001, a technician from NCAR was present at the NRC chamber in Ottawa to make the necessary changes to the APS machine. The major modifications to the machine are listed in the subsections below in bullet form.

2.1.4.1 System Software Changes

- The latest version of *Labview* was installed and configured;
- The output of elapsed test time was changed to minutes instead of seconds;
- The allowable snow mass to trigger a warning signal to empty the collection bucket was increased;
- A variable *autorate* function was designed and installed. The variable *autorate* feature allows the user to alter the command rate of snow intensity and to program a desired rate fluctuation for any test. This feature also provides the user with the ability to read electronic files from other tests and use them as a template for icing intensity. When electronic files are being read, the system will automatically use the mean snow rate if the electronic file terminates (the external data file is no longer providing data) before the test is complete. The command rate will fall to zero for a few seconds, before resuming at the mean;
- A delay was built into the software to allow the analytical balance to stabilize before snow weight data recording begins. This delay would also remove divergence in the *linear autorate* due to fluctuating balance readings;
- The allowable speed of the translator was increased; and

- The software was modified to ensure that the fans stay on at all times to keep the air shroud clear, and to ensure that the translator moves forward only if the drill is on.

2.1.4.2 System Hardware Changes

- A PCI interface card was installed in the desktop computer;
- A curved snow distribution plenum with two fans was installed above the drill bit to improve the snow distribution patterns (described earlier in this report and shown in Photo 2.7);
- All fans previously used for snow circulation and distribution were removed (and replaced by the above system);
- The plate heater was removed; and
- Modifications were made to the system wiring for temperature logging and for the stepper-motor.

2.2 Intra-Laboratory Snow Reconciliation

The intra-laboratory snow reconciliation test program was performed to evaluate and compare the endurance times obtained by APS, AMIL, and NCAR in both natural and artificial snow. The methodologies for the conduct of outdoor and indoor tests are included in this section.

2.2.1 Natural Snow Tests (APS, AMIL, and NCAR Natural snow Data)

APS, AMIL, and NCAR performed natural snow endurance time tests in 2000-01 using common procedures and fluids from the same production batches.

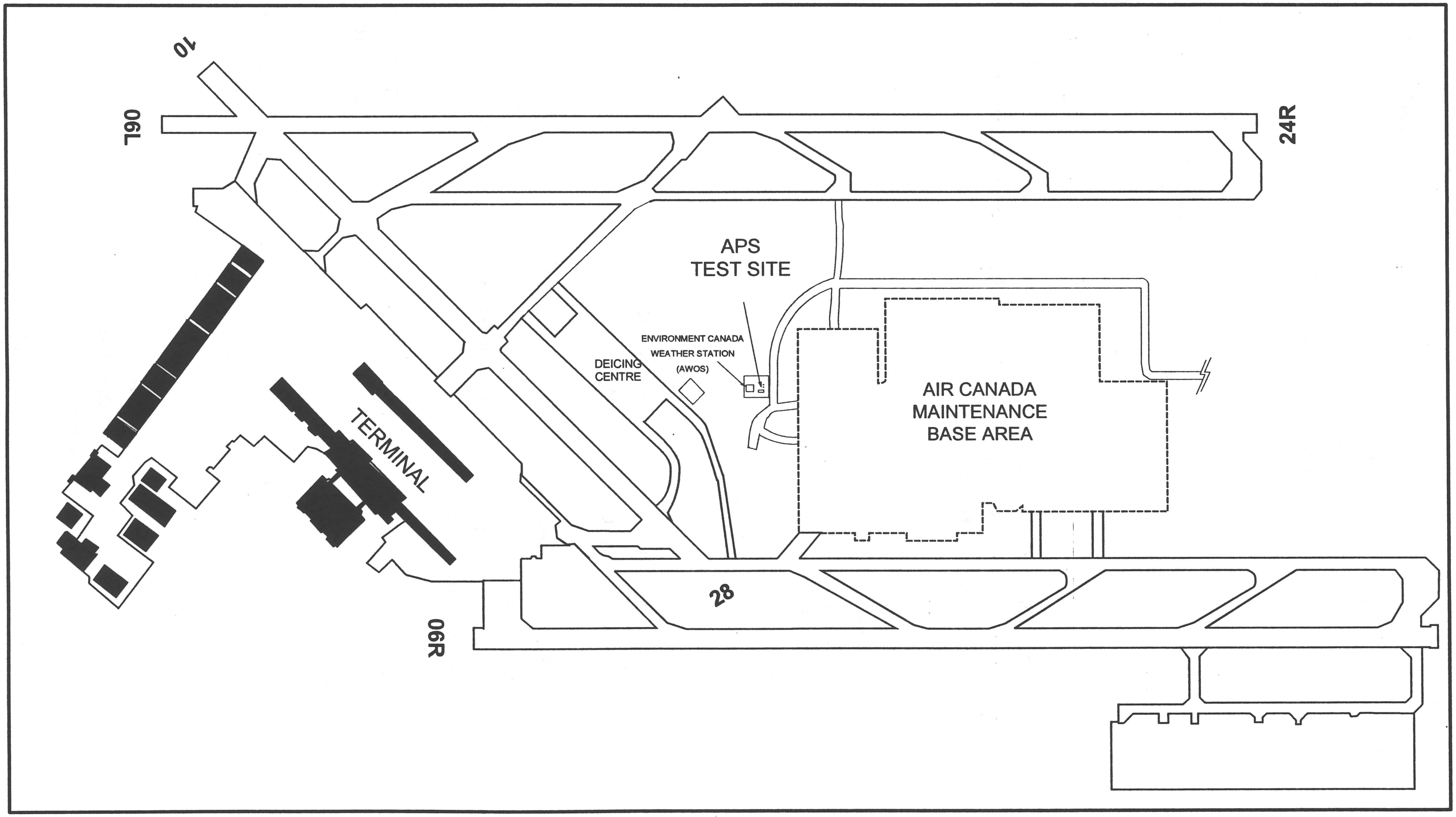
2.2.1.1 Test Sites

APS performed natural snow testing for the 2000-01 winter at the Dorval test site. The location of the test site is shown on the plan view of the airport in Figure 2.3. Photo 2.8 presents an overall view of the test site with the associated test equipment. The APS test site is located adjacent to Environment Canada's Atmospheric Environment Services automated weather observation station (Photo 2.9).

AMIL and NCAR also generated outdoor test data at their respective facilities.

FIGURE 2.3

APS TEST SITE LOCATION AT DORVAL AIRPORT



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2.2.1.2 Description of Test Procedures

In December 2000, APS, AMIL, NCAR, Transport Canada, and the Federal Aviation Administration held a conference call to discuss and define the test procedures for outdoor natural snow tests. The goal was to develop a common procedure that would produce a common database of tests.

The test procedure was written by APS personnel and provided to the various testing facilities and regulatory authorities. The agreed upon procedure is essentially the same procedure used by APS for conducting outdoor endurance time tests over the past decade. This procedure is provided in Appendix C.

To help identify differences in the data produced by the various testing laboratories, it was decided that the following test information would be recorded for each fluid test:

- Fluid manufacturer, fluid name, and fluid dilution;
- Outside air temperature;
- Wind speed and wind direction;
- Fluid application temperature;
- Plate temperature throughout the test;
- Fluid failure time;
- Snowfall intensity;
- Brix/Refractive index of the fluid at failure;
- Photography of the fluid end condition; and
- Photography of the snowflakes.

One litre of Type IV fluid was applied to each of the test plates from 1-litre containers until the entire test section surface was covered (see Photo 2.10). Type IV fluids were applied to test surfaces at ambient outside air temperature.

Following the fluid failure of each test, a fluid sample was collected within 1 cm of the failure front, and the refractive index of the fluid sample was recorded.

Photography of the appearance of failure for each natural snow test was recorded. Photos were taken at the moment of fluid failure and 5 minutes following the fluid failure for each test.

To characterize the snowflakes observed during natural snow testing, a 30-cm x 30-cm black felt-covered board was exposed to the snow prior to and following the completion of each test. A ruler with millimetre increments was placed on the board to measure the individual flakes (see Section 4 Photos).

The determination of defined end conditions evolved from the experience the APS team has accumulated from previous winter season test programs. The following description provides the general guidelines observers used to judge when fluid failure occurred and to determine the extent of contamination or failure in natural or simulated snow conditions:

- There is a visible accumulation of snow bridging on top of the fluid or plate when viewed from the front. There should be an indication that the fluid can no longer absorb the precipitation at this point.

The standard flat plate end condition was achieved when failures occurred either at any 5 of the crosshair markings on the plate, or when the general failure coverage reached 1/3 of the entire test plate surface.

The determination of fluid failure was deemed the most likely reason for potential differences in fluid endurance times from laboratory to laboratory. In January 2001, personnel from AMIL were present at an outdoor natural snow event at the Dorval test site, and received training in the traditional methods of calling fluid failures in natural snow conditions.

The test set-up for APS outdoor natural snow trials as part of the intra-laboratory snow reconciliation is shown in Photo 2.11.

2.2.1.3 Data Forms

Two data forms were used to manually record the data at Dorval Airport during the snow reconciliation tests. The form used to record the fluid failure times is shown in Table 2.2. The second form (Table 2.3) was used to record data relating to meteorological conditions during the tests. One half of this form was designated for plate pan precipitation rate measurements, and the rest of the page was reserved for documentation of meteorological conditions and any changes that occurred during tests.

TABLE 2.2

END CONDITION DATA FORM - AMIL RECONCILIATION

REMEMBER TO SYNCHRONIZE TIME WITH AES - USE REAL TIME

VERSION 1.0 Winter 2000/2001

LOCATION: **DATE:** **RUN # :** **STAND # :**

TEMPERATURE AT START OF TEST _______ ºC

WIND DIRECTION AT START OF TEST _______ º

DIRECTION OF STAND AT START OF TEST _______ º

OTHER COMMENTS (Fluid Batch, etc):

	PRINT	SIGN
FAILURES CALLED BY :		
HAND WRITTTEN BY :		
TEST SITE LEADER :		

***TIME (After Fluid Application) TO FAILURE FOR INDIVIDUAL CROSSHAIRS (hr:min)**

Time of Fluid Application: _______ hr:min:ss _______ hr:min:ss _______ hr:min:ss

	Plate 1			Plate 2			Plate 3		
FLUID NAME									
B1 B2 B3									
C1 C2 C3									
D1 D2 D3									
E1 E2 E3									
F1 F2 F3									
PHOTO # AT FAIL PHOTO # AT FAIL + 5min.									
CALCULATED FAILURE TIME (MINUTES)									
BRIX AT FAILURE / TEMPERATURE AT START	/			/			/		

Time of Fluid Application: _______ hr:min:ss _______ hr:min:ss _______ hr:min:ss

	Plate 4			Plate 5			Plate 6		
FLUID NAME									
B1 B2 B3									
C1 C2 C3									
D1 D2 D3									
E1 E2 E3									
F1 F2 F3									
PHOTO # AT FAIL PHOTO # AT FAIL + 5min.									
CALCULATED FAILURE TIME (MINUTES)									
BRIX AT FAILURE / TEMPERATURE AT START	/			/			/		

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At: Data Form

TABLE 2.3

METEO/PLATE PAN DATA FORM - AMIL RECONCILIATION

REMEMBER TO SYNCHRONIZE TIME WITH AES - USE REAL TIME — VERSION 1.0 — Winter 2000/2001

LOCATION:	DATE:	RUN # :	STAND # :

PLATE PAN WEIGHT MEASUREMENTS *

PAN #	t TIME BEFORE (hh:mm:ss)	BUFFER TIME (Seconds)	t TIME AFTER (hh:mm:ss)	BUFFER TIME (Seconds)	w WEIGHT BEFORE (grams)	w WEIGHT AFTER (grams)	COMPUTE RATE (Δ w*4.7/ Δt) (g/dm^2/h)

*MEASUREMENTS AT 5 MIN. INTERVALS (STAGGERED).

METEO OBSERVATIONS **

TIME (hr:min)	TYPE ZR, ZL,S, SG IP, IC, BS, SP	SNOW CLASSIF. (See Fig. 3)	PHOTO # of SNOWFLAKES	WIND SPEED at 2 m (Km/h)

**observations at beginning, end, and every 10 min. intervals. Additional observations when there are significant changes.

COMMENTS : ______________________________

____

____

____

	PRINT	SIGN
WRITTEN & PERFORMED BY :		
PHOTO BY :		
TEST SITE LEADER :		

I:\cm1680\reports\NCAR\Table 2.2-2.3.xls
At: Meteo & Pan

2.2.1.4 Equipment

Figure 2.4 shows a schematic of the test platform traditionally used in outdoor trials at the Dorval test site. For 2000-01 snow reconciliation testing, the 12-position test stand was replaced by individual 6-plate test stands. This ensured that all test plates were at the same height above the ground. Each plate was mounted on the test stand, which had a working surface inclined at 10º to the horizontal.

Figure 2.4 also depicts the size and surface markings on a standard flat plate. Three parallel lines were drawn at 2.5 cm (1 in.), 15 cm (6 in.), and 30 cm (12 in.) from the top of the plate. The plates were marked with 15 crosshairs, which were used to determine whether test end conditions were achieved.

Figure 2.5 shows the collection (plate) pan. The plate pan was the same size as a standard flat plate and was used to make precipitation rate measurements during outdoor tests.

Fluid freeze points were measured using a hand-held Misco refractometer with a Brix scale (see Photo 2.12).

Type T Kapton insulated thermocouple probes were embedded in the test plates to monitor plate temperatures during a test. The accuracy of the thermocouples is 1.0ºC over the range -250ºC to +404°C. Data from the thermocouples was recorded with a logger.

A 35-mm camera with a zoom lens (focal length set to 50-mm), and 800 ASA film (preferably Fuji), was used to record the photographic documentation. A time stamp was also required for each photograph.

Photographs were taken from a camera mounted on a tripod. The tripod set-up was mobile. Photographic lighting consisted of a mobile spotlight with two 500-W halogen bulbs positioned at a 45° angle and 5 feet from the back of the test plate. The halogen lights were turned on for the photography at all times of day to promote consistency. For night photography, a color correction filter (CC10B) was placed on the lens.

The additional equipment used in snow reconciliation testing is listed and described in the natural snow holdover time test procedure in the Transport Canada report, TP 13659E, *Aircraft Ground De/Anti-icing Fluid Holdover Time and Endurance Time Testing Program for the 1999-2000 Winter*, (4).

FIGURE 2.4

FLAT PLATE TEST SET-UP

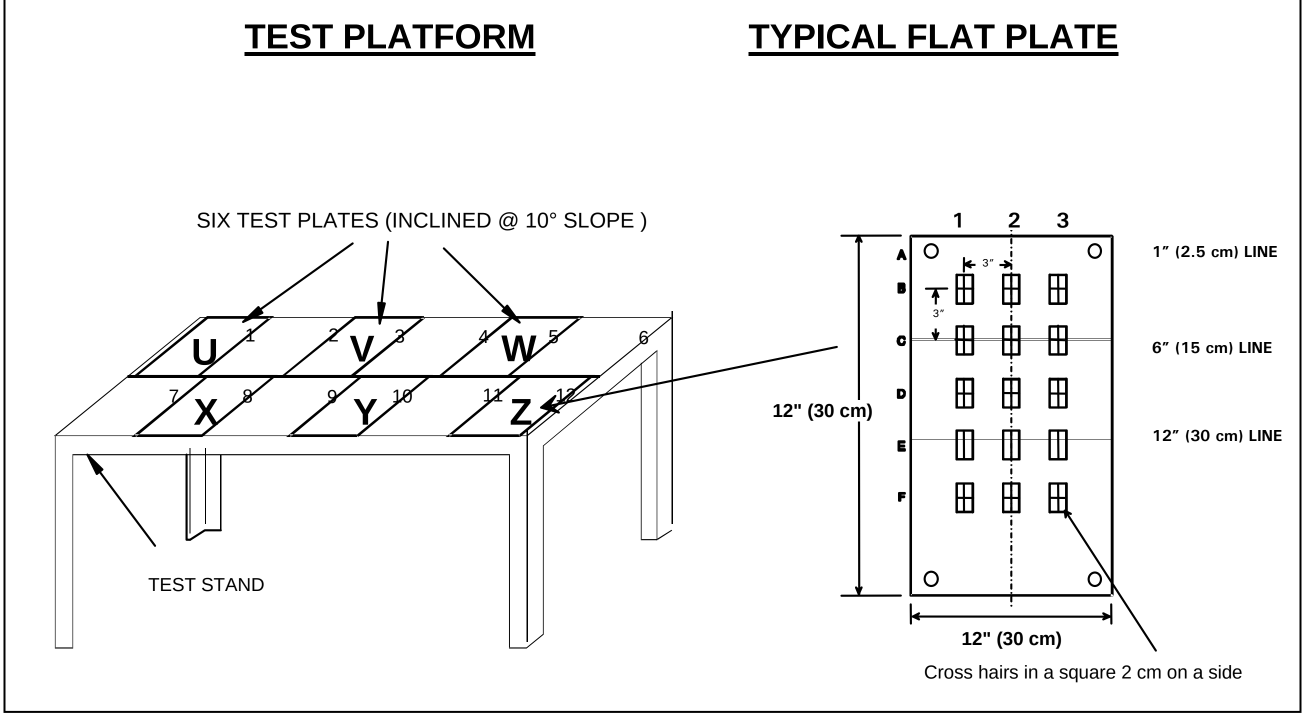
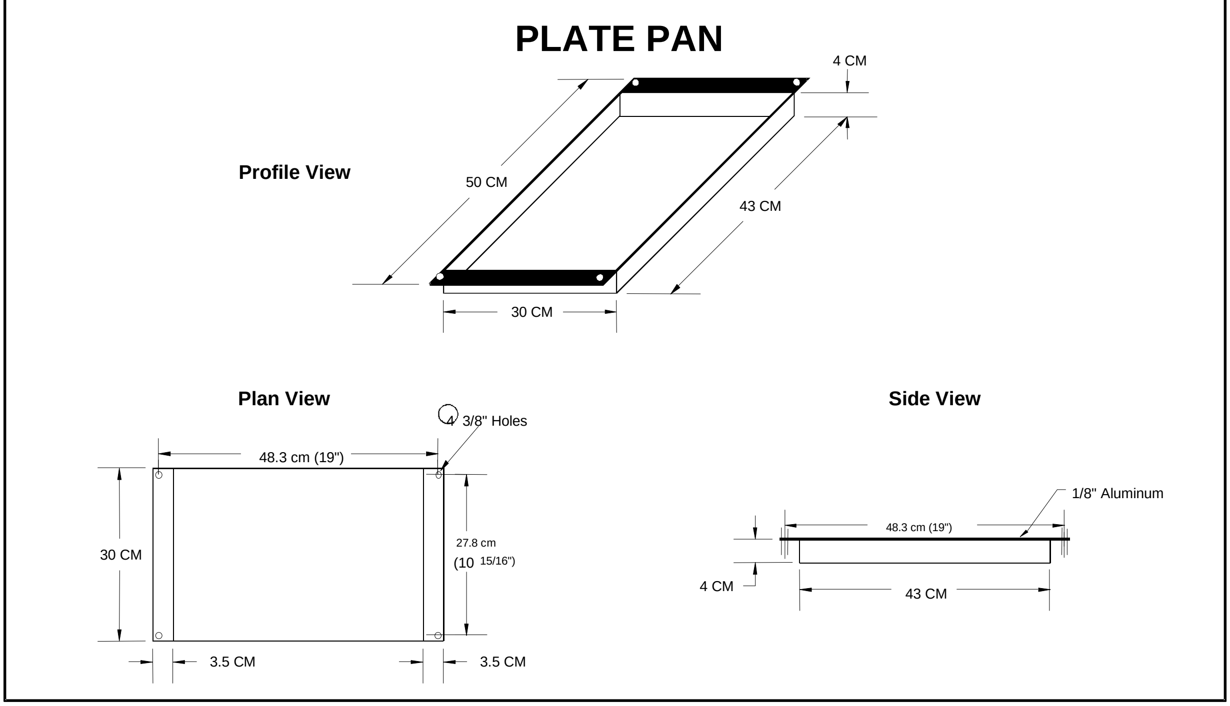


FIGURE 2.5

SCHEMATICS OF PLATE PAN



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2.2.1.5 Fluids

One ethylene glycol-based Type IV fluid and two propylene glycol-based Type IV fluids were tested in natural snow as part of the snow reconciliation test program. To ensure that all laboratories tested fluid of the same viscosity, test samples were delivered from the fluid manufacturers to the testing facilities from the same production batches.

The following fluids and dilutions, along with their viscosities (in centipoise) and their refractive indexes (in °Brix), were tested in 2000-01 natural snow testing:

- UCAR Ultra+ neat, viscosity 32 500 cp, Brix 41;
- Kilfrost ABC-S neat, viscosity 27 300 cp, Brix 36;
- Kilfrost ABC-S 75/25 fluid/water concentration, viscosity 23 300 cp, Brix 28;
- Kilfrost ABC-S 50/50 fluid/water concentration, viscosity 2 000 cp, Brix 19;
- SPCA AD-480 neat, viscosity 20 500 cp, Brix 37;
- SPCA AD-480 75/25 fluid/water concentration, viscosity 30 500 cp, Brix 28.75; and
- SPCA AD-480 50/50 fluid/water concentration, viscosity 7 900 cp, Brix 20.5.

APS personnel measured all Type IV fluid viscosities using the methods specified for each fluid by the respective fluid manufacturer. The manufacturer-specified methods for viscosity measurement were described in the 1999-2000 Transport Canada report, TP 13659E, *Aircraft Ground De/Anti-icing Fluid Holdover Time and Endurance Time Testing Program for the 1999-2000 Winter*, (4).

2.2.1.6 Personnel

Three APS personnel were required for the conduct of natural snow reconciliation trials. The staff positions, and a brief description of their individual tasks, are presented below:

- **End condition tester**: determined and recorded the end condition times for each test plate; assisted in fluid application;
- **Meteo tester**: determined ice catch for each test; observed and recorded meteorological conditions throughout the test session; cleaned plates prior to onset of testing; and applied test fluids; and

- **Photographer**: recorded photographic documentation of the fluid failure for each test and characterized the snowflakes for each test by recording macro photography of the individual snowflakes.

2.2.2 Artificial Snow Tests (Indoor vs. Outdoor Comparison)

Artificial snow tests were conducted using the parameters outlined in the Proposed AS 5485 to compare the results of indoor and outdoor endurance time tests.

2.2.2.1 Test Sites

Artificial snow tests with the NCAR system were performed at the NRC CEF in Ottawa. The chamber is described in Subsection 2.1.1.

Indoor artificial snow trials on Type IV fluids were performed by APS at the NRC facility in Ottawa between June 4 to 7, and June 26 to 28, 2001.

2.2.2.2 Description of Test Procedures

The test procedure established by APS for the snowmaker trials is provided in Appendix B.

All Type IV tests were conducted according to the guidelines set in this procedure. All failure calls were made according to flat plate failure call standards for snow precipitation. The trials were performed on a standard aluminium plate (500-mm by 300-mm) that was fixed to the fluid collection bucket of the snowmaker assembly. The plate and collection bucket assembly were levelled to maintain the test surface at a 10° incline.

Type IV tests were conducted at 10 and 25 g/dm^2/h. These snow precipitation rate limits have traditionally been used for the evaluation of snow endurance times, and have been proposed for future use in AS 5485.

The snowfall rate measurement was incorporated into the snowmaker system and recorded automatically to a data file. The system software maintained the desired rate following algorithms for either the *linear* or *variable autorate* function.

The fluid failure time for any test is the difference between the moment that the *begin experiment* software button is activated, and the plate failure is called visually and the *end experiment* software button is pressed. The user sets the precipitation rate and the software maintains the command rate throughout the test.

The procedure used for artificial snow trials was similar to the standard holdover time procedure used by APS for natural snow trials.

The NCAR artificial snow test procedure involved several major steps:

1. Empty fluid collection bucket;
2. Prepare and secure ice core;
3. Begin precipitation and data logging;
4. Clean panels;
5. Apply (pour) fluids to test panels. Type IV fluids were applied at the ambient air temperature. Fluids were poured using a single-step fluid application;
6. Record the start of the holdover time after the fluid was applied; and
7. Continue testing until at least five crosshairs or 1/3 of the plate have failed.

The Type IV fluids were tested at neat, 75/25, and 50/50 concentrations.

The snowmaking machine was operated according to the guidelines set forth by NCAR in the operation manual supplied with the system. This manual is included in Appendix B.

2.2.2.3 Data Forms

The data form employed during indoor artificial snow trials is shown in Table 2.4. A single data form was required for each test due to the automatic rate logging capability of the system.

2.2.2.4 Equipment

The NCAR snowmaker is described in Subsection 2.1.3.

A complete list of the equipment required for all tests with the NCAR system is included within the procedure in Appendix B.

TABLE 2.4
END CONDITION DATA FORM
NCAR SNOW MAKER

Winter 1999/2000

LOCATION:	DATE:	RUN # :	STAND # :

OAT: ________ °C

PRECIPITATION RATE: ________ g/dm²/h

FLUID TEMPERATURE: ________ °C

FLUID QUANTITY APPLIED: ________ Litres

PLATE WASHING METHOD: ______________

OTHER COMMENTS (Fluid Batch, etc):

____

____

____

____

____

____

____

____

	PRINT	SIGN
FAILURES CALLED BY :		
HAND WRITTTEN BY :		
LEADER :		

***TIME (After Fluid Application) TO FAILURE FOR INDIVIDUAL CROSSHAIRS (h:min)**

Time of Fluid Application: ______ h:min

FLUID NAME			
B1 B2 B3			
C1 C2 C3			
D1 D2 D3			
E1 E2 E3			
F1 F2 F3			

CALCULATED FAILURE TIME (MINUTES) [ ]

2.2.2.5 Fluids

The seven fluids tested in indoor NCAR trials are listed in Subsection 2.2.1.5.

To allow for a direct comparison of the test results, the fluids tested by APS with the NCAR snowmaker were from the same batch of fluids used during natural snow trials. In addition, AMIL and NCAR used fluids from the same production batches.

2.2.2.6 Personnel

Two APS personnel were required to conduct the indoor trials with the NCAR snowmaker. One person poured the fluids, observed the plate failures, and ran the snowmaking system. A second person assisted with the set-up of the machine and the replacement of ice cores, and participated in various maintenance activities.

2.3 NCAR Snow Reconciliation

The objective of these tests was to determine the reasons for differences between the endurance time results obtained in natural snow tests and those achieved under artificial snow with the NCAR snowmaker.

2.3.1 Test Sites

The bucket assembly used for NCAR indoor tests was positioned outdoors for natural snow testing during the winter of 2000-01 at the Dorval Airport test site. This natural snow testing was conducted at the same time as the intra-laboratory snow reconciliation tests outlined in Subsection 2.2.1.

The indoor snow trials were aimed at reconciling differences between indoor and outdoor tests using the NCAR bucket assembly. Data points collected outdoors on the NCAR bucket assembly were to be duplicated indoors with the NCAR snowmaking system using the newly designed *variable autorate* function. This new function would allow the variable rates that were observed in outdoor tests to be reproduced in a laboratory setting. APS attempted to complete the indoor tests at the National Research Council CEF in Ottawa on two occasions in June 2001; however, due to problems with the NCAR machine, these tests were unsuccessful.

The test data from the outdoor natural snow bucket trials, including the electronic data files, were then provided to NCAR, where the tests were reproduced indoors by NCAR at their facility in Boulder, Colorado, in June and July 2001.

2.3.2 Description of Test Procedures

The test procedure developed by APS for the NCAR snow reconciliation trials under natural snow conditions is included in Appendix D. The test procedure for artificial snow with the NCAR machine is provided in Appendix B. All Type IV tests were conducted according to the attached procedure, and all failure calls were made according to the flat plate failure call standards for snow precipitation.

For natural snow tests, precipitation rates were collected by the NCAR bucket assembly, which was placed on the test stand outdoors (see Photo 2.13). Cables were run from the bucket assembly into the test trailer, where the laptop and *Labview* software recorded test information such as snowfall rate over time and plate temperature. The rate technician also collected snowfall rates with plate pans, and recorded wind speed and direction data.

The procedure was developed to reproduce the collected outdoor NCAR data indoors using the NCAR snow machine. A new program was designed by NCAR to allow the electronic files collected outdoors (containing the fluctuating rates observed in natural snow tests on the bucket) to be used as a template for indoor artificial snow trials. As such, the indoor tests would be conducted using the same rate profiles recorded in outdoor testing. This procedure allowed for a direct comparison of the indoor and outdoor data, because all tests were run using the same rates and rate profiles, and the same ambient temperature. The wind, however, would not be reproduced in indoor trials.

The procedure used for artificial snow trials was similar to the standard holdover time procedure used by APS for natural snow trials. Rate measurement was incorporated into the snowmaker system and recorded automatically to a data file. The system software maintained the desired rate following algorithms for either *linear* or *variable autorate.*

2.3.3 Data Forms

One data form was required for all outdoor and indoor natural snow tests conducted with the NCAR system due to the automatic rate logging capability of the system. This form is shown in Table 2.4. Outdoor trials also made use of a data form used to record the rate of natural snow precipitation using plate pans and the observed meteorological conditions. This form is shown in Table 2.3.

2.3.4 Equipment

The equipment for these trials is included in the procedures in Appendices B and D.

2.3.5 Fluids

The seven fluids tested are listed in Subsection 2.2.1.5.

2.3.6 Personnel

Three APS personnel were required to conduct the outdoor tests using the NCAR bucket assembly. The staff positions and a brief description of their individual tasks are listed below:

- **End condition tester**: determined and recorded the end condition times for each test plate; assisted in fluid application;
- **Meteo tester**: operated the NCAR *Labview* software; ensured all electronic files were saved following each test; observed and recorded rates and meteorological conditions throughout the test session; cleaned the test plate prior to onset of testing, and applied test fluids; and
- **Photographer**: recorded photographic documentation of the fluid failure for each test; characterized the snowflakes for each test by recording macro photography of the individual snowflakes.

Two APS personnel were required to conduct the indoor trials with the NCAR snowmaker. One person poured the fluids, observed the plate failures, and ran the snowmaking system. A second person assisted with the set-up of the machine and the replacement of ice cores, and participated in various maintenance activities.

2.4 Comparison of Indoor and Outdoor Endurance Times for a Certified Type IV Fluid

2.4.1 Test Sites

Endurance time testing of a certified Type IV fluid in natural snow was conducted by APS at the Dorval Airport test site during the 2000-01 test season.

Indoor fluid trials with the same Type IV fluid were conducted by APS during the month of October 2000 at the Centre de Recherche Industrielle du Quebec (CRIQ), located in Montreal (see Photos 2.14 and 2.15).

2.4.2 Description of Test Procedures

The natural snow tests with this fluid were conducted using the SAE-designed test procedures that have been used for several years. These test procedures are described in TP 13659E (4).

Indoor trials using the NCAR snow system were conducted at 10 and 25 g/dm^2/h. These snow precipitation rate limits have traditionally been used for the evaluation of snow endurance times, and have been proposed for future use in AS 5485.

2.4.3 Data Forms

A single data form was required for the indoor snow tests due to the automatic rate logging capability of the system. This form is shown in Table 2.4.

Two data forms were used to record the test data at Dorval Airport during the outdoor natural snow tests. The form used to record the fluid failure times is shown in Table 2.2. The second form (Table 2.3) was used to record data relating to meteorological conditions during the tests. One half of this form was designated for plate pan precipitation rate measurements, and the rest of the page was reserved for documentation of meteorological conditions and any changes that occurred during tests.

2.4.4 Equipment

A list of the equipment used in for these trials has been included in the procedures described in TP 13659E (4) and in the equipment list in Appendix B.

2.4.5 Fluids

The same Type IV fluid was used in the indoor and outdoor tests. The Type IV fluid was fully certified for use. It was propylene glycol-based, and was tested in the following dilutions: 100/0, 75/25, and 50/50.

Throughout this report, the fluid is referred to as Type IV Product A.

2.4.6 Personnel

The outdoor trials were conducted as part of the holdover time test program. These trials require a minimum of two APS personnel: one poured fluids and observed plate failures, and a second technician measured the precipitation rates, cleaned plates and assisted in preparing fluids.

Two APS personnel were required to conduct the indoor trials with the NCAR snowmaker. One person poured the fluids, observed the plate failures, and ran the snowmaking system. A second person assisted with the set-up of the machine, the replacement of ice cores, and participated in various maintenance activities.

Photo 2.1
Outside View of National Research Council Climatic Engineering Facility

Photo 2.2
Inside View of Small End of Climatic Engineering Facility

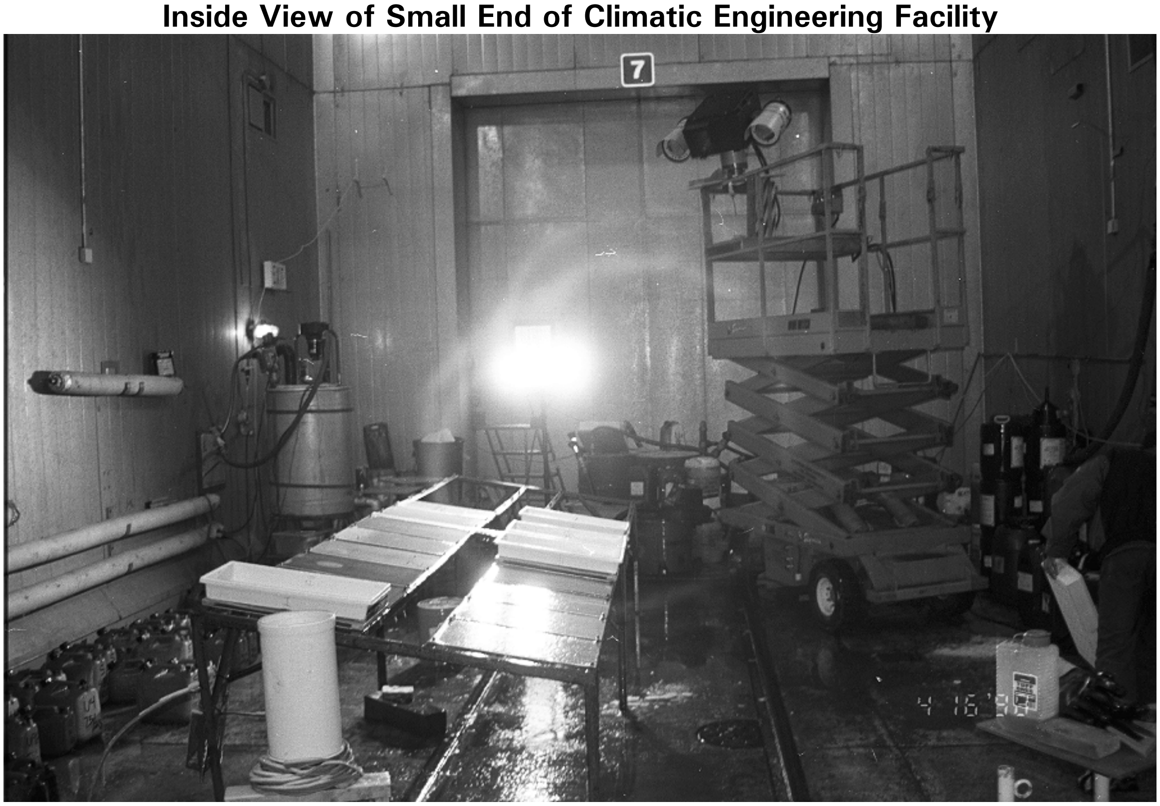


Photo 2.3
Inside View of Large End of Climatic Engineering Facility

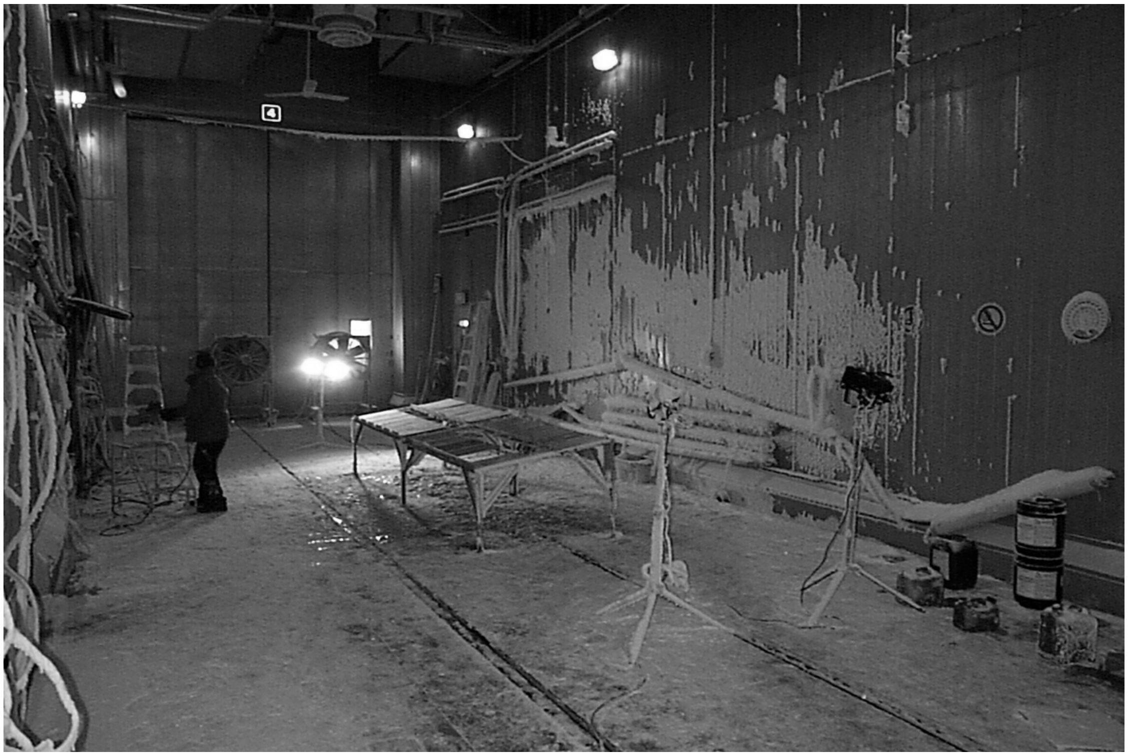


Photo 2.4
Snow Distribution Set-up for NCAR Snow Machine

Photo 2.5
Snow Distribution Trial

Photo 2.6
Third Generation Artificial Snow Machine

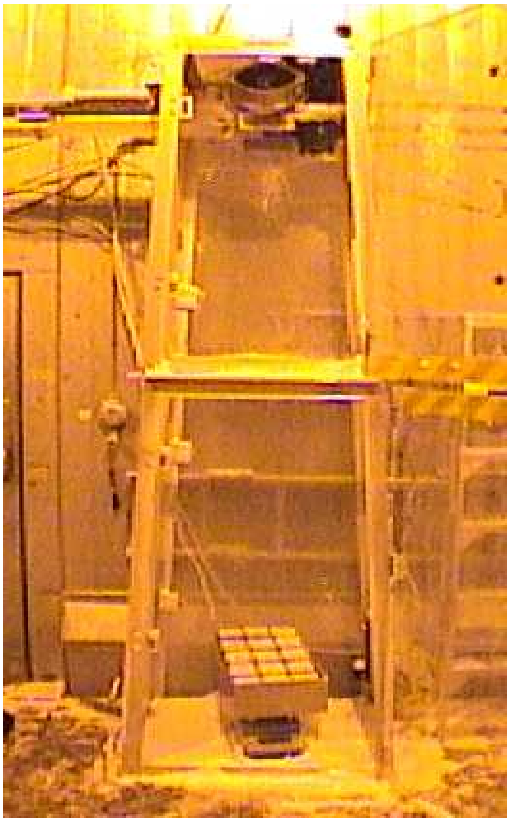


Photo 2.7
Snow Distribution Plenum

Photo 2.8
View of Dorval Test Site and Associated Equipment

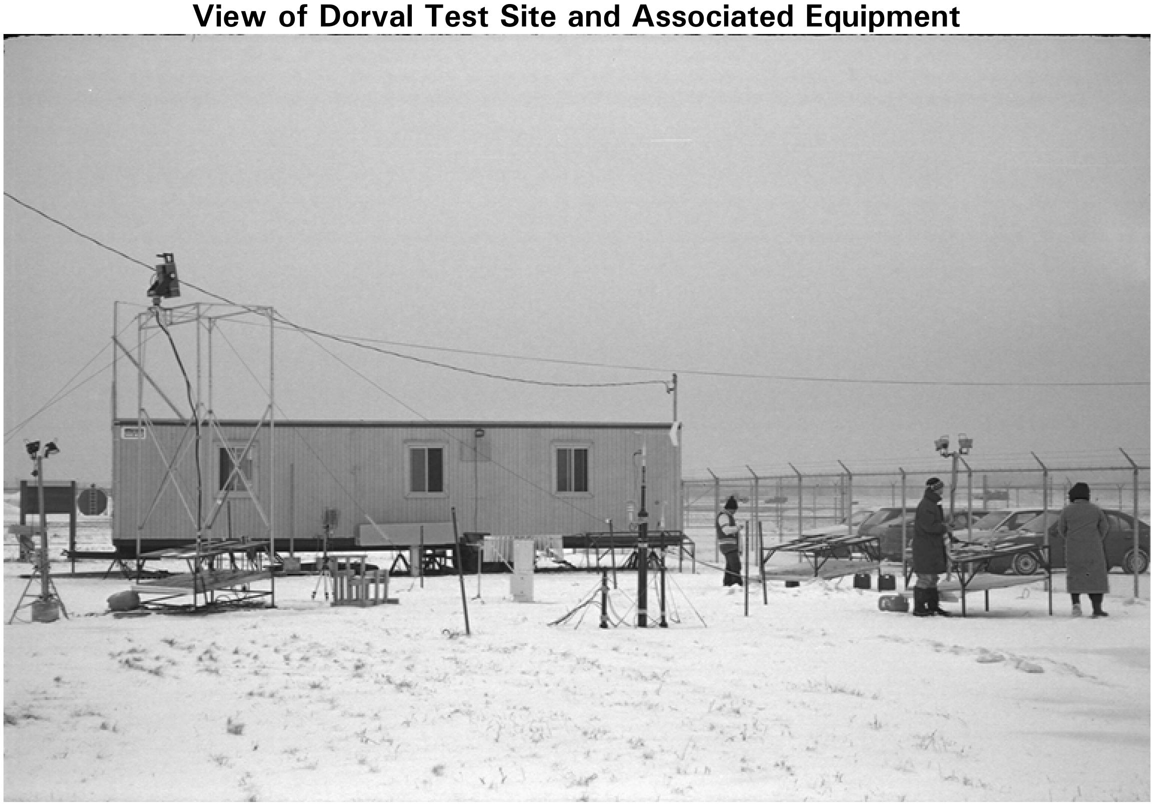


Photo 2.9
Meteorological Service of Canada Automated Weather Station Instruments

Photo 2.10
Fluid Application

Photo 2.11
APS Outdoor Snow Trials

Photo 2.12
Misco Refractometer used to Measure Freeze Point

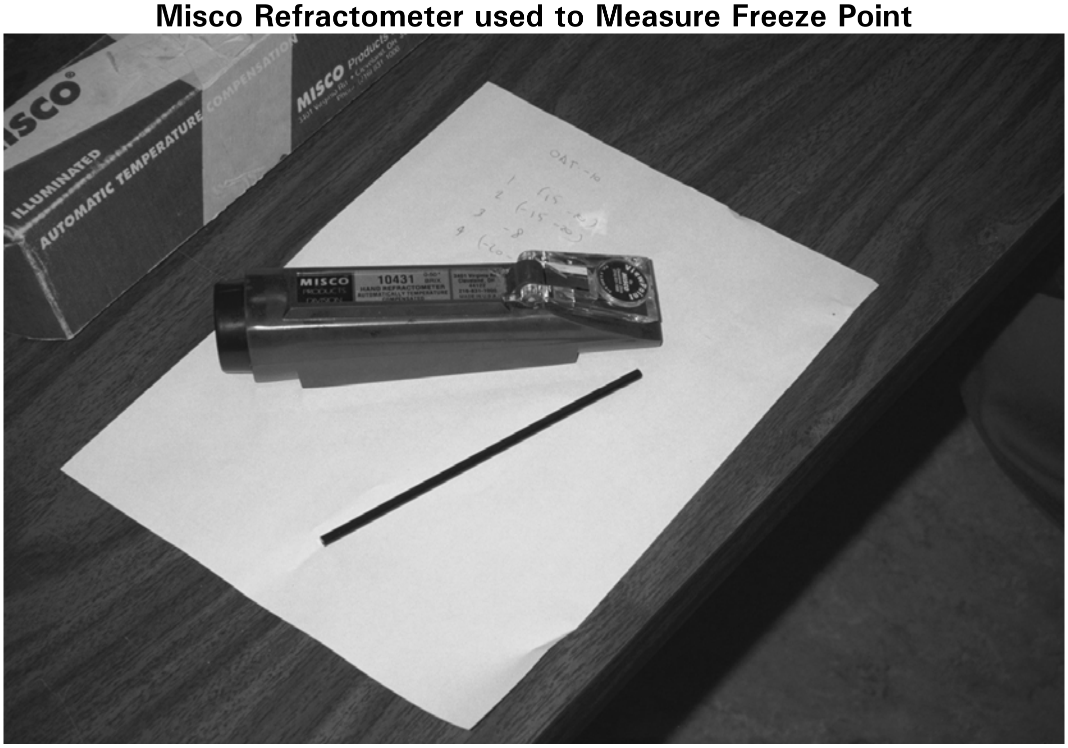
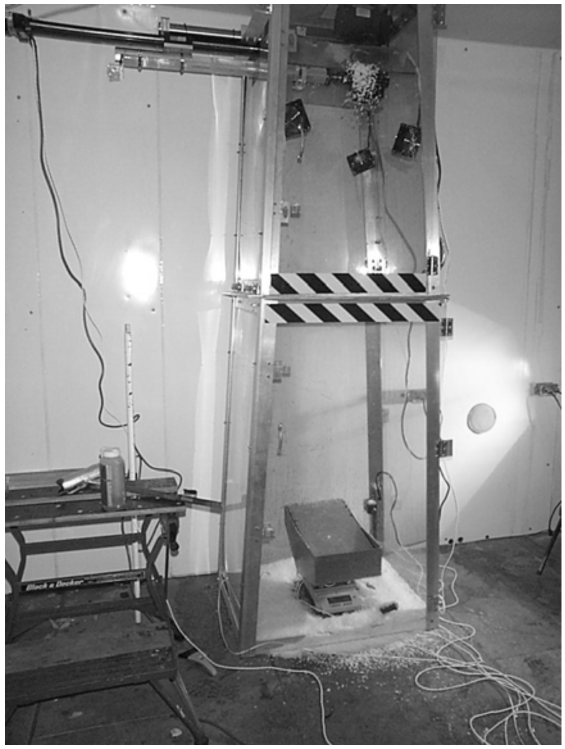


Photo 2.13
NCAR Bucket Assembly during Outdoor Testing

Photo 2.14
Test Chamber at CRIQ

Photo 2.15
NCAR Artificial Snow Machine at CRIQ



3. DESCRIPTION AND PROCESSING OF DATA

This section describes the processing of data for each test objective.

All tests conducted with the NCAR snow machine prior to June 2001 used the second-generation system described in last year's Transport Canada report, TP 13661E, *A Second Generation Snowmaking System - Prototype Testing*, (2). Modifications were made to the second-generation system in June by NCAR staff, and additional testing was conducted in two separate sessions in June 2001.

3.1 Conformance of the NCAR Artificial Snow Generation System with the Test Parameters Outlined in the Proposed Aerospace Standard 5485

3.1.1 Rate Distribution

The procedure for determining the distribution of snowfall rates using the NCAR machine is described in Subsection 2.1.2.

Distribution trials were conducted with 15 individually pre-weighed pans covering the test plate. Precipitation was produced at a specific icing intensity rate and for a set period of time. The pans were then reweighed and the amount of snow collected was determined. This data provided icing intensity distribution and the range across the test plate. The data from the 15 pans was then transformed to the 10 pans as specified in the Proposed AS 5485, using the conversion procedure described in Subsection 2.1.2.

In April 2001, 19 rate distributions were conducted at the NRC facility in Ottawa using the second-generation NCAR machine. The results of these tests appear in Table 3.1. Due to problems with the snow machine, the values for distribution tests 5, 7, and 12 are not included in the table.

In June 2001, 16 rate distribution trials were performed in two separate sessions at the NRC in Ottawa using the newly-modified NCAR snowmaker. The snow distribution results from these tests appear in Table 3.2.

The data for each snow distribution trial are provided in Appendix E. The icing intensity range for each distribution test in Appendix E is the difference (in $g/dm^2/h$) between the ice catch pan that has collected the most snow and that that has collected the least snow.

TABLE 3.1

NCAR Icing Intensity Results

April 2001

For 10 Ice Catch Pans

Test No.	Range Obtained g/dm²/h	AS 5485 Proposed Range g/dm²/h	Command Rate g/dm²/h	AS 5485 Proposed Icing Intensity g/dm²/h	Chamber Temperature (ºC)
1	6.4	≤4.0	25	25±1.0	-14
2	5.1	≤4.0	25	25±1.0	-14
3	8.6	≤1.5	10	10±0.5	-14
4	10.7	≤4.0	25	25±1.0	-14
5					
6	14.9	≤4.0	25	25±1.0	-3
7					
8	25.7	≤4.0	25	25±1.0	-3
9	27.6	≤4.0	25	25±1.0	-3
10	17.3	≤4.0	25	25±1.0	-3
11	14.1	≤4.0	25	25±1.0	-3
12					
13	18.3	≤4.0	25	25±1.0	-3
14	13.2	≤4.0	25	25±1.0	-3
15	12.7	≤4.0	25	25±1.0	-3
16	8.0	≤4.0	25	25±1.0	-3
17	8.5	≤4.0	25	25±1.0	-3
18	11.2	≤4.0	25	25±1.0	-3
19	14.0	≤4.0	25	25±1.0	-3

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TABLE 3.2

NCAR Icing Intensity Results

June 2001

For 10 Ice Catch Pans

June 4 to 7, 2001

Test no.	Range Obtained g/dm²/h	AS 5485 Specified Range g/dm²/h	Command Rate g/dm²/h	AS 5485 Specified Icing Intensity g/dm²/h	Chamber Temperature (ºC)
1	12.3	≤4.0	25	25 ±1.0	-3
2	5.5	≤4.0	25	25 ±1.0	-3
3	6.2	≤4.0	25	25 ±1.0	-3
4	6.7	≤1.5	10	10 ±0.5	-3
5	8.9	≤4.0	25	25 ±1.0	-3
6	8.5	≤4.0	10	10 ±0.5	-31
7	5.3	≤1.5	10	10 ±0.5	-31
8	17.9	≤4.0	25	25 ±1.0	-31

June 26 to 28, 2001

Test no.	Range Obtained g/dm²/h	AS 5485 Specified Range	Command Rate g/dm²/h	AS 5485 Specified Icing Intensity g/dm²/h	Chamber Temperature (ºC)
1	4.4	≤1.5	10	10 ±0.5	-29
2	3.1	≤1.5	10	10 ±0.5	-25
3	9.3	≤4.0	25	25 ±1.0	-11
4	9.6	≤4.0	25	25 ±1.0	-21
5	13.1	≤4.0	25	25 ±1.0	-11
6	4.7	≤1.5	10	10 ±0.5	-15
7	5.0	≤1.5	10	10 ±0.5	-15
8	7.5	≤4.0	25	25 ±1.0	-5

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3.2 Intra-Laboratory Snow Reconciliation

The intra-laboratory snow reconciliation test program was performed to evaluate and compare the endurance times obtained by APS, AMIL, and NCAR in both natural and artificial snow.

3.2.1 Natural Snow Tests (APS, AMIL, and NCAR Natural Snow Data)

APS personnel conducted 95 Type IV fluid endurance time tests in natural snow during the winter of 2000-01 at the Dorval test site. An additional 82 tests were performed by AMIL at their facility in Chicoutimi. A summary of the tests conducted by APS and AMIL appears in Table 3.3. These test data were obtained using common test procedures and fluid from the same production batches.

The test logs for APS and AMIL natural snow endurance time testing appear in Appendix F.

3.2.1.1 Standard Plate Temperature Profiles

Two thermocouples were embedded in each of the test plates used in natural snow testing. The thermocouples were linked to a data logger and the plate temperatures were recorded at 4-second intervals. The temperature profiles for each outdoor test were recorded and the data is available, if required. An example of the temperature profiles of a standard test plate with fluid during a natural snow event is shown in Figure 3.1.

3.2.1.2 Photographs of Fluid Failure and Snowflake Size

Photography of the appearance of failure for each natural snow endurance time test was recorded by APS personnel. Photos were taken at the moment of fluid failure and 5 minutes following fluid failure for each test. Examples of the photos recorded for one test in natural snow are shown in Photos 3.1 and 3.2.

In addition, to characterize the snowflakes observed during natural snow testing, a felt-covered board was exposed to the snow prior to and following the completion of each test. A ruler with millimetre increments

TABLE 3.3

Natural Snow Endurance Time Tests

Winter 2000-2001

Total Tests: 177

	APS	AMIL	Total
Kilfrost ABC-S 100	14	9	23
Kilfrost ABC-S 75/25	15	19	34
Kilfrost ABC-S 50/50	8	2	10
SPCA AD-480 100	15	9	24
SPCA AD-480 75/25	17	11	28
SPCA AD-480 50/50	10	0	10
UCAR Ultra+ 100	16	32	48
Total:	95	82	177

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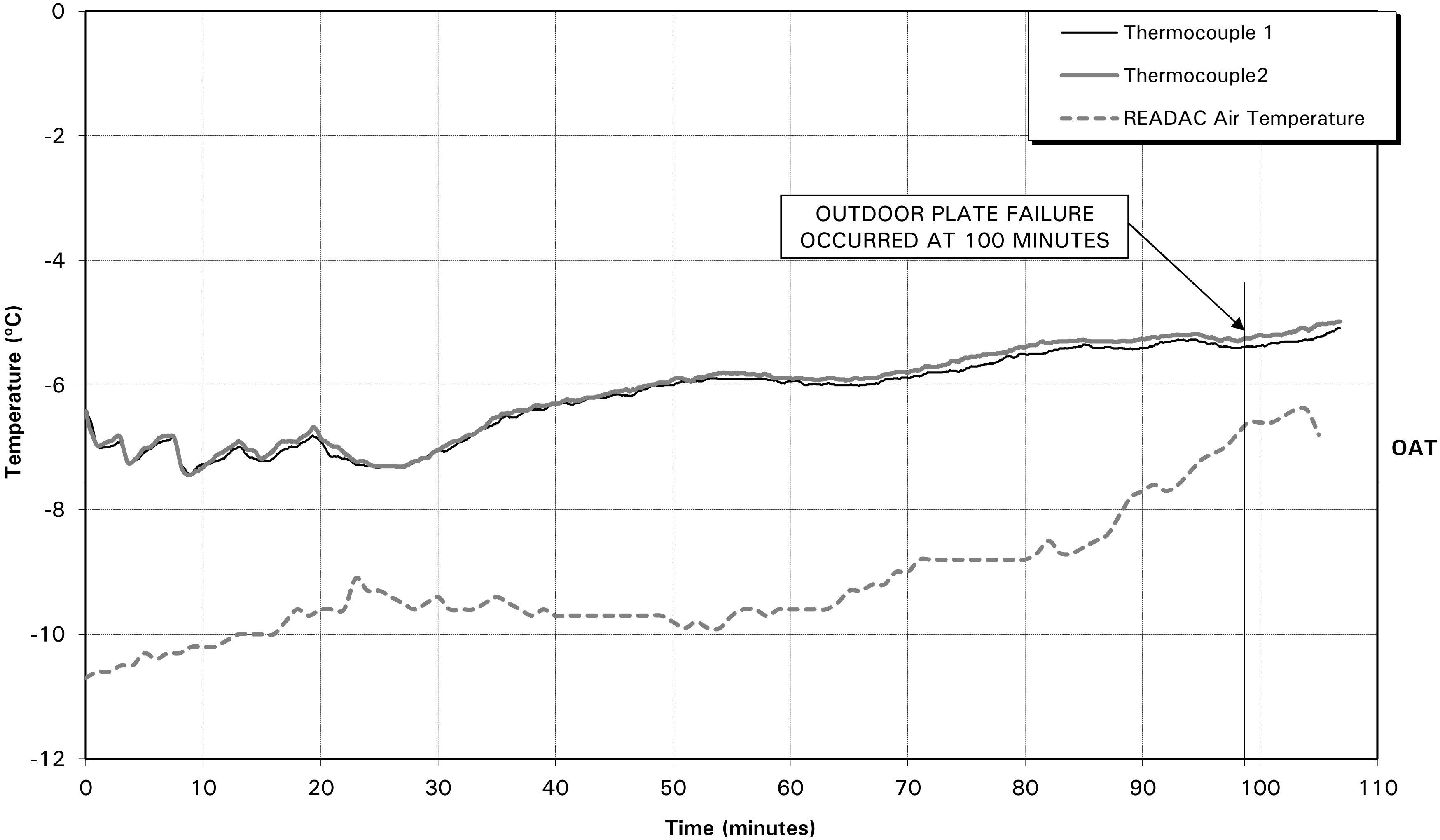
FIGURE 3.1

Temperature Profiles on a Standard Flat Plate

SPCA AD-480 75/25

Wind Speed 16 km/h Icing Intensity 10.5 g/dm^2/h



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was placed on the board to measure the individual flakes. Photographs of the snowflakes for each test were recorded before and after the failure of each plate (see Photo 3.3).

All photo documentation recorded by APS can be made available, if required.

3.2.2 Artificial snow tests (Indoor vs. outdoor comparison)

Thirty-six indoor artificial snow tests were conducted by APS personnel at the NRC facility in Ottawa using the NCAR snowmaker. Type IV tests were conducted at 10 and 25 $g/dm^2/h$. These snow precipitation rate limits have traditionally been used for the evaluation of snow endurance times. The test log containing the 36 indoor snow tests appears in Appendix G.

3.2.2.1 NCAR Plate Temperature Profiles

A thermocouple embedded within each of the test plates was used in artificial snow testing. The thermocouples were linked to a laptop computer and *Labview* software and the plate temperatures for each indoor test were recorded at 8-second intervals. An example of the temperature profiles of a NCAR plate with fluid during a simulated snow event is shown in Figure 3.2.

3.3 NCAR Snow Reconciliation

The bucket assembly used for NCAR indoor tests was positioned outdoors for natural snow testing during the winter of 2000-01 at the Dorval Airport test site. In total, 18 fluid endurance time tests on the bucket assembly were conducted in natural snow. These results appear in Table 3.4, in the *Natural Snow Data* columns.

The indoor snow trials were aimed at reconciling differences between indoor and outdoor tests using the NCAR bucket assembly. The 18 data points collected outdoors by APS on the NCAR bucket assembly were to be duplicated indoors with the NCAR snowmaking system, using the newly designed *variable autorate* function. APS attempted on two occasions in June 2001 to complete the indoor tests at the National Research Council CEF in Ottawa; however, due to problems with the NCAR machine, these tests were unsuccessful.

FIGURE 3.2

Plate Temperature (°C) Profile For Indoor Artificial Snow Test

SPCA AD-480 75/25

Command Rate:10 g/dm²/h , OAT:-13.0°C

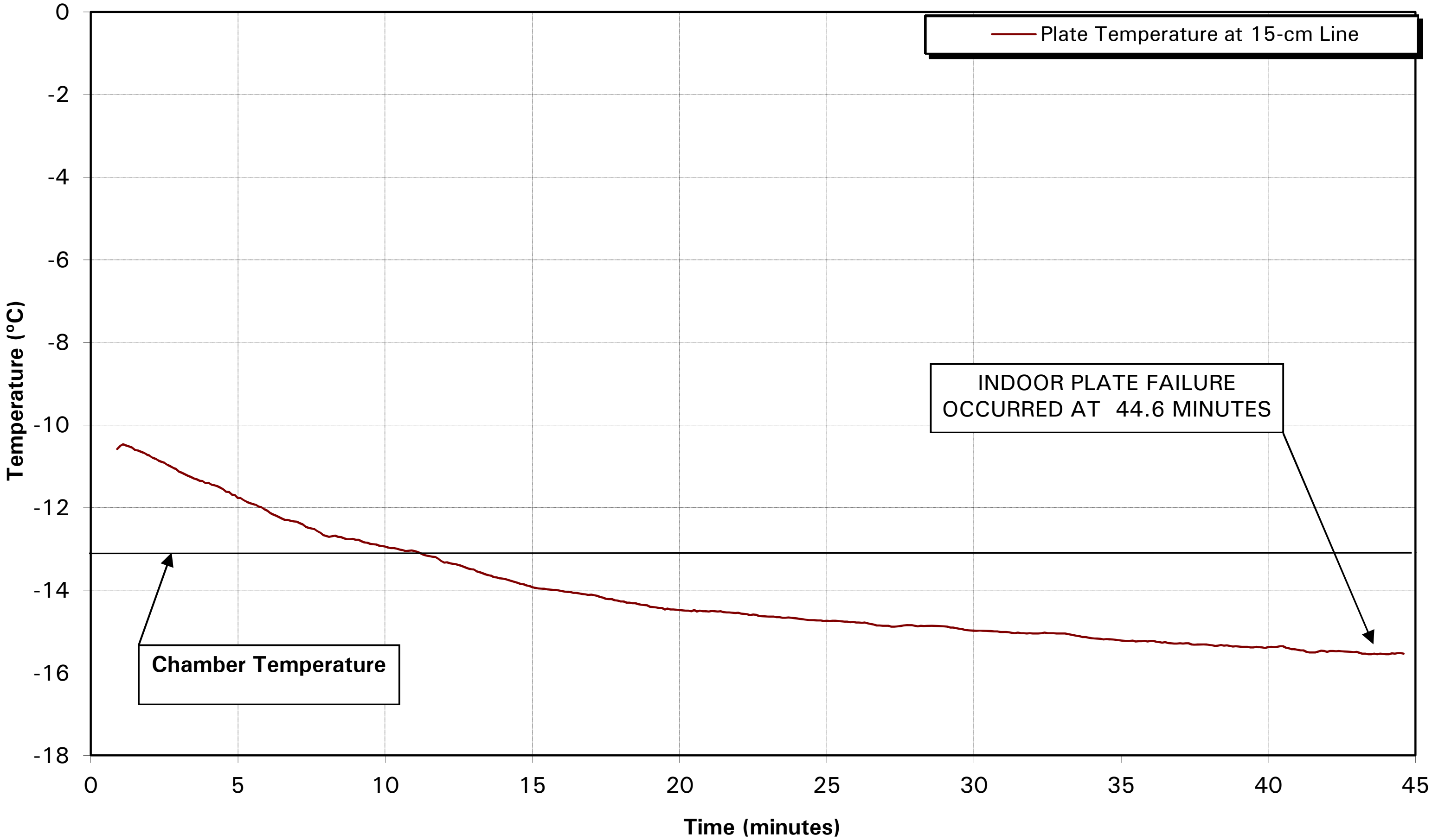

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Table 3.4

Comparison of Results Using NCAR Electronic Data Files

Fluid Name	Fluid Dilution	Outdoor Test Date	Outdoor Snow Data: Fail Time [min.]	Outdoor Snow Data: Actaul Icing Intensity	Outdoor Snow Data: Air Temperature (°C)	Outdoor Snow Data: Fluid Brix	Indoor Snow Data: Fail Time [min.]	Indoor Snow Data: Actual Icing Intensity	Indoor Snow Data: Air Temperature (°C)	Indoor Snow Data: Fluid Brix
UCAR ULTRA +	Neat	Feb-05-01	49.5	14.9	-6.8	11				
SPCA AD-480	Neat	Feb-14-01	111.3	7.5	-5.0	12	90.7	6.0	-6.2	18
KILFROST ABC-S	Neat	Feb-14-01	82.5	13.0	-5.0	12	47.5	15.3	-5.3	19
SPCA AD-480	75%	Feb-14-01	78.5	8.1	-4.0	12	51.0	8.3	-3.7	14.5
KILFROST ABC-S	50%	Feb-19-01	9.2	27.1	-3.0	10				
UCAR ULTRA +	Neat	Feb-19-01	22.3	32.4	-3.0	8				
KILFROST ABC-S	Neat	Feb-23-01	103.0	2.1	-17.0	25	never failed	2.2	-16.3	25.5
SPCA AD-480	Neat	Feb-23-01	96.8	1.1	-17.0	26.5				
SPCA AD-480	75%	Feb-25-01	62.3	9.1	-10.0	16	41.7	9.2	-9.7	19
UCAR ULTRA +	Neat	Feb-25-01	32.2	27.4	-9.0	14	29.8	22.4	-7.9	16
SPCA AD-480	50%	Mar-05-01	25.3	11.7	-3.0	7				
KILFROST ABC-S	50%	Mar-05-01	18.3	9.1	-3.0	7				
SPCA AD-480	50%	Mar-05-01	33.0	6.5	-3.0	7.5				
KILFROST ABC-S	75%	Mar-06-01	76.5	9.3	-3.0	6.75				
KILFROST ABC-S	75%	Mar-11-01	88.0	12.0	-1.0					
KILFROST ABC-S	75%	Mar-13-01	59.0	5.5	-7.0	16	50.0	5.2	-8.1	
SPCA AD-480	Neat	Mar-13-01	40.5	22.4	-6.7	16	31.0	16.6	-6.0	20.3
SPCA AD-480	75%	Mar-13-01	34.5	9.2	-7.0	16	24.3	15.5	-6.0	17.3

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The test data from the outdoor natural snow bucket trials, including the electronic data files, were then provided to NCAR. The tests were then reproduced indoors by NCAR at their facility in Boulder, Colorado. Of the 18 files provided to NCAR, only 8 were successfully reproduced indoors. These tests also appear in Table 3.4, in the *Indoor Snow Data* columns.

The average rates of the indoor and outdoor tests in Table 3.3 were not always identical. This was due in large part to the inferior failure times of the indoor tests. In all indoor tests, the rate profiles of the indoor and outdoor tests were essentially the same up to the failure point of the indoor plate. In several cases, the outdoor rates fluctuated following the failure point of the indoor test, which ultimately led to differences in the average rate.

3.3.1 NCAR Bucket Plate Temperature Profiles

The NCAR snowmaker automatically logs the plate temperature at the 15-cm (6-in) line on the test plate. These data have been charted to compare the temperature behaviour of fluids as they moved toward failure in indoor and outdoor tests with the NCAR bucket assembly. An example of the temperature profiles recorded on the NCAR bucket assembly during a natural snow event is shown in Figure 3.3. An example of the temperature profile of a fluid on the NCAR bucket assembly during an indoor snow event is shown in Figure 3.2. The plate temperature data were recorded for all indoor and outdoor tests.

3.4 Comparison of Indoor and Outdoor Endurance Times for a Certified Type IV New Fluid

Endurance time test data were generated in natural snow and artificial snow for Type IV Product A, a propylene glycol-based, certified Type IV fluid. The failure times recorded from the artificial snow flat plate trials were compared to the natural snow regression curves for each fluid dilution tested. The natural snow curves are power law regression curves based on all available data for each fluid dilution. Artificial snow trials were performed at precipitation rates of 10 and 25 $g/dm^2/h$.

In total, 53 tests were completed with three dilutions of Type IV Product A in natural snow. In addition, 23 tests were performed in artificial snow using the second-generation NCAR machine. These results were compared and are discussed in Subsection 4.4.

A log of these tests has been included in Appendix H.

FIGURE 3.3

Plate Temperature (°C) Profile for Natural Snow Testing at Dorval

SPCA AD-480 75/25 (NCAR BUCKET)

Icing Intensity: 9.2 g/dm²/h OAT:-3.4°C

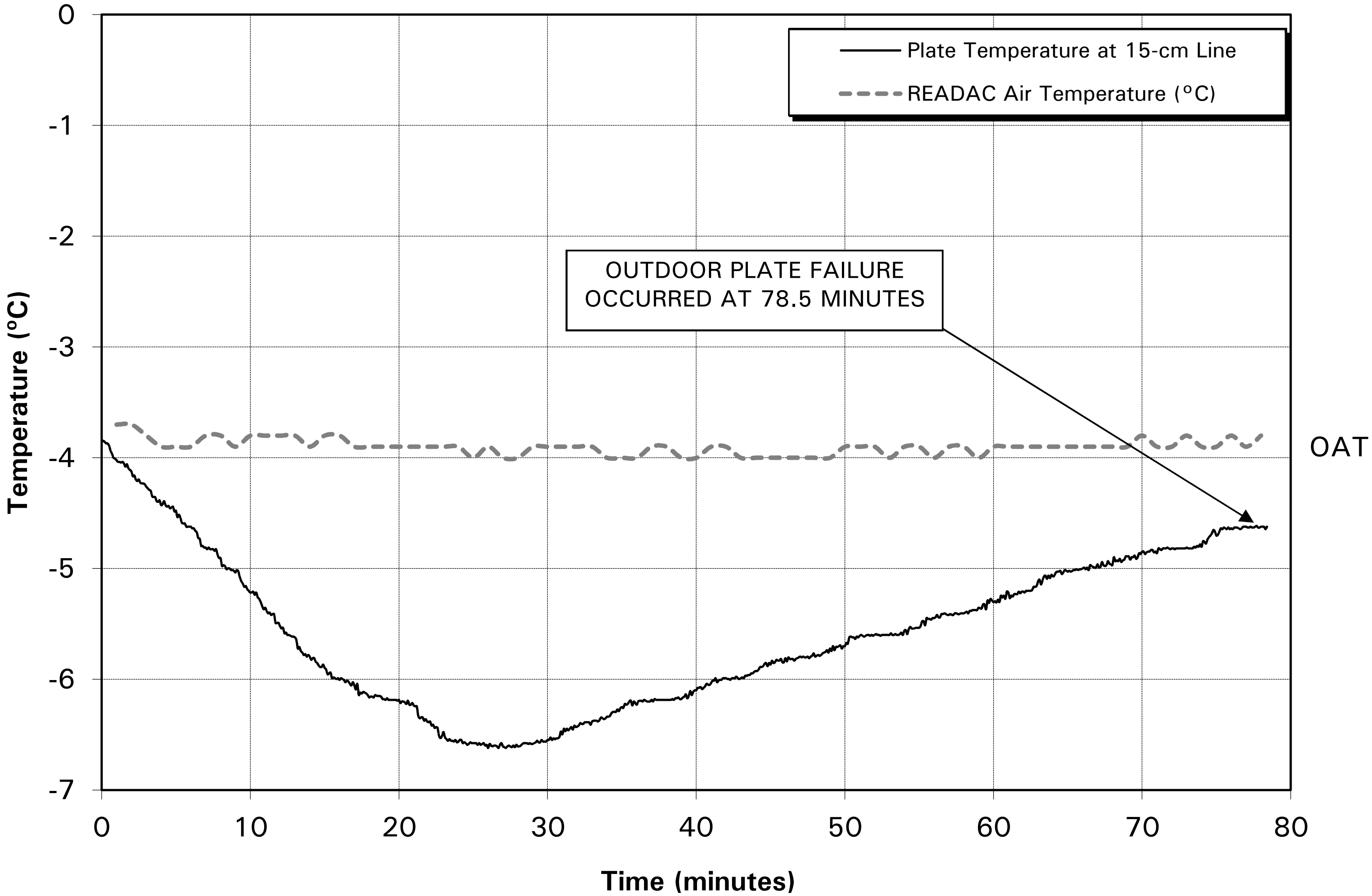

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Photo 3.1
Intra-Laboratory Natural Snow Tests
Kilfrost ABC-S 75/25 Fluid at Plate Failure

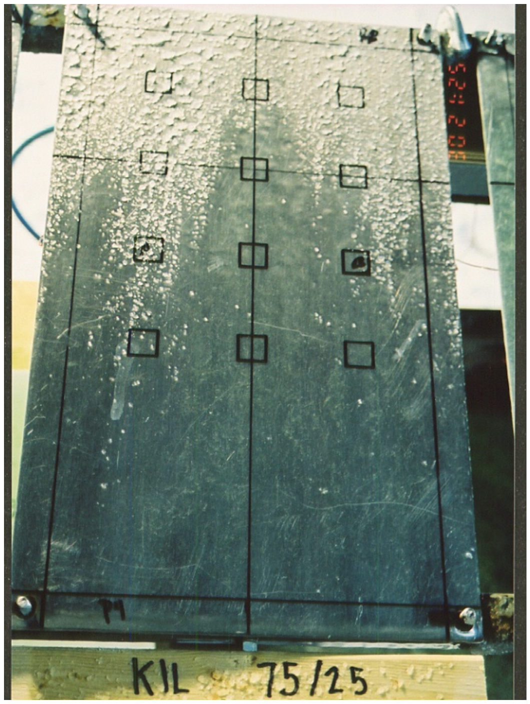


Photo 3.2
Intra-Laboratory Natural Snow Tests
Kilfrost ABC-S 75/25 Fluid Five Minutes Following Plate Failure

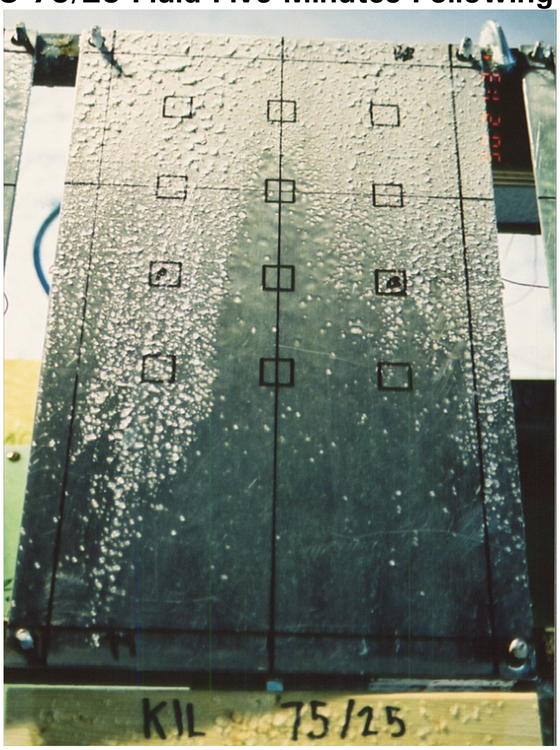
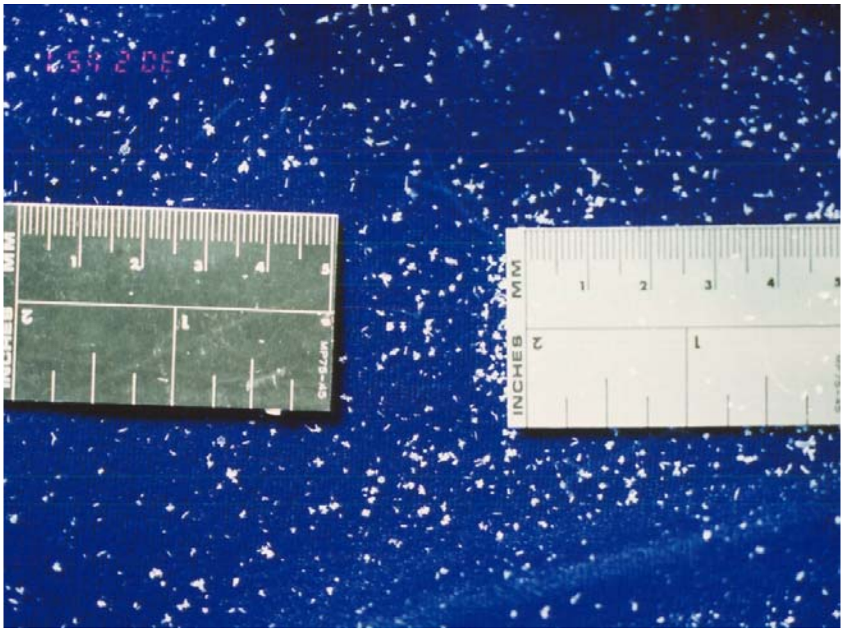


Photo 3.3
Snowflake Characterization – Natural Snow



4. ANALYSIS AND OBSERVATIONS

This section presents discussions of the observations made during the trials, and compares the experimental data collected indoors with data from natural snow trials.

4.1 Snow Distribution Trials

The initial comments recorded by the test observers during the snow distribution trials include the following:

- The snow “flakes” have a distinctive shape that is unlike natural snow; it forms mostly long curled shavings;
- The distribution of precipitation is not always consistent; some sections of the test plate received significantly more snow;
- Snow clumping occurs on the air shroud at the top of the snowmaker; these clumps sometimes fall on the test plate below; and
- The ice cores are less prone to cracks or breaks if kept from subliming after removal from the aluminium tubes.

4.1.1 Snowflake Characteristics

The flakes produced by the snowmaker were shavings cut from a long ice core, and were similar in size at all temperatures. Based on visual observation, the flakes were, on average, larger than those found in nature, especially at colder temperatures. Natural snow typically forms smaller crystals at colder temperatures. The flat or curled, non-dendritic shape of the artificial snow caused the flakes to sit on top of the fluid surface and required additional time to be absorbed, especially on top of a highly viscose fluid at colder temperatures. This caused fluids to fail prematurely.

During June 2001 testing, photos of the snow generated by the NCAR machine were recorded at –14°C. An example of the snow generated at this temperature appears in Photo 4.1. The rate of precipitation for this test was 10 $g/dm^2/h$. The diameter of the snowflakes in this photo ranges from less than 1 mm to 15 mm. The average diameter is roughly 3 to 4 mm.

Tests were also conducted in natural snow at the Dorval test site at -14°C during the winter of 2000-01 (see Photo 4.2). In this case, most if not all of the snowflakes had diameters less than 1 mm. While it is noteworthy that this was only one test, the size of the snowflakes at this temperature was typical of those observed by APS personnel in previous years.

Since the snowflakes produced by the NCAR snowmaker are similar at all temperatures, natural snowflakes at -3°C and the snowflakes produced by the NCAR snowmaker at -3°C may also be compared. Natural snow observed at the Dorval test site at -3°C is shown in Photo 4.3. The diameter of the snowflakes presented in this photo ranges from about 0.5 mm to 3 mm, with an average diameter of roughly 1 to 1.5 mm. These snowflakes are typical of those observed in the past by APS personnel at Dorval at this temperature.

The diameters presented above lend support to visual observations that the flakes produced by the NCAR snowmaker were, on average, larger than those found in nature. This seems to be especially true at colder temperatures.

4.1.2 Snow Distribution Trial Results

The main focus of the snow distribution trials was to determine the variation in icing intensity range over the surface of the test plate. The results of these trials indicated that the distribution was not uniform.

In April 2001, 19 rate distributions were conducted at the NRC facility in Ottawa using the second-generation NCAR machine. Under the direction of NCAR, four additional fans were installed, making eight in total. This eight-fan system was intended to improve the snow distribution over the test plate. Unfortunately, these distribution trials provided very unsatisfactory results. The results of the April 2001 distribution trials are presented in Table 3.1.

The results obtained for distribution range in the April 2001 trials were 1.3 to 6.9 times greater than the acceptable range in AS 5485. The average icing intensity range obtained was 3.6 times the acceptable range outlined in AS 5485. As a result of these distribution trials, all endurance time testing with the NCAR snowmaker was halted pending further modifications.

In June 2001, modifications were made to the NCAR machine to improve the snow distribution over the test plate. A snow distribution plenum was received in mid-April 2001 and installed for the June tests. It consisted of a curved acrylic box whose bottom panel was drilled with an evenly-spaced grid of holes. The top of the plenum box supported two large fans. These two fans pressurized the plenum box and the air was forced out through the tiny holes on the underside of the box.

The snow distribution plenum was supported over the drill bit and directed the snow downward. This configuration was supposed to create a more even snow distribution and to prevent snow from accumulating on the upper shroud. Accumulated snow had a tendency to fall onto test plates, which may have changed failure times.

During the installation of the snow distribution plenum in June, it was decided to remove all eight fans along the wall of the chamber and to rely entirely on the two large fans at the top of the machine during operation.

Sixteen rate distribution trials were performed on two separate sessions at the NRC in Ottawa in June 2001 using the newly modified NCAR snowmaker. The snow distribution results from these tests appear in Table 3.2.

Snow struck the plenum from the spinning drill bit and tended to stick there. This phenomenon disturbed the airflow pattern and caused snow to occasionally drop onto the plate below. Snow sticking to the shroud was most notable at warmer temperatures Photo 4.4 shows the snow clumping that can occur on the new shroud. This snow accumulation inhibits airflow from the fans and disrupts the snow distribution.

The results obtained for the distribution range in the June 2001 trials were 1.4 to 4.5 times greater than the acceptable ranges in AS 5485. The average icing intensity range obtained was 2.8 times the acceptable range proposed in AS 5485. These results were a slight improvement over the April 2001 distribution results, but were still far from the specified limits in the Proposed AS 5485.

Most importantly, none of the 35 distribution trials conducted with the NCAR snowmaker in April and June 2001 were within the prescribed limits outlined in the Proposed AS 5485. The resolution of snow intensity distribution issues must be considered of the highest priority for future use of the NCAR machine.

4.1.3 Ice Core Preparation

For best results, it is recommended that the aluminium tubes used for the production of ice cores be insulated.

The ice cores were produced in aluminium tubes as shown in Photo 4.5. These aluminium tubes contributed to the production of ice cores with a reduced tendency to crack and shatter. The AS 5485 procedure suggests the use of insulated tubes for the production of ice cores. When the ice cores are frozen in insulated tubes, the water freezes from the bottom up and less air is trapped in the ice.

Insulation tubes were not available for the June 2001 trials and therefore were not used. Less core breakage was observed when the ice cores were removed from the aluminium tubes and stored overnight in closed PVC storage containers, as recommended in the NCAR operation manual. This also reduced the sublimation of the ice cores, which changes their shape and diameter and may also lead to increased core breakage.

4.2 Intra-Laboratory Snow Reconciliation

The intra-laboratory snow reconciliation test program was performed to evaluate and compare the endurance times obtained by APS, AMIL, and NCAR in both natural and artificial snow.

4.2.1 Outdoor Natural Snow Testing

APS and AMIL conducted natural snow endurance time testing of three Type IV fluids at various dilutions using common test procedures. NCAR was to participate in these flat plate trials, but instead focused their efforts on NCAR bucket assembly tests in natural snow. These tests are discussed in Subsection 4.3.

Following completion of the outdoor testing, the test data compiled by APS and AMIL were combined and the endurance times for the various fluids were determined using a regression analysis.

Data corresponding to each fluid were assembled and sorted according to dilution and temperature range. The data for each fluid and dilution in the snow holdover time table were plotted. The data points on each graph were used to fit an equation of the form:

$$t = cR^a(2-T)^b$$

where

t = Time (minutes);
R = Rate of precipitation (g/dm^2/h);
T = Temperature; and
a, b, c = Coefficients determined from the regression.

The coefficient *a* gives the rate dependency of the failure time.

Because natural snow can occur at temperatures approaching 2°C, the general form of the regression equation for natural snow used *2-T* to prevent taking the log of a negative number.

Best-fit curves were then plotted for each fluid and dilution using the most restrictive (lowest) temperature for that cell. For example, in cases of natural snow tests conducted at ambient temperatures between -3°C and -14°C, the temperature value used in the regression analysis was -14°C.

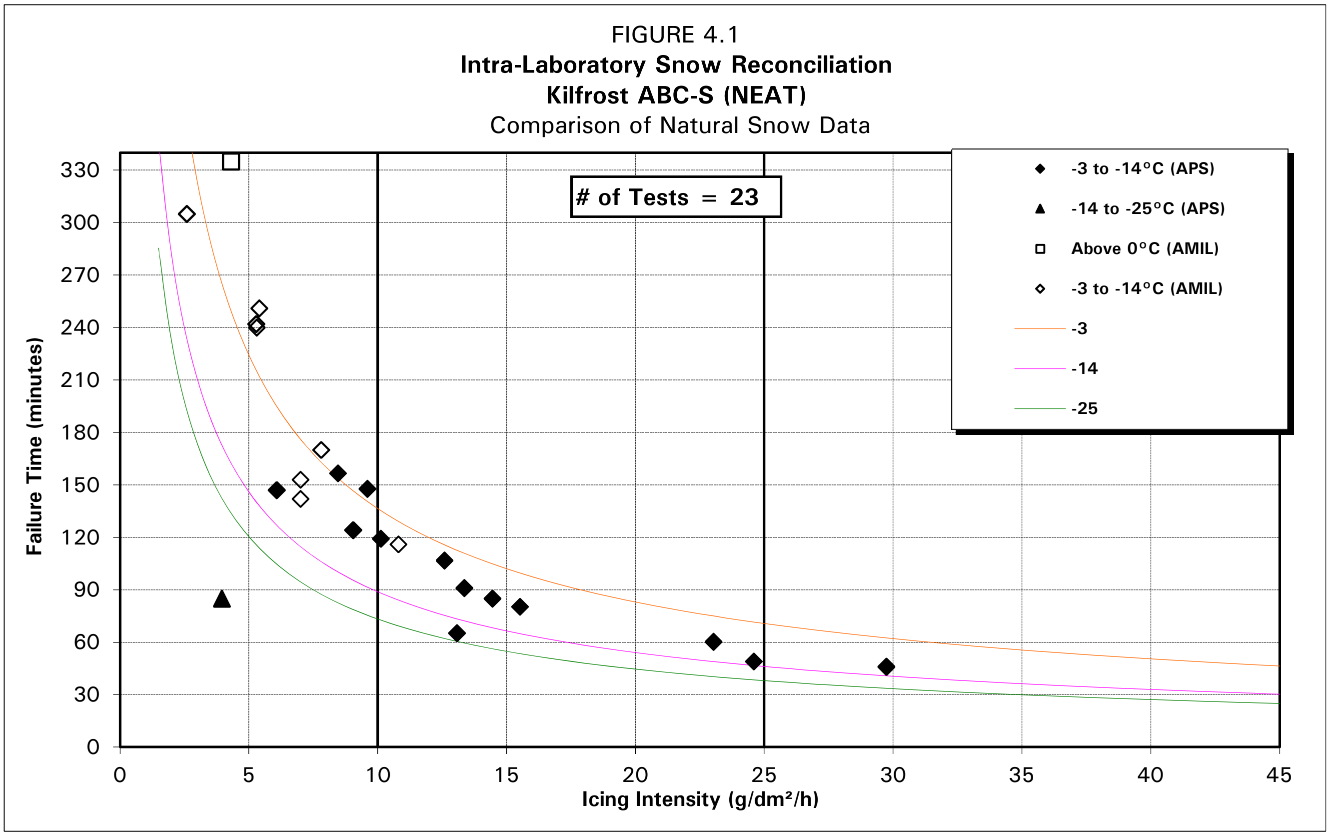
The upper and lower endurance time values for each fluid and dilution were determined from the points at which the best-fit curve intersected the lower and upper precipitation limits of 10 and 25 $g/dm^2/h$, respectively.

Figures 4.1 to 4.7 present the natural snow test data by APS and AMIL and the regression curves generated for each data set. In general, the data produced by APS and AMIL compares quite well, although most of the AMIL data were collected at lower precipitation rates.

4.2.2 Indoor Artificial Snow Testing

Thirty-six indoor artificial snow tests were conducted by APS personnel at the NRC facility in Ottawa using the NCAR snowmaker. All tests were conducted at 10 and 25 $g/dm^2/h$. These snow precipitation rate limits have traditionally been used for the evaluation of snow endurance times, and have been proposed for future use in AS 5485. The results of the indoor snow trials, presented for each fluid and dilution, appear in Figures 4.8 to 4.14.

The majority of the tests were conducted at ambient temperatures other than those prescribed in the Proposed AS 5485. Because of calibration problems with the snowmaker in April 2001, APS personnel were forced to abandon the indoor endurance time trials with the NCAR machine. The tests were re-scheduled for June when other testing was performed by APS at the CEF in Ottawa. The NCAR machine was positioned in the far end of the NRC chamber where temperatures were often colder than in the regular test area for endurance time tests.



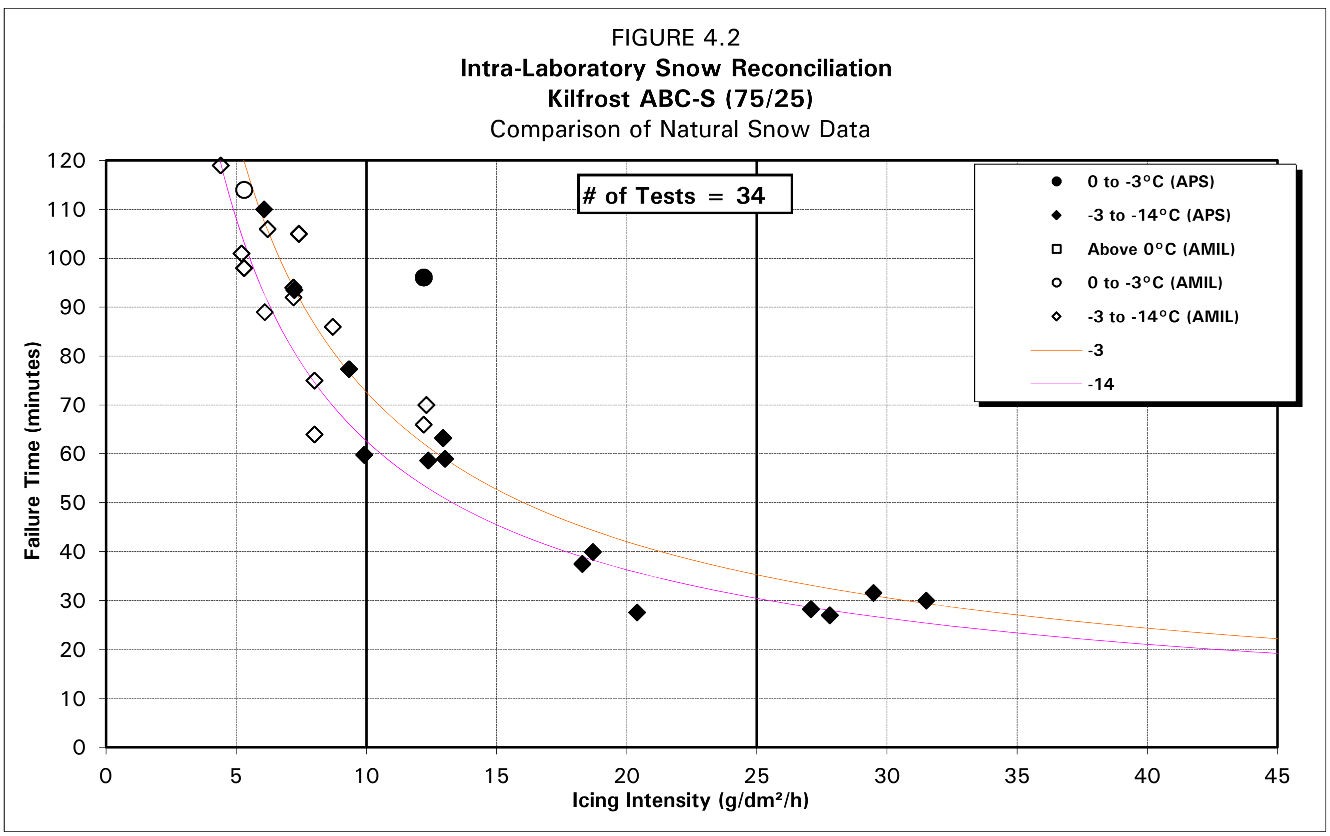


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FIGURE 4.3
Intra-Laboratory Snow Reconciliation
Kilfrost ABC-S (50/50)
Comparison of Natural Snow Data

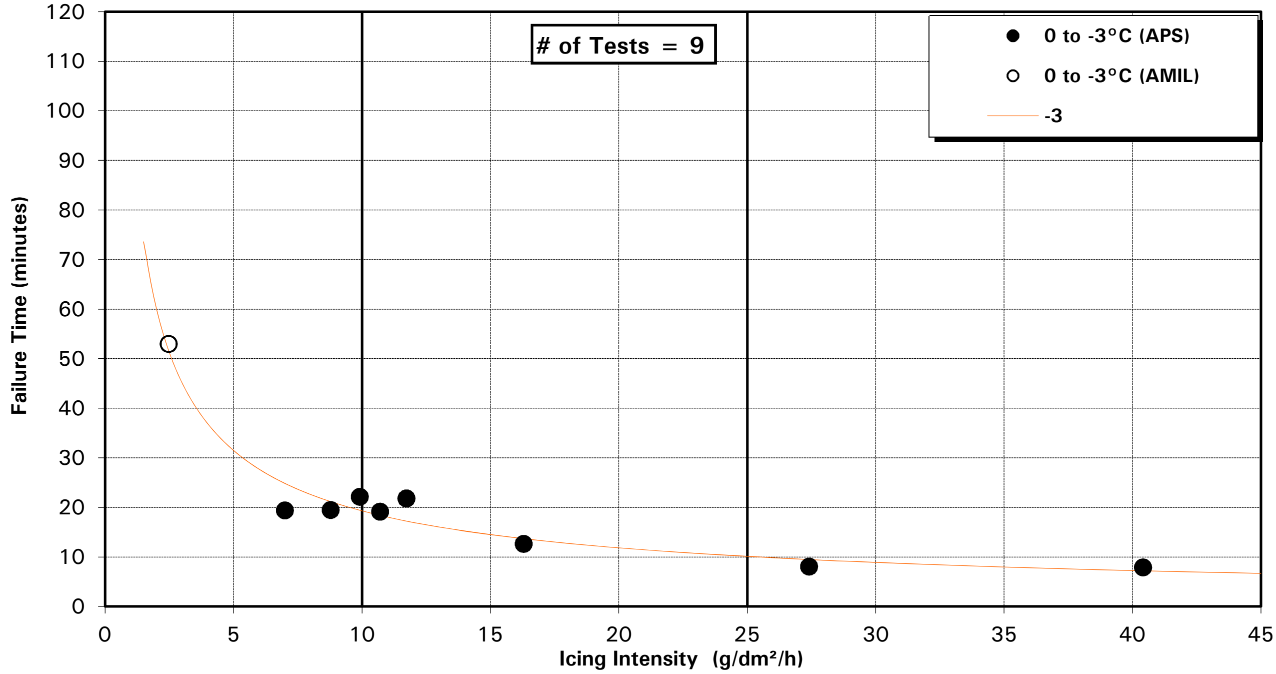

FIGURE 4.4
Intra-Laboratory Snow Reconciliation
SPCA AD-480 (NEAT)
Comparison of Natural Snow Data

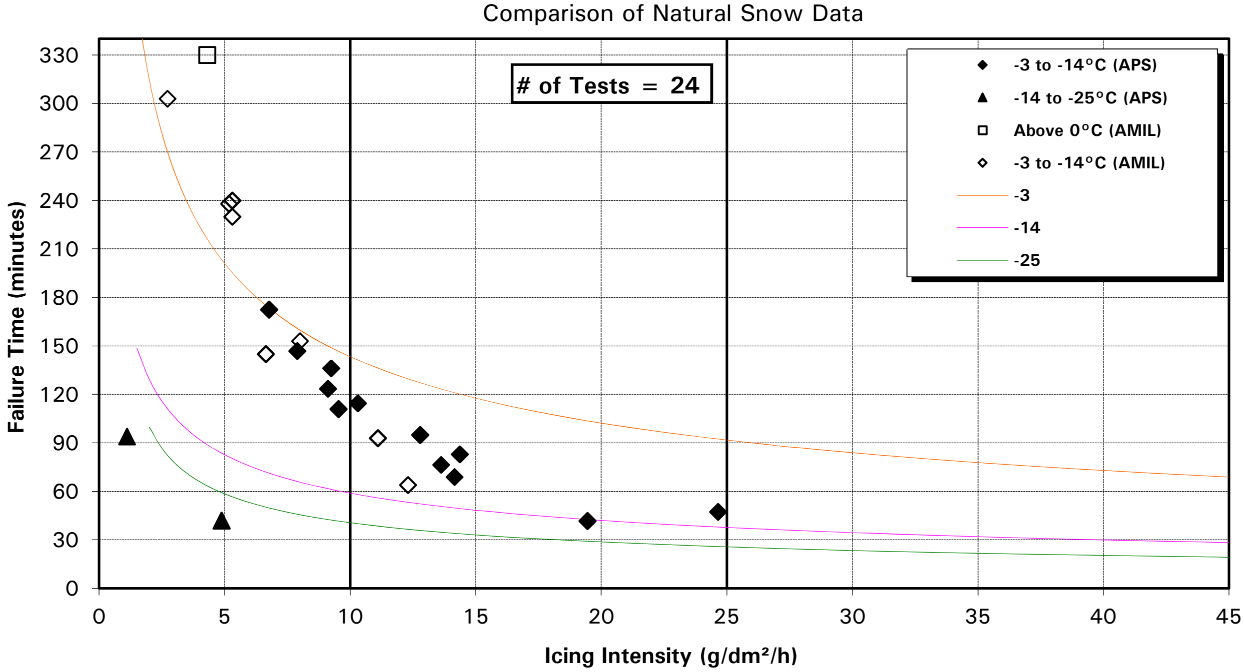

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FIGURE 4.5

Intra-Laboratory Snow Reconciliation

SPCA AD-480 (75/25)

Comparison of Natural Snow Data

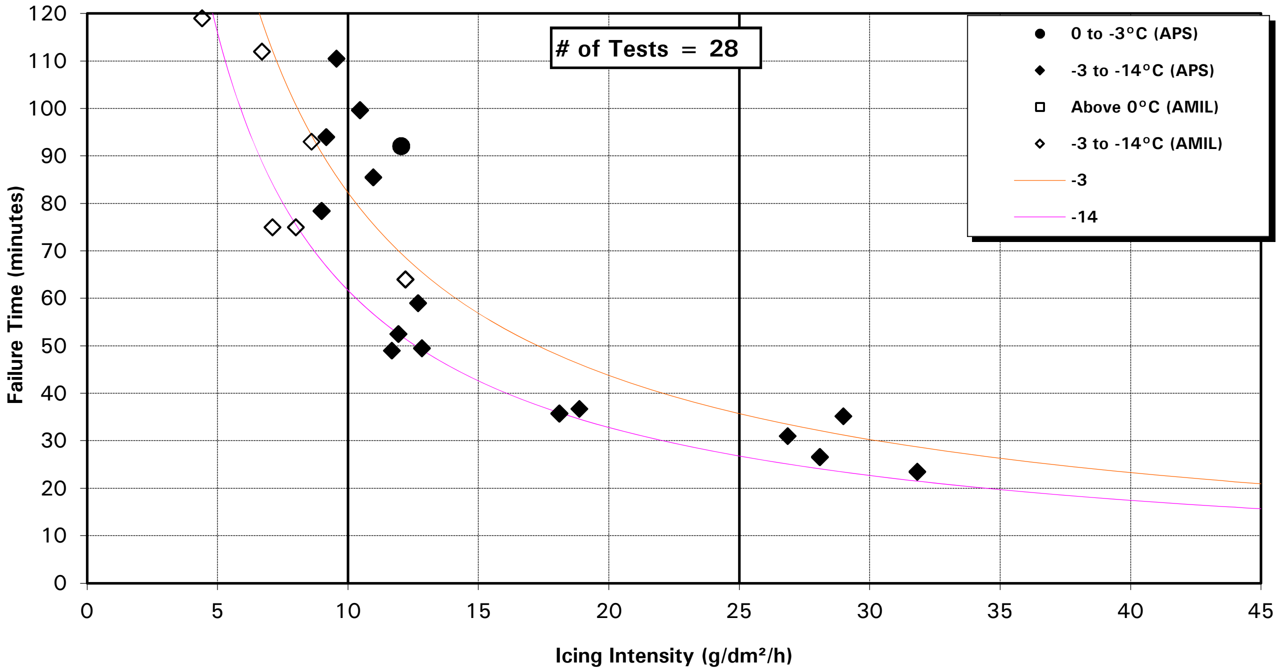

FIGURE 4.6

Intra-Laboratory Snow Reconciliation

SPCA AD-480 (50/50)

Comparison of Natural Snow Data

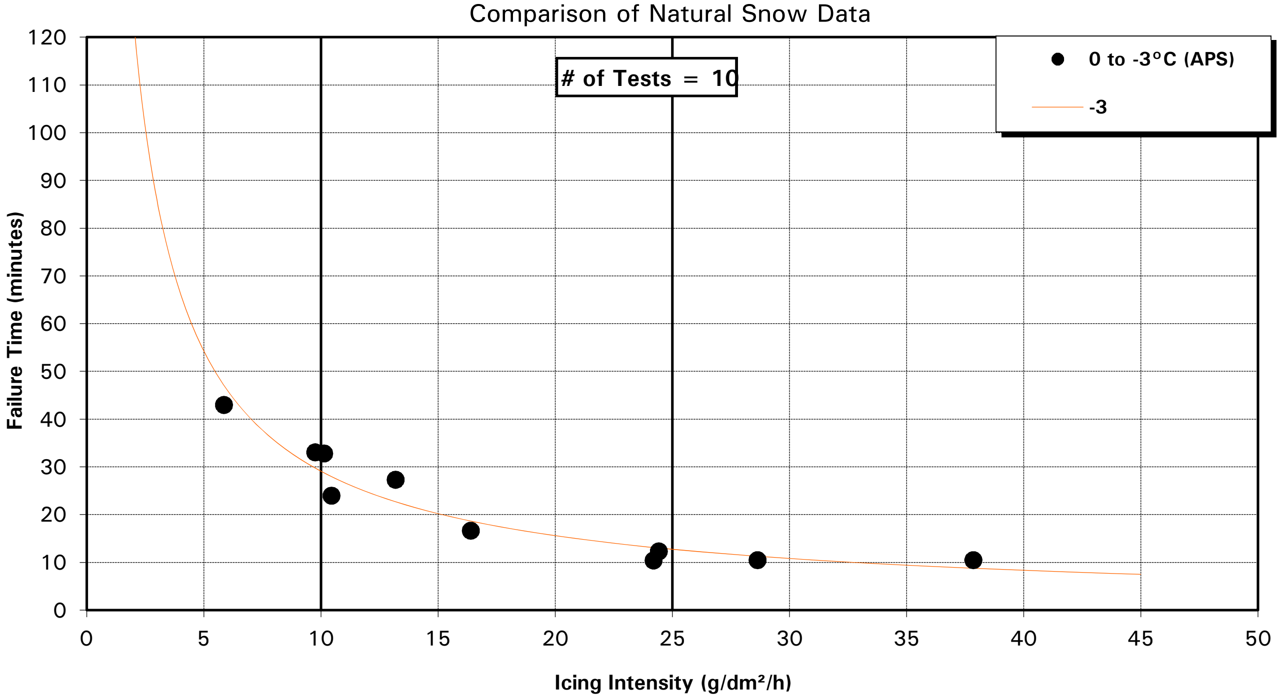

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FIGURE 4.7
Intra-Laboratory Snow Reconciliation
UCAR Ultra + (NEAT)
Comparison of Natural Snow Data

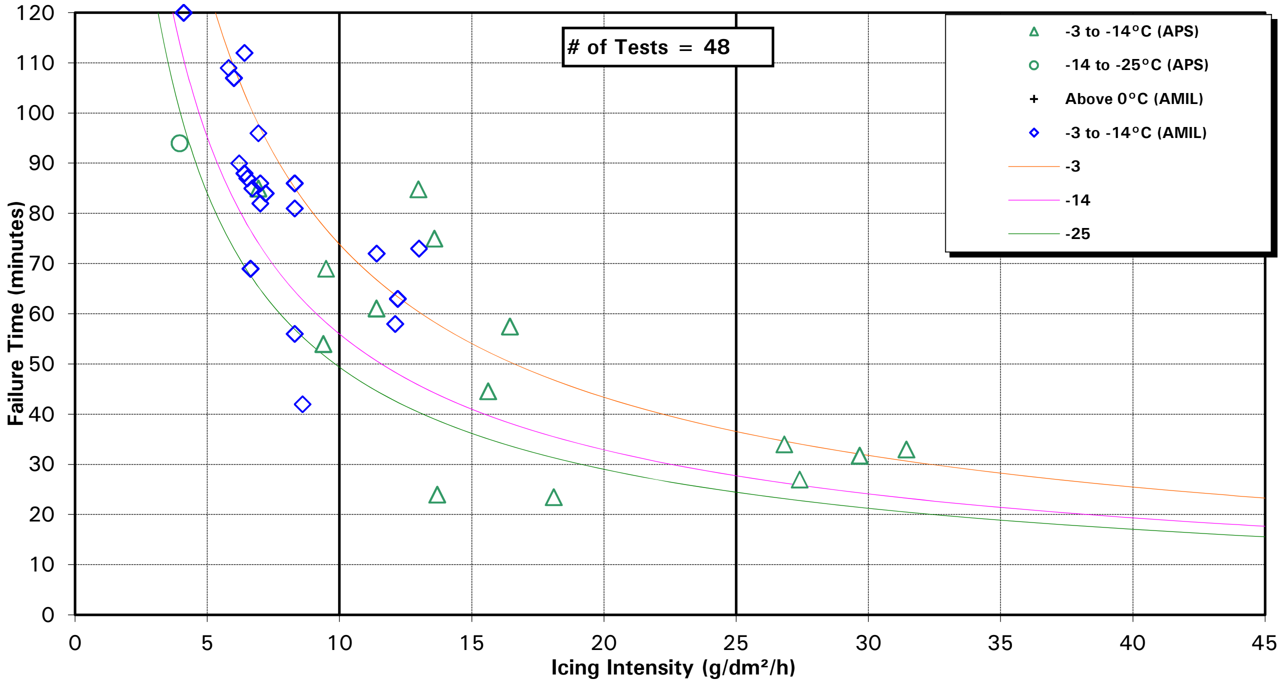
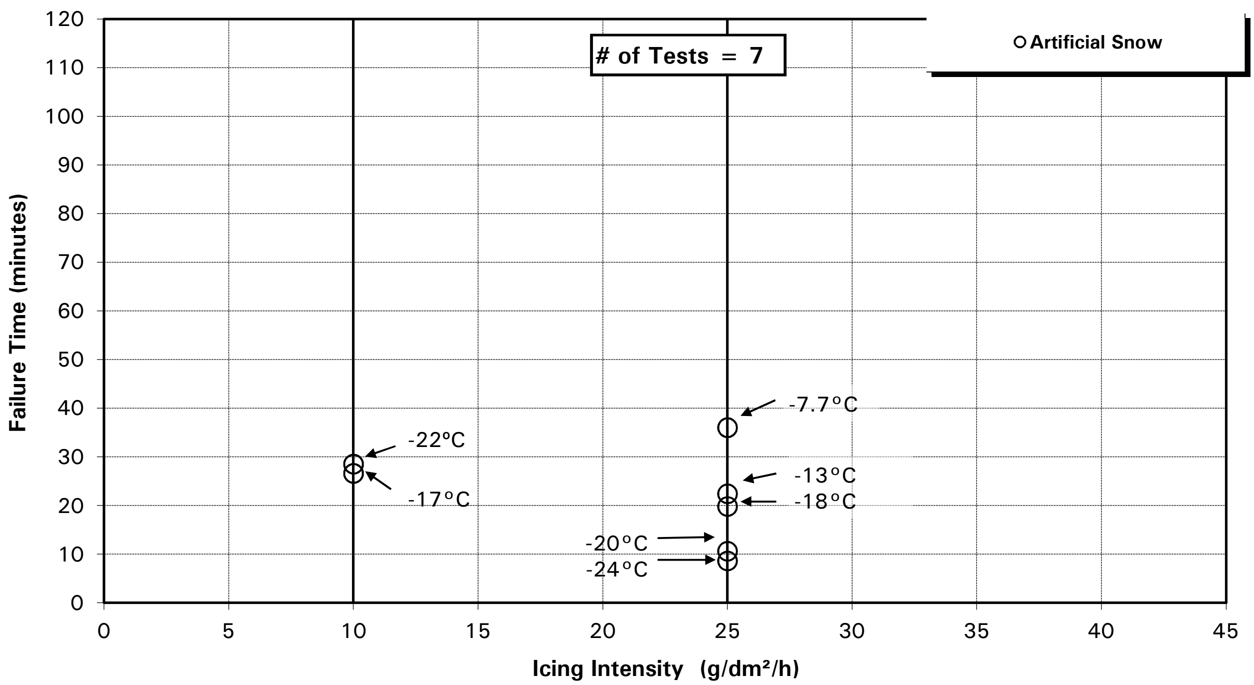


FIGURE 4.8
Intra-Laboratory Snow Reconciliation
Kilfrost ABC-S (NEAT)
Artificial Snow Data



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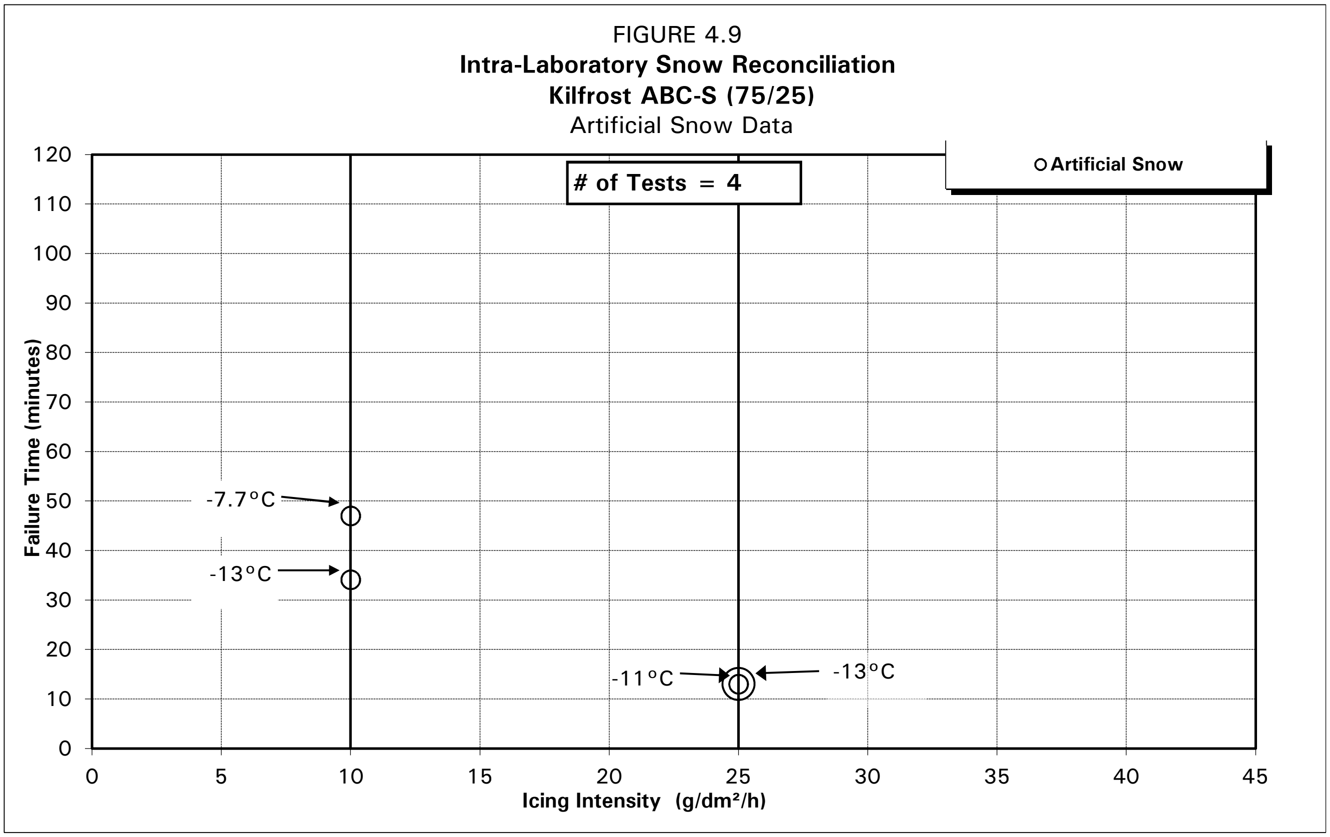

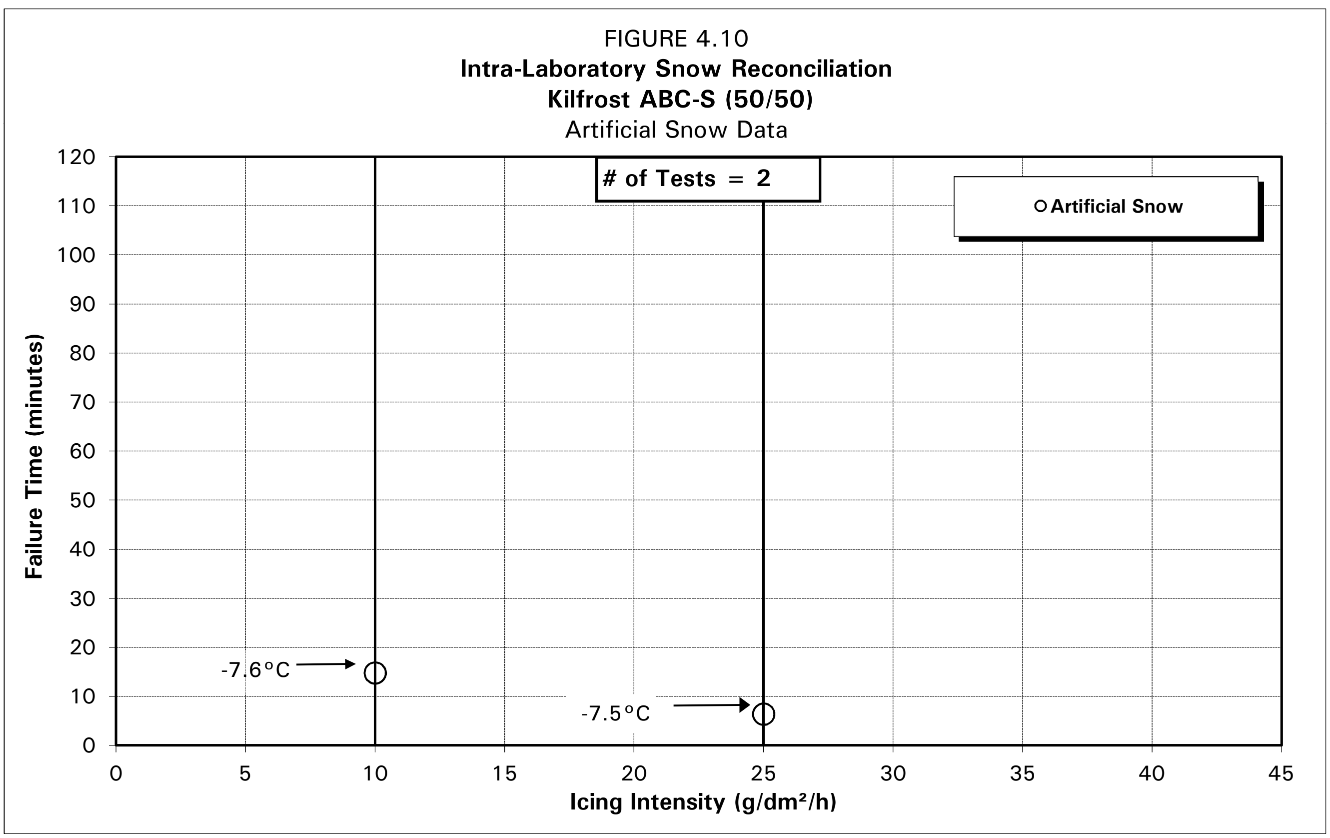

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FIGURE 4.11

Intra-Laboratory Snow Reconciliation

SPCA AD-480 (NEAT)

Artificial Snow Data

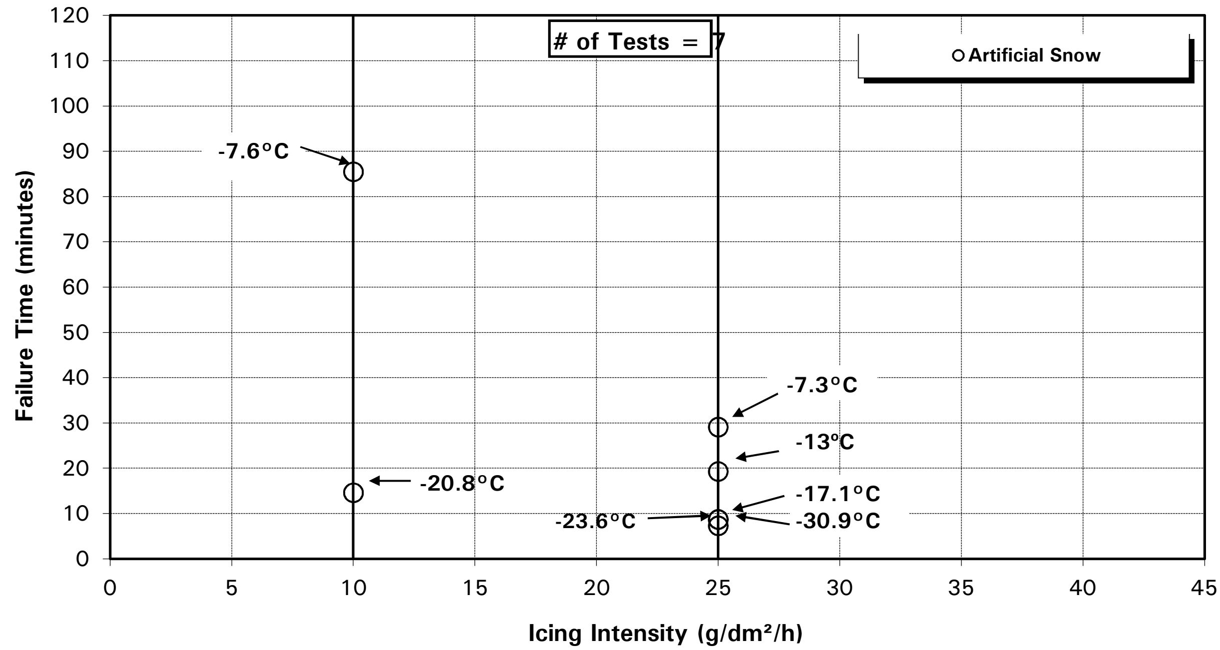
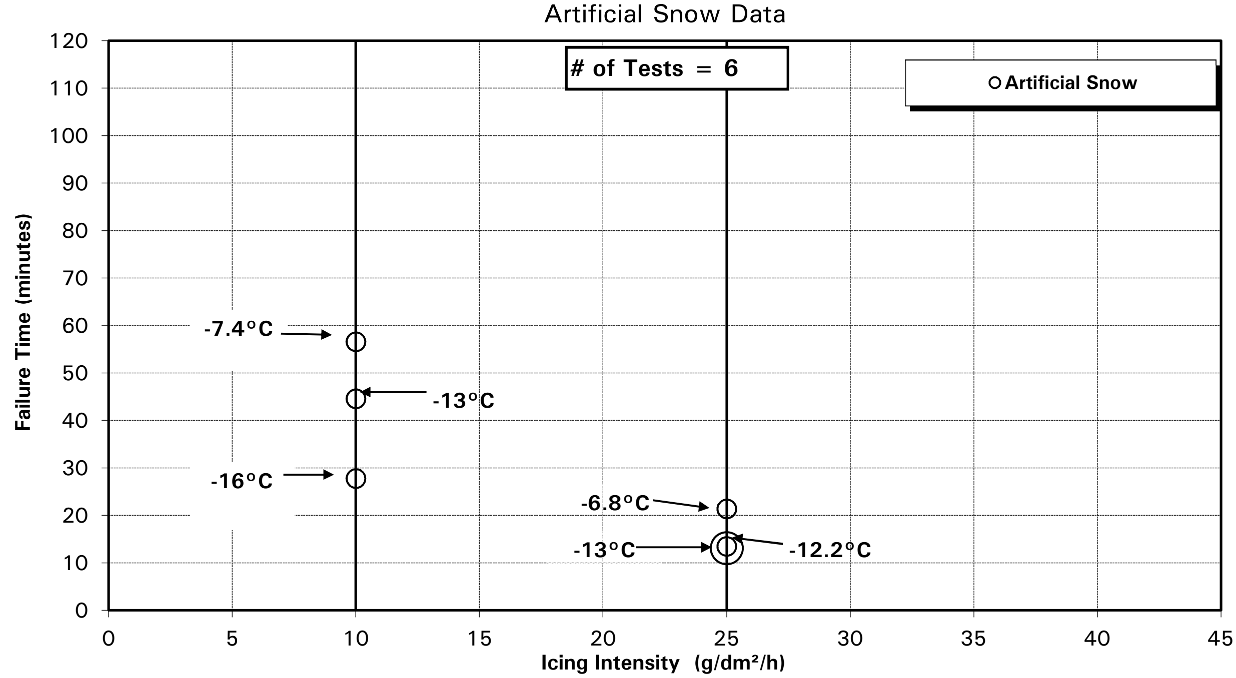


FIGURE 4.12

Intra-Laboratory Snow Reconciliation

SPCA AD-480 (75/25)

Artificial Snow Data



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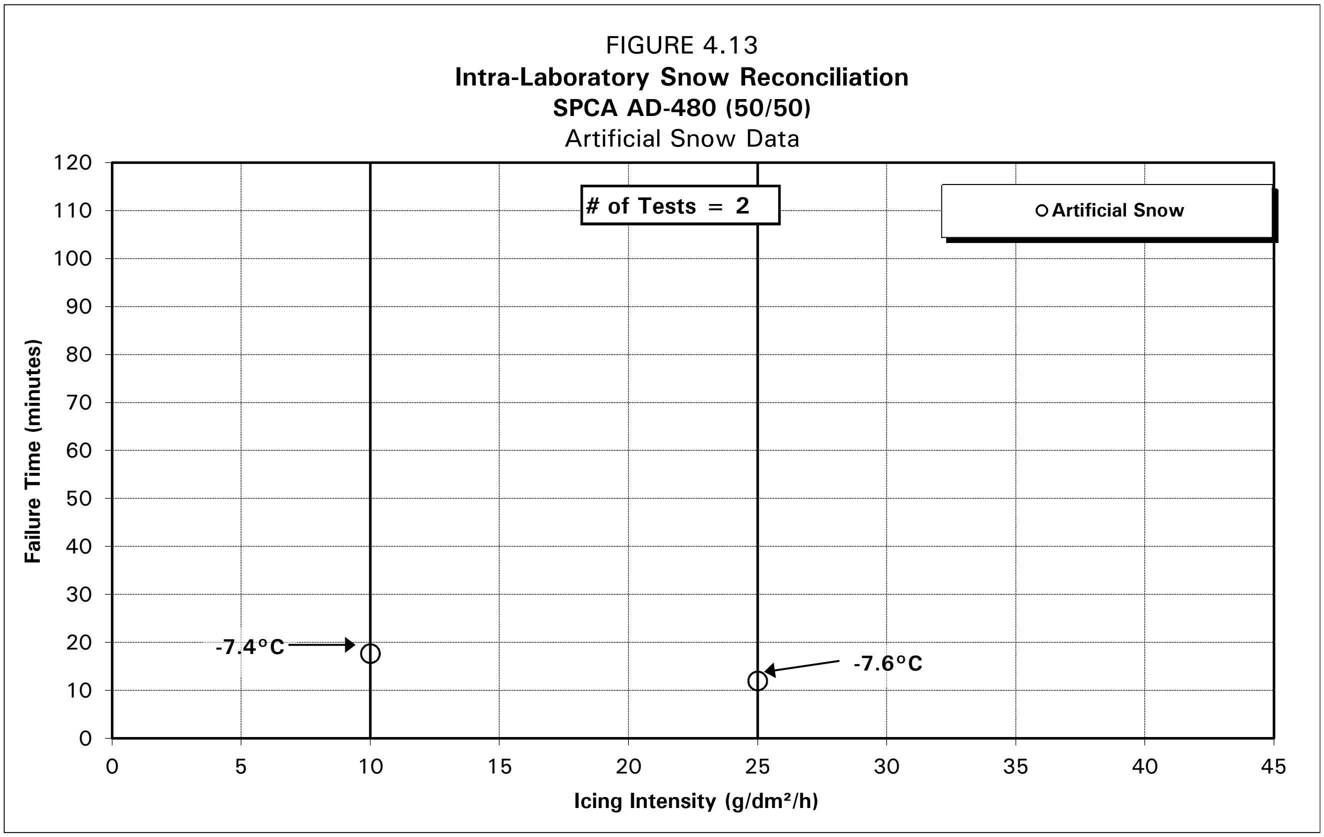

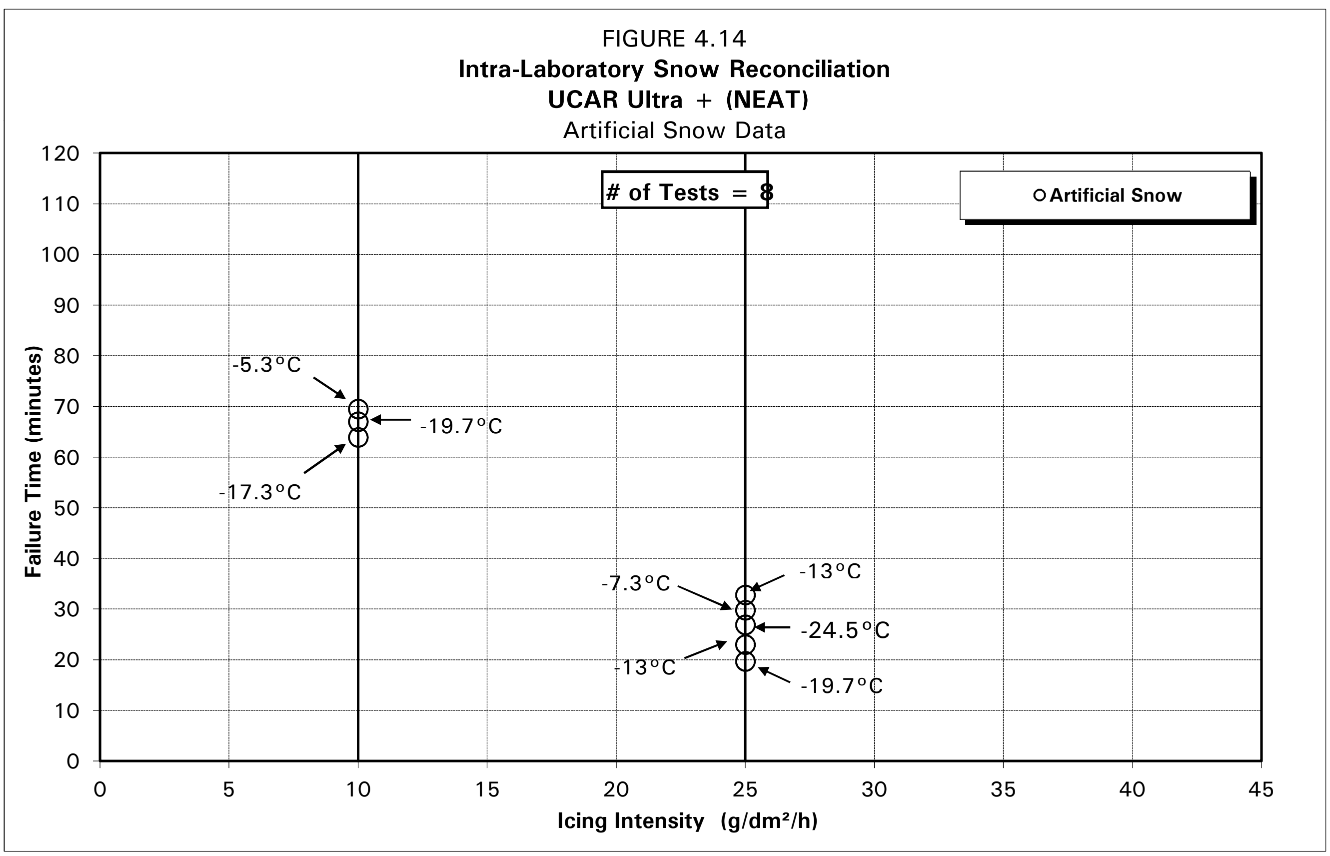

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4.2.3 Comparison of the Indoor and Natural Snow Results

In the determination of fluid holdover times, power law curves are plotted for each fluid and dilution using the most restrictive (lowest) temperature in each cell of the holdover time table. Traditionally, curves have been drawn at 0°C, -3°C, -14°C, and -25°C. Because the indoor data was not collected at these temperatures, regression curves for the outdoor test data were drawn at the same temperatures in which the indoor tests were run. This allowed for a direct comparison of the test results.

The results of the comparison between indoor and outdoor endurance time tests appear in the bar charts shown in Figures 4.15 to 4.21. A summary of the differences between the endurance time results of indoor and natural snow tests appears in Table 4.1.

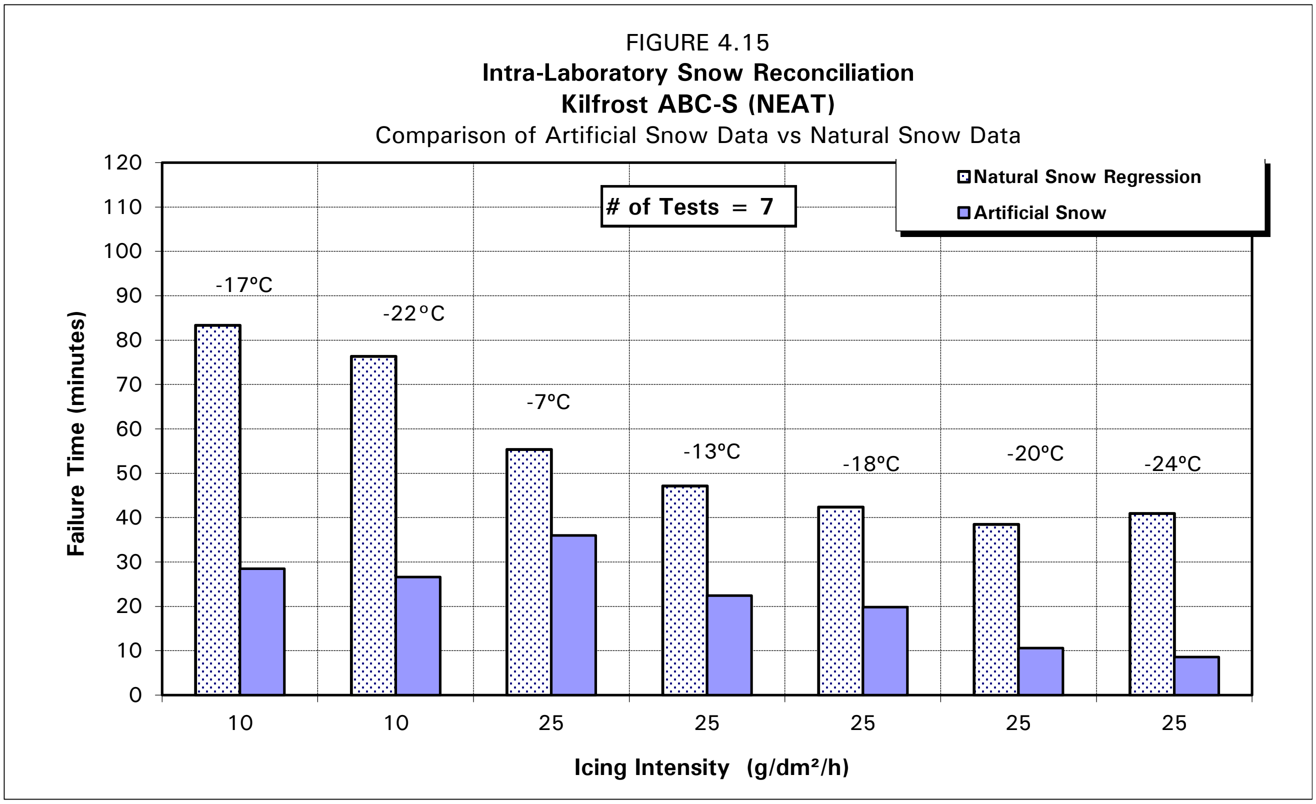
Although 50/50 dilutions of Type IV fluid should never be used below -3°C, the indoor tests with the 50/50 dilutions of the propylene glycol-based Type IV fluids were all conducted below this temperature due the position of the NCAR machine within the test chamber. The indoor test results with the 50/50 fluids will be presented in Subsection 4.2.3.1 for informational purposes only.

Analysis of the data collected indicates that the Type IV failure times were generally shorter for the trials performed with the snowmaking system than in natural snow.

The fluids can be separated into two categories: propylene glycol-based fluids and ethylene glycol-based fluids.

4.2.3.1 Propylene Glycol-Based Type IV Test Results

Snow bridging occurred frequently during trials with propylene fluids. This type of failure could also be partially attributed to the larger flakes produced by the snowmaker. With propylene fluids in snow, the fluid film had to absorb the lower levels of precipitation before the rest of the flakes could be absorbed. Because of the larger snowflake dimensions, the snow had a tendency to rest on top of the fluid film and to accumulate more quickly than the quantity of precipitation being absorbed, reducing the overall effectiveness of the anti-icing fluid and contributing to inferior endurance times for tests conducted in artificial snow.



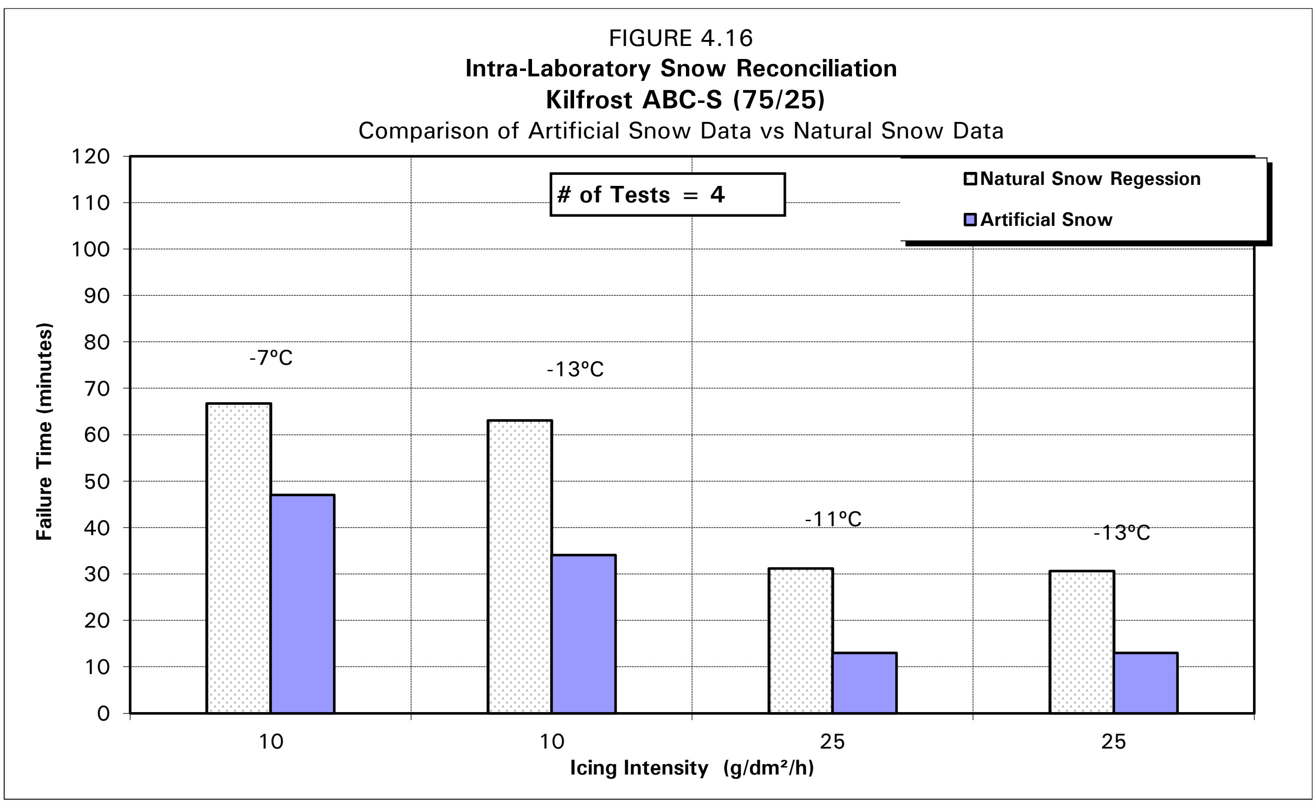


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FIGURE 4.17
Intra-Laboratory Snow Reconciliation
Kilfrost ABC-S (50/50)
Comparison of Artificial Snow Data vs Natural Snow Data

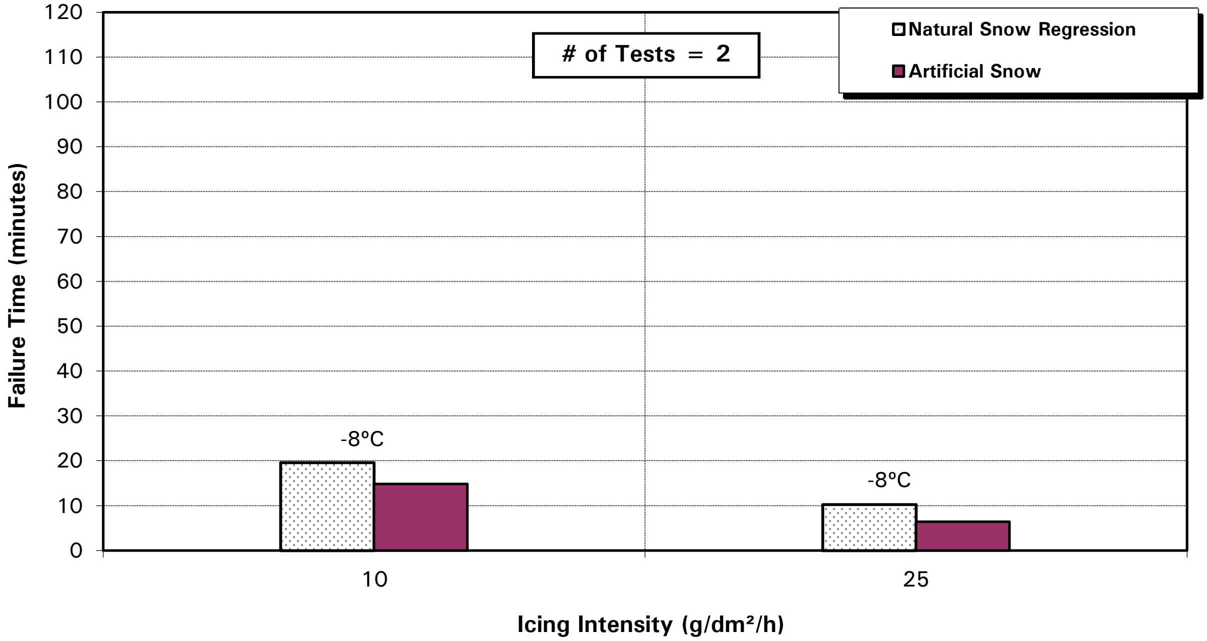
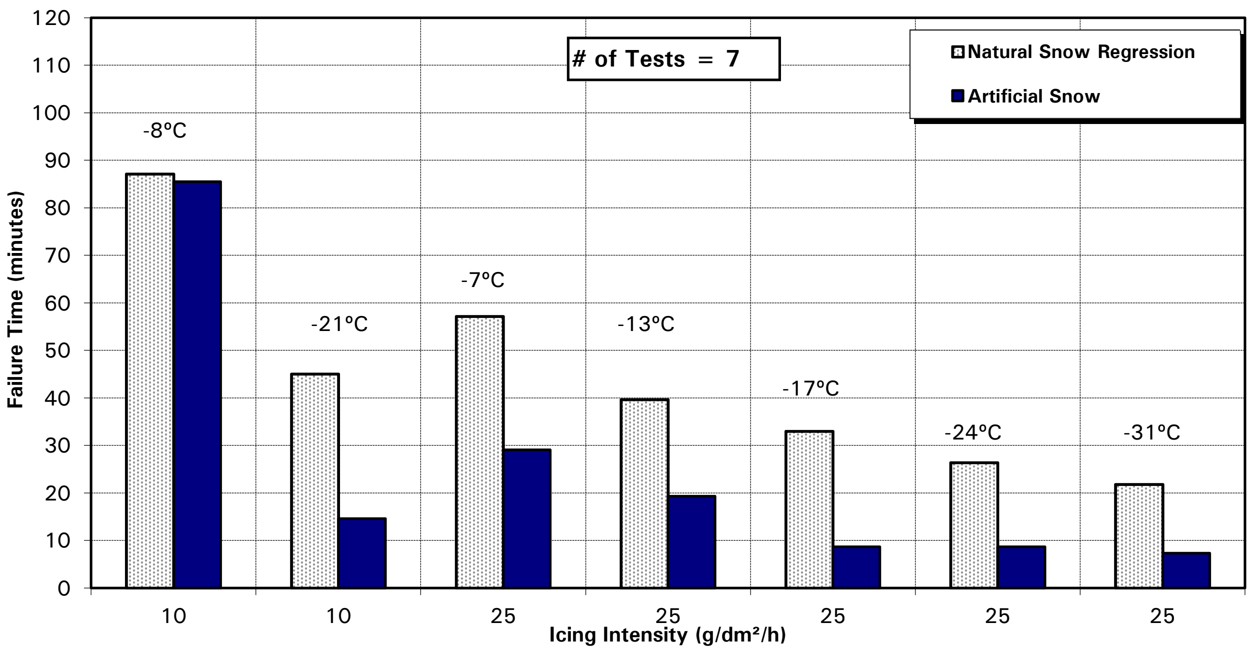


FIGURE 4.18
Intra-Laboratory Snow Reconciliation
SPCA AD-480 (NEAT)
Comparison of Artificial Snow Data vs Natural Snow Data



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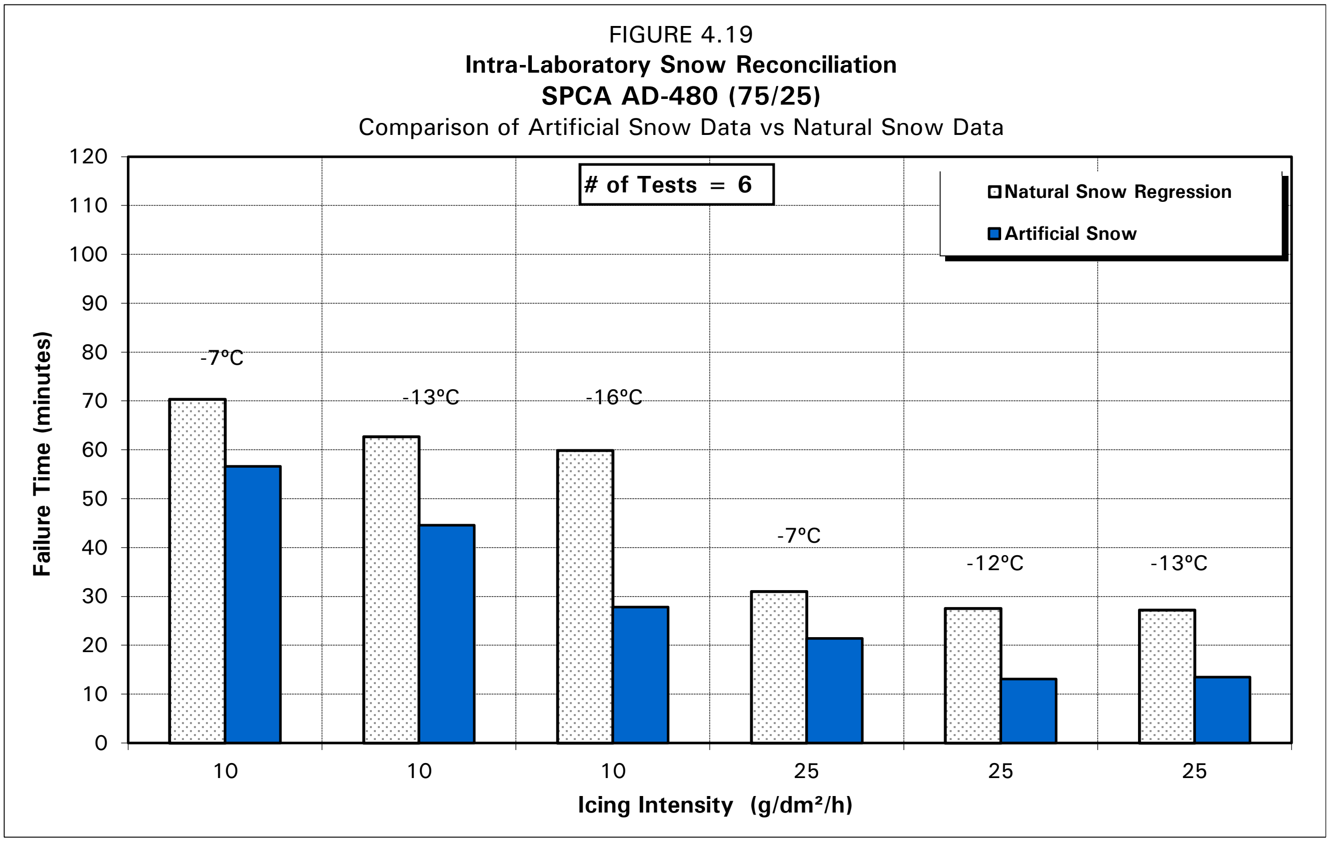

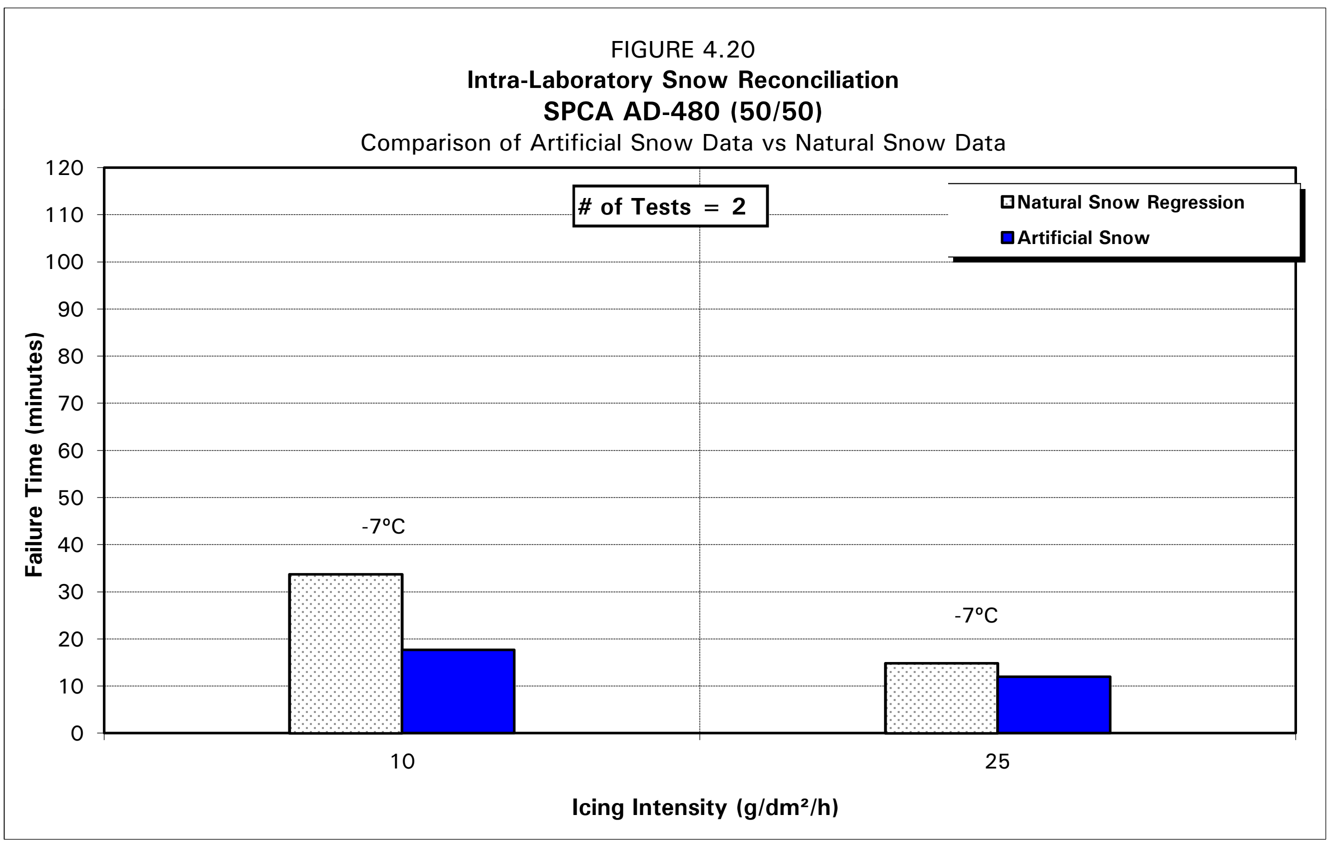

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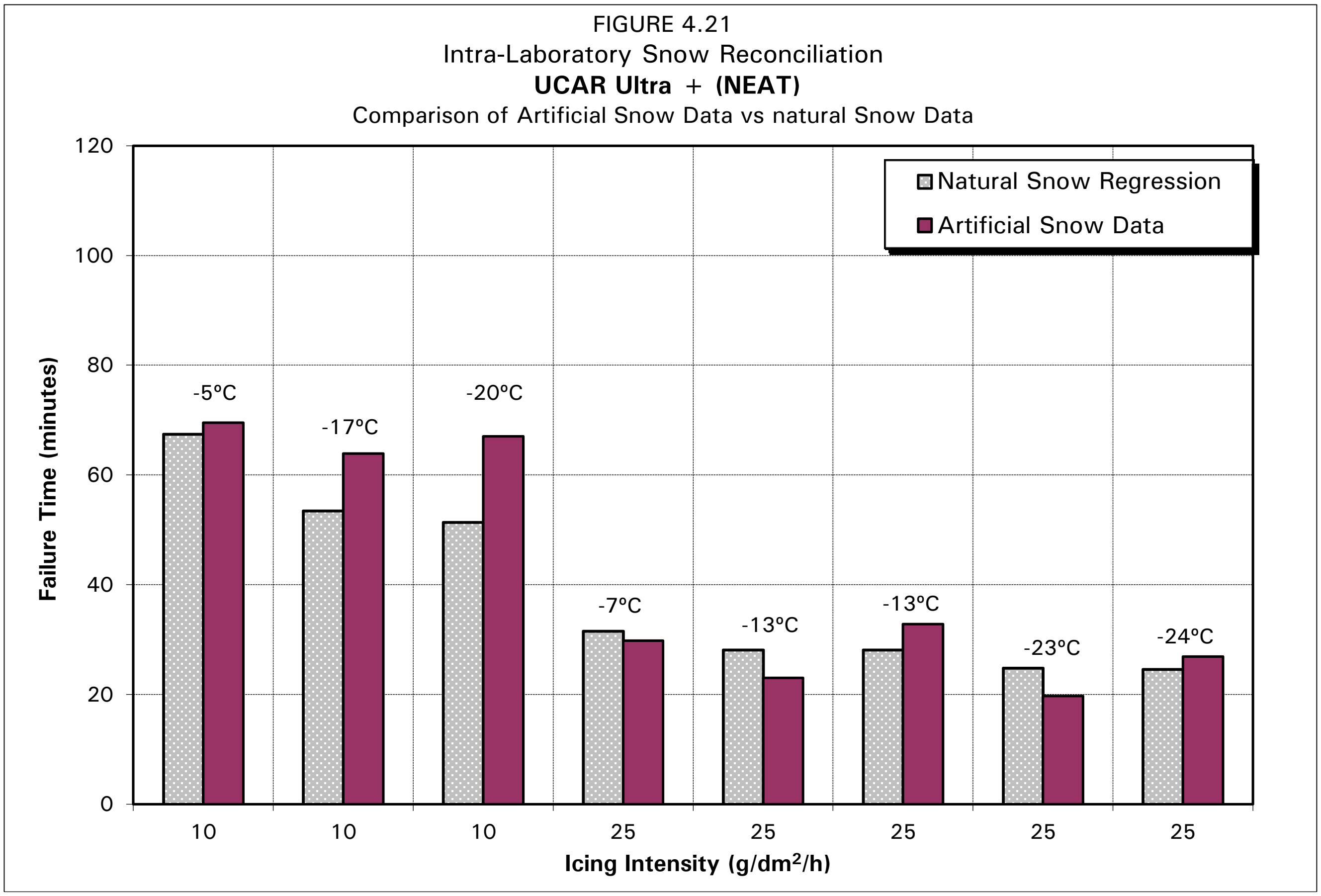

FIGURE 4.21
Intra-Laboratory Snow Reconciliation
UCAR Ultra + (NEAT)
Comparison of Artificial Snow Data vs natural Snow Data
Natural Snow Regression
Artificial Snow Data
Failure Time (minutes)
0
20
40
60
80
100
120
-5°C
-17°C
-20°C
-7°C
-13°C
-13°C
-23°C
-24°C
10
10
10
25
25
25
25
25
Icing Intensity (g/dm²/h)

TABLE 4.1

Percent Difference Between Artificial Snow and Natural Snow Failure Time

		Test #	Failure time Artificial Snow (minutes)	Failure time Natural Snow (minutes)*	Percent of natural snow HOT	Percent by fluid and concentration	Percent by fluid
KILFROST	100%	37	36	55	65%	**40%**	**48%**
		49	22	47	48%		
		50	29	82	35%		
		52	20	42	47%		
		57	27	76	35%		
		59	11	41	26%		
		60	9	38	23%		
	75%	43	47	67	70%	**52%**	
		53	13	31	42%		
		54	13	31	42%		
		55	34	63	54%		
	50%	45	7	10	65%	**70%**	
		47	15	20	75%		
SPCA 480	100%	13	86	87	98%	**48%**	**56%**
		15	36	57	64%		
		25	19	40	49%		
		26	9	33	26%		
		33	7	22	33%		
		34	9	26	33%		
		35	15	45	32%		
	75%	17	57	70	81%	**64%**	
		19	22	31	70%		
		29	14	27	50%		
		31	45	63	71%		
		32	28	60	46%		
	50%	21	18	34	52%	**66%**	
		23	12	15	80%		
UCAR	100%	1	70	67	104%	**104%**	**104%**
		3	30	32	93%		
		7	23	28	82%		
		5	64	53	121%		
		8	33	28	117%		
		9	67	51	131%		
		11	20	25	79%		
		12	27	25	108%		
				Average:	64%		

*Values taken from regression data - natural snow 2000/2001

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Trials were conducted with two different propylene glycol-based fluids. These fluids, Kilfrost ABC-S and SPCA AD-480, were tested in all standard dilutions.

The holdover time graphs for Kilfrost ABC-S, presented in Figures 4.15 to 4.17, show significant differences between the failure times recorded during natural versus artificial snow. Artificial snow produced failure times that were, on average, only 48 percent of the natural snow results. For the Kilfrost ABC-S Neat concentration, the indoor endurance times were, on average, only 40 percent of the outdoor endurance times.

The second fluid that was tested in all dilutions was SPCA AD-480. The graphs shown in Figures 4.18 to 4.20 indicate slightly less variation between the artificial snow and natural snow failure times for this fluid. Artificial snow produced failure times that were, on average, only 48 percent of the natural snow results. In the neat concentration, SPCA AD-480 indoor artificial snow endurance times were, on average, 48 percent of the outdoor endurance times. In diluted forms, SPCA AD-480 demonstrated indoor failure times that were, on average, 65 percent of the outdoor endurance times.

It is also noteworthy that several of the indoor propylene glycol-based fluid endurance times were below the current SAE generic Type IV guidelines in the -3°C to -14°C and -14°C to -25°C cells.

4.2.3.2 Ethylene Glycol-Based Type IV Test Results

Trials were conducted with one ethylene glycol-based Type IV fluid, Dow/UCAR Ultra+. The results of indoor snow tests were compared to the outdoor (natural snow) test data. The results are shown in Figure 4.21. Since this fluid is only certified for use in undiluted concentration, only the neat fluid was tested.

The ethylene glycol-based fluid Ultra+ did not exhibit large variations between the artificial snow trials and the natural snow trials. The difference between the natural snow regression values and the artificial snow failure times was marginal for this fluid. On average, the indoor endurance times were 106% of the natural snow results. A significant difference between this fluid and all other fluids tested was the flake acceptance demonstrated by Ultra+. In all temperatures and precipitation conditions tested, Ultra+ easily accepted contamination within the fluid matrix.

4.3 NCAR Snow Reconciliation

The purpose of NCAR snow reconciliation tests was to determine and understand the differences in the endurance times obtained in natural snow tests and those conducted under artificial snow with the NCAR system.

The bucket assembly used for NCAR indoor tests was positioned outdoors for natural snow testing during the winter of 2000-01 at the Dorval Airport test site. Eighteen fluid endurance time tests on the bucket assembly were conducted in natural snow events.

The 18 data points collected outdoors by APS on the NCAR bucket assembly were to be duplicated indoors with the NCAR snowmaking system using the newly designed *variable autorate* function. This function uses the electronic rate profile of the outdoor test as a template to run the indoor test. Due to difficulties with the advancement of the snow machine and software, the test data from APS outdoor natural snow bucket trials, including the electronic data files, were provided to NCAR. Personnel from NCAR ran the tests on behalf of APS.

4.3.1 Comparison of Outdoor Natural Snow Results on The NCAR Bucket Assembly and Standard Flat Plates

The bucket assembly used for indoor artificial snow tests was positioned outdoors on a test stand for natural snow testing at the Dorval Airport test site. Eighteen fluid endurance time tests were conducted in natural snow events on the bucket assembly. In 17 of the 18 natural snow trials, a standard test plate was positioned beside the bucket. The same fluid was poured on the bucket and the plate to examine the effect of the test surface on endurance time. The results of this comparison appear in Table 4.2.

The endurance times of the Type IV fluids poured on the bucket assembly and flat plates were virtually identical. Eleven minutes in total separate the bucket and plate endurance times for the 17 tests.

4.3.2 Comparison of Indoor and Natural Snow Results using the NCAR Bucket Assembly

The endurance time test results of the outdoor natural snow tests on the NCAR bucket assembly appear in Figures 4.22 to 4.28.

Table 4.2
Comparison of NCAR Bucket and Flat Plate Endurance Times in Natural Snow

Date	Fluid	Dilution	**Failure Time on Bucket (minutes)**	**Failure Time on Flat Plate (minutes)**	**Wind Speed (km/h) READAC**
14-Feb-01	Kilfrost ABC-S	100	83	85	3.5
23-Feb-01	Kilfrost ABC-S	100	103	85	19.5
11-Mar-01	Kilfrost ABC-S	75	88	96	13.0
13-Mar-01	Kilfrost ABC-S	75	59	59	22.0
19-Feb-01	Kilfrost ABC-S	50	9	8	19.0
5-Mar-01	Kilfrost ABC-S	50	18	20	30.0
14-Feb-01	SPCA AD-480	100	111	111	9.0
23-Feb-01	SPCA AD-480	100	97	94	17.0
13-Mar-01	SPCA AD-480	100	41	47	26.0
14-Feb-01	SPCA AD-480	75	79	78	4.0
25-Feb-01	SPCA AD-480	75	62	59	20.0
13-Mar-01	SPCA AD-480	75	35	36	26.0
19-Feb-01	SPCA AD-480	50	10	12	23.0
5-Mar-01	SPCA AD-480	50	33	43	31.0
5-Feb-01	Ucar Ultra+	100	50	45	14.4
19-Feb-01	Ucar Ultra+	100	22	32	31.0
25-Feb-01	Ucar Ultra+	100	32	33	4.3
		Total	932	943	

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FIGURE 4.22
EFFECT OF TEMPERATURE AND RATE OF PRECIPITATION ON ENDURANCE TIME
KILFROST ABC-S (NEAT)
NATURAL SNOW-NCAR BUCKET

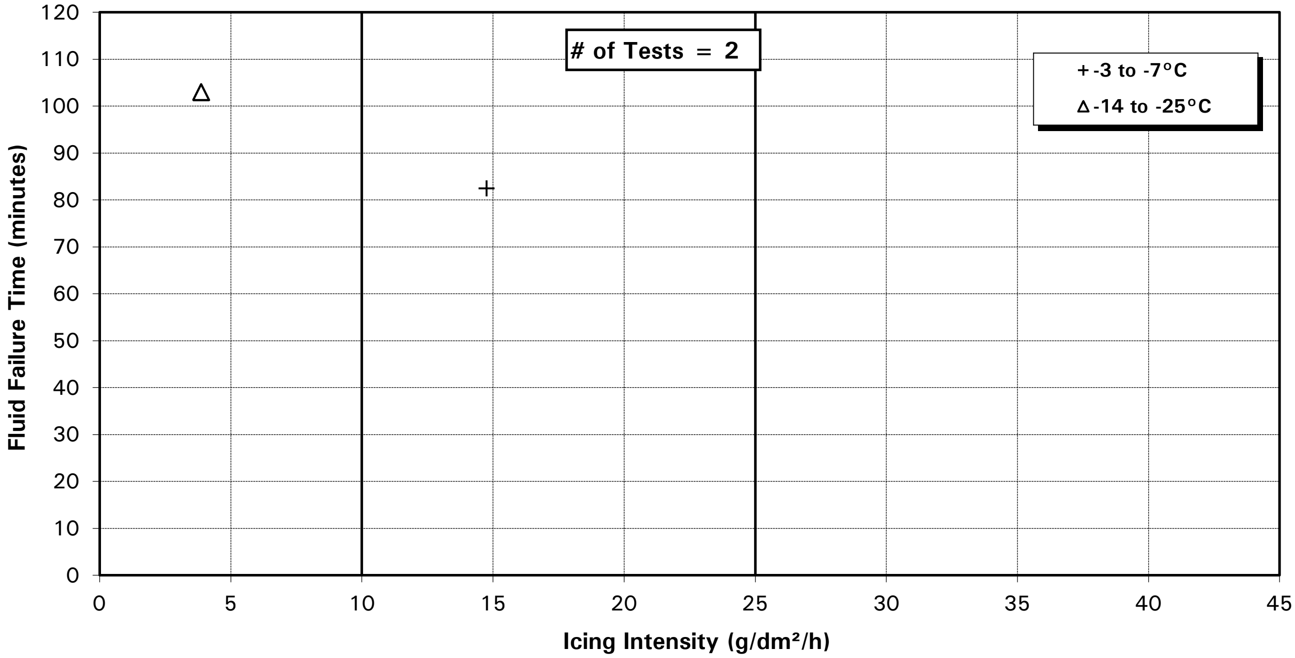

FIGURE 4.23
EFFECT OF TEMPERATURE AND RATE OF PRECIPITATION ON ENDURANCE TIME
KILFROST ABC-S (75/25)
NATURAL SNOW-NCAR BUCKET

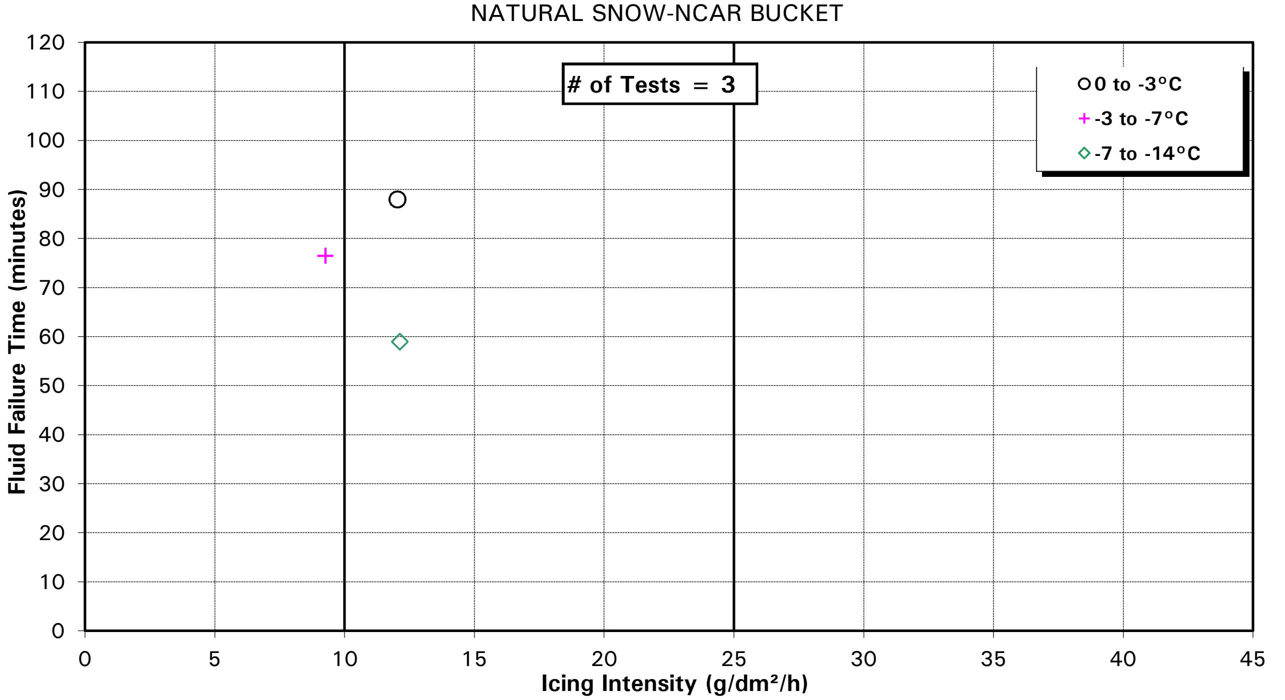

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FIGURE 4.24
EFFECT OF TEMPERATURE AND RATE OF PRECIPITATION ON ENDURANCE TIME
KILFROST ABC-S (50/50)
NATURAL SNOW-NCAR BUCKET

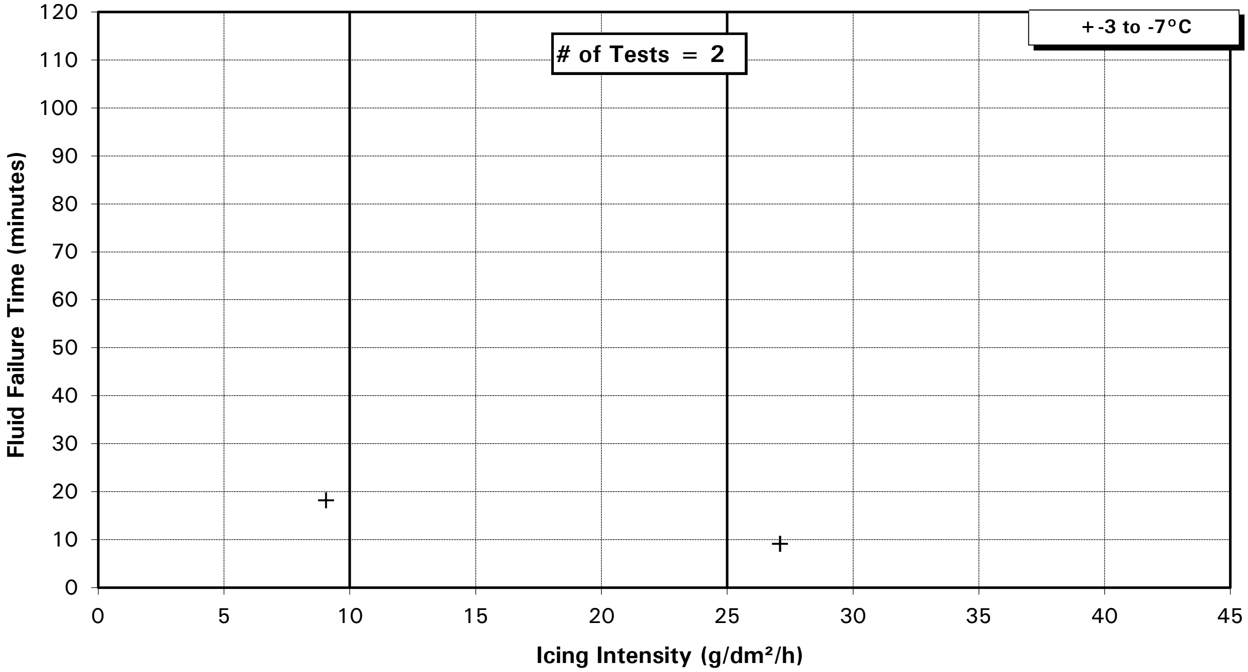

FIGURE 4.25
EFFECT OF TEMPERATURE AND RATE OF PRECIPITATION ON ENDURANCE TIME
SPCA AD-480 (NEAT)
NATURAL SNOW-NCAR BUCKET

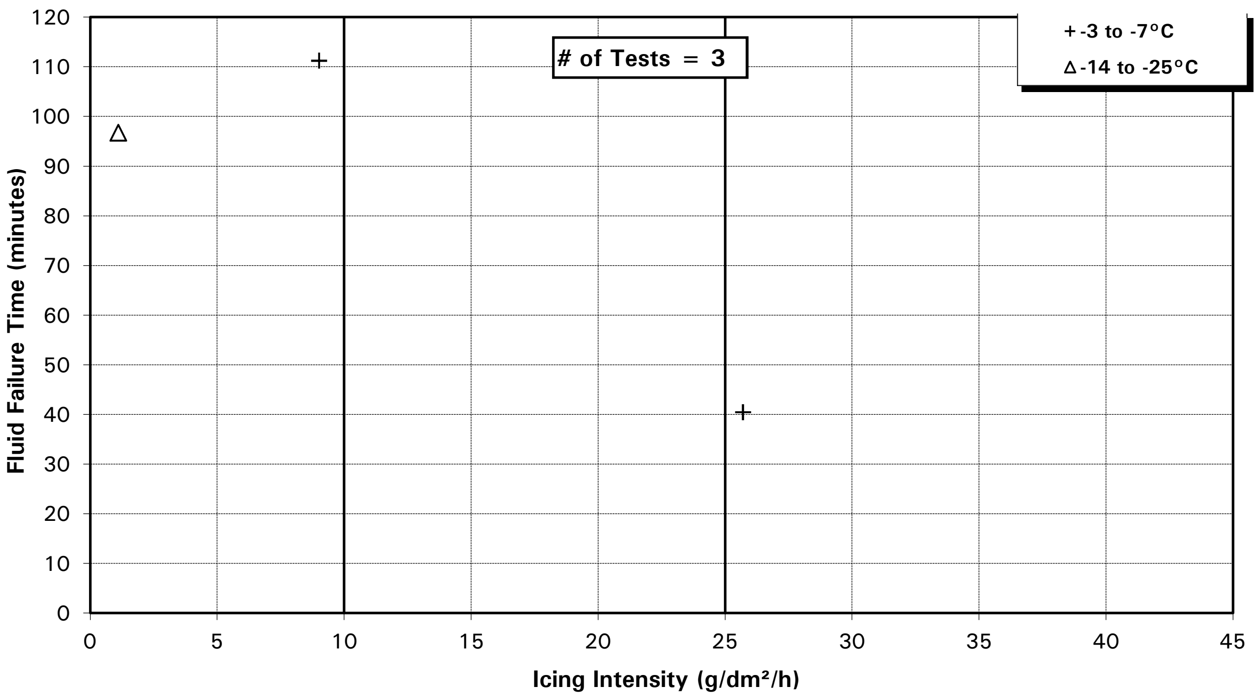

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FIGURE 4.26
EFFECT OF TEMPERATURE AND RATE OF PRECIPITATION ON ENDURANCE TIME
SPCA AD-480 (75/25)
NATURAL SNOW-NCAR BUCKET

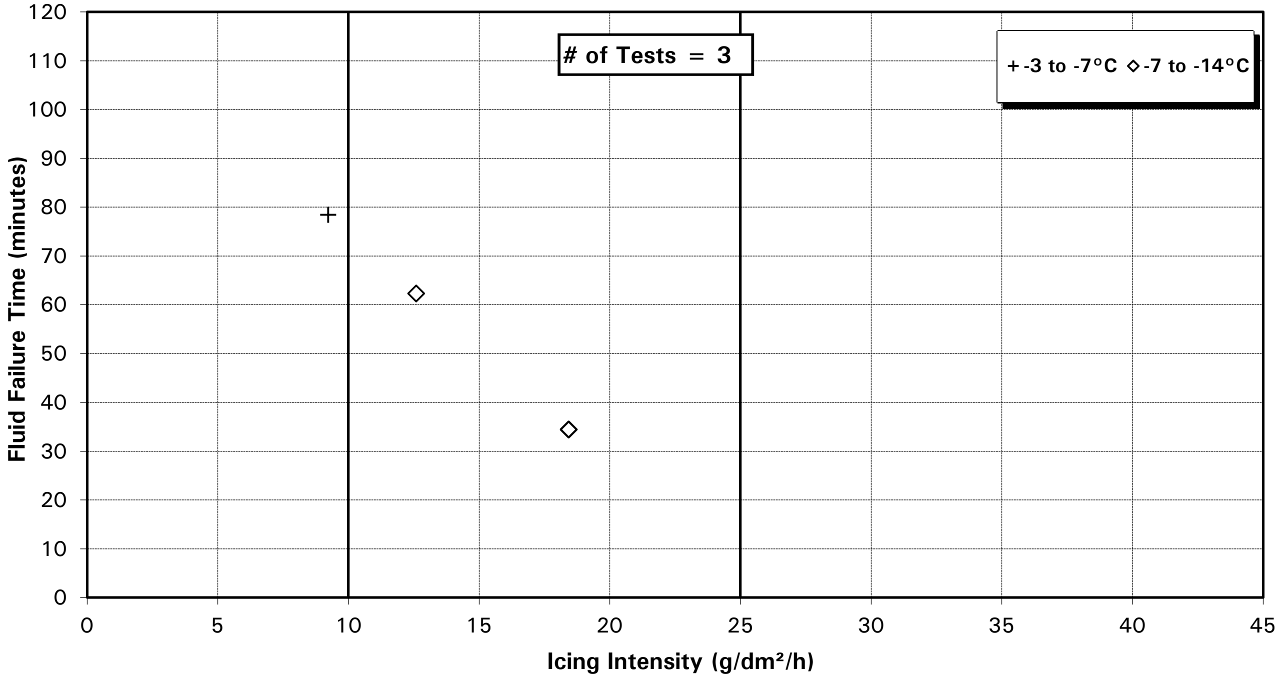

FIGURE 4.27
EFFECT OF TEMPERATURE AND RATE OF PRECIPITATION ON ENDURANCE TIME
SPCA AD-480 (50/50)
NATURAL SNOW-NCAR BUCKET

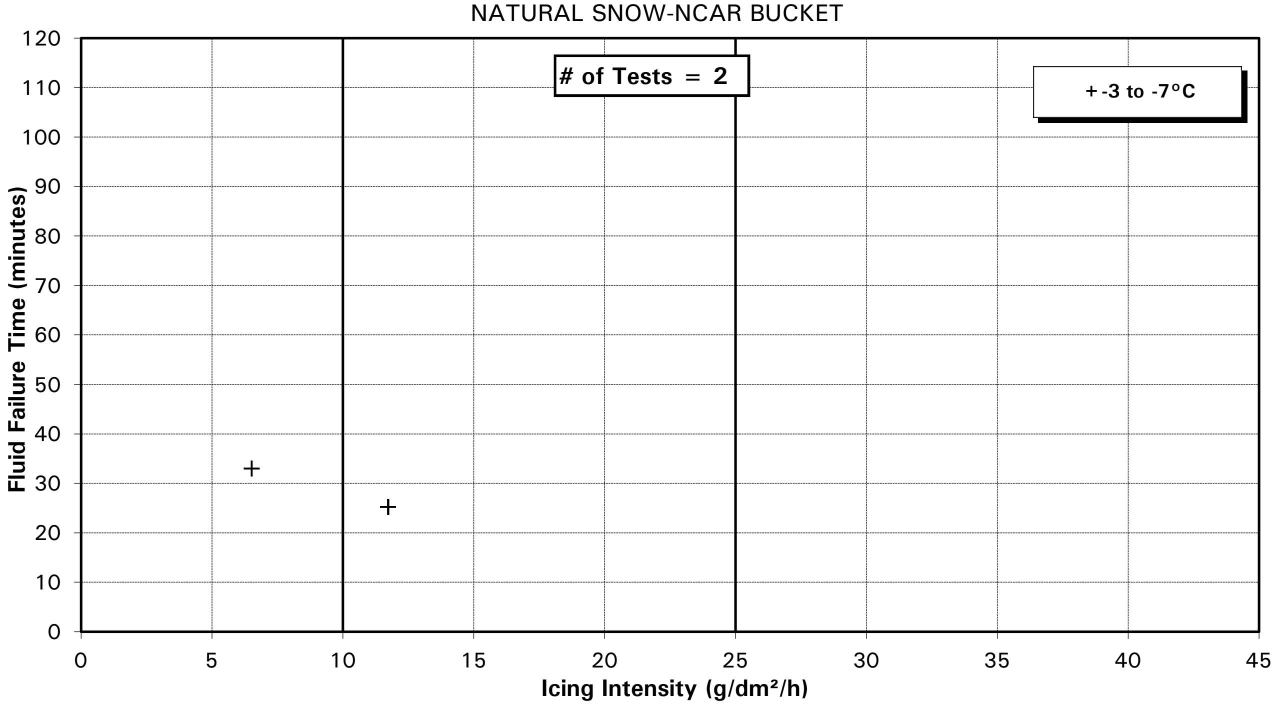

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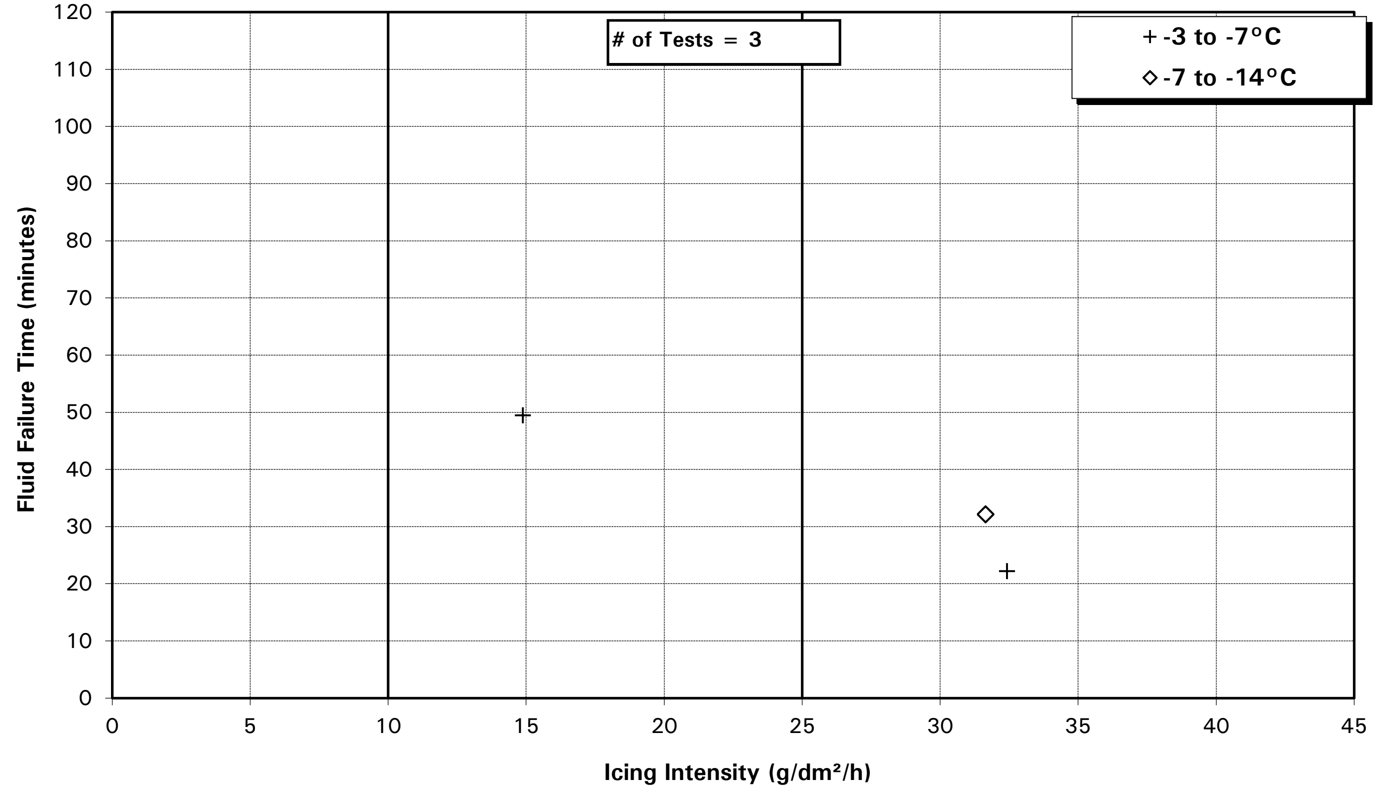
FIGURE 4.28
EFFECT OF TEMPERATURE AND RATE OF PRECIPITATION ON ENDURANCE TIME
UCAR ULTRA+ (NEAT)
NATURAL SNOW-NCAR BUCKET



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Of the 18 tests conducted on the bucket assembly during natural snow events, only 8 were successfully reproduced indoors by NCAR personnel in Boulder, Colorado. Due to difficulties, the other 10 electronic precipitation rate files provided to NCAR were not run. The test data from the 8 valid tests were provided to APS.

A summary of the differences between the endurance time results of APS outdoor and NCAR indoor tests appears in Figure 4.29.

In all cases, the results of indoor tests with the NCAR snowmaker were inferior to the outdoor tests on the bucket assembly. The results of indoor tests using the *variable autorate* function were, in general, closer to the outdoor natural snow results than tests conducted using the precipitation rate limits of 10 and 25 $g/dm^2/h$.

It is notable that the Brix (refractive index) values at plate failure of all fluids in tests conducted by NCAR personnel were higher than those of natural snow tests conducted by APS personnel. The higher Brix values signify that plate failures were called sooner by NCAR personnel.

4.3.2.1 SPCA AD-480

For SPCA AD-480 Neat, the two tests conducted indoors had, on average, 79 percent of the endurance time of the outdoor tests. For SPCA AD-480 75/25, the three tests conducted indoors had, on average, 67 percent of the endurance time of the outdoor tests.

4.3.2.2 Kilfrost ABC-S

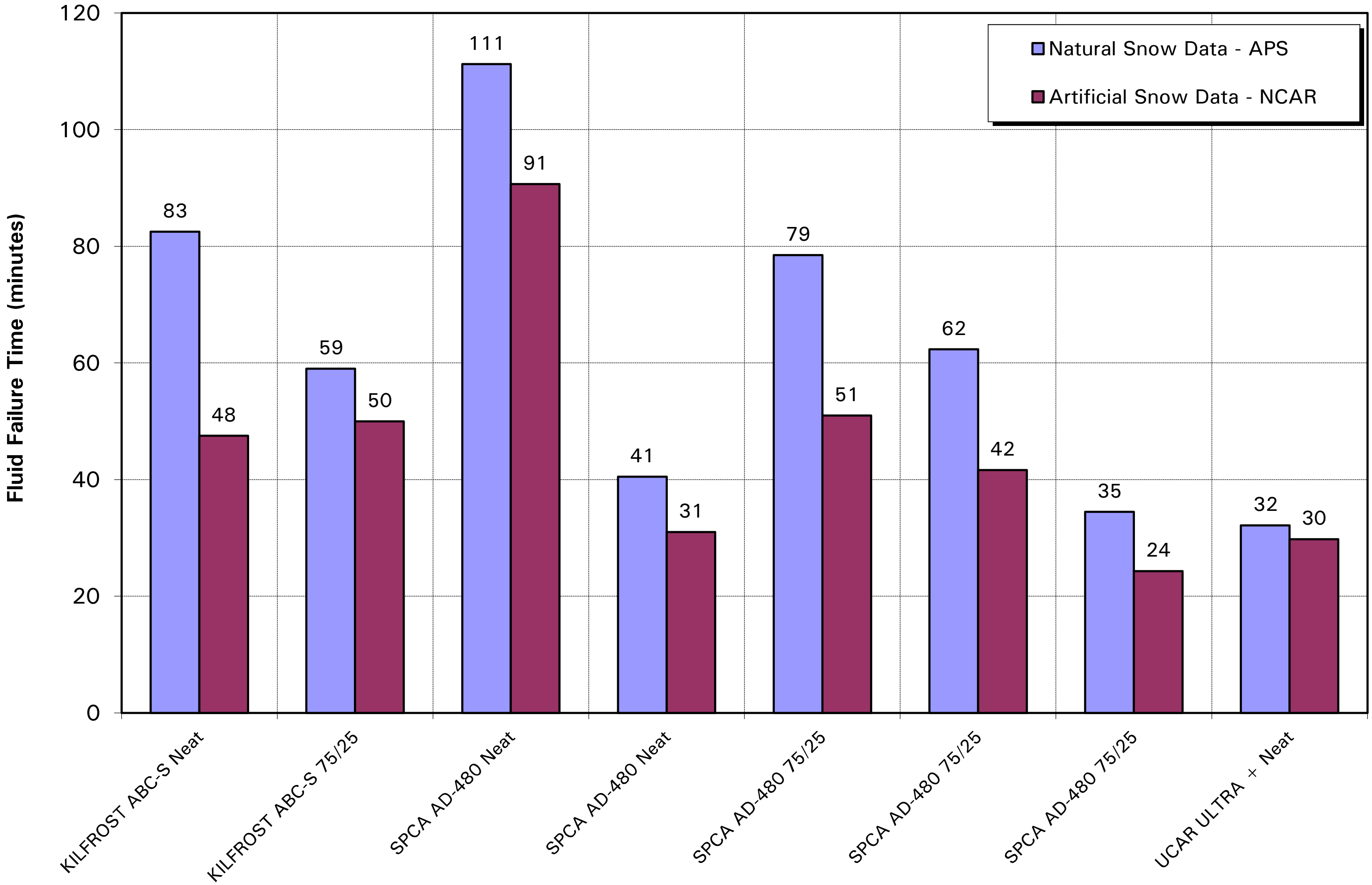
Only two tests were conducted inside using Kilfrost ABC-S. For Kilfrost ABC-S Neat, the sole test conducted indoors had an endurance time equivalent to 58 percent of the endurance time of the outdoor tests. For Kilfrost ABC-S 75/25, the one test conducted indoors had 85 percent of the endurance time of the outdoor test.

4.3.2.3 Dow/UCAR Ultra+

For Dow/UCAR Ultra+ Neat, the one test conducted indoors had an endurance time equivalent to 93% of the endurance time of the outdoor test.

FIGURE 4.29

NCAR Snow Reconciliation
Endurance Time Comparison



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4.3.3 Effects of Wind and Plate Temperature on Snow Endurance Times

Certain factors, such as wind and plate temperature, have long been identified as potential causes of discrepancies between indoor (artificial) and outdoor (natural) snow failure times.

During natural snow trials, the fluids covering the test plates were usually subjected to significant winds. Air surrounding the test plate in artificial snow trials was calm.

In addition to keeping fluids on the test plates (since all tests are placed into the wind in outdoor trials), wind may also warm the test plates neutralizing some the cooling of the test plate due to the latent heat of the snow melting on the panel.

To examine this effect, two tests conducted outdoors with similar test parameters, other than wind speed and average rate of snowfall, were selected.

- Test A19
    - Fluid: SPCA AD-480 100/0;
    - OAT: -6.7°C;
    - Wind speed: 26 km/h; and
    - Average rate: 25.7 g/dm^2/h.
- Test A6
    - Fluid: SPCA AD-480 100/0;
    - OAT: -5°C;
    - Wind speed: 9 km/h; and
    - Average rate: 9 g/dm^2/h.

The plate temperatures of the two tests listed above appear in Figures 4.30 and 4.31. The temperature profiles from the duplicate NCAR tests that were conducted for each outdoor test in controlled laboratory conditions are also shown in these graphs.

For Test A19 (Figure 4.30), both temperature profiles descended from -6.7°C to approximately -9°C within about 6 minutes of the onset of testing. The outdoor temperature profile then levelled off and gradually started to climb. At failure in the outdoor test, the temperature of the test plate was slightly above -8°C.

FIGURE 4.30

Effect of Wind on Plate Temperature (°C) - Indoor and Outdoor Tests

SPCA AD-480 NEAT (Test A19)

Outdoor Wind Speed 26 km/h OAT:-6.7°C

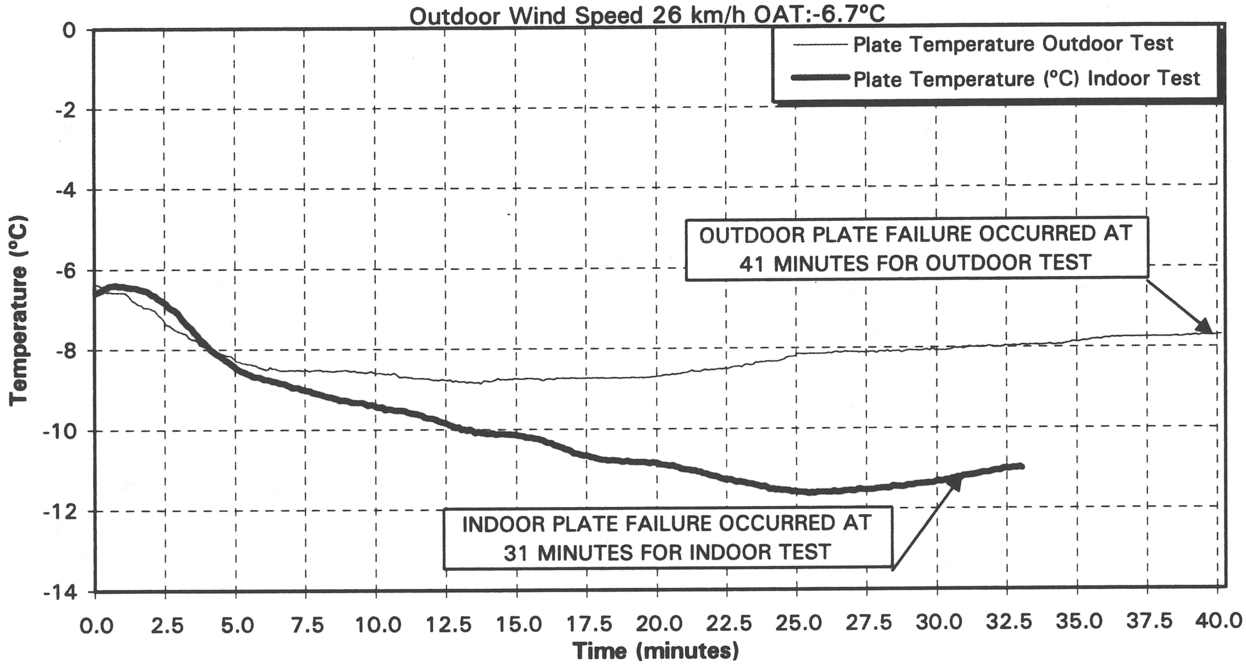
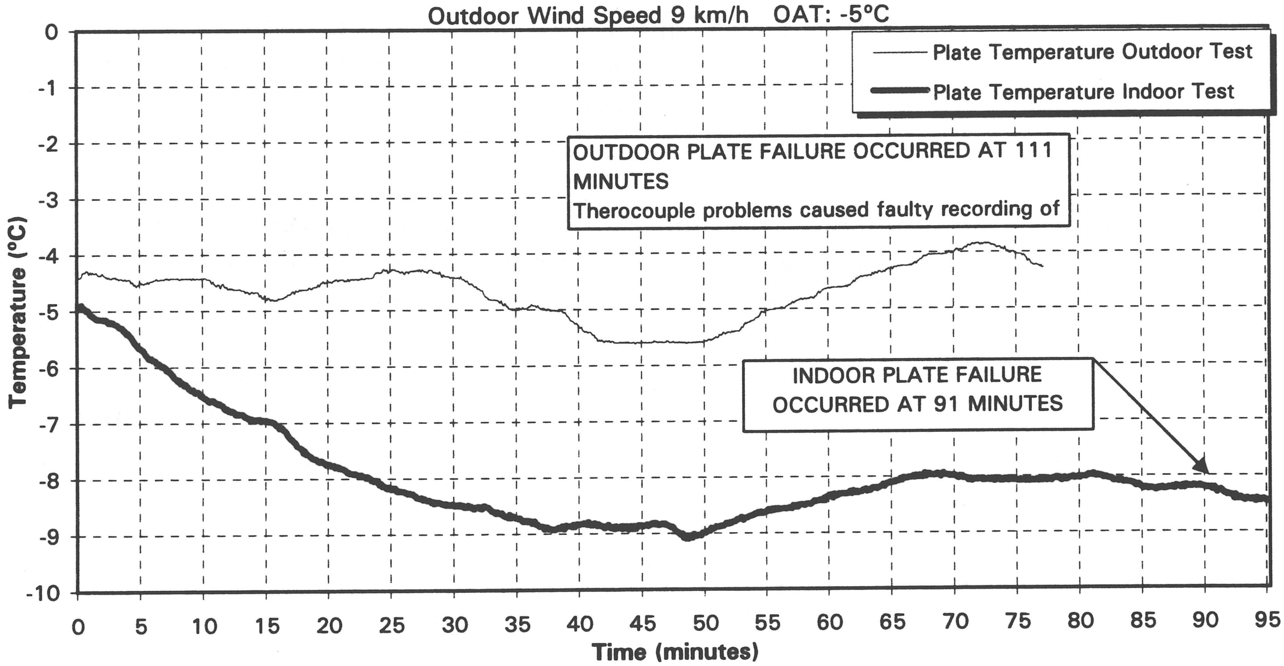


FIGURE 4.31

Effect Of Wind on Plate Temperature Profile - Indoor and Outdoor Tests

SPCA AD-480 NEAT (Test A6)

Outdoor Wind Speed 9 km/h OAT: -5°C



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At:fig 4.30 4.31 (2)

The temperature profile of the indoor duplicate test of A19 was considerably different. Following a similar descent to -9°C, the indoor temperature curve continued to descend. After 25 minutes, the temperature of the indoor test plate was almost -12°C (by comparison, the outdoor plate was at -8°C after 25 minutes). At failure in the indoor test, the temperature of the test plate was approximately -11°C.

For Test A6 (Figure 4.31), there was a slight difference in the initial plate temperatures at the start of the indoor and outdoor tests (about 0.5°C). After the start of the test, the temperature of the outdoor plate only descended only marginally, to a low of -5.5°C after 45 minutes of testing. Due to malfunction of the thermocouple embedded within the test plate for the outdoor test, the temperature of the plate at failure was unknown. Extrapolation from the previous readings suggests an anticipated value around -5°C.

The temperature profile of the indoor duplicate test of A6 was again considerably different. The temperature of the indoor test plate dropped from -5°C to -9°C after 45 minutes, and was in the vicinity of -8.5°C at failure.

Despite differences in the wind speeds in Tests A19 and A6, the temperature profiles of the outdoor tests and indoor duplicates showed similar trends. In both cases, the indoor tests had wider differences in start and end temperatures than did the outdoor tests.

For both Tests A19 and A6, the indoor plates were approximately 3°C colder than the outdoor plates at failure. In both cases, the indoor artificial snow results were approximately 80% of the numbers obtained in outdoor natural snow testing.

Plate temperature has a definite effect on fluid endurance times, since anti-icing fluid performance is adversely affected by reductions in temperature, especially the performance of propylene glycol-based fluids.

The effect of wind has not been proven, although it does appear that wind helped to counter the cooling of the plate during the absorption of snowfall. It is also likely that wind helped to keep fluid on the plate in outdoor trials.

A more in-depth study of the effects of wind and plate temperature should be undertaken in the upcoming test season.

4.4 Comparison of Indoor and Outdoor Endurance Times for a Certified Type IV Fluid

Endurance time test data for Type IV Product A, a propylene glycol-based, certified Type IV fluid, were generated in natural snow and artificial snow. The failure times recorded from the artificial snow flat plate trials were compared to a natural snow regression curve for each fluid dilution tested. This fluid was only tested by APS and was not part of the intra-laboratory snow reconciliation program.

The viscosity of the neat fluid was 5,540 cp (method: 20°C, 0.3 RPM, Spindle LV1, 600 ml beaker, 500 ml fluid, 33 min 20 sec, with guard leg)

The comparison of indoor and outdoor results for standard dilutions of Type IV Product A appear as listed.

- Neat fluid results appear in Figures 4.32 and 4.33;
- 75/25 fluid results appear in Figures 4.34 and 4.35; and
- 50/50 fluid results appear in Figures 4.36 and 4.37.

A summary of the compiled results appears in Table 4.3. All endurance times in Table 4.2 were rounded to the nearest whole 5-minute value, but were not cut off at 2 hours. This was done to allow for a proper comparison of the test results.

For the Neat and 75/25 dilutions of Type IV Product A, the indoor endurance times were, on average, 62 percent of the values obtained in outdoor testing. For the 50/50 dilution of Type IV Product A, the indoor endurance times were 80 percent of the values obtained in outdoor testing.

These values, although different than those presented for the other propylene fluids in Subsection 4.2, clearly indicate that endurance times generated by the NCAR machine for propylene glycol-based fluids are inferior to those observed in outdoor testing.

FIGURE 4.32
EFFECT OF TEMPERATURE AND RATE OF PRECIPITATION ON ENDURANCE TIME
TYPE IV PRODUCT A (NEAT)
ARTIFICIAL SNOW

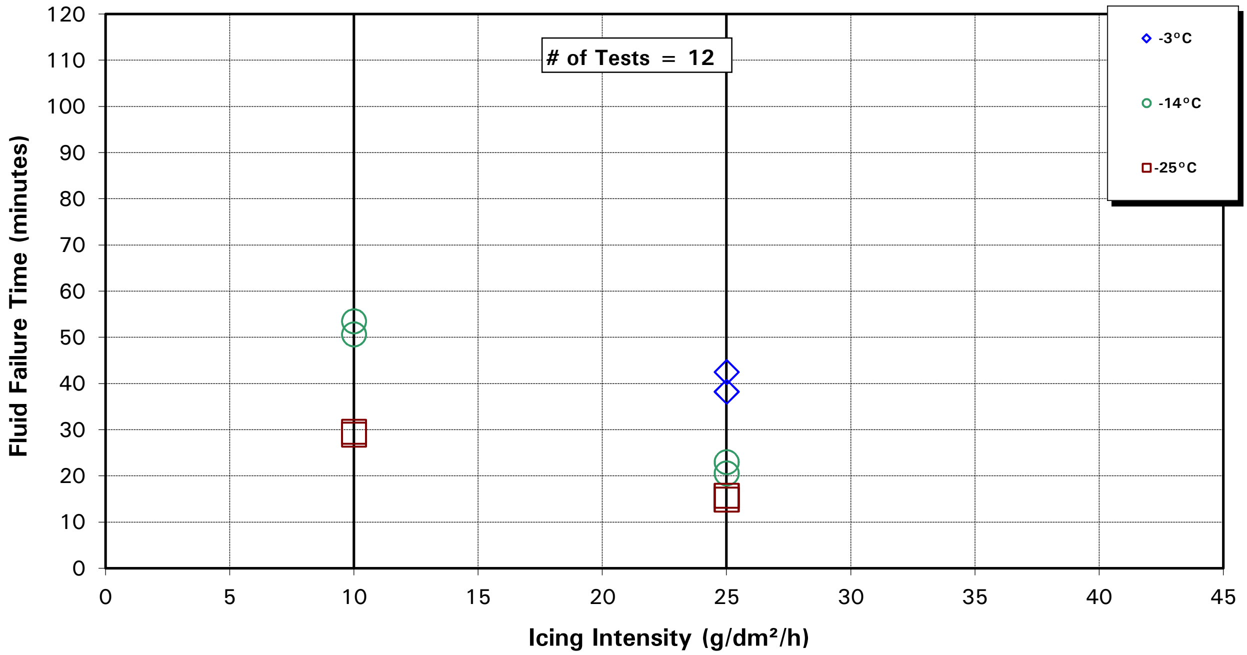
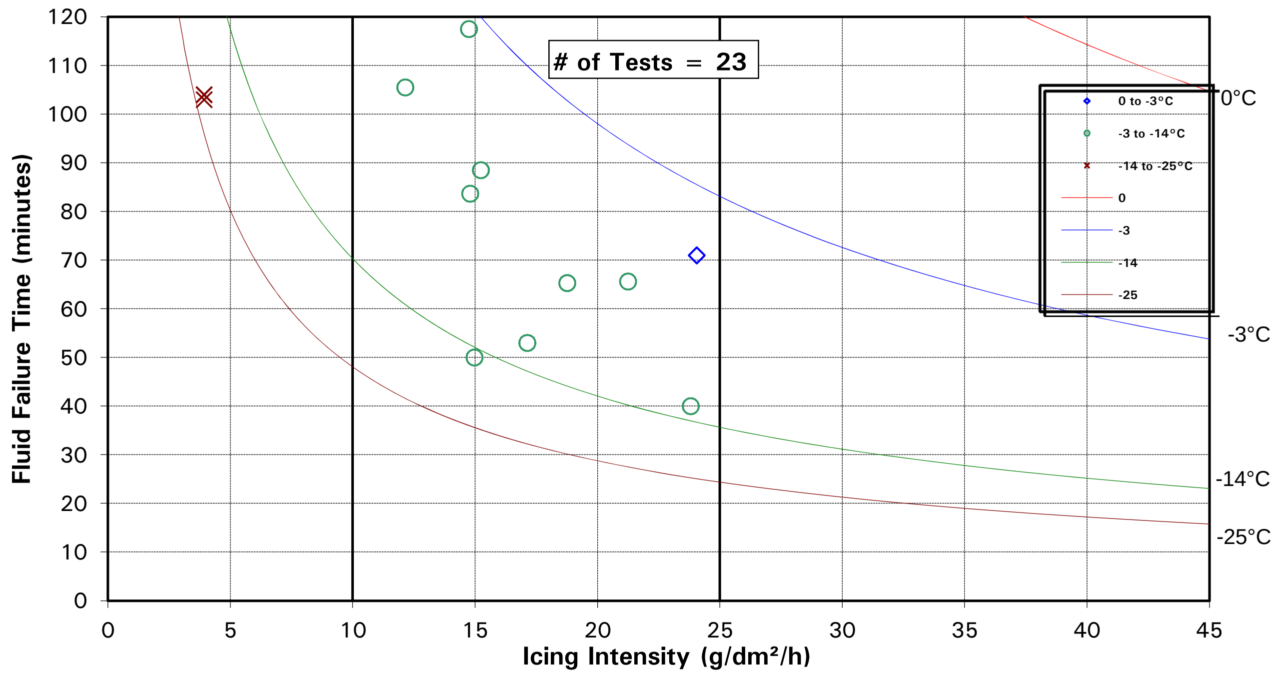


FIGURE 4.33
EFFECT OF TEMPERATURE AND RATE OF PRECIPITATION ON ENDURANCE TIME
TYPE IV PRODUCT A (NEAT)
NATURAL SNOW



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At:neat

FIGURE 4. 34
EFFECT OF TEMPERATURE AND RATE OF PRECIPITATION ON ENDURANCE TIME
TYPE IV PRODUCT A (75/25)
ARTIFICIAL SNOW

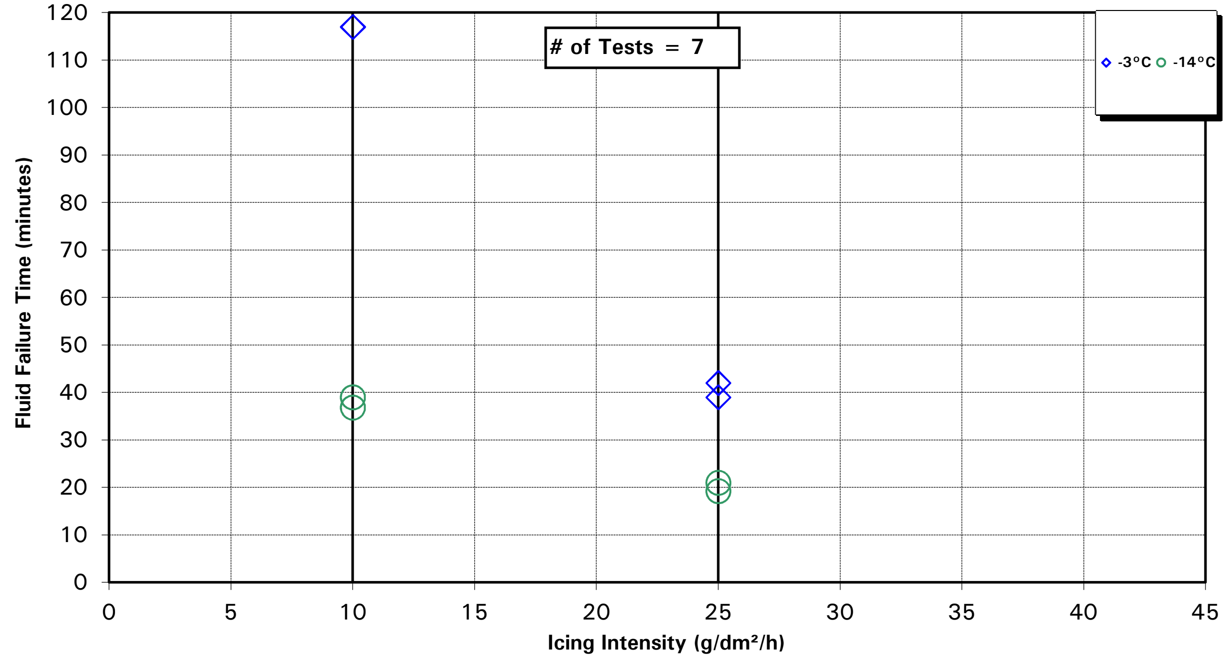


FIGURE 4.35
EFFECT OF TEMPERATURE AND RATE OF PRECIPITATION ON ENDURANCE TIME
TYPE IV PRODUCT A (75/25)
NATURAL SNOW

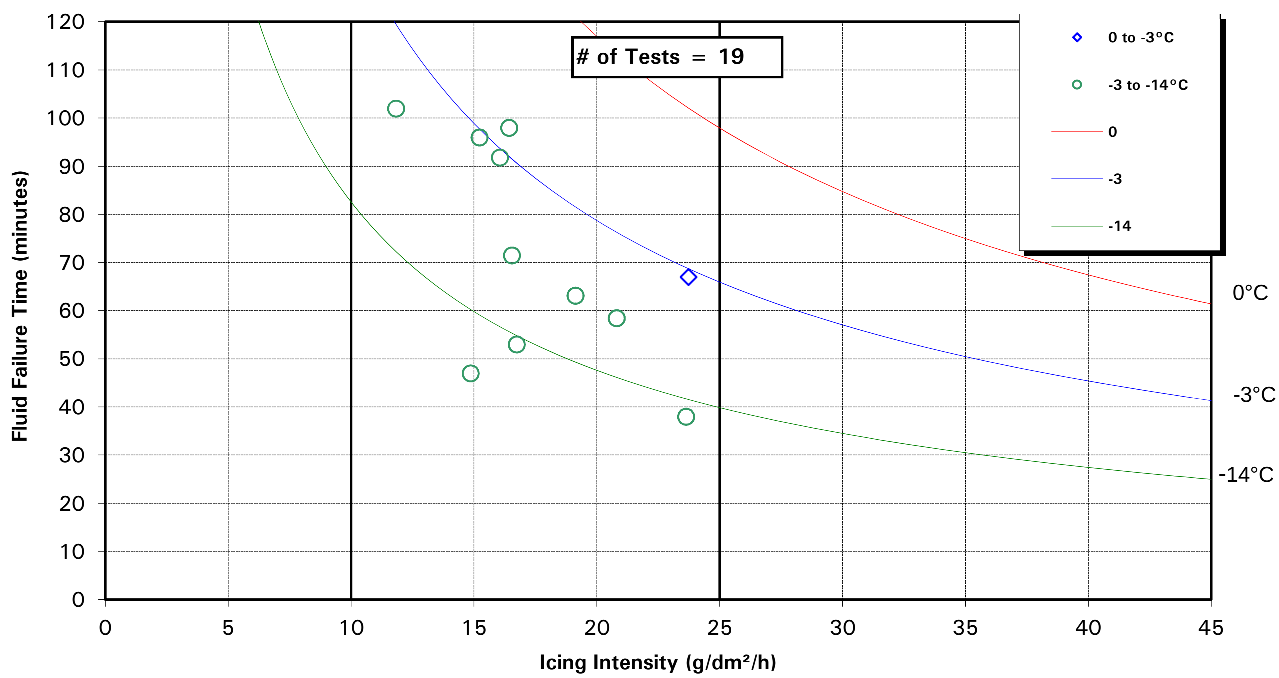


FIGURE 4.36
EFFECT OF TEMPERATURE AND RATE OF PRECIPITATION ON ENDURANCE TIME
TYPE IV PRODUCT A (50/50)
ARTIFICIAL SNOW

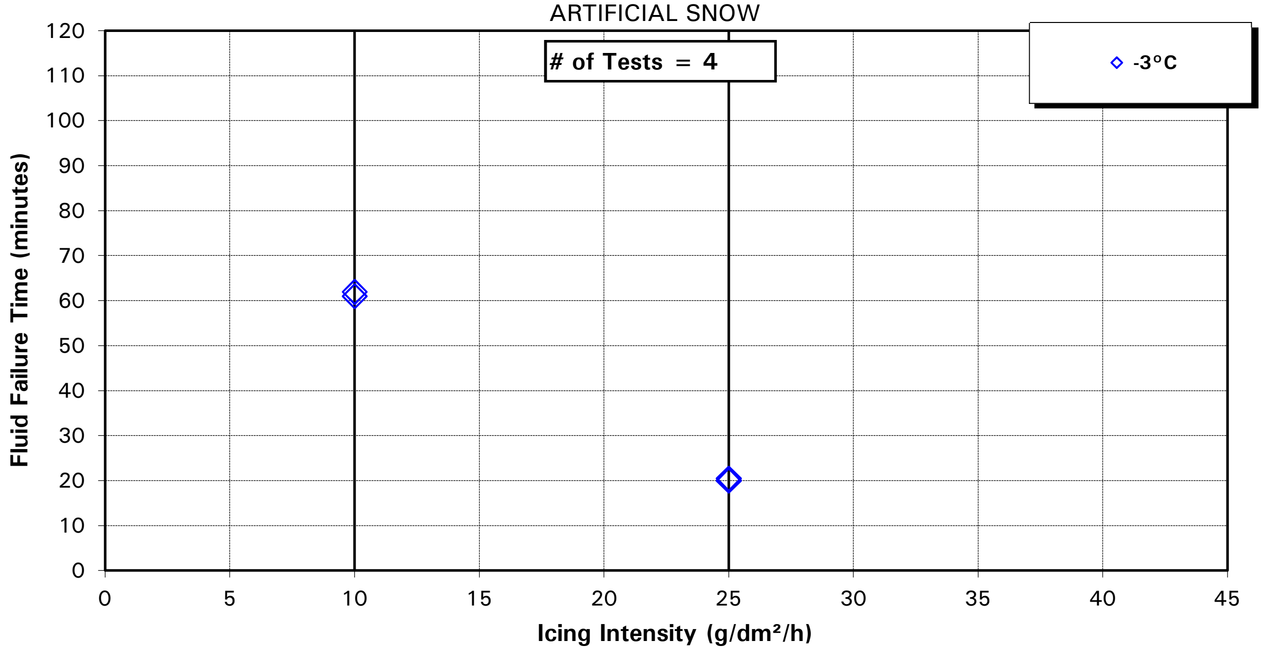
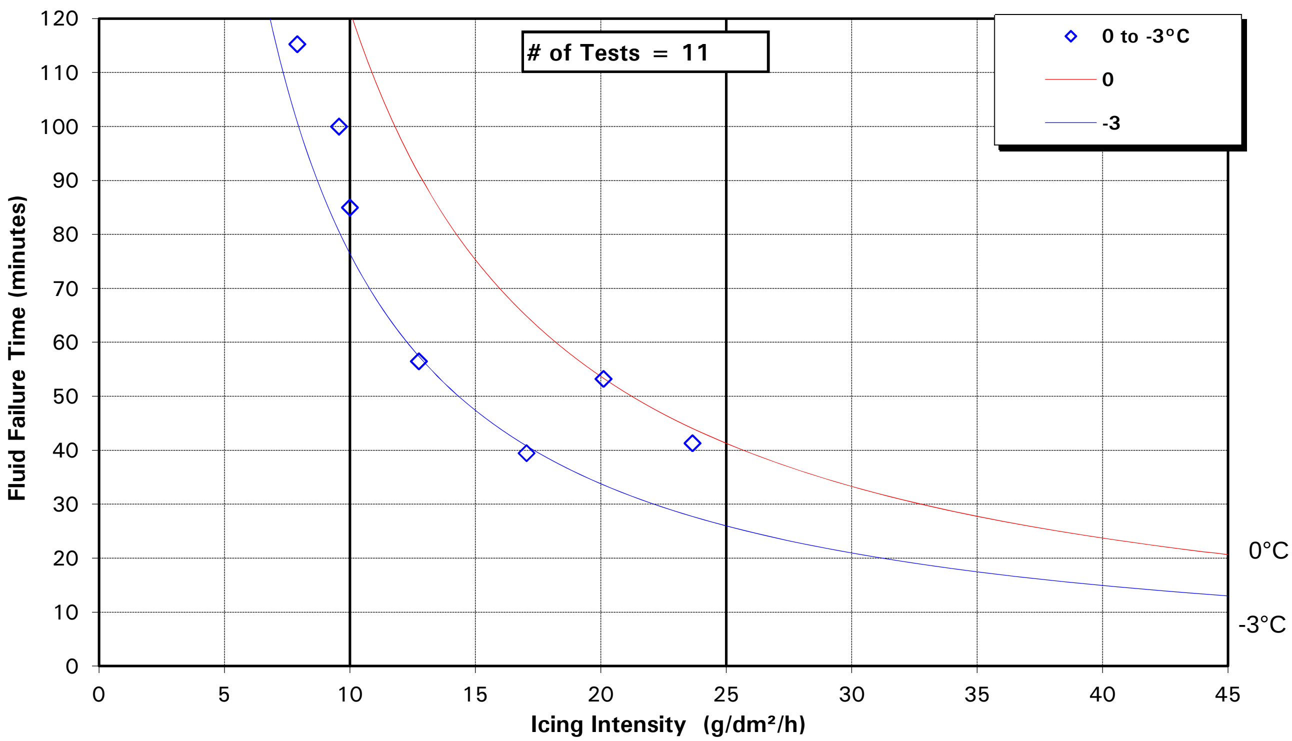


FIGURE 4.37
EFFECT OF TEMPERATURE AND RATE OF PRECIPITATION ON ENDURANCE TIME
TYPE IV PRODUCT A (50/50)
NATURAL SNOW



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At:5050

TABLE 4.3

Comparison of Indoor and Outdoor Endurance Times for New Fluids

Summary of Differences Between Indoor and Outdoor Snow Data for TYPE IV PRODUCT A

Fluid	Dilution	Temperature (°C)	Endurance Times (minutes)			
			Artificial Snow Data		Natural Snow Data	
			10 g/dm²/h	25 g/dm²/h	10 g/dm²/h	25 g/dm²/h
TYPE IV Product A	Neat	-3°C	125	40	165	85
TYPE IV Product A	Neat	-14°C	50	20	70	35
TYPE IV Product A	Neat	-25°C	30	10	50	25
TYPE IV Product A	75%	-3°C	120	40	135	65
TYPE IV Product A	75%	-14°C	40	20	85	40
TYPE IV Product A	50%	-3°C	60	20	75	25

* Times were rounded to nearest whole 5 minute value, but not cut off at 120 minutes.

I:\Groups\CM1680(exBM3833)\reports\NCAR\Table 4.3.xls
At:TABLE 4.3

4.5 Proposed Correlation Method Between Artificial and Natural Snow

The snow endurance times generated by NCAR and AMIL artificial snow methods do not correlate with the outdoor natural snow endurance times. Both machines give endurance times that are lower than the outdoor times. The reasons believed to cause these lower times have been presented at industry meetings and are discussed in Transport Canada report, TP 13488E, *A Snow Generation System - Prototype Testing*, (1). The following variables are believed to affect fluid endurance times and contribute to lower artificial snow times:

- Wind;
- Plate temperature;
- Snowflake size;
- Fluid viscosity; and
- Fluid dilution.

An effort to understand and determine the importance of these variables on endurance time is currently underway. Following this investigation, methods for negating the influence of each variable will need to be devised. A validation period would then be required to verify the new test methods. This process will take considerable time.

An approach that may provide an interim solution in developing indoor endurance times is proposed in Subsection 4.5.1.

4.5.1 Creation of a Ratio

A five-part process to establish a correlation between outdoor and indoor data sets is proposed. This method would have to be applied for each fluid dilution to be tested.

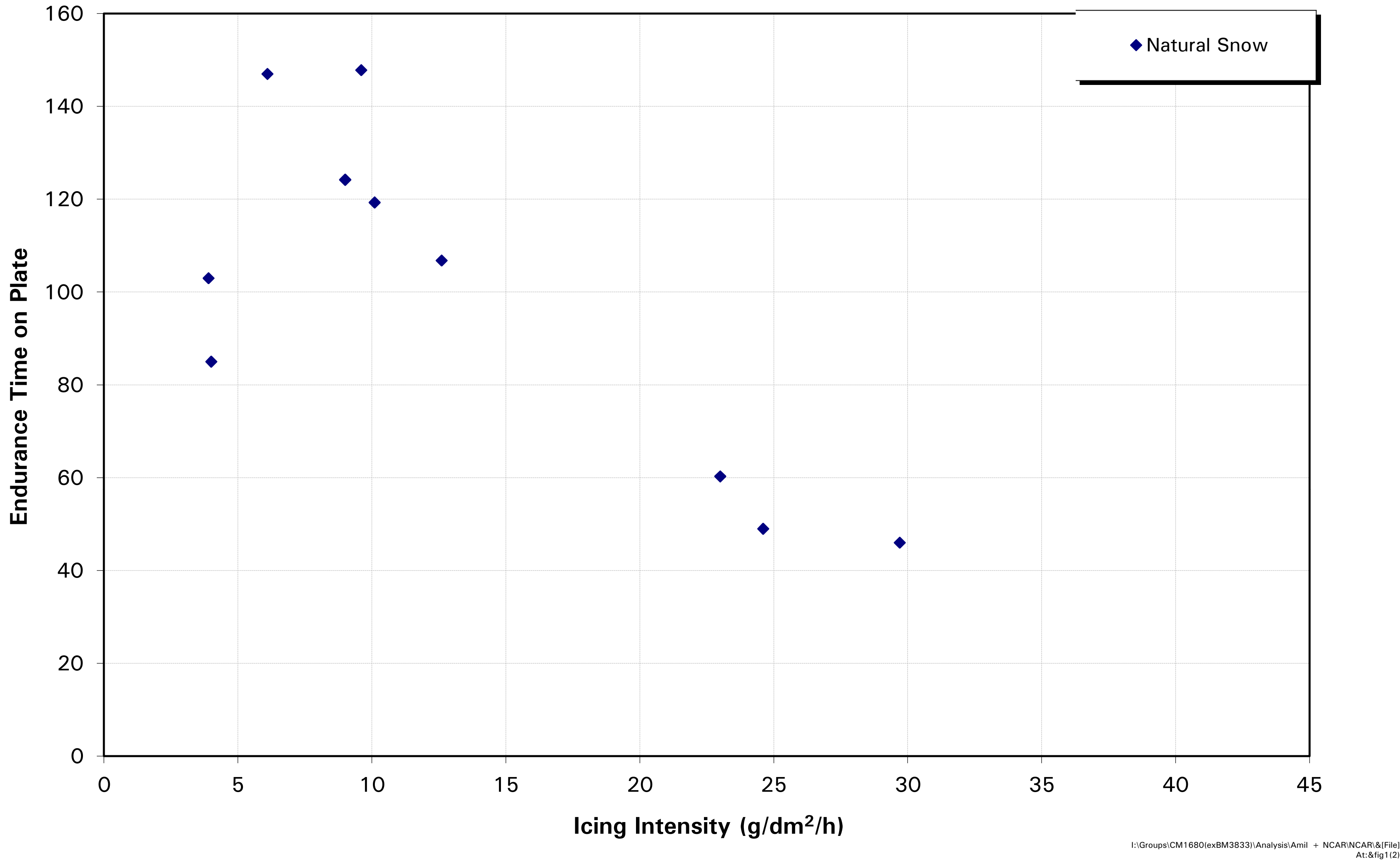
4.5.1.1 Step 1: Outdoor Natural Snow Testing

Natural snow tests would be performed under natural snow conditions using standard holdover time testing methods. Icing intensity measurements would be taken frequently; for example, every five minutes. Figure 4.38 shows sample data collected under natural snow conditions.

FIGURE 4.38

Natural Snow Endurance Times

Neat Fluid



I:\Groups\CM1680(exBM3833)\Analysis\Amil + NCAR\NCAR\Figure 4.38.xls
At:fig 1 (2)

Below are the proposed criteria for outdoor tests:

- Tests should be done for each fluid dilution;
- 5 to 10 points should be collected (the number of points should be determined in conjunction with the industry);
- Data should be included from 2 to 3 storms;
- A minimum test point distribution should contain the following:
  - 2 points when the temperature is less than or equal to -7ºC for neat and 75/25 concentrations;
  - 2 points when the temperature is greater than or equal to -3ºC;
  - 1 point when the icing intensity is greater than or equal to 20 $g/dm^2/h$;
  - 2 points when the icing intensity is less than or equal to 10 $g/dm^2/h$; and
  - 1 point when the icing intensity is between 10 to 20 $g/dm^2/h$.

4.5.1.2 Step 2: Indoor Replication

The natural snow tests would then be replicated indoors using an artificial snow machine. The tests would follow the same icing intensity and temperature as observed for the outdoor tests. Figure 4.39 shows natural snow data and the corresponding artificial snow data collected at the same rate and temperature; this data will then be used in Step 3.

4.5.1.3 Step 3: Ratio of Artificial to Natural Snow

A ratio comparing the point taken outdoors to the identical indoor test would be created. The ratio is generated from the natural snow value divided by the corresponding artificial snow point. A global average of the ratio is obtained for all the tests performed. A separate ratio is determined for each dilution.

4.5.1.4 Step 4: Holdover Time Tests Under Artificial Snow

The new fluid should then be tested for each dilution at all holdover time cell temperatures and at the standard rates of 10 and 25 $g/dm^2/h$. For example, for the cell 0 to -3ºC using a 50/50 fluid dilution tests should be conducted at 10 and 25 $g/dm^2/h$ at a temperature of -3ºC.

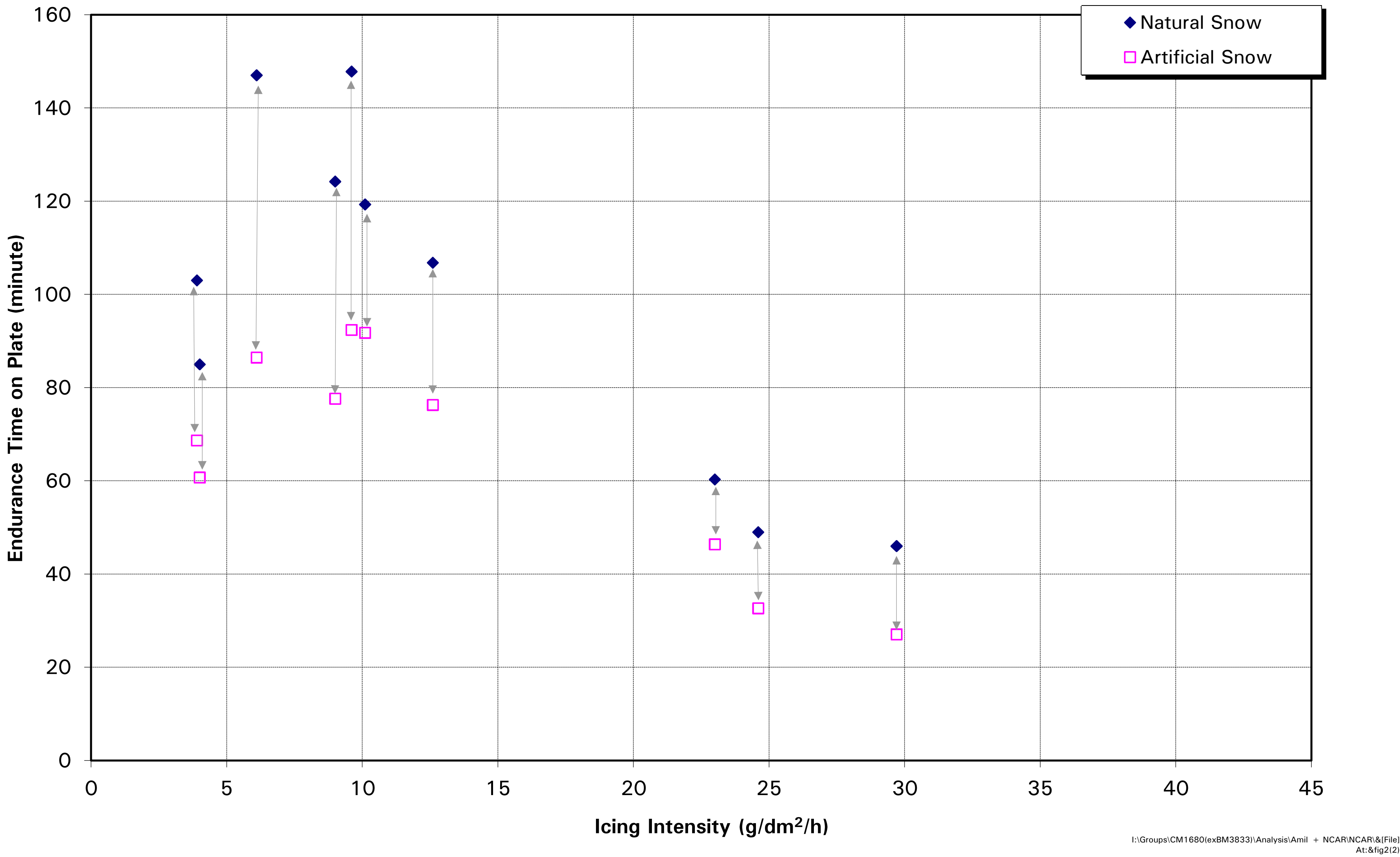
4.5.1.5 Step 5: Application of the Ratio

The ratio obtained in Step 3 above can now be applied to the artificial snow holdover time values obtained in Step 4. This would provide values comparable to those obtained under natural snow. Figure 4.40 shows artificial data and the subsequent endurance times obtained with the ratio.

FIGURE 4.39

Natural Snow Versus Artificial Snow Endurance Times

Neat Fluid

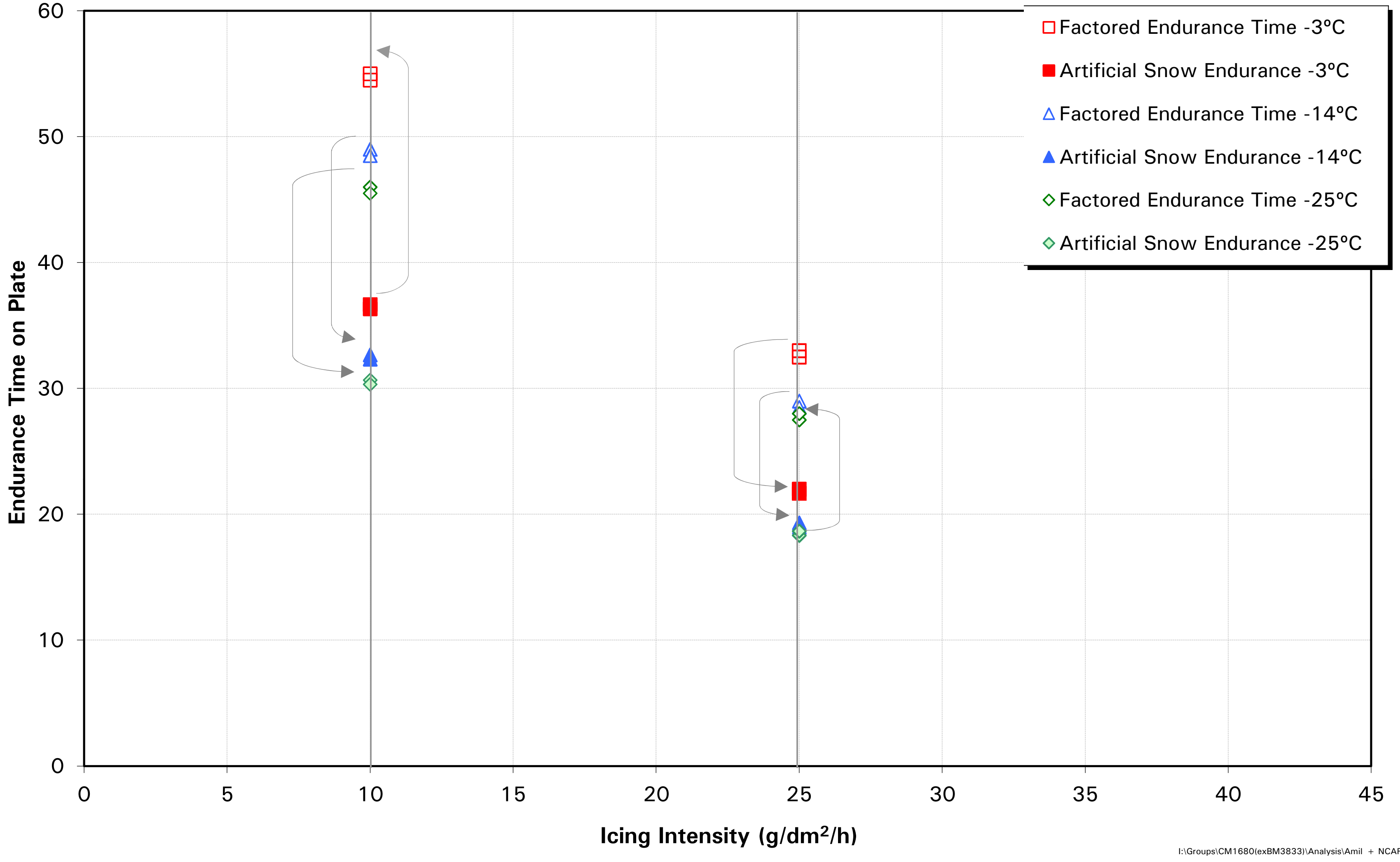


I:\Groups\CM1680(exBM3833)\Analysis\Amil + NCAR\NCAR\Figure 4.39.xls
At:fig 2 (2)

FIGURE 4.40

Natural Snow Endurance Times Factored From Artificial Endurance Times

Neat Fluid



I:\Groups\CM1680(exBM3833)\Analysis\Amil + NCAR\NCAR\Figure 4.40.xls
At:fig 3 (2)

4.5.2 Advantages and Disadvantages

This five-step method would allow for the immediate use of the snow machine, before all the differences with it have been resolved. This would allow year-round testing capabilities.

The artificial snow machine should not be considered as a substitute for outdoor natural snow tests, but could allow for the testing of fluids at any time of the year. Natural snow tests would provide realistic endurance time values for fluids being tested with the snowmaker and would allow for continued comparison of the artificial snow data to show improvements or failures in the machine.

The snow machine would allow for the testing of a new fluid in the absence of conditions necessary for outdoor natural snow testing. A fluid manufacturer may wish to test a new fluid during the summer months, for example. In this case, the new fluid may have to:

- Contend with the indoor endurance times until natural snow testing could be accomplished;
- Contend with generic Type IV holdover times until natural snow testing could be accomplished; or
- Contend with no snow endurance times at all.

4.5.3 Future Discussion

The five-step procedure presented above should be considered at a future meeting held to discuss artificial snow generation and changes to the Proposed AS 5485. The ratio could allow for the continued use and testing of artificial snow machines.

As snow machines begin to accurately simulate natural snow in the laboratory, the ratio will become one. The ratio can then be used as a test to ensure that the machine continues to perform as an accurate representation of natural snow.

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Photo 4.1

Snow Generated by the NCAR Machine at -14ºC

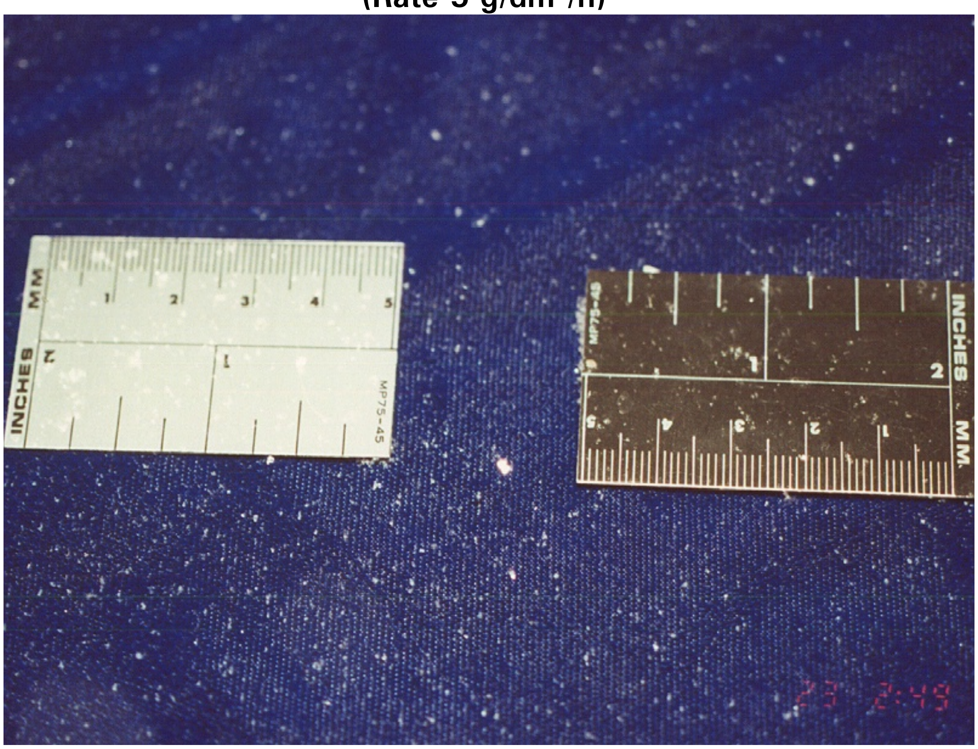
(Rate 10 g/dm^2/h)

Scale: 1cm equals 3 cm

Photo 4.2

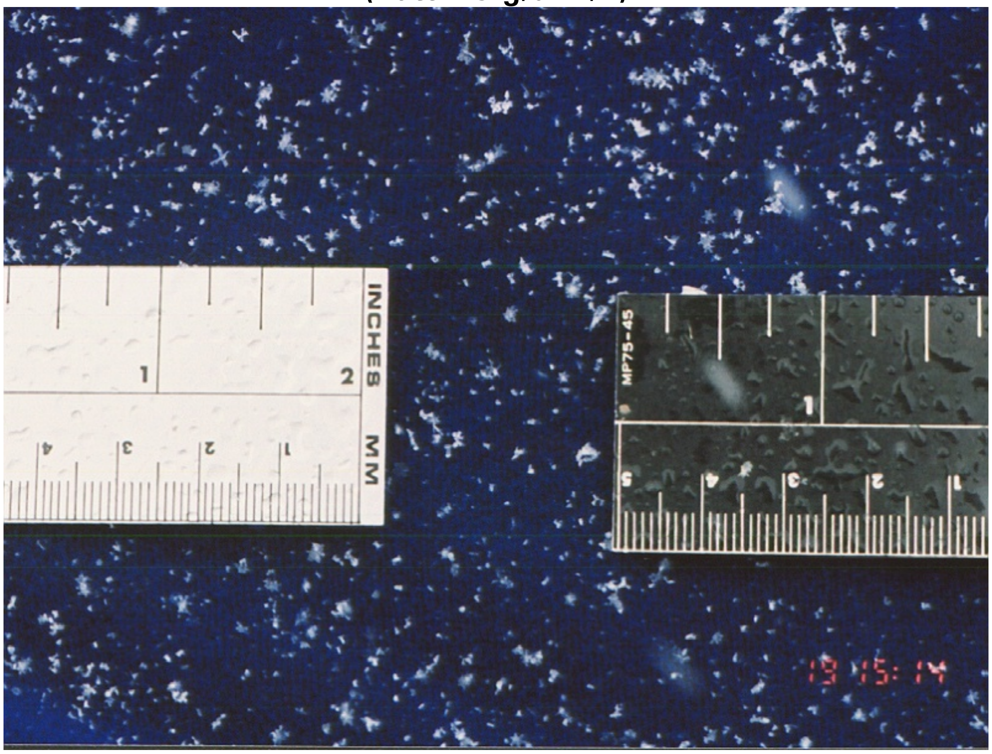
Natural Snow Observed at Dorval Test Site at -14ºC

(Rate 5 g/dm^2/h)



Scale: 1cm equals 1cm

Photo 4.3
Natural Snow Observed at Dorval Test Site -3°C
(Rate 25 g/dm^2/h)



Scale: 1cm equals 0.9 mm

Photo 4.4
Snow Clumping on the Snow Distribution Plenum

Photo 4.5
Aluminium Ice Core Tubes

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5. CONCLUSIONS

5.1 Snow Distribution Trials

The NCAR machine has demonstrated its ability to produce artificial snow. The modifications made to both the software and the hardware in June 2001 have greatly improved the machine's general functionality over previous versions.

Tests of snowfall distribution over the test plate were conducted in April and June 2001. These results showed that the NCAR machine is presently well outside the specifications for the distribution outlined in the Proposed AS 5485.

The results obtained for distribution range in April 2001 trials using the second-generation NCAR machine were 1.3 to 6.9 times greater than the acceptable range in AS 5485. The average icing intensity range obtained was 3.6 times higher than the acceptable range outlined in AS 5485.

Additional distribution tests were conducted in June 2001, following several modifications to the second-generation NCAR machine. The results obtained in these trials were 1.4 to 4.5 times greater than the acceptable ranges in AS 5485. The average icing intensity range obtained was 2.8 times higher than the acceptable range in AS 5485. These results were a slight improvement over the April 2001 distribution results, but were still nowhere near being within the specified limits in the Proposed AS 5485.

Most importantly, none of the 35 distribution trials conducted with the NCAR snowmaker in April and June 2001 were within the prescribed limits outlined within the Proposed AS 5485.

Additional modifications are needed for the NCAR machine to meet these basic requirements. The resolution of snow intensity distribution issues must be considered of the highest priority for future use of the NCAR machine.

A brief study of the snowflake diameters produced by the NCAR machine lends support to visual observations indicating that the flakes produced by the NCAR snowmaker were, on average, larger than those found in nature. This seemed to be especially true at colder temperatures.

5.2 Intra-Laboratory Snow Reconciliation

In general, the outdoor natural snow data collected by APS and AMIL seemed to compare quite well, although most of the AMIL outdoor data was collected at much lower precipitation rates. The outdoor data from the two laboratories were combined and subjected to a regression analysis that produced the outdoor fluid holdover times subsequently used for comparison with the numbers generated from indoor tests.

Analysis of the indoor artificial snow data indicated that the Type IV failure times were generally shorter for the trials performed with the snowmaking system than those obtained from natural snow testing.

Snow bridging occurred frequently during indoor trials with propylene fluids and contributed to inferior endurance times. For Kilfrost ABC-S fluid, the artificial snow failure times were, on average, only 48% of the natural snow results. For the Kilfrost ABC-S Neat concentration, the indoor endurance times were, on average, only 40% of the outdoor endurance times. For SPCA AD-480, the artificial snow failure times were, on average, only 56% of the natural snow results. In the neat concentration, SPCA AD-480 indoor snow endurance times were, on average, 48% of the outdoor endurance times. In diluted forms, SPCA AD-480 demonstrated indoor failure times that were, on average, 65% of the outdoor endurance times.

The artificial snow fluid failure times generated for the two propylene fluids were also inferior to the SAE Type IV generic values at colder temperatures.

Trials were also conducted on one ethylene glycol-based Type IV fluid, Dow/UCAR Ultra+. Because this fluid is only certified for use in undiluted concentration, only the neat fluid was tested. The ethylene-based fluid Ultra+ did not exhibit large variations between the artificial snow trials and the natural snow trials. On average, the indoor endurance times were 106% of the natural snow results. A significant difference between this fluid and the propylene fluids tested is the failure mechanism. Ultra+ tends to dilute at all temperatures, and does not promote snow bridging-style failures.

5.3 NCAR Snow Reconciliation

The bucket assembly used for NCAR indoor tests was positioned outdoors for natural snow testing during the winter of 2000-01 at the Dorval Airport test site, where 18 fluid endurance time tests were conducted in natural snow events.

The 18 data points collected outdoors by APS on the NCAR bucket assembly were to be duplicated indoors with the NCAR snowmaking system using the newly designed *variable autorate* function. This function uses the electronic rate profile of the outdoor test as a template to run the indoor test. Due to problems with the snow machine and software, the test data from APS outdoor natural snow bucket trials, including the electronic data files, were provided to NCAR. Personnel at NCAR ran the tests on behalf of APS.

In all cases, the results of indoor tests with the NCAR snowmaker were inferior to the outdoor tests on the bucket assembly. The results of tests using the *variable autorate* function were, in general, closer to the natural snow results than tests conducted using the precipitation rate limits of 10 and 25 g/dm^2/h.

For SPCA AD-480 Neat, the two tests conducted indoors had, on average, 79% of the endurance time of the outdoor tests. For SPCA AD-480 75/25, the three tests conducted indoors had, on average, 67% of the endurance time of the outdoor tests.

For Kilfrost ABC-S Neat, the one test conducted indoors had an endurance time equivalent to 58% of the endurance time of the outdoor test. For Kilfrost ABC-S 75/25, the one test conducted indoors had 85% of the endurance time of the outdoor test.

For Dow/UCAR Ultra+ Neat, the one test conducted indoors had an endurance time equivalent to 93% of the endurance time of the outdoor test.

5.4 Comparison of Indoor and Outdoor Endurance Times for a Certified Type IV Fluid

Endurance time test data were generated for Type IV Product A, a certified propylene glycol-based Type IV fluid (designated Product A), in natural snow and artificial snow. For the Neat and 75/25 dilutions of Type IV Product A, the indoor endurance times were, on average, 62% of the values obtained in outdoor testing. For the 50/50 dilution of Type IV Product A, the indoor endurance times were 80% of the values obtained in outdoor testing.

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6. RECOMMENDATIONS

6.1 Conformance of the NCAR Artificial Snow Generation System with the Test Parameters Outlined in the Proposed Aerospace Standard AS 5485

The snowfall distribution over the test surface must be uniform and within the ranges specified in the Proposed AS 5485. At present, the NCAR machine consistently falls short of these requirements.

Additional modifications are needed for the NCAR machine to meet these basic requirements. The resolution of snow intensity distribution issues must be considered of the highest priority for future use of the NCAR machine.

In the future, it may be advantageous to change the specifications set out in the Proposed AS 5485 to ease the problems currently experienced during testing with the snow machine. One possible method would be to reduce the number of ice catch plates used in distribution trials.

Rate distribution trials should also be performed in natural snow. The data from the trials could be used to evaluate the performance of the NCAR snowmaker and re-examine the tolerances specified in the Aerospace Standard.

6.2 Intra-Laboratory Reconciliation

New fluids should be tested with the NCAR system once modifications have been performed to compare endurance times at several ambient temperatures and with several fluid dilutions. Both propylene glycol- and ethylene glycol-based fluids should be tested.

6.3 NCAR Snow Reconciliation

Examination of the snowflake diameters produced by the NCAR machine provided support to visual observations indicating that the flakes were larger than those found in nature. The effects of snowflake size should be studied to determine the impact of the artificial snowflake size on holdover time. The correct flake size, as a function of temperature, required to reconcile natural and artificial snow should be identified.

A more in-depth study of the effects of wind and plate temperature should be undertaken in the upcoming test season.

It is recommended that further testing be performed to reconcile fluid failure times of artificial snow and natural snow using the NCAR bucket assembly. All test variables (such as ambient temperature, plate temperature, relative humidity, and precipitation rates) should be recorded in natural snow trials and duplicated during indoor artificial snow trials using the *variable autorate* function. This would allow direct comparison, because the rate profiles would be the same as those found outdoors.

6.4 Proposed Correlation Method Between Artificial and Natural Snow

The use of the ratio method for determining snow endurance times should be considered at future snow reconciliation meetings. The ratio method could allow for the continued use and testing of artificial snow machines.

REFERENCES

1. Hunt, M., Hanna, M., Chaput, M., Ruggi, E., *A Snow Generation System – Prototype Testing,* APS Aviation Inc., Montreal, October 1999, Transport Canada Report, TP 13488E, 34.

2. Hunt, M., Hanna, M. *A Second Generation Snowmaking System – Prototype Testing,* APS Aviation Inc., Montreal, August 2000, Transport Canada Report, TP 13661E, 63.

3. Society of Automotive Engineers (SAE) Aerospace Standard AS 5485, *Endurance Time Tests for Aircraft Deicing/Anti-icing Fluids: SAE Type I, II, III, and IV* (unpublished).

4. Chaput, M., D'Avirro, J., Hanna, *Aircraft Ground De/Anti-icing Fluid Holdover Time Field Testing Program for the 1999-2000 Winter*, APS Aviation Inc., Montreal, August 2000, Transport Canada report, TP 13659E, 395.

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APPENDIX A

WORK STATEMENT - PROJECT DESCRIPTION EXCERPT FROM TDC

APPENDIX A

PROJECT DESCRIPTION EXCERPT FROM TRANSPORTATION DEVELOPMENT CENTRE WORK STATEMENT DC 187 AIRCRAFT & ANTI-ICING FLUID WINTER TESTING 2000 -2001

(January 2001)

5. DETAILED STATEMENT OF WORK

Over the past several years, TDC has managed and, through its contractor, APS, conducted tests at various sites in Canada; it has also co-ordinated world-wide testing and evaluation of evolving technologies related to de/anti-icing operations with the co-operation of the Federal Aviation Administration, the National Research Council, Atmospheric Environment Services, Transport Canada, several major airlines, and deicing fluid manufacturers. This winter the TDC contractor will conduct the following research and testing, primarily in Montreal and Ottawa,

5.1 Holdover Time Testing

5.1.1 Holdover Time Testing and Evaluation of De/Anti-Icing Fluids for SAE

5.1.1.1 **Natural Snow Tests at Dorval**

5.1.1.1.1 The contractor shall prepare a test procedure.

5.1.1.1.2 Conduct flat plate tests under conditions of natural snow at the Dorval Airport test site to record fluid holdover times. All testing will be performed using the methodology developed in the conduct of similar tests for Transport Canada in past years.

5.1.1.1.3 Develop individual fluid holdover times for snow, based on samples of newly certified or re-certified Type I, Type II, Type III and Type IV fluids supplied by fluid manufacturers, under as wide a range of temperature, precipitation rate, precipitation type, and wind conditions as can be experienced. Testing is anticipated for two new Type IV fluids, two Type II fluids, as well as one Type I fluid.

5.1.1.1.4 Analyze the data collected and report the findings.

5.1.1.2 **Holdover Time Tests in Simulated Precipitation at NRC**

5.1.1.2.1 Prepare a test procedure for the conduct of holdover time tests in simulated precipitation at NRC.

5.1.1.2.2 Conduct flat plate tests under conditions of freezing drizzle, light freezing rain, freezing fog, and rain on a cold-soaked surface at the National Research Council Climatic Engineering Facility in Ottawa to record fluid holdover times. All testing will be performed using the methodology developed in the conduct of similar tests for Transport Canada in past years.

5.1.1.2.3 Develop individual fluid holdover times for all simulated precipitation conditions, based on samples of newly certified or re-certified fluids supplied by fluid manufacturers, under defined test parameters, such as temperature and precipitation rate. Two Type IV fluids, two Type II fluids, as well as one Type I fluid are anticipated for testing.

5.1.1.2.4 Analyze the data collected and report the findings.

5.1.2 Testing in Natural Snow for Comparison with Simulated Snow Tests

5.1.2.1 Prepare a test procedure for the conduct of Type I holdover time tests in natural precipitation.

5.1.2.2 Conduct further testing in natural snow conditions, using the same fluids as tested in simulated conditions during the last test season in order to compare the holdover times in natural and simulated conditions using the NCAR artificial snow generation system.

5.1.2.3 Re-evaluate Type I holdover times in natural snow with the new fluids using both the current test method and the newly proposed Type I fluid test protocol.

5.1.2.4 Conduct all holdover time trials in natural snow with Type I fluids at the Dorval test site at the same time as tests with new fluids to reduce costs.

5.1.2.5 Analyze the data collected and report the findings.

5.1.3 Holdover Time Testing in Simulated Frost at IREQ

The need to carry out frost testing has been expressed by several members of the SAE G-12 Holdover Time Subcommittee. During the 1999-2000 winter test season, APS conducted preliminary calibration tests in simulated frost conditions at the

Institut de Recherche d'Hydro-Québec (IREQ) cold chamber in Varennes. Results of the calibration trials revealed that frost was producible at IREQ, and that the rates of deposition obtained at two temperatures (-3°C and -25°C) were similar to those proposed for use in future endurance time trials in simulated frost. Endurance time tests were conducted as part of these calibration trials with selected fluids, and in some cases, the endurance times obtained were significantly below the numbers approved for use in the various SAE holdover time tables.

5.1.3 1 Prepare a test procedure for the conduct of frost calibration and frost holdover time tests in simulated frost conditions.

5.1.3.2 Conduct additional frost calibration trials to fully determine the exact parameters required to perform holdover time tests in all the frost conditions. Trials will be performed to create a set of rate correction curves to relate the decreasing frost rate obtained on a bare surface during a long test, to the actual frost rate on the fluid covered surface. The required parameters will be identified and all the calibration trials will be performed as part of this set of trials. It is anticipated that two days of calibration is required at each of the five test temperatures, 0°C, -3°C, -10°C, -14°C, and -25°C, for a total of ten days.

5.1.3.3 Conduct holdover time testing in frost conditions at IREQ as part of the winter holdover time test program. Individual fluid holdover times for frost based on samples of newly certified or re-certified fluids supplied by the fluid manufacturers, will be obtained under defined test parameters, such as temperature, frost deposition rate, and relative humidity. Testing shall be conducted over a ten-day period at IREQ with three anti-icing fluids and two deicing fluids.

5.1.3.4 Analyze the data collected and report the findings.

5.1.4 Round Robin Holdover Time Testing

Tests conducted by TDC have provided holdover time guidelines to pilots and operators for several years. Round Robin testing of Type IV fluid must be performed to reconcile the differences in anti-icing fluid failure times in natural and simulated snow. Results of recent TDC holdover time tests using the NCAR artificial snow generation system indicate that the failure times for several Type IV fluids were up to 50% shorter than the times obtained from natural snow trials. Furthermore, the results of APS tests in natural and simulated snow are not in accordance with results obtained using AMIL's artificial snow method. In addition, APS and AMIL shall carry out testing under conditions of freezing rain and drizzle.

In 1998-99, a reference fluid (Fluid X) was proposed by the SAE to allow a comparison of different laboratory snowmaking methods. Unfortunately, the viscosity of Fluid X was found to be unstable, and use of the fluid was discontinued.

At the SAE G-12 Fluids Subcommittee meeting in Toulouse, it was proposed that certified fluids be used in the future to compare natural and simulated snow test data obtained from various sources.

5.1.4.1 Prepare a test procedure for the conduct of round-robin testing in snow and also for freezing rain and freezing drizzle.

5.1.4.2 Conduct natural snow tests in conjunction with outdoor testing of new fluids. Simulated snow testing will be completed using the NCAR system at one of several climatic chambers, including NRC, PMG Technologies, Centre du Recherche Industrielle du Québec (CRIQ) or IREQ. A total of 10 days of climatic chamber use will be planned for these trials. It is anticipated that tests will be conducted with three Type IV fluids (one ethylene and two propylene) of the same batch to obtain similar results in natural snow and using both artificial snow methods.

5.1.4.3 Collect a minimum of 20 data points per fluid dilution in natural snow under the widest possible range of temperatures, precipitation rates, precipitation types, and wind conditions.

5.1.4.4 Conduct a minimum of two tests in simulated snow for each fluid dilution, at each of the snow rate limits, for each cell of the snow column.

5.1.4.5 travel to AMIL on two occasions during natural snow events to aid AMIL personnel in the determination of fluid failures in order to minimize the impact of the fluid failure call variable.

5.1.4.6 Conduct round robin testing in other simulated conditions covered by the various holdover time tables.

5.1.4.7 Aanalyze the data collected and report the findings.

5.1.5 Evaluation of the IREQ Chamber for Freezing Fog Holdover Time Testing

Aircraft de/anti-icing fluid holdover time testing in freezing fog has been conducted by APS at the National Research Council's Climatic Engineering Facility in Ottawa for several years. While the NRC facility has yielded good results for trials involving freezing fog, the daily calibration required for the conduct of tests in freezing fog is often excessive.

During the 1999-2000 test season, APS conducted preliminary calibration tests at the IREQ facility in Varennes. The results of these trials indicated that freezing fog could be produced at the facility, but several changes would need to be made to the current set-up in order to produce freezing fog with precipitation rates and rate distributions in the range required by the proposed Aerospace Standard 5485.

5.1.5.1 Establish the costs of conducting freezing fog holdover time testing at IREQ vs. NRC, and identify the benefits of such testing. Discus with IREQ their capabilities and charges..

5.1.5.2 Prepare a test procedure for the conduct of freezing fog testing at IREQ.

5.1.5.3 Obtain the approval of Transport Canada to conduct the freezing fog tests

5.1.5.4 Conduct the freezing fog tests at IREQ.

5.1.5.5 Analyze the data collected and report the findings.

5.1.6 Evaluation of Winter Weather Data

A study of the snow weather data has been undertaken since 1995 to ascertain the suitability of the precipitation rate ranges used for fluid holdover time evaluation in snow. Winter weather data will be collected and examined from Environment Canada for six weather stations within Quebec (Dorval, Quebec City, Rouyn, Pointe-au-Père, Frelighsburg, and High Falls).

During the 1999-2000 test season, APS collected one fog deposition measurement in an attempt to determine typical fog deposition rates that occur in natural conditions. The observed rate of fog deposition was below the current lower precipitation rate used in the evaluation of fluid holdover times in this condition.

5.1.6.1 Snow Rates

5.1.6.1.1 Examine the precipitation rate/temperature data from the different stations to determine the variance of the data in warmer and colder regions.

5.1.6.1.2 Examine the various temperature ranges used to establish holdover times to determine the frequency of precipitation that occurs within each temperature range.

5.1.6.1.3 Analyze the data collected and report the findings.

5.1.6.2 Fog Deposition Rates

5.1.6.2.1 Prepare a procedure for the collection of fog deposition rates in natural fog conditions.

5.1.6.2.2 Collect fog deposition measurements on at least two occasions.

5.1.6.2.3 Analyze the data collected and report the findings.

5.1.7 Documentation of Fluid Failure Characteristics

The objective of this study will be to document the appearance and properties of anti-icing fluids when they reach their operational limits.

Laboratory trials were conducted in past years under controlled conditions of ambient temperature and artificial precipitation; and natural snow trials were conducted in conditions selected for the desired precipitation rates and ambient air temperature. Documentation included photographic and videotape records, visual description, readings from various ice detection sensors, and measurements of physical characteristics such as adherence, viscosity, fluid concentration, and film thickness

5.1.7.1 Prepare a procedure for the conduct of trials to document the appearance of fluid failure characteristics.

5.1.7.2 Conduct trials outdoors during holdover time snow testing to collect missing data at temperatures of 0°C to -5°C. It is anticipated that one session will be sufficient to collect the information.

5.1.7.3 Analyze the data collected and report the findings.

5.6 Simulated Snow Validation

TDC undertook a research program in 1999-2000 to evaluate the precipitation conditions produced, as well as the general functionality of the second-generation model of the snowmaking system developed by the National Center for Atmospheric Research (NCAR). The first-generation system was tested as part of the 1998-99 research program.

Type I and Type IV fluids were tested in simulated snow conditions at various ambient temperatures and precipitation rates. The failure times observed during these trials were generally shorter than the times published in the holdover time tables. The findings of these tests identified the need to reconcile the differences between natural and artificial snow.

5.6.1 Natural Snow Reconciliation

5.6.1.1 Prepare a procedure for the conduct of natural snow reconciliation trials.

5.6.1.2 Evaluate the modified second-generation NCAR system for the future conduct of holdover time testing in simulated snow conditions. Tests will initially be conducted with the snowmaker assembly in natural precipitation. The outdoor conditions will then be reproduced in a laboratory to compare the failure times in both conditions. Indoor tests will be conducted in a small climatic chamber at PMG Technologies, Institut de Recherche d'Hydro-Québec, or at NRC. Tests will be conducted with three Type IV fluids (one ethylene- and two propylene-based fluids) and one Type I fluid over a range of temperatures and snowfall.
Tests will be conducted on a pro-active basis. Artificial snow tests will be performed soon after each natural snow sessions to obtain comparative data. A total of four artificial snow sessions are anticipated.

5.6.1.3 Analyze the data collected and report the findings.

5.6.2 Fluid Holdover Time Tests

5.6.2.1 Prepare a procedure for the conduct of natural snow reconciliation trials.

5.6.2.2 Perform a further series of trials with the artificial snowmaker to compare indoor failure times with the SAE holdover times for these fluids.
A total of 10 days of climatic chamber use will be planned for the conduct of the proposed tests. The test will be performed in conjunction with the holdover time tests and the climatic chamber rental will be covered under the holdover time proposal.

5.6.2.3 Analyze the data collected

5.6.2.4 Prepare a detailed report of findings.

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APPENDIX B

EXPERIMENTAL PROGRAM

TRIALS TO ASSESS THE PERFORMANCE OF THE NCAR SNOW GENERATION SYSTEM

BM3833.001

EXPERIMENTAL PROGRAM

TRIALS TO ASSESS THE PERFORMANCE OF THE NCAR SNOW GENERATION SYSTEM

Winter 2000/01

Prepared for

Transportation Development Centre
Transport Canada

Prepared by: Michael Chaput

Reviewed by: John D'Avirro

APS AVIATION INC.

March 8, 2001
Version 1.0

EXPERIMENTAL PROGRAM
TRIALS TO ASSESS THE PERFORMANCE OF THE NCAR SNOW GENERATION SYSTEM

Winter 2000/01

This set of tests will produce the data required for further evaluating the snow precipitation produced by the NCAR snow generation system. The failure times from natural snow trials and artificial snow trials will be compared and the differences will be analyzed.

1. OBJECTIVES

The purpose of these tests is to evaluate the NCAR system for the future conduct of holdover time testing.

There are three objectives to the NCAR indoor snow testing:

1. **NCAR Snow Reconciliation**: To determine the reasons for differences in endurance times obtained in natural snow tests and tests conducted with the NCAR artificial snow generation system;
2. **Intra-Laboratory Snow Reconciliation**: To determine differences in snow endurance times generated by APS, AMIL, and NCAR, in natural and simulated snow; and
3. **Holdover Time Testing**: To generate endurance times in artificial snow for new fluids.

2. TEST REQUIREMENTS

All indoor snow trials will be conducted at PMG Technologies, CRIQ, Institut de Recherche d'Hydro-Québec, or at NRC in Ottawa.

All Type IV fluids must be tested at outside air temperature. If the cold chamber is not maintained at low temperatures over night, the fluids must be refrigerated to ensure temperature is according to requirements.

Type I fluids must be at room temperature until the test is performed. They must not be stored in the cold chamber. Tests with Type I fluids will use fluid samples diluted to a 10°C buffer.

For snow reconciliation tests, the same conditions experienced in outdoor trials with the NCAR rate collection apparatus (see procedures in document entitled *Trials to Determine the Differences Between Natural Snow and the NCAR Snow Generation System – Outdoor Snow*), will be recreated in the laboratory.

3. EQUIPMENT

Attachment I presents a list of required equipment for the holdover time tests.

All additional equipment required for the operation of the snowmaking system is included in the snowmaking machine operators' manual, supplied by NCAR (Attachment II).

4. PERSONNEL

The personnel requirements for the holdover time tests are as follows:

- One person to pour the fluids and to call the failure on the plate.
- One person part-time to assist in preparing the snow generation system (particularly for Type I trials) and to verify its correct operation.

5. SUMMARY OF PROCEDURES

The ice core tubes must be filled with de-mineralized water and cooled to below 0°C, a minimum of twelve hours before testing begins.

The procedures for the holdover time tests are as indicated in the *Experimental Program For Dorval Natural Precipitation Flat Plate Testing* with the exception that the plate rate pans are not required since the rates are collected by the NCAR system.

The major steps in the artificial snow flat plate test procedure are:

1. Empty fluid collection bucket;
2. Prepare and secure ice core;
3. Begin precipitation and data logging;
4. Clean panels and start;
5. Apply (pour fluids to test panels. Type I fluids are at room temperature. Type II and Type IV fluids are at the test air temperature. Fluids are poured using a single-step fluid application;

6. Record the start of the holdover time after fluid is applied;
7. Record crosshair end condition times; and
8. Continue testing until at least five crosshairs or 1/3 of the plate have failed.

The operation of the snowmaking system is detailed in the snowmaking machine operators' manual supplied by NCAR (Attachment III).

5.1 NCAR Snow Reconciliation Tests

For these tests, the test results obtained in outdoor trials with the NCAR snow collection bucket will be reproduced in a laboratory environment, using the same temperatures, precipitation rates (including rate fluctuations), and fluids as in outdoor trials. It is anticipated that 5 tests will be performed per fluid, for a total of 35 tests. The matrix of tests for NCAR Snow Reconciliation tests is included in Table I.

5.2 Intra-Laboratory Snow Reconciliation Tests

These tests will be conducted using precipitation rates of 10 and 25 g/dm2/h, at the most restrictive temperature in each cell of the holdover time table. The same fluids used in outdoor trials, UCAR Ultra+, SPCA AD-480, and Kilfrost ABC-S will be employed. The matrix of tests for Intra-Laboratory Snow Reconciliation tests is included in Table II.

5.3 Holdover Time Testing of New Fluids

Time permitting, tests aimed at determining the holdover time performance of new fluids will be performed using the NCAR snow machine. Tests will be conducted using precipitation rates of 10 and 25 g/dm2/h, at the most restrictive temperature in each cell of the holdover time table. The matrix of tests for Intra-Laboratory Snow Reconciliation tests is included in Table III.

6. DATA FORM

The holdover time tests will only require the end condition data form modified for simulated snow trials. This form is included as Figure 1.

ATTACHMENT B-I
TEST EQUIPEMENT CHECKLIST

- Snow making machine and related equipment;
- Aluminum plate;
- Fluid thickness gauge;
- Squeegee/scraper;
- Extension cord;
- Paper towels;
- Rags;
- Flood lights;
- Stopwatch;
- Wet vacuum;
- Brixometer;
- Data forms;
- Clipboard;
- Video camera;
- Photo camera; and
- RH meter.

APPENDIX C

EXPERIMENTAL PROGRAM

ENDURANCE TIME TEST PROCEDURES
FOR NATURAL SNOW
AOS/NCAR RECONSILIATION

BM3833

EXPERIMENTAL PROGRAM

ENDURANCE TIME TEST PROCEDURES – NATURAL SNOW APS/AMIL/NCAR RECONCILIATION

Winter 2000/2001

Prepared for

Transportation Development Centre
Transport Canada

Prepared by: Michael Chaput

Reviewed by: John D'Avirro

December 22, 2000
Version 1.0

APS AVIATION INC.

ENDURANCE TIME TEST PROCEDURES – NATURAL SNOW

APS/AMIL/NCAR RECONCILIATION

1. PURPOSE:

The purpose of this document is to outline the procedures to be employed for the conduct of anti-icing endurance time testing in natural snow. This testing will be conducted by APS, AMIL, and NCAR, as part of the snow endurance time reconciliation test program sponsored by Transport Canada and the FAA.

2. TESTING AGENT DUTIES:

2.1 Run and Report Viscosity:

The testing agent shall verify the viscosity of the samples received, using the fluid manufacturer's designated method of viscosity measurement, and report these values.

2.2 Verify Refractive Index/Brix:

The designated testing agent shall ensure that the refractive index/brix of the neat and diluted Type IV samples is within experimental error of the values provided by the fluid manufacturers.

2.3 Fluid Dilution:

The testing agent is not required to dilute fluids for testing. To ensure that all fluid samples used in snow endurance time testing are identical, fluids will be delivered to the various testing agents pre-diluted by the fluid manufacturers. Test will be conducted using Type IV 100/00, 75/25, and 50/50.

3. ENDURANCE TIME TEST—GENERAL:

3.1 Summary of the Tests

Fluids to be evaluated are applied to test plates exposed to natural snow. Endurance times are evaluated by measuring the minimum exposure time before a specified degree of freezing occurs.

3.2 Data to be Recorded

For all outdoor natural snow tests, the following data should be recorded:

- Outside air temperature
- Fluid manufacturer, fluid name, and fluid dilution
- Wind speed and direction
- Fluid failure time
- Fluid application temperature
- Snowfall intensity
- Brix / refractive index at failure
- Photography of end condition and snowflakes

3.3 Test Plates

The test plates are made of aluminum alloy AMS 4037. The dimensions of the test plates are 30 cm wide x 50 cm long x 0.32 cm thick, with an average surface roughness ≤ 0.5 μm. The test plate is positioned on the test stand and inclined at 10° ± 0.2°. Each 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.

3.4 Test Panel Orientation

If there is any wind, orient the test stand so that the test panels are facing into the wind direction at the beginning of the test and the wind is blowing up the panels. The stand should be positioned within 15° of the wind direction.

i.e. -------→ /
wind panel

If the wind shifts during the test do not move the stand; simply note it on the data sheet. The test stand should not be re-oriented until all plates on the test stand have failed. A sub-test with neat or 75/25 fluid should not be started unless the test stand is within 15° of the wind direction.

Wind velocity measurements should be recorded continuously or on ten-minute intervals using an anemometer positioned at 2 meters above the ground. The wind direction should also be recorded throughout the test.

3.5 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 isopropyl alcohol and a squeegee. 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 isopropyl before the second test; a thorough rinse with the fluid to be tested is sufficient.

3.6 Fluid Application

Pour 1 litre of Type IV fluid onto the plates from 1-litre containers, until the entire test section surface is covered. Type IV fluids are to be applied to test surfaces at ambient outside air temperature. The fluid temperature at the start of each test should be measured and recorded.

3.7 Wait Time

No wait time is required following the application of fluids to the plates. The test start time begins when the fluid application process is complete.

3.8 Appearance of Failure:

The plate failure time is that time required for the plate end condition to be achieved. This occurs when the accumulating snow fails to be absorbed within at least 15 seconds at any five of the crosshair marks on the panels or when 1/3 of the test panel is covered with accumulating snow.

In all natural snow tests, regardless of the method of fluid failure, an accumulation of snow is apparent in the failed areas. Type IV fluid failures in natural snow tests normally occur when:

- The fluid has “eroded” due to dilution and snow begins to accumulate on the plate surface (dilution failure); and

- The fluid no longer absorbs the snow and it begins to rest on top of the fluid (snow-bridging failure).

A typical dilution-style failure is shown in Photo 1. In this case, the fluid has been diluted due to ongoing precipitation and the fluid film has eroded substantially. Failures have reached just beyond the 3″ line on the plate (white snow is visible in the failed area). Dilution failures normally occur from top-to-bottom on the test surface, and are common at warm temperatures and low rates of precipitation. Ethylene-based Type IV fluids usually fail in this manner.

A snow-bridging failure is shown in Photo 2. In this case, the fluid resists dilution and a thick film of fluid remains on the entire plate surface. Plate failure has occurred in this test because snow, resting on top of the fluid, already covers more than 1/3 of the plate surface. Snow-bridging failures do not always occur in top-to-bottom fashion, and are common at cold temperatures and high rates of precipitation. Propylene-based Type IV fluids usually fail in this manner.

3.9 Sample Collected Following Failure

Following the failure of each test, collect a fluid sample within 1 cm below the failure front. The refractive index / Brix of the fluid sample should be recorded.

3.10 Photography of the End Condition

Photography of the appearance of failure for each natural snow test is required. Photos are to be taken at the moment of fluid failure and 5 minutes following the fluid failure.

A 35mm camera with a zoom lens (focal length set to 50mm), and 800 ASA film (preferably Fuji), will be used to record the photographic documentation. A time stamp is also required for each photograph. In addition, test information such as the fluid name, dilution, plate #, will be written on plastified paper and clipped to the test stand next to the individual test plates to identify the plates in the various photographs.

Photographs will be taken from a camera mounted on a tripod positioned approximately 16′′ back from the bottom of the test plate, from a height of approximately 24″ above the plate. The tripod set-up must be mobile. Flash photography should not be performed. Photographic lighting will consist of a mobile spotlight with two 500W halogen bulbs positioned at a 45° angle at distance of 5 feet from the back of the test plate. The halogens lights shall be turned on for the process of taking photos regardless of the time of day to promote continuity. For night photography, a color correction filter (CC10B) will be placed on the lens (a different filter diameter may be required depending on camera lens diameter).

Photo C-1
Dilution Failure

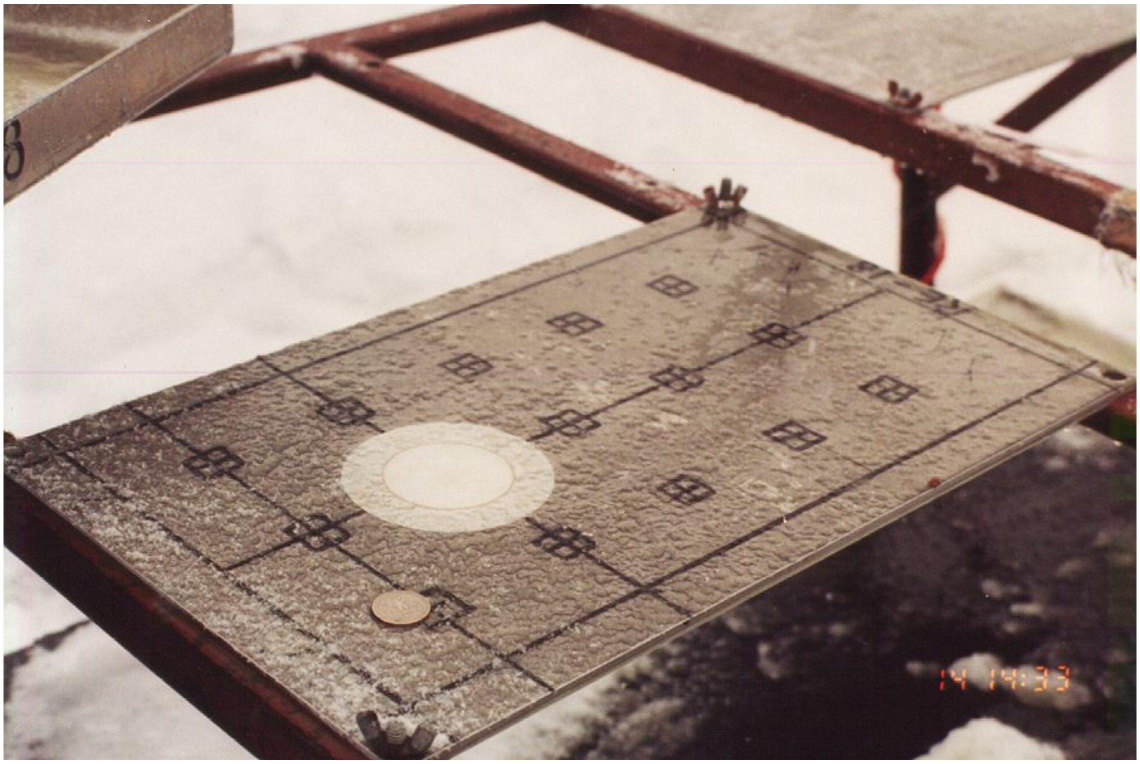

Photo C-2
Snow-bridging failure

3.11 Snowflake Characterization/Photography

To characterize the snowflakes observed during natural snow testing, a 30cm x 30cm black felt-covered board will be exposed to the snow prior to and after the completion of each test. A ruler with millimetre increments should be placed on the board to measure the individual flakes. To prevent the break up of snow aggregates upon impact with the felt-covered board, the board should be lowered 1 m/s during the snow collection phase.

Photographs of the snowflakes for each test should taken prior to and following the failure of each plate. Also, if the size and nature of the snowflakes change during any test, a photograph of the snowflake should be recorded. The classification of solid precipitation has been included in Figure 4 and should be recorded for each test.

A 35mm camera with a macro lens (set to the closest setting, 55-60mm), and 800 ASA film (preferably Fuji), will be used to record the photographic documentation. A time stamp is also required for each photograph.

3.12 Method for the Determination of Snowfall Intensity

Plate pans, measuring 30 cm wide x 50 cm long (including the lips) x 4 cm deep thick, will be placed at a 10º inclination on the test stand and will be used to collect and weigh snow. Prior to each pre-test weighing, the bottom and sides of the pan must be wetted with Type IV anti-icing fluid to prevent blowing snow from escaping the pan. Weigh the wetted pan prior to testing (APS uses a scale with an accuracy of 0.2 grams). The pans should be placed on the test stand and re-weighed individually at 5-minute intervals; one pan must remain on the test stand at all times during the process of weighing the pans. The plate pans should be carefully rotated frequently to prevent accumulating snow from blowing away. The pans should be re-positioned on the test stand as long as the duration of the last test panel.

4. DATA FORMS:

Two data forms will be used to manually record data at Dorval Airport during the snow reconciliation tests during 2000-01 winter season. The form used to record fluid failure times for each crosshair on the plates is shown in Table 1. The second form (Table 2) is used to record data relating to meteorological conditions during tests. One half of the form is designated for plate pan precipitation rate measurements, and the rest of the page is reserved for documentation of meteorological conditions and any changes to them that may occur during tests.

APPENDIX D

EXPERIMENTAL PROGRAM

TRIALS TO DETERMINE THE DIFFERENCE BETWEEN NATURAL SNOW AND THE NCAR SNOW GENERATION SYSTEM

BM3833

EXPERIMENTAL PROGRAM

TRIALS TO DETERMINE THE DIFFERENCES BETWEEN NATURAL SNOW AND THE NCAR SNOW GENERATION SYSTEM

OUTDOOR SNOW

Winter 2000/2001

Prepared for

Transportation Development Centre
Transport Canada

Prepared by: Michael Chaput

Reviewed by: John D'Avirro

December 22, 2000
Version 1.0

APS AVIATION INC.

TRIALS TO DETERMINE THE DIFFERENCES BETWEEN NATURAL SNOW AND THE NCAR SNOW GENERATION SYSTEM

Winter 2000/01

1. PURPOSE

The purpose of this work is to determine the reasons for differences in endurance times obtained in natural snow tests and tests conducted with the NCAR artificial snow generation system.

Tests will be performed using the procedures outlined and the data forms included in the *Endurance Time Test Procedures – Natural Snow APS/AMIL/NCAR Reconciliation* procedural document.

2. TEST REQUIREMENTS

Outdoor trials will be conducted at the APS test site located at Dorval Airport.

Temperatures, precipitation rates, relative humidity and other ambient conditions will be recorded during the natural snow trials and duplicated during the indoor trials. Environmental conditions will be monitored by automated sensors. The wind speed and direction will be recorded at 10 m level.

All Type IV fluids must be tested at the ambient air temperature.

Approximately 5 outdoor trials and 5 indoor trials are anticipated for each fluid.

In order to eliminate variables, the snowfall accumulation on the NCAR plate will be measured on a minute-by-minute basis along with the temperature of the plate at the 6″ line in the center of the plate with a thermocouple embedded in the rear of the plate. The individual outdoor test conditions, including fluctuations in the rate, will then be reproduced in the laboratory trials.

Tests should ideally be conducted in low wind / no wind conditions. Test plates may be shielded from the wind in future trials with a snow fence.

3. TEST SET-UP

Tests will be conducted on a three-plate stand. A standard test plate, equipped with thermocouples, will be placed at the first position on this stand. The plate is tilted to a 10° angle that is checked prior to every fluid test with a digital level. This standard test plate will be referred to as the "free-standing plate".

The second plate is part of the NCAR snow machine tray assembly. This plate will be referred to as the "tray assembly plate". The assembly will be placed on an elevated platform at position 2 on the three-plate stand. The tray assembly is placed on the same electronic balance used in the snow machine tests.

Both the free-standing plate and the tray assembly plate will be positioned at the same height level.

The third position on the stand will be reserved for the collection of precipitation rates using a rate pan.

Wires with quick disconnects are run from the thermistor on the tray assembly plate and from the balance into the trailer. A PC in the trailer running labview software collects the temperature and mass data every 6 seconds and archives it onto a disk.

4. EQUIPEMENT

- Two standard test plates, 30 cm x 50 cm;
- Three thermocouples, two for the free-standing plate, one for the tray assembly plate;
- Tray assembly for fluid containment;
- Three-plate test stand;
- Two precipitation rate pans;
- PC that automatically records the mass of the snow on the plate and the temperature of the plate (Micron laptop); and
- Deicing fluids from a common production run also delivered to NCAR (Kilfrost ABC-S Type IV, SPCA AD-480 Type IV, and Ultra+ Type IV).

5. TEST PROCEDURES

Tests will be performed using the procedures outlined in the *Endurance Time Test Procedures – Natural Snow APS/AMIL/NCAR Reconciliation* procedural document.

When measuring precipitation rates with the rate pans, care must be taken to ensure that one pan remains on the test stand at all times. Prior to removing a rate pan from the stand, weigh a new pan and place it on the stand at the same position as the plate to be weighed. Continue to alternate the plates at 5-minute intervals until the end of the test.

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APPENDIX E

DATA FROM RATE DISTRIBUTION TRIALS

NCAR Snowmaker Detailed Icing Intensity and Range

TEST #1 April 2, 2001 Command Rate: 25 g/dm2/hr

AS 5485 requirements

Rate: 25 g/dm^2/hr ± 1.0

temp = -14.0°C range: ≤ 4.0 g/dm^2/hr

Rate for 6 Pans

top left

		1/3 avg	range
22.94	22.35	22.64	3.77
22.05	19.61	2/3 avg	
23.27	23.38	22.07	

bottom right

mean: 22.26

Percent Change

		1/3 avg	
3.0%	0.4%	1.7%	1.7%
-1.0%	-11.9%	2/3 avg	
4.5%	5.0%	-0.9%	-0.9%

Rate for 10 Pans

top left

		Range
23.32	23.59	6.37
22.37	20.47	
21.83	19.12	
22.37	20.20	
23.86	25.49	

bottom right

mean: 22.26

4.8%	6.0%	0.8%
0.5%	-8.0%	
-1.9%	-14.1%	
0.5%	-9.3%	
7.2%	14.5%	-0.5%

Rates for 15 Pans

top left

				Range
22.4	25.2	22.8	23	8.14
22.8	21.6	19.9	21	
22.0	21.6	17.9	20	
22.4	22.4	19.1	21	
23.6	24.4	26.0	25	
23	23	21	22	

bottom right

mean: 22.3

Percent Change

top left		top right
0.5%	13.3%	2.3%
2.3%	-3.2%	-10.5%
-1.3%	-3.2%	-19.6%
0.5%	0.5%	-14.1%
6.0%	9.6%	16.9%

bottom right

I:\Groups\CM1680\Analysis\NRC 2001 JUNE\ncar rate distribution\NCAR APRIL rate distribution.xls
At:april1
Printed:4:53 PM, 7/29/2015

NCAR Snowmaker Detailed Icing Intensity and Range

TEST #2 April 2, 2001 Command Rate: 25 g/dm2/h

AS 5485 requirements
Rate: 25 g/dm^2/h **± 1.0**
temp = -14.0°C **range: ≤ 4.0 g/dm^2/hr**

Rate for 6 Pans

top left		1/3 avg	range
21.76	22.55	22.15	2.86
21.19	20.66	2/3 avg	
23.52	22.46	21.96	
	bottom right		

mean: 22.02

Percent Change

		1/3 avg	
-1.2%	2.4%	0.6%	0.6%
-3.8%	-6.2%	2/3 avg	
6.8%	2.0%	-0.3%	-0.3%

Rate for 10 Pans

top left		Range
23.08	24.40	5.05
19.78	19.78	
21.54	20.22	
21.54	22.86	
24.84	22.20	
	bottom right	

mean: 22.02

4.8%	10.8%	-1.2%
-10.2%	-10.2%	
-2.2%	-8.2%	
-2.2%	3.8%	
12.8%	0.8%	0.8%

Rates for 15 Pans

top left				Range
22.4	24.4	24.4	24	5.94
19.8	19.8	19.8	20	
21.1	22.4	19.1	21	
21.1	22.4	23.1	22	
25.1	24.4	21.1	24	
22	23	22	22	
		bottom right		

mean: 22.0

Percent Change

top left		top right
1.8%	10.8%	10.8%
-10.2%	-10.2%	-10.2%
-4.2%	1.8%	-13.2%
-4.2%	1.8%	4.8%
13.8%	10.8%	-4.2%
		bottom right

NCAR Snowmaker Detailed Icing Intensity and Range

TEST #3 April 2, 2001 Command Rate: 10 g/dm2/h

AS 5485 requirements

Rate:10g/dm^2/h **±0.5**

temp = -14.0°C **Range: ≤1.5 g/dm^2/h**

Rate for 6 Pans

top left

		1/3 avg	**range**
14.55	**11.44**	**12.99**	**6.50**
10.09	**8.05**	2/3 avg	
11.60	**10.63**	**10.09**	

bottom right

mean: 11.06

Percent Change

		1/3 avg	
31.6%	**3.4%**	**17.5%**	17.5%
-8.7%	**-27.2%**	2/3 avg	
4.9%	**-3.9%**	**-8.7%**	-8.7%

Rate for 10 Pans

top left

		Range
16.38	**13.69**	**8.59**
11.81	**8.05**	
9.40	**7.79**	
10.47	**8.86**	
12.35	**11.81**	

bottom right

mean: 11.06

48.1%	**23.8%**	12.9%
6.8%	**-27.2%**	
-15.0%	**-29.6%**	
-5.3%	**-19.9%**	
11.7%	**6.8%**	-8.6%

Rate for 15 Pans

top left

				Range
16.9	**15.3**	**12.9**	15	**9.66**
12.9	**9.7**	**7.2**	10	
9.7	**8.9**	**7.2**	9	
10.5	**10.5**	**8.1**	10	
12.1	**12.9**	**11.3**	12	
12	11	9	11	

bottom right

mean: 11.1

Percent Change

52.9%	**38.3%**	**16.5%**
38.3%	**-12.6%**	**-34.5%**
-12.6%	**-19.9%**	**-34.5%**
-5.3%	**-5.3%**	**-27.2%**
9.2%	**16.5%**	**1.9%**

bottom right

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NCAR Snowmaker Detailed Icing Intensity and Range

TEST #4 April 2, 2001 Command Rate: 25 g/dm2/h

AS 5485 requirements

Rate: 25 $g/dm^2/h \pm 1.0$

temp = -14.0°C range: $\leq$ 4.0 $g/dm^2/h$

Rate for 6 Pans

top left		1/3 avg	range
31.68	31.37	31.52	6.26
32.04	30.06	2/3 avg	
36.20	29.94	32.06	
	bottom right		

mean: 31.88

Percent Change

		1/3 avg	
-0.6%	-1.6%	-1.1%	-1.1%
0.5%	-5.7%	2/3 avg	
13.5%	-6.1%	0.6%	0.6%

Rate for 10 Pans

top left		Range
32.48	33.27	10.69
30.50	28.51	
32.48	29.70	
32.28	32.67	
38.81	28.12	
	bottom right	

mean: 31.88

1.9%	4.3%	-2.2%
-4.3%	-10.6%	
1.9%	-6.8%	
1.2%	2.5%	
21.7%	-11.8%	1.4%

Rates for 15 Pans

top left				Range
31.6	34.5	32.8	33	16.08
31.0	29.8	28.0	30	
32.8	32.2	28.6	31	
31.0	35.1	31.6	33	
44.1	28.6	28.0	34	
34	32	30	32	
		bottom right		

mean: 32.0

Percent Change

top left		top right
-1.2%	8.1%	2.5%
-3.1%	-6.8%	-12.4%
2.5%	0.6%	-10.6%
-3.1%	9.9%	-1.2%
37.9%	-10.6%	-12.4%
		bottom right

NCAR Snowmaker Detailed Icing Intensity and Range

TEST #6 April 3, 2001 Command Rate: 25 g/dm2/h

AS 5485 requirements

Rate: 25 $g/dm^2/h \pm 1.0$

temp = -3.0°C range: $\leq$ 4.0 $g/dm^2/h$

Rate for 6 Pans

top left		1/3 avg	range
19.39	14.96	17.17	9.31
24.27	19.97	2/3 avg	
22.91	18.96	21.53	
	bottom right		

mean: 20.07

Percent Change

		1/3 avg	
-3.4%	-25.5%	-14.5%	-14.5%
20.9%	-0.5%	2/3 avg	
14.1%	-5.6%	7.2%	7.2%

Rate for 10 Pans

top left		Range
13.73	12.93	14.93
27.87	18.00	
23.33	20.88	
23.47	19.20	
22.53	18.80	
	bottom right	

mean: 20.07

-31.6%	-35.6%	-9.7%
38.8%	-10.3%	
16.2%	4.0%	
16.9%	-4.4%	
12.2%	-6.3%	6.4%

Rates for 15 Pans

top left				Range
14.0	13.2	12.8	13	16.80
29.6	24.4	14.8	23	
24.0	22.0	20.3	22	
23.6	23.2	17.2	21	
23.2	21.2	17.6	21	
23	21	17	20	
		bottom right		

mean: 20.1

Percent Change

top left		top right
-30.3%	-34.2%	-36.2%
47.4%	21.5%	-26.3%
19.6%	9.6%	1.2%
17.6%	15.6%	-14.3%
15.6%	5.6%	-12.3%
		bottom right

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NCAR Snowmaker Detailed Icing Intensity and Range

TEST #8 April 4, 2001 Command Rate: 25 g/dm2/h

AS 5485 requirements

Rate: 25 g/dm^2/h ± 1.0

temp = -3.0°C range: ≤ 4.0 g/dm^2/h

Rate for 6 Pans

top left

		1/3 avg	range
34.91	26.75	30.83	17.79
21.41	17.31	2/3 avg	
17.12	18.19	18.51	

bottom right

mean: 22.61

Percent Change

		1/3 avg	
54.4%	18.3%	36.3%	36.3%
-5.3%	-23.5%	2/3 avg	
-24.3%	-19.6%	-18.2%	-18.2%

Rate for 10 Pans

top left

		Range
40.40	31.07	25.73
26.67	20.27	
21.73	17.20	
15.20	14.67	
18.40	20.53	

bottom right

mean: 22.61

78.7%	37.4%	30.9%
17.9%	-10.4%	
-3.9%	-23.9%	
-32.8%	-35.1%	
-18.6%	-9.2%	-20.6%

Rates for 15 Pans

top left

				Range
42.4	36.4	28.4	36	28.00
28.4	23.2	18.8	23	
21.2	22.8	14.4	19	
15.2	15.2	14.4	15	
18.0	19.2	21.2	19	
25	23	19	23	

bottom right

mean: 22.6

Percent Change

top left		top right
87.5%	61.0%	25.6%
25.6%	2.6%	-16.9%
-6.3%	0.8%	-36.3%
-32.8%	-32.8%	-36.3%
-20.4%	-15.1%	-6.3%

bottom right

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NCAR Snowmaker Detailed Icing Intensity and Range

TEST #9 April 4, 2001 Command Rate: 25 g/dm2/h

AS 5485 requirements

Rate: 25 g/dm^2/h ± **1.0**

temp = -3.0°C **range: ≤ 4.0 g/dm^2/h**

Rate for 6 Pans

top left		1/3 avg	range
20.69	16.16	18.43	**20.45**
22.69	17.20	2/3 avg	
36.61	35.28	27.95	
	bottom right		

mean: 24.77

Percent Change

		1/3 avg	
-16.5%	-34.8%	-25.6%	-25.6%
-8.4%	-30.6%	2/3 avg	
47.8%	42.4%	12.8%	12.8%

Rate for 10 Pans

top left		Range
20.80	17.33	**27.60**
20.53	14.40	
21.33	15.47	
28.93	25.20	
41.73	42.00	
	bottom right	

mean: 24.77

-16.0%	-30.0%	-26.3%
-17.1%	-41.9%	
-13.9%	-37.6%	
16.8%	1.7%	
68.5%	69.5%	17.5%

Rates for 15 Pans

top left				Range
	21.6	15.2	18	**32.40**
22.0	17.6	12.8	17	
22.8	18.4	14.0	18	
29.2	28.4	23.6	27	
40.0	45.2	40.4	42	
29	26	21	25	
		bottom right		

mean: 25.1

Percent Change

top left		top right
#VALUE!	-13.9%	-39.4%
-12.3%	-29.8%	-49.0%
-9.1%	-26.7%	-44.2%
16.4%	13.2%	-5.9%
59.5%	80.2%	61.0%
		bottom right

NCAR Snowmaker Detailed Icing Intensity and Range

TEST #10 April 4, 2001 Command Rate: 25 g/dm2/h

AS 5485 requirements

Rate: 25 g/dm^2/h ± 1.0

temp = -3.0°C range: ≤ 4.0 g/dm^2/h

Rate for 6 Pans

top left		1/3 avg	range
18.36	16.99	17.68	13.45
25.52	22.40	2/3 avg	
30.06	30.44	27.10	
	bottom right		

mean: 23.96

Percent Change

		1/3 avg	
-23.4%	-29.1%	-26.2%	-26.2%
6.5%	-6.5%	2/3 avg	
25.4%	27.0%	13.1%	13.1%

Rate for 10 Pans

top left		Range
16.76	16.00	17.33
20.76	18.48	
26.67	22.48	
26.86	26.10	
32.19	33.33	
	bottom right	

mean: 23.96

-30.0%	-33.2%	-24.9%
-13.4%	-22.9%	
11.3%	-6.2%	
12.1%	8.9%	
34.3%	39.1%	16.6%

Rates for 15 Pans

top left				Range
17.1	16.0	16.0	16	18.86
21.1	20.0	17.7	20	
28.0	24.0	21.7	25	
26.9	26.9	25.7	26	
30.9	34.9	32.6	33	
25	24	23	24	
		bottom right		

mean: 24.0

Percent Change

top left		top right
-28.5%	-33.2%	-33.2%
-11.8%	-16.5%	-26.1%
16.9%	0.2%	-9.4%
12.1%	12.1%	7.3%
28.8%	45.5%	35.9%
		bottom right

NCAR Snowmaker Detailed Icing Intensity and Range

TEST #11 April 4, 2001 Command Rate: 25 g/dm2/h

AS 5485 requirements

Rate: 25 g/dm^2/h ± **1.0**

temp = -3.0°C **range: ≤ 4.0 g/dm^2/h**

Rate for 6 Pans

top left		1/3 avg	range
29.14	20.20	24.67	11.37
23.25	21.11	2/3 avg	
17.77	21.78	20.98	
	bottom right		

mean: 22.21

Percent Change

		1/3 avg	
31.2%	-9.0%	11.1%	11.1%
4.7%	-4.9%	2/3 avg	
-20.0%	-1.9%	-5.5%	-5.5%

Rate for 10 Pans

top left		Range
31.17	20.20	14.05
26.09	20.20	
23.81	21.40	
18.73	21.14	
17.12	22.21	
	bottom right	

mean: 22.21

40.4%	-9.0%	9.9%
17.5%	-9.0%	
7.2%	-3.6%	
-15.7%	-4.8%	
-22.9%	0.0%	-6.6%

Rates for 15 Pans

top left				Range
34.5	24.5	18.1	26	19.67
27.3	23.7	18.5	23	
23.7	24.1	20.1	23	
18.5	19.3	22.1	20	
14.8	21.7	22.5	20	
24	23	20	22	
		bottom right		

mean: 22.2

Percent Change

top left		top right
55.4%	10.2%	-18.7%
22.9%	6.6%	-16.9%
6.6%	8.4%	-9.6%
-16.9%	-13.3%	-0.6%
-33.1%	-2.4%	1.2%
		bottom right

NCAR Snowmaker Detailed Icing Intensity and Range

TEST #12 April 4, 2001 Command Rate: 25 g/dm2/h

AS 5485 requirements

Rate: 25 g/dm^2/h ± **1.0**

temp = -3.0°C **range: ≤ 4.0 g/dm^2/h**

Rate for 6 Pans

top left		1/3 avg	range
22.54	#VALUE!	#VALUE!	#VALUE!
27.44	#VALUE!	2/3 avg	
		#VALUE!	
	bottom right		

mean: #VALUE!

Percent Change

		1/3 avg	
#VALUE!	#VALUE!	#VALUE!	#VALUE!
#VALUE!	#VALUE!	2/3 avg	
#VALUE!	#VALUE!	#VALUE!	#VALUE!

Rate for 10 Pans

top left		Range
22.92	21.83	9.76
21.97		
31.19	25.49	
21.69	21.42	
	bottom right	

mean: 23.79

-3.7%	-8.2%	-6.5%
-7.7%		
31.1%	7.2%	
-8.8%	-9.9%	
		4.9%

Rates for 15 Pans

top left				Range
23.2	22.4	21.6	22	11.39
22.0	22.0		22	
32.5	28.5	24.0	28	
21.6	22.0	21.2	22	
			#DIV/0!	
25	24	22	#DIV/0!	
		bottom right		

mean: 23.7

Percent Change

top left		top right
-2.2%	-5.6%	-9.0%
-7.3%	-7.3%	
37.3%	20.1%	1.2%
-9.0%	-7.3%	-10.8%
		bottom right

NCAR Snowmaker Detailed Icing Intensity and Range

TEST #13 April 4, 2001 Command Rate: 25 g/dm2/h

AS 5485 requirements

Rate: 25 g/dm^2/h ± 1.0

temp = -3.0°C range: ≤ 4.0 g/dm^2/h

Rate for 6 Pans

top left		1/3 avg	range
22.29	23.20	22.74	10.97
24.23	24.00	2/3 avg	
30.29	19.31	24.46	
	bottom right		

mean: 23.89

Percent Change

		1/3 avg	
-6.7%	-2.9%	-4.8%	-4.8%
1.4%	0.5%	2/3 avg	
26.8%	-19.1%	2.4%	2.4%

Rate for 10 Pans

top left		Range
22.29	22.29	18.29
22.29	24.57	
26.29	25.14	
20.00	20.00	
37.14	18.86	
	bottom right	

mean: 23.89

-6.7%	-6.7%	-4.3%
-6.7%	2.9%	
10.0%	5.3%	
-16.3%	-16.3%	
55.5%	-21.1%	2.9%

Rates for 15 Pans

top left				Range
22.3	22.3	22.3	22	27.43
20.6	25.7	24.0	23	
24.0	30.9	22.3	26	
20.6	18.9	20.6	20	
46.3	18.9	18.9	28	
27	23	22	24	
		bottom right		

mean: 23.9

Percent Change

top left		top right
-6.7%	-6.7%	-6.7%
-13.9%	7.7%	0.5%
0.5%	29.2%	-6.7%
-13.9%	-21.1%	-13.9%
93.8%	-21.1%	-21.1%
		bottom right

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NCAR Snowmaker Detailed Icing Intensity and Range

TEST #14 June 28, 2001 Command Rate: 25 g/dm2/h

AS 5485 requirements
Rate: 25 $g/dm^2/h \pm 1.0$
temp = -3.0°C range: $\leq$ 4.0 $g/dm^2/h$

Rate for 6 Pans

top left

		1/3 avg	range
23.20	18.50	20.85	9.26
27.77	21.78	2/3 avg	
23.35	21.50	23.60	

bottom right

mean: 22.68

Percent Change

		1/3 avg	
2.3%	-18.4%	-8.1%	-8.1%
22.4%	-4.0%	2/3 avg	
3.0%	-5.2%	4.0%	4.0%

Rate for 10 Pans

top left

		Range
21.03	15.61	13.16
26.45	22.84	
28.77	22.06	
26.06	19.87	
21.55	22.58	

bottom right

mean: 22.68

-7.3%	-31.2%	-5.3%
16.6%	0.7%	
26.8%	-2.7%	
14.9%	-12.4%	
-5.0%	-0.5%	3.5%

Rates for 15 Pans

top left

				Range
20.5	22.1	12.4	18	28.26
23.6	32.1	18.2	25	
22.8	40.6	12.8	25	
23.6	31.0	14.3	23	
21.3	22.1	22.8	22	
22	30	16	23	

bottom right

mean: 22.7

Percent Change

top left top right

-9.6%	-2.7%	-45.4%
4.1%	41.6%	-19.8%
0.7%	79.2%	-43.7%
4.1%	36.5%	-36.9%
-6.1%	-2.7%	0.7%

bottom right

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At:april14
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NCAR Snowmaker Detailed Icing Intensity and Range

TEST #15 April 4, 2001 Command Rate: 25 g/dm2/h

AS 5485 requirements

Rate: 25 $g/dm^2/h \pm 1.0$

temp = -3.0°C range: $\leq$ 4.0 $g/dm^2/h$

Rate for 6 Pans

top left

		1/3 avg	range
21.00	12.33	16.67	8.67
19.33	14.40	2/3 avg	
18.47	19.27	17.87	

bottom right

mean: 17.47

Percent Change

		1/3 avg	
20.2%	-29.4%	-4.6%	-4.6%
10.7%	-17.6%	2/3 avg	
5.7%	10.3%	2.3%	2.3%

Rate for 10 Pans

top left

		Range
18.33	12.33	12.67
25.00	12.33	
18.00	14.67	
17.67	15.67	
19.00	21.67	

bottom right

mean: 17.47

5.0%	-29.4%	-2.7%
43.1%	-29.4%	
3.1%	-16.0%	
1.1%	-10.3%	
8.8%	24.0%	1.8%

Rates for 15 Pans

top left

				Range
20.0	15.0	11.0	15	20.00
31.0	13.0	12.0	19	
17.0	20.0	12.0	16	
18.0	17.0	15.0	17	
18.0	21.0	22.0	20	
21	17	14	17	

bottom right

mean: 17.5

Percent Change

top left		top right
14.5%	-14.1%	-37.0%
77.5%	-25.6%	-31.3%
-2.7%	14.5%	-31.3%
3.1%	-2.7%	-14.1%
3.1%	20.2%	26.0%

bottom right

NCAR Snowmaker Detailed Icing Intensity and Range

TEST #16 April 4, 2001 Command Rate: 25 g/dm2/h

AS 5485 requirements
Rate: 25 g/dm^2/h ± 1.0
temp = -3.0°C **range: ≤ 4.0 g/dm^2/h**

Rate for 6 Pans

top left		1/3 avg	range
27.07	22.75	24.91	5.28
24.69	23.47	2/3 avg	
26.16	21.79	24.03	
	bottom right		

mean: 24.32

Percent Change

		1/3 avg	
11.3%	-6.5%	2.4%	2.4%
1.5%	-3.5%	2/3 avg	
7.6%	-10.4%	-1.2%	-1.2%

Rate for 10 Pans

top left		Range
29.47	21.73	8.00
23.47	24.27	
26.00	23.87	
22.00	21.47	
28.93	22.00	
	bottom right	

mean: 24.32

21.2%	-10.6%	1.7%
-3.5%	-0.2%	
6.9%	-1.9%	
-9.5%	-11.7%	
19.0%	-9.5%	-1.1%

Rates for 15 Pans

top left				Range
32.4	23.6	20.8	26	12.40
23.2	24.0	24.4	24	
27.2	23.6	24.0	25	
22.0	22.0	21.2	22	
30.4	26.0	20.0	25	
27	24	22	24	
		bottom right		

mean: 24.3

Percent Change

top left		top right
33.2%	-3.0%	-14.5%
-4.6%	-1.3%	0.3%
11.8%	-3.0%	-1.3%
-9.5%	-9.5%	-12.8%
25.0%	6.9%	-17.8%
		bottom right

NCAR Snowmaker Detailed Icing Intensity and Range

TEST #17 April 4, 2001 Command Rate: 25 g/dm2/h

AS 5485 requirements

Rate: 25 $g/dm^2/h \pm 1.0$

temp = -3.0°C range: $\leq$ 4.0 $g/dm^2/h$

Rate for 6 Pans

top left		1/3 avg	range
26.29	22.67	24.48	6.19
22.72	21.39	2/3 avg	
23.31	20.11	21.88	
	bottom right		

mean: 22.75

Percent Change

		1/3 avg	
15.6%	-0.4%	7.6%	7.6%
-0.1%	-6.0%	2/3 avg	
2.5%	-11.6%	-3.8%	-3.8%

Rate for 10 Pans

top left		Range
27.20	24.00	8.53
24.93	20.67	
21.60	21.33	
23.87	22.27	
22.93	18.67	
	bottom right	

mean: 22.75

19.6%	5.5%	6.4%
9.6%	-9.1%	
-5.0%	-6.2%	
4.9%	-2.1%	
0.8%	-17.9%	-4.3%

Rates for 15 Pans

top left				Range
23.2	35.2	18.4	26	17.60
25.2	24.4	18.8	23	
19.6	25.6	19.2	21	
21.6	28.4	19.2	23	
24.0	20.8	17.6	21	
23	27	19	23	
		bottom right		

mean: 22.7

Percent Change

top left		top right
2.0%	54.7%	-19.1%
10.8%	7.3%	-17.4%
-13.8%	12.5%	-15.6%
-5.0%	24.9%	-15.6%
5.5%	-8.6%	-22.6%
		bottom right

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At:april17
Printed:4:53 PM, 7/29/2015

NCAR Snowmaker Detailed Icing Intensity and Range

TEST #18 April 5, 2001 Command Rate: 25 g/dm2/h

AS 5485 requirements
Rate: 25 $g/dm^2/h \pm 1.0$
temp = -3.0°C range: $\leq$ 4.0 $g/dm^2/h$

Rate for 6 Pans

top left		1/3 avg	range
26.05	25.84	25.95	4.51
23.52	21.55	2/3 avg	
23.31	22.29	22.67	
	bottom right		

mean: 23.76

Percent Change

		1/3 avg	
9.7%	8.8%	9.2%	9.2%
-1.0%	-9.3%	2/3 avg	
-1.9%	-6.2%	-4.6%	-4.6%

Rate for 10 Pans

top left		Range
23.87	23.33	11.20
29.33	29.60	
21.07	18.40	
25.07	22.93	
22.13	21.87	
	bottom right	

mean: 23.76

0.4%	-1.8%	11.7%
23.5%	24.6%	
-11.3%	-22.6%	
5.5%	-3.5%	
-6.8%	-8.0%	-7.8%

Rates for 15 Pans

top left				Range
19.2	33.2	18.4	24	23.60
24.4	39.2	24.8	29	
19.6	24.0	15.6	20	
22.0	31.2	18.8	24	
21.6	23.2	21.2	22	
21	30	20	24	
		bottom right		

mean: 23.8

Percent Change

top left		top right
-19.2%	39.7%	-22.6%
2.7%	65.0%	4.4%
-17.5%	1.0%	-34.3%
-7.4%	31.3%	-20.9%
-9.1%	-2.4%	-10.8%
		bottom right

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At:april18
Printed:4:53 PM, 7/29/2015

NCAR Snowmaker Detailed Icing Intensity and Range

TEST #19 April 5, 2001 Command Rate: 25 g/dm2/h

AS 5485 requirements

Rate: 25 $g/dm^2/h \pm 1.0$

temp = -3.0°C range: $\leq$ 4.0 $g/dm^2/h$

Rate for 6 Pans

top left

		1/3 avg	range
25.97	32.64	29.31	9.73
27.52	30.77	2/3 avg	
30.59	22.91	27.95	

bottom right

mean: 28.40

Percent Change

		1/3 avg	
-8.5%	14.9%	3.2%	3.2%
-3.1%	8.4%	2/3 avg	
7.7%	-19.3%	-1.6%	-1.6%

Rate for 10 Pans

top left

		Range
26.40	32.00	14.00
25.33	33.60	
26.13	30.93	
33.87	27.47	
28.40	19.87	

bottom right

mean: 28.40

-7.0%	12.7%	3.3%
-10.8%	18.3%	
-8.0%	8.9%	
19.2%	-3.3%	
0.0%	-30.0%	-2.2%

Rates for 15 Pans

top left

				Range
20.8	37.6	29.2	29	27.20
17.6	40.8	30.0	29	
17.6	43.2	24.8	29	
29.2	43.2	19.6	31	
28.8	27.6	16.0	24	
23	38	24	28	

bottom right

mean: 28.4

Percent Change

top left		top right
-26.8%	32.4%	2.8%
-38.0%	43.7%	5.6%
-38.0%	52.1%	-12.7%
2.8%	52.1%	-31.0%
1.4%	-2.8%	-43.7%

bottom right

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At:april19
Printed:4:53 PM, 7/29/2015

NCAR Snowmaker Detailed Icing Intensity and Range

Test # 1 June 4, 2001 Command Rate: 25 g/dm2/h

AS 5485 requirements

Rate: 25 g/dm^2/h ± 1.0

OAT = -3°C **range ≤ 4.0 g/dm^2/h**

Rate for 6 Pans

top left		1/3 avg	range
28.32	20.53	24.43	9.12
29.31	24.08	2/3 avg	
29.65	24.75	26.95	
	bottom right		

mean: 26.11

Percent Change

		1/3 avg
8.5%	-21.3%	-6.4%
12.3%	-7.8%	2/3 avg
13.6%	-5.2%	3.2%

Rate for 10 Pans

top left		Range
27.20	18.13	12.27
30.00	24.13	
29.33	24.00	
28.53	24.27	
30.40	25.07	
	bottom right	

mean: 26.11

4.2%	-30.5%	-4.7%
14.9%	-7.6%	
12.4%	-8.1%	
9.3%	-7.0%	
16.4%	-4.0%	3.2%

Rate for 15 plates

top left				range
28.0	25.6	14.4	23	16.00
30.0	30.0	21.2	27	
28.8	30.4	20.8	27	
28.0	29.6	21.6	26	
30.4	30.4	22.4	28	
29	29	20	26	
		bottom right		

mean: 26.1

Percent Change

7.3%	-1.9%	-44.8%
14.9%	14.9%	-18.8%
10.3%	16.4%	-20.3%
7.3%	13.4%	-17.3%
16.4%	16.4%	-14.2%

NCAR Snowmaker Detailed Icing Intensity and Range

Test # 2 June 4, 2001 Command Rate: 25 g/dm2/h

AS 5485 requiremer ± 1.0
Rate: 25 g/dm^2/h
temp = -3°C **range ≤ 4.0 g/dm^2/h**

Rate for 6 Pans

top left		1/3 avg	range
25.63	24.69	25.16	3.59
25.96	24.31	2/3 avg	
27.89	27.04	26.30	
	bottom right		

mean: 25.92

Percent Change

		1/3 avg	
-1.1%	-4.7%	-9.3%	-2.9%
0.2%	-6.2%	2/3 avg	
7.6%	4.3%	1.5%	1.5%

Rate for 10 Pans

top left		Range
24.80	24.13	5.47
26.87	25.53	
25.73	23.87	
25.73	24.40	
29.33	28.80	
	bottom right	

mean: 25.92

-4.3%	-6.9%	-2.3%
3.7%	-1.5%	
-0.7%	-7.9%	
-0.7%	-5.9%	
13.2%	11.1%	1.5%

Rate for 15 Pans

top left		top right	24	range
22.6	29.2	21.6	26	11.00
25.6	29.4	23.6	25	
24.2	28.8	21.4	25	
23.8	29.6	21.8	29	
27.8	32.4	27.0	26	
25	30	23		
bottom left		bottom right		

mean: 25.9

Percent Change

-12.8%	12.7%	-16.7%
-1.2%	13.4%	-9.0%
-6.6%	11.1%	-17.4%
-8.2%	14.2%	-15.9%
7.3%	25.0%	4.2%

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At:4th(#2)
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NCAR Snowmaker Detailed Icing Intensity and Range

Test # 3 June 4, 2001 Command Rate: 25 g/dm2/h

AS 5485 requirements

Rate: 25 $g/dm^2/h \pm 1.0$

temp = -3°C **range $\leq$ 4.0 $g/dm^2/h$**

Rate for 6 Pans

top left			
		1/3 avg	**range**
19.14	17.14	18.14	4.35
19.31	18.67	2/3 avg	
21.49	20.71	20.05	
	bottom right		

mean: 19.41

Percent Change

		1/3 avg	
-1.4%	-11.7%	-12.9%	-6.5%
-0.5%	-3.8%	2/3 avg	
10.7%	6.7%	3.3%	3.3%

Rate for 10 Pans

top left		Range
18.70	16.10	6.15
19.80	18.70	
18.55	18.75	
21.10	18.40	
21.75	22.25	
	bottom right	

mean: 19.41

-3.7%	-17.1%	-5.6%
2.0%	-3.7%	
-4.4%	-3.4%	
8.7%	-5.2%	
12.1%	14.6%	3.7%

Rate for 15 Pans

top left		top right		range
17.7	20.7	13.8	17	11.25
19.1	21.3	17.4	19	
17.6	20.6	17.9	19	
21.0	21.3	17.0	20	
20.1	25.1	20.9	22	
19	22	17	19	
bottom left		bottom right		

mean: 19.4

Percent Change

-8.8%	6.6%	-28.9%
-1.9%	9.7%	-10.4%
-9.6%	5.9%	-8.0%
8.2%	9.7%	-12.7%
3.6%	29.1%	7.4%

NCAR Snowmaker Detailed Icing Intensity and Range

Test # 4 June 4, 2001 Command Rate: 10 g/dm2/h

AS 5485 requirements

Rate: 10 $g/dm^2/h \pm 0.5$

temp = -3°C **range: $\leq$ 1.5 $g/dm^2/h$**

Rate for 6 Pans

top left		1/3 avg	range
7.61	8.12	7.87	5.38
7.65	9.05	2/3 avg	
3.66	5.88	6.56	
	bottom right		

mean: 6.99

Percent Change

		1/3 avg	
8.8%	16.1%	12.5%	12.5%
9.4%	29.3%	2/3 avg	
-47.7%	-16.0%	-6.2%	-6.2%

Rate for 10 Pans

top left		Range
6.87	7.18	6.72
8.72	9.54	
8.21	9.44	
4.92	7.38	
2.82	4.87	
	bottom right	

mean: 6.99

-1.8%	2.6%	15.5%
24.6%	36.4%	
17.3%	34.9%	
-29.6%	5.6%	
-59.7%	-30.4%	-10.3%

Rate for 15 Pans

top left		top right		range
6.8	7.1	7.2	7	7.08
8.3	9.5	9.5	9	
7.5	9.5	9.4	9	
4.3	6.2	8.0	6	
2.5	3.5	5.5	4	
6	7	8	7	
bottom left		bottom right		

mean: 7.0

top left top right

Pecent Change

-3.2%	1.2%	3.4%
18.8%	36.4%	36.4%
7.8%	36.4%	34.2%
-38.4%	-12.0%	14.4%
-64.8%	-49.4%	-20.8%

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At:4th(#4)
Printed:4:56 PM, 7/29/2015

NCAR Snowmaker Detailed Icing Intensity and Range

Test # 5 June 5, 2001 Command Rate: 25 g/dm2/h

AS 5485 requirements

Rate: 25 g/dm^2/h ± 1.0

temp = -3°C **Range: ≤ 4.0 g/dm^2/h**

Rate for 6 Pans

top left		1/3 avg	range
28.43	27.23	27.83	6.33
28.25	24.04	2/3 avg	
25.56	22.09	24.99	
	bottom right		

mean: 25.93

Percent Change

		1/3 avg	
9.6%	5.0%	7.3%	7.3%
8.9%	-7.3%	2/3 avg	
-1.4%	-14.8%	-3.7%	-3.7%

Rate for 10 Pans

top left		Range
26.80	27.73	8.93
30.87	26.47	
28.20	23.80	
25.80	22.33	
25.40	21.93	
	bottom right	

mean: 25.93

3.3%	6.9%	7.8%
19.0%	2.1%	
8.7%	-8.2%	
-0.5%	-13.9%	
-2.1%	-15.4%	-5.2%

Rate for 15 Pans

top left		top right		range
25.8	28.8	27.2	27	12.20
30.4	31.8	23.8	29	
27.4	29.8	20.8	26	
24.8	27.8	19.6	24	
25.0	26.2	19.8	24	
27	29	22	26	
bottom left		bottom right		

mean: 25.9

Percent Change

-0.5%	11.1%	4.9%
17.2%	22.6%	-8.2%
5.7%	14.9%	-19.8%
-4.4%	7.2%	-24.4%
-3.6%	1.0%	-23.7%

NCAR Snowmaker Detailed Icing Intensity and Range

Test # 6 June 7, 2001 Command Rate: 10 g/dm2/h

AS 5485 requirements

Rate: 10 $g/dm^2/h \pm 0.5$

temp = -31.1°C range: $\leq$ 1.5 $g/dm^2/h$

AS 5485 icing intensity rate is only 5 $\pm$ 0.2 $g/dm^2/h$ below -25°C

range: $\leq$ 0.8 $g/dm^2/h$

Rate for 6 Pans

top left			
		1/3 avg	**range**
9.65	**10.30**	**9.98**	**6.83**
9.70	**11.47**	2/3 avg	
4.64	**7.45**	**8.32**	
	bottom right		

mean: 8.87

Percent Change

		1/3 avg	
8.8%	**16.1%**	**12.5%**	12.5%
9.4%	**29.3%**	2/3 avg	
-47.7%	**-16.0%**	**-6.2%**	-6.2%

Rate for 10 Pans

top left		**Range**
8.72	**9.11**	**8.52**
11.06	**12.10**	
10.41	**11.97**	
6.24	**9.37**	
3.58	**6.18**	
	bottom right	

mean: 8.87

-1.8%	**2.6%**	15.5%
24.6%	**36.4%**	
17.3%	**34.9%**	
-29.6%	**5.6%**	
-59.7%	**-30.4%**	-10.3%

Rates for 15 Pans

top left		top right		**range**
8.6	**9.0**	**9.2**	9	**8.97561**
10.5	**12.1**	**12.1**	12	
9.6	**12.1**	**11.9**	11	
5.5	**7.8**	**10.1**	8	
3.1	**4.5**	**7.0**	5	
7	9	10	9	
bottom left		bottom right		

mean: 8.9

Percent Change

top left		top right
-3.2%	**1.2%**	**3.4%**
18.8%	**36.4%**	**36.4%**
7.8%	**36.4%**	**34.2%**
-38.4%	**-12.0%**	**14.4%**
-64.8%	**-49.4%**	**-20.8%**
bottom left		bottom right

NCAR Snowmaker Detailed Icing Intensity and Range

Test # 7 June 7, 2001 Command Rate: 10 g/dm2/h

AS 5485 requirements

Rate: 10 $g/dm^2/h \pm 0.5$

temp = -31.2°C range: ≤ 1.5 $g/dm^2/h$

SAE icing intensity rate is only 5 ± 0.2 $g/dm^2/h$ below -25°C

range: ≤ 0.8 $g/dm^2/h$

Rate for 6 Pans

top left		1/3 avg	range
8.50	9.09	8.79	4.00
9.09	10.15	2/3 avg	
6.15	8.20	8.40	
	bottom right		

mean: 8.53

Percent Change

		1/3 avg	
-0.4%	6.5%	3.1%	3.1%
6.6%	19.0%	2/3 avg	
-27.9%	-3.9%	-1.5%	-1.5%

Rate for 10 Pans

top left		Range
7.71	8.20	5.30
9.68	10.42	
9.36	10.22	
7.71	9.68	
5.12	7.21	
	bottom right	

mean: 8.53

-9.6%	-3.9%	5.5%
13.5%	22.2%	
9.7%	19.8%	
-9.6%	13.5%	
-40.0%	-15.4%	-3.7%

Rates for 15 Pans

top left		top right		range
7.4	8.3	8.1	8	6.29
9.1	10.9	10.2	10	
9.2	9.5	10.5	10	
7.0	9.1	10.0	9	
4.6	6.1	7.8	6	
7	9	9	9	
bottom left		bottom right		

mean: 8.5

Percent Change

top left		top right
-13.2%	-2.4%	-4.5%
6.3%	28.0%	19.3%
8.5%	11.4%	23.7%
-17.6%	6.3%	17.2%
-45.8%	-28.4%	-8.9%
bottom left		bottom right

NCAR Snowmaker Detailed Icing Intensity and Range

Test # 8 June 7,2001 Command Rate 25 g/dm2/h

AS 5485 requirements

Rate 25 g/dm^2/h ± 1.0

temp = -30.5°C **Range: ≤ 4.0 g/dm^2/h**

SAE icing intensity rate is only 5 ± 0.2 g/dm^2/h below -25°C

range: ≤ 0.8 g/dm^2/h

Rate for 6 Pans

top left			range
		1/3 avg	
26.22	29.07	27.64	13.47
33.11	37.13	2/3 avg	
23.66	29.74	30.91	
	bottom right		

mean: 29.82

Percent Change

		1/3 avg	
-12.1%	-2.5%	-7.3%	-7.3%
11.0%	24.5%	2/3 avg	
-20.6%	-0.3%	3.7%	3.7%

top left		Range
22.41	25.03	17.91
31.94	35.29	
35.29	38.85	
27.75	33.82	
20.94	27.02	
	bottom right	

mean: 29.83

-24.9%	-16.1%	-3.9%
7.1%	18.3%	
18.3%	30.2%	
-7.0%	13.4%	
-29.8%	-9.4%	2.6%

Rates for 15 Pans

top left		top right		range
21.0	25.1	24.8	24	24.19
28.6	38.6	33.6	34	
31.7	42.4	37.1	37	
24.5	34.2	33.6	31	
18.2	26.4	27.3	24	
25	33	31	30	
bottom left		bottom right		

mean: 29.8

Percent Change

top left		top right	
-29.4%	-15.7%	-16.8%	-4.0%
-4.1%	29.6%	12.7%	
6.4%	42.2%	24.3%	
-17.8%	14.8%	12.7%	
-38.9%	-11.5%	-8.4%	2.6%
bottom left		bottom right	

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At:7th(#3)
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NCAR Snowmaker Detailed Icing Intensity and Range

TEST # 1 June 26, 2001 Command Rate: 10 g/dm2/h

AS 5485 requirements

Rate: 10 g/dm^2/h ±**0.5**

OAT = -29.0°C **range ≤ 1.5g/dm^2/h**

Rate for 6 Pans

top left		1/3 avg	range
8.64	8.33	8.48	3.39
9.87	8.95	2/3 avg	
7.06	6.48	8.09	
	bottom right		

mean: 8.22

Percent Change

		1/3 avg
5.1%	1.3%	-6.4%
20.0%	8.9%	2/3 avg
-14.1%	-21.1%	-1.6%

Rate for 10 Pans

top left		Range
8.04	7.52	4.44
9.54	9.54	
10.33	9.28	
8.82	7.39	
5.88	5.88	
	bottom right	

mean: 8.22

-2.2%	-8.6%	5.3%
16.1%	16.1%	
25.6%	12.9%	
7.3%	-10.2%	
-28.5%	-28.5%	-3.6%

Rate for 15 plates

top left				range
7.4	9.2	6.7	8	5.48
8.8	11.0	8.8	10	
10.0	11.0	8.4	10	
9.2	8.0	7.1	8	
5.5	6.7	5.5	6	
8	9	7	8	
		bottom right		

mean: 8.2

Percent Change

-9.4%	12.1%	-18.9%
7.3%	33.5%	7.3%
21.6%	33.5%	2.5%
12.1%	-2.2%	-14.1%
-33.2%	-18.9%	-33.2%

NCAR Snowmaker Detailed Icing Intensity and Range

TEST #2 June 26, 2001 Command Rate: 10 g/dm2/h

AS 5485 requirements
Rate: 10 g/dm^2/h ± 0.5
temp = -24.7°C range ≤ 1.5 g/dm^2/h

Rate for 6 Pans

top left

		1/3 avg	range
9.39	9.37	9.38	2.21
10.03	11.08	2/3 avg	
8.87	9.31	9.82	

bottom right

mean: 9.68

Percent Change

		1/3 avg	
-2.9%	-3.2%	-9.4%	-3.0%
3.7%	14.5%	2/3 avg	
-8.3%	-3.8%	1.5%	1.5%

Rate for 10 Pans

top left		Range
8.69	8.56	3.12
10.46	10.58	
10.03	11.50	
9.60	10.34	
8.38	8.62	

bottom right

mean: 9.68

-10.2%	-11.5%	-1.1%
8.1%	9.4%	
3.7%	18.8%	
-0.8%	6.8%	
-13.4%	-10.9%	0.7%

Rate for 15 Pans

top left			9	range
8.3	9.6	8.1	11	4.59
9.9	11.6	10.1	11	
8.8	12.5	11.0	10	
8.6	11.6	9.7	9	
7.9	9.4	8.3	10	
9	11	9		

bottom right

mean: 9.7

Percent Change

-14.7%	-1.4%	-16.6%
2.4%	19.5%	4.3%
-9.0%	29.0%	13.8%
-10.9%	19.5%	0.5%
-18.5%	-3.3%	-14.7%

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At:26th 2
Printed:4:58 PM, 7/29/2015

NCAR Snowmaker Detailed Icing Intensity and Range

TEST # 3 June 26, 2001 Command Rate: 25 g/dm2/h

AS 5485 requirements
Rate: 25 $g/dm^2/h \pm 1.0$
temp = -10.5°C **range ≤ 4.0 $g/dm^2/h$**

Rate for 6 Pans

top left		1/3 avg	**range**
24.62	27.81	26.22	**4.21**
25.82	28.43	2/3 avg	
25.34	24.22	25.95	
	bottom right		

mean: 26.04

Percent Change

		1/3 avg	
-5.4%	6.8%	-5.7%	0.7%
-0.9%	9.2%	2/3 avg	
-2.7%	-7.0%	-0.3%	-0.3%

Rate for 10 Pans

top left		**Range**
22.39	25.26	**9.32**
27.97	31.63	
25.58	27.81	
24.38	27.09	
25.98	22.31	
	bottom right	

mean: 26.04

-14.0%	-3.0%	3.0%
7.4%	21.5%	
-1.8%	6.8%	
-6.4%	4.0%	
-0.2%	-14.3%	-2.0%

Rate for 15 Pans

top left				**range**
20.5	26.0	24.8	24	**14.09**
24.6	34.6	30.1	30	
23.4	29.9	26.8	27	
21.7	29.6	25.8	26	
27.2	23.4	21.7	24	
24	29	26	26	
		bottom right		

mean: 26.0

Percent Change

-21.1%	0.1%	-4.5%
-5.4%	33.1%	15.7%
-10.0%	14.7%	2.8%
-16.5%	13.8%	-0.9%
4.7%	-10.0%	-16.5%

NCAR Snowmaker Detailed Icing Intensity and Range

TEST # 4 June 27, 2001 Command Rate: 25 g/dm2/h

AS 5485 requirements
Rate: 25 g/dm^2/h ± 1.0
temp = -20.6°C Range: ≤ 4.0 g/dm^2/h

Rate for 6 Pans

top left		1/3 avg	range
25.52	28.55	27.03	6.80
23.59	26.70	2/3 avg	
24.86	21.75	24.23	
	bottom right		

mean: 25.16

Percent Change

		1/3 avg	
1.4%	13.5%	7.4%	7.4%
-6.2%	6.1%	2/3 avg	
-1.2%	-13.6%	-3.7%	-3.7%

Rate for 10 Pans

top left		Range
25.73	29.42	9.56
25.19	27.24	
23.14	27.24	
23.34	24.57	
25.87	19.86	
	bottom right	

mean: 25.16

2.3%	16.9%	6.9%
0.1%	8.2%	
-8.0%	8.2%	
-7.2%	-2.3%	
2.8%	-21.1%	-4.6%

Rate for 15 Pans

top left				range
23.6	30.2	29.1	28	12.51
23.4	28.9	26.5	26	
20.1	29.3	26.3	25	
21.5	27.1	23.4	24	
26.7	24.4	17.6	23	
23	28	25	25	
		bottom right		

mean: 25.2

Percent Change

-6.4%	19.6%	15.6%
-7.2%	14.8%	5.0%
-20.2%	16.4%	4.2%
-14.5%	7.4%	-7.2%
5.8%	-3.1%	-30.0%

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NCAR Snowmaker Detailed Icing Intensity and Range

TEST # 5 June 27, 2001 Command Rate: 25 g/dm2/h

AS 5485 requirements

Rate: 25 g/dm^2/h ± 1.0

temp = -10.9°C   Range: ≤ 4.0 g/dm^2/h

Rate for 6 Pans

top left		1/3 avg	range
21.58	27.08	24.33	9.04
23.79	28.77	2/3 avg	
30.63	27.41	27.65	
	bottom right		

mean: 26.54

Percent Change

		1/3 avg	
-18.7%	2.0%	-8.3%	-8.3%
-10.4%	8.4%	2/3 avg	
15.4%	3.3%	4.2%	4.2%

Rate for 10 Pans

top left		Range
21.99	27.77	13.13
20.96	26.05	
23.64	27.90	
27.08	34.09	
32.99	22.96	
	bottom right	

mean: 26.54

-17.1%	4.6%	-8.9%
-21.0%	-1.9%	
-10.9%	5.1%	
2.0%	28.4%	
24.3%	-13.5%	5.9%

Rate for 15 Pans

top left				range
17.9	30.1	26.6	25	18.74
17.5	27.8	25.1	23	
19.6	31.7	25.9	26	
22.4	36.2	33.0	31	
34.6	29.7	19.6	28	
22	31	26	27	
		bottom right		

mean: 26.5

Percent Change

-32.4%	13.4%	0.2%
13.4%	4.9%	-5.2%
-26.2%	19.6%	-2.1%
-15.3%	36.7%	24.3%
30.5%	11.9%	-26.2%

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NCAR Snowmaker Detailed Icing Intensity and Range

TEST # 6 June 27, 2001 Command Rate: 10 g/dm2/h

AS 5485 requirements
Rate:10g/dm^2/h ± 0.5
temp = -14.7°C Range: ≤ 1.5 g/dm^2/h

Rate for 6 Pans

top left		1/3 avg	range
10.49	9.65	10.07	2.90
9.76	10.32	2/3 avg	
12.56	10.45	10.77	
	bottom right		

mean: 10.54

Percent Change

		1/3 avg	
-0.4%	-8.4%	-4.4%	-4.4%
-7.4%	-2.0%	2/3 avg	
19.1%	-0.9%	2.2%	2.2%

Rate for 10 Pans

top left		Range
10.54	9.52	4.65
10.42	9.86	
9.29	10.54	
10.48	10.14	
13.94	10.65	
	bottom right	

mean: 10.54

0.0%	-9.7%	-4.3%
-1.1%	-6.5%	
-11.8%	0.0%	
-0.5%	-3.8%	
32.3%	1.1%	2.9%

Rate for 15 Pans

top left				range
10.0	11.6	8.5	10	6.46
10.0	11.2	9.2	10	
8.0	11.9	9.9	10	
9.9	11.7	9.3	10	
14.4	12.9	9.5	12	
10	12	9	11	
		bottom right		

mean: 10.5

Percent Change

-4.8%	9.7%	-19.4%
9.7%	6.5%	-12.9%
-24.2%	12.9%	-6.5%
-6.5%	11.3%	-11.3%
37.1%	22.6%	-9.7%

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NCAR Snowmaker Detailed Icing Intensity and Range

TEST #7 June 27, 2001 Command Rate: 10 g/dm2/h

AS 5485 requirements

Rate:10g/dm^2/h ± 0.5

temp = -14.7°C Range: ≤ 1.5 g/dm^2/h

Rate for 6 Pans

top left		1/3 avg	range
12.41	11.23	11.82	3.11
11.67	14.34	2/3 avg	
11.60	14.12	12.93	
	bottom right		

mean: 12.56

Percent Change

		1/3 avg	
-1.2%	-10.6%	-5.9%	-5.9%
-7.1%	14.2%	2/3 avg	
-7.7%	12.4%	2.9%	2.9%

Rate for 10 Pans

top left		Range
12.00	9.93	5.04
13.04	13.19	
11.70	14.96	
10.22	13.63	
12.52	14.44	
	bottom right	

mean: 12.56

-4.5%	-21.0%	-4.2%
3.8%	5.0%	
-6.8%	19.1%	
-18.6%	8.5%	
-0.4%	15.0%	2.8%

Rate for 15 Pans

top left				range
11.8	12.4	8.7	11	6.44
12.4	14.2	12.7	13	
10.2	14.7	15.1	13	
8.9	12.9	14.0	12	
11.8	14.0	14.7	13	
11	14	13	13	
		bottom right		

mean: 12.6

Percent Change

-6.3%	-0.9%	-31.0%
-0.9%	13.2%	0.8%
-18.6%	16.7%	20.3%
-29.2%	2.6%	11.4%
-6.3%	11.4%	16.7%

NCAR Snowmaker Detailed Icing Intensity and Range

TEST #8 June 28, 2001 Command Rate: 25 g/dm2/h

AS 5485 requirements

Rate: 25 g/dm^2/h **± 1.0**

temp = -4.8°C **range: ≤ 4.0 g/dm^2/h**

Rate for 6 Pans

top left		1/3 avg	range
22.02	25.65	23.83	6.03
22.24	27.20	2/3 avg	
23.11	28.05	25.15	
	bottom right		

mean: 24.71

Percent Change

		1/3 avg	
-10.9%	3.8%	-3.6%	-3.6%
-10.0%	10.1%	2/3 avg	
-6.5%	13.5%	1.8%	1.8%

Rate for 10 Pans

top left		Range
20.95	25.34	7.48
23.62	26.11	
21.90	27.48	
21.90	27.48	
23.92	28.43	
	bottom right	

mean: 24.71

-15.2%	2.5%	-2.9%
-4.4%	5.7%	
-11.4%	11.2%	
-11.4%	11.2%	
-3.2%	15.0%	1.9%

Rates for 15 Pans

top left				range
18.7	25.4	25.3	23	11.21
21.9	27.0	25.6	25	
18.9	27.9	27.2	25	
18.7	28.3	27.0	25	
23.1	25.4	29.9	26	
20	27	27	25	
		bottom right		

mean: 24.7

Percent Change

top left		top right
-24.4%	3.0%	2.3%
-11.4%	9.5%	3.7%
-23.6%	13.1%	10.2%
-24.4%	14.6%	9.5%
-6.3%	3.0%	21.0%
		bottom right

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APPENDIX F

INTRA-LABORATORY SNOW RECONSILIATION TEST LOGS

Intra-Laboratory Snow Reconciliation
Natural Snow Tests @ Dorval 2000-2001

Test no.	Form no.	Date	Run no.	Stand no.	Start Time (Local)	Fail Time (Local)	Fluid Dilution	Fluid Name	Fluid Type	FFP (°C)	Fluid Brix	Fluid Temp. (°C)	Plate Locat'n	Fail Time [min.]	AVG PAN [g/dm²/hr]	Pan diff %	READAC Data rate [g/dm²/hr]	temp [C]	Wind Sp [kph]	wind dir	visibility (mi)	APS OBS data temp [C]	Wet Dry	Snow Type	stnd dir (°)	D angle (°)	comments
test	form	date	run	stand	start_time	fail_time	dil	fld_name	fld_type	FFP	Brx	fld_tmp	plate	fail	rate	p_diff	REA_rate	REA_temp	REA_win	REA_di	REA_vi	OBS_tem	OBS_wd	bs_snov	std_dir	del_ang	comments
1	A1	Jan-30-01	A1	1	19:32:00	20:26:00	Neat	UCAR ULTRA +	4		8	-4	2	54.0	9.4	13%	7.9	-4.2	29	32	0.8	-4.0				32	
2	A1	Jan-30-01	A1	1	19:33:00	22:00:00	Neat	KILFROST ABC-S	4		10	-4	3	147.0	6.1	5%	10.2	-4.2	32	32	0.7	-4.0				32	
3	A1	Jan-30-01	A1	1	19:34:00	21:24:00	75%	KILFROST ABC-S	4b		8	-4	4	110.0	6.1	14%	10.8	-4.2	30	32	0.7	-4.0				32	
4	A1	Jan-30-01	A1	1	19:34:30	22:27:00	Neat	SPCA AD-480	4		10	-4	5	172.5	6.8	1%	9.8	-4.2	33	31	0.6	-4.0				31	
5	A1	Jan-30-01	A1	1	19:35:00	21:53:00	75%	SPCA AD-480	4b		10	-4	2	138.0	6.0	6%	10.3	-4.2	31	32	0.6	-4.0				32	
6	A3	Jan-31-01	A1	1	13:46:40	15:11:30	Neat	UCAR ULTRA +	4		12	-9	2	84.8	13.0	3%	3.0	-9.0	20	321	1.0	-9.0				321	
7	A3	Jan-31-01	A1	1	13:47:15	15:34:00	Neat	KILFROST ABC-S	4		13	-9	3	106.8	12.6	1%	2.5	-9.0	20	320	1.0	-9.0				320	
8	A3	Jan-31-01	A1	1	13:47:50	14:46:50	75%	KILFROST ABC-S	4b		14	-9	4	59.0	13.0	5%	3.0	-9.0	20	319	0.8	-9.0				319	
9	A3	Jan-31-01	A1	1	13:48:30	15:23:30	Neat	SPCA AD-480	4		14	-9	5	95.0	12.8	2%	2.8	-9.0	20	321	1.0	-9.0				321	
10	A3	Jan-31-01	A1	1	13:49:00	14:38:30	75%	SPCA AD-480	4b		15	-9	6	49.5	12.8	6%	3.0	-9.0	19	318	0.8	-9.0				318	
12	A5	Feb-05-01	A1	1	10:44:25	11:29:00	Neat	UCAR ULTRA +	4		12	-7	2	44.6	15.6	24%	6.5	-6.8	15	39	0.6	-8.0				39	Aircraft Running up at Air Canada
13	A5	Feb-05-01	A1	1	10:45:45	11:51:00	Neat	KILFROST ABC-S	4		12.75	-7	3	65.3	13.1	20%	6.1	-6.7	16	42	0.6	-8.0				42	Aircraft Running up at Air Canada
14	A5	Feb-05-01	A1	1	10:46:25	11:14:00	75%	KILFROST ABC-S	4b		12	-7	4	27.6	20.4	28%	6.7	-6.6	15	33	0.6	-8.0				33	Aircraft Running up at Air Canada
15	A5	Feb-05-01	A1	1	10:47:25	12:42:00	Neat	SPCA AD-480	4		10	-7	5	114.6	10.3	13%	5.8	-6.5	16	40	0.7	-8.0				40	Aircraft Running up at Air Canada
16	A5	Feb-05-01	A1	1	10:48:20	12:28:00	75%	SPCA AD-480	4b		10.5	-7	6	99.7	10.5	14%	5.8	-6.6	16	41	0.7	-8.0				41	Aircraft Running up at Air Canada
18	A6	Feb-14-01	A1	1	11:48:00	13:13:00	Neat	UCAR ULTRA +	4		13	-6	2	85.0	6.9	13%		-5.0				-5.0				0	Wind shifted 12:40
19	A6	Feb-14-01	A1	1	11:48:45	13:48:00	Neat	KILFROST ABC-S	4			-6	3	119.3	10.1	10%		-5.0				-5.0				0	Wind shifted 12:40
20	A6	Feb-14-01	A1	1	11:49:30	13:23:00	75%	KILFROST ABC-S	4b		13	-5	4	93.5	7.2	13%		-5.0				-5.0				0	Wind shifted 12:40
21	A6	Feb-14-01	A1	1	11:50:00	13:41:00	Neat	SPCA AD-480	4		13	-7	5	111.0	9.5	9%		-5.0				-5.0				0	Wind shifted 12:40
22	A6	Feb-14-01	A1	1	11:50:30	13:41:00	75%	SPCA AD-480	4b		13	-7	6	110.5	9.6	9%		-5.0				-5.0				0	Wind shifted 12:40
24	A7	Feb-14-01	A2	1	14:11:30	15:09:00	Neat	UCAR ULTRA +	4		13	-6	2	57.5	16.4	6%		-5.0				-5.0				0	
25	A7	Feb-14-01	A2	1	14:10:00	15:35:00	Neat	KILFROST ABC-S	4		12	-7	3	85.0	14.5	4%		-5.0				-5.0				0	
26	A7	Feb-14-01	A2	1	14:12:30	14:52:27	75%	KILFROST ABC-S	4b		12.5	-7	4	40.0	18.7	5%		-5.0				-5.0				0	
27	A7	Feb-14-01	A2	1	14:13:00	15:36:00	Neat	SPCA AD-480	4		14	-6	5	83.0	14.4	4%		-5.0				-5.0				0	
28	A7	Feb-14-01	A2	1	14:13:30	14:50:13	75%	SPCA AD-480	4b		13.25	-6	6	36.7	18.9	6%		-5.0				-5.0				0	
30	A8	Feb-14-01	A3	1	20:35:00	21:44:00	Neat	UCAR ULTRA +	4		11	-6	2	69.0	9.5	8%		-4.0				-4.0				0	
31	A8	Feb-14-01	A3	1	20:35:50	22:40:00	Neat	KILFROST ABC-S	4		14	-6	3	124.2	9.0	6%		-4.0				-4.0				0	
32	A8	Feb-14-01	A3	1	20:36:45	21:36:35	75%	KILFROST ABC-S	4b		12	-6	4	59.8	9.9	8%		-4.0				-4.0				0	
33	A8	Feb-14-01	A3	1	20:37:30	22:41:00	Neat	SPCA AD-480	4		12	-6	5	123.5	9.1	6%		-4.0				-4.0				0	
34	A8	Feb-14-01	A3	1	20:38:15	21:56:40	75%	SPCA AD-480	4b		12	-6	6	78.4	9.0	8%		-4.0				-4.0				0	
35	A8	Feb-14-01	A3s	1	22:14:30	22:36:40	50%	KILFROST ABC-S	4a		11.5		2	22.2	9.9	11%		-2.9				-2.9				0	
36	A8	Feb-14-01	A3s	1	22:15:20	22:39:20	50%	SPCA AD-480	4a		12	11	6	24.0	10.4	3%		-2.9				-2.9				0	
38	A9	Feb-19-01	A1	1	14:11:00	14:45:00	Neat	UCAR ULTRA +	4		10	-2	2	34.0	26.8	8%		-3.0				-3.0				0	
39	A9	Feb-19-01	A1	1	14:11:25	14:19:30	50%	KILFROST ABC-S	4a		9	-3	3	8.1	27.4	18%		-3.0				-3.0				0	
40	A9	Feb-19-01	A1	1	14:12:00	14:40:15	75%	KILFROST ABC-S	4b		8.75	-2	4	28.3	27.1	10%		-3.0				-3.0				0	
41	A9	Feb-19-01	A1	1	14:12:30	14:23:00	50%	SPCA AD-480	4a		9	-3	5	10.5	28.6	10%		-3.0				-3.0				0	
42	A9	Feb-19-01	A1	1	14:13:00	14:44:00	75%	SPCA AD-480	4b		10	-3	6	31.0	26.9	8%		-3.0				-3.0				0	
43	A9	Feb-19-01	A1s	1	14:30:15	14:40:40	50%	SPCA AD-480	4a		9	-3	1	10.4	24.2	5%		-3.0				-3.0				0	
44	A9	Feb-19-01	A1s	1	14:30:40	14:43:00	50%	SPCA AD-480	4a		10	-3	5	12.3	24.4	3%		-3.0				-3.0				0	
46	A10	Feb-19-01	A2	1	15:00:15	15:32:00	Neat	UCAR ULTRA +	4		8.5	0	2	31.8	29.7	7%		-3.0				-3.0				0	
47	A10	Feb-19-01	A2	1	15:01:00	15:08:55	50%	KILFROST ABC-S	4a		9	-2	3	7.9	40.4	8%		-3.0				-3.0				0	
48	A10	Feb-19-01	A2	1	15:01:30	15:33:05	75%	KILFROST ABC-S	4b		9	0	4	31.6	29.5	7%		-3.0				-3.0				0	
49	A10	Feb-19-01	A2	1	15:02:00	15:12:30	50%	SPCA AD-480	4a		10	-2	5	10.5	37.8	12%		-3.0				-3.0				0	
50	A10	Feb-19-01	A2	1	15:02:30	15:37:40	75%	SPCA AD-480	4b			-2	6	35.2	29.0	8%		-3.0				-3.0				0	
52	A11	Feb-23-01	A1	1	1:19:00	3:45:00	Neat	UCAR ULTRA +	4		25.5		2	146.0	3.5	11%		-17.0				-17.0				0	
53	A11	Feb-23-01	A1	1	1:20:00	2:45:00	Neat	KILFROST ABC-S	4		24	-14	3	85.0	4.0	8%		-17.0				-17.0				0	
54	A11	Feb-23-01	A1	1	1:21:00	2:55:00	Neat	UCAR ULTRA +	4		25.5		4	94.0	4.0	9%		-17.0				-17.0				0	
55	A11	Feb-23-01	A1	1	1:22:00	2:04:00	Neat	SPCA AD-480	4		25	-15	5	42.0	4.9	4%		-17.0				-17.0				0	Failures difficult to call
56	A11	Feb-23-01	A1	1	1:22:00	2:04:00	Neat	SPCA AD-480	4		24	-15	6	42.0	4.9	4%		-17.0				-17.0				0	Failures difficult to call
58	A12	Feb-23-01	A2	1	4:06:00	5:40:00	Neat	SPCA AD-480	4		26	-16	6	94.0	1.1	15%		-17.0				-17.0				0	
60	A13	Feb-25-01	A1	1	6:24:00	7:39:00	Neat	UCAR ULTRA +	4		15	-11	2	75.0	13.6	11%		-10.0				-10.0				0	
61	A13	Feb-25-01	A1	1	6:25:00	7:56:00	Neat	KILFROST ABC-S	4		16	-10	3	91.0	13.4	9%		-10.0				-10.0				0	
62	A13	Feb-25-01	A1	1	6:25:45	7:29:00	75%	KILFROST ABC-S	4b		16.5	-10	4	63.3	12.9	10%		-10.0				-10.0				0	
63	A13	Feb-25-01	A1	1	6:26:30	7:43:00	Neat	SPCA AD-480	4			-11	5	76.5	13.6	10%		-10.0				-10.0				0	
64	A13	Feb-25-01	A1	1	6:27:00	7:26:00	75%	SPCA AD-480	4b		15	-10	6	59.0	12.7	10%		-10.0				-10.0				0	

I:\Groups\CM1680(exBM3833)\Analysis\Amil + NCAR/AMIL 2000-2001 Snow Log-ANALYSIS.xls
At: Dorval Log
Printed:4:21 PM, 7/29/2015

Intra-Laboratory Snow Reconciliation
Natural Snow Tests @ Dorval 2000-2001

Test no.	Form no.	Date	Run no.	Stand no.	Start Time (Local)	Fail Time (Local)	Fluid Dilution	Fluid Name	Fluid Type	FFP (°C)	Fluid Brix	Fluid Temp. (°C)	Plate Locat'n	Fail Time [min.]	AVG PAN [g/dm²/hr]	Pan diff %	READAC Data rate [g/dm²/hr]	READAC Data temp [C]	READAC Data Wind Sp [kph]	READAC Data wind dir	READAC Data visibility (mi)	APS OBS data temp [C]	APS OBS data Wet Dry	Snow Type	stnd dir (°)	D angle (°)	comments
66	A14	Feb-25-01	A2	1	8:18:00	8:51:00	Neat	UCAR ULTRA +	4		17	-9	2	33.0	31.4	12%		-9.0				-9.0				0	
67	A14	Feb-25-01	A2	1	8:19:00	9:05:00	Neat	KILFROST ABC-S	4			-10	3	46.0	29.7	9%		-9.0				-9.0				0	
68	A14	Feb-25-01	A2	1	8:20:00	8:50:00	75%	KILFROST ABC-S	4b		17	-9	4	30.0	31.5	13%		-9.0				-9.0				0	
70	A14	Feb-25-01	A2	1	8:21:30	8:45:00	75%	SPCA AD-480	4b		17	-9	6	23.5	31.8	15%		-9.0				-9.0				0	
71	A15	Mar-05-01	A1	1	21:55:25	22:56:30	Neat	UCAR ULTRA +	4		7	-2	1	61.1	11.4	2%		-3.0				-3.0				0	
72	A15	Mar-05-01	A1	1	21:56:15	0:24:00	Neat	KILFROST ABC-S	4		10	-2	2	147.8	9.6	11%		-3.0				-3.0				0	
73	A15	Mar-05-01	A1	1	21:57:10	22:19:00	50%	KILFROST ABC-S	4a		7	-2	3	21.8	11.7	4%		-3.0				-3.0				0	
74	A15	Mar-05-01	A1	1	21:57:50	0:14:00	Neat	SPCA AD-480	4		7.5	-2	4	136.2	9.2	3%		-3.0				-3.0				0	
75	A15	Mar-05-01	A1	1	21:58:30	23:24:00	75%	SPCA AD-480	4b		7	-2	5	85.5	11.0	0%		-3.0				-3.0				0	
76	A15	Mar-05-01	A1	1	21:59:10	22:26:30	50%	SPCA AD-480	4a		6.75	-2	6	27.3	13.2	3%		-3.0				-3.0				0	
79	A15	Mar-05-01	A1s	1	22:33:30	22:53:00	50%	KILFROST ABC-S	4a		6.5	-2	3	19.5	8.8	1%		-3.0				-3.0				0	
80	A15	Mar-05-01	A1s	1	22:34:10	23:07:00	50%	SPCA AD-480	4a		7	-3	6	32.8	10.1	2%		-3.0				-3.0				0	
82	A15	Mar-05-01	A1s	1	23:20:05	23:39:30	50%	KILFROST ABC-S	4a		8.25	-2	3	19.4	7.0	4%		-3.0				-3.0				0	
83	A15	Mar-05-01	A1s	1	23:21:00	0:04:00	50%	SPCA AD-480	4a				6	43.0	5.9	6%		-3.0				-3.0				0	
84	A16	Mar-06-01	A2	1	0:54:20	2:11:40	75%	KILFROST ABC-S	4b		7	-2	1	77.3	9.3	2%		-3.0				-3.0				0	
85	A16	Mar-06-01	A2	1	0:55:20	3:32:00	Neat	KILFROST ABC-S	4		6.75	-2	2	156.7	8.5	33%		-3.0				-3.0				0	
86	A16	Mar-06-01	A2	1	0:56:20	1:15:30	50%	KILFROST ABC-S	4a		8	-2	3	19.2	10.7	2%		-3.0				-3.0				0	
87	A16	Mar-06-01	A2	1	0:57:10	3:24:00	Neat	SPCA AD-480	4		7.5	-3	4	146.8	7.9	12%		-3.0				-3.0				0	
88	A16	Mar-06-01	A2	1	0:58:00	2:32:00	75%	SPCA AD-480	4b		6.5	-2	5	94.0	9.2	13%		-3.0				-3.0				0	
89	A16	Mar-06-01	A2	1	0:58:30	1:31:35	50%	SPCA AD-480	4a		7.25	-2	6	33.1	9.8	3%		-3.0				-3.0				0	
92	A17	Mar-11-01	A1	1	11:40:55	13:17:00	75%	KILFROST ABC-S	4b				1	96.1	12.2	8%		-1.0				-1.0				0	
93	A17	Mar-11-01	A1	1	11:42:30	11:55:10	50%	KILFROST ABC-S	4a				3	12.7	16.3	6%		-1.0				-1.0				0	
94	A17	Mar-11-01	A1	1	11:43:55	13:16:00	75%	SPCA AD-480	4b				5	92.1	12.0	8%		-1.0				-1.0				0	
95	A17	Mar-11-01	A1	1	11:44:40	12:01:20	50%	SPCA AD-480	4a				6	16.7	16.4	6%		-1.0				-1.0				0	
96	A18	Mar-13-01	A1	1	3:39:00	4:03:00	Neat	UCAR ULTRA +	4		15	-7	1	24.0	13.7	3%		-7.0				-7.0				0	
97	A18	Mar-13-01	A1	1	3:39:40	5:00:00	Neat	KILFROST ABC-S	4		16	-7	2	80.3	15.5	1%		-7.0				-7.0				0	
98	A18	Mar-13-01	A1	1	3:40:20	4:39:00	75%	KILFROST ABC-S	4b		16	-7	3	58.7	12.4	2%		-7.0				-7.0				0	
99	A18	Mar-13-01	A1	1	3:41:00	4:50:00	Neat	SPCA AD-480	4		16	-6	4	69.0	14.2	4%		-7.0				-7.0				0	
100	A18	Mar-13-01	A1	1	3:41:30	4:34:00	75%	SPCA AD-480	4b		16	-6	5	52.5	11.9	2%		-7.0				-7.0				0	
101	A18	Mar-13-01	A1	1	3:42:00	4:31:00	75%	SPCA AD-480	4b		16	-6	1	49.0	11.7	3%		-7.0				-7.0				0	
104	A19	Mar-13-01	A2	1	5:08:00	5:35:00	Neat	UCAR ULTRA +	4		16	-7	1	27.0	27.4	4%		-6.7				-6.7				0	
105	A19	Mar-13-01	A2	1	5:09:00	5:58:00	Neat	KILFROST ABC-S	4		17	-7	2	49.0	24.6	1%		-6.7				-6.7				0	
106	A19	Mar-13-01	A2	1	5:10:00	5:37:00	75%	KILFROST ABC-S	4b		18	-7	3	27.0	27.8	4%		-6.7				-6.7				0	
107	A19	Mar-13-01	A2	1	5:10:40	5:58:00	Neat	SPCA AD-480	4		17	-7	4	47.3	24.6	1%		-6.7				-6.7				0	
108	A19	Mar-13-01	A2	1	5:11:25	5:38:00	75%	SPCA AD-480	4b		17	-7	1	26.6	28.1	4%		-6.7				-6.7				0	
110	A20	Mar-13-01	A3	1	6:07:00	6:30:30	Neat	UCAR ULTRA +	4		15	-7	1	23.5	18.1	5%		-7.0				-7.0				0	
111	A20	Mar-13-01	A3	1	6:07:45	7:08:00	Neat	KILFROST ABC-S	4			-7	2	60.3	23.0	5%		-7.0				-7.0				0	
112	A20	Mar-13-01	A3	1	6:08:30	6:46:00	75%	KILFROST ABC-S	4b		17	-7	3	37.5	18.3	7%		-7.0				-7.0				0	
113	A20	Mar-13-01	A3	1	6:09:15	6:51:00	Neat	SPCA AD-480	4			-7	4	41.8	19.4	7%		-7.0				-7.0				0	
114	A20	Mar-13-01	A3	1	6:10:15	6:46:00	75%	SPCA AD-480	4b		16	-7	5	35.8	18.1	7%		-7.0				-7.0				0	

APPENDIX G

SIMULATED SNOW TEST LOG

SIMULATED SNOW (NCAR) AT CEF-NRC (OTTAWA) FOR 2000-01

ID No.	Form No.	Date	Start Time (Local)	End Time (Local)	Fluid Type	Fluid Name	Fluid Dilution	fail time [min.]	Rate of precep. [g/dm*²/hr]	Condition Temp [C]	Chamber Temp (°C)	Fluid Temp (ºC)	comments
1	1	Jun-06-01	9:40:40	10:50:14	4	UCAR ULTRA +	Neat	69.6	10.0	-3.0	-5.3	-4.6	
3	3	Jun-06-01	17:10:06	17:39:58	4	UCAR ULTRA +	Neat	29.9	25.0	-3.0	-7.5	-5.5	Autorate turned on after 2 minute delay
5	5	Jun-07-01	14:19:49	15:23:42	4	UCAR ULTRA +	Neat	63.9	10.0	-14.0	-17.3	-19.6	
7	7	Jun-05-01	13:09:51	13:32:45	4	UCAR ULTRA +	Neat	22.9	25.0	-14.0	-13.0	-11.0	
8	8	Jun-28-01	14:18:00	14:50:50	4	UCAR ULTRA +	Neat	32.8	25.0	-14.0	-13.0	-17.1	Build up on shroud during test
9	9	Jun-28-01	7:28:23	8:35:23	4	UCAR ULTRA +	Neat	67.0	10.0	-25.0	-20.9	-24.2	
11	11	Jun-28-01	5:49:00	6:08:40	4	UCAR ULTRA +	Neat	19.7	25.0	-25.0	-23.5	-22.9	
12	12	Jun-28-01	13:23:44	13:50:39	4	UCAR ULTRA +	Neat	26.9	25.0	-25.0	-24.5	-20.7	
13	13	Jun-06-01	11:05:19	12:30:42	4	SPCA AD-480	Neat	85.4	10.0	-3.0	-7.6	-5.0	
15	15	Jun-06-01	17:48:05	18:17:10	4	SPCA AD-480	Neat	29.1	25.0	-3.0	-7.3	-5.2	
17	17	Jun-06-01	12:48:24	13:44:53	4b	SPCA AD-480	75%	56.5	10.0	-3.0	-7.4	-6.0	
19	19	Jun-06-01	18:41:31	19:02:55	4b	SPCA AD-480	75%	21.4	25.0	-3.0	-6.8	-6.7	
21	21	Jun-06-01	13:53:10	14:10:52	4a	SPCA AD-480	50%	17.7	10.0	-3.0	-7.4	-6.0	Failure missed by five minutes
23	23	Jun-06-01	14:23:42	14:35:36	4a	SPCA AD-480	50%	11.9	25.0	-3.0	-7.6	-6.2	Failure missed by five minutes
25	25	Jun-05-01	14:48:22	15:07:39	4	SPCA AD-480	Neat	19.3	25.0	-14.0	-13.0	-6.5	
26	26	Jun-07-01	15:34:05	15:42:45	4	SPCA AD-480	Neat	8.7	25.0	-14.0	-16.7	-17.1	
29	29	Jun-05-01	14:28:40	14:42:10	4b	SPCA AD-480	75%	13.5	25.0	-14.0	-13.0	-10.0	
30	30	Jun-27-01	15:30:22	15:43:28	4b	SPCA AD-480	75%	13.1	25.0	-14.0	-12.2	-11.3	
31	31	Jun-28-01	10:17:10	11:01:44	4b	SPCA AD-480	75%	44.6	10.0	-14.0	-13.0	-11.1	erradic cutting of blade/dull blade
32	32	Jun-07-01	16:13:42	16:41:27	4b	SPCA AD-480	75%	27.8	10.0	-14.0	-17.4	-16.0	
33	33	Jun-07-01	8:46:50	8:54:08	4	SPCA AD-480	Neat	7.3	25.0	-25.0	-31.0	-24.7	
34	34	Jun-28-01	12:46:28	12:55:07	4	SPCA AD-480	Neat	8.7	25.0	-25.0	-23.6	-19.1	
35	35	Jun-28-01	11:53:38	12:08:14	4	SPCA AD-480	Neat	14.6	10.0	-25.0	-20.6	-16.8	Honed drill bit
37	37	Jun-06-01	14:50:28	15:26:28	4	KILFROST ABC-S	Neat	36.0	25.0	-3.0	-7.6	-6.2	
43	43	Jun-06-01	15:30:24	16:17:23	4b	KILFROST ABC-S	75%	47.0	10.0	-3.0	-7.7	-6.8	
45	45	Jun-06-01	16:21:50	16:28:14	4a	KILFROST ABC-S	50%	6.4	25.0	-3.0	-7.5	-6.5	
47	47	Jun-06-01	16:49:31	17:04:19	4a	KILFROST ABC-S	50%	14.8	10.0	-3.0	-7.6	-7.0	
49	49	Jun-05-01	15:21:03	15:43:27	4	KILFROST ABC-S	Neat	22.4	25.0	-14.0	-13.0	-7.8	
50	50	Jun-28-01	11:19:25	11:47:54	4	KILFROST ABC-S	Neat	28.5	10.0	-14.0	-17.0	-16.7	Honed drill bit
52	52	Jun-07-01	16:45:36	17:05:25	4	KILFROST ABC-S	Neat	19.8	25.0	-14.0	-18.0	-17.2	
53	53	Jun-05-01	12:47:00	13:00:00	4b	KILFROST ABC-S	75%	13.0	25.0	-14.0	-13.0	-7.0	Failure missed by five minutes
54	54	Jun-26-01	15:12:09	15:25:08	4b	KILFROST ABC-S	75%	13.0	25.0	-14.0	-11.0	-10.6	
55	55	Jun-05-01	15:47:33	16:21:39	4b	KILFROST ABC-S	75%	34.1	10.0	-14.0	-13.0	-9.5	
57	57	Jun-28-01	12:15:58	12:42:35	4	KILFROST ABC-S	Neat	26.6	10.0	-25.0	-22.2	-20.6	
59	59	Jun-28-01	8:42:50	8:53:25	4	KILFROST ABC-S	Neat	10.6	25.0	-25.0	-20.0	-25.1	Door opened at 4.5minutes
60	60	Jun-28-01	13:11:35	13:20:12	4	KILFROST ABC-S	Neat	8.6	25.0	-25.0	-24.1	-20.1	

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APPENDIX H

TEST LOGS FOR
INDOOR AND NATURAL SNOW TESTS
WITH A CERTIFIED TYPE IV FLUID

Comparison of Indoor and Outdoor Endurance Times for New Fluids

Summary of Natural Snow Tests TYPE IV PRODUCT A

Test #	Form #	Date	Fluid Name	Fluid Dilution	Fluid Type	Fail Time (min)	Actual Rate of Precip (g/dm²/hr)	Ambient Temp (°C)	Precipitation (Type)
4	2	11-Dec-00	TYPE IV Product A	Neat	4	83.7	14.8	-5.1	Natural Snow
5	2	11-Dec-00	TYPE IV Product A	75%	4b	98.0	16.4	-5.2	Natural Snow
6	2	11-Dec-00	TYPE IV Product A	Neat	4	88.5	15.2	-5.2	Natural Snow
7	2	11-Dec-00	TYPE IV Product A	75%	4b	91.8	16.1	-5.2	Natural Snow
23	8	14-Dec-00	TYPE IV Product A	Neat	4	50.0	15.0	-12.1	Natural Snow
24	8	14-Dec-00	TYPE IV Product A	75%	4b	53.0	16.7	-12.1	Natural Snow
25	8	14-Dec-00	TYPE IV Product A	Neat	4	53.0	17.1	-12.1	Natural Snow
26	8	14-Dec-00	TYPE IV Product A	75%	4b	47.0	14.9	-12.1	Natural Snow
30	10	14-Dec-00	TYPE IV Product A	Neat	4	40.0	23.8	-11.2	Natural Snow
31	10	14-Dec-00	TYPE IV Product A	75%	4b	38.0	23.6	-11.2	Natural Snow
47	16	30-Dec-00	TYPE IV Product A	75%	4b	63.1	19.1	-4.5	Natural Snow
48	16	30-Dec-00	TYPE IV Product A	Neat	4	65.3	18.8	-4.5	Natural Snow
49	16	30-Dec-00	TYPE IV Product A	75%	4b	58.5	20.8	-4.6	Natural Snow
50	16	30-Dec-00	TYPE IV Product A	Neat	4	65.6	21.2	-4.7	Natural Snow
51	17	15-Jan-01	TYPE IV Product A	Neat	4	157.6	7.2	-7.9	Natural Snow
54	17	15-Jan-01	TYPE IV Product A	75%	4b	143.9	6.4	-7.9	Natural Snow
61	18	30-Jan-01	TYPE IV Product A	Neat	4	130.0	11.0	-3.7	Natural Snow
62	18	30-Jan-01	TYPE IV Product A	75%	4b	126.0	11.1	-3.6	Natural Snow
67	19	30-Jan-01	TYPE IV Product A	75%	4b	188.0	6.7	-2.8	Natural Snow
74	20	31-Jan-01	TYPE IV Product A	Neat	4	175.0	7.4	-7.6	Natural Snow
75	20	31-Jan-01	TYPE IV Product A	75%	4b	150.0	6.6	-7.5	Natural Snow
86	22	31-Jan-01	TYPE IV Product A	Neat	4	208.0	5.9	-8.6	Natural Snow
87	22	31-Jan-01	TYPE IV Product A	75%	4b	142.0	7.6	-8.5	Natural Snow
103	27	5-Feb-01	TYPE IV Product A	Neat	4	117.5	14.7	-7.5	Natural Snow
106	27	5-Feb-01	TYPE IV Product A	75%	4b	96.0	15.2	-7.6	Natural Snow
112	29	5-Feb-01	TYPE IV Product A	Neat	4	182.0	6.5	-4.9	Natural Snow
115	29	5-Feb-01	TYPE IV Product A	75%	4b	166.0	6.2	-4.9	Natural Snow
116	30	14-Feb-01	TYPE IV Product A	Neat	4	165.0	9.1	-6.6	Natural Snow
119	30	14-Feb-01	TYPE IV Product A	75%	4b	126.0	10.5	-6.7	Natural Snow
126	31	14-Feb-01	TYPE IV Product A	75%	4b	71.5	16.5	-6.0	Natural Snow
129	32	14-Feb-01	TYPE IV Product A	Neat	4	302.0	3.1	-4.5	Natural Snow
132	32	14-Feb-01	TYPE IV Product A	75%	4b	281.0	2.7	-4.5	Natural Snow
147	34	19-Feb-01	TYPE IV Product A	50%	4a	56.5	12.7	-2.5	Natural Snow
167	36	19-Feb-01	TYPE IV Product A	75%	4b	67.0	23.7	-2.3	Natural Snow
173	36	19-Feb-01	TYPE IV Product A	Neat	4	71.0	24.1	-2.4	Natural Snow
182	38	22-Feb-01	TYPE IV Product A	Neat	4	127.0	3.2	-15.3	Natural Snow
185	38	22-Feb-01	TYPE IV Product A	Neat	4	130.0	3.2	-15.3	Natural Snow
197	39	23-Feb-01	TYPE IV Product A	Neat	4	132.0	2.9	-15.5	Natural Snow
202	40	23-Feb-01	TYPE IV Product A	Neat	4	104.0	3.9	-16.5	Natural Snow
205	40	23-Feb-01	TYPE IV Product A	Neat	4	103.0	3.9	-16.5	Natural Snow
208	41	23-Feb-01	TYPE IV Product A	Neat	4	302.0	1.6	-15.7	Natural Snow
220	42	25-Feb-01	TYPE IV Product A	75%	4b	102.0	11.8	-8.8	Natural Snow
221	42	25-Feb-01	TYPE IV Product A	Neat	4	105.5	12.1	-8.8	Natural Snow
251	44	5-Mar-01	TYPE IV Product A	50%	4a	137.0	7.0	-2.1	Natural Snow
252	44	5-Mar-01	TYPE IV Product A	50%	4a	127.0	7.0	-2.1	Natural Snow
254	44	5-Mar-01	TYPE IV Product A	50%	4a	142.0	6.8	-2.1	Natural Snow
280	46	5-Mar-01	TYPE IV Product A	50%	4a	115.3	7.9	-1.9	Natural Snow
292	47	6-Mar-01	TYPE IV Product A	Neat	4	186.0	6.6	-1.5	Natural Snow
293	47	6-Mar-01	TYPE IV Product A	75%	4b	184.5	6.6	-1.5	Natural Snow
300	47	6-Mar-01	TYPE IV Product A	50%	4a	135.5	7.3	-1.6	Natural Snow
332	50	11-Mar-01	TYPE IV Product A	50%	4a	85.0	10.0	-1.3	Natural Snow
333	50	11-Mar-01	TYPE IV Product A	50%	4a	100.0	9.6	-1.3	Natural Snow
348	50	11-Mar-01	TYPE IV Product A	Neat	4	130.0	11.4	-1.4	Natural Snow
385	52	13-Mar-01	TYPE IV Product A	75%	4b	57.3	22.8	-6.1	Natural Snow
405	54	13-Mar-01	TYPE IV Product A	50%	4a	41.3	23.7	-0.9	Natural Snow
412	54	13-Mar-01	TYPE IV Product A	50%	4a	39.5	17.0	-0.8	Natural Snow
413	54	13-Mar-01	TYPE IV Product A	Neat	4	88.0	19.5	-0.9	Natural Snow
418	54	13-Mar-01	TYPE IV Product A	50%	4a	53.3	20.1	-0.8	Natural Snow

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