TP 15052E

Development of Type I Fluid Holdover Times for Use on Aircraft with Composite Surfaces

Volume 2 of 2: Supporting Research (Conducted Winters 2004-05 to 2008-09)




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Prepared by:

APS Aviation Inc.

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by:
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APS Aviation Inc.

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EXECUTIVE SUMMARY

In recent years, there has been an increase in the use of composite materials in the manufacturing of aircraft components, including wings. As de/anti-icing fluid holdover times were originally developed based on tests conducted exclusively on aluminum test surfaces, it was unclear if published holdover times were valid for use on aircraft surfaces constructed of composite materials. This resulted in the need for a research program to examine de/anti-icing fluid endurance times on composite material surfaces.

Under contract to Transport Canada and the Federal Aviation Administration (FAA), and with guidance from both organizations, APS Aviation Inc. (APS) began this research in the winter of 2004-05. The research program spanned six winters and culminated in the publication of composite-specific holdover times for Type I fluids for use in the winter 2010-11 operating season. This report documents this research.

Report Format

This report is presented in two volumes. Volume 1 documents the extensive testing and analysis carried out in the winter of 2009-10 to determine appropriate holdover times for Type I fluids on composite surfaces. Volume 2 documents the composite research that was conducted in the winters of 2004-05 through 2008-09.

Exploratory Research: Winters 2004-05 to 2008-09

For the most part, the research conducted during the first five years of the research program was exploratory, evaluating different composite materials, evaluating different fluid types, and establishing appropriate test methodologies for determining Type I holdover times on composite surfaces.

In the winter of 2004-05, testing was conducted on unpainted composite surfaces in natural snow and simulated freezing precipitation with all fluid types. The testing showed fluid endurance times were longer on composite surfaces than on aluminum surfaces. As this result was unexpected, the test procedure was examined, and it was determined that test surfaces would need to be painted to generate results on aluminum and composite surfaces that could be accurately compared.

In the winter of 2005-06, testing was conducted in natural snow, simulated freezing precipitation and natural frost with four composite materials and a standard aluminum material. The composite test surfaces were painted white for testing. Fluid endurance times were found to be similar on all four composite materials, despite differences in their compositions, structures, and thicknesses. The endurance times measured on composite surfaces were also compared to those measured on aluminum surfaces. The test results showed that endurance times of Type II, III and IV fluids are similar on composite and aluminum surfaces, but endurance times of Type I fluids are shorter on composite surfaces than on aluminum surfaces. Further testing with Type I fluids was recommended.

During the winters of 2006-07 and 2007-08, testing was conducted with Type I fluids to determine if the endurance time reductions observed on composite surfaces in natural snow in 2005-06 could be replicated using standard test protocols. Testing was conducted on white-painted leading edge thermal equivalent boxes rather than on flat plates, as was done in 2005-06. The results confirmed the previous findings: endurance times were on average 31 percent shorter on composite surfaces than on aluminum surfaces.

During the winter of 2008-09, testing was conducted with Type I fluids to determine if the reductions observed on composite surfaces in simulated freezing precipitation in 2005-06 could be replicated using standard test protocols. Testing was conducted with fluids applied at 20°C, rather than at 60°C as was done in 2005-06. The results confirmed the previous findings: endurance times were on average 24 percent shorter on composite surfaces than on aluminum surfaces.

Development of Type I Composite Holdover Times: Winter 2009-10

During the winter of 2009-10, an extensive test program was carried out with five representative Type I fluids on composite surfaces in all weather conditions for which holdover times are currently provided (snow, frost, freezing fog, freezing drizzle, light freezing rain and rain on cold-soaked wing). All testing was conducted using the standard Type I holdover time testing protocol. This testing enabled the development of composite-specific holdover times for Type I fluids.

Different analysis methodologies were used to determine snow (regression analysis), freezing precipitation (regression analysis, weighted average), and frost (minimum values, ratio analysis) holdover times. For the most part, methodologies similar to those used to determine the corresponding aluminum holdover times were used. The resulting composite holdover times were generally shorter than the existing aluminum holdover times.

Transport Canada and the FAA incorporated the derived Type I holdover times for composite surfaces into their Holdover Time Guidelines publications for use in the winter 2010-11 operating season. The composite holdover times were incorporated directly into the existing Type I tables.

Conclusions

The six-year research program resulted in several conclusions about de/anti-icing fluid endurance times on composite materials:

- Endurance times of Type I fluids are roughly 30 percent shorter on composite surfaces than on aluminum surfaces, likely due to four factors: material thermal conductivity, fluid enrichment, surface temperature stabilization, and fluid dilution;
- Endurance times of Type II, III and IV fluids are similar on composite and aluminum surfaces, likely because the longer fluid protection time provided by the more viscous fluids negates the factors that impact Type I fluids; and
- Further testing is required to determine if Type III holdover times are valid when Type III fluids are applied heated on composite surfaces.

Recommendations

It is recommended that:

- Further testing be conducted with Type III fluids to determine the validity of Type III holdover times for heated Type III fluid applications;
- Full-scale testing be conducted to validate the reductions in Type I endurance times measured on standard test surfaces; and
- Aerodynamic testing be conducted in the wind tunnel to investigate the aerodynamic effects of the reduced Type I fluid endurance times observed on composite surfaces.

Supplemental Research: Use of -3°C Buffer Fluid on Composite Surfaces

A supplemental test program was carried out in the winter of 2009-10 to examine the use of -3°C buffer fluids (fluid mixed to a freezing point 3°C above the ambient temperature) as the first-step fluid in two-step de/anti-icing operations. The research indicated that -3°C buffer fluids may not always provide the 3-minute protection time that guidance materials state first-step fluids provide, especially if the fluid is applied on a composite surface. Changes to guidance materials are recommended.

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SOMMAIRE

Depuis quelques années, les matériaux composites sont de plus en plus utilisés dans la construction de composants d'aéronef, comme les ailes. Puisque les durées d'efficacité des liquides de dégivrage et d'antigivrage ont à l'origine été déterminées au moyen d'essais réalisés exclusivement sur des surfaces en aluminium, la validité de ces durées d'efficacité publiées pour les surfaces d'aéronef construites à partir de matériaux composites était incertaine. Un programme de recherche était donc nécessaire pour examiner les durées d'endurance des liquides de dégivrage et d'antigivrage sur les surfaces en matériaux composites.

En vertu d'un contrat avec Transports Canada et la Federal Aviation Administration (FAA) et avec les conseils de ces deux organisations, APS Aviation Inc. (APS) a amorcé cette recherche au cours de l'hiver 2004-2005. Le programme s'est déroulé durant six hivers et a abouti à la publication de durées d'efficacité des liquides de type I applicables aux matériaux composites pour qu'elles puissent être utilisées à l'hiver 2010-2011. La recherche est présentée dans le présent rapport.

Format du rapport

Le présent rapport est présenté en deux volumes. Le volume 1 documente les essais rigoureux et les analyses réalisés à l'hiver 2009-2010 dans le but de déterminer les bonnes durées d'efficacité des liquides de type I sur les surfaces composites. Le volume 2 documente la recherche menée sur les matériaux composites de l'hiver 2004-2005 à l'hiver 2008-2009.

Recherche exploratoire : hivers 2004-2005 à 2008-2009

La recherche menée durant les cinq premières années du programme était principalement exploratoire, évaluant différents matériaux composites et différents types de liquides et établissant les méthodes d'essai appropriées pour déterminer les durées d'efficacité des liquides de type I sur les surfaces en matériaux composites.

Au cours de l'hiver 2004-2005, des essais ont été réalisés avec tous les types de liquides sur des surfaces composites non peintes dans des conditions de neige naturelle et de précipitations verglaçantes simulées. Selon les résultats obtenus, les durées d'endurance des liquides étaient plus longues sur les surfaces en matériaux composites que sur celles en aluminium. Comme cette constatation était inattendue, la méthode d'essai a été examinée, et il a été déterminé que les surfaces d'essai devaient être peintes afin de générer des résultats permettant de

comparer avec exactitude les surfaces en aluminium et celles en matériaux composites.

Au cours de l'hiver 2005-2006, des essais ont été menés sur quatre matériaux composites et une surface en aluminium standard dans des conditions de neige naturelle, de précipitations verglaçantes simulées et de givre naturel. Les surfaces en matériaux composites ont été peintes en blanc pour les essais. Les durées d'endurance des liquides se sont avérées semblables pour les quatre matériaux composites, malgré les différences de composition, de structure et d'épaisseur. Les durées d'endurance mesurées sur les surfaces composites ont également été comparées à celles mesurées sur les surfaces en aluminium. Les résultats ont montré que les durées d'endurance des liquides de type II, III et IV sont semblables tant sur les surfaces composites que sur celles en aluminium, mais que les durées d'endurance des liquides de type I sont plus courtes sur les surfaces composites que sur celles en aluminium. Il a été recommandé de réaliser d'autres essais sur les liquides de type I.

Au cours des hivers 2006-2007 et 2007-2008, des essais ont été réalisés sur les liquides de type I afin de déterminer si la réduction des durées d'endurance observée en 2005-2006 sur les surfaces composites dans des conditions de neige naturelle pourrait être obtenue au moyen des protocoles d'essai standards. Les essais ont été menés sur des boîtes peintes en blanc conçues pour offrir un équivalent thermique du bord d'attaque d'une aile plutôt que sur des plaques planes comme en 2005-2006. Les résultats ont permis de confirmer les conclusions précédentes : les durées d'endurance étaient en moyenne 31 pour cent plus courtes sur les surfaces en matériaux composites que sur celles en aluminium.

Au cours de l'hiver 2008-2009, des liquides de type I ont été testés afin de déterminer si la réduction des durées d'endurance observée en 2005-2006 sur les surfaces composites dans des conditions simulées de précipitations verglaçantes pourrait être obtenue au moyen des protocoles d'essai standards. Les liquides testés ont été appliqués à 20 °C plutôt qu'à 60 °C, comme c'était le cas en 2005-2006. Les résultats ont permis de confirmer les conclusions précédentes : les durées d'endurance étaient en moyenne 24 pour cent plus courtes sur les surfaces en matériaux composites que sur celles en aluminium.

Établissement des durées d'efficacité pour les liquides de type I sur des matériaux composites : hiver 2009-2010

Au cours de l'hiver 2009-2010, cinq liquides de type I représentatifs ont été soumis à des essais rigoureux sur des surfaces composites dans toutes les conditions météorologiques pour lesquelles des durées d'efficacité sont actuellement fournies (la neige, le givre, le brouillard verglaçant, la bruine verglaçante, la pluie verglaçante faible et la pluie sur aile imprégnée de froid). Tous les essais ont été menés au moyen du protocole d'essai standard sur les durées d'efficacité des liquides de type I. Ils ont permis d'élaborer les durées d'efficacité des liquides de type I applicables aux matériaux composites.

Différentes méthodes d'analyse ont été utilisées pour déterminer les durées d'efficacité dans des conditions de neige (analyse de régression), de précipitations verglaçantes (analyse de régression et moyenne pondérée) et de givre (valeurs minimales et analyse de ratios). Les méthodes étaient pour la plupart semblables à celles utilisées pour déterminer les durées d'efficacité correspondantes pour les surfaces en aluminium. Les durées d'efficacité ainsi déterminées pour les matériaux composites étaient généralement plus courtes que celles publiées pour les surfaces en aluminium.

Transports Canada et la FAA ont intégré les durées d'efficacité des liquides de type I ainsi obtenues pour les matériaux composites à leurs lignes directrices publiées pour qu'elles puissent être utilisées à l'hiver 2010-2011. Les durées d'efficacité ont été ajoutées directement dans les tableaux existants pour les liquides de type I.

Conclusions

Le programme de recherche de six ans a donné lieu à plusieurs conclusions relatives aux durées d'endurance des liquides de dégivrage et d'antigivrage sur les matériaux composites :

- Les durées d'endurance des liquides de type I sont environ 30 pour cent plus courtes sur les surfaces en matériaux composites que sur celles en aluminium, probablement en raison de quatre facteurs : la conductivité thermique des matériaux, l'enrichissement du liquide, la stabilisation de la température de la surface et la dilution du liquide ;

- Les durées d'endurance des liquides de type II, III et IV sont semblables tant pour les surfaces composites que pour celles en aluminium, probablement parce que la durée de protection plus longue fournie par les liquides plus visqueux annule l'effet des facteurs touchant les liquides de type I ; et

- D'autres essais doivent être menés afin de déterminer si les durées d'efficacité des liquides de type III sont valides lorsque ceux-ci sont appliqués chauffés sur des surfaces en matériaux composites.

Recommandations

Les recommandations suivantes ont été formulées :

- D'autres essais devraient être réalisés afin de déterminer la validité des durées d'efficacité des liquides de type III appliqués chauffés ;
- Des essais en grandeur réelle devraient être réalisés afin de confirmer la réduction des durées d'endurance des liquides de type I mesurée sur des surfaces d'essai standards ; et
- Des essais aérodynamiques devraient être réalisés en soufflerie afin d'étudier les effets aérodynamiques des durées d'endurance réduites des liquides de type I observées sur les surfaces composites.

Recherche supplémentaire : utilisation de liquides avec valeur tampon de -3 °C sur les surfaces composites

Un programme d'essais supplémentaire a été réalisé au cours de l'hiver 2009-2010 afin d'étudier l'utilisation de liquides avec valeur tampon de -3 °C (c'est-à-dire des liquides mélangés de façon que leur point de congélation soit de 3 °C supérieurs à la température ambiante) pour la première des deux étapes des opérations de dégivrage et d'antigivrage. Les résultats ont révélé que les liquides avec valeur tampon de -3 °C ne fournissent pas toujours la protection de trois minutes requises par les lignes directrices pour les liquides de première étape, surtout s'ils sont appliqués sur une surface en matériaux composites. Des changements devraient donc être apportés aux lignes directrices.

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GLOSSARY

APS	APS Aviation Inc.
ARP	Aerospace Recommended Practice
FAA	Federal Aviation Administration
LETE	Leading Edge Thermal Equivalent
MSC	Meteorological Service of Canada
NRC	National Research Council Canada
OAT	Outside Air Temperature
SAE	SAE International
TDC	Transportation Development Centre

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1. INTRODUCTION

Under winter precipitation conditions, aircraft are cleaned with a freezing point depressant fluid and protected against further accumulation by an additional application of such a fluid, possibly thickened to extend the protection time. Aircraft ground deicing had, until recently, never been researched and there is still an incomplete understanding of the hazard and potential solutions to reduce the risks posed by the operation of aircraft in winter precipitation conditions. This "winter operations contaminated aircraft – ground" program of research is aimed at overcoming this lack of knowledge.

Since the early 1990s, the Transportation Development Centre (TDC) of Transport Canada (TC) has managed and conducted de/anti-icing related tests at various sites in Canada; it has also coordinated worldwide testing and evaluation of evolving technologies related to de/anti-icing operations with the co-operation of the United States Federal Aviation Administration (FAA), the National Research Council Canada (NRC), the Meteorological Service of Canada (MSC), several major airlines, and deicing fluid manufacturers. The TDC is continuing its research, development, testing and evaluation program.

Under contract to the TDC, with financial support from the FAA, APS Aviation Inc. (APS) has undertaken research activities to further advance aircraft ground de/anti-icing technology.

1.1 Background

In recent years, there has been an increase in the use of composite materials in the manufacturing of aircraft components, including wings. There is no indication that this trend will slow down, as evidenced by the use of significant composite materials in the construction of the Airbus A380 and Boeing 787 and by the significant benefits of using composite materials, including reduced aircraft weight, increased fuel efficiency, and improved maintainability.

As de/anti-icing fluid holdover times were originally developed for aluminum aircraft surfaces, research was required to determine if the published holdover times were valid for use on aircraft constructed from composite materials. Under contract to Transport Canada and the FAA, and with guidance from both organizations, APS started this research in the winter of 2004-05. The research project spanned six winters and has culminated in the development of new holdover times for Type I fluids on composite surfaces.

This two-volume report documents the research conducted by APS as part of the six-year (2004-05 through 2009-10) composite research program.

1.2 Report Format and Content

This report is presented in two volumes:

- Volume 1: Primary Research (Conducted Winter 2009-10) and Analysis; and
- Volume 2: Supporting Research (Conducted Winters 2004-05 to 2008-09).

The contents of the two volumes are summarized below.

1.2.1 Volume 1

Volume 1 documents the extensive testing and analysis carried out in the winter of 2009-10 to determine appropriate holdover times for Type I fluids on composite surfaces. The 2009-10 research has been included in Volume 1 as it provides the primary data from which the Type I composite holdover times were derived.

1.2.2 Volume 2

Volume 2 (this volume) documents the composite testing and research that was conducted in the winters of 2004-05 through 2008-09. For the most part, this research was exploratory, looking at different composite materials, evaluating different fluid types, and finally establishing appropriate test methodologies for determining Type I holdover times on composite surfaces. These methodologies were used to carry out the extensive testing conducted in 2009-10.

1.3 Project Objectives

The initial objective of the composite research project was to determine if fluid endurance times are similar on aluminum and composite surfaces. Research in the early years of the project showed that Type II, III, and IV fluid endurance times were similar on composite and aluminum surfaces, but Type I fluid endurance times were shorter on composite surfaces than on aluminum surfaces. The objective of the project then shifted to determining appropriate holdover times for Type I fluids on composite surfaces: this involved validating the observed reductions, determining appropriate test protocols, and collecting sufficient data to produce composite-specific Type I holdover times.

The project objectives for each winter of testing are summarized below.

- Winter 2004-05: To conduct preliminary work with all fluid types in snow, frost, and freezing precipitation to examine endurance times on composite surfaces.

- Winter 2005-06: To conduct testing with all fluid types on four different composite surfaces in snow, frost, and freezing precipitation. Most testing was conducted with heated fluids to examine the impact of heat on endurance times. Testing was conducted on white-painted test surfaces.

- Winter 2006-07: To conduct testing with Type I fluids in natural snow using the current Type I test protocol (tests conducted on leading edge thermal equivalent boxes) to validate the results obtained in 2005-06 (tests conducted on flat plates).

- Winter 2007-08: To collect additional data to meet the 2006-07 objective.

- Winter 2008-09: To conduct testing with Type I fluids in freezing precipitation using the current Type I test protocol (fluids at 20°C) to validate the results obtained in 2005-06 (fluids at 60°C).

- Winter 2009-10: To collect a complete data set of composite endurance time data in all weather conditions encompassed by the Type I holdover time guidelines using the current Type I protocol and to use this data to develop holdover times for Type I fluids on composite surfaces.

The detailed project objectives are provided in Appendix A in excerpts from the relevant TDC statements of work.

1.4 Volume Format and Content

Volume 2 (this volume) includes eight sections. A short description of the content of each section is listed below.

a) Section 1 contains an introduction and background information on the project and provides the project and report objectives;

b) Section 2 describes the general test methodology followed in composite surface research conducted in the winters of 2004-05 to 2008-09;

c) Section 3 provides a review of composite surface testing conducted in the winter of 2004-05;

d) Section 4 provides a review of composite surface testing conducted in the winter of 2005-06;

e) Section 5 details composite surface testing conducted in the winters of 2006-07 and 2007-08;

f) Section 6 details composite surface testing conducted in the winter of 2008-09;

g) Section 7 presents the conclusions derived from the research conducted from 2004-05 to 2008-09; and

h) Section 8 presents the recommendations that came out of the first five winters of testing (2004-05 through 2008-09).

2. METHODOLOGY

This section describes the test methodology and experimental procedures that were used to conduct composite surface research in the winters of 2004-05 through 2008-09. The section contains general information that pertains to all years of testing. Additional details of the test methodologies and procedures used in individual winters are provided in subsequent sections of this report:

- Winter 2004-05: Subsection 3.2;
- Winter 2005-06: Subsection 4.2;
- Winter 2006-07 and 2007-08: Subsection 5.2; and
- Winter 2008-09: Subsection 6.2.

2.1 General

The composite research consisted primarily of endurance time tests carried out on various test surfaces, with different fluids, under different precipitation conditions and ambient temperatures. Tests were generally conducted using standard endurance time testing procedures.

2.2 Test Sites

Tests were conducted outdoors in natural precipitation conditions and indoors in simulated precipitation conditions.

2.2.1 Outdoor Test Site

Natural snow testing was conducted outdoors at the APS test site located at the Montreal–Pierre Elliott Trudeau International Airport (Photo 2.1 and Photo 2.2). The location of the test site is shown on a plan view of the airport in Figure 2.1. The airport is located adjacent to the MSC weather station.

2.2.2 Indoor Test Site

Simulated freezing precipitation testing was conducted indoors at the NRC Climatic Engineering Facility in Ottawa (Photo 2.3) using a sprayer assembly (Photo 2.4) to simulate the required freezing precipitation conditions: freezing fog, freezing drizzle, and light freezing rain.

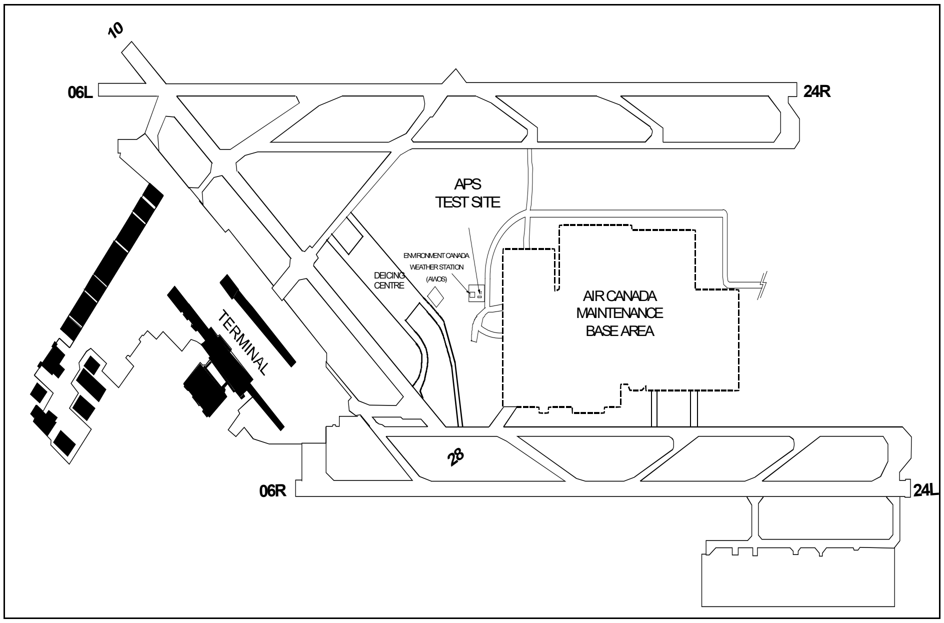

Figure 2.1: Plan View of APS Montreal–Trudeau Airport Test Site

2.3 Test Protocol

Comparative endurance time testing was the protocol used to compare endurance times on composite surfaces to endurance times on aluminum surfaces.

The endurance time tests were generally carried out according to SAE International (SAE) standard test protocol for conducting endurance time testing: Aerospace Recommended Practice (ARP) 5945, *Endurance Time Tests for Aircraft Deicing/Anti-Icing Fluids: SAE Type I* (3) provides the protocol for testing with Type I fluids, and ARP5485A, *Endurance Time Tests for Aircraft Deicing/Anti-Icing Fluids: SAE Type II, III, and IV* (4) provides the protocol for testing with Type II, III, and IV fluids.

Several modifications were made to the standard test protocols in some years. Specifically, changes were made to fluid temperature, fluid quantity, and test surface configuration (see Subsection 2.5.3). These changes are summarized in Table 2.1 and detailed further in subsequent subsections of this report (see Subsections 3.2, 4.2, 5.2, and 6.2).

Table 2.1: Summary of Test Protocols

Winter	Fluid	Procedure Location	Precipitation Condition	Test Surface Configuration	Test Surface Materials / Finishes	Fluid Temp. (Qty)
2004-05	Type II/III/IV	Appendix B	Snow Freezing Precip.	Flat Plate	• Unpainted Aluminum • Unpainted Composite (Comp 05)	• OAT (1 L)
	Type I	Appendix B	Snow Freezing Precip.	Flat Plate	• Unpainted Aluminum • Unpainted Composite (Comp 05)	• 20°C (1 L)
		Appendix B	Frost	Frosticator Plate	• Painted Aluminum • Painted Composite (Comp 05)	• 20°C (0.5 L)
2005-06	Type II/III/IV	Appendix C	Snow	Flat Plate	• Unpainted aluminum (fluid at OAT) • Painted aluminum • Painted composite (Comp 05, Comp 06 Thin, Comp 06 Thick, GLARE)	• OAT (1 L) • 60°C (0.5 L)
		Appendix D	Freezing Precip.	Flat Plate	• Unpainted aluminum (fluid at OAT) • Painted aluminum • Painted composite (Comp 05)	• 60°C (1 L)
	Type I	Appendix C	Snow	Flat Plate	• Unpainted aluminum (LETE box) • Painted aluminum • Painted composite (Comp 05, Comp 06 Thin, Comp 06 Thick, GLARE)	• 60°C (0.5 L)
		Appendix D	Freezing Precip.	Flat Plate	• Unpainted aluminum (fluid at 20°C) • Painted aluminum • Painted composite (Comp 05)	• 60°C (1 L) • 20°C (1 L)
		Appendix C	Frost	Frosticator Plate	• Painted aluminum • Painted composite (Comp 05, Comp 06 Thin, Comp 06 Thick, GLARE)	• 60°C (0.5 L)
2006-07 and 2007-08	Type I	Appendix E	Snow	LETE Box	• Unpainted Aluminum • Painted Aluminum • Painted Composite (Comp 05)	• 60°C (0.5 L) • 20°C (0.5 L)
2008-09	Type I	Appendix D	Freezing Precip.	Flat Plate	• Unpainted Aluminum • Painted Aluminum • Painted Composite (Comp 05)	• 20°C (1 L)

2.4 Test Procedures

Detailed procedures were written to provide guidance to conduct the required tests. Some of the procedures were used in a single winter only; others were used in multiple years of testing. The procedures are included as appendices to this report. The procedures are listed below along with the winter(s) in which they were used and the appendix in which they can be found.

1. *Experimental Program: Effect of Heat on Endurance Time of Anti-Icing Fluids (Subproject: Endurance Time of Non-Aluminum Plates)* (December 2004)
    - Winter(s) in Use: 2004-05
    - Location: Appendix B

2. *Experimental Program: Outdoor Endurance Time Testing on Non-Aluminum Plates* (January 2006)
    - Winter(s) in Use: 2005-06
    - Location: Appendix C

3. *Experimental Program: Indoor Endurance Time Testing on Non-Aluminum Plates* (March 2006)
    - Winter(s) in Use: 2005-06 and 2008-09
    - Location: Appendix D

4. *Experimental Program: Type I Endurance Time Testing on Non-Aluminum Leading Edge Thermal Equivalent Boxes – Natural Snow* (November 2006)
    - Winter(s) in Use: 2006-07 and 2007-08
    - Location: Appendix E

2.5 Test Surfaces

Testing was carried out on several test surfaces over the six winters of testing (see Table 2.1). The test surface materials, finishes, and configurations used in the testing are described in this section. Photos at the end of this section show several of the test surfaces. Additional photos are provided in subsequent sections.

2.5.1 Test Surface Materials

In each winter of testing, tests were conducted on both composite and aluminum surfaces.

The purpose of the aluminum surface was to provide a baseline result to which the composite surface results could be compared. Only one aluminum material was used for the standard holdover time testing: 0.32 cm thick Alclad 2024 T3 aluminum.

In the first winter of testing (2004-05), testing was carried out on one composite surface. The surface was made of carbon fibre fabric constructed using a cross weave. The following winter (2005-06), testing was carried out on four composite materials; details and photos of these materials are provided in Subsection 4.2.1. Testing in 2005-06 showed endurance times were similar on all four composite surfaces. Therefore, in subsequent winters, testing was conducted with just one representative composite surface.

2.5.2 Test Surface Finishes

Both the aluminum and composite test surfaces were primed and painted white with aircraft grade paint for frost testing. The surfaces were painted to allow for effective and equal radiative cooling during active frost conditions.

In the first winter of testing, the test surfaces used in snow and freezing precipitation testing were left unpainted. However, after some unexpected results were obtained, it was hypothesized that the results may have been affected by black body radiation heat transfer and by experimental error caused by the difficulty in visually determining fluid failure on differing bare material colours (see Subsection 3.4.3). Therefore, in subsequent winters, both aluminum and composite surfaces were painted white to prevent the impact of these factors. In some winters, unpainted aluminum surfaces were also tested in addition to the painted aluminum surfaces. The tests with unpainted aluminum surfaces were conducted to provide a reference to the results obtained using standard holdover time test procedures (i.e., the procedures that were used to obtain the holdover times published in the holdover time guidelines).

2.5.3 Test Surface Configurations

Three test surface configurations were used in testing. The majority of tests were conducted using the standard flat plate test surface configuration, but the frosticator plate configuration was used in frost testing and the Leading Edge Thermal Equivalent (LETE) box configuration was used in select snow testing. The three test surface configurations are described below.

2.5.3.1 Flat Plates

Aluminum and composite flat plates were constructed in accordance with standard flat plate dimensions (see Figure 2.2). An unpainted aluminum flat plate is shown in Photo 2.5; an unpainted composite flat plate is shown in Photo 2.6.

Flat plates were used for all freezing precipitation testing, snow testing with Type II/II/IV fluids, and some snow testing with Type I fluids (see Table 2.1).

2.5.3.2 Leading Edge Thermal Equivalent (LETE) Boxes

Aluminum LETE boxes were developed many years ago to simulate the surface temperature profile of an aircraft wing leading edge when treated with heated Type I fluid. The boxes are built by mounting a standard aluminum flat plate (Figure 2.2) onto an aluminum frame to create an empty box. The aluminum used in the frame is the same as the aluminum used in standard holdover time testing flat plates (see Subsection 2.5.1). Photo 2.7 shows an unpainted aluminum LETE box.

For the purposes of this testing, composite LETE boxes had to be built. The composite boxes were constructed using the standard LETE box dimensions (see Figure 2.3). The composite boxes were constructed by affixing a composite flat plate top to a standard aluminum frame (sides and bottom). Photo 2.8 shows a white-painted composite LETE box.

LETE boxes were used for select testing with Type I fluids in natural snow conditions (flat plates were used in initial research with Type I fluid in natural snow in 2004-05 and 2005-06). The current protocol for conducting holdover time tests requires the use of these boxes when testing Type I fluids in natural snow and when testing any fluids in simulated rain on a cold-soaked wing.

2.5.3.3 Frosticator Plates

Frost testing was conducted on frosticator plates, which are the current standard test surface used in frost holdover time testing. Frosticator plates are constructed by attaching a Styrofoam insulation backing to a flat plate (either aluminum or composite; see Subsection 2.5.1). As described in Subsection 2.5.2, the surfaces of frosticator plates are always painted white for testing. The insulation prevents heat exchange via the underside of the flat plate and the painted surface allows effective radiative cooling during active frost conditions. Photo 2.9 shows a white-painted aluminum frosticator plate.

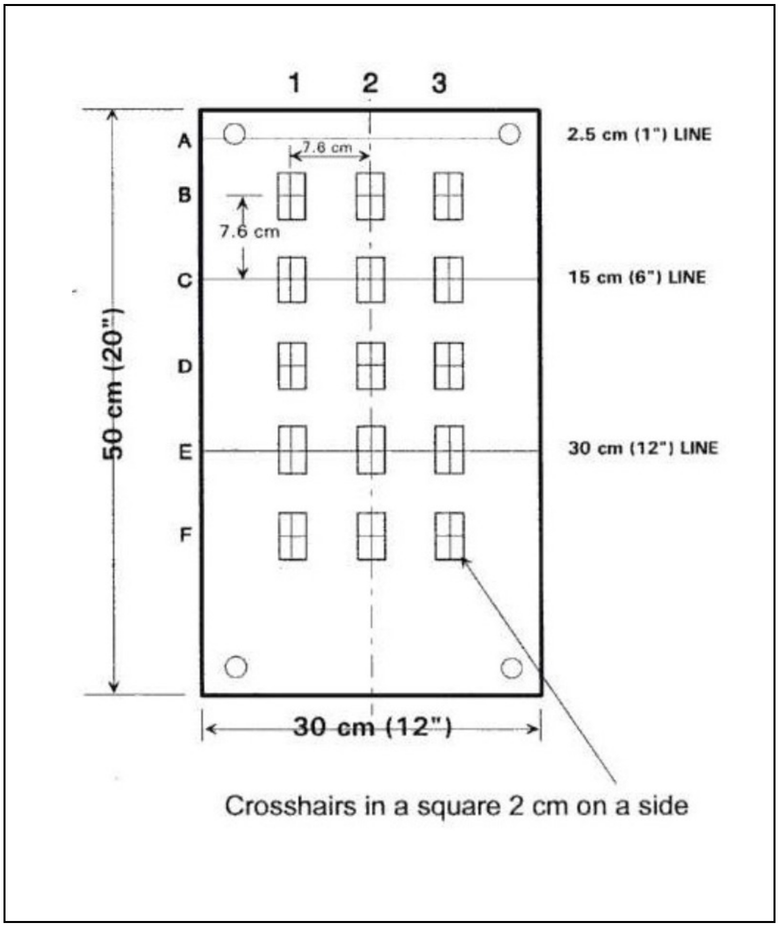

Figure 2.2: Schematic of Standard Holdover Time Testing Flat Plate

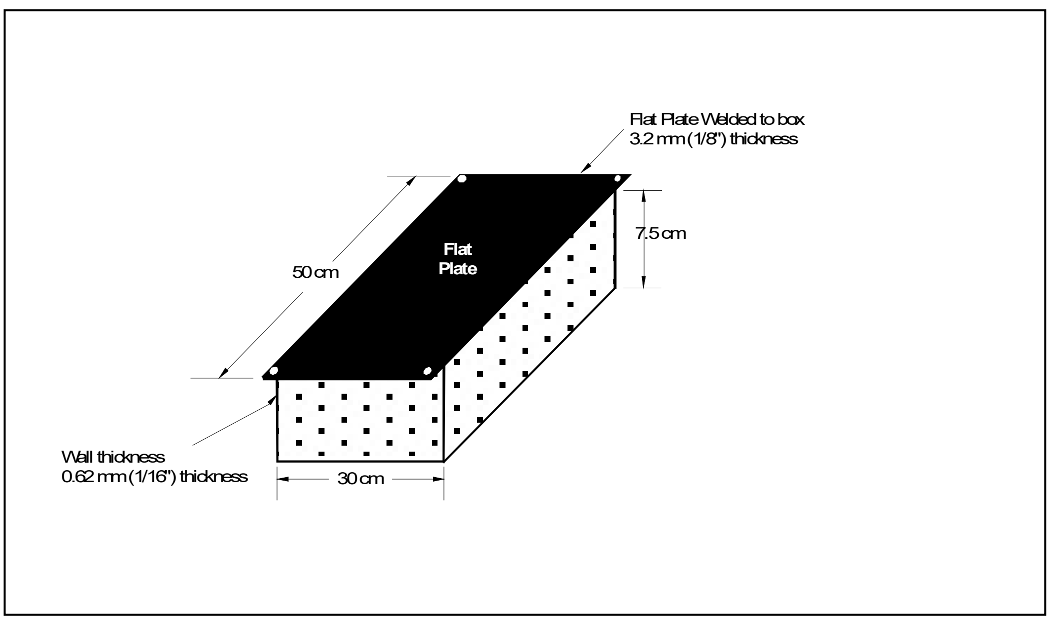

Figure 2.3: Schematic of Leading Edge Thermal Equivalent Box

2.6 Equipment

The equipment required for conducting the composite endurance time tests was generally standard holdover time testing equipment. Several of the key pieces of equipment used in the testing are described below.

2.6.1 Thermistor Probes

Each LETE box had a thermistor probe installed on the inside of the box, on the underside of the top test plate, at the 15 cm line, inset one-third of the width from the edge. Surface temperature data was collected during the test event and was stored in a data logger.

2.6.2 Wet Film Thickness Gauge

Wet film fluid thickness measurements were recorded during select endurance time tests. Figure 2.4 shows a schematic of the wet film thickness gauges. Photo 2.10 shows the actual thickness gauges used for testing.

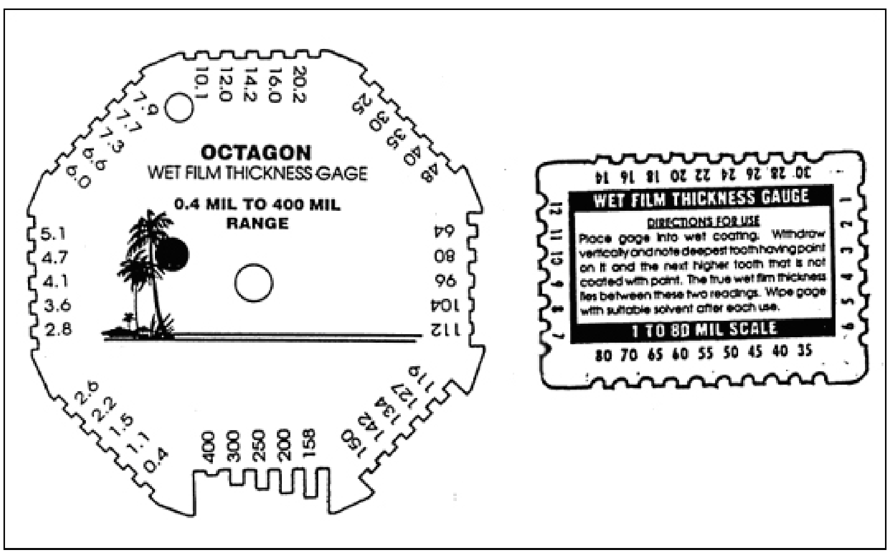

Figure 2.4: Wet Film Thickness Gauges

2.6.3 Brixometer

Brix measurements were used to provide Type I fluid concentration data. Photo 2.11 shows a Brixometer.

2.6.4 Twelve-Hole Fluid Spreader

Fluid was applied with the standard twelve-hole spreader (Photo 2.12) for all heated fluid endurance time tests. The twelve-hole spreader allowed for an even distribution of fluid along the top of the test plate.

2.6.5 Equipment Calibration

APS measurement instruments and test equipment are calibrated and verified on an annual basis. This calibration is carried out according to a calibration plan derived from approved ISO 9001:2000 standards and developed internally by APS.

2.7 Fluids

The composite surface research project involved testing with all de/anti-icing fluid types (Types I, II, III, and IV).

Type II, III, and IV fluids in 100/0, 75/25, and 50/50 dilutions were tested in the winters of 2004-05 and 2005-06.

Type I fluids were tested in all five winters of testing documented in this report. They were tested at a 10°C buffer (fluid was mixed to a freezing point 10°C below the ambient temperature prior to each test).

The specific fluid brands tested each year are provided in subsequent sections of this report (see Subsections 3.2.3, 3.2.3, 4.2.3, 5.2.3, and 6.2.3).

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Photo 2.1: APS Test Site – View from Test Pad

Photo 2.2: APS Test Site – View from Trailer

Photo 2.3: Inside View of NRC Climate Engineering Facility

Photo 2.4: Sprayer Assembly Used to Produce Fine Droplets

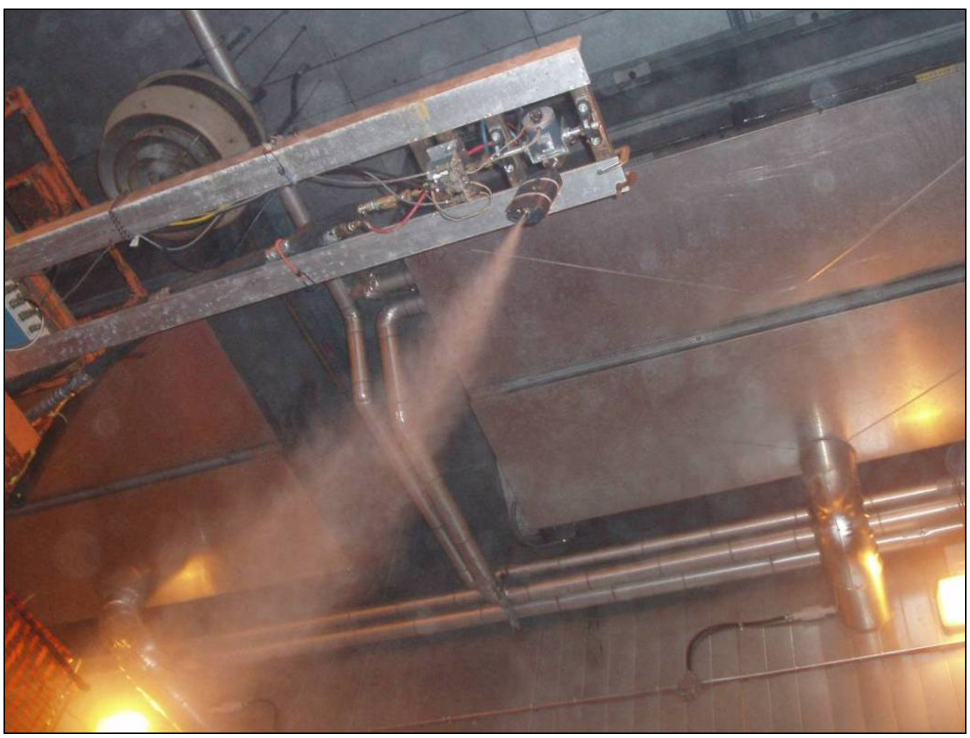

Photo 2.5: Unpainted Aluminum Flat Plate

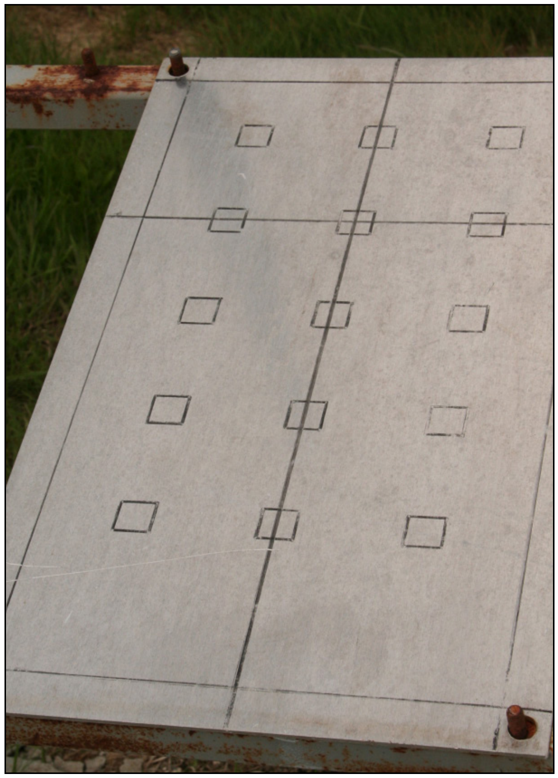

Photo 2.6: Unpainted Composite (Comp 05) Flat Plate

Photo 2.7: Unpainted Aluminum Leading Edge Thermal Equivalent Box

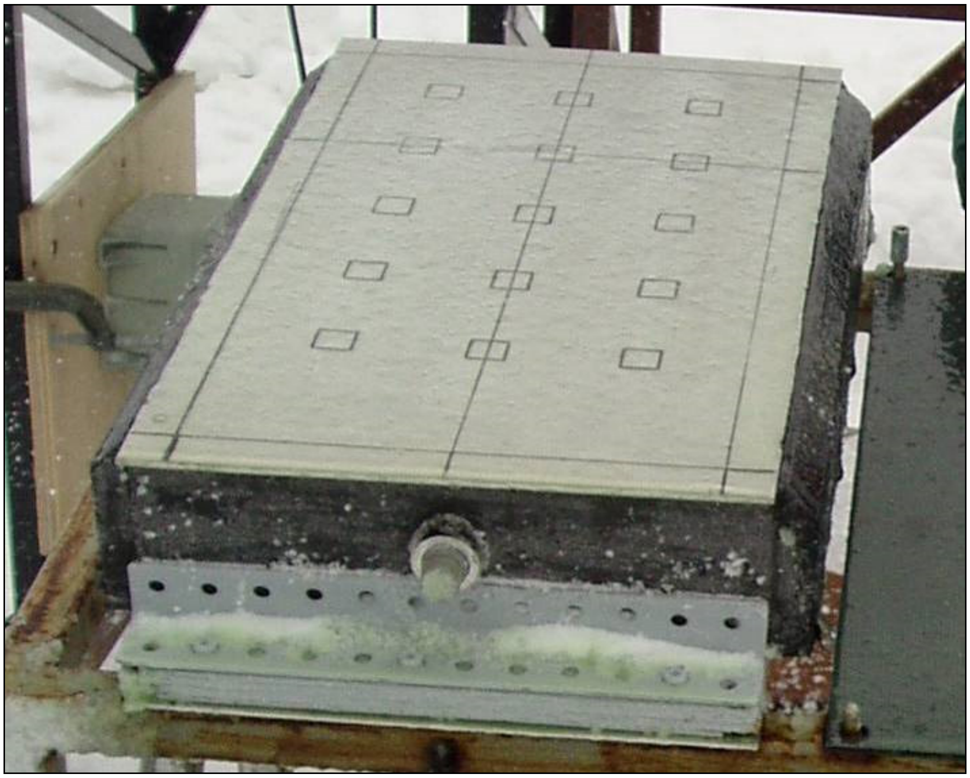

Photo 2.8: White-Painted Composite Leading Edge Thermal Equivalent Boxes

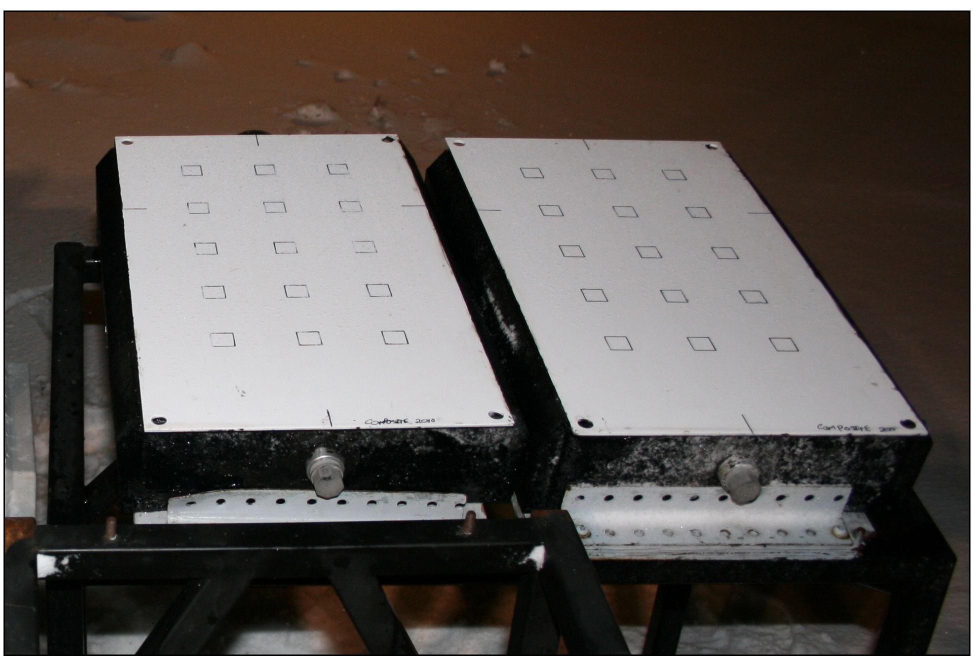

Photo 2.9: White-Painted Aluminum Frosticator Plate

Photo 2.10: Wet Film Thickness Gauges

Photo 2.11: Hand-Held Brixometer

Photo 2.12: Twelve-Hole Spreader Used for Fluid Application

3. 2004-05 RESEARCH

This section provides a review of the composite research conducted in the winter of 2004-05. This research was previously published in the Transport Canada report, TP 14448E, *Aircraft Ground Deicing Fluid Endurance Times on Composite Surfaces* (1).

3.1 Objective

The objective in the winter of 2004-05 was to conduct preliminary research comparing fluid endurance times on a composite surface to fluid endurance times on an aluminum surface. Tests were carried out in natural snow, freezing precipitation, and natural frost conditions. Tests were conducted with Type I, II, III, and IV fluids.

3.2 Methodology

The methodology used for conducting composite testing is described in Section 2. Additional details specific to the testing conducted in 2004-05 are provided in this section.

3.2.1 Test Surfaces

Testing was conducted with two test surface materials in the winter of 2004-05: standard aluminum and a representative composite material. The composite material was a cross weave carbon fibre fabric, which is pictured in Photo 2.6. (Note: The composite surface tested in 2004-05 is referred to as Comp 05 elsewhere in this report.)

Snow and freezing precipitation testing were carried out with the test surface in standard flat plate configuration (see Subsection 2.5.3.1). The flat plate test surfaces are shown in Photos 2.5 (aluminum) and 2.6 (composite). Frost testing was carried out using the frosticator plate configuration (see Subsection 2.5.3.3 and Photo 2.9), as is standard protocol for frost holdover time testing.

For frost testing the test surfaces were painted white (see Subsection 2.5.2); for snow and freezing precipitation testing the test surfaces were unpainted.

3.2.2 Test Procedures

In the winter of 2004-05, fluid endurance times were evaluated on a composite surface in natural snow, simulated freezing precipitation, and natural frost. Testing was conducted in conjunction with another project, and the test procedure written to detail the testing was contained within the procedure for the other project. The procedure, entitled *Experimental Program: Effect of Heat on Endurance Time of Anti-Icing Fluids (Subproject: Endurance Time of Non-Aluminum Plates)*, is included in Appendix B.

Standard endurance time testing protocols were generally followed. Tests were conducted simultaneously on the two test surfaces (aluminum and composite). Fluid amounts, application methods, and temperatures varied depending on the precipitation condition and fluid type being tested.

- <u>Fluid Amount</u>: For snow and freezing precipitation tests, 1 L of fluid was applied to each test surface. For frost tests, 0.5 L of fluid was applied to each test surface.

- <u>Fluid Temperature</u>: Type II, III, and IV fluids were applied at ambient temperature. Type I fluids were applied heated to 20°C.

- <u>Fluid Application Method</u>: Type II, III, and IV fluids were hand-poured onto the test surface. Type I fluids were applied using a twelve-hole spreader (see Subsection 2.6.4).

The test surface configuration varied by precipitation type. Standard flat plates (described in Subsection 2.5.3.1) were used in snow and freezing precipitation testing; frosticator plates (described in Subsection 2.5.3.3) were used in frost.

These differences resulted in three different test setups. These setups are shown in Figure 3.1 (snow and freezing precipitation tests with Type II, III, IV fluids), Figure 3.2 (snow and freezing precipitation tests with Type I fluids), and Figure 3.3 (frost tests with Type I fluids). It should be noted that no frost tests were conducted with Type II, III, or IV fluids.

The snow test setup is also shown in Photo 3.1. (Note: The LETE box at the left of the photo is not part of the composite surface testing.)

Position 1 (Baseline Alum. Test)	Position 2 (Composite Test)
Aluminum	Composite
Flat Plate	Flat Plate
1 L of Fluid	1 L of Fluid
Apply at OAT	Apply at OAT
Hand Pour	Hand Pour

Figure 3.1: Test Setup (Snow and Freezing Precipitation) – Type II, III, IV Fluids

Position 1 (Baseline Alum. Test)	Position 2 (Composite Test)
Aluminum	Composite
Flat Plate	Flat Plate
1 L of Fluid	1 L of Fluid
Apply at 20°C	Apply at 20°C
Spreader	Spreader

Figure 3.2: Test Setup (Snow and Freezing Precipitation) – Type I Fluids

Position 1 (Baseline Alum. Test)	Position 2 (Composite Test)
Aluminum	Composite
Frosticator Plate	Frosticator Plate
0.5 L of Fluid	0.5 L of Fluid
Apply at 20°C	Apply at 20°C
Spreader	Spreader

Figure 3.3: Test Setup (Frost) – Type I Fluids

3.2.3 Fluids

In the winter of 2004-05, testing was conducted with Type I, II, III, and IV fluids. Table 3.1 lists the fluid brands and dilutions that were tested. Type II/III/IV fluids were tested in 100/0, 75/25, and/or 50/50 dilutions. Type I fluid was tested at a 10°C buffer; fluid was mixed to a freezing point 10°C below the prevailing ambient temperature for each test.

Table 3.1: Fluids Used in 2004-05 Testing

Fluid Type	Fluid Name	Fluid Dilutions Tested
I	Clariant Safewing MP I 1938 ECO	10°C Buffer
I	HOC SafeTemp I	10°C Buffer
I	Dow UCAR ADF	10°C Buffer
II	Clariant Safewing MP II 2025 ECO	100/0, 75/25, 50/50
III	Clariant Safewing MP IIII 2031 ECO	100/0, 75/25
IV	Kilfrost P1637	100/0, 75/25
IV	Octagon MaxFlo	100/0, 75/25
IV	Dow UCAR Ultra+	100/0

3.3 Data

The data collected from the tests conducted in the winter of 2004-05 is presented in the following subsections.

3.3.1 Logs of Tests

Logs of the tests conducted in snow, frost, and freezing precipitation were created to document the results of testing carried out in 2004-05. A separate log was created for each of the three precipitation types, as follows:

- Table 3.2: Natural Snow;
- Table 3.3: Simulated Freezing Precipitation; and
- Table 3.4: Natural Frost.

The logs provide detailed information for each test conducted. Each row contains data specific to one test. Below is a brief description of the column headings included in the logs.

Test #:	Exclusive number identifying each test.
Date:	Date when the test was conducted.
Run #:	Run number in which the test was performed.
Fluid Name:	Fluid manufacturer and fluid brand name.
Fluid Dil.:	Fluid dilution (10°B = fluid mixed to a freezing point 10°C below the ambient temperature).
Fluid Type:	SAE designated fluid type (I, II, III, or IV).
Fluid Temp.:	Fluid temperature prior to application, measured in °C.
Test Surface:	Test surface material: aluminum or composite.
Precip. Type:	Dominant precipitation type during each test.
Start Time:	Start time for the test, recorded in local time.
Fail Time:	Fluid failure time, recorded in local time.
Endurance Time:	Fluid endurance time, measured in minutes.
Precip. Rate:	Average precipitation rate, measured in $g/dm^2/h$, collected using standard holdover time precipitation measurement methods.
Ambient Temp.:	Ambient temperature, measured in °C. In snow and frost: the average of hourly OAT readings for the duration of the test, provided by Environment Canada. In freezing precipitation: average ambient temperature in the climatic chamber.
RH:	The average of hourly relative humidity readings for the duration of the test, measured in percentage, provided by Environment Canada (frost only).
Wind Speed:	The average of hourly wind speed readings for the duration of the test, measured in km/h, provided by Environment Canada (frost only).

Plate Temp.: The average of the plate surface temperature prior to fluid application and following fluid failure, measured in °C (frost only).

ΔT (Delta T): Difference between the ambient temperature and the plate temperature (frost only).

Initial Brix: Fluid Brix, measured in degrees, prior to fluid application (frost only).

Final Brix: Fluid Brix, measured in degrees, at fluid failure (frost only).

Table 3.2: Log of Tests (2004-05) – Natural Snow

Test #	Date	Run #	Fluid Name	Fluid Dil.	Fluid Type	Fluid Temp. (°C)	Test Surface	Precip. Type	Start Time	Fail Time	Endur. Time (min.)	Precip. Rate (g/dm²/h)	Ambient Temp. (°C)
1	Jan-6-05	1	Clariant MP III 2031	100%	III	OAT	Composite	Snow	16:53:00	17:03:30	10.5	28.9	-12.2
2	Jan-6-05	1	Clariant MP III 2031	100%	III	OAT	Aluminum	Snow	16:53:00	17:03:00	10	28.7	-12.2
4	Jan-6-05	2	Clariant MP III 2031	75%	III	OAT	Composite	Snow	16:24:30	16:32:30	8.0	31.6	-12.3
5	Jan-6-05	2	Clariant MP III 2031	75%	III	OAT	Aluminum	Snow	16:24:30	16:32:30	8.0	31.6	-12.3
7	Jan-6-05	3	Clariant MP III 2031	75%	III	OAT	Aluminum	Snow	17:33:30	17:40:30	7.0	37.1	-12.1
8	Jan-6-05	3	Clariant MP III 2031	75%	III	OAT	Composite	Snow	17:33:30	17:41:30	8.0	36.6	-12.1
10	Feb-10-05	1	Clariant MP III 2031	100%	III	OAT	Composite	Snow	12:18:30	12:56:00	37.5	5.7	-5.7
11	Feb-10-05	1	Clariant MP III 2031	100%	III	OAT	Aluminum	Snow	12:18:00	12:54:00	36.0	5.6	-5.7
13	Feb-10-05	2	Clariant MP III 2031	75%	III	OAT	Composite	Snow	13:25:00	13:46:00	21.0	9.5	-5.1
14	Feb-10-05	2	Clariant MP III 2031	75%	III	OAT	Aluminum	Snow	13:25:15	13:43:00	17.8	9.6	-5.1
16	Feb-10-05	3	Kilfrost P1637	75%	IV	OAT	Composite	Snow	14:40:30	15:40:00	59.5	8.5	-5.4
17	Feb-10-05	3	Kilfrost P1637	75%	IV	OAT	Aluminum	Snow	14:40:00	15:37:00	57.0	8.8	-5.4
20	Feb-21-05	1	Octagon MaxFlo	75%	IV	OAT	Composite	Snow	6:02:00	6:36:00	34.0	4.2	-14.4
21	Feb-21-05	1	Octagon MaxFlo	75%	IV	OAT	Aluminum	Snow	6:02:30	6:33:00	30.5	4.1	-14.4
23	Feb-21-05	2	Octagon MaxFlo	100%	IV	OAT	Composite	Snow	6:57:15	7:56:00	58.8	6.0	-14.3
24	Feb-21-05	2	Octagon MaxFlo	100%	IV	OAT	Aluminum	Snow	6:57:40	7:56:00	58.3	6.0	-14.3
26	Feb-21-05	3	Kilfrost P1637	75%	IV	OAT	Composite	Snow	8:48:20	9:36:00	47.7	3.7	-13.9
27	Feb-21-05	3	Kilfrost P1637	75%	IV	OAT	Aluminum	Snow	8:48:40	9:28:00	39.3	3.9	-13.5
29	Feb-21-05	4	Dow UCAR Ultra+	100%	IV	OAT	Composite	Snow	9:47:20	12:18:00	150.7	3.5	-12.2 to -7.5
30	Feb-21-05	4	Dow UCAR Ultra+	100%	IV	OAT	Aluminum	Snow	9:47:40	12:20:00	152.3	3.5	-12.2 to -7.5
32	Feb-21-05	5	Clariant MP III 2031	75%	III	OAT	Composite	Snow	12:47:30	13:04:00	16.5	13.7	-6.3
33	Feb-21-05	5	Clariant MP III 2031	75%	III	OAT	Aluminum	Snow	12:48:00	13:04:00	16.0	13.8	-6.3
35	Feb-21-05	6	Clariant MP III 2031	100%	III	OAT	Composite	Snow	13:13:15	13:35:00	21.8	14.0	-6.2
36	Feb-21-05	6	Clariant MP III 2031	100%	III	OAT	Aluminum	Snow	13:13:40	13:35:00	21.3	14.0	-6.2
38	Feb-21-05	7	Kilfrost P1637	100%	IV	OAT	Composite	Snow	13:46:30	15:03:00	76.5	12.5	-5.9
39	Feb-21-05	7	Kilfrost P1637	100%	IV	OAT	Aluminum	Snow	13:47:00	14:54:00	67.0	12.6	-5.9
40	Feb-21-05	8	Clariant MP I 1938	10°B	I	20	Composite	Snow	15:12:20	15:21:00	8.7	15.3	-5.7

Table 3.2: Log of Tests (2004-05) – Natural Snow (cont'd)

Test #	Date	Run #	Fluid Name	Fluid Dil.	Fluid Type	Fluid Temp. (°C)	Test Surface	Precip. Type	Start Time	Fail Time	Endur. Time (min.)	Precip. Rate (g/dm²/h)	Ambient Temp. (°C)
41	Feb-21-05	8	Clariant MP I 1938	10°B	I	20	Aluminum	Snow	15:12:50	15:20:00	7.2	15.5	-5.7
43	Mar-7-05	1	Kilfrost P1637	75%	IV	OAT	Composite	Snow	11:44:30	12:04:00	19.5	11.9	-13.0
44	Mar-7-05	1	Kilfrost P1637	75%	IV	OAT	Aluminum	Snow	11:44:47	12:03:00	18.2	11.9	-13.0
46	Mar-7-05	2	Clariant MP III 2031	100%	III	OAT	Composite	Snow	12:31:33	13:07:00	35.5	8.4	-12.8
47	Mar-7-05	2	Clariant MP III 2031	100%	III	OAT	Aluminum	Snow	12:31:54	13:03:00	31.1	7.8	-12.8
49	Mar-7-05	3	Clariant MP III 2031	75%	III	OAT	Composite	Snow	13:36:00	14:05:00	29.0	4.4	-12.2
50	Mar-7-05	3	Clariant MP III 2031	75%	III	OAT	Aluminum	Snow	13:36:51	14:00:00	23.2	4.5	-12.2
52	Mar-7-05	4	Dow UCAR Ultra+	100%	IV	OAT	Composite	Snow	15:04:38	17:02:00	117.4	5.0	-10.5
53	Mar-7-05	4	Dow UCAR Ultra+	100%	IV	OAT	Aluminum	Snow	15:04:47	16:56:00	111.2	4.6	-10.5
55	Mar-7-05	5	Clariant MP III 2031	100%	III	OAT	Composite	Snow	17:57:51	18:27:00	29.2	11.0	-11.3
56	Mar-7-05	5	Clariant MP III 2031	100%	III	OAT	Aluminum	Snow	17:58:07	18:25:00	26.9	11.0	-11.3
58	Mar-7-05	6	Clariant MP III 2031	75%	III	OAT	Composite	Snow	18:35:39	18:58:00	22.4	8.4	-10.9
59	Mar-7-05	6	Clariant MP III 2031	75%	III	OAT	Aluminum	Snow	18:35:57	18:53:30	17.6	9.4	-10.9
60	Mar-7-05	7	HOC Safe Temp I	10°B	I	20	Composite	Snow	19:08:00	19:24:20	16.3	16.8	-10.6
61	Mar-7-05	7	HOC Safe Temp I	10°B	I	20	Aluminum	Snow	19:08:30	19:21:00	12.5	11.1	-10.6

Table 3.3: Log of Tests (2004-05) – Freezing Precipitation

Test #	Date	Run #	Fluid Name	Fluid Dil.	Fluid Type	Fluid Temp. (°C)	Test Surface	Precip. Type	Start Time	Fail Time	Endur. Time (min.)	Precip. Rate (g/dm²/h)	Ambient Temp. (°C)
60	Mar-7-05	7	HOC Safe Temp I	10°B	I	20	Composite	Ice Pellets	19:08:00	19:24:20	16.3	16.8	-10.6
61	Mar-7-05	7	HOC Safe Temp I	10°B	I	20	Aluminum	Ice Pellets	19:08:30	19:21:00	12.5	11.1	-10.6
5	Apr-5-05	H10	Clariant MP II 2025	75%	II	OAT	Composite	Freezing Drizzle	15:39:58	16:05:00	25	13.2	-10.4
6	Apr-5-05	H10	Clariant MP II 2025	75%	II	OAT	Aluminum	Freezing Drizzle	15:40:40	16:07:00	26.3	13.2	-10.5
12	Apr-5-05	H23	Clariant MP II 2025	100%	II	OAT	Composite	Light Freezing Rain	18:44:50	19:11:00	26.2	25.2	-9.9
13	Apr-5-05	H23	Clariant MP II 2025	100%	II	OAT	Aluminum	Light Freezing Rain	18:44:10	19:09:00	24.8	25.2	-9.9
21	Apr-6-05	H20	Clariant MP I 1938	10°B	I	20	Composite	Light Freezing Rain	9:44:35	9:52:00	7.4	13.4	-10.6
22	Apr-6-05	H20	Clariant MP I 1938	10°B	I	20	Aluminum	Light Freezing Rain	9:45:05	9:50:35	5.5	13.4	-10.6
25	Apr-6-05	H14	Clariant MP III 2031	75%	III	OAT	Composite	Light Freezing Rain	13:12:55	13:24:20	11.4	13.3	-3.2
26	Apr-6-05	H14	Clariant MP III 2031	75%	III	OAT	Aluminum	Light Freezing Rain	13:12:24	13:23:50	11.4	13.3	-3.2
38	Apr-7-05	H3	Dow UCAR ADF	10°B	I	20	Composite	Freezing Drizzle	9:09:50	9:22:00	12.2	5.4	-3.4
39	Apr-7-05	H3	Dow UCAR ADF	10°B	I	20	Aluminum	Freezing Drizzle	9:10:45	9:23:30	12.8	5.4	-3.4
40	Apr-7-05	H1	Clariant MP II 2025	50%	II	OAT	Composite	Freezing Drizzle	9:45:40	9:57:00	11.3	5.4	-3.3
41	Apr-7-05	H1	Clariant MP II 2025	50%	II	OAT	Aluminum	Freezing Drizzle	9:45:10	9:57:00	11.8	5.4	-3.3

Table 3.4: Log of Tests (2004-05) – Natural Frost

Test #	Date	Run #	Fluid Name	Fluid Dil.	Fluid Type	Fluid Temp. (°C)	Test Surface	Start Time	Fail Time	Endur. Time (min.)	Precip. Rate (g/dm²/h)	Ambient Temp. (°C)	RH (%)	Wind Speed (km/h)	Plate Temp. (°C)	ΔT (°C)	Initial Brix (°)	Final Brix (°)
C1	Jan-27-05	1	Dow UCAR ADF	10°B	I	20	Composite	23:23:30	0:58:00	94.5	0.038	-20.4	60	7	-24.1	3.7	28.5	25.0
C2	Jan-27-05	1	Dow UCAR ADF	10°B	I	20	Aluminum	23:23:50	1:35:00	131.2	0.038	-20.8	61	7	-25.4	4.6	28.5	26.0
C3	Jan-27-05	2	Clariant MP I 1938	10°B	I	20	Composite	1:54:15	4:05:00	130.8	0.051	-21.7	63	8	-25.6	3.9	34.0	29.5
C4	Jan-27-05	2	Clariant MP I 1938	10°B	I	20	Aluminum	1:54:45	4:21:00	146.3	0.051	-21.7	63	8	-26.3	4.6	34.0	30.0
C5	Jan-28-05	1	Clariant MP I 1938	10°B	I	20	Composite	22:57:15	1:55:00	177.8	0.042	-14.6	65	8	-18.0	3.4	30.5	24.5
C6	Jan-28-05	1	Clariant MP I 1938	10°B	I	20	Aluminum	22:57:30	2:25:00	207.5	0.042	-14.6	65	8	-18.6	4.0	30.5	25.5
C7	Jan-28-05	2	Dow UCAR ADF	10°B	I	20	Composite	2:34:15	4:45:00	130.8	0.050	-14.9	68	9	-18.8	3.9	25.5	10.75
C8	Jan-28-05	2	Dow UCAR ADF	10°B	I	20	Aluminum	2:34:30	5:05:00	150.5	0.050	-14.9	68	9	-19.4	4.5	25.5	20.25
C9	Jan-31-05	2	Dow UCAR ADF	10°B	I	20	Composite	22:17:20	23:16:00	58.7	0.160	-12.0	79	3	-18.7	6.7	24.0	20.5
C10	Jan-31-05	2	Dow UCAR ADF	10°B	I	20	Aluminum	22:17:40	23:35:00	77.3	0.131	-11.9	78	3	-18.9	7.0	24.0	20.0
C11	Jan-31-05	3	Clariant MP I 1938	10°B	I	20	Composite	1:46:05	3:05:00	78.9	0.108	-14.2	87	6	-17.9	3.7	30.0	22.0
C12	Jan-31-05	3	Clariant MP I 1938	10°B	I	20	Aluminum	1:46:25	3:28:00	101.6	0.108	-14.3	87	6	-18.6	4.3	30.0	24.0

3.3.2 Summary of Tests Conducted

Comparative endurance time testing was conducted in natural snow, simulated freezing precipitation, and natural frost with Type I, II, III, and IV fluids. Tables 3.5 to 3.7 list the number of comparative test runs completed for each fluid type and fluid application temperature in snow, freezing precipitation, and frost.

Table 3.5: Summary of 2004-05 Test Runs – Natural Snow

Fluid Type / Temperature	# Comparative Test Runs
Type I	2
Type II	0
Type III	11
Type IV	8
TOTAL	**21**

Table 3.6: Summary of 2004-05 Test Runs – Simulated Freezing Precipitation

Fluid Type / Temperature	# Comparative Test Runs
Type I	3
Type II	3
Type III	1
Type IV	0
TOTAL	**7**

Table 3.7: Summary of 2004-05 Test Runs – Natural Frost

Fluid Type / Temperature	# Comparative Test Runs
Type I	6
Type II	0
Type III	0
Type IV	0
TOTAL	**6**

3.3.3 Natural Snow Weather Conditions

A total of 21 comparative tests (42 individual tests) were conducted in natural snow. Distribution graphs of the snow tests conducted by precipitation rate and wind speed are shown in Figures 3.4 and 3.5, respectively. Figure 3.4 shows that 52 percent of the tests were conducted in light or very light snow (precipitation rates below 10 g/dm^2/h). Figure 3.5 shows that 62 percent of the tests were conducted when wind speeds were greater than 28 km/h.

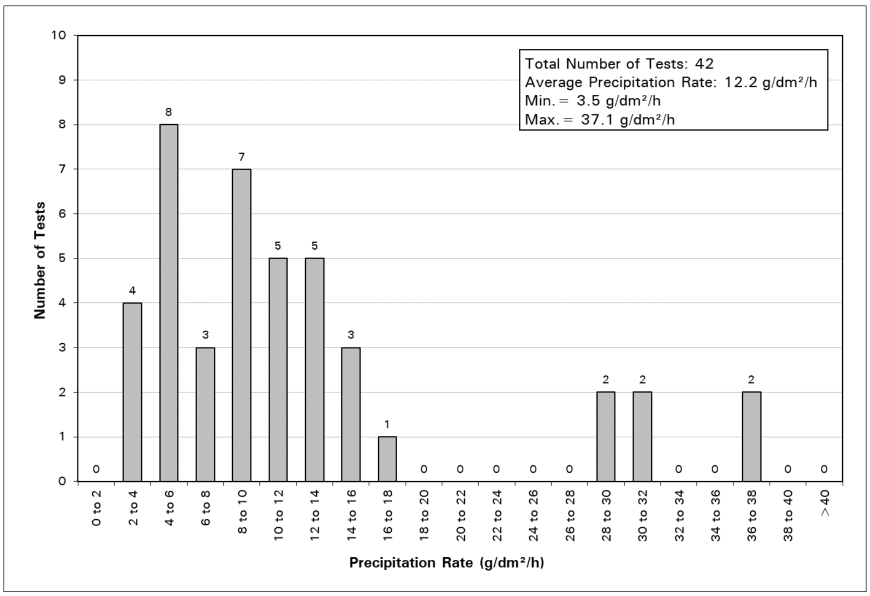

Figure 3.4: Distribution of Precipitation Rate – Natural Snow Tests 2004-05

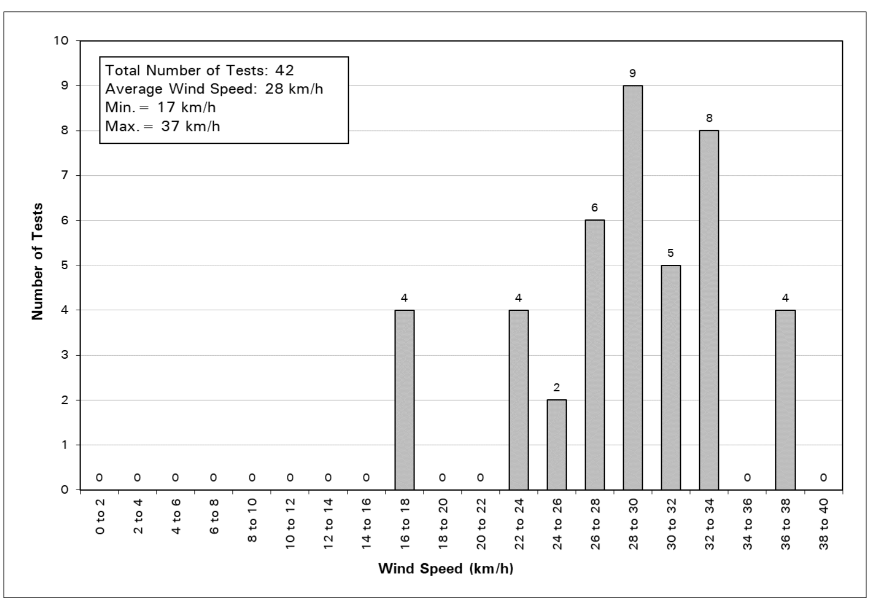

Figure 3.5: Distribution of Wind Speed – Natural Snow Tests 2004-05

3.3.4 Surface Temperature/Fluid Brix Profiles

Several parameters were documented during each fluid endurance time test. Fluid dilution (fluid Brix) and fluid thickness was measured at set intervals for the duration of the test, while plate surface temperature was logged on an ongoing basis. These parameters were used to construct charts to better illustrate the aluminum and composite test plate temperature profiles, as well as fluid thickness decay and fluid dilution.

The charts have not been included in this report. However, they are available in TP 14448E (1) – refer to Subsection 5.2 (frost), Appendix C (snow), and Appendix D (freezing precipitation).

3.4 Analysis and Observations

An analysis of the relative endurance time performance of fluids on composite surfaces is presented in this section. Observations of factors that are likely contributing to the results are provided in Subsections 3.4.3 (snow and freezing precipitation) and 3.4.4 (frost).

3.4.1 Comparative Bar Charts

The test data is presented in this subsection in bar charts. Adjacent sets of bars on the charts represent the endurance time (in minutes) measured using the aluminum and composite test surfaces. Pertinent test information for each comparative test is labelled at the bottom of each pair of bars.

Figure 3.6 demonstrates the results obtained in natural snow. In 20 of the 21 comparative tests conducted, endurance times were longer on the composite surface than on the aluminum surface.

Figure 3.7 demonstrates the results obtained in simulated freezing precipitation. In 2 of the 6 comparative tests conducted, endurance times were longer on the composite surface than on the aluminum surface.

Figure 3.8 demonstrates the results obtained in natural frost. In all 6 comparative tests conducted, endurance times were shorter on the composite surface than on the aluminum surface.

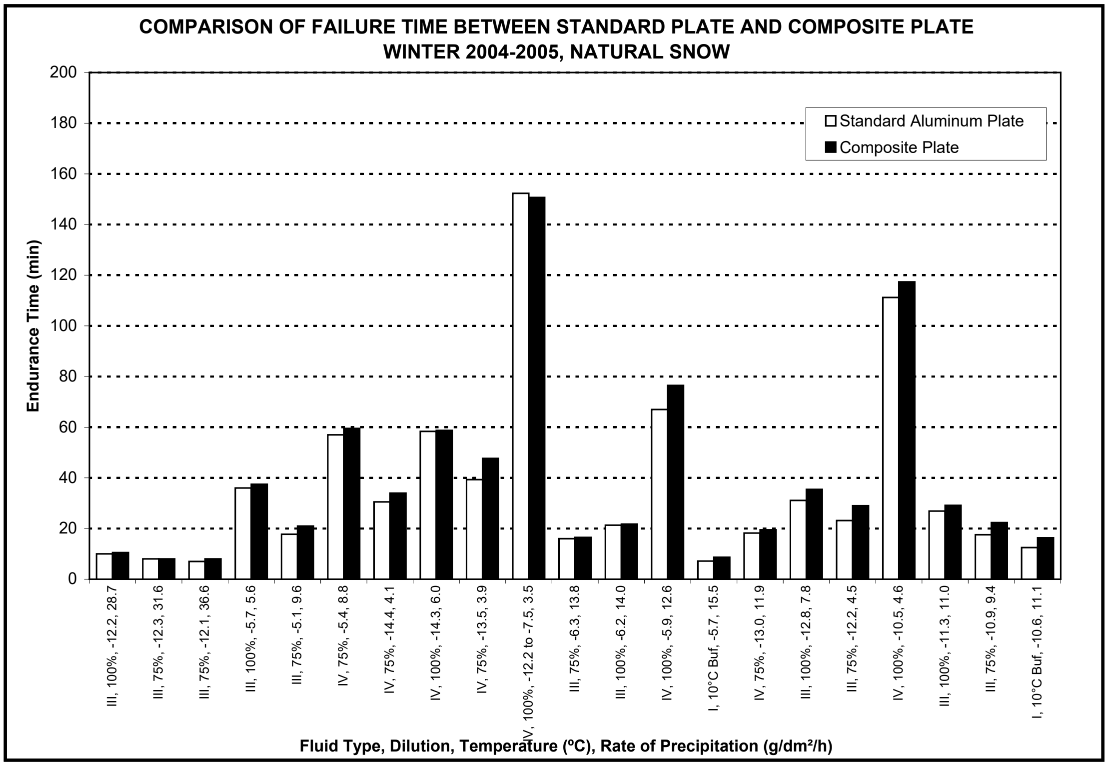

Figure 3.6: Failure Time Comparison – Natural Snow

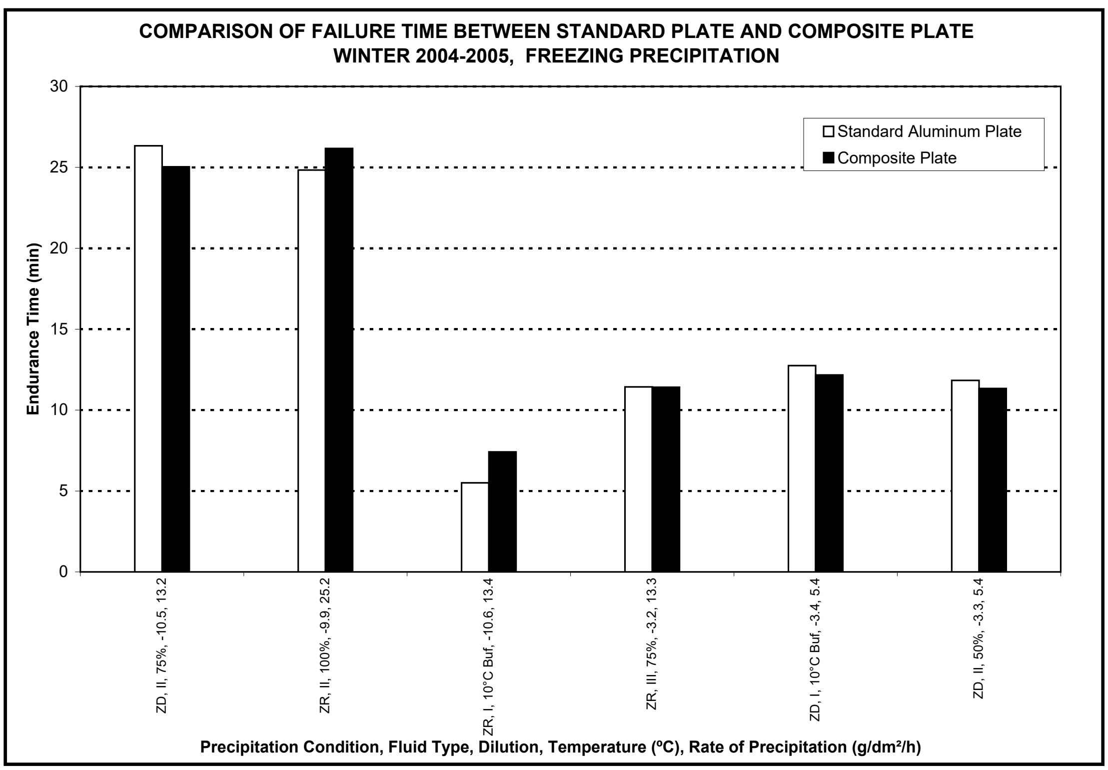

Figure 3.7: Endurance Time Comparison – Freezing Precipitation

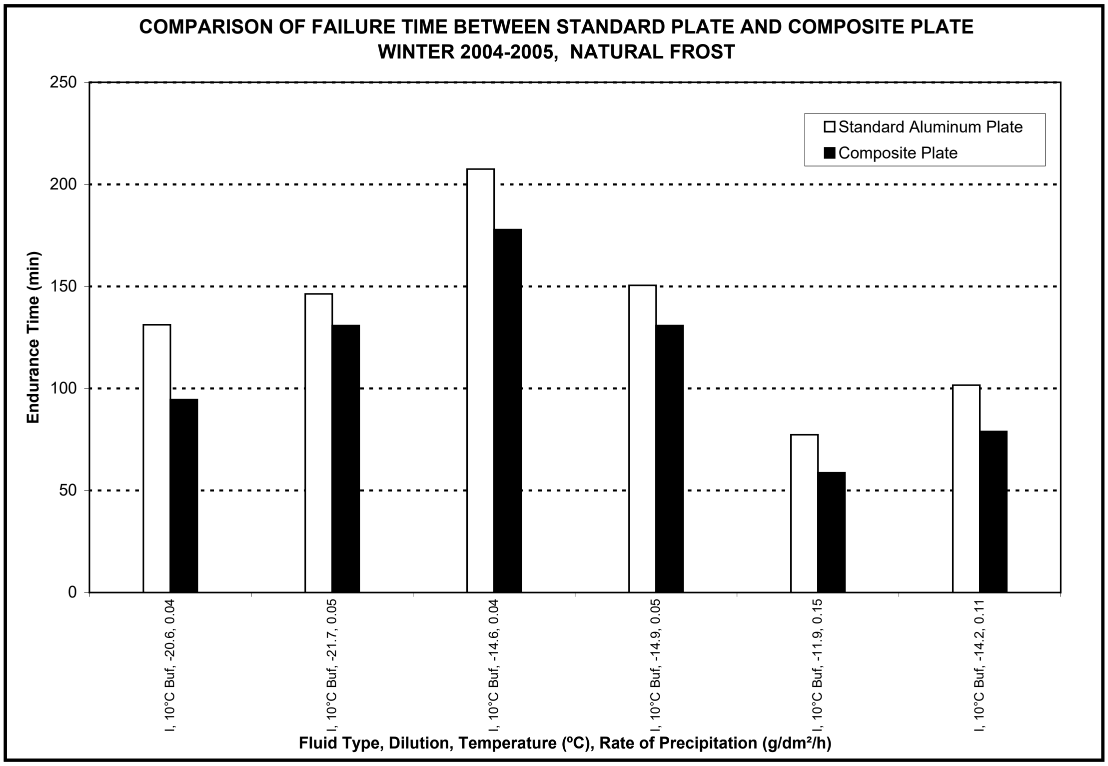

Figure 3.8: Endurance Time Comparison – Natural Frost

3.4.2 Ratio Analysis

A ratio analysis was completed to determine the relationship between fluid endurance times measured on composite test surfaces and those measured on aluminum test surfaces.

Tables 3.8 to 3.10 contain the data used in the analysis. The data has been sorted by precipitation type: natural snow in Table 3.8, freezing precipitation in Table 3.9, and natural frost in Table 3.10.

For each comparative test, the pertinent test numbers are provided, as well as the composite endurance time, aluminum endurance time, and endurance time ratio, which is the composite endurance time divided by the aluminum endurance time.

In snow and freezing precipitation, fluid endurance times measured on the composite plate were generally equal or longer in comparison to the aluminum test plate; this was particularly evident in the natural snow tests. On average, snow endurance times were 11 percent ± 10 percent longer on composite surfaces, and freezing precipitation endurance times were 4 percent ± 15 percent longer on composite surfaces.

Table 3.8: Endurance Time Ratio Analysis – Natural Snow

Test #	Composite Plate Endurance Time (min)	Aluminum Plate Endurance Time (min)	Endurance Time % Ratio (Comp / Alum)
1-2	10.5	10.0	105%
4-5	8.0	8.0	100%
7-8	8.0	7.0	114%
10-11	37.5	36.0	104%
13-14	21.0	17.8	118%
16-17	59.5	57.0	104%
20-21	34.0	30.5	111%
23-24	58.8	58.3	101%
26-27	47.7	39.3	121%
29-30	150.7	152.3	99%
32-33	16.5	16.0	103%
35-36	21.8	21.3	102%
38-39	76.5	67.0	114%
40-41	8.7	7.2	121%
43-44	19.5	18.2	107%
46-47	35.5	31.1	114%
49-50	29.0	23.2	125%
52-53	117.4	111.2	106%
55-56	29.2	26.9	108%
58-59	22.4	17.6	127%
60-61	16.3	12.5	131%
		Average:	111%
		Standard Deviation:	10%

Table 3.9: Endurance Time Ratio Analysis – Freezing Precipitation

Test #	Composite Plate Endurance Time (min)	Aluminum Plate Endurance Time (min)	Endurance Time % Ratio (Comp / Alum)
5-6	25.0	26.3	95%
12-13	26.2	24.8	105%
21-22	7.4	5.5	135%
25-26	11.4	11.4	100%
38-39	12.2	12.8	95%
40-41	11.3	11.8	96%
		Average:	104%
		Standard Deviation:	15%

Table 3.10: Endurance Time Ratio Analysis – Frost

Test #	Composite Plate Endurance Time (min)	Aluminum Plate Endurance Time (min)	Endurance Time % Ratio (Comp / Alum)
C1-C2	94.5	131.2	72%
C3-C4	130.8	146.3	89%
C5-C6	177.8	207.5	86%
C7-C8	130.8	150.5	87%
C9-C10	58.7	77.3	76%
C11-C12	78.9	101.6	78%
		Average:	81%
		Standard Deviation:	7%

In frost, fluid endurance times measured on the composite plate were on average 20 percent shorter than fluid endurance times measured on the aluminum plate. It should be noted that only Type I fluids were tested in frost; Type II, III, and IV fluids were not tested. Therefore, these results apply only to Type I fluids in frost.

It should be noted that the fluid endurance time ratio may exhibit significant variance for fluids with shorter endurance times. For example, tests 21 and 22 in freezing precipitation demonstrated a 35 percent difference in endurance time during a Type I fluid comparative endurance time test. The percentage difference was very high due to the short endurance time; however, the absolute value of the 35 percent difference is only a 2-minute difference in endurance times.

Further discussion on the factors contributing to the longer composite endurance times seen in snow and freezing precipitation and the factors contributing to the shorter composite endurance times seen in frost is provided in Subsections 3.4.3 and 3.4.4.

3.4.3 Factors Contributing to Extended Composite Endurance Times (Seen in Snow and Freezing Precipitation Tests)

The extended fluid endurance time seen on the composite test surface in snow and freezing precipitation was linked to two factors: black body radiation heat transfer and experimental error. Both are discussed below.

3.4.3.1 Black Body Radiation Heat Transfer

The aluminum and composite test plates were left unpainted for testing in freezing precipitation and snow. The bare aluminum material is grey, which is less likely to absorb thermal energy (emitted by the surrounding environment) than the significantly darker bare composite material. The deicing fluid covering the test surface is likely to absorb the thermal energy attracted by the test plates. Due to the difference in colour of the bare materials, the composite test plate will attract a greater amount of thermal energy that will be absorbed by the fluid layer, which in turn will slightly extend the fluid endurance time.

A variance in the measured fluid thickness was also apparent. The fluid thickness was slightly less on the composite test plate than on the aluminum plate following fluid application. The decreased fluid thickness on the composite test plate may be due to the higher fluid temperature caused by the greater amount of absorbed thermal energy from the test surface. The increase in temperature will reduce the fluid viscosity, in turn decreasing fluid thickness.

The temperature profiles do not clearly demonstrate this theory; however, the thermistor probe was applied to the underside of each test plate. If the thermistor probe had been applied to the top of the test plate, within the fluid layer, a more significant variance in temperature may have been apparent.

3.4.3.2 Experimental Error

Fluid failure was not as easily identified on the composite test plate as on the aluminum test plate. This was due mainly to the black and grey “grid” pattern caused by the interwoven fibres of the carbon fibre material. Consequently, the recorded endurance time on the composite test plate may have been slightly extended.

3.4.4 Factors Contributing to Reduced Composite Endurance Times (Seen in Frost Tests with Heated Type I Fluids)

The reduction in fluid endurance time for heated Type I fluids on composite surfaces in frost was examined. The reduced fluid endurance time was linked to a combination of four factors: material conductivity, fluid enrichment, surface temperature stabilization, and fluid dilution.

3.4.4.1 Material Conductivity

Aluminum materials behave as energy conductors, whereas composite materials behave as energy insulators. The aluminum test surface will absorb more energy from the warm fluid application, and attain a greater peak temperature than the composite test surface.

3.4.4.2 Fluid Enrichment

Previous tests conducted by APS have shown that heated Type I fluids will undergo fluid enrichment when applied to a colder surface. The extent of fluid enrichment is a direct function of the difference in temperature between fluid and surface, and, in this case, more significantly, the increase in temperature of the treated surface. During Type I fluid endurance tests, the surface temperature of the aluminum test plate was observed to rise higher than that of the composite plate. The higher temperature differential on the aluminum test plate will cause a greater amount of enrichment in the applied fluid which will consequently be higher in glycol concentration than fluid on the composite plate.

3.4.4.3 Surface Temperature Stabilization

Prior to fluid application, the exposed test surface temperature in frost conditions will be several degrees below the outside ambient temperature. The heated Type I fluid application will result in a rise in the test plate surface temperature. Following fluid application, the aluminum plate will attain a higher peak temperature in comparison to the composite plate. When cooling begins, the composite plate will stabilize to a temperature below the outside air temperature (OAT) earlier than the aluminum test plate. As a result, frost accretion and consequently fluid dilution will begin earlier on the composite test plate.

During the tests, it was noted that the aluminum test plate would reach a stable temperature slightly lower than that on the composite test plate. This finding was counter-intuitive based on the analysis results, which showed an extended fluid endurance time on the aluminum test plate in comparison to the composite test plate; reduced surface temperature should result in a reduced fluid endurance time.

3.4.4.4 Fluid Dilution

Fluid dilution occurs as frost begins to accrete on the fluid-covered test surface. Following Type I fluid application, the glycol concentration on the aluminum surface is greater than that on the composite surface due to enrichment. As a result, the fluid on the aluminum surface will be able to absorb a greater amount of water from the frost accretion before diluting to the fluid freezing point and being subject to fluid failure. The composite test plate surface temperature will stabilize earlier in comparison to the aluminum test plate and, as a result, the composite test plate will begin to undergo frost accretion and consequently fluid dilution earlier than the aluminum test plate.

3.5 Conclusions and Recommendations

The flat plate tests conducted in the winter of 2004-05 showed fluid endurance times are similar or longer on composite surfaces in snow and freezing precipitation and shorter with heated Type I fluids in frost. However, these results were considered preliminary, as only one composite material was tested and because questions arose about the validity of the test surface configurations used in testing.

A combination of black body radiation heat transfer and experimental error was thought to have caused the slight extension in fluid endurance times measured in snow and freezing precipitation. Four factors (material conductivity, fluid enrichment, surface temperature stabilization, and fluid dilution) were concluded to be responsible for the reduction in Type I fluid endurance times in frost.

Two recommendations came out of the 2004-05 testing. The first was that further work should be completed to make changes to the procedure:

- It was recommended that different composite materials used in aircraft construction be explored to substantiate any varying effects on fluid endurance time;
- It was recommended that the structural design and use of composite materials in operational aircraft be investigated to determine representative configurations appropriate for measuring endurance times on composite test surfaces; and
- It was recommended that comparative endurance time testing in snow and freezing precipitation conditions be conducted using painted aluminum and composite test surfaces to equalize black body radiation heat transfer and eliminate experimental error caused by conducting visual inspections on different surface finishes.

The second recommendation that came out of the 2004-05 testing was to collect additional data with Type I fluids in frost to confirm the reduced endurance times observed on composite surfaces.

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Photo 3.1: 2004-05 Test Setup

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4. 2005-06 RESEARCH

This section provides a review of the composite surface research conducted in the winter of 2005-06. This research was previously published in the Transport Canada report, TP 14720E, *Effect of Heat on Fluid Endurance Times Using Composite Surfaces* (2).

4.1 Objective

The objective of the composite surface project in the winter of 2005-06 was to measure endurance times of Type I, II, III, and IV fluids on four white-painted composite surfaces and compare them to endurance times on a white-painted aluminum surface. Tests were carried out with heated and unheated fluids in natural snow, simulated freezing precipitation, and natural frost conditions.

4.2 Methodology

The methodology used for conducting composite surface testing is described in Section 2 Additional details specific to the testing conducted in 2005-06 are provided in this section.

4.2.1 Test Surfaces

Six test surfaces were used in 2005-06, including four painted composite surfaces, an unpainted aluminum surface, and a painted aluminum surface.

The selection of the four composite materials was based on availability and usage in current aircraft construction. All four composite materials were primed and painted white with aircraft grade paint to provide equal surface roughness and finish and to reduce the variability in radiation effects associated with the different bare material colours.

Two aluminum surfaces were tested: a standard (unpainted) aluminum surface and a standard aluminum surface painted white, as described above.

Table 4.1 details the six test surfaces tested. Photos are provided at the end of this section of an unpainted aluminum flat plate (Photo 4.1), an unpainted carbon fibre cross weave fabric flat plate (Photo 4.2), an unpainted carbon fibre unidirectional tape flat plate (Photo 4.3), and an unpainted glass-reinforced fibre metal laminate flat plate (Photo 4.4).

The test surfaces were tested in different configurations in different precipitation conditions, as detailed in Table 4.2. The test surface configurations are described in Subsection 2.5.3.

Table 4.1: Test Surface Materials Used in 2005-06 Testing

Test Surface*	Material / Structure	Finish	Thickness
Standard Aluminum (Aluminum)	Alcad 2024 T3	Unpainted	0.32 cm
White-Painted Aluminum (White Aluminum)	Alcad 2024 T3	Painted	0.32 cm
Carbon Fibre Cross Weave Fabric (Comp 05)	Carbon Fibre / Cross Weave	Painted	0.32 cm
Carbon Fibre Unidirectional Tape Thin (Comp 06 Thin)	Carbon Fibre / Unidirectional Tape	Painted	0.35 cm
Carbon Fibre Unidirectional Tape Thick (Comp 06 Thick)	Carbon Fibre / Unidirectional Tape	Painted	0.57 cm
Glass-Reinforced Fibre Metal Laminate (GLARE)	Alternating Layers of 2024 T3 Aluminum and Glass Reinforced Fibre /	Painted	0.38 cm

*The abbreviated name (shown in parentheses) is used elsewhere in this report.

Table 4.2: Test Surface Configurations Used in 2005-06 Testing

Test Surface Material	Frost	Freezing Precipitation	Snow (Type II/III/IV)	Snow (Type I)
Unpainted Aluminum	Frosticator Plate	Flat Plate	Flat Plate	LETE Box
White-Painted Aluminum	Frosticator Plate	Flat Plate	Flat Plate	Flat Plate
Composite (Comp 05, Comp 06 Thin, Comp 06 Thick, GLARE)	Frosticator Plate	Flat Plate	Flat Plate	Flat Plate

4.2.2 Test Procedures

Fluid endurance times were evaluated on four composite surfaces in snow, frost, and freezing precipitation with Type I, II, III, and IV fluids. Detailed test procedures were written to describe how testing should be carried out. These procedures are included as appendices to this report, as follows:

- Appendix C: *Experimental Program: Outdoor Endurance Time Testing on Non-Aluminum Plates* (used for outdoor testing in natural snow and natural frost); and
- Appendix D: *Experimental Program: Indoor Endurance Time Testing on Non-Aluminum Plates* (used for indoor simulated freezing precipitation testing in freezing drizzle and light freezing rain).

Standard endurance time testing protocols were generally followed. Additional information on the test setup in snow, frost, and freezing precipitation is provided below.

4.2.2.1 Natural Snow Test Procedures

In natural snow, tests were conducted simultaneously on the six test surfaces described in Subsection 4.2.1. Tests were conducted with heated Type I fluids, heated Type II/III/IV fluids and unheated (i.e., OAT) Type II/III/IV fluids.

Figures 4.1, 4.2, and 4.3 show the test setup, including test surfaces, fluid quantities, fluid temperatures, and application methods used in testing with Type II/III/IV fluids at OAT, Type II/III/IV fluids at 60°C, and Type I fluids at 60°C, respectively. The natural snow setup for Type II/III/IV fluids is also shown in Photo 4.5.

Position 1	Position 2	Position 3	Position 4	Position 5	Position 6
Aluminum	White Alum.	Comp 05	Comp 06 Thin	Comp 06 Thick	GLARE
Flat Plate	Flat Plate	Flat Plate	Flat Plate	Flat Plate	Flat Plate
1 L of Fluid	1 L of Fluid	1 L of Fluid	1 L of Fluid	1 L of Fluid	1 L of Fluid
Apply at OAT	Apply at OAT	Apply at OAT	Apply at OAT	Apply at OAT	Apply at OAT
Hand Pour	Hand Pour	Hand Pour	Hand Pour	Hand Pour	Hand Pour

Figure 4.1: Test Setup (Snow) – Type II/III/IV Fluids at OAT

Position 1	Position 2	Position 3	Position 4	Position 5	Position 6
Aluminum Flat Plate 1 L of Fluid Apply at OAT Hand Pour	White Alum. Flat Plate 0.5 L of Fluid Apply at 60ºC Spreader	Comp 05 Flat Plate 0.5 L of Fluid Apply at 60ºC Spreader	Comp 06 Thin Flat Plate 0.5 L of Fluid Apply at 60ºC Spreader	Comp 06 Thick Flat Plate 0.5 L of Fluid Apply at 60ºC Spreader	GLARE Flat Plate 0.5 L of Fluid Apply at 60ºC Spreader

Figure 4.2: Test Setup (Snow) – Type II/III/IV Fluids at 60°C

Position 1	Position 2	Position 3	Position 4	Position 5	Position 6
Aluminum LETE Box 0.5 L of Fluid Apply at OAT Spreader	White Alum. Flat Plate 0.5 L of Fluid Apply at 60ºC Spreader	Comp 05 Flat Plate 0.5 L of Fluid Apply at 60ºC Spreader	Comp 06 Thin Flat Plate 0.5 L of Fluid Apply at 60ºC Spreader	Comp 06 Thick Flat Plate 0.5 L of Fluid Apply at 60ºC Spreader	GLARE Flat Plate 0.5 L of Fluid Apply at 60ºC Spreader

Figure 4.3: Test Setup (Snow) – Type I Fluids at 60°C

4.2.2.2 Freezing Precipitation Test Procedures

Testing in simulated freezing precipitation conditions (freezing drizzle and light freezing rain) was conducted in conjunction with holdover time testing. Testing with all fluid types was conducted with fluid heated to 60°C. Some testing was also conducted with Type I fluids at 20°C.

Testing was conducted on three test surfaces: a standard aluminum flat plate, a white-painted aluminum flat plate, and a representative white-painted composite surface. Comp 05 was used as the representative composite surface. Standard holdover time tests on an aluminum flat plate were used as the baseline tests.

Figure 4.4 and Figure 4.5 show the test setup for freezing precipitation tests, including test surfaces, fluid quantities, fluid temperatures, and application methods used in testing with Type II/III/IV fluids at 60°C and Type I fluids at 20°C or 60°C, respectively. The freezing precipitation setup is also shown in Photo 4.6.

Position HOT	Position 1	Position 2
Aluminum	White Alum.	Comp 05
Flat Plate	Flat Plate	Flat Plate
1 L of Fluid	1 L of Fluid	1 L of Fluid
Apply at OAT	Apply at 60ºC	Apply at 60ºC
Hand Pour	Spreader	Spreader

Figure 4.4: Test Setup (Freezing Precipitation) – Type II/III/IV Fluids at 60°C

Position HOT	Position 1	Position 2
Aluminum	White Alum.	Comp 05
Flat Plate	Flat Plate	Flat Plate
1 L of Fluid	1 L of Fluid	1 L of Fluid
Apply at 20ºC	Apply at 20/60ºC	Apply at 20/60ºC
Spreader	Spreader	Spreader

Figure 4.5: Test Setup (Freezing Precipitation) – Type I Fluids at 20°C or 60°C

4.2.2.3 Natural Frost Test Procedures

Testing in natural frost conditions was conducted in conjunction with frost holdover time testing. Testing was conducted on frosticator plates, as described in Subsection 2.5.3.3. Testing was conducted with Type I fluids only; fluids were tested at 60°C.

Tests were conducted simultaneously on five of the six test surfaces described in Subsection 4.2.1; the sixth surface, the unpainted aluminum surface, was not tested in frost. Figure 4.6 shows the test setup for frost tests, including test surfaces, fluid quantities, fluid temperatures, and application methods used.

Position 1	Position 2	Position 3	Position 4	Position 5
White Alum.	Comp 05	Comp 06 Thin	Comp 06 Thick	GLARE
Frosticator Plate	Frosticator Plate	Frosticator Plate	Frosticator Plate	Frosticator Plate
0.5 L of Fluid	0.5 L of Fluid	0.5 L of Fluid	0.5 L of Fluid	0.5 L of Fluid
Apply at 60°C	Apply at 60°C	Apply at 60°C	Apply at 60°C	Apply at 60°C
Spreader	Spreader	Spreader	Spreader	Spreader

Figure 4.6: Test Setup (Frost) – Type I Fluids

4.2.3 Fluids

In 2005-06, Type I, II, III, and IV fluids were tested. Type II/III/IV fluids were tested in 100/0, 75/25, and 50/50 dilutions. Type I fluid was tested at a 10°C buffer; fluid was mixed to a freezing point 10°C below the prevailing OAT for each test. Table 4.3 lists the fluids tested.

Table 4.3: Fluids Used in 2005-06 Testing

Fluid Type	Fluid Name	Batch #	Viscosity (mPa.s)
I	UCAR ADF EG	Aeromag	n/a
I	Battelle D3 ADF	51381	n/a
II	Kilfrost ABC-2000	P1795	1,900[a]
II	Kilfrost P1792	1792-1	3,040[a]
II	Kilfrost P1792-2	1792-2	3,550[a]
III	Clariant Safewing MP III 2031 ECO	TV420	24[b]
IV	Clariant Launch 2	TV428	3,340[c]
IV	Octagon MaxFlo	041206-023	8,670[c]

[a] Brookfield Spindle LV2-disc with guard leg, 150 mL of fluid, at 20°C, 0.3 rpm, 10 mins
[b] Brookfield Spindle LV0, UL Adapter, 16 mL of fluid, at 20°C, 0.3 rpm, 10 mins
[c] Brookfield Spindle LV1 with guard leg, 500 mL of fluid, at 20°C, 0.3 rpm, 10 mins

4.3 Data

The data collected from the tests conducted in the winter of 2005-06 is presented in the following subsections.

4.3.1 Logs of Tests

Logs of the tests conducted in snow, frost, and freezing precipitation were created to document the test results. A separate log was created for each of the three precipitation types, as follows:

- Table 4.4: Natural Snow;
- Table 4.5: Simulated Freezing Precipitation; and
- Table 4.6: Natural Frost.

The logs provide detailed information for each test conducted. Each row contains data specific to one test. Below is a brief description of the column headings included in the logs.

Test #:	Exclusive number identifying each test.
Date:	Date when the test was conducted.
Run #:	Run number in which the test was performed.
Fluid Name:	Fluid manufacturer and fluid brand name.
Fluid Dil.:	Fluid dilution (10°B = fluid mixed to a freezing point 10°C below the ambient temperature).
Fluid Type:	SAE designated fluid type (I, II, III, or IV).
Fluid Temp.:	Fluid temperature prior to application, measured in °C.
Test Surface:	Test surface (see Subsection 4.2.1).
Precip. Type:	Dominant precipitation type during each test.
Start Time:	Start time for the test, recorded in local time.
Fail Time:	Fluid failure time, recorded in local time.
Endurance Time:	Fluid endurance time, measured in minutes.

Precip. Rate:	Precipitation rate, measured in g/dm²/h. In snow and frost: collected by two precipitation pans at set intervals for the duration of the test run. In freezing precipitation: desired average precipitation rate.
Ambient Temp.:	Ambient temperature, measured in °C. In snow and frost: the average of hourly OAT readings for the duration of the test, provided by Environment Canada. In freezing precipitation: desired ambient temperature in the climatic chamber.
Wind Speed:	The average of hourly wind speed readings for the duration of the test, measured in km/h, provided by Environment Canada (snow and frost only).
ET Ratio:	Endurance time of the test as a percentage of the white aluminum endurance time.
RH:	The average of hourly relative humidity readings for the duration of the test, measured in percentage, provided by Environment Canada (frost only).
Plate Temp.:	The average of the plate surface temperature prior to fluid application and following fluid failure, measured in °C (frost only).
ΔT (Delta T):	Difference between the ambient temperature and the plate temperature (frost only).
Initial Brix:	Fluid Brix, measured in degrees, prior to fluid application (frost only).
Final Brix:	Fluid Brix, measured in degrees, at fluid failure (frost only).

Table 4.4: Log of Tests (2005-06) – Natural Snow

Test #	Date	Run #	Fluid Name	Fluid Dil.	Fluid Type	Fluid Temp. (°C)	Test Surface	Precip. Type	Start Time	Fail Time	Endur. Time (min)	Precip. Rate (g/dm²/h)	Ambient Temp. (°C)	Wind Speed (km/h)	ET Ratio (relative to white alum.)
1	Feb-16-06	1	UCAR ADF EG	10°B	I	60	Alum. Box	Snow	10:01:28	10:09:00	7.5	12.9	-8.1	30	-
2	Feb-16-06	1	UCAR ADF EG	10°B	I	60	White Alum.	Snow	10:02:10	10:06:00	3.8	11.2	-8.1	30	100%
3	Feb-16-06	1	UCAR ADF EG	10°B	I	60	Comp 05	Snow	10:02:48	10:05:00	2.2	11.2	-8.1	30	57%
4	Feb-16-06	1	UCAR ADF EG	10°B	I	60	Comp 06 Thin	Snow	10:03:15	10:05:00	1.7	11.2	-8.1	30	46%
5	Feb-16-06	1	UCAR ADF EG	10°B	I	60	Comp 06 Thick	Snow	10:03:40	10:05:00	1.3	11.2	-8.1	30	35%
6	Feb-16-06	1	UCAR ADF EG	10°B	I	60	GLARE	Snow	10:04:10	10:05:00	0.8	11.2	-8.1	30	22%
7	Feb-16-06	2	Octagon MaxFlo	75%	IV	OAT	Alum. Box	Snow	10:29:45	10:48:00	18.3	27.5	-8.1	30	-
8	Feb-16-06	2	Octagon MaxFlo	75%	IV	OAT	White Alum.	Snow	10:30:06	10:47:00	16.9	27.5	-8.1	30	100%
9	Feb-16-06	2	Octagon MaxFlo	75%	IV	OAT	Comp 05	Snow	10:30:15	10:46:00	15.8	27.5	-8.1	30	93%
10	Feb-16-06	2	Octagon MaxFlo	75%	IV	OAT	Comp 06 Thin	Snow	10:30:37	10:46:00	15.4	27.6	-8.1	30	91%
11	Feb-16-06	2	Octagon MaxFlo	75%	IV	OAT	Comp 06 Thick	Snow	10:30:20	10:46:00	15.7	27.5	-8.1	30	93%
12	Feb-16-06	2	Octagon MaxFlo	75%	IV	OAT	GLARE	Snow	10:30:06	10:47:00	16.9	27.5	-8.1	30	100%
13	Feb-16-06	3	Octagon MaxFlo	100%	IV	OAT	Alum. Box	Snow	11:19:05	11:46:00	26.9	29.6	-9.2	30	-
14	Feb-16-06	3	Octagon MaxFlo	100%	IV	OAT	White Alum.	Snow	11:19:20	11:53:00	33.7	28.4	-9.2	30	100%
15	Feb-16-06	3	Octagon MaxFlo	100%	IV	OAT	Comp 05	Snow	11:19:45	11:50:00	30.3	28.9	-9.2	30	90%
16	Feb-16-06	3	Octagon MaxFlo	100%	IV	OAT	Comp 06 Thin	Snow	11:19:55	11:52:00	32.1	28.5	-9.2	30	95%
17	Feb-16-06	3	Octagon MaxFlo	100%	IV	OAT	Comp 06 Thick	Snow	11:19:45	11:46:00	26.3	29.5	-9.2	30	78%
18	Feb-16-06	3	Octagon MaxFlo	100%	IV	OAT	GLARE	Snow	11:19:20	11:46:00	26.7	29.5	-9.2	30	79%
19	Feb-16-06	4	Octagon MaxFlo	75%	IV	OAT	Alum. Plate	Snow	12:27:35	12:47:30	19.9	21.0	-9.4	32	-
20	Feb-16-06	4	Octagon MaxFlo	75%	IV	OAT	White Alum.	Snow	12:27:50	12:47:00	19.2	21.4	-9.4	32	100%
21	Feb-16-06	4	Octagon MaxFlo	75%	IV	OAT	Comp 05	Snow	12:28:15	12:45:00	16.8	22.9	-9.4	32	87%
22	Feb-16-06	4	Octagon MaxFlo	75%	IV	OAT	Comp 06 Thin	Snow	12:28:30	12:46:00	17.5	22.1	-9.4	32	91%
23	Feb-16-06	4	Octagon MaxFlo	75%	IV	OAT	Comp 06 Thick	Snow	12:28:30	12:45:00	16.5	22.8	-9.4	32	86%
24	Feb-16-06	4	Octagon MaxFlo	75%	IV	OAT	GLARE	Snow	12:28:15	12:47:30	19.3	20.6	-9.4	32	100%
25	Feb-16-06	5	Octagon MaxFlo	100%	IV	OAT	Alum. Plate	Snow	13:19:30	14:14:00	54.5	15.0	-8.9	25	-
26	Feb-16-06	5	Octagon MaxFlo	100%	IV	OAT	White Alum.	Snow	13:19:45	14:10:00	50.3	15.1	-8.9	25	100%
27	Feb-16-06	5	Octagon MaxFlo	100%	IV	OAT	Comp 05	Snow	13:20:00	14:12:00	52.0	15.0	-8.9	25	103%
28	Feb-16-06	5	Octagon MaxFlo	100%	IV	OAT	Comp 06 Thin	Snow	13:20:00	14:10:00	50.0	15.1	-8.9	25	100%
29	Feb-16-06	5	Octagon MaxFlo	100%	IV	OAT	Comp 06 Thick	Snow	13:19:45	14:12:00	52.3	15.0	-8.9	25	104%
30	Feb-16-06	5	Octagon MaxFlo	100%	IV	OAT	GLARE	Snow	13:19:30	14:10:00	50.5	15.1	-8.9	25	100%

Table 4.4: Log of Tests (2005-06) – Natural Snow (cont'd)

Test #	Date	Run #	Fluid Name	Fluid Dil.	Fluid Type	Fluid Temp. (°C)	Test Surface	Precip. Type	Start Time	Fail Time	Endur. Time (min)	Precip. Rate (g/dm²/h)	Ambient Temp. (°C)	Wind Speed (km/h)	ET Ratio (relative to white alum.)
31	Feb-16-06	6	UCAR ADF EG	10°B	I	60	Alum. Box	Snow	14:29:45	14:35:45	6.0	11.8	-8.8	28	-
32	Feb-16-06	6	UCAR ADF EG	10°B	I	60	White Alum.	Snow	14:29:51	14:35:30	5.7	11.8	-8.8	28	100%
33	Feb-16-06	6	UCAR ADF EG	10°B	I	60	Comp 05	Snow	14:30:15	14:34:30	4.3	11.8	-8.8	28	75%
34	Feb-16-06	6	UCAR ADF EG	10°B	I	60	Comp 06 Thin	Snow	14:30:31	14:34:35	4.1	11.8	-8.8	28	72%
35	Feb-16-06	6	UCAR ADF EG	10°B	I	60	Comp 06 Thick	Snow	14:30:45	14:35:05	4.3	11.8	-8.8	28	77%
36	Feb-16-06	6	UCAR ADF EG	10°B	I	60	GLARE	Snow	14:31:05	14:35:40	4.6	11.8	-8.8	28	81%
37	Feb-21-06	7	Octagon MaxFlo	50%	IV	OAT	Alum. Plate	Snow	11:19:10	11:43:00	23.8	4.8	-3.7	22	-
38	Feb-21-06	7	Octagon MaxFlo	50%	IV	60	White Alum.	Snow	11:19:40	12:17:00	57.3	2.8	-3.7	22	100%
39	Feb-21-06	7	Octagon MaxFlo	50%	IV	60	Comp 05	Snow	11:20:00	12:29:00	69.0	2.5	-3.7	22	120%
40	Feb-21-06	7	Octagon MaxFlo	50%	IV	60	Comp 06 Thin	Snow	11:20:15	12:28:00	67.8	2.5	-3.7	22	118%
41	Feb-21-06	7	Octagon MaxFlo	50%	IV	60	Comp 06 Thick	Snow	11:20:30	12:31:00	70.5	2.4	-3.7	22	123%
42	Feb-21-06	7	Octagon MaxFlo	50%	IV	60	GLARE	Snow	11:20:45	12:30:00	69.3	2.4	-3.7	22	121%
49	Feb-22-06	8	Octagon MaxFlo	100%	IV	OAT	Alum. Plate	Snow	22:41:05	0:45:00	123.9	6.3	-1.5	8	-
50	Feb-22-06	8	Octagon MaxFlo	100%	IV	60	White Alum.	Snow	22:41:40	0:22:00	100.3	5.5	-1.5	8	100%
51	Feb-22-06	8	Octagon MaxFlo	100%	IV	60	Comp 05	Snow	22:42:12	0:12:30	90.3	5.2	-1.5	8	90%
52	Feb-22-06	8	Octagon MaxFlo	100%	IV	60	Comp 06 Thin	Snow	22:42:48	0:16:00	93.2	5.3	-1.5	8	93%
53	Feb-22-06	8	Octagon MaxFlo	100%	IV	60	Comp 06 Thick	Snow	22:43:31	0:15:20	91.8	5.2	-1.5	8	92%
54	Feb-22-06	8	Octagon MaxFlo	100%	IV	60	GLARE	Snow	22:44:15	0:22:00	97.7	5.5	-1.5	8	97%
56	Feb-23-06	9	Clariant MP III 2031	100%	III	60	White Alum.	Snow	1:28:06	2:31:00	62.9	0.9	-2.2	4	100%
57	Feb-23-06	9	Clariant MP III 2031	100%	III	60	Comp 05	Snow	1:28:36	2:29:00	60.4	0.9	-2.2	4	96%
58	Feb-23-06	9	Clariant MP III 2031	100%	III	60	Comp 06 Thin	Snow	1:29:08	2:28:00	58.9	0.9	-2.2	4	94%
59	Feb-23-06	9	Clariant MP III 2031	100%	III	60	Comp 06 Thick	Snow	1:29:33	2:26:00	56.5	0.9	-2.2	4	90%
60	Feb-23-06	9	Clariant MP III 2031	100%	III	60	GLARE	Snow	1:30:00	2:28:00	58.0	0.9	-2.2	4	92%
67	Feb-23-06	10	UCAR ADF EG	10°B	I	60	Alum. Box	Snow	23:44:17	23:54:20	10.1	19.2	-1.1	14	-
68	Feb-23-06	10	UCAR ADF EG	10°B	I	60	White Alum.	Snow	23:44:41	23:52:50	8.2	17.9	-1.1	14	100%
69	Feb-23-06	10	UCAR ADF EG	10°B	I	60	Comp 05	Snow	23:45:06	23:49:35	4.5	14.1	-1.1	14	55%
70	Feb-23-06	10	UCAR ADF EG	10°B	I	60	Comp 06 Thin	Snow	23:45:34	23:50:15	4.7	14.1	-1.1	14	57%
71	Feb-23-06	10	UCAR ADF EG	10°B	I	60	Comp 06 Thick	Snow	23:46:09	23:52:15	6.1	18.0	-1.1	14	75%
72	Feb-23-06	10	UCAR ADF EG	10°B	I	60	GLARE	Snow	23:46:39	23:53:10	6.5	19.6	-1.1	14	80%
79	Feb-25-06	11	Octagon MaxFlo	100%	IV	OAT	Alum. Plate	Snow	14:11:15	15:34:00	82.8	7.1	-13.7	37	-
80	Feb-25-06	11	Octagon MaxFlo	100%	IV	60	White Alum.	Snow	14:11:43	15:56:30	104.8	7.9	-13.7	37	100%

Table 4.4: Log of Tests (2005-06) – Natural Snow (cont'd)

Test #	Date	Run #	Fluid Name	Fluid Dil.	Fluid Type	Fluid Temp. (°C)	Test Surface	Precip. Type	Start Time	Fail Time	Endur. Time (min)	Precip. Rate (g/dm²/h)	Ambient Temp. (°C)	Wind Speed (km/h)	ET Ratio (relative to white alum.)
81	Feb-25-06	11	Octagon MaxFlo	100%	IV	60	Comp 05	Snow	14:12:05	15:51:00	98.9	7.7	-13.7	37	94%
82	Feb-25-06	11	Octagon MaxFlo	100%	IV	60	Comp 06 Thin	Snow	14:12:27	15:48:00	95.6	7.6	-13.7	37	91%
83	Feb-25-06	11	Octagon MaxFlo	100%	IV	60	Comp 06 Thick	Snow	14:12:53	15:57:00	104.1	7.9	-13.7	37	99%
84	Feb-25-06	11	Octagon MaxFlo	100%	IV	60	GLARE	Snow	14:13:15	15:56:30	103.3	7.9	-13.7	37	99%
85	Feb-25-06	12	Kilfrost ABC 2000	100%	II	OAT	Alum. Plate	Snow	16:16:28	16:45:00	28.5	6.9	-13.6	39	-
86	Feb-25-06	12	Kilfrost ABC 2000	100%	II	60	White Alum.	Snow	16:16:48	16:57:00	40.2	6.4	-13.6	39	100%
87	Feb-25-06	12	Kilfrost ABC 2000	100%	II	60	Comp 05	Snow	16:17:10	16:57:00	39.8	6.3	-13.6	39	99%
88	Feb-25-06	12	Kilfrost ABC 2000	100%	II	60	Comp 06 Thin	Snow	16:17:35	16:57:00	39.4	6.3	-13.6	39	98%
89	Feb-25-06	12	Kilfrost ABC 2000	100%	II	60	Comp 06 Thick	Snow	16:17:50	16:58:00	40.2	6.2	-13.6	39	100%
90	Feb-25-06	12	Kilfrost ABC 2000	100%	II	60	GLARE	Snow	16:18:15	16:59:00	40.8	6.2	-13.6	39	101%
91	Feb-25-06	13	Dow UCAR ADF	10°B	I	60	Alum. Box	Snow	17:53:45	18:15:00	21.3	2.4	-12.5	32	-
92	Feb-25-06	13	Dow UCAR ADF	10°B	I	60	White Alum.	Snow	17:54:20	18:07:00	12.7	2.7	-12.5	32	100%
93	Feb-25-06	13	Dow UCAR ADF	10°B	I	60	Comp 05	Snow	17:54:45	18:07:00	12.2	2.7	-12.5	32	97%
94	Feb-25-06	13	Dow UCAR ADF	10°B	I	60	Comp 06 Thin	Snow	17:55:15	18:07:00	11.7	2.6	-12.5	32	93%
95	Feb-25-06	13	Dow UCAR ADF	10°B	I	60	Comp 06 Thick	Snow	17:55:40	18:07:00	11.3	2.6	-12.5	32	89%
96	Feb-25-06	13	Dow UCAR ADF	10°B	I	60	GLARE	Snow	17:56:08	18:07:00	10.9	2.5	-12.5	32	86%
97	Mar-3-06	14	Octagon MaxFlo	75%	IV	OAT	Alum. Plate	Snow	13:19:25	15:34:00	134.6	3.7	-9.2	35	-
98	Mar-3-06	14	Octagon MaxFlo	75%	IV	60	White Alum.	Snow	13:19:45	15:41:00	141.3	4.1	-9.2	35	100%
99	Mar-3-06	14	Octagon MaxFlo	75%	IV	60	Comp 05	Snow	13:20:05	15:38:00	137.9	4.0	-9.2	35	98%
100	Mar-3-06	14	Octagon MaxFlo	75%	IV	60	Comp 06 Thin	Snow	13:20:25	15:36:00	135.6	3.8	-9.2	35	96%
101	Mar-3-06	14	Octagon MaxFlo	75%	IV	60	Comp 06 Thick	Snow	13:20:45	15:35:00	134.3	3.7	-9.2	35	95%
102	Mar-3-06	14	Octagon MaxFlo	75%	IV	60	GLARE	Snow	13:21:05	15:36:45	135.7	3.8	-9.2	35	96%
103	Mar-3-06	15	Dow UCAR ADF	10°B	I	60	Alum. Box	Snow	15:46:30	15:55:15	8.7	7.1	-8.3	30	-
104	Mar-3-06	15	Dow UCAR ADF	10°B	I	60	White Alum.	Snow	15:46:50	15:55:00	8.2	7.0	-8.3	30	100%
105	Mar-3-06	15	Dow UCAR ADF	10°B	I	60	Comp 05	Snow	15:47:12	15:53:00	5.8	7.0	-8.3	30	71%
106	Mar-3-06	15	Dow UCAR ADF	10°B	I	60	Comp 06 Thin	Snow	15:47:30	15:53:15	5.8	7.0	-8.3	30	70%
107	Mar-3-06	15	Dow UCAR ADF	10°B	I	60	Comp 06 Thick	Snow	15:47:50	15:53:40	5.8	7.0	-8.3	30	71%
108	Mar-3-06	15	Dow UCAR ADF	10°B	I	60	GLARE	Snow	15:48:10	15:54:45	6.6	7.0	-8.3	30	81%

Table 4.5: Log of Tests (2005-06) – Simulated Freezing Precipitation

Test #	Date	Run #	Fluid Name	Fluid Dil.	Fluid Type	Fluid Temp. (°C)	Test Surface	Precip. Type	Ambient Temp. (°C)	Start Time	Fail Time	Endur. Time (min)	Precip. Rate (g/dm²/h)	ET Ratio (relative to white alum.)
1	Apr-5-06	1	Kilfrost P1792	75%	II	60	White Alum.	Freezing Drizzle	-10	9:42:50	10:30:00	47.2	5	100%
2	Apr-5-06	1	Kilfrost P1792	75%	II	60	Comp 05	Freezing Drizzle	-10	9:42:30	10:31:00	48.5	5	103%
3	Apr-5-06	1	Kilfrost P1792	75%	II	OAT	Std Alum.	Freezing Drizzle	-10	12:52:00	13:11:20	19.3	5	-
4	Apr-5-06	1	Kilfrost P1792	75%	II	OAT	Std Alum.	Freezing Drizzle	-10	12:52:30	13:14:45	22.3	5	-
5	Apr-5-06	2	Battelle D3 ADF	10°B	I	60	White Alum.	Freezing Drizzle	-10	11:01:30	11:16:30	15.0	5	100%
6	Apr-5-06	2	Battelle D3 ADF	10°B	I	60	Comp 05	Freezing Drizzle	-10	11:02:15	11:14:10	11.9	5	79%
7	Apr-5-06	2	Battelle D3 ADF	10°B	I	20	Std Alum.	Freezing Drizzle	-10	12:53:20	13:00:50	7.5	5	-
8	Apr-5-06	2	Battelle D3 ADF	10°B	I	20	Std Alum.	Freezing Drizzle	-10	12:54:00	13:01:40	7.7	5	-
9	Apr-5-06	3	Clariant Launch 2	100%	IV	60	White Alum.	Light Freezing Rain	-10	15:23:15	15:58:30	35.3	25	100%
10	Apr-5-06	3	Clariant Launch 2	100%	IV	60	Comp 05	Light Freezing Rain	-10	15:23:45	16:03:30	39.8	25	113%
11	Apr-5-06	3	Clariant Launch 2	100%	IV	OAT	Std Alum.	Light Freezing Rain	-10	15:18:00	15:44:30	26.5	25	-
12	Apr-5-06	3	Clariant Launch 2	100%	IV	OAT	Std Alum.	Light Freezing Rain	-10	15:11:00	15:35:40	24.7	25	-
13	Apr-5-06	4	Battelle D3 ADF	10°B	I	60	White Alum.	Light Freezing Rain	-10	16:25:30	16:38:30	13.0	25	100%
14	Apr-5-06	4	Battelle D3 ADF	10°B	I	60	Comp 05	Light Freezing Rain	-10	16:26:00	16:35:00	9.0	25	69%
15	Apr-5-06	4	Battelle D3 ADF	10°B	I	20	Std Alum.	Light Freezing Rain	-10	16:16:50	16:21:35	4.7	25	-
16	Apr-5-06	4	Battelle D3 ADF	10°B	I	20	Std Alum.	Light Freezing Rain	-10	16:17:30	16:21:55	4.4	25	-
17	Apr-5-06	5	Clariant Launch 2	100%	IV	60	White Alum.	Light Freezing Rain	-10	18:59:00	19:50:00	51.0	13	100%
18	Apr-5-06	5	Clariant Launch 2	100%	IV	60	Comp 05	Light Freezing Rain	-10	18:59:45	19:49:00	49.3	13	97%
19	Apr-5-06	5	Clariant Launch 2	100%	IV	OAT	Std Alum.	Light Freezing Rain	-10	19:34:30	20:21:00	46.5	13	-
20	Apr-5-06	5	Clariant Launch 2	100%	IV	OAT	Std Alum.	Light Freezing Rain	-10	19:35:00	20:20:30	45.5	13	-
21	Apr-5-06	6	Battelle D3 ADF	10°B	I	60	White Alum.	Light Freezing Rain	-10	20:18:00	20:30:00	12.0	13	100%
22	Apr-5-06	6	Battelle D3 ADF	10°B	I	60	Comp 05	Light Freezing Rain	-10	20:18:45	20:30:00	11.3	13	94%
23	Apr-5-06	6	Battelle D3 ADF	10°B	I	20	Std Alum.	Light Freezing Rain	-10	21:00:10	21:05:15	5.1	13	-
24	Apr-5-06	6	Battelle D3 ADF	10°B	I	20	Std Alum.	Light Freezing Rain	-10	21:01:15	21:06:15	5.0	13	-
25	Apr-25-06	7	Battelle D3 ADF	10°B	I	60	White Alum.	Light Freezing Rain	-10	19:18:40	19:32:00	13.3	13	100%
26	Apr-25-06	7	Battelle D3 ADF	10°B	I	60	Comp 05	Light Freezing Rain	-10	19:19:20	19:27:00	7.7	13	58%
27	Apr-6-06	8	Kilfrost P1792	75%	II	60	White Alum.	Freezing Drizzle	-10	9:32:30	9:59:00	26.5	13	100%
28	Apr-6-06	8	Kilfrost P1792	75%	II	60	Comp 05	Freezing Drizzle	-10	10:45:52	11:06:50	21.0	13	79%
29	Apr-6-06	8	Kilfrost P1792	75%	II	OAT	Std Alum.	Freezing Drizzle	-10	10:09:50	10:23:00	13.2	13	-
30	Apr-6-06	8	Kilfrost P1792	75%	II	OAT	Std Alum.	Freezing Drizzle	-10	10:10:20	10:23:00	12.7	13	-
31	Apr-6-06	9	Battelle D3 ADF	10°B	I	60	White Alum.	Freezing Drizzle	-10	10:14:00	10:24:50	10.8	13	100%

Table 4.5: Log of Tests (2005-06) – Simulated Freezing Precipitation (cont'd)

Test #	Date	Run #	Fluid Name	Fluid Dil.	Fluid Type	Fluid Temp. (°C)	Test Surface	Precip. Type	Ambient Temp. (°C)	Start Time	Fail Time	Endur. Time (min)	Precip. Rate (g/dm²/h)	ET Ratio (relative to white alum.)
32	Apr-6-06	9	Battelle D3 ADF	10°B	I	60	Comp 05	Freezing Drizzle	-10	10:28:45	10:36:30	7.8	13	72%
33	Apr-6-06	9	Battelle D3 ADF	10°B	I	20	Std Alum.	Freezing Drizzle	-10	10:42:10	10:47:00	4.8	13	-
34	Apr-6-06	9	Battelle D3 ADF	10°B	I	20	Std Alum.	Freezing Drizzle	-10	10:43:00	10:48:00	5.0	13	-
35	Apr-6-06	10	Kilfrost P1792	50%	II	60	White Alum.	Freezing Drizzle	-3	12:26:15	12:55:00	28.8	13	100%
36	Apr-6-06	10	Kilfrost P1792	50%	II	60	Comp 05	Freezing Drizzle	-3	12:59:36	13:23:00	23.4	13	81%
37	Apr-6-06	10	Kilfrost P1792	50%	II	OAT	Std Alum.	Freezing Drizzle	-3	16:19:15	16:28:15	9.0	13	-
38	Apr-6-06	10	Kilfrost P1792	50%	II	OAT	Std Alum.	Freezing Drizzle	-3	17:02:00	17:12:30	10.5	13	-
39	Apr-26-06	11	Battelle D3 ADF	10°B	I	20	White Alum.	Freezing Drizzle	-3	20:17:50	20:37:00	19.2	13	100%
40	Apr-26-06	11	Battelle D3 ADF	10°B	I	20	Comp 05	Freezing Drizzle	-3	20:20:20	20:32:00	11.7	13	61%
41	Apr-6-06	11	Battelle D3 ADF	10°B	I	20	Std Alum.	Freezing Drizzle	-3	17:37:45	17:46:30	8.7	13	-
42	Apr-6-06	11	Battelle D3 ADF	10°B	I	20	Std Alum.	Freezing Drizzle	-3	17:38:45	17:47:50	9.1	13	-
43	Apr-7-06	12	Kilfrost P1792	50%	II	60	White Alum.	Freezing Drizzle	-3	9:30:30	10:06:00	35.5	5	100%
44	Apr-7-06	12	Kilfrost P1792	50%	II	60	Comp 05	Freezing Drizzle	-3	10:09:40	10:47:00	37.3	5	105%
45	Apr-7-06	12	Kilfrost P1792	50%	II	OAT	Std Alum.	Freezing Drizzle	-3	16:04:50	16:22:30	17.7	5	-
46	Apr-7-06	12	Kilfrost P1792	50%	II	OAT	Std Alum.	Freezing Drizzle	-3	16:06:30	16:23:40	17.2	5	-
47	Apr-7-06	13	Battelle D3 ADF	10°B	I	60	White Alum.	Freezing Drizzle	-3	11:15:00	11:44:30	29.5	5	100%
48	Apr-7-06	13	Battelle D3 ADF	10°B	I	60	Comp 05	Freezing Drizzle	-3	11:50:30	12:15:00	24.5	5	83%
49	Apr-27-06	13	Battelle D3 ADF	10°B	I	20	Std Alum.	Freezing Drizzle	-3	11:02:30	11:17:55	15.4	5	-
50	Apr-27-06	13	Battelle D3 ADF	10°B	I	20	Std Alum.	Freezing Drizzle	-3	11:03:00	11:18:15	15.3	5	-
51	Apr-25-06	14	Kilfrost P1792-2	75%	II	60	White Alum.	Freezing Drizzle	-10	15:17:30	15:47:00	29.5	13	100%
52	Apr-25-06	14	Kilfrost P1792-2	75%	II	60	Comp 05	Freezing Drizzle	-10	15:18:00	15:51:00	33.0	13	112%
53	Apr-25-06	14	Kilfrost P1792-2	75%	II	OAT	Std Alum.	Freezing Drizzle	-10	14:51:00	15:20:00	29.0	13	-
54	Apr-25-06	14	Kilfrost P1792-2	75%	II	OAT	Std Alum.	Freezing Drizzle	-10	14:51:30	15:20:00	28.5	13	-
55	Apr-26-06	15	Kilfrost P1792-2	75%	II	60	White Alum.	Light Freezing Rain	-3	16:27:00	17:01:45	34.8	25	100%
56	Apr-26-06	15	Kilfrost P1792-2	75%	II	60	Comp 05	Light Freezing Rain	-3	16:27:30	16:59:45	32.3	25	93%
57	Apr-26-06	15	Kilfrost P1792-2	75%	II	OAT	Std Alum.	Light Freezing Rain	-3	16:24:00	16:55:10	31.2	25	-
58	Apr-26-06	15	Kilfrost P1792-2	75%	II	OAT	Std Alum.	Light Freezing Rain	-3	16:24:30	16:57:20	32.8	25	-
59	Apr-26-06	16	Kilfrost P1792-2	50%	II	60	White Alum.	Light Freezing Rain	-3	21:06:10	21:34:00	27.8	13	100%
60	Apr-26-06	16	Kilfrost P1792-2	50%	II	60	Comp 05	Light Freezing Rain	-3	21:06:20	21:31:14	24.9	13	90%
61	Apr-26-06	16	Kilfrost P1792-2	50%	II	OAT	Std Alum.	Light Freezing Rain	-3	18:20:30	18:42:00	21.5	13	-
62	Apr-26-06	16	Kilfrost P1792-2	50%	II	OAT	Std Alum.	Light Freezing Rain	-3	18:21:00	18:42:00	21.0	13	-

Table 4.6: Log of Tests (2005-06) – Natural Frost

Test #	Date	Run #	Fluid Name	Fluid Dil.	Fluid Type	Fluid Temp. (°C)	Test Surface	Start Time	Fail Time	Endur. Time (min)	Precip. Rate (g/dm²/h)	Ambient Temp. (°C)	RH (%)	Wind Speed (km/h)	Plate Temp. (°C)	ΔT (°C)	Initial Brix (°)	Final Brix (°)
1	Feb-10-06	1	Dow UCAR ADF	10°B	I	60	White Alum.	22:37:25	1:00:00	142.6	0.03	-13.4	65	2.7	-22.2	8.8	25.25	23.00
2	Feb-10-06	1	Dow UCAR ADF	10°B	I	60	Comp 05	22:37:40	0:18:00	100.3	0.03	-13.4	65	2.7	-22.2	8.8	25.25	23.00
3	Feb-10-06	1	Dow UCAR ADF	10°B	I	60	Comp 06 Thin	22:37:55	0:12:00	94.1	0.03	-13.4	65	2.7	-22.3	8.9	25.25	22.00
4	Feb-10-06	1	Dow UCAR ADF	10°B	I	60	Comp 06 Thick	22:38:15	0:30:00	111.8	0.03	-13.4	65	2.7	-21.9	8.5	25.25	21.50
5	Feb-10-06	1	Dow UCAR ADF	10°B	I	60	GLARE	22:38:30	0:37:00	118.5	0.03	-13.4	65	2.7	-21.1	7.7	25.25	21.50
6	Feb-10-06	2	Dow UCAR ADF	10°B	I	60	White Alum.	1:30:35	3:55:00	144.4	0.08	-14.6	73	4.5	-20.2	5.6	25.25	20.00
7	Feb-10-06	2	Dow UCAR ADF	10°B	I	60	Comp 05	1:30:55	3:07:00	96.1	0.10	-14.6	73	4.5	-20.8	6.2	25.25	20.00
8	Feb-10-06	2	Dow UCAR ADF	10°B	I	60	Comp 06 Thin	1:31:15	3:13:00	101.8	0.10	-14.6	73	4.5	-20.7	6.1	25.25	20.50
9	Feb-10-06	2	Dow UCAR ADF	10°B	I	60	Comp 06 Thick	1:31:30	2:56:00	84.5	0.10	-14.6	73	4.5	-20.3	5.7	25.25	18.50
10	Feb-10-06	2	Dow UCAR ADF	10°B	I	60	GLARE	1:31:55	3:20:00	108.1	0.10	-14.6	73	4.5	-20.3	5.7	25.25	20.00
11	Feb-10-06	3	Dow UCAR ADF	10°B	I	60	White Alum.	4:06:40	5:59:00	112.3	0.11	-16.0	75	5.0	-20.5	4.5	25.25	20.25
12	Feb-10-06	3	Dow UCAR ADF	10°B	I	60	Comp 05	4:06:55	5:46:00	99.1	0.11	-16.0	75	5.0	-20.5	4.5	25.25	21.00
13	Feb-10-06	3	Dow UCAR ADF	10°B	I	60	Comp 06 Thin	4:07:15	5:39:00	91.8	0.11	-16.0	75	5.0	-20.3	4.3	25.25	21.00
14	Feb-10-06	3	Dow UCAR ADF	10°B	I	60	Comp 06 Thick	4:07:35	5:27:00	79.4	0.11	-16.0	75	5.0	-20.3	4.3	25.25	19.50
15	Feb-10-06	3	Dow UCAR ADF	10°B	I	60	GLARE	4:07:55	5:45:00	97.1	0.11	-16.0	75	5.0	-20.3	4.3	25.25	19.00
16	Mar-27-06	1	Dow UCAR ADF	10°B	I	60	White Alum.	23:02:50	0:55:00	112.2	0.18	-0.1	72	2.0	-6.7	6.6	17.50	8.00
17	Mar-27-06	1	Dow UCAR ADF	10°B	I	60	Comp 05	23:03:15	0:40:00	96.7	0.18	-0.1	72	2.0	-7.3	7.2	17.50	8.75
18	Mar-27-06	1	Dow UCAR ADF	10°B	I	60	Comp 06 Thin	23:03:45	0:30:00	86.2	0.18	-0.1	72	2.0	-7.3	7.2	17.50	7.50
19	Mar-27-06	1	Dow UCAR ADF	10°B	I	60	Comp 06 Thick	23:04:15	0:55:00	110.8	0.18	-0.1	72	2.0	-7.0	6.9	17.50	9.00
20	Mar-27-06	1	Dow UCAR ADF	10°B	I	60	GLARE	23:04:40	0:55:00	110.3	0.18	-0.1	72	2.0	-6.1	6.0	17.50	8.50
21	Mar-27-06	2	Dow UCAR ADF	10°B	I	60	White Alum.	1:32:00	3:45:00	133.0	0.15	-1.5	73	3.5	-8.3	6.8	20.00	9.00
22	Mar-27-06	2	Dow UCAR ADF	10°B	I	60	Comp 05	1:32:30	3:15:00	102.5	0.15	-1.5	73	3.5	-9.0	7.5	20.00	9.50
23	Mar-27-06	2	Dow UCAR ADF	10°B	I	60	Comp 06 Thin	1:33:10	3:15:00	101.8	0.15	-1.5	73	3.5	-9.0	7.5	20.00	8.00
24	Mar-27-06	2	Dow UCAR ADF	10°B	I	60	Comp 06 Thick	1:33:40	3:15:00	101.3	0.15	-1.5	73	3.5	-8.7	7.2	20.00	9.00
25	Mar-27-06	2	Dow UCAR ADF	10°B	I	60	GLARE	1:34:10	3:15:00	100.8	0.15	-1.5	73	3.5	-7.7	6.2	20.00	7.50
26	Mar-27-06	3	Dow UCAR ADF	10°B	I	60	White Alum.	4:09:06	6:10:00	120.9	0.16	-1.7	73	2.7	-8.4	6.7	20.75	10.00
27	Mar-27-06	3	Dow UCAR ADF	10°B	I	60	Comp 05	4:09:36	5:36:00	86.4	0.16	-1.7	73	2.7	-9.6	7.9	20.75	10.00
28	Mar-27-06	3	Dow UCAR ADF	10°B	I	60	Comp 06 Thin	4:10:04	5:35:00	84.9	0.16	-1.7	73	2.7	-9.5	7.8	20.75	10.50
29	Mar-27-06	3	Dow UCAR ADF	10°B	I	60	Comp 06 Thick	4:10:31	5:36:00	85.5	0.16	-1.7	73	2.7	-9.5	7.8	20.75	9.50
30	Mar-27-06	3	Dow UCAR ADF	10°B	I	60	GLARE	4:10:53	5:40:00	89.1	0.16	-1.7	73	2.7	-7.8	6.1	20.75	10.00

4.3.2 Summary of Tests Conducted

Comparative endurance time testing was conducted in natural snow, natural frost, and simulated freezing precipitation using various fluids, some applied heated and some applied at OAT. Tables 4.7, 4.8, and 4.9 list the number of comparative test runs completed for each fluid type and fluid application temperature in natural snow, simulated freezing precipitation, and natural frost, respectively.

Table 4.7: Summary of 2005-06 Test Runs – Natural Snow

Fluid Type / Temperature	# Comparative Test Runs
Type I Heated (60°C)	5
Type II Heated (60°C)	1
Type III Heated (60°C)	1
Type IV Heated (60°C)	4
Type IV at OAT	4
TOTAL	**15**

Table 4.8: Summary of 2005-06 Test Runs – Simulated Freezing Precipitation

Fluid Type / Temperature	# Comparative Test Runs
Type I Heated (60°C)	6
Type I Heated (20°C)	1
Type II Heated (60°C)	7
Type IV Heated (60°C)	2
TOTAL	**16**

Table 4.9: Summary of 2005-06 Test Runs – Natural Frost

Fluid Type / Temperature	# Comparative Test Runs
Type I Heated (60°C)	6
TOTAL	**6**

4.3.3 Natural Snow Weather Conditions

A total of 15 comparative tests (89 individual tests) were conducted in natural snow. Charts showing the distribution of snow tests by precipitation rate and wind speed are shown in Figures 4.7 and 4.8, respectively. Figure 4.7 shows that 53 percent of the tests were conducted in light or very light snow (precipitation rates below 10 g/dm^2/h). Figure 4.8 shows that 61 percent of the tests were conducted when wind speeds were greater than 28 km/h.

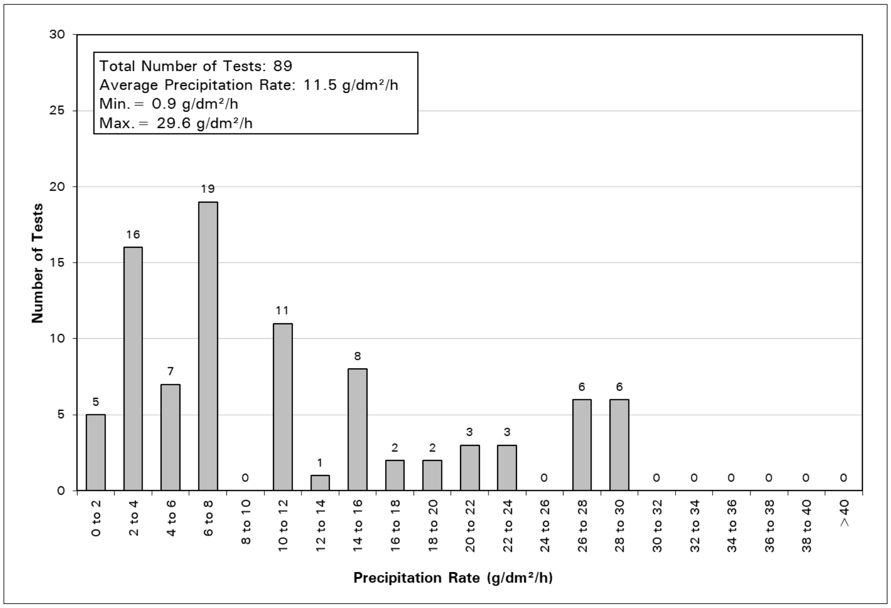

Figure 4.7: Distribution of Precipitation Rate – Natural Snow Tests 2005-06

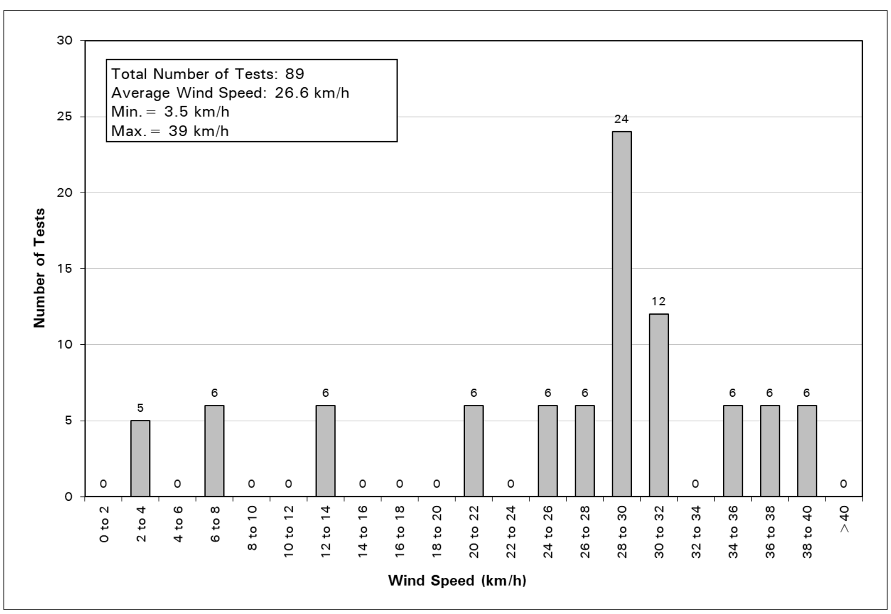

Figure 4.8: Distribution of Wind Speed – Natural Snow Tests 2005-06

4.3.4 Surface Temperature/Fluid Brix Profiles

Several parameters were documented during each fluid endurance time test. Data pertaining to fluid dilution (fluid Brix) and fluid thickness was collected at set intervals for the duration of the test, while plate surface temperature was logged on an ongoing basis. These parameters were used to construct charts to better illustrate the aluminum and composite test plate temperature profiles, as well as fluid thickness decay and fluid dilution.

The charts have not been included in this report. However, they are available in TP 14720E (2) – refer to Appendix D (natural snow), Appendix E (freezing precipitation), and Appendix F (natural frost).

The charts were reviewed to examine the differences in the four composite surfaces tested. In general, the Comp 05 and Comp 06 thin surface temperatures rose to values slightly less than that of the aluminum test plate; however, they cooled more quickly. The Comp 06 thick and GLARE test plates reached peak temperatures that were lower than that of the white aluminum test plate; however, they retained the heat for longer.

4.4 Analysis

An analysis of the relative endurance time performance of fluids on composite surfaces is presented in the following subsections.

4.4.1 Comparative Bar Charts

The test data is presented in this subsection in a series of bar charts. There is one bar chart provided for each unique combination of precipitation type, fluid type, and fluid temperature. Adjacent sets of bars represent the endurance time (in minutes) measured using the aluminum and composite test surfaces. Pertinent test information for each comparative test – fluid dilution, temperature, and rate of precipitation (calculated with respect to the white aluminum test plate) – is labelled at the bottom of each group of bars.

Figures 4.9 to 4.12 demonstrate the results obtained from the 15 comparative test runs conducted in natural snow conditions.

Figures 4.13 to 4.16 demonstrate the results obtained from the 16 comparative test runs conducted in simulated freezing precipitation conditions.

Figure 4.17 demonstrates the results obtained from the 6 comparative test runs conducted with Type I fluids in natural frost conditions (no Type II, III, or IV fluids were tested in natural frost).

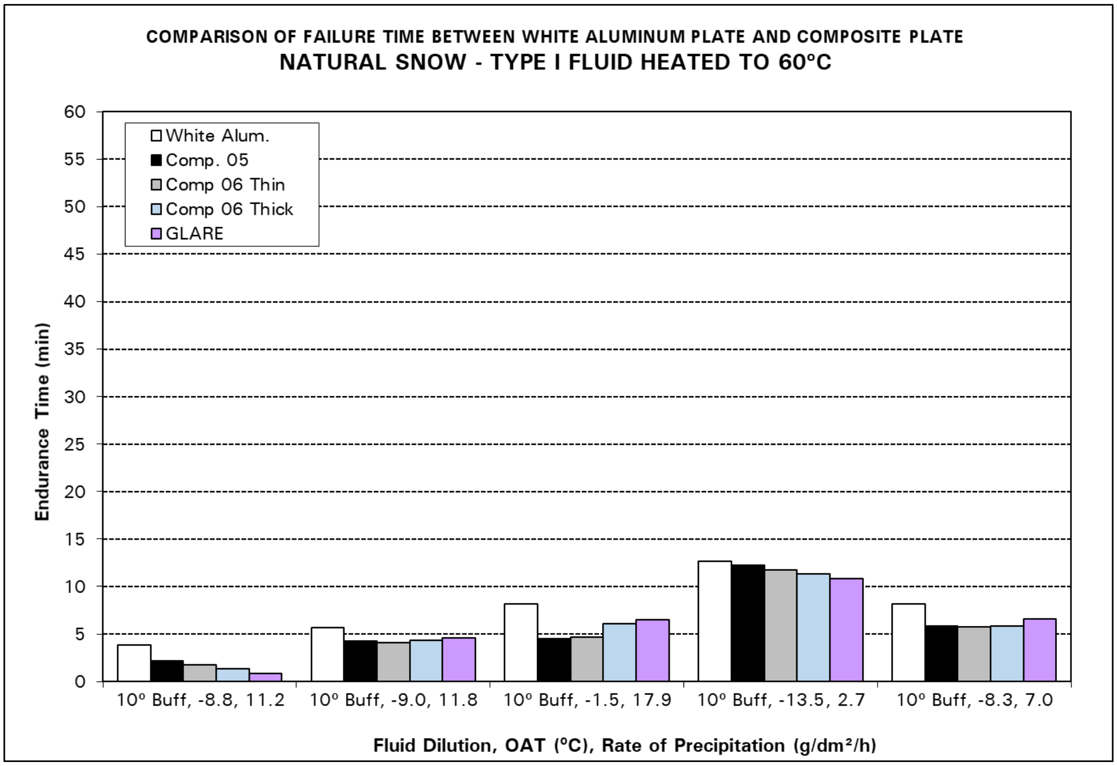

Figure 4.9: Failure Time Comparison – Type I Fluid, 60°C, Natural Snow

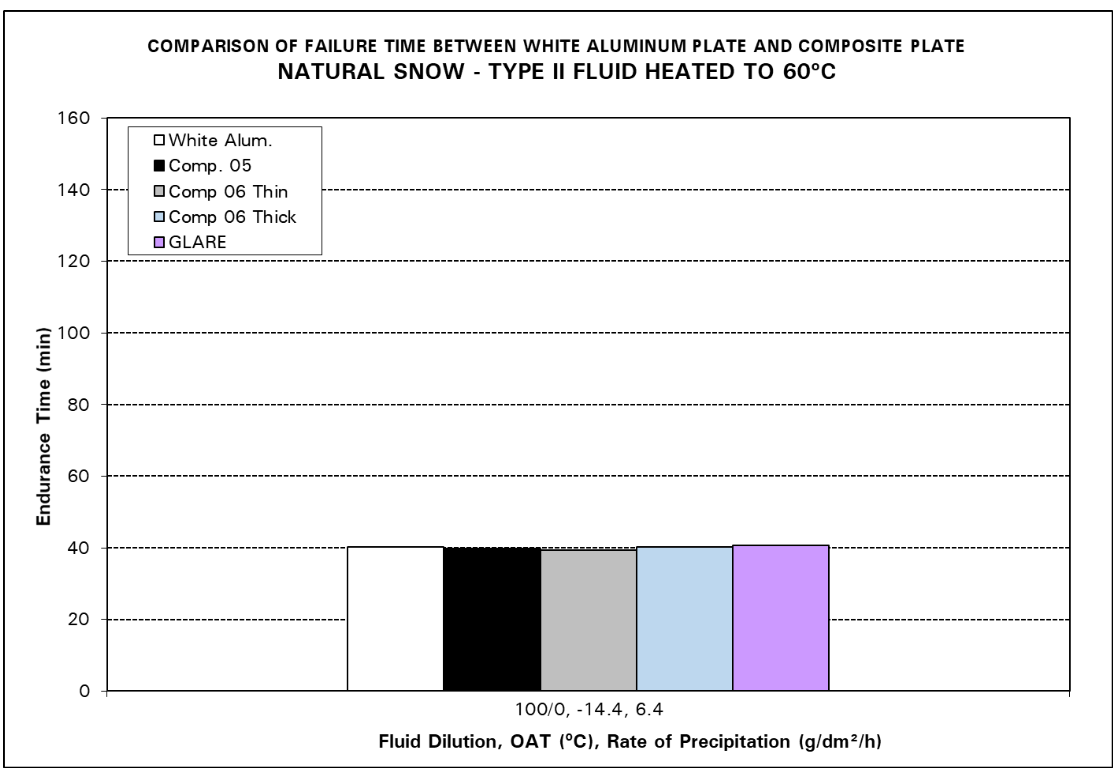

Figure 4.10: Failure Time Comparison – Type II Fluid, 60°C, Natural Snow

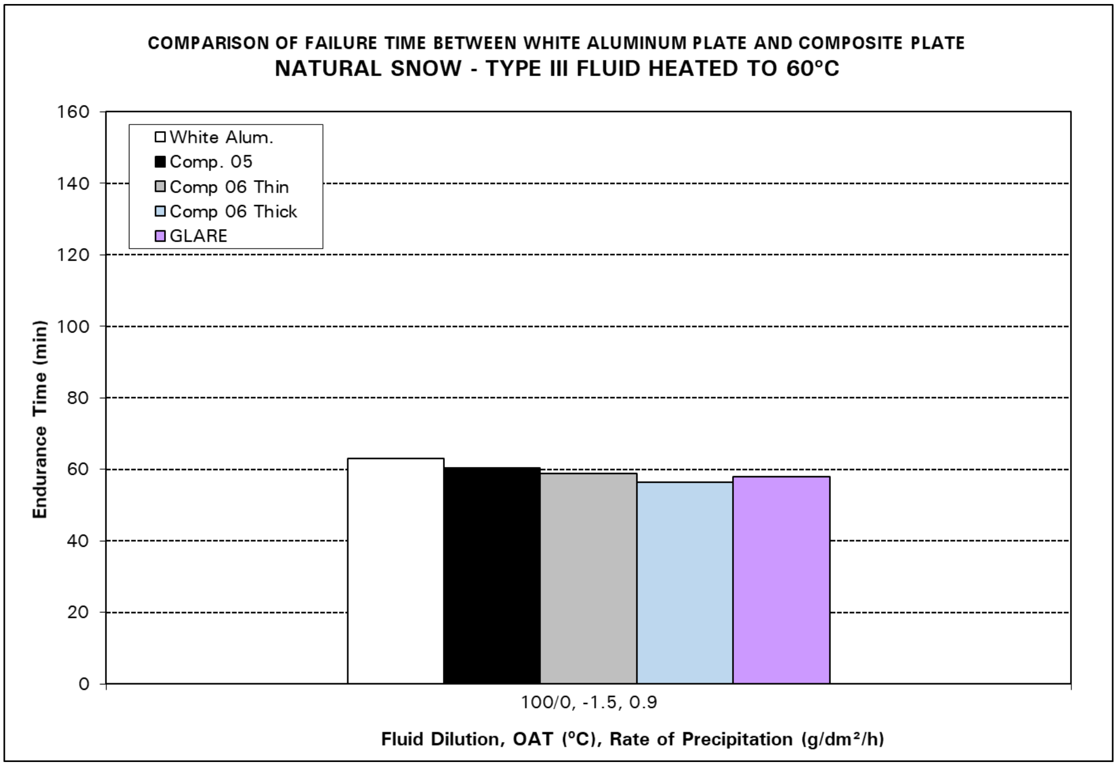

Figure 4.11: Failure Time Comparison – Type III Fluid, 60°C, Natural Snow

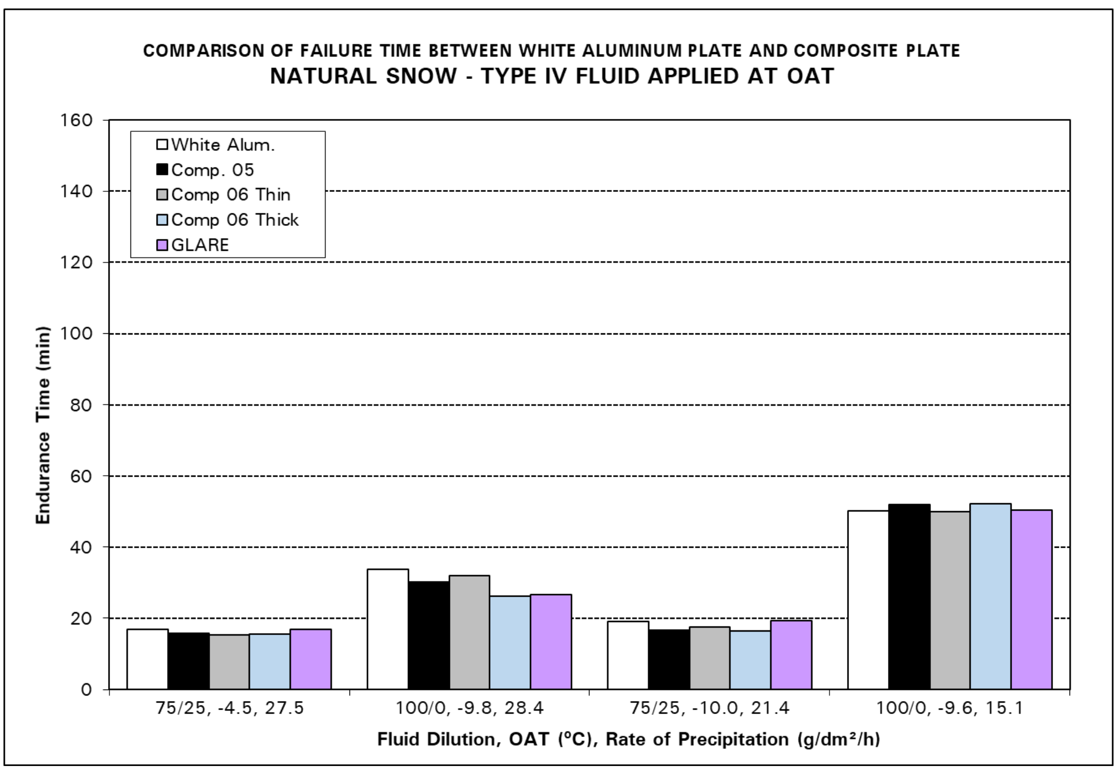

Figure 4.12: Failure Time Comparison – Type IV Fluid, OAT, Natural Snow

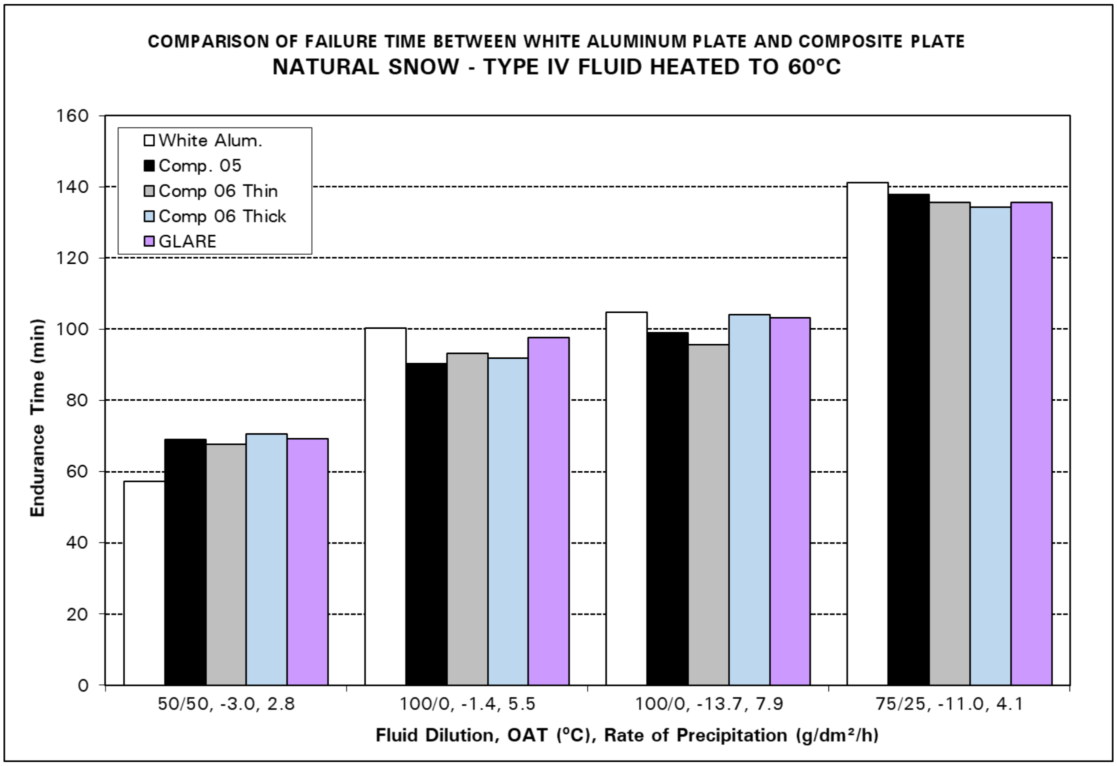

Figure 4.13: Failure Time Comparison – Type IV Fluid, 60°C, Natural Snow

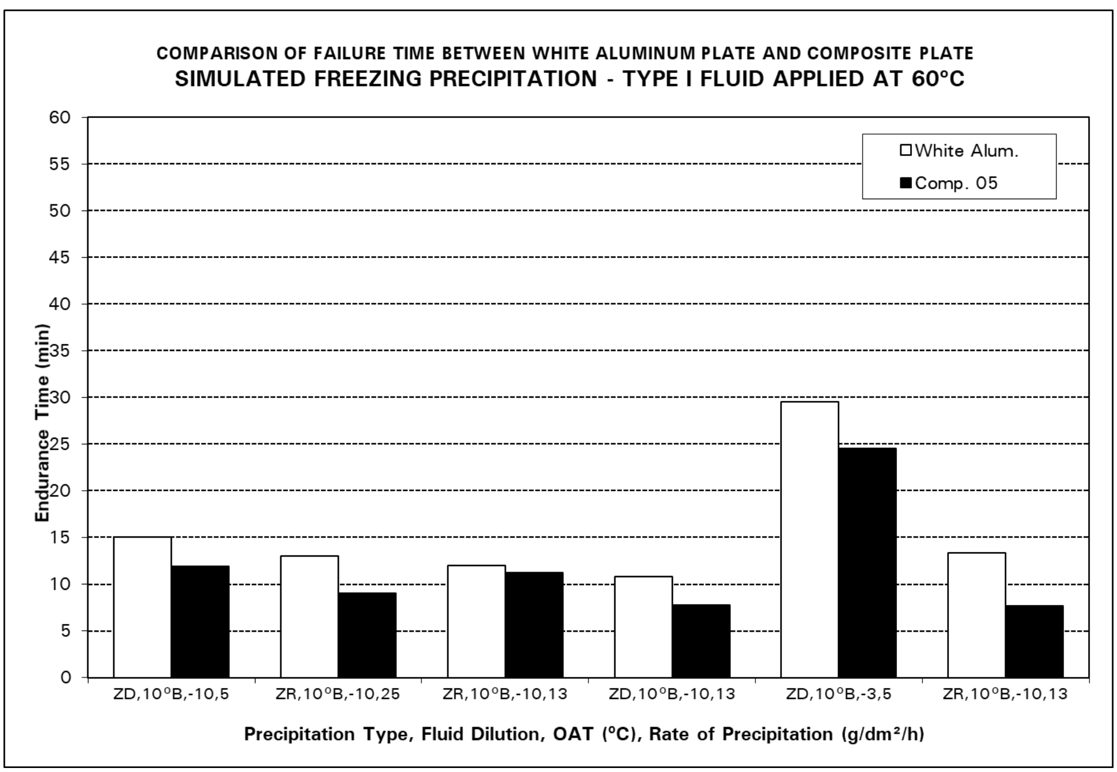

Figure 4.14: Failure Time Comparison – Type I Fluid, 60°C, Freezing Precipitation

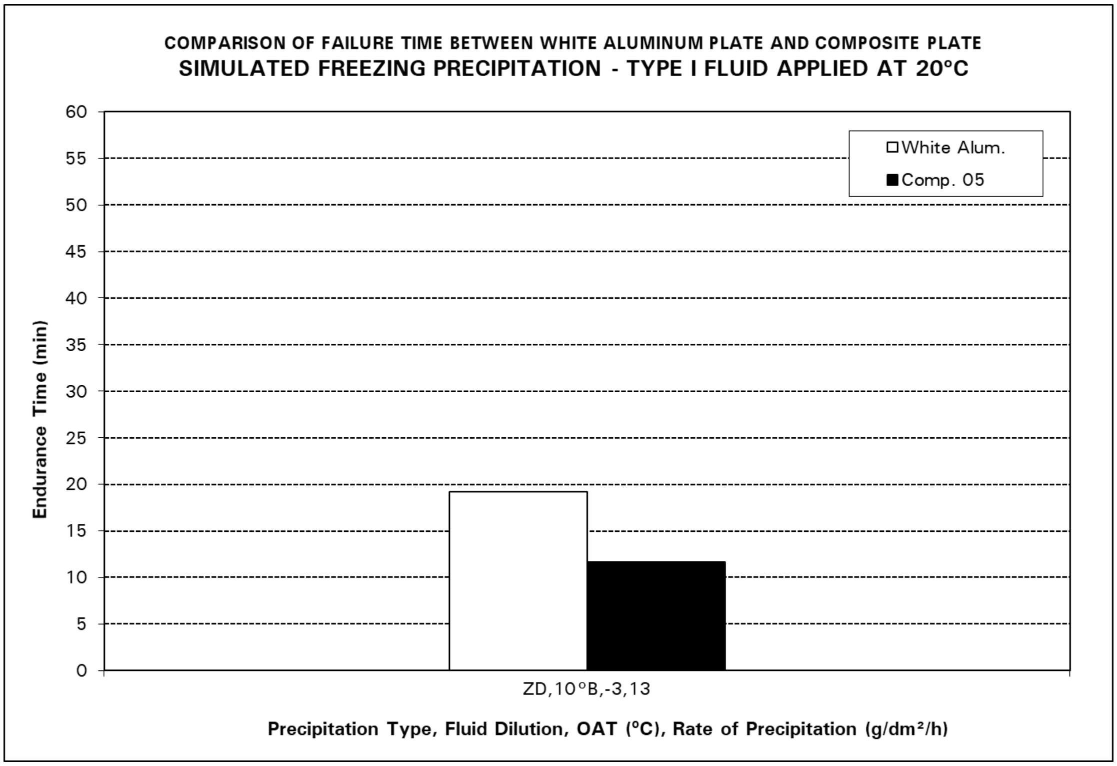

Figure 4.15: Failure Time Comparison – Type I Fluid, 20°C, Freezing Precipitation

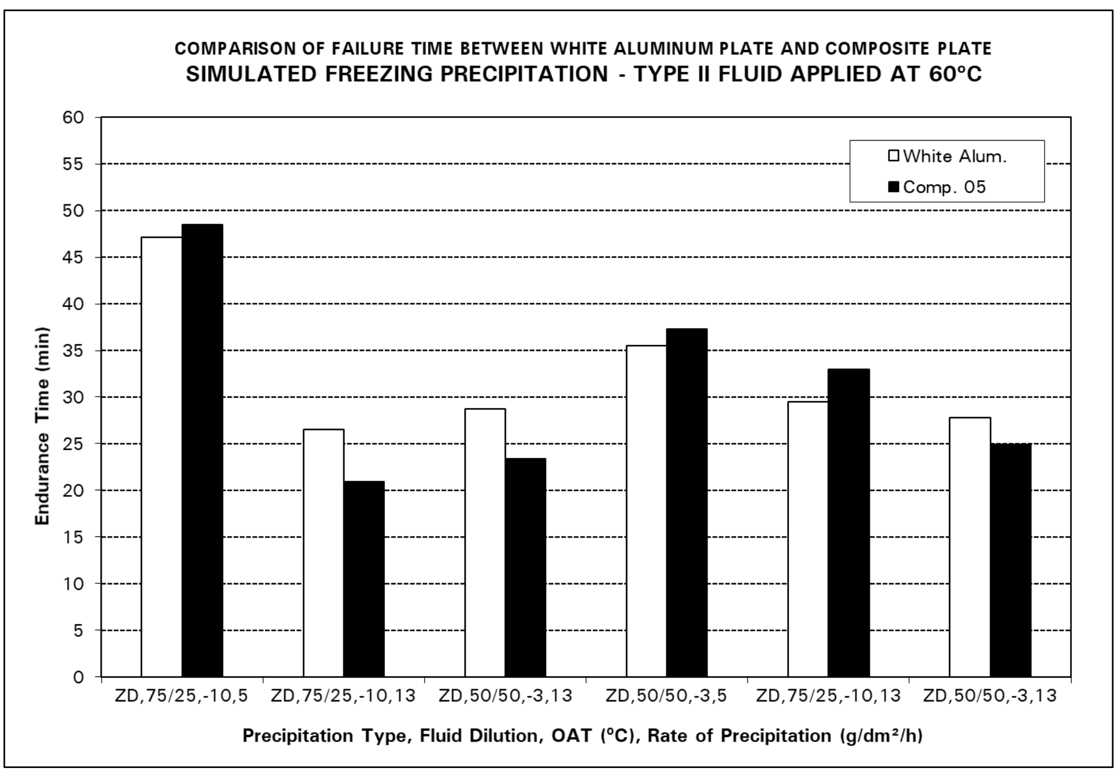

Figure 4.16: Failure Time Comparison – Type II Fluid, 60°C, Freezing Precipitation

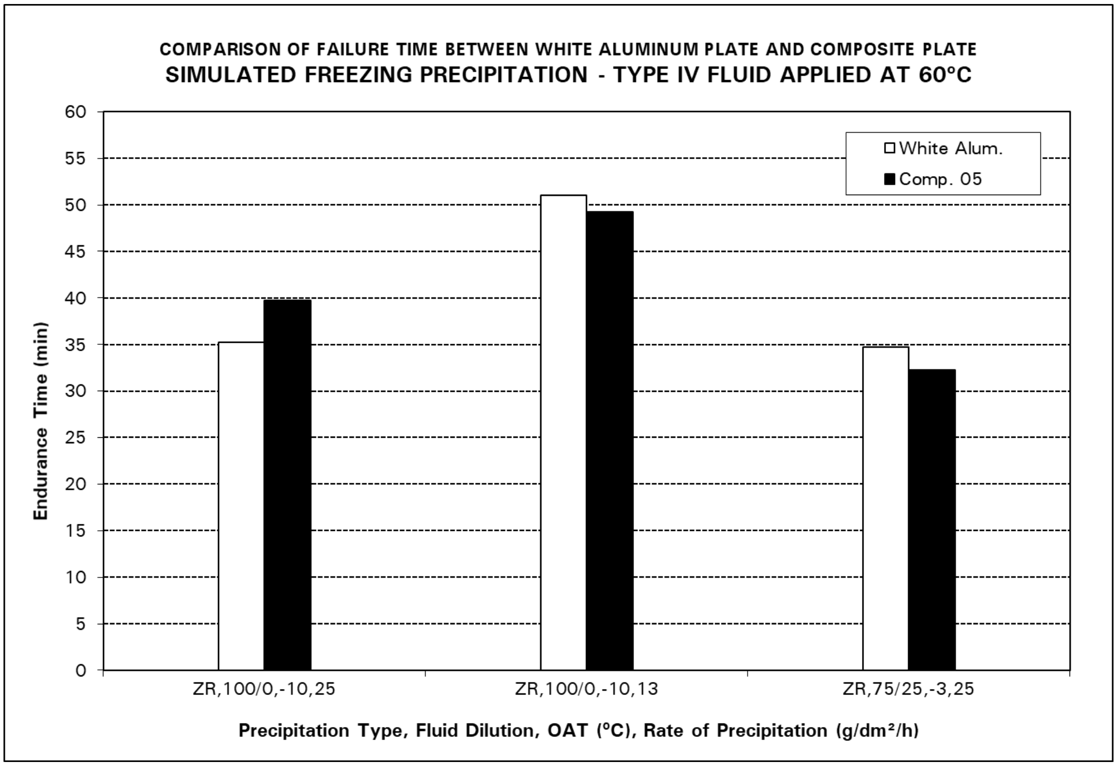

Figure 4.17: Failure Time Comparison – Type IV Fluid, 60°C, Freezing Precipitation

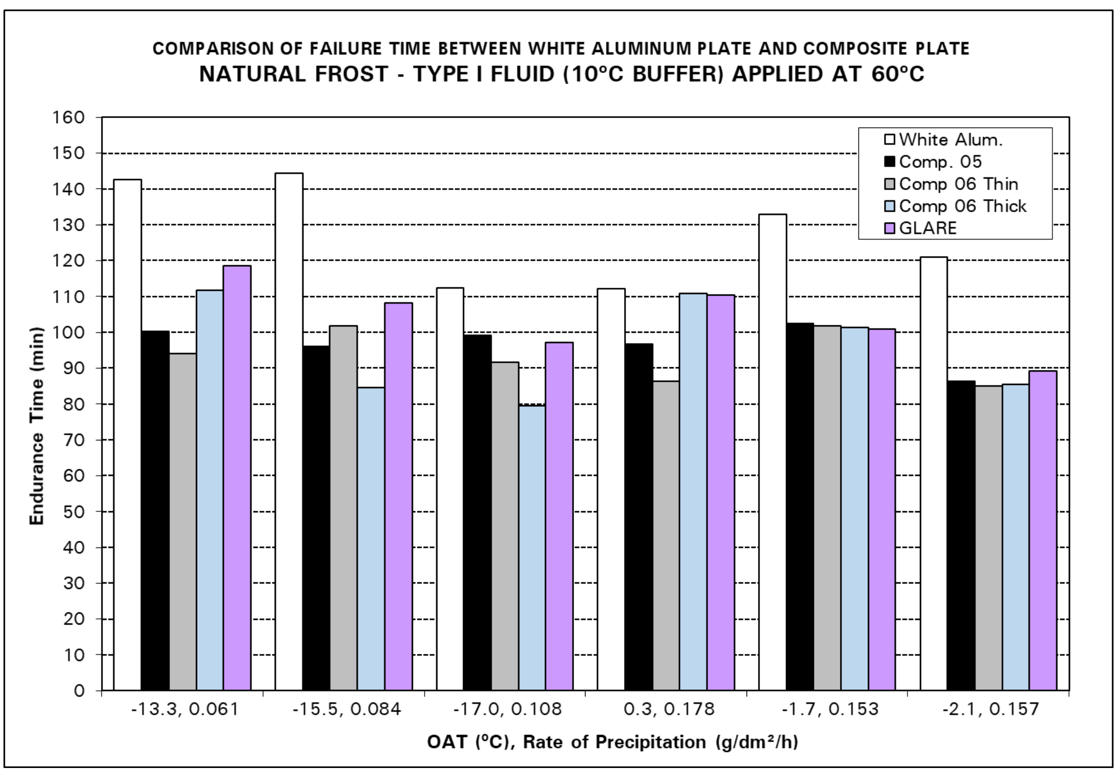

Figure 4.18: Failure Time Comparison – Type I Fluid, 60°C, Natural Frost

4.4.2 Ratio Analysis

A ratio analysis was completed to determine the relationship between fluid endurance times on composite and aluminum test surfaces. As endurance times were found to be similar on all four composite materials tested, one composite surface, Comp 05, was selected to represent the composite endurance time in the comparative analysis. The Comp 05 endurance times were compared to the endurance times measured on the white-painted aluminum surface.

Tables 4.10 to 4.12 contain the data used in the analysis. The data has been sorted by precipitation type: natural snow in Table 4.10, freezing precipitation in Table 4.11, and natural frost in Table 4.12. Within each table, the data has been further separated into fluid type / fluid temperature combinations.

For each comparative test, the pertinent test numbers are provided, as well as the aluminum endurance time, composite endurance time, endurance time ratio, and endurance time difference (in minutes).

It should be noted that the fluid endurance time ratio may exhibit significant variance for fluids with shorter endurance times. For example, in Table 4.10, tests 2 and 3 in natural snow indicated that the composite endurance time was almost half of the aluminum endurance time. Due to the short endurance time, the ratio was very high; however, the endurance time was only 1.6 minutes longer than on the composite test plate.

Further discussion on the results of the ratio analysis is provided by fluid type in the subsections below.

4.4.2.1 Type II/III/IV Fluids: Snow and Freezing Precipitation

The comparative analysis showed that, on average, Type II/III/IV fluid endurance times on the composite test surface were comparable to endurance times on the white-painted aluminum surface. In natural snow conditions, the difference in endurance times was less than 10 percent for 8 of the 10 comparative tests conducted. In simulated freezing precipitation conditions, the difference in endurance times was less than 13 percent for 7 of the 9 comparative tests conducted.

The results indicate that endurance times of Type II/III/IV fluids on composite surfaces are comparable to endurance times on aluminum surfaces.

Table 4.10: Comparative Endurance Time Analysis – Natural Snow

Test #	Comp 05 Endurance Time (min)	White Alum. Endurance Time (min)	Endurance Time % Ratio [Comp 05 / White Alum.]	Endurance Time Difference (min.) [Comp 05 - White Alum.]
Type I Fluid Heated to 60°C				
2-3	2.2	3.8	57%	-1.6
32-33	4.3	5.7	75%	-1.4
68-69	4.5	8.2	55%	-3.7
92-93	12.2	12.7	97%	-0.4
104-105	5.8	8.2	71%	-2.4
		Average:	71%	-1.9
		Standard Deviation:	17%	1.2
Type II Fluid Heated to 60°C				
86-87	39.8	40.2	99%	-0.4
Type III Fluid Heated to 60°C				
56-57	60.4	62.9	96%	-2.5
Type IV Fluid Heated to 60°C				
38-39	69.0	57.3	120%	11.7
50-51	90.3	100.3	90%	-10.0
80-81	98.9	104.8	94%	-5.9
98-99	137.9	141.3	98%	-3.3
		Average:	101%	-1.9
		Standard Deviation:	14%	9.5
Type IV Fluid at OAT				
8-9	15.8	16.9	93%	-1.1
14-15	30.3	33.7	90%	-3.4
20-21	16.8	19.2	87%	-2.4
26-27	52.0	50.3	103%	1.7
		Average:	93%	-1.3
		Standard Deviation:	7%	2.2

Table 4.11: Comparative Endurance Time Analysis – Freezing Precipitation

Test #	Comp 05 Endurance Time (min)	White Alum. Endurance Time (min)	Endurance Time % Ratio [Comp 05 / White Alum.]	Endurance Time Difference (min.) [Comp 05 - White Alum.]
Type I Fluid Heated to 20°C				
39-40	11.7	19.2	61%	-7.5
Type I Fluid Heated to 60°C				
5-6	11.9	15.0	79%	-3.1
13-14	9.0	13.0	69%	-4.0
21-22	11.3	12.0	94%	-0.8
25-26	7.7	13.3	58%	-5.7
31-32	7.8	10.8	72%	-3.1
47-48	24.5	29.5	83%	-5.0
		Average:	76%	-3.6
		Standard Deviation:	13%	1.7
Type II Fluid Heated to 60°C				
1-2	48.5	47.2	103%	1.3
27-28	21.0	26.5	79%	-5.5
35-36	23.4	28.8	81%	-5.4
43-44	37.3	35.5	105%	1.8
51-52	33.0	29.5	112%	3.5
59-60	24.9	27.8	89%	-2.9
		Average:	95%	-1.2
		Standard Deviation:	14%	3.9
Type IV Fluid Heated to 60°C				
9-10	39.8	35.3	113%	4.5
17- 18	49.3	51.0	97%	-1.8
55-56	32.3	34.8	93%	-2.5
		Average:	101%	0.1
		Standard Deviation:	11%	3.8

Table 4.12: Comparative Endurance Time Analysis – Natural Frost

Test #	Comp 05 Endurance Time (min)	White Alum. Endurance Time (min)	Endurance Time % Ratio [Comp 05 / White Alum.]	Endurance Time Difference (min.) [Comp 05 - White Alum.]
Type I Fluid Heated to 60°C				
1-5	100.3	142.6	70%	-42.2
6-10	96.1	144.4	67%	-48.3
11-15	99.1	112.3	88%	-13.3
16-20	96.7	112.2	86%	-15.4
21-25	102.5	133.0	77%	-30.5
26-30	86.4	120.9	71%	-34.5
		Average:	77%	-30.7
		Standard Deviation:	9%	14.1

4.4.2.2 Type I Fluids: Snow, Freezing Precipitation, and Frost

The endurance time ratios were larger for Type I fluids. Endurance times on composite surfaces were on average 29 percent shorter in snow and 26 percent shorter in freezing precipitation. Upon further investigation, it was observed that the difference in measured endurance times was less than 5 minutes for 10 of the 12 snow and freezing precipitation tests conducted.

Testing with Type I fluids in natural frost showed that, on average, fluid endurance times were 23 percent shorter on the composite test surface than on the white-painted aluminum surface. During four of the six runs conducted, this reduction resulted in a difference of more than 30 minutes.

These results indicate that endurance times of Type I fluids on composite surfaces are shorter than endurance times on aluminum surfaces.

4.5 Conclusions and Recommendations

Conclusions and recommendations were drawn from comparisons of the results measured on different composite materials and results measured on composite and aluminum materials.

4.5.1 Composite Materials

The testing conducted in the winter of 2005-06 found that fluid endurance times are similar on various composite materials. The four composite materials included in the testing differed in their material composition, structure, and thickness. It was concluded that testing on one representative composite surface could provide results that would apply to most composite surfaces. It was recommended that a single representative composite material be used in future testing.

4.5.2 Composite vs. Aluminum Endurance Times

The testing conducted in the winter of 2005-06 showed that endurance times of Type II, III, and IV fluids are similar on composite and aluminum surfaces. However, it showed that endurance times of Type I fluids are shorter on composite surfaces than on aluminum surfaces. Further testing with Type I fluids was recommended to investigate the reductions observed. It was recommended that the testing be carried out using standard endurance time test methodologies. In snow, this meant conducting tests with composite surfaces configured as LETE boxes rather than as flat plates. In freezing precipitation, this meant conducting tests with fluids at 20°C, rather than at 60°C.

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Photo 4.1: Unpainted Aluminum Test Plate

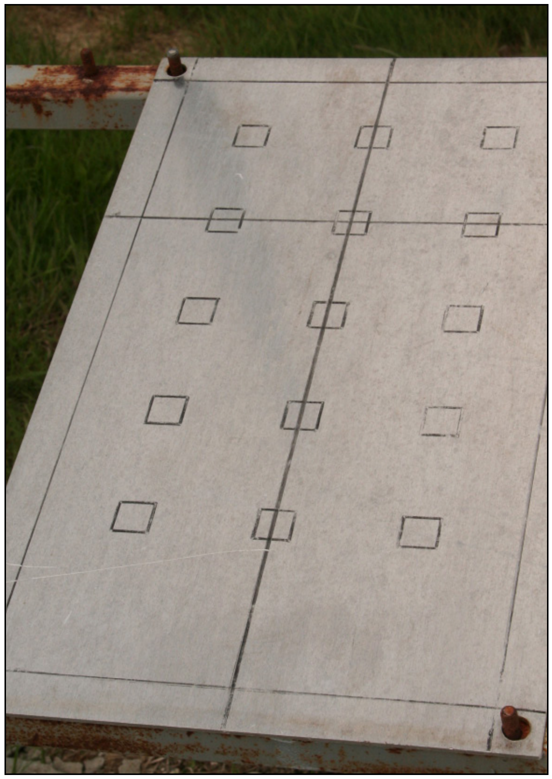


Photo 4.2: Unpainted Carbon Fibre Cross Weave Fabric Test Plate

Photo 4.3: Unpainted Carbon Fibre Unidirectional Tape Test Plate

Photo 4.4: Unpainted Glass-Reinforced Fibre Metal Laminate Test Plate

Photo 4.5: Outdoor Test Setup (2005-06)

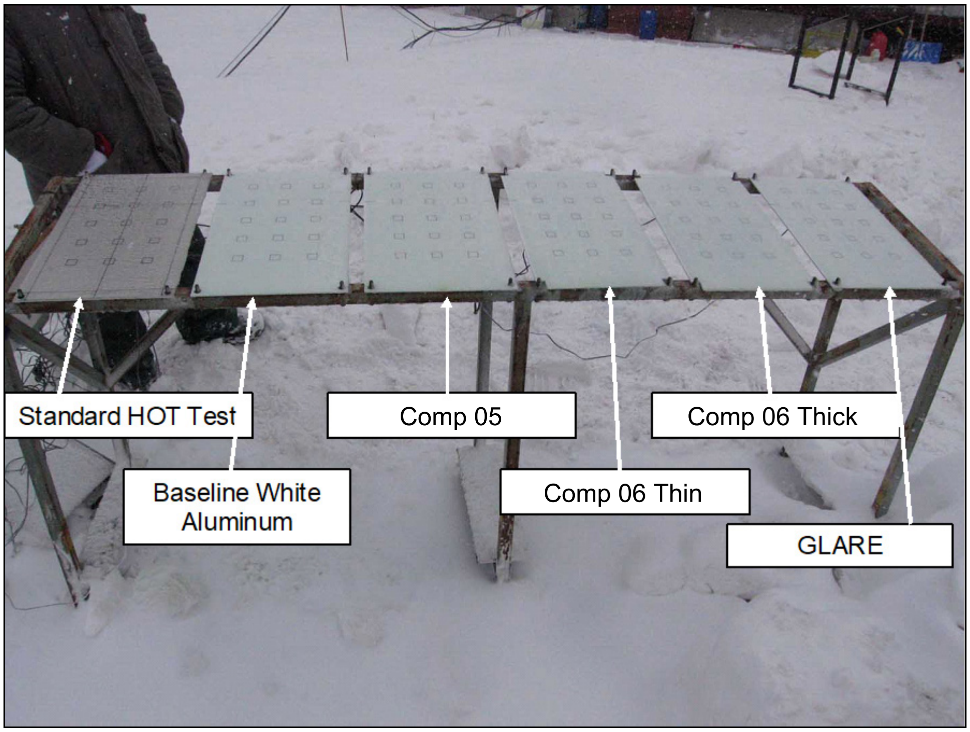
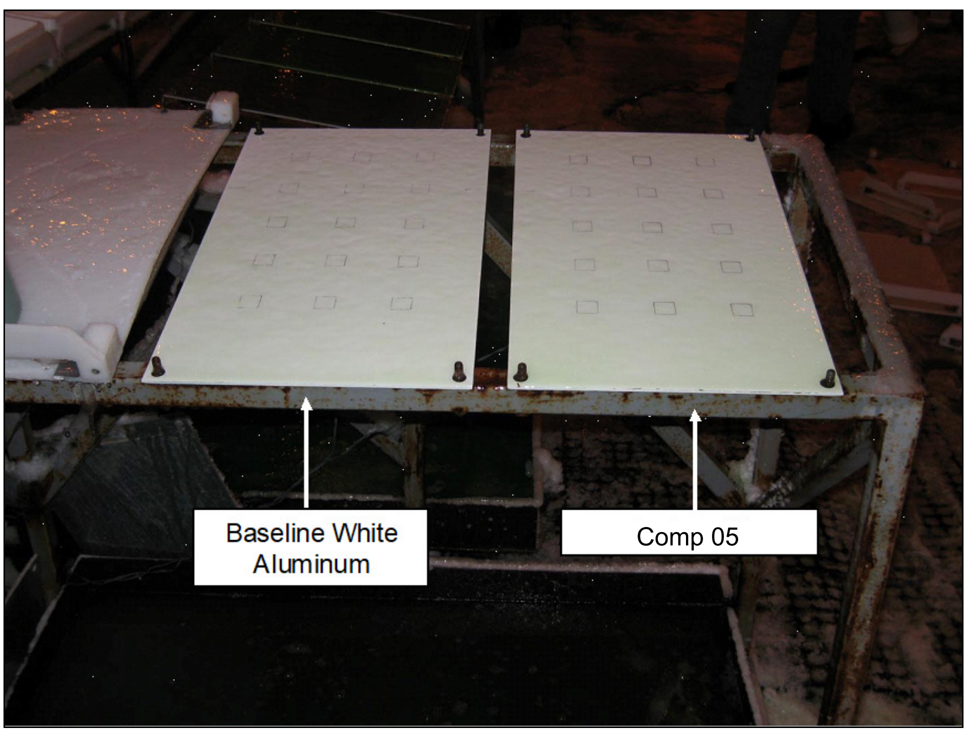


Photo 4.6: Indoor Test Setup (2005-06)



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5. 2006-07 AND 2007-08 RESEARCH

This section documents the composite research that was conducted in the winters of 2006-07 and 2007-08. This research was first documented in two interim reports, which were provided to Transport Canada and the FAA.

5.1 Objective

Testing conducted with Type I fluids in natural snow in the winter of 2005-06 showed fluid endurance times on composite flat plates were shorter than fluid endurance times on aluminum flat plates. The objective of the composite project in the winters of 2006-07 and 2007-08 was to determine if these results could be replicated using the current Type I protocol, which requires testing be conducted on LETE boxes (rather than on flat plates). Testing was carried out over two winters due to limited data being collected in light snow conditions in the winter of 2006-07.

5.2 Methodology

The methodology used for conducting composite testing is described in Section 2. Additional details specific to the testing conducted in 2006-07 and 2007-08 are provided in this section.

5.2.1 Test Surfaces

Three test surfaces were used in the winters of 2006-07 and 2007-08. All were configured as LETE boxes. The test surface materials and finishes are detailed in Table 5.1.

Table 5.1: Test Surfaces Used in 2005-06 Testing

Name	Surface Material	Side / Bottom Material	Finish
1. Aluminum LETE Box[1]	Alclad 2024	Alclad 2024	Unpainted
2. White Aluminum LETE Box	Alclad 2024	Alclad 2024	White-painted
3. White Composite LETE Box[1]	Comp 05[2]	Alclad 2024	White-painted

[1] Aluminum LETE box shown in Photo 2.7; white composite LETE box shown in Photo 2.8
[2] Carbon fibre cross weave fabric (see Table 4.1)

The white aluminum surface provided the baseline results to which the white composite surface results were compared. The unpainted aluminum surface results represented a standard holdover time test result. Tests on the unpainted aluminum surface were conducted for reference only.

5.2.2 Test Procedure

In 2006-07 and 2007-08, comparative endurance time tests were carried out with Type I fluid in natural snow on LETE boxes.

A detailed test procedure was written to describe how the testing should be carried out. This procedure, entitled *Experimental Program: Type I Endurance Time Testing on Non-Aluminum Leading Edge Thermal Equivalent Boxes – Natural Snow*, is provided in Appendix E.

Tests were conducted using standard endurance time testing protocols. Tests were conducted simultaneously on the three test surfaces described in Subsection 5.2.1. Most tests were conducted with Type I fluids heated to 60°C; limited tests were conducted with fluids heated to 20°C.

Figure 5.1 shows the test setup, including the test surfaces, fluid quantities, fluid temperatures, and application methods used in testing. The setup is also shown in Photo 5.1.

Position 1	**Position 2**	**Position 3**
Aluminum	White Alum.	White Comp.
LETE Box	LETE Box	LETE Box
0.5 L of Fluid	0.5 L of Fluid	0.5 L of Fluid
Apply at 60/20ºC	Apply at 60/20ºC	Apply at 60/20ºC
Spreader	Spreader	Spreader

Figure 5.1: Test Setup (2006-07 and 2007-08)

5.2.3 Fluids

In 2006-07 and 2007-08, only Type I fluids were tested. The fluids were tested at a 10°C buffer; each fluid was mixed to a freezing point 10°C below the prevailing OAT for each test. Table 5.2 lists the fluids tested in 2006-07 and 2007-08.

Table 5.2: Fluids Used in 2006-07 and 2007-08 Testing

Fluid Type	Fluid Name	Fluid Base
Type I	Dow UCAR ADF	Ethylene-glycol
Type I	Dow UCAR PG ADF	Propylene-glycol
Type I	Octagon Octaflo EF	Propylene-glycol

5.3 Data

The data collected during the tests conducted in the winters of 2006-07 and 2007-08 is presented in the following subsections.

5.3.1 Log of Tests

A log was created to document the results of testing carried out in the winters of 2006-07 and 2007-08. The log, presented in Table 5.3, provides relevant information for each test. Each row contains data specific to one test. Below is a brief description of each column heading in the log.

Test #: Exclusive number identifying each test.

Date: Date when the test was conducted.

Run #: Run number in which the test was performed.

Fluid Name: Fluid manufacturer and fluid brand name.

Fluid Dil.: Fluid dilution (10°B = fluid mixed to a freezing point 10°C below the ambient temperature).

Fluid Type: SAE designated fluid type.

Fluid Temp.: Fluid temperature prior to application, measured in °C.

Test Surface:	Test surface material composition: unpainted aluminum (aluminum), white-painted aluminum (white alum.), or white-painted composite (white comp.).
Precip. Type:	Dominant precipitation type during each test.
Start Time:	Start time for the test, recorded in local time.
Fail Time:	Fluid failure time, recorded in local time.
Endurance Time:	Fluid endurance time, measured in minutes.
Precip. Rate:	Average precipitation rate, measured in $g/dm^2/h$, collected by two precipitation pans at set intervals for the duration of the test run.
Ambient Temp.:	The average of hourly OAT readings for the duration of the test, measured in °C, provided by Environment Canada.
Wind Speed:	The average of hourly wind speed readings for the duration of the test, measured in km/h, provided by Environment Canada.
Initial Brix:	Fluid Brix, measured in degrees, at fluid failure.
Final Brix:	Fluid Brix, measured in degrees, prior to fluid application.

Table 5.3: Log of Tests (2006-07/2007-08) – Natural Snow

Test #	Date	Run #	Fluid Name	Fluid Dil.	Fluid Type	Fluid Temp. (°C)	Test Surface	Precip. Type	Start Time	Fail Time	Endur. Time (min)	Precip. Rate (g/dm²/h)	Ambient Temp. (°C)	Wind Speed (km/h)	Initial Brix (°C)	Final Brix (°C)
1	Mar-2-07	1	Dow UCAR ADF	10°B	I	60	Aluminum	Snow	6:26:27	6:29:00	2.6	73.0	-8.1	32.0	22.00	NR
2	Mar-2-07	1	Dow UCAR ADF	10°B	I	60	White Alum.	Snow	6:26:41	6:29:00	2.3	73.0	-8.1	32.0	22.00	NR
3	Mar-2-07	1	Dow UCAR ADF	10°B	I	60	White Comp.	Snow	6:26:53	6:28:30	1.6	73.0	-8.1	32.0	22.00	NR
4	Mar-2-07	2	Dow UCAR ADF	10°B	I	60	Aluminum	Snow	7:16:39	7:18:23	1.7	80.0	-7.1	33.0	22.00	NR
5	Mar-2-07	2	Dow UCAR ADF	10°B	I	60	White Alum.	Snow	7:16:50	7:18:39	1.8	80.0	-7.1	33.0	22.00	NR
6	Mar-2-07	2	Dow UCAR ADF	10°B	I	60	White Comp.	Snow	7:17:03	7:18:14	1.2	80.0	-7.1	33.0	22.00	NR
7	Mar-2-07	3	Dow UCAR ADF	10°B	I	20	Aluminum	Snow	7:45:31	7:46:49	1.3	89.0	-7.1	33.0	22.00	NR
8	Mar-2-07	3	Dow UCAR ADF	10°B	I	20	White Alum.	Snow	7:45:43	7:46:55	1.2	89.0	-7.1	33.0	22.00	NR
9	Mar-2-07	3	Dow UCAR ADF	10°B	I	20	White Comp.	Snow	7:45:57	7:46:45	0.8	89.0	-7.1	33.0	22.00	NR
10	Mar-2-07	4	Octagon Octaflo EF	10°B	I	60	Aluminum	Snow	8:38:48	8:40:25	1.6	120.0	-6.4	37.0	24.00	NR
11	Mar-2-07	4	Octagon Octaflo EF	10°B	I	60	White Alum.	Snow	8:39:00	8:41:00	2.0	120.0	-6.4	37.0	24.00	NR
12	Mar-2-07	4	Octagon Octaflo EF	10°B	I	60	White Comp.	Snow	8:39:10	8:40:20	1.2	120.0	-6.4	37.0	24.00	NR
13	Mar-2-07	5	Octagon Octaflo EF	10°B	I	60	Aluminum	Snow	11:54:32	12:00:42	6.2	31.0	-3.1	43.0	21.50	NR
14	Mar-2-07	5	Octagon Octaflo EF	10°B	I	60	White Alum.	Snow	11:54:42	12:00:30	5.8	31.0	-3.1	43.0	21.50	NR
15	Mar-2-07	5	Octagon Octaflo EF	10°B	I	60	White Comp.	Snow	11:54:53	11:57:40	2.8	31.0	-3.1	43.0	21.50	NR
16	Mar-2-07	6	Dow UCAR ADF	10°B	I	60	Aluminum	Snow	12:54:32	13:00:11	5.7	25.0	-2.6	33.0	17.00	NR
17	Mar-2-07	6	Dow UCAR ADF	10°B	I	60	White Alum.	Snow	12:54:46	12:59:27	4.7	25.0	-2.6	33.0	17.00	NR
18	Mar-2-07	6	Dow UCAR ADF	10°B	I	60	White Comp.	Snow	12:54:56	12:58:00	3.1	25.0	-2.6	33.0	17.00	NR
19	Mar-2-07	7	Dow UCAR ADF	10°B	I	60	Aluminum	Snow	13:28:53	13:33:37	4.7	48.0	-2.3	26.0	17.00	NR
20	Mar-2-07	7	Dow UCAR ADF	10°B	I	60	White Alum.	Snow	13:29:03	13:32:52	3.8	48.0	-2.3	26.0	17.00	NR
21	Mar-2-07	7	Dow UCAR ADF	10°B	I	60	White Comp.	Snow	13:29:14	13:31:33	2.3	48.0	-2.3	26.0	17.00	NR
22	Mar-2-07	8	Dow UCAR ADF	10°B	I	60	Aluminum	Snow	14:24:02	14:30:05	6.0	34.0	-1.9	20.0	16.00	NR
23	Mar-2-07	8	Dow UCAR ADF	10°B	I	60	White Alum.	Snow	14:24:13	14:29:02	4.8	34.0	-1.9	20.0	16.00	NR
24	Mar-2-07	8	Dow UCAR ADF	10°B	I	60	White Comp.	Snow	14:24:26	14:27:30	3.1	34.0	-1.9	20.0	16.00	NR
25	Mar-2-07	9	Dow UCAR ADF	10°B	I	20	Aluminum	Snow	14:40:25	14:43:43	3.3	50.0	-1.9	20.0	16.00	NR
26	Mar-2-07	9	Dow UCAR ADF	10°B	I	20	White Alum.	Snow	14:40:36	14:43:23	2.8	50.0	-1.9	20.0	16.00	NR
27	Mar-2-07	9	Dow UCAR ADF	10°B	I	20	White Comp.	Snow	14:40:48	14:42:29	1.7	50.0	-1.9	20.0	16.00	NR
28	Mar-2-07	10	Dow UCAR ADF	10°B	I	60	Aluminum	Snow	16:01:55	16:24:00	22.1	4.0	-2.0	30.0	16.00	NR
29	Mar-2-07	10	Dow UCAR ADF	10°B	I	60	White Alum.	Snow	16:02:05	16:23:30	21.4	4.0	-2.0	30.0	16.00	NR
30	Mar-2-07	10	Dow UCAR ADF	10°B	I	60	White Comp.	Snow	16:02:15	16:20:00	17.7	4.0	-2.0	30.0	16.00	NR

Table 5.3: Log of Tests (2006-07/2007-08) – Natural Snow (cont'd)

Test #	Date	Run #	Fluid Name	Fluid Dil.	Fluid Type	Fluid Temp. (°C)	Test Surface	Precip. Type	Start Time	Fail Time	Endur. Time (min)	Precip. Rate (g/dm²/h)	Ambient Temp. (°C)	Wind Speed (km/h)	Initial Brix (°)	Final Brix (°)
31	Mar-2-07	11	Dow UCAR ADF	10°B	I	60	Aluminum	Snow	16:43:20	16:53:30	10.2	13.0	-2.0	30.0	17.00	NR
32	Mar-2-07	11	Dow UCAR ADF	10°B	I	60	White Alum.	Snow	16:43:30	16:51:45	8.3	13.0	-2.0	30.0	17.00	NR
33	Mar-2-07	11	Dow UCAR ADF	10°B	I	60	White Comp.	Snow	16:43:40	16:49:30	5.8	13.0	-2.0	30.0	17.00	NR
34	Mar-2-07	12	Dow UCAR ADF	10°B	I	60	Aluminum	Snow	17:36:26	17:47:30	11.1	12.0	-1.8	9.0	17.00	NR
35	Mar-2-07	12	Dow UCAR ADF	10°B	I	60	White Alum.	Snow	17:36:36	17:45:45	9.1	12.0	-1.8	9.0	17.00	NR
36	Mar-2-07	12	Dow UCAR ADF	10°B	I	60	White Comp.	Snow	17:36:46	17:42:30	5.7	12.0	-1.8	9.0	17.00	NR
37	Mar-16-07	1	Dow UCAR ADF	10°B	I	60	Aluminum	Snow	21:46:23	21:58:00	11.6	5.5	-7.0	41.0	20.50	NR
38	Mar-16-07	1	Dow UCAR ADF	10°B	I	60	White Alum.	Snow	21:46:35	21:57:00	10.4	5.5	-7.0	41.0	20.50	NR
39	Mar-16-07	1	Dow UCAR ADF	10°B	I	60	White Comp.	Snow	21:46:46	21:53:00	6.2	5.5	-7.0	41.0	20.50	NR
40	Mar-16-07	2	Dow UCAR ADF	10°B	I	60	Aluminum	Snow	22:21:00	22:26:20	5.3	17.0	-7.8	41.0	20.50	NR
41	Mar-16-07	2	Dow UCAR ADF	10°B	I	60	White Alum.	Snow	22:21:10	22:25:45	4.6	17.0	-7.8	41.0	20.50	NR
42	Mar-16-07	2	Dow UCAR ADF	10°B	I	60	White Comp.	Snow	22:21:20	22:25:00	3.7	17.0	-7.8	41.0	20.50	NR
43	Mar-16-07	3	Dow UCAR ADF	10°B	I	60	Aluminum	Snow	23:00:41	23:05:40	5.0	25.0	-7.6	33.0	20.50	NR
44	Mar-16-07	3	Dow UCAR ADF	10°B	I	60	White Alum.	Snow	23:00:52	23:05:00	4.1	25.0	-7.6	33.0	20.50	NR
45	Mar-16-07	3	Dow UCAR ADF	10°B	I	60	White Comp.	Snow	23:01:02	23:04:10	3.1	25.0	-7.6	33.0	20.50	NR
46	Mar-16-07	4	Dow UCAR ADF	10°B	I	60	Aluminum	Snow	23:37:30	23:43:00	5.5	21.0	-7.6	33.0	21.50	NR
47	Mar-16-07	4	Dow UCAR ADF	10°B	I	60	White Alum.	Snow	23:37:42	23:42:49	5.1	21.0	-7.6	33.0	21.50	NR
48	Mar-16-07	4	Dow UCAR ADF	10°B	I	60	White Comp.	Snow	23:37:58	23:42:00	4.0	21.0	-7.6	33.0	21.50	NR
49	Mar-17-07	5	Dow UCAR ADF	10°B	I	60	Aluminum	Snow	0:33:34	0:38:20	4.8	33.0	-7.6	37.0	22.00	NR
50	Mar-17-07	5	Dow UCAR ADF	10°B	I	60	White Alum.	Snow	0:33:46	0:38:00	4.2	33.0	-7.6	37.0	22.00	NR
51	Mar-17-07	5	Dow UCAR ADF	10°B	I	60	White Comp.	Snow	0:33:57	0:37:00	3.1	33.0	-7.6	37.0	22.00	NR
52	Mar-17-07	6	Dow UCAR ADF	10°B	I	60	Aluminum	Snow	1:25:08	1:28:40	3.5	43.0	-7.7	43.0	21.50	NR
53	Mar-17-07	6	Dow UCAR ADF	10°B	I	60	White Alum.	Snow	1:25:19	1:28:30	3.2	43.0	-7.7	43.0	21.50	NR
54	Mar-17-07	6	Dow UCAR ADF	10°B	I	60	White Comp.	Snow	1:25:30	1:28:00	2.5	43.0	-7.7	43.0	21.50	NR
55	Jan-18-08	1	Dow UCAR ADF	10°B	I	60	White Comp.	Snow	6:13:00	6:18:00	5.0	15.8	-0.3	26.0	15.00	NR
56	Jan-18-08	1	Dow UCAR ADF	10°B	I	60	White Alum.	Snow	6:12:50	6:19:30	6.7	16.0	-0.3	26.0	15.00	NR
57	Jan-18-08	1	Dow UCAR ADF	10°B	I	60	Aluminum	Snow	6:12:36	6:21:00	8.4	16.1	-0.3	26.0	15.00	NR
58	Jan-18-08	2	Dow UCAR ADF	10°B	I	60	White Comp.	Snow	7:03:40	7:07:00	3.3	23.5	-0.4	26.0	15.00	3.50
59	Jan-18-08	2	Dow UCAR ADF	10°B	I	60	White Alum.	Snow	7:03:20	7:09:00	5.7	22.7	-0.4	26.0	15.00	3.00
60	Jan-18-08	2	Dow UCAR ADF	10°B	I	60	Aluminum	Snow	7:03:00	7:12:00	9.0	20.5	-0.4	26.0	15.00	0.00

Table 5.3: Log of Tests (2006-07/2007-08) – Natural Snow (cont'd)

Test #	Date	Run #	Fluid Name	Fluid Dil.	Fluid Type	Fluid Temp. (°C)	Test Surface	Precip. Type	Start Time	Fail Time	Endur. Time (min)	Precip. Rate (g/dm²/h)	Ambient Temp. (°C)	Wind Speed (km/h)	Initial Brix (°)	Final Brix (°)
61	Jan-18-08	4	Dow UCAR PG ADF	10°B	I	60	White Comp.	Snow	8:09:10	8:19:30	10.3	6.8	2.0	20.0	20.00	1.25
62	Jan-18-08	4	Dow UCAR PG ADF	10°B	I	60	White Alum.	Snow	8:09:00	8:23:00	14.0	6.8	2.0	20.0	20.00	0.00
63	Jan-18-08	4	Dow UCAR PG ADF	10°B	I	60	Aluminum	Snow	8:08:40	No Fail	No Fail	6.8	2.0	20.0	20.00	NR
64	Jan-22-08	1	Dow UCAR ADF	10°B	I	60	White Comp.	Snow	8:21:20	8:26:00	4.7	5.2	-8.0	17.0	21.50	11.25
65	Jan-22-08	1	Dow UCAR ADF	10°B	I	60	White Alum.	Snow	8:21:05	8:28:00	6.9	4.7	-8.0	17.0	21.50	9.00
66	Jan-22-08	1	Dow UCAR ADF	10°B	I	60	Aluminum	Snow	8:20:50	8:29:00	8.2	4.6	-8.0	17.0	21.50	8.50
67	Jan-22-08	2	Dow UCAR ADF	10°B	I	60	White Comp.	Snow	9:03:22	9:07:00	3.6	7.7	-7.9	17.0	21.50	9.50
68	Jan-22-08	2	Dow UCAR ADF	10°B	I	60	White Alum.	Snow	9:03:10	9:09:30	6.3	9.8	-7.9	17.0	21.50	3.50
69	Jan-22-08	2	Dow UCAR ADF	10°B	I	60	Aluminum	Snow	9:03:00	9:10:30	7.5	10.2	-7.9	17.0	21.50	3.50
70	Jan-22-08	3	Dow UCAR ADF	10°B	I	20	White Comp.	Snow	9:52:06	9:55:30	3.4	9.0	-7.7	15.0	21.50	10.50
71	Jan-22-08	3	Dow UCAR ADF	10°B	I	20	White Alum.	Snow	9:51:40	9:55:30	3.8	9.1	-7.7	15.0	21.50	8.50
72	Jan-22-08	3	Dow UCAR ADF	10°B	I	20	Aluminum	Snow	9:51:30	9:56:30	5.0	8.3	-7.7	15.0	21.50	7.00
73	Jan-22-08	4	Dow UCAR ADF	10°B	I	60	White Comp.	Snow	10:51:35	10:55:00	3.4	11.8	-8.2	12.0	21.50	7.00
74	Jan-22-08	4	Dow UCAR ADF	10°B	I	60	White Alum.	Snow	10:51:25	10:56:00	4.6	11.8	-8.2	12.0	21.50	4.00
75	Jan-22-08	4	Dow UCAR ADF	10°B	I	60	Aluminum	Snow	10:51:15	10:56:30	5.3	11.8	-8.2	12.0	21.50	4.00
76	Jan-22-08	5	Dow UCAR ADF	10°B	I	60	White Comp.	Snow	11:52:30	11:57:00	4.5	10.9	-7.6	9.0	21.50	5.50
77	Jan-22-08	5	Dow UCAR ADF	10°B	I	60	White Alum.	Snow	11:52:15	11:58:30	6.3	10.5	-7.6	9.0	21.50	2.00
78	Jan-22-08	5	Dow UCAR ADF	10°B	I	60	Aluminum	Snow	11:52:00	11:58:45	6.7	10.5	-7.6	9.0	21.50	2.00
79	Jan-22-08	6	Dow UCAR ADF	10°B	I	60	White Comp.	Snow	15:02:30	15:10:30	8.0	3.7	-6.1	7.0	18.75	6.50
80	Jan-22-08	6	Dow UCAR ADF	10°B	I	60	White Alum.	Snow	15:02:20	15:13:00	10.7	3.5	-6.1	7.0	18.75	4.00
81	Jan-22-08	6	Dow UCAR ADF	10°B	I	60	Aluminum	Snow	15:02:10	15:14:45	12.6	3.3	-6.1	7.0	18.75	3.50
82	Feb-1-08	1	Octagon Octaflo EF	10°B	I	20	White Comp.	Snow	12:10:00	12:13:00	3.0	8.4	-7.6	26.0	25.00	19.00
83	Feb-1-08	1	Octagon Octaflo EF	10°B	I	20	White Alum.	Snow	12:09:45	12:14:00	4.3	8.9	-7.6	26.0	25.00	18.50
84	Feb-1-08	1	Octagon Octaflo EF	10°B	I	20	Aluminum	Snow	12:09:30	12:14:30	5.0	9.0	-7.6	26.0	25.00	18.00
85	Feb-1-08	2	Octagon Octaflo EF	10°B	I	60	White Comp.	Snow	12:29:45	12:33:00	3.3	22.1	-7.6	26.0	25.00	4.50
86	Feb-1-08	2	Octagon Octaflo EF	10°B	I	60	White Alum.	Snow	12:29:30	12:33:45	4.3	21.9	-7.6	26.0	25.00	11.00
87	Feb-1-08	2	Octagon Octaflo EF	10°B	I	60	Aluminum	Snow	12:29:15	12:33:45	4.5	21.8	-7.6	26.0	25.00	10.50
88	Feb-1-08	3	Octagon Octaflo EF	10°B	I	60	White Comp.	Snow	12:58:15	13:00:30	2.3	26.1	-7.4	33.0	25.00	8.75
89	Feb-1-08	3	Octagon Octaflo EF	10°B	I	60	White Alum.	Snow	12:57:55	13:01:00	3.1	26.1	-7.4	33.0	25.00	7.25
90	Feb-1-08	3	Octagon Octaflo EF	10°B	I	60	Aluminum	Snow	12:57:40	13:01:00	3.3	26.1	-7.4	33.0	25.00	7.50

Table 5.3: Log of Tests (2006-07/2007-08) – Natural Snow (cont'd)

Test #	Date	Run #	Fluid Name	Fluid Dil.	Fluid Type	Fluid Temp. (°C)	Test Surface	Precip. Type	Start Time	Fail Time	Endur. Time (min)	Precip. Rate (g/dm²/h)	Ambient Temp. (°C)	Wind Speed (km/h)	Initial Brix (°)	Final Brix (°)
91	Feb-5-08	1	Dow UCAR ADF	10°B	I	60	White Comp.	Snow	3:58:00	4:02:30	4.5	10.2	-4.9	22.0	18.50	11.00
92	Feb-5-08	1	Dow UCAR ADF	10°B	I	60	White Alum.	Snow	3:57:45	4:04:00	6.2	10.4	-4.9	22.0	18.50	7.00
93	Feb-5-08	1	Dow UCAR ADF	10°B	I	60	Aluminum	Snow	3:57:30	4:04:30	7.0	10.4	-4.9	22.0	18.50	6.00
94	Feb-9-08	1	Octagon Octaflo EF	10°B	I	60	White Comp.	Snow	20:54:20	20:59:00	4.7	8.2	-3.7	17.0	23.00	14.50
95	Feb-9-08	1	Octagon Octaflo EF	10°B	I	60	White Alum.	Snow	20:54:10	21:02:00	7.8	8.1	-3.7	17.0	23.00	9.00
96	Feb-9-08	1	Octagon Octaflo EF	10°B	I	60	Aluminum	Snow	20:54:00	21:03:00	9.0	7.9	-3.7	17.0	23.00	7.00
97	Feb-13-08	1	Octagon Octaflo EF	10°B	I	60	White Comp.	Snow	4:08:35	4:09:30	0.9	36.4	-12.6	26.0	29.50	12.00
98	Feb-13-08	1	Octagon Octaflo EF	10°B	I	60	White Alum.	Snow	4:08:15	4:10:30	2.2	40.2	-12.6	26.0	29.50	7.00
99	Feb-13-08	1	Octagon Octaflo EF	10°B	I	60	Aluminum	Snow	4:08:05	4:10:30	2.4	39.6	-12.6	26.0	29.50	8.00

NR = no reading

5.3.2 Summary of Tests Conducted

Comparative endurance time testing was conducted with Type I fluids in natural snow using various fluids. Table 5.4 lists the number of comparative test runs completed by the different fluid application temperatures. As illustrated in the table, most tests were conducted with fluid applied at 60°C.

Table 5.4: Summary of 2006-07/2007-08 Test Runs

Fluid Type / Temperature	# Comparative Test Runs
Type I Heated (20°C)	4
Type I Heated (60°C)	29
TOTAL	**33**

5.3.3 Natural Snow Weather Conditions

A total of 33 comparative tests (99 individual tests) were conducted in natural snow. Distribution graphs of the snow tests conducted by precipitation rate and wind speed are shown in Figures 5.2 and 5.3, respectively. Figure 5.2 shows that 24 percent of the tests were conducted in light or very light snow (precipitation rates below 10 $g/dm^2/h$). Figure 5.3 shows 55 percent of the tests were conducted when wind speeds were less than 28 km/h.

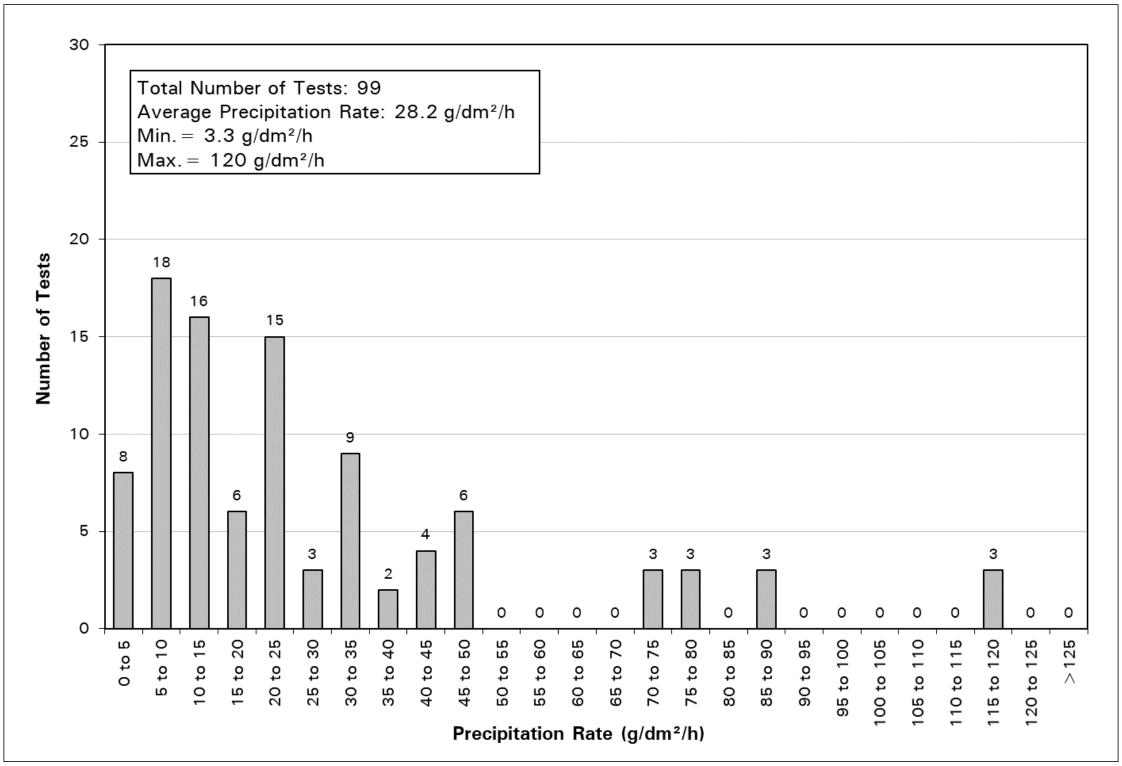


Figure 5.2: Distribution of Precipitation Rate – 2006-07/2007-08 Snow Tests

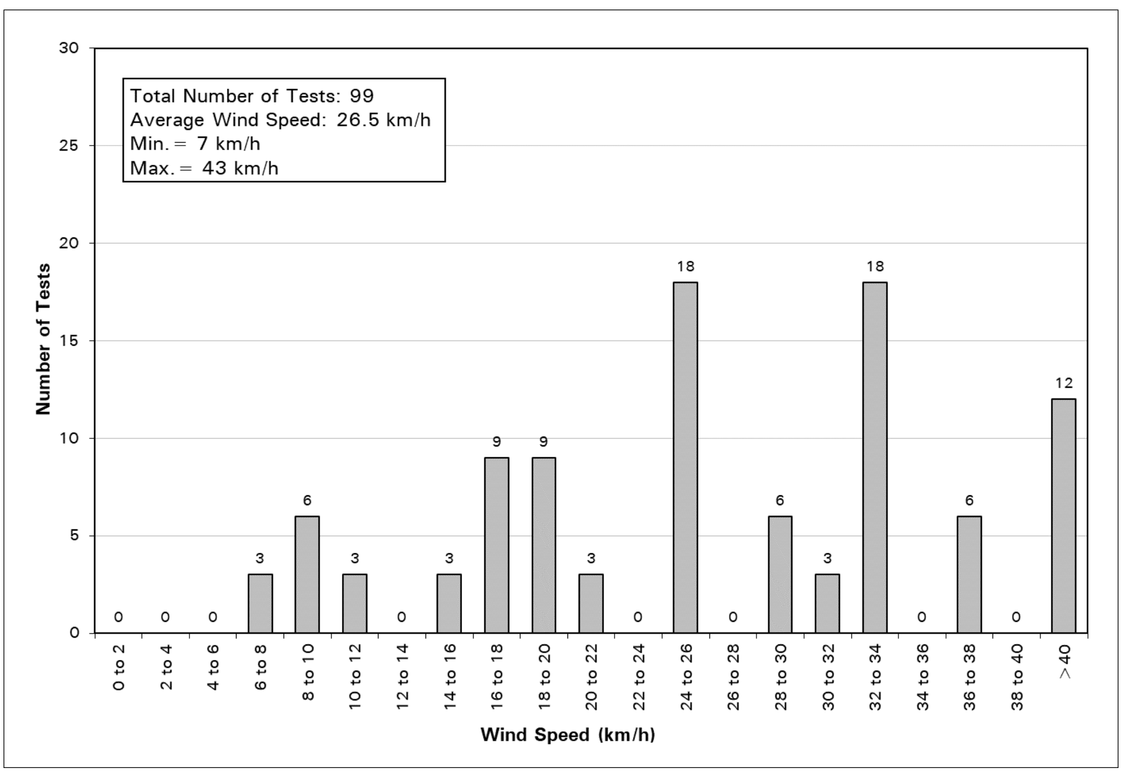


Figure 5.3: Distribution of Wind Speed – 2006-07/2007-08 Snow Tests

5.3.4 Surface Temperature Profiles

Several parameters were documented during each fluid endurance time test conducted. Data collected pertaining to fluid dilution (fluid Brix) was measured at set intervals for the duration of the test, while surface temperature was logged on an ongoing basis. The surface temperature data was used to construct charts to better illustrate the aluminum and composite test surface temperature profiles. The charts are included in Appendix F.

5.4 Analysis and Observations

An analysis of the relative endurance time performance of fluids on composite surfaces is presented in the following subsections. An observation of factors that likely contribute to the results is provided in Subsection 5.4.5.

5.4.1 Comparative Bar Charts

The data from the 33 comparative tests conducted is presented in bar charts in this subsection. There is one bar chart provided for tests conducted with fluids heated to 60°C (Figure 5.4) and one bar chart provided for tests conducted with fluids heated to 20°C (Figure 5.5).

Adjacent sets of bars represent the endurance time (in minutes) measured using the painted aluminum and composite test surfaces. Pertinent information for each comparative test – fluid, OAT, and rate of precipitation (calculated with respect to the white aluminum test plate) – is labelled at the bottom of each pair of bars.

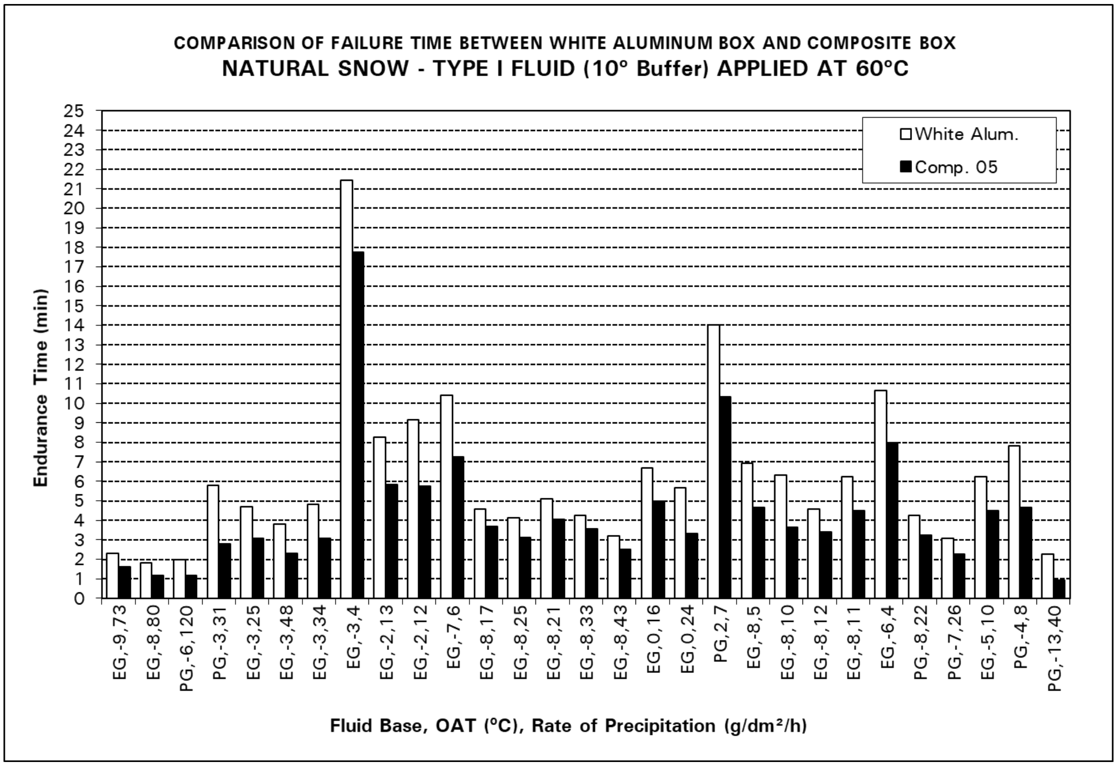


Figure 5.4: Endurance Time Comparison – Type I Fluid, 60°C, Natural Snow

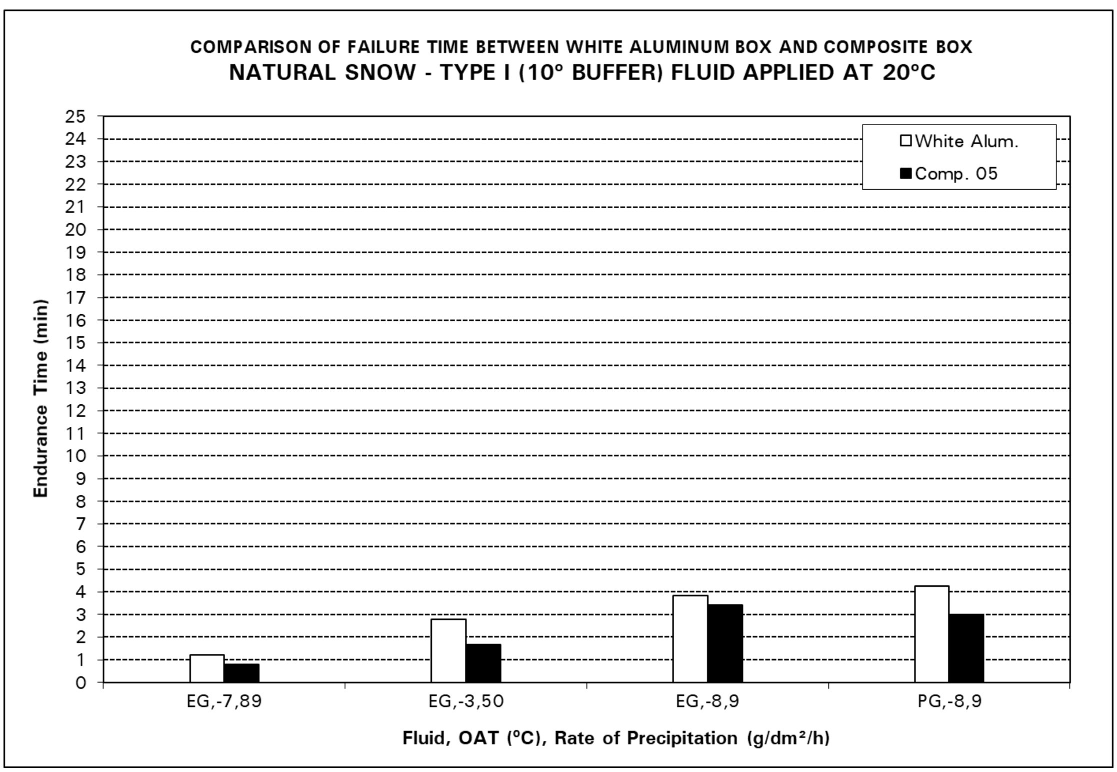


Figure 5.5: Endurance Time Comparison – Type I Fluid, 20°C, Natural Snow

5.4.2 Ratio Analysis: Composite vs. White-Painted Aluminum

A comparative analysis was completed to determine the relationship between fluid endurance times measured on composite LETE boxes and on aluminum LETE boxes. For each test run, the fluid endurance time measured on the composite LETE box was compared to the fluid endurance time measured on the white-painted aluminum LETE box.

Table 5.5 contains the data used in the analysis. Within the table, the data has been separated by fluid application temperature. For each comparative test, the pertinent test numbers are provided, as well as the aluminum endurance time, composite endurance time, endurance time ratio, and endurance time difference (in minutes).

On average, endurance times measured on the composite box were 31 percent ± 10 percent shorter than endurance times measured on the white aluminum box.

5.4.3 Ratio Analysis: Composite vs. Unpainted Aluminum

In order to verify the correlation between the white-painted composite LETE box and the unpainted aluminum LETE box (which is the standard test surface used to derive Type I holdover times), the analysis described in Subsection 4.3 was repeated using the unpainted aluminum LETE box endurance times in place of the painted aluminum endurance times.

Table 5.6 demonstrates the results obtained. On average, endurance times measured on the composite box were 40 percent shorter than endurance times measured on the unpainted aluminum box. This result indicates that although the composite material accounts for the greater part of the reduction in Type I endurance time, the white paint also reduces Type I endurance time. This is important when considering changes to Type I holdover times, as current aircraft construction always has composite surfaces painted, whereas aluminum surfaces can sometimes be left bare, or unpainted.

Table 5.5: Comparative Endurance Time Analysis – White Aluminum vs. Composite

Test #	White Composite Endurance Time (min)	White Aluminum Endurance Time (min)	Endurance Time Ratio [White Comp. / White Alum.]	Endurance Time Difference (min) [White Comp. - White Alum.]
Type I Fluid Heated to 60ºC				
2-3	1.6	2.3	70%	-0.7
5-6	1.2	1.8	65%	-0.6
11-12	1.2	2.0	58%	-0.8
14-15	2.8	5.8	48%	-3.0
17-18	3.1	4.7	65%	-1.6
20-21	2.3	3.8	61%	-1.5
23-24	3.1	4.8	64%	-1.7
29-30	17.7	21.4	83%	-3.7
32-33	5.8	8.3	71%	-2.4
35-36	5.7	9.1	63%	-3.4
38-39	6.2	10.4	69%	-3.2
41-42	3.7	4.6	80%	-0.9
44-45	3.1	4.1	76%	-1.0
47-48	4.0	5.1	79%	-1.1
50-51	3.1	4.2	84%	-0.7
53-54	2.5	3.2	79%	-0.7
55-56	5.0	6.7	75%	-1.7
58-59	3.3	5.7	59%	-2.3
61-62	10.3	14.0	74%	-3.7
64-65	4.7	6.9	67%	-2.2
67-68	3.6	6.3	57%	-2.7
73-74	3.4	4.6	75%	-1.2
76-77	4.5	6.3	72%	-1.8
79-80	8.0	10.7	75%	-2.7
85-86	3.3	4.3	76%	-1.0
88-89	2.3	3.1	73%	-0.8
91-92	4.5	6.2	72%	-1.7
94-95	4.7	7.8	60%	-3.2
97-98	0.9	2.2	41%	-1.3
		Average	69%	-1.8
		Std Dev	10%	1.0
Type I Fluid Heated to 20ºC				
8-9	0.8	1.2	67%	-0.4
26-27	1.7	2.8	60%	-1.1
70-71	3.4	3.8	89%	-0.4
82-83	3.0	4.3	71%	-1.3
		Average	64%	-0.7
		Std Dev	12%	0.4
		Total Average	**69%**	**-1.7**
		Total Std Dev	**10%**	**1.0**

Table 5.6: Comparative Endurance Time Analysis – Unpainted Aluminum vs. Composite

Test #	White Composite Endurance Time (min)	Unpainted Aluminum Endurance Time (min)	Endurance Time Ratio [Comp. / White Alum.]	Endurance Time Difference (min) [White Comp. – Alum.]
Type I Fluid Heated to 60ºC				
1,3	1.6	2.6	62%	-1.0
4,6	1.2	1.7	70%	-0.5
10,12	1.2	1.6	73%	-0.4
13,15	2.8	6.2	45%	-3.4
16,18	3.1	5.7	54%	-2.6
19,21	2.3	4.7	49%	-2.4
22,24	3.1	6.0	51%	-2.9
28,30	17.7	22.1	80%	-4.4
31,33	5.8	10.2	57%	-4.4
34,36	5.7	11.1	52%	-5.4
37,39	6.2	11.6	53%	-5.4
40,42	3.7	5.3	69%	-1.6
43,45	3.1	5.0	63%	-1.9
46,48	4.0	5.5	73%	-1.5
49,51	3.1	4.8	65%	-1.7
52,54	2.5	3.5	71%	-1.0
57,55	5.0	8.4	60%	-3.4
60,58	3.3	9.0	37%	-5.7
63,61	10.3	N/A		
66,64	4.7	8.2	57%	-3.5
69,67	3.6	7.5	48%	-3.9
75,73	3.4	5.3	64%	-1.9
78,76	4.5	6.7	67%	-2.2
81,79	8.0	12.6	63%	-4.6
87,85	3.3	4.5	72%	-1.2
90,88	2.3	3.3	68%	-1.0
93,91	4.5	7.0	64%	-2.5
96,94	4.7	9.0	52%	-4.3
99,97	0.9	2.4	38%	-1.5
		Average	60%	-2.7
		Std Dev	11%	1.6
Type I Fluid Heated to 20ºC				
7,9	0.8	1.3	62%	-0.5
25,27	1.7	3.3	51%	-1.6
72,70	3.4	5.0	68%	-1.6
84,82	3.0	5.0	60%	-2.0
		Average	60%	-1.4
		Std Dev	7%	0.6
		Average	**60%**	**-2.6**
		Total Std Dev	**10%**	**1.5**

5.4.4 Comparison of 2006-07/2007-08 and 2005-06 Results

The 2006-07/2007-08 testing with Type I fluids heated to 60°C provided fluid endurance times that were on average 31 percent shorter on composite LETE boxes than on white aluminum LETE boxes.

Similar testing had been conducted in 2005-06 with Type I fluids heated to 60°C but applied to flat plates. The results from that testing provided fluid endurance times that were on average 29 percent shorter on composite plates than on aluminum plates.

The 2006-07/2007-08 testing therefore confirms the earlier reductions seen in Type I holdover times in natural snow, and confirms the reproducibility of the reductions using the current Type I protocol.

5.4.5 Factors Contributing to Shorter Type I Endurance Times on Composite Surfaces

Several factors are believed to contribute to the shorter endurance times of Type I fluids on composite surfaces. An examination of surface temperature and fluid dilution shows that, in general, composite test surfaces rise to temperatures slightly lower than white aluminum surfaces. The white aluminum surface also retains the heat for slightly longer. The latter was linked to the following factors and is visually described in Figure 5.6.

5.4.5.1 Material Thermal Conductivity

Aluminum materials behave as thermal energy conductors, whereas composite materials behave as thermal energy insulators. The aluminum surface absorbs a greater amount of heat provided by the heated fluid in comparison to the composite surface; following fluid application, the aluminum surface will attain a peak temperature greater than the composite surfaces.

5.4.5.2 Fluid Enrichment

Previous tests have shown that heated fluids will undergo fluid enrichment when applied to a colder surface. The extent of fluid enrichment is a direct function of the difference in temperature between fluid and surface, and, in this case, more significantly, the increase in temperature of the treated surface. Due to the greater temperature increase on the aluminum surface, the fluid applied to that surface will undergo a greater amount of fluid enrichment and will consequently be slightly higher in glycol concentration than fluid on the composite surface.

5.4.5.3 Surface Temperature Stabilization

Following fluid application, the aluminum surface will attain a higher peak temperature than the composite surface. When cooling begins, the temperature of the composite surface will stabilize towards the OAT more quickly than the aluminum surface. As a result, the fluid on the composite surface will be subjected to earlier freezing.

5.4.5.4 Fluid Dilution

Following fluid application, glycol concentration on the aluminum surface is greater than that on the composite surface due to fluid enrichment. As a result, the fluid on the aluminum surface will be able to absorb a greater amount of water from the precipitation. The composite surface fluid will dilute and reach its fluid freezing point more quickly, and, as a result, will be subject to earlier freezing and fluid failure.

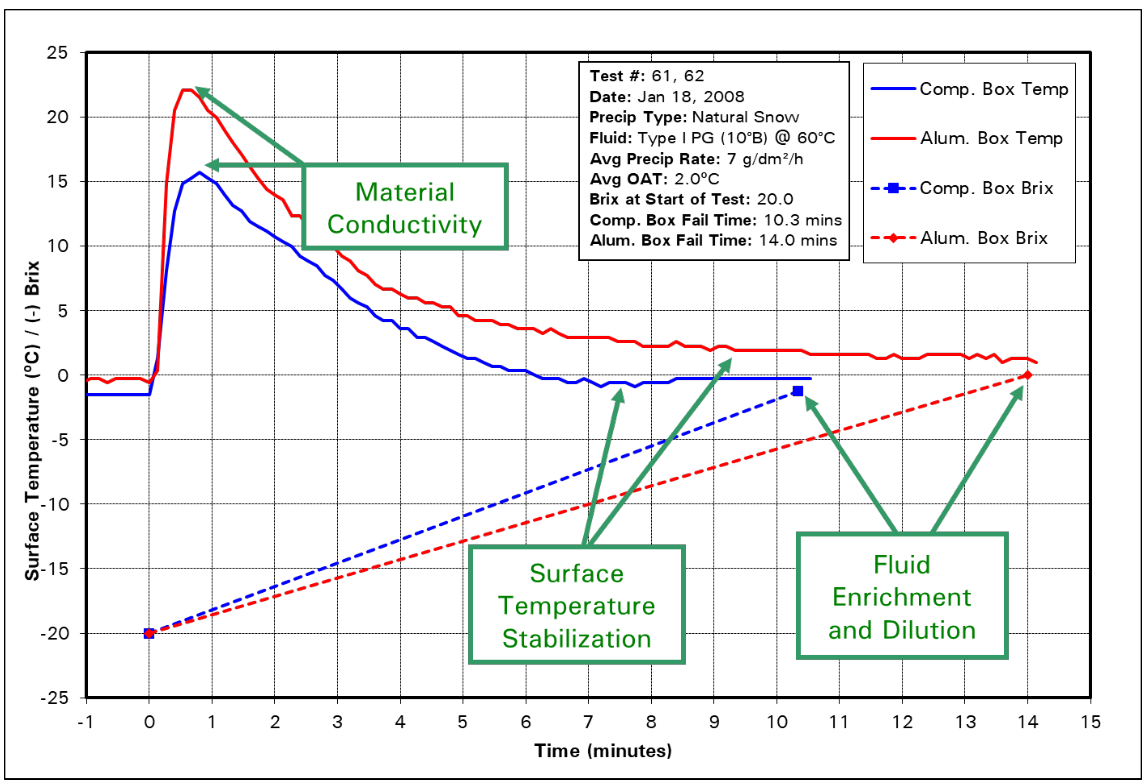


Figure 5.6: Effect of Heat on Type I Endurance Times on Composite Surfaces

5.4.5.5 Summary

The lower fluid endurance times of heated Type I fluids on composite LETE boxes was linked to the four factors described above: material conductivity, fluid enrichment, surface temperature stabilization, and fluid dilution.

It should be noted that although this trend was prominent with Type I heated fluids in natural snow due to their relatively short endurance times, it was also seen during the natural frost testing conducted with Type I fluids during the winter of 2005-06.

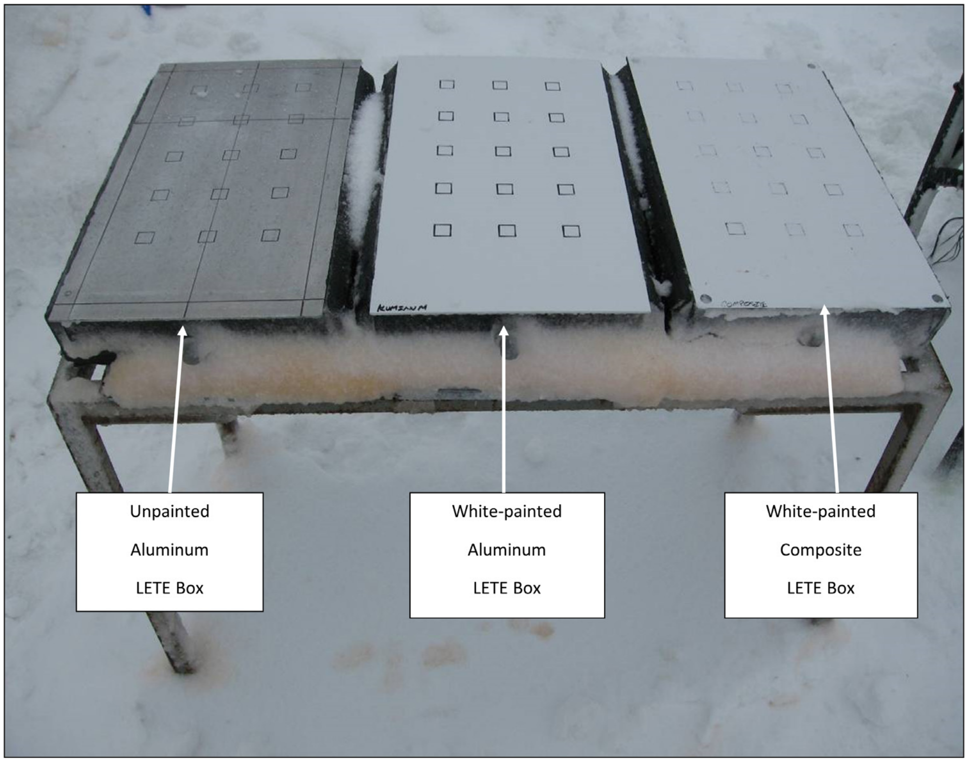
Previous testing conducted during the winter of 2005-06 with Type II/III/IV heated fluids demonstrated similar behaviour. However, due to the longer fluid protection time provided by the more viscous fluids, the differences in endurance times were smaller; discrepancies were considered minimal and within experimental error.

5.5 Conclusions and Recommendations

The results derived from the natural snow testing conducted with Type I fluids on LETE boxes in the winters of 2006-07 and 2007-08 confirmed the reductions in endurance times seen on composite surfaces in the winter of 2005-06 when tests were conducted on flat plates.

It was recommended that changes be made to the holdover time guidelines to account for the reductions. Consultation with industry was recommended to determine the best way to incorporate the changes.

Photo 5.1: Test Setup (2006-07 and 2007-08)



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6. 2008-09 RESEARCH

This section documents the composite surface research that was conducted in the winter of 2008-09. This research was first documented in an interim report, which was provided to Transport Canada and the FAA.

6.1 Objective

Testing conducted with Type I fluids in simulated freezing precipitation in the winter of 2005-06 showed fluid endurance times on composite surfaces were shorter than fluid endurance times on aluminum surfaces. Most of this testing was carried out using fluids heated to 60°C.

The objective of the composite project in 2008-09 was to determine if the 2005-06 results could be replicated using the current Type I protocol, which, in simulated freezing precipitation, requires testing to be conducted with fluids applied at 20°C.

6.2 Methodology

The methodology used for conducting composite testing is described in Section 2. Additional details specific to the testing conducted in 2008-09 are provided in this section.

6.2.1 Test Surfaces

Three test surfaces were used in the winter of 2008-09. All were tested in standard flat plate configuration. The test surface materials and finishes are detailed in Table 6.1. Refer to Photo 2.5 for a picture of the aluminum flat plate and Photo 2.6 for a picture of the white composite flat plate.

Table 6.1: Test Surfaces Used in 2008-09 Testing

Name	Surface Material	Finish
1. Aluminum Flat Plate	Alclad 2024	Unpainted
2. White Aluminum Flat Plate	Alclad 2024	White-painted
3. White Composite Flat Plate	Comp 05*	White-painted

* Carbon fibre cross weave fabric (see Table 4.1)

The white aluminum surface provided the baseline results to which the white composite surface results were compared. The aluminum surface results represented a standard holdover time test result. Tests on the aluminum surface were conducted for reference only.

6.2.2 Test Procedure

In 2008-09, comparative endurance time testing was carried out with Type I fluids in simulated freezing precipitation (freezing drizzle and light freezing rain). Testing was conducted in conjunction with holdover time testing.

The test procedure that was developed and used in 2005-06 for endurance time testing of composite surfaces in freezing precipitation was used again in 2008-09. The procedure, entitled *Experimental Program: Indoor Endurance Time Testing on Non-Aluminum Plates*, is provided in Appendix D. The one change that was made to the procedure was that all tests were carried out using fluids heated to 20°C rather than 60°C, as was done in 2005-06. This change was to enable tests to be conducted according to the current Type I protocol.

Each test run consisted of three tests: one on each of the three test surfaces described in Subsection 6.2.1 (aluminum, white aluminum, white composite). Tests were conducted simultaneously on the white aluminum and composite surfaces; the aluminum test was conducted independently, as it was part of holdover time testing.

Figure 6.1 shows the test setup, including the test surfaces, fluid quantities, fluid temperatures, and application methods used. The test setup is also shown in Photo 6.1.

Position HOT	Position 1	Position 2
Aluminum	White Alum.	White Composite
Flat Plate	Flat Plate	Flat Plate
1 L of Fluid	1 L of Fluid	1 L of Fluid
Apply at 20°C	Apply at 20°C	Apply at 20°C
Spreader	Spreader	Spreader

Figure 6.1: Test Setup (2008-09)

6.2.3 Fluids

In 2008-09, only Type I fluids were tested. The fluids were tested at a 10°C buffer; each fluid was mixed to a freezing point 10°C below the prevailing OAT for each test. Table 6.2 lists the fluids tested.

Table 6.2: Fluids Used in 2008-09 Testing

Fluid Type	Fluid Name	Fluid Base
Type I	Dow UCAR ADF	Ethylene-glycol
Type I	Octagon Octaflo EF	Propylene-glycol

6.3 Data

The data collected from the tests is presented in the following subsections.

6.3.1 Log of Tests

A log was created to document the results of testing carried out in 2008-09. The log, presented in Table 6.3, provides relevant information for each test. Each row contains data specific to one test. Below is a brief description of each column heading in the log.

Test #: Exclusive number identifying each test.

Date: Date when the test was conducted.

Run #: Run number in which the test was performed.

Fluid Name: Fluid manufacturer and fluid brand name.

Fluid Dil.: Fluid dilution (10°B = fluid mixed to a freezing point 10°C below the ambient temperature).

Fluid Type: SAE designated fluid type.

Fluid Temp.: Fluid temperature prior to application, measured in °C.

Test Surface: Test plate material: unpainted aluminum (Std. Al.), white-painted composite (Comp 05) or white-painted aluminum (White Al.).

Ambient Temp.:	Desired average ambient temperature in climatic chamber, measured in °C.
Precip. Type:	Simulated precipitation type during each test.
Start Time:	Start time for the test, recorded in local time.
Fail Time:	Fluid failure time, recorded in local time.
Endurance Time:	Fluid endurance time, measured in minutes.
Precip. Rate:	Precipitation rate, measured in $g/dm^2/h$, collected by using standard indoor holdover time rate measurement procedure.
Initial Brix:	Fluid Brix, measured in degrees, at fluid failure.
Final Brix:	Fluid Brix, measured in degrees, prior to fluid application.

Table 6.3: 2008-09 Log of Tests (Simulated Freezing Precipitation)

Test #	Date	Run #	Fluid Name	Fluid Dil.	Fluid Type	Fluid Temp. (°C)	Test Surface	Ambient Temp. (°C)	Precip. Type	Start Time	Fail Time	Endur. Time (min)	Precip. Rate (g/dm²/h)	Initial Brix (°)	Final Brix (°)
1	Mar-30-09	1	Octagon Octaflo	10°B	I	20	White Al.	-10	Light Freezing Rain	10:38:25	10:45:15	6.8	13.2	26.75	4.75
2	Mar-30-09	1	Octagon Octaflo	10°B	I	20	Comp 05	-10	Light Freezing Rain	10:38:44	10:45:20	6.6	13.0	26.75	5.00
3	Mar-30-09	1	Octagon Octaflo	10°B	I	20	Std. Al.	-10	Light Freezing Rain	10:39:09	10:46:00	6.9	13.7	26.75	4.50
4	Mar-30-09	2	Octagon Octaflo	10°B	I	20	White Al.	-10	Light Freezing Rain	14:18:48	14:24:30	5.7	28.1	26.75	1.00
5	Mar-30-09	2	Octagon Octaflo	10°B	I	20	Comp 05	-10	Light Freezing Rain	14:19:09	14:23:30	4.4	27.6	26.75	1.50
6	Mar-30-09	2	Octagon Octaflo	10°B	I	20	Std. Al.	-10	Light Freezing Rain	14:18:25	14:23:30	5.1	26.6	26.75	2.00
7	Mar-30-09	3	Octagon Octaflo	10°B	I	20	White Al.	-10	Freezing Drizzle	19:27:04	19:33:00	5.9	16.3	26.75	4.00
8	Mar-30-09	3	Octagon Octaflo	10°B	I	20	Comp 05	-10	Freezing Drizzle	19:26:25	19:31:00	4.6	12.4	26.75	4.00
9	Mar-30-09	3	Octagon Octaflo	10°B	I	20	Std. Al.	-10	Freezing Drizzle	19:27:41	19:33:00	5.3	15.9	26.75	1.00
10	Mar-31-09	4	Dow UCAR ADF	10°B	I	20	White Al.	-10	Freezing Drizzle	18:10:37	18:18:30	7.9	7.9	22.90	3.00
11	Mar-31-09	4	Dow UCAR ADF	10°B	I	20	Comp 05	-10	Freezing Drizzle	18:11:04	18:16:45	5.7	6.9	22.90	4.00
12	Mar-31-09	4	Dow UCAR ADF	10°B	I	20	Std. Al.	-10	Freezing Drizzle	18:11:36	18:19:30	7.9	6.1	22.90	5.00
13	Apr-1-09	5	Octagon Octaflo	10°B	I	20	White Al.	-3	Light Freezing Rain	9:13:28	9:25:45	12.3	23.7	21.50	1.00
14	Apr-1-09	5	Octagon Octaflo	10°B	I	20	Comp 05	-3	Light Freezing Rain	9:13:57	9:22:30	8.5	24.8	21.50	1.50
15	Apr-1-09	5	Octagon Octaflo	10°B	I	20	Std. Al.	-3	Light Freezing Rain	9:12:57	9:25:20	12.4	25.8	21.50	0.50
16	Apr-1-09	6	Octagon Octaflo	10°B	I	20	White Al.	-3	Light Freezing Rain	17:15:45	17:28:30	12.8	13.6	21.50	0.50
17	Apr-1-09	6	Octagon Octaflo	10°B	I	20	Comp 05	-3	Light Freezing Rain	17:16:25	17:27:00	10.6	12.8	21.50	0.50
18	Apr-1-09	6	Octagon Octaflo	10°B	I	20	Std. Al.	-3	Light Freezing Rain	17:15:20	17:27:30	12.2	14.1	21.50	1.25
19	Apr-2-09	7	Dow UCAR ADF	10°B	I	20	White Al.	-3	Freezing Drizzle	11:01:30	11:13:30	12.0	14.7	17.60	1.00
20	Apr-2-09	7	Dow UCAR ADF	10°B	I	20	Comp 05	-3	Freezing Drizzle	11:00:00	11:10:00	10.0	13.5	17.60	1.50
21	Apr-2-09	7	Dow UCAR ADF	10°B	I	20	Std. Al.	-3	Freezing Drizzle	11:00:50	11:12:00	11.2	15.3	17.60	1.25
22	Apr-2-09	8	Octagon Octaflo	10°B	I	20	White Al.	-3	Freezing Drizzle	15:09:50	15:24:30	14.7	7.2	21.50	2.25
23	Apr-2-09	8	Octagon Octaflo	10°B	I	20	Comp 05	-3	Freezing Drizzle	15:10:25	15:22:00	11.6	6.9	21.50	2.25
24	Apr-2-09	8	Octagon Octaflo	10°B	I	20	Std. Al.	-3	Freezing Drizzle	15:09:20	15:22:30	13.2	7.4	21.50	2.50

6.3.2 Summary of Tests Conducted

Comparative endurance time testing was conducted with Type I fluids in light freezing rain and freezing drizzle at several ambient temperatures. Table 6.4 lists the number of comparative test runs completed in each simulated weather condition.

Table 6.4: Summary of 2008-09 Test Runs

Fluid Type / Temperature	Condition	# Comparative Test Runs
Type I Heated (20°C)	Light Freezing Rain (-10°C)	2
Type I Heated (20°C)	Light Freezing Rain (-3°C)	2
Type I Heated (20°C)	Freezing Drizzle (-10°C)	2
Type I Heated (20°C)	Freezing Drizzle (-3°C)	2
TOTAL		**8**

6.3.3 Fluid Brix and Surface Temperature Data

Several parameters were documented during each fluid endurance time test conducted. Data collected pertaining to fluid dilution (fluid Brix) was measured prior to fluid application, while plate surface temperature was logged on an ongoing basis. The temperature data has been archived and is available; however, it has not been included in this report.

6.4 Analysis and Observations

An analysis of the relative endurance time performance of fluids on composite surfaces (Subsections 6.4.1 and 6.4.2) and a comparison of these results to the results obtained in similar testing in 2005-06 (Subsection 6.4.3) are provided.

6.4.1 Comparative Bar Chart

The data from the 8 comparative tests conducted in the winter of 2008-09 is presented in the bar chart shown in Figure 6.2. Adjacent sets of bars represent the endurance time (in minutes) measured using the white aluminum and composite test surface. Pertinent information for each comparative test – precipitation type, ambient temperature, and rate of precipitation (expected average rate) – is labelled below each pair of bars.

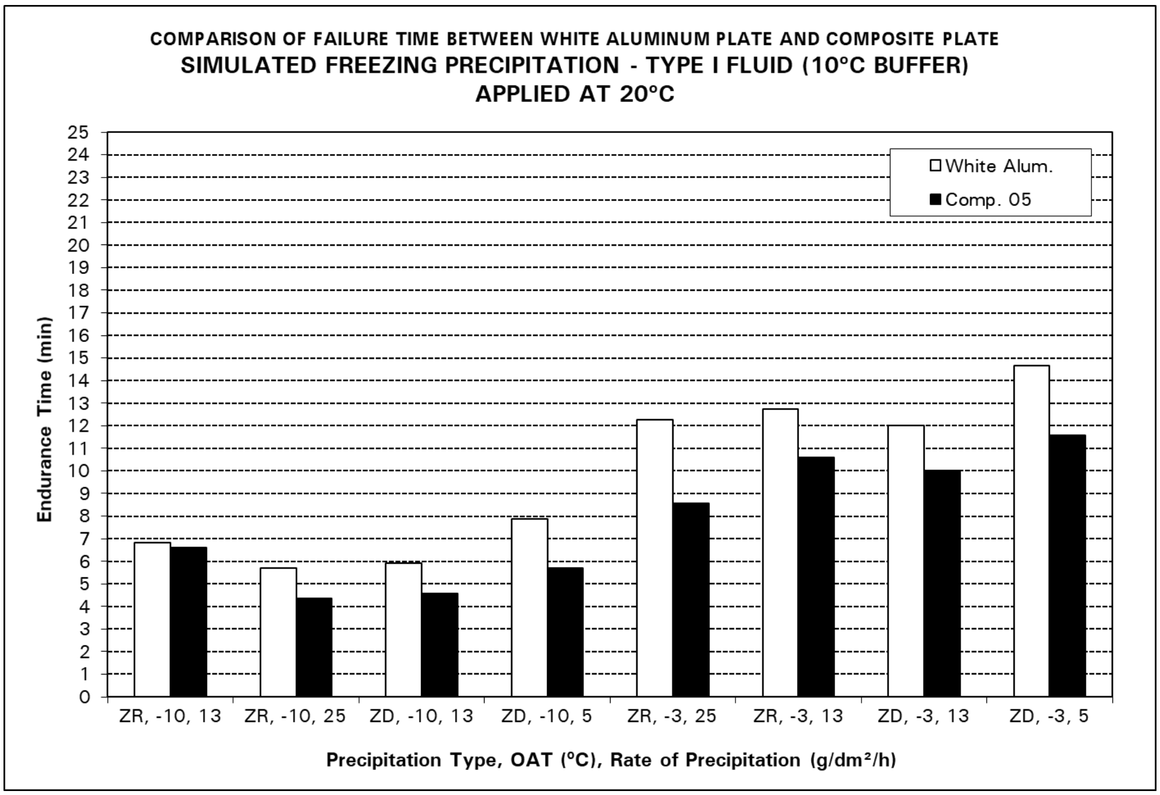


Figure 6.2: Endurance Time Comparison – Type I Fluid, 20°C, Freezing Precipitation

6.4.2 Ratio Analysis

A comparative analysis was completed to determine the relationship between the fluid endurance times measured on composite test surfaces and on white-painted aluminum test surfaces. The data used in the analysis is shown in Table 6.2.

For each comparative test, the pertinent test numbers are provided, as well as the composite endurance time, aluminum endurance time, endurance time ratio, and absolute endurance time difference (in minutes).

The results indicate Type I endurance times in freezing precipitation are 20 percent ± 8 percent shorter on white-painted composite surfaces than on white-painted aluminum surfaces.

Table 6.5: Endurance Time Analysis – Simulated Freezing Precipitation

Test #	White Composite Plate Endurance Time (min)	White Aluminum Plate Endurance Time (min)	Endurance Time % Ratio [Comp / Alum.]	Endurance Time Difference (min.) [Comp - Alum.]
Type I Fluid Heated to 20°C				
1-2	6.6	6.8	97%	-0.2
4-5	4.4	5.7	76%	-1.4
7-8	4.6	5.9	77%	-1.3
10-11	5.7	7.9	72%	-2.2
13-14	8.5	12.3	70%	-3.7
16-17	10.6	12.8	83%	-2.2
19-20	10.0	12.0	83%	-2.0
22-23	11.6	14.7	79%	-3.1
		Average:	80%	-2.0
		Std Deviation:	8%	1.1

6.4.3 Comparison of 2008-09 Results to 2005-06 Results

The 2008-09 testing with Type I fluids heated to 20°C indicates that fluid endurance times are on average 20 percent shorter on white composite plates than on white aluminum plates in freezing precipitation conditions.

Similar testing was conducted in 2005-06 with Type I fluids heated to 60°C. The results from that testing provided fluid endurance times on average 24 percent shorter on white composite plates than on white aluminum plates.

These results indicate that the added heat provided by the warmer 60°C fluid generates longer endurance times; however, the added heat may also produce slightly greater reductions to the endurance times measured on the composite surface relative to the aluminum surface.

It should be noted that the difference in composite versus aluminum endurance times was less than 5 minutes in all but two of the 2005-06 and 2008-09 tests. When considering the short Type I endurance times and the resulting impact of experimental error on these short tests, the average differences in the two data sets (2005-06 and 2008-09) can be considered negligible.

Combining both Type I data sets (2005-06 and 2008-09) shows composite endurance times are on average 23 percent shorter than aluminum endurance times. These results are in accordance with the results obtained during natural snow and natural frost testing using various composite flat plates and LETE boxes.

6.5 Conclusions and Recommendations

The results derived from the freezing precipitation testing conducted in 2008-09 using the current Type I test protocol (fluids heated to 20°C) confirmed the reductions in Type I endurance times seen on composite surfaces in the winter of 2005-06 when tests were conducted with fluids heated to 60°C.

As a result of the combined research findings from the winters of 2004-05 to 2008-09, which concluded that Type I holdover times are reduced on composite surfaces, and as a result of feedback from industry, it was recommended that comprehensive Type I endurance time testing be conducted to develop holdover times for use with composite materials. It was recommended that the testing be conducted with several representative fluids and carried out according to the protocol provided by ARP5945 in all conditions for which Type I holdover times are provided: freezing fog, snow, freezing drizzle, light freezing rain, rain on a cold-soaked wing, and frost.

6.6 Changes to Guidance Materials

Regulators provided interim guidance for composite surfaces for the winter of 2009-10. Transport Canada provided this guidance by adding a paragraph to TP 14052, which was published in the 2009-10 holdover time guidelines. The paragraph is excerpted below.

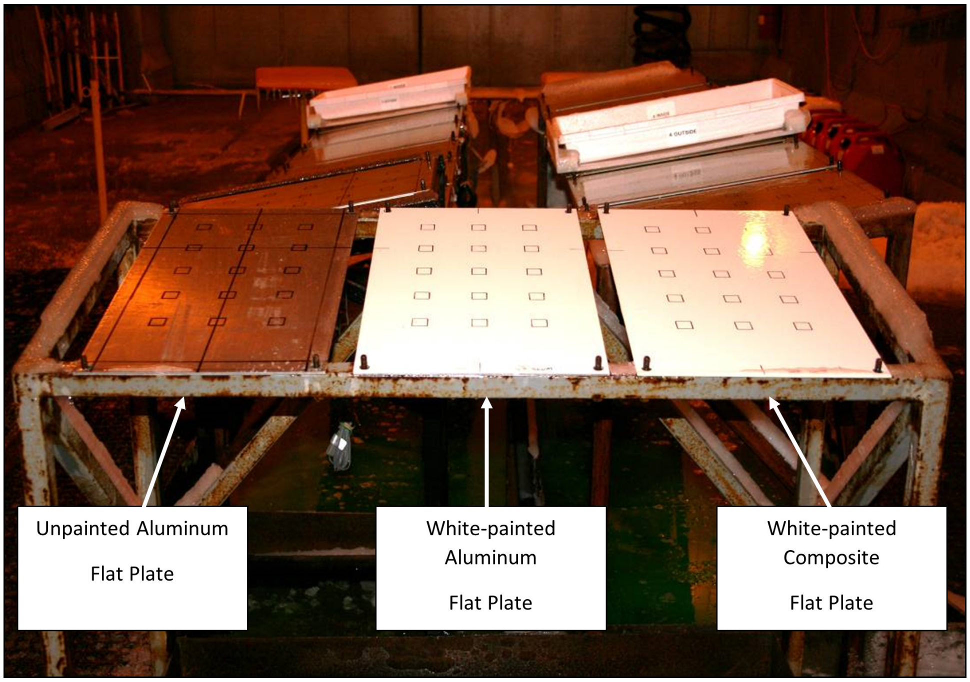
> *11.1.12 Type I HOT Guidelines for Aircraft with Critical Surfaces Constructed Using Composite Materials*
>
> *Preliminary research has shown that for aircraft with large portions of critical surfaces constructed using composite materials, Type I fluid holdover times could be shorter by up to 30% as compared to the current holdover times. Further testing is expected to develop Type I holdover times specific for aircraft with critical surfaces constructed using composite materials.*

The FAA provided the guidance in its "Revised FAA-Approved Deicing Program Updates, Winter 2009–2010" notice (Notice N 8900.104). The relevant section of the notice is excerpted below.

> *9b. Type I Holdover Times on Aircraft Largely Constructed with Composite Materials*
>
> *Preliminary research has shown that for aircraft with large portions of critical surfaces constructs using composite materials, Type I fluid HOTs could be shorter by up to 30 percent compared to current HOTs. Further testing is expected to develop Type I HOTs specific for aircraft constructed using composite materials.*

This guidance was provided as an interim measure until a comprehensive test program could be completed that would enable the development of composite-specific Type I holdover times in all conditions.

Photo 6.1: Test Setup (2008-09)



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7. CONCLUSIONS

The conclusions drawn from the composite research conducted in the winters of 2004-05, 2005-06, 2006-07, 2007-08, and 2008-09 are described below.

7.1 Type II/III/IV Fluids

Comparative endurance time tests were conducted with Type II, III, and IV fluids in natural snow and simulated freezing precipitation in two winters: 2004-05 and 2005-06. The tests conducted in 2004-05 showed endurance times of Type II, III, and IV fluids were longer on composite surfaces than on aluminum surfaces. However, faults in the test design – specifically, the experimental error related to calling visual fluid failure on different test surfaces and the differences in black body radiation heat transfer caused by differences in the unpainted test surfaces – were considered to be the cause of these unexpected results.

Testing was conducted with Type II, III, and IV fluids in natural snow and simulated freezing precipitation again in 2005-06. Testing was conducted with composite and aluminum test surfaces painted white with aircraft grade paint to eliminate the previously identified weaknesses in the test design.

The results of testing in 2005-06 showed that endurance times of Type II, III, and IV fluids are similar on composite and aluminum surfaces in snow and freezing precipitation.

7.2 Type I Fluids

Comparative endurance time tests were conducted with Type I fluids in five winters: 2004-05 through 2008-09. Testing was conducted in natural snow, freezing precipitation, and natural frost in the first two winters (2004-05 and 2005-06), in natural snow in the next two winters (2006-07 and 2007-08), and in freezing precipitation in the final winter (2008-09).

Testing with Type I fluids on composite surfaces showed reductions in fluid endurance times. These results were confirmed over the five-year test program using several modifications to the test procedures, including testing on several test surface configurations – testing on flat plates and LETE boxes, testing with fluids applied at both 20°C and 60°C, and testing using both painted and unpainted aluminum surfaces as the comparative surface. Similar results were seen in natural snow, simulated precipitation, and natural frost.

The reductions in endurance times of Type I fluids were linked to four factors: material thermal conductivity, fluid enrichment, surface temperature stabilization, and fluid dilution. A combination of these four factors accounted for the reduced fluid endurance time measured on the composite surfaces.

7.3 Composite Test Surfaces

Testing conducted with four different composite materials in the winter of 2005-06 showed that fluid endurance times are similar on a variety of composite materials. The four composite materials included in the testing differed in their material composition, structure, and thickness. It was concluded that testing on one representative composite surface would provide results that apply to most composite surfaces.

8. RECOMMENDATIONS

The following recommendations were provided at the end of the winter of 2008-09 as a result of the testing conducted with composite surfaces in the winters of 2004-05, 2005-06, 2006-07, 2007-08, and 2008-09, as well as industry feedback regarding the results obtained.

8.1 Extensive Test Program with Type I Fluids

After the winter of 2008-09, it was recommended that an extensive test program be carried out with several Type I fluids in all weather conditions encompassed by the holdover time guidelines to enable the development of composite-specific holdover times for Type I fluids. This work was conducted in the winter of 2009-10 and is documented in Volume 1 of this report.

8.2 Full-Scale Validation of Type I Endurance Time Reductions

It was recommended that full-scale Type I endurance time testing be conducted with operational aircraft to validate the results observed on the test surfaces described in this report (flat plates, LETE boxes, and frosticator plates). Comparative tests could be conducted simultaneously on two aircraft: one with critical surfaces made entirely of composite materials and one with critical surfaces made entirely of aluminum materials. Another possibility would be to conduct tests on an aircraft that has both composite and aluminum components. The components could be observed to determine if the composite components become contaminated prior to the aluminum components.

It should be noted that initial efforts were made in 2008-09 to obtain aircraft with critical surfaces made entirely of composite materials. As these aircraft are newer generation, they are not readily available and aircraft could not be found for testing.

8.3 Aerodynamic Evaluation of Type I Endurance Time Reductions

It was recommended that aerodynamic testing be conducted in the wind tunnel to investigate the aerodynamic effects of the reduced Type I fluid endurance times observed on composite surfaces. Testing could be conducted by exposing the deiced wing model surface to contamination levels beyond fluid failure to simulate early failure on composite surfaces of a primarily aluminum aircraft. Testing could be conducted in snow or freezing rain conditions.

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REFERENCES

1. Ruggi, M., *Aircraft Ground Deicing Fluid Endurance Times on Composite Surfaces*, APS Aviation Inc., Transportation Development Centre, Montreal, September 2005, TP 14448E, XX (to be published).

2. Ruggi, M., *Effect of Heat on Fluid Endurance Times Using Composite Surfaces*, APS Aviation Inc., Transportation Development Centre, Montreal, October 2006, TP 14720E, XX (to be published).

3. SAE International Aerospace Recommended Practice 5945, *Endurance Time Tests for Aircraft Deicing/Anti-Icing Fluids: SAE Type I*, July 2007.

4. SAE International Aerospace Recommended Practice 5485A, *Endurance Time Tests for Aircraft Deicing/Anti-Icing Fluids: SAE Type II, III, and IV*, July 2007.

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APPENDIX A

TRANSPORTATION DEVELOPMENT CENTRE
WORK STATEMENT EXCERPTS
AIRCRAFT & ANTI-ICING FLUID WINTER TESTING
(WINTERS 2004-05 TO 2009-10)

TRANSPORTATION DEVELOPMENT CENTRE
WORK STATEMENT EXCERPT
AIRCRAFT & ANTI-ICING FLUID
WINTER TESTING 2004-05

6.21 Endurance Time Testing of Non-Aluminum Plates

a) Develop a procedure for testing outdoors on non- aluminum plates;

b) Conduct comparative tests with selected fluids including Type I under selected conditions;

c) Analyze data; and

d) Prepare a report.

TRANSPORTATION DEVELOPMENT CENTRE
WORK STATEMENT EXCERPT
AIRCRAFT & ANTI-ICING FLUID
WINTER TESTING 2005-06

5.2 FLUID PERFORMANCE RESEARCH

5.2.4 Endurance Time Testing of Non-Aluminum Plates

a) Investigate common operational aircraft configurations to explore the different materials and designs used, and issue a new test procedure based on the findings;

b) Acquire new materials based on the investigation;

c) Conduct comparative tests with selected fluids including Type I under selected conditions;

d) Analyze the data collected; and

e) Report the findings.

TRANSPORTATION DEVELOPMENT CENTRE
WORK STATEMENT EXCERPT
AIRCRAFT & ANTI-ICING FLUID
WINTER TESTING 2006-07

6.2.5 Endurance Time Testing of Non-Aluminum Plates

a) Investigate common operational aircraft configurations to validate using leading edge thermal equivalent boxes constructed using composite materials for Type I comparative endurance time testing;

b) Acquire new materials based on the investigation;

c) Conduct comparative testing with Type I fluid during natural snow and freezing precipitation conditions; and

d) Conduct a limited number of comparative tests with Type IV heated fluids in natural snow conditions to validate results obtained during the winter of 2005-06.

TRANSPORTATION DEVELOPMENT CENTRE
WORK STATEMENT EXCERPT
AIRCRAFT & ANTI-ICING FLUID
WINTER TESTING 2007-08

7.2 FLUID PERFORMANCE RESEARCH

7.2.6 Endurance Time Testing of Non-Aluminum Plates

a) Conduct additional comparative testing with Type I fluid during natural snow conditions using composite leading edge thermal equivalent surfaces. Additional data in natural snow conditions during very light and light precipitation events is required to confirm the reduced endurance times observed using composite test surfaces;

b) Analyze the data collected;

c) Report the findings;

d) Develop and review alternatives for possible required changes to HOT tables and complete a detailed preparation of the proposed changes for each of the alternatives. Detailed changes should be applied to all tables in the HOT Guidelines; this will allow for a better understanding of the possible operational impacts; and

e) Present these and previous results at the SAE G-12 annual meeting.

TRANSPORTATION DEVELOPMENT CENTRE
WORK STATEMENT EXCERPT
AIRCRAFT & ANTI-ICING FLUID
WINTER TESTING 2008-09

4.2 DE/ANTI-ICING FLUIDS RESEARCH (AND HOLDOVER TIME CREATION)

4.2.3 Endurance Time Testing of Non-Aluminum Plates

a) Develop procedure and methodology for testing:
   a. Full-Scale Validation of Type I Endurance Time Reduction
   b. Aerodynamic Evaluation of Type I Endurance Time Reductions (to be included in wind tunnel procedure)
   c. Further Composite Testing in Simulated Freezing Precipitation Conditions
   d. Further Composite Testing In Frost (to be included in Frost procedure);

b) Plan and coordinate the construction of a representative composite construction airfoil for us in the full scale validation of the Type I endurance time reductions;

c) Conduct full-scale comparative endurance time testing using both a composite and aluminum construction airfoil in natural snow conditions to validate the Type I endurance time reductions. Testing will be conducted on 3-4 events to capture various precipitation rates and temperature;

d) Conduct limited additional comparative testing at the NRC Climatic Environment Facility (CEF) with Type I fluid during simulated freezing precipitation conditions. Additional data in simulated freezing precipitation conditions is required to confirm the reduced endurance times observed using composite test surfaces;

e) Analyze the data collected;

f) Develop and review alternatives for possible required changes to HOT tables and complete a detailed preparation of the proposed changes for each of the alternatives. Detailed changes should be applied to all tables in the HOT Guidelines; this will allow for a better understanding of the possible operational impacts. Consultations will be conducted with industry members; and

g) Report the findings, and present results at the SAE G-12 annual and fall meeting.

TRANSPORTATION DEVELOPMENT CENTRE
WORK STATEMENT EXCERPT
AIRCRAFT & ANTI-ICING FLUID
WINTER TESTING 2009-10

5.2 DE/ANTI-ICING FLUIDS RESEARCH (AND HOLDOVER TIME CREATION)

5.2.4 Development of Type I HOT's for Composite Surfaces & Evaluation of First Step

a) Develop procedure and methodology for substantiating Type I HOT's for use on composite materials in accordance with ARP 5945;

b) Plan and coordinate construction of composite plate and composite cold-soak boxes;

c) Conduct natural snow and natural frost tests at the P.E.T test site with 4-6 representative fluids. 6 days of natural snow tests are anticipated with an additional 2 days of natural frost testing;

d) Conduct testing at the NRC Climatic Environment Facility (CEF) with 4-6 representative fluids in all simulated HOT conditions: freezing fog, freezing drizzle, light freezing rain, rain on a cold soaked wing. Testing will be conducted in conjunction with HOT testing to reduce associated costs. 2.5 days of testing are anticipated at the NRC facility. This will require three persons for all conditions;

e) Analyze the data collected;

f) Evaluate first step 3-minute rule for use with composite surfaces (this work may be conducted analytically following the substantiation of the Type I HOT's for composite materials work); additional testing may be required;

g) Develop alternatives for providing Type I fluid guidance material for use with composite material aircraft i.e. reduced Type I HOT's, separate Type I table; and

h) Report the findings, and present results at the SAE G-12 annual and fall meeting.

APPENDIX B

EXPERIMENTAL PROGRAM:
EFFECT OF HEAT ON ENDURANCE TIME OF ANTI-ICING FLUIDS
(SUBPROJECT: ENDURANCE TIME OF NON-ALUMINUM PLATES)
(DEC 2004)

CM1892.001 (04-05)

EXPERIMENTAL PROGRAM
EFFECT OF HEAT ON ENDURANCE TIME OF ANTI-ICING FLUIDS
(Subproject: Endurance Time of Non-Aluminum Plates)

Winter 2004-05

Prepared for

Transportation Development Centre
Transport Canada

Prepared by: John D'Avirro/Nicoara Moc

Reviewed by: John D'Avirro

APS Aviation Inc.

December 23, 2004
Version 1.0

EXPERIMENTAL PROGRAM
EFFECT OF HEAT ON ENDURANCE TIME OF ANTI-ICING FLUIDS
(Subproject: Endurance Time of Non-Aluminum Plates)

Winter 2004-05

1. BACKGROUND

At an SAE G-12 HOT Subcommittee meeting in November 2000, discussion focused on the need to recognize the contribution of heat in the endurance time test procedure for Type I fluids. Heated Type II and IV fluids at 50/50 and 75/25 concentrations were currently being used in one-step deicing procedures. A motion was made for the test procedure for these fluids to also recognize the contribution of heat and use the same box that is used in tests with the Type I fluids. This is particularly true in European operations.

In 2001-02, preliminary tests were conducted to investigate whether heat significantly influences the endurance times for Type II and Type IV fluids. Five different fluid brands were used for these exploratory tests.

The tests showed that the effect of heat did not reduce endurance times. In some cases, a significant improvement was observed.

Further investigation was recommended.

2. OBJECTIVE

The objective of this research program is to investigate the impact of the test procedure (application method) on endurance time performance. At the same time, the impact of test plate material (non-aluminum) will be explored.

The following are the detailed objectives.

- Effect of heat on Neat and Diluted Type II and Type IV fluid endurance times.
- Effect of heat on Type III fluid (Neat and Diluted) endurance times: currently some operators are considering the use of Type III fluid in the same manner as Type I fluid.

In addition to the previously mentioned objectives, endurance times of fluid on non-aluminum plates will be examined.

The objective of these tests will be to compare the endurance times using the above methods with the endurance times using the standard protocols.

The matrix of outdoor tests is included in Table 1. In addition, a preliminary plan of indoor tests is also included in Table 2.

3. PROCEDURE

Endurance time tests will be conducted with the various fluids at the Dorval airport test site. Standard fluid endurance time test procedures will apply. The tests will be conducted simultaneously following the application methods described below.

3.1 Outdoor Tests with Type II/III/IV Fluids

Position 1: Baseline Standard Test:
1 L of fluid poured (with no spreader) at OAT onto an aluminum plate.

Position 2: Heated Test:
0.5 L of fluid warmed at 60 °C and poured with the warm 12-hole spreader (if fluid is too viscous, then hand pour) onto a box.

Position 3: Non-Aluminum Plate Test:
1 L of fluid poured (with no spreader) at OAT onto a non-aluminum plate.

The summary of these application methods is shown in Figure 1.

Position 1 (Baseline Standard Test)	**Position 2 (Heated Test)**	**Position 3 (Non-Aluminum Plate Test)**
• Plate • 1 L of fluid • Apply at OAT • Poured	• Box (empty) @ OAT • 0.5 L of fluid • Applied at 60 °C • Poured with the 12 hole spreader	• Plate • 1 L of fluid • Apply at OAT • Poured

Figure 1: Position on Stand – Outdoor Tests with Type II/III/IV Fluids

3.2 Indoor Tests Type II/III/IV Fluids

Position 1: Baseline Standard Test:
1 L of fluid poured (with no spreader) at OAT onto an aluminum plate.

Position 2: Heated Test:
1.0 L of fluid warmed at 60 °C and poured with the warm 12-hole spreader (if fluid is too viscous, then hand pour) onto a plate.

Position 3: Non-Aluminum Plate Test:
1 L of fluid poured (with no spreader) at OAT onto a non-aluminum plate.

The summary of these application methods is shown in Figure 2.

Position 1 (Baseline Standard Test)	Position 2 (Heated Test)	Position 3 (Non-Aluminum Plate Test)
• Plate • 1 L of fluid • Apply at OAT • Poured	• Plate • 1.0 L of fluid • Applied at 60 °C • Poured with the 12 hole spreader	• Plate • 1 L of fluid • Apply at OAT • Poured

Figure 2: Position on Stand – Indoor Tests with Type II/III/IV Fluids

3.3 Outdoor Tests with Type I Fluid

To minimize costs, a non-aluminum box was not developed. Therefore tests shall be conducted on plates as described below.

Position 1: Baseline Standard Test:
1 L of fluid poured at 20°C onto an aluminum plate.

Position 2: Non-Aluminum Plate Test:
1 L of fluid poured at 20°C onto a non-aluminum plate.

The summary of these application methods is shown in Figure 3.

Position 1 (Baseline Standard Test)	Position 2 (Non-Aluminum Plate Test)
• Plate • 1 L of fluid • Apply at 20°C. • Poured • Use 10°C buffer fluid	• Plate • 1 L of fluid • Apply at 20°C • Poured • Use 10°C buffer fluid

Figure 3: Position on Stand – Outdoor Tests with Type I Fluid

3.4 Indoor Tests with Type I Fluid

Position 1: Baseline Standard Test:
1 L of fluid poured at 20°C onto an aluminum plate.

Position 2: Non-Aluminum Plate Test:
1 L of fluid poured at 20°C onto a non-aluminum plate.

The summary of these application methods is shown in Figure 4.

Position 1 (Baseline Standard Test)	Position 2 (Non-Aluminum Plate Test)
• Plate • 1 L of fluid • Apply at 20°C • Poured • Use 10°C buffer fluid	• Plate • 1 L of fluid • Apply at 20°C • Poured • Use 10°C buffer fluid

Figure 4: Position on Stand – Indoor Tests with Type I Fluid

4. FLUIDS

The following fluids (see Table 3) will be used:

- Type III Clariant 2031
- Type I Clariant 1938 PG
- Type IV Dow Ultra+
- Type I Dow EG ADF
- Type IV Kilfrost ABC-S

5. EQUIPMENT

- Logging of temperatures will be required for these tests; and
- Brix measurements and thickness measurements will be needed for a small number of tests.

6. PERSONNEL

Three individuals will be required to conduct these tests. The test manager will measure endurance times. An assistant is required to collect rates and assist with fluid application. A third person is required to prepare the fluids.

7. DATA FORM

The standard endurance time test data forms will be used. To measure fluid Brix and thickness on selected tests, use Table 4.

EXPERIMENTAL PROGRAM: EFFECT OF HEAT ON ENDURANCE TIME OF ANTI-ICNG FLUIDS

TABLE 1: MATRIX OF OUTDOOR TESTS

Test #	Fluid Type	Fluid Brand*	Dilution	Precip Type	Test Temp. [°C]	Precip Rate [g/dm²/h]	STD Test	Heated Box (outdoor)	Non-Aluminum**	Comments
1	III	Clariant 2031	100	Outdoor Snow	any	Any	1	1	1	
2	III	Clariant 2031	100	Outdoor Snow	any	Any	1	1	1	53 tests were conducted with Type III neat outside, so approx. 5 tests would be reasonable for comparison; various temp and rate conditions
3	III	Clariant 2031	100	Outdoor Snow	any	Any	1	1	1	
4	III	Clariant 2031	100	Outdoor Snow	any	Any	1	1		
5	III	Clariant 2031	100	Outdoor Snow	any	Any	1	1		
6	III	Clariant 2031	75	Outdoor Snow	>-14ºC	Any	1	1	1	
7	III	Clariant 2031	75	Outdoor Snow	>-14ºC	Any	1	1	1	
8	III	Clariant 2031	75	Outdoor Snow	>-14ºC	Any	1	1	1	
9	III	Clariant 2031	75	Outdoor Snow	>-14ºC	Any	1	1		
10	III	Clariant 2031	75	Outdoor Snow	>-14ºC	Any	1	1		
11	III	Clariant 2031	75	Outdoor Snow	>-14ºC	Any	1	1		
12	III	Clariant 2031	75	Outdoor Snow	>-14ºC	Any	1	1		
13	III	Clariant 2031	50	Outdoor Snow	>-3ºC	Any	1	1	1	
14	III	Clariant 2031	50	Outdoor Snow	>-3ºC	Any	1	1	1	
15	III	Clariant 2031	50	Outdoor Snow	>-3ºC	Any	1	1	1	
16	III	Clariant 2031	50	Outdoor Snow	>-3ºC	Any	1	1		
17	III	Clariant 2031	50	Outdoor Snow	>-3ºC	Any	1	1		
18	IV	Dow Ultra+	100	Outdoor Snow	any	Any	1	1	1	
19	IV	Dow Ultra+	100	Outdoor Snow	any	Any	1	1	1	
20	IV	Dow Ultra+	100	Outdoor Snow	any	Any	1	1	1	
21	IV	Dow Ultra+	100	Outdoor Snow	any	Any	1	1	1	
22	IV	Dow Ultra+	100	Outdoor Snow	any	Any	1	1	1	
23	IV	Dow Ultra+	100	Outdoor Snow	any	Any	1	1	1	
24	IV	Dow Ultra+	100	Outdoor Snow	any	Any	1	1	1	
25	II,III, IV	Product A (new)	100	Outdoor Snow	any	Any	1	1	1	
26	II,III, IV	Product A (new)	100	Outdoor Snow	any	Any	1	1	1	
27	II,III, IV	Product A (new)	100	Outdoor Snow	any	Any	1	1	1	
28	II,III, IV	Product A (new)	75	Outdoor Snow	>-14ºC	Any	1	1	1	
29	II,III, IV	Product A (new)	75	Outdoor Snow	>-14ºC	Any	1	1	1	
30	II,III, IV	Product A (new)	50	Outdoor Snow	>-3ºC	Any	1	1	1	
31	II,III, IV	Product A (new)	50	Outdoor Snow	>-3ºC	Any	1	1	1	
32	II,III, IV	Product B (new)	100	Outdoor Snow	any	Any	1	1	NR for Prod B	
33	II,III, IV	Product B (new)	100	Outdoor Snow	any	Any	1	1	NR for Prod B	
34	II,III, IV	Product B (new)	100	Outdoor Snow	any	Any	1	1	NR for Prod B	
35	II,III, IV	Product B (new)	75	Outdoor Snow	>-14ºC	Any	1	1	NR for Prod B	
36	II,III, IV	Product B (new)	75	Outdoor Snow	>-14ºC	Any	1	1	NR for Prod B	
37	II,III, IV	Product B (new)	50	Outdoor Snow	>-3ºC	Any	1	1	NR for Prod B	
38	II,III, IV	Product B (new)	50	Outdoor Snow	>-3ºC	Any	1	1	NR for Prod B	
39	II,III, IV	Product C (new)	100	Outdoor Snow	any	Any	1	1	1	
40	II,III, IV	Product C (new)	100	Outdoor Snow	any	Any	1	1	1	
41	II,III, IV	Product C (new)	100	Outdoor Snow	any	Any	1	1	1	
42	II,III, IV	Product C (new)	75	Outdoor Snow	>-14ºC	Any	1	1	1	
43	II,III, IV	Product C (new)	75	Outdoor Snow	>-14ºC	Any	1	1	1	
44	II,III, IV	Product C (new)	50	Outdoor Snow	>-3ºC	Any	1	1	1	
45	II,III, IV	Product C (new)	50	Outdoor Snow	>-3ºC	Any	1	1	1	
46	II,III, IV	Product D (new)	100	Outdoor Snow	any	Any	1	1	NR for Prod D	
47	II,III, IV	Product D (new)	100	Outdoor Snow	any	Any	1	1	NR for Prod D	
48	II,III, IV	Product D (new)	100	Outdoor Snow	any	Any	1	1	NR for Prod D	
49	II,III, IV	Product D (new)	75	Outdoor Snow	>-14ºC	Any	1	1	NR for Prod D	
50	II,III, IV	Product D (new)	75	Outdoor Snow	>-14ºC	Any	1	1	NR for Prod D	
51	II,III, IV	Product D (new)	50	Outdoor Snow	>-3ºC	Any	1	1	NR for Prod D	
52	II,III, IV	Product D (new)	50	Outdoor Snow	>-3ºC	Any	1	1	NR for Prod D	
53	IV	Kilfrost ABC-S	100	Outdoor Snow	any	Any	1	1	1	
54	IV	Kilfrost ABC-S	100	Outdoor Snow	any	Any	1	1	1	
55	IV	Kilfrost ABC-S	100	Outdoor Snow	any	Any	1	1	1	
56	IV	Kilfrost ABC-S	75	Outdoor Snow	>-14ºC	Any	1	1	1	
57	IV	Kilfrost ABC-S	75	Outdoor Snow	>-14ºC	Any	1	1	1	
58	IV	Kilfrost ABC-S	50	Outdoor Snow	>-3ºC	Any	1	1	1	
59	IV	Kilfrost ABC-S	50	Outdoor Snow	>-3ºC	Any	1	1	1	
60	I	Dow EG ADF	10 Deg B	Outdoor Snow	any	Any	1		1	For STD/non-al test apply fluid @ 20C not OAT
61	I	Dow EG ADF	10 Deg B	Outdoor Snow	any	Any	1		1	For STD/non-al test apply fluid @ 20C not OAT
62	I	Dow EG ADF	10 Deg B	Outdoor Snow	any	Any	1		1	For STD/non-al test apply fluid @ 20C not OAT
63	I	Clariant 1938 PG	10 Deg B	Outdoor Snow	any	Any	1		1	For STD/non-al test apply fluid @ 20C not OAT
64	I	Clariant 1938 PG	10 Deg B	Outdoor Snow	any	Any	1		1	For STD/non-al test apply fluid @ 20C not OAT
65	I	Clariant 1938 PG	10 Deg B	Outdoor Snow	any	Any	1		1	For STD/non-al test apply fluid @ 20C not OAT

*** Note that if a new product A, B, C or D is a Type III, then this could be used for testing for one of these sets of tests.**
**** Note that tests that do not have non-aluminum plates are lower priority.**

EXPERIMENTAL PROGRAM: EFFECT OF HEAT ON ENDURANCE TIME OF ANTI-ICNG FLUIDS

TABLE 2: MATRIX OF INDOOR TESTS

Test #	Fluid Type	Fluid Brand*	Dilution	Precip Type	Test Temp. [°C]	Precip Rate [g/dm²/h]	STD Test	Non-Aluminum**	Heated Plate (indoor)	Comments
101	III	Clariant 2031	100	ZD	-3	TBD	1	1	1	TBD after outdoor tests
102	III	Clariant 2031	75	ZD	-3	TBD	1	1	1	TBD after outdoor tests
103	III	Clariant 2031	50	ZD	-3	TBD	1	1	1	TBD after outdoor tests
104	III	Clariant 2031	100	ZR	-3	TBD	1	1	1	TBD after outdoor tests
105	III	Clariant 2031	75	ZR	-3	TBD	1	1	1	TBD after outdoor tests
106	III	Clariant 2031	50	ZR	-3	TBD	1	1	1	TBD after outdoor tests
107	III	Clariant 2031	100	ZD	-10	TBD	1	1	1	TBD after outdoor tests
108	III	Clariant 2031	75	ZD	-10	TBD	1	1	1	TBD after outdoor tests
109	III	Clariant 2031	100	ZR	-10	TBD	1	1	1	TBD after outdoor tests
110	III	Clariant 2031	75	ZR	-10	TBD	1	1	1	TBD after outdoor tests
111	IV	Dow Ultra+	100	ZD	-3	TBD	1	1	1	TBD after outdoor tests
112	IV	Dow Ultra+	100	ZR	-3	TBD	1	1	1	TBD after outdoor tests
113	IV	Dow Ultra+	100	ZD	-10	TBD	1	1	1	TBD after outdoor tests
114	IV	Dow Ultra+	100	ZR	-10	TBD	1	1	1	TBD after outdoor tests
115	II,III, IV	Product A (new)	100	ZD	-3	TBD	1	1	1	TBD after outdoor tests
116	II,III, IV	Product A (new)	100	ZR	-3	TBD	1	1	1	TBD after outdoor tests
117	II,III, IV	Product A (new)	100	ZD	-10	TBD	1	1	1	TBD after outdoor tests
118	II,III, IV	Product A (new)	100	ZR	-10	TBD	1	1	1	TBD after outdoor tests
119	II,III, IV	Product A (new)	75	ZD	-3	TBD	1	1	1	TBD after outdoor tests
120	II,III, IV	Product A (new)	75	ZR	-3	TBD	1	1	1	TBD after outdoor tests
121	II,III, IV	Product A (new)	75	ZD	-10	TBD	1	1	1	TBD after outdoor tests
122	II,III, IV	Product A (new)	75	ZR	-10	TBD	1	1	1	TBD after outdoor tests
123	II,III, IV	Product A (new)	50	ZD	-3	TBD	1	1	1	TBD after outdoor tests
124	II,III, IV	Product A (new)	50	ZR	-3	TBD	1	1	1	TBD after outdoor tests
125	II,III, IV	Product B (new)	100	ZD	-3	TBD	1	NR for Prod B	1	TBD after outdoor tests
126	II,III, IV	Product B (new)	100	ZR	-3	TBD	1	NR for Prod B	1	TBD after outdoor tests
127	II,III, IV	Product B (new)	100	ZD	-10	TBD	1	NR for Prod B	1	TBD after outdoor tests
128	II,III, IV	Product B (new)	100	ZR	-10	TBD	1	NR for Prod B	1	TBD after outdoor tests
129	II,III, IV	Product B (new)	75	ZD	-3	TBD	1	NR for Prod B	1	TBD after outdoor tests
130	II,III, IV	Product B (new)	75	ZR	-3	TBD	1	NR for Prod B	1	TBD after outdoor tests
131	II,III, IV	Product B (new)	75	ZD	-10	TBD	1	NR for Prod B	1	TBD after outdoor tests
132	II,III, IV	Product B (new)	75	ZR	-10	TBD	1	NR for Prod B	1	TBD after outdoor tests
133	II,III, IV	Product B (new)	50	ZD	-3	TBD	1	NR for Prod B	1	TBD after outdoor tests
134	II,III, IV	Product B (new)	50	ZR	-3	TBD	1	NR for Prod B	1	TBD after outdoor tests
135	II,III, IV	Product C (new)	100	ZD	-3	TBD	1	1	1	TBD after outdoor tests
136	II,III, IV	Product C (new)	100	ZR	-3	TBD	1	1	1	TBD after outdoor tests
137	II,III, IV	Product C (new)	100	ZD	-10	TBD	1	1	1	TBD after outdoor tests
138	II,III, IV	Product C (new)	100	ZR	-10	TBD	1	1	1	TBD after outdoor tests
139	II,III, IV	Product C (new)	75	ZD	-3	TBD	1	1	1	TBD after outdoor tests
140	II,III, IV	Product C (new)	75	ZR	-3	TBD	1	1	1	TBD after outdoor tests
141	II,III, IV	Product C (new)	75	ZD	-10	TBD	1	1	1	TBD after outdoor tests
142	II,III, IV	Product C (new)	75	ZR	-10	TBD	1	1	1	TBD after outdoor tests
143	II,III, IV	Product C (new)	50	ZD	-3	TBD	1	1	1	TBD after outdoor tests
144	II,III, IV	Product C (new)	50	ZR	-3	TBD	1	1	1	TBD after outdoor tests
145	II,III, IV	Product D (new)	100	ZD	-3	TBD	1	NR for Prod D	1	TBD after outdoor tests
146	II,III, IV	Product D (new)	100	ZR	-3	TBD	1	NR for Prod D	1	TBD after outdoor tests
147	II,III, IV	Product D (new)	100	ZD	-10	TBD	1	NR for Prod D	1	TBD after outdoor tests
148	II,III, IV	Product D (new)	100	ZR	-10	TBD	1	NR for Prod D	1	TBD after outdoor tests
149	II,III, IV	Product D (new)	75	ZD	-3	TBD	1	NR for Prod D	1	TBD after outdoor tests
150	II,III, IV	Product D (new)	75	ZR	-3	TBD	1	NR for Prod D	1	TBD after outdoor tests
151	II,III, IV	Product D (new)	75	ZD	-10	TBD	1	NR for Prod D	1	TBD after outdoor tests
152	II,III, IV	Product D (new)	75	ZR	-10	TBD	1	NR for Prod D	1	TBD after outdoor tests
153	II,III, IV	Product D (new)	50	ZD	-3	TBD	1	NR for Prod D	1	TBD after outdoor tests
154	II,III, IV	Product D (new)	50	ZR	-3	TBD	1	NR for Prod D	1	TBD after outdoor tests
155	IV	Kilfrost ABC-S	100	ZD	-3	TBD	1	1	1	TBD after outdoor tests
156	IV	Kilfrost ABC-S	100	ZR	-3	TBD	1	1	1	TBD after outdoor tests
157	IV	Kilfrost ABC-S	100	ZD	-10	TBD	1	1	1	TBD after outdoor tests
158	IV	Kilfrost ABC-S	100	ZR	-10	TBD	1	1	1	TBD after outdoor tests
159	IV	Kilfrost ABC-S	75	ZD	-3	TBD	1	1	1	TBD after outdoor tests
160	IV	Kilfrost ABC-S	75	ZR	-3	TBD	1	1	1	TBD after outdoor tests
161	IV	Kilfrost ABC-S	75	ZD	-10	TBD	1	1	1	TBD after outdoor tests
162	IV	Kilfrost ABC-S	75	ZR	-10	TBD	1	1	1	TBD after outdoor tests
163	IV	Kilfrost ABC-S	50	ZD	-3	TBD	1	1	1	TBD after outdoor tests
164	IV	Kilfrost ABC-S	50	ZR	-3	TBD	1	1	1	TBD after outdoor tests
165	I	Dow EG ADF	10 Deg B	ZD	-3	TBD	1	1		For STD/non-al test apply fluid @ 20C not OAT
166	I	Dow EG ADF	10 Deg B	ZD	-10	TBD	1	1		For STD/non-al test apply fluid @ 20C not OAT
167	I	Dow EG ADF	10 Deg B	ZR	-10	TBD	1	1		For STD/non-al test apply fluid @ 20C not OAT
168	I	Clariant 1938 PG	10 Deg B	ZD	-3	TBD	1	1		For STD/non-al test apply fluid @ 20C not OAT
169	I	Clariant 1938 PG	10 Deg B	ZD	-10	TBD	1	1		For STD/non-al test apply fluid @ 20C not OAT
170	I	Clariant 1938 PG	10 Deg B	ZR	-10	TBD	1	1		For STD/non-al test apply fluid @ 20C not OAT

*** Note that if a new product A, B, C or D is a Type III, then this could be used for testing for one of these sets of tests.**
**** Note that tests that do not have non-aluminum plates are lower priority.**

TABLE 3: LIST OF FLUIDS NEEDED (NON-ALUMINUM, HEATED TYPE III, HEATED TYPE II/IV)

Fluid	Dilution	Quantity Needed	Batch No. (Location)		Comments/Location
Clariant 2031	100	15 L	TV390 (25)		
	75	20 L	TV390 (23)		
	50	10 L	TV390 (24)		
Ultra +	100	20 L	QI13555D2(23)		Barrel
Clariant 1938 Type I		9 L	TV363 (34)		
UCAR EG Type I		9 L	TV363 (34)		Need to locate
ABC-S	100	9 L	13402 (30)		Shed
	75	6 L			
	50	6 L			

EXPERIMENTAL PROGRAM: EFFECT OF HEAT ON ENDURANCE TIME OF ANTI-ICNG FLUIDS

TABLE 4: FLUID BRIX/THICKNESS DATA FORM

DATE: ______________ **PERFORMED BY:** ______________

RUN #: ______________ **WRITTEN BY:** ______________

STAND: ______________ **LOCATION:** ______________

Plate / BOX: Fluid:			Plate / BOX: Fluid:			Plate / BOX: Fluid:		
TIME	**Brix at 15 cm Line**	**Thick. at 15 cm Line**	**TIME**	**Brix at 15 cm Line**	**Thick. at 15 cm Line**	**TIME**	**Brix at 15 cm Line**	**Thick. at 15 cm Line**

APPENDIX C

EXPERIMENTAL PROGRAM:
OUTDOOR ENDURANCE TIME TESTING ON NON-ALUMINUM PLATES
(JAN 2006)

CM2020.001 (05-06)

EXPERIMENTAL PROGRAM
OUTDOOR ENDURANCE TIME TESTING ON NON-ALUMINUM PLATES

Winter 2005-06

Prepared for

Transportation Development Centre
Transport Canada

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Reviewed by: John D'Avirro

APS Aviation Inc.

January 12, 2006
Version 1.0

EXPERIMENTAL PROGRAM
OUTDOOR ENDURANCE TIME TESTING ON NON-ALUMINUM PLATES

Winter 2005-06

1. BACKGROUND

In recent years there has been an increase in the manufacturing of aircraft wings with non-aluminum materials. The trend has not slowed. In fact, a significant amount of the materials being used for the construction of the Airbus A 380 and the Boeing 787 are composite. The benefits of using composite materials in the construction of critical aircraft components include reduced aircraft weight, increased fuel efficiency, and improved maintainability.

As a result of the recent trend towards the use of composite materials in the construction of aircraft, a validation of the current holdover time values is required. The correlation between fluid endurance times measured on aluminum and non-aluminum surfaces is required to ensure that the guidelines for the use of deicing fluids on aircraft using composite materials is adequate.

2. OBJECTIVE

The objective of this project is to investigate the impact of non-aluminum test plate material on fluid endurance time. Comparative testing will be conducted during natural snow and simulated freezing precipitation conditions to evaluate the differences in fluid endurance time. Additional testing will be conducted in natural frost conditions. This procedure describes the outdoor natural snow tests. A separate procedure will be prepared at a later date for the indoor tests; this will be based on the results of the outdoor tests.

3. PROCEDURE

Endurance time tests will be conducted with the various fluids at the P. E. Trudeau airport test site. Standard fluid endurance time test procedures will apply. The tests will be conducted simultaneously using multiple test surfaces. A six position test stand will be required for testing. Test stand positions one through five will include a standard HOT test surface (box for Type I Application and plate for Type II, III, and IV application) which will be the baseline endurance time test, a grey painted aluminum surface, and three different grey painted composite test surfaces representative of aircraft construction material.

The sixth position will have rate pan for measuring the rate of precipitation during each comparative test. Figure 3.1 demonstrates the setup required.

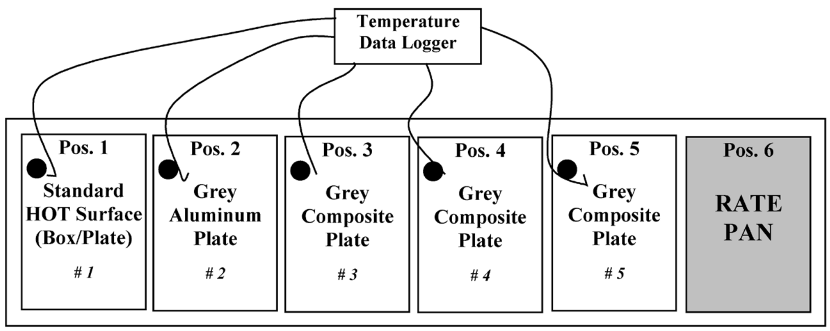

Figure 3.1: Six Position Test Stand Setup

3.1 Outdoor Tests with Type II/III/IV Fluids at Ambient Temperature

1L of fluid at ambient temperature should be poured simultaneously onto each test plate (positions 1-5). The fluid should be hand poured from a 1L container. The same fluid and dilution should be applied to each test surface. Rate measurements should be taken every 5-10 minutes depending on the intensity of precipitation.

3.2 Outdoor Tests with Heated Type II/III/IV Fluids

1L of fluid at OAT should be hand poured onto test plate position 1. Simultaneously, 0.5 L of fluid heated to 60 °C should be poured onto test plate positions 2-5 with a warm 12-hole spreader (if fluid is too viscous, then hand pour). The same fluid and dilution should be applied to each test surface. Rate measurements should be taken every 5-10 minutes depending on the intensity of precipitation.

3.3 Outdoor Tests with Heated Type I Fluids

Half a litre of fluid at 60 °C should be hand poured onto the box on position 1. Simultaneously, 0.5 L of fluid heated to 60 °C should be poured onto test plate positions 2-5 with a warm 12-hole spreader (if fluid is too viscous, then hand pour). The same fluid and dilution (to a 10ºC buffer) should be applied to each test surface. Rate measurements should be taken every 5-10 minutes depending on the intensity of precipitation.

4. TEST SURFACES

A maximum of five test plates will be used during each test. One standard HOT test surface (box for Type I Application and plate for Type II, III, and IV application) will be used during each test as the baseline test. The remaining four test plates will include a grey painted aluminum surface, and three different grey painted composite test surfaces representative of aircraft construction material. The following is a list of the projected plates to be used for this years testing. This list may change depending on the availability of the materials required to produce the composite test plates.

- Standard HOT Test Surface (Box or Plate depending on Test)
- Grey Painted Aluminum Test Plate (same as used for HOT testing but painted)
- Grey Painted Carbon Fibre Test Plate (composite plate used during 2004-2005 testing)
- Grey Painted GLARE Test Plate (same material as used on Airbus A380)
- Grey Painted Thermoplastic Test Plate (same material as used on Airbus A380)
- Grey Painted Composite Test Plate (same material as used on Boeing Aircraft)

It is important that the all test plates (excluding the standard HOT test surface) be painted grey with aircraft grade paint, to ensure that all test surfaces will be experiencing the same black body radiation during testing.

5. TEST PLAN

A test plan was compiled based on the results from previous testing. The larger part of this years testing will be conducted using heated Type I application. The test plan is included in Attachment I.

6. FLUIDS

The fluids in Table 6.1 will be used for the comparative endurance time testing:

Table 6.1: List of Fluids Required for Testing

Fluid	Fluid Type	Dilution	Quantity Needed
UCAR EG ADF	I	Conc	25 L
Clariant 2025 (LV)	II	100	5 L
Clariant 2031	III	100	5 L
Octagon Maxflo	IV	100	20 L
	IV	75	5 L
	IV	50	5 L

7. EQUIPMENT

- Logging of temperatures will be required for these tests; and
- Brix measurements and thickness measurements will be needed for a small number of tests.

8. PERSONNEL

Two individuals will be required to conduct these tests. The test manager will measure endurance times. An assistant is required to collect rates, prepare fluids, and assist with fluid application.

9. DATA FORMS

The standard endurance time test data forms will be used (see Attachment II and III). To measure fluid Brix and thickness on selected tests, use Attachment IV.

ATTACHMENT I: MATRIX OF OUTDOOR TESTS

Run #	Test #	Fluid Type	Fluid Brand	Dilution	Precip Type	OAT [°C]	Fluid Temp. [°C]	Precip Rate [g/dm²/h]	Test Surface
1	1	I	Type I EG	10°C Buffer	Outdoor Snow	>-3°C	60	Any	Std. HOT
	2	I	Type I EG	10°C Buffer	Outdoor Snow	>-3°C	60	Any	Alum.
	3	I	Type I EG	10°C Buffer	Outdoor Snow	>-3°C	60	Any	Comp 1
	4	I	Type I EG	10°C Buffer	Outdoor Snow	>-3°C	60	Any	Comp 2
	5	I	Type I EG	10°C Buffer	Outdoor Snow	>-3°C	60	Any	Comp 3
2	6	I	Type I EG	10°C Buffer	Outdoor Snow	>-3°C	60	Any	Std. HOT
	7	I	Type I EG	10°C Buffer	Outdoor Snow	>-3°C	60	Any	Alum.
	8	I	Type I EG	10°C Buffer	Outdoor Snow	>-3°C	60	Any	Comp 1
	9	I	Type I EG	10°C Buffer	Outdoor Snow	>-3°C	60	Any	Comp 2
	10	I	Type I EG	10°C Buffer	Outdoor Snow	>-3°C	60	Any	Comp 3
3	11	I	Type I EG	10°C Buffer	Outdoor Snow	>-3°C	60	Any	Std. HOT
	12	I	Type I EG	10°C Buffer	Outdoor Snow	>-3°C	60	Any	Alum.
	13	I	Type I EG	10°C Buffer	Outdoor Snow	>-3°C	60	Any	Comp 1
	14	I	Type I EG	10°C Buffer	Outdoor Snow	>-3°C	60	Any	Comp 2
	15	I	Type I EG	10°C Buffer	Outdoor Snow	>-3°C	60	Any	Comp 3
4	16	I	Type I EG	10°C Buffer	Outdoor Snow	>-14°C	60	Any	Std. HOT
	17	I	Type I EG	10°C Buffer	Outdoor Snow	>-14°C	60	Any	Alum.
	18	I	Type I EG	10°C Buffer	Outdoor Snow	>-14°C	60	Any	Comp 1
	19	I	Type I EG	10°C Buffer	Outdoor Snow	>-14°C	60	Any	Comp 2
	20	I	Type I EG	10°C Buffer	Outdoor Snow	>-14°C	60	Any	Comp 3
5	21	I	Type I EG	10°C Buffer	Outdoor Snow	>-14°C	60	Any	Std. HOT
	22	I	Type I EG	10°C Buffer	Outdoor Snow	>-14°C	60	Any	Alum.
	23	I	Type I EG	10°C Buffer	Outdoor Snow	>-14°C	60	Any	Comp 1
	24	I	Type I EG	10°C Buffer	Outdoor Snow	>-14°C	60	Any	Comp 2
	25	I	Type I EG	10°C Buffer	Outdoor Snow	>-14°C	60	Any	Comp 3
6	26	I	Type I EG	10°C Buffer	Outdoor Snow	>-14°C	60	Any	Std. HOT
	27	I	Type I EG	10°C Buffer	Outdoor Snow	>-14°C	60	Any	Alum.
	28	I	Type I EG	10°C Buffer	Outdoor Snow	>-14°C	60	Any	Comp 1
	29	I	Type I EG	10°C Buffer	Outdoor Snow	>-14°C	60	Any	Comp 2
	30	I	Type I EG	10°C Buffer	Outdoor Snow	>-14°C	60	Any	Comp 3
7	31	I	Type I EG	10°C Buffer	Outdoor Snow	>-14°C	60	Any	Std. HOT
	32	I	Type I EG	10°C Buffer	Outdoor Snow	>-14°C	60	Any	Alum.
	33	I	Type I EG	10°C Buffer	Outdoor Snow	>-14°C	60	Any	Comp 1
	34	I	Type I EG	10°C Buffer	Outdoor Snow	>-14°C	60	Any	Comp 2
	35	I	Type I EG	10°C Buffer	Outdoor Snow	>-14°C	60	Any	Comp 3
8	36	I	Type I EG	10°C Buffer	Outdoor Snow	>-25°C	60	Any	Std. HOT
	37	I	Type I EG	10°C Buffer	Outdoor Snow	>-25°C	60	Any	Alum.
	38	I	Type I EG	10°C Buffer	Outdoor Snow	>-25°C	60	Any	Comp 1
	39	I	Type I EG	10°C Buffer	Outdoor Snow	>-25°C	60	Any	Comp 2
	40	I	Type I EG	10°C Buffer	Outdoor Snow	>-25°C	60	Any	Comp 3
9	41	I	Type I EG	10°C Buffer	Outdoor Snow	>-25°C	60	Any	Std. HOT
	42	I	Type I EG	10°C Buffer	Outdoor Snow	>-25°C	60	Any	Alum.
	43	I	Type I EG	10°C Buffer	Outdoor Snow	>-25°C	60	Any	Comp 1
	44	I	Type I EG	10°C Buffer	Outdoor Snow	>-25°C	60	Any	Comp 2
	45	I	Type I EG	10°C Buffer	Outdoor Snow	>-25°C	60	Any	Comp 3

ATTACHMENT I: MATRIX OF OUTDOOR TESTS (cont.)

Run #	Test #	Fluid Type	Fluid Brand	Dilution	Precip Type	OAT [°C]	Fluid Temp. [°C]	Precip Rate [g/dm²/h]	Test Surface
10	46	II	Clariant 2025	Neat	Outdoor Snow	any	60	Any	Std. HOT
	47	II	Clariant 2025	Neat	Outdoor Snow	any	60	Any	Alum.
	48	II	Clariant 2025	Neat	Outdoor Snow	any	60	Any	Comp 1
	49	II	Clariant 2025	Neat	Outdoor Snow	any	60	Any	Comp 2
	50	II	Clariant 2025	Neat	Outdoor Snow	any	60	Any	Comp 3
11	51	III	Clariant 2031	Neat	Outdoor Snow	any	60	Any	Std. HOT
	52	III	Clariant 2031	Neat	Outdoor Snow	any	60	Any	Alum.
	53	III	Clariant 2031	Neat	Outdoor Snow	any	60	Any	Comp 1
	54	III	Clariant 2031	Neat	Outdoor Snow	any	60	Any	Comp 2
	55	III	Clariant 2031	Neat	Outdoor Snow	any	60	Any	Comp 3
12	56	IV	Octagon Maxflo	50/50	Outdoor Snow	>-3ºC	60	Any	Std. HOT
	57	IV	Octagon Maxflo	50/50	Outdoor Snow	>-3ºC	60	Any	Alum.
	58	IV	Octagon Maxflo	50/50	Outdoor Snow	>-3ºC	60	Any	Comp 1
	59	IV	Octagon Maxflo	50/50	Outdoor Snow	>-3ºC	60	Any	Comp 2
	60	IV	Octagon Maxflo	50/50	Outdoor Snow	>-3ºC	60	Any	Comp 3
13	61	IV	Octagon Maxflo	Neat	Outdoor Snow	>-3ºC	60	Any	Std. HOT
	62	IV	Octagon Maxflo	Neat	Outdoor Snow	>-3ºC	60	Any	Alum.
	63	IV	Octagon Maxflo	Neat	Outdoor Snow	>-3ºC	60	Any	Comp 1
	64	IV	Octagon Maxflo	Neat	Outdoor Snow	>-3ºC	60	Any	Comp 2
	65	IV	Octagon Maxflo	Neat	Outdoor Snow	>-3ºC	60	Any	Comp 3
14	66	IV	Octagon Maxflo	75/25	Outdoor Snow	>-14ºC	60	Any	Std. HOT
	67	IV	Octagon Maxflo	75/25	Outdoor Snow	>-14ºC	60	Any	Alum.
	68	IV	Octagon Maxflo	75/25	Outdoor Snow	>-14ºC	60	Any	Comp 1
	69	IV	Octagon Maxflo	75/25	Outdoor Snow	>-14ºC	60	Any	Comp 2
	70	IV	Octagon Maxflo	75/25	Outdoor Snow	>-14ºC	60	Any	Comp 3
15	71	IV	Octagon Maxflo	Neat	Outdoor Snow	>-14ºC	60	Any	Std. HOT
	72	IV	Octagon Maxflo	Neat	Outdoor Snow	>-14ºC	60	Any	Alum.
	73	IV	Octagon Maxflo	Neat	Outdoor Snow	>-14ºC	60	Any	Comp 1
	74	IV	Octagon Maxflo	Neat	Outdoor Snow	>-14ºC	60	Any	Comp 2
	75	IV	Octagon Maxflo	Neat	Outdoor Snow	>-14ºC	60	Any	Comp 3
16	76	IV	Octagon Maxflo	Neat	Outdoor Snow	>-25ºC	60	Any	Std. HOT
	77	IV	Octagon Maxflo	Neat	Outdoor Snow	>-25ºC	60	Any	Alum.
	78	IV	Octagon Maxflo	Neat	Outdoor Snow	>-25ºC	60	Any	Comp 1
	79	IV	Octagon Maxflo	Neat	Outdoor Snow	>-25ºC	60	Any	Comp 2
	80	IV	Octagon Maxflo	Neat	Outdoor Snow	>-25ºC	60	Any	Comp 3
17	76	IV	Octagon Maxflo	Neat	Outdoor Snow	Any	OAT	Any	Std. HOT
	77	IV	Octagon Maxflo	Neat	Outdoor Snow	Any	OAT	Any	Alum.
	78	IV	Octagon Maxflo	Neat	Outdoor Snow	Any	OAT	Any	Comp 1
	79	IV	Octagon Maxflo	Neat	Outdoor Snow	Any	OAT	Any	Comp 2
	80	IV	Octagon Maxflo	Neat	Outdoor Snow	Any	OAT	Any	Comp 3

Note: If a new Type I, II, III, or IV product becomes available, additional testing could be conducted with the new product

ATTACHMENT II: END CONDITION FORM FOR ENDURANCE TIME TESTING

REMEMBER TO SYNCHRONIZE TIME WITH MSC - USE LOCAL TIME

LOCATION:	DATE:	RUN NUMBER:	STAND # :

TIME TO FAILURE FOR INDIVIDUAL CROSSHAIRS (real time)

Time of Fluid Application:	______	______	______	______	______	______
Initial Plate Temperature (°C) (NEEDS TO BE WITHIN 2°C OF AIR TEMP)	______	______	______	______	______	______
Initial Fluid Temperature (°C) (NEEDS TO BE WITHIN 3°C OF AIR TEMP)	______	______	______	______	______	______
	Plate 1	**Plate 2**	**Plate 3**	**Plate 4**	**Plate 5**	**Plate 6**
FLUID NAME/DILUTION						
B1 B2 B3						
C1 C2 C3						
D1 D2 D3						
E1 E2 E3						
F1 F2 F3						
TIME TO FIRST PLATE FAILURE WITHIN WORK AREA						

Time of Fluid Application:	______	______	______	______	______	______
Initial Plate Temperature (°C) (NEEDS TO BE WITHIN 2°C OF AIR TEMP)	______	______	______	______	______	______
Initial Fluid Temperature (°C) (NEEDS TO BE WITHIN 3°C OF AIR TEMP)	______	______	______	______	______	______
	Plate 7	**Plate 8**	**Plate 9**	**Plate 10**	**Plate 11**	**Plate 12**
FLUID NAME/DILUTION						
B1 B2 B3						
C1 C2 C3						
D1 D2 D3						
E1 E2 E3						
F1 F2 F3						
TIME TO FIRST PLATE FAILURE WITHIN WORK AREA						

AMBIENT TEMPERATURE: ________°C

COMMENTS: ________________________________

NOTE: **PLEASE ENSURE CORRECT FUNCTIONING OF PLATE TEMPERATURE LOGGING SYSTEM AT START OF TEST. AT THE END OF TEST SESSION, SAVE THE ELECTRONIC LOGGER FILE ON A FLOPPY DISK AND ALSO E-MAIL IT TO THE OFFICE. LABEL THE DISKETTE AND PLACE IT WITHIN THE DATA FORM ENVELOPE.**

FAILURES CALLED BY: ____________________

LEADER / MANAGER: ____________________

ATTACHMENT III: Meteorological and Precipitation Rate Data Form

REMEMBER TO SYNCHRONIZE TIME WITH MSC - USE LOCAL TIME

LOCATION:	**DATE:**	**RUN # :**	**STAND # :**
HAND HELD VIDEO CASSETTE #:			

PLATE PAN WEIGHT MEASUREMENTS *

PAN #	t TIME BEFORE (h:min:s)	BUFFER TIME (s)	t TIME AFTER (h:min:s)	BUFFER TIME (s)	w WEIGHT BEFORE (g)	w WEIGHT AFTER (g)	COMPUTE RATE (Δ w*4.7/ Δt) (g/dm^2/h)	WIND SPEED** (km/h)	WIND DIR*** (°)

* Measurements every 10 min. and at failure time of each test panel.
** Wind speed measurements required every time the precipitation rate is measured and only if data not available from MSC.
*** Wind direction shall be recorder at least every 15 minutes.

METEO OBSERVATIONS ****

TIME (h:min)	TYPE (Table 1) ZR, ZL,S, SG IP, IC, BS	CLASSIF. (See snow classification diagram.)	If SNOW, WET or DRY

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

AIR TEMPERATURE AT START OF TEST ______________ °C

WIND DIRECTION AT START OF TEST ______________ °

TEST STAND ORIENTATION
(measured along long axes of the test panels) ______________

COMMENTS : ____

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

ATTACHMENT IV: FLUID BRIX/THICKNESS DATA FORM

DATE: ______________ PERFORMED BY: ______________

RUN #: ______________ WRITTEN BY: ______________

STAND: ______________ LOCATION: ______________

Plate / BOX: Fluid:			Plate / BOX: Fluid:			Plate / BOX: Fluid:			Plate / BOX: Fluid:		
TIME	Brix at 15 cm Line	Thick. at 15 cm Line	TIME	Brix at 15 cm Line	Thick. at 15 cm Line	TIME	Brix at 15 cm Line	Thick. at 15 cm Line	TIME	Brix at 15 cm Line	Thick. at 15 cm Line

APPENDIX D

EXPERIMENTAL PROGRAM:
INDOOR ENDURANCE TIME TESTING ON NON-ALUMINUM PLATES
(MAR 2006)

CM2020.002 (2006)

EXPERIMENTAL PROGRAM
INDOOR ENDURANCE TIME TESTING ON NON-ALUMINUM PLATES

Winter 2005-06

Prepared for

Transportation Development Centre
Transport Canada

Prepared by: Marco Ruggi

Reviewed by: John D'Avirro

APS Aviation Inc.

March 28, 2006
Version 1.0

EXPERIMENTAL PROGRAM
INDOOR ENDURANCE TIME TESTING ON NON-ALUMINUM PLATES

Winter 2005-06

1. BACKGROUND

In recent years there has been an increase in the manufacturing of aircraft wings with non-aluminum materials. The trend has not slowed. In fact, a significant amount of the materials being used for the construction of the Airbus A 380 and the Boeing 787 are composite. The benefits of using composite materials in the construction of critical aircraft components include reduced aircraft weight, increased fuel efficiency, and improved maintainability.

As a result of the recent trend towards the use of composite materials in the construction of aircraft, a validation of the current holdover time values is required. The correlation between fluid endurance times measured on aluminum and non-aluminum surfaces is required to ensure that the guidelines for the use of deicing fluids on aircraft using composite materials is adequate.

2. OBJECTIVE

The objective of this project is to investigate the impact of non-aluminum test plate material on fluid endurance time. Comparative testing will be conducted during natural snow and simulated freezing precipitation conditions to evaluate the differences in fluid endurance time. Additional testing will be conducted in natural frost conditions. This procedure describes the indoor simulated freezing precipitation tests.

3. PROCEDURE

Endurance time tests will be conducted with various fluids at the National Research Council (NRC) Climatic Engineering Facility (CEF) in Ottawa. Standard fluid endurance time test procedures will apply. The tests will be conducted simultaneously using two test surfaces. A two-position test stand will be required for testing. Test stand position one will include a white painted aluminum plate, and test stand position two will include a white painted cross weave carbon fibre test plate (Carbon 05). Tests will be conducted in accordance with standard endurance time testing; baseline endurance time test results using unpainted aluminum plates will be recorded. Figure 3.1 demonstrates the setup required.

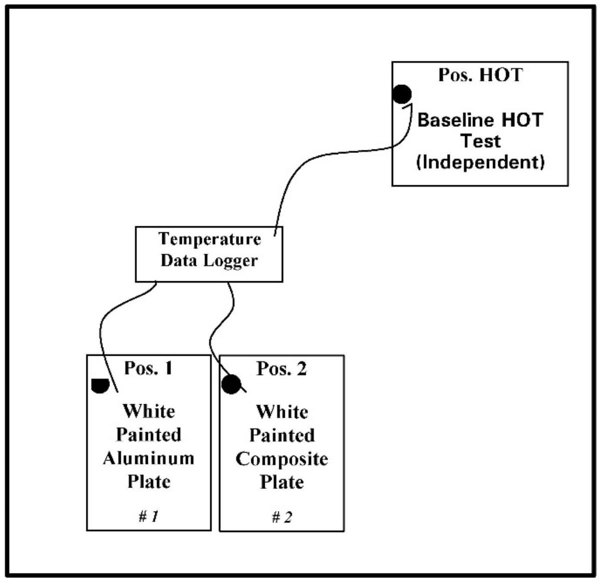

Figure 3.1: Test Stand Setup for Indoor Testing

3.1 Indoor Tests with Type II/III/IV Fluids at Ambient Temperature

1 L of fluid heated to 60°C should be simultaneously poured onto test plate positions 1 and 2 with a warm 12-hole spreader (if fluid is too viscous, then hand pour). The same fluid and dilution should be applied to each test surface. If possible, testing should be conducted during the same time frame as the respective baseline HOT time test.

3.2 Indoor Tests with Heated Type I Fluids

1 L of fluid heated to 20 °C should be simultaneously poured onto test plate positions 1 and 2 with a warm 12-hole spreader (if fluid is too viscous, then hand pour). The same fluid and dilution should be applied to each test surface. If possible, testing should be conducted during the same time frame as the respective baseline HOT time test.

4. TEST SURFACES

Based on the results from the testing conducted during the winter of 2005-06 during natural snow conditions, the test procedure was reduced to include only two test plates: white painted aluminum and white painted cross weave carbon fibre (Carbon 05). The baseline tests will be conducted independently during standard HOT testing using unpainted aluminum test plates.

5. TEST PLAN

A test plan was compiled based on the results from previous testing. Testing will be conducted using heated Type I and heated Type II/III/IV applications. The test plan is included in Attachment I.

6. FLUIDS

The fluids in Table 6.1 will be used for the comparative endurance time testing:

Table 6.1: List of Fluids Required for Testing

Fluid	Fluid Type	Dilution	Quantity Needed
Batelle D3 ADF**	I	Conc	12L
Kilfrost Type II*	II	75/25	4L
Kilfrost Type II*	II	50/50	4L
Clariant Launch 2	IV	100	4L
Clariant Launch I2	IV	75/25	4L

Note: Fluid requirements do not include Baseline HOT tests
* If Kilfrost Type II fluid is not available, replace with Clariant Launch 2
** If Battelle Type I is not available, replace with UCAR EG ADF and omit Baseline HOT

7. EQUIPMENT

- Two Position Stand
- White Painted Aluminum Plate
- White Painted Carbon Cross Weave Carbon Fibre Plate
- Smart reader 8 Channel
- Smart Reader Interface
- Thermistors
- ¼" cable for interface (30 ft)
- Refractometer
- Thickness gauges
- 12 hole spreader
- Microwave
- Pour Bottles (x5)
- Thermos (x2)
- Squeegee

8. PERSONNEL

Two individuals will be required to conduct these tests. The test manager will measure endurance times. An assistant is required to measure thickness and brix, prepare fluids, and assist with fluid application.

9. DATA FORMS

The standard endurance time test data form will be used (see Attachment II). To measure fluid Brix and thickness on selected tests, use Attachment III.

ATTACHMENT I: MATRIX OF INDOOR TESTS

Test #	Precipitation Type	Temp (°C)	Precip. Rate (g/dm²/h)	Fluid Brand	Dilution (BRIX)	Test Surface	Comments
C1a	Freezing Drizzle	-3	5	Kilfrost P1792 (Type II)*	50/50	White Al.	1 L, 12-hole spreader, 60°C
C1b	Freezing Drizzle	-3	5	Kilfrost P1792 (Type II)*	50/50	Comp 05	1 L, 12-hole spreader, 60°C
C1c	Freezing Drizzle	-3	5	Kilfrost P1792 (Type II)*	50/50	Plate	Do not run, see ET Test 57***
C2a	Freezing Drizzle	-3	5	Batelle D3 ADF**	10°buf (26.75)	White Al.	1 L, 12-hole spreader, 20°C
C2b	Freezing Drizzle	-3	5	Batelle D3 ADF**	10°buf (26.75)	Comp 05	1 L, 12-hole spreader, 20°C
C2c	Freezing Drizzle	-3	5	Batelle D3 ADF**	10°buf (26.75)	Plate	Do not run, see ET Test 33***
C3a	Freezing Drizzle	-3	13	Kilfrost P1792 (Type II)*	50/50	White Al.	1 L, 12-hole spreader, 60°C
C3b	Freezing Drizzle	-3	13	Kilfrost P1792 (Type II)*	50/50	Comp 05	1 L, 12-hole spreader, 60°C
C3c	Freezing Drizzle	-3	13	Kilfrost P1792 (Type II)*	50/50	Plate	Do not run, see ET Test 25***
C4a	Freezing Drizzle	-3	13	Batelle D3 ADF**	10°buf (26.75)	White Al.	1 L, 12-hole spreader, 20°C
C4b	Freezing Drizzle	-3	13	Batelle D3 ADF**	10°buf (26.75)	Comp 05	1 L, 12-hole spreader, 20°C
C4c	Freezing Drizzle	-3	13	Batelle D3 ADF**	10°buf (26.75)	Plate	Do not run, see ET Test 1***
C5a	Freezing Drizzle	-10	5	Kilfrost P1792 (Type II)*	75/25	White Al.	1 L, 12-hole spreader, 60°C
C5b	Freezing Drizzle	-10	5	Kilfrost P1792 (Type II)*	75/25	Comp 05	1 L, 12-hole spreader, 60°C
C5c	Freezing Drizzle	-10	5	Kilfrost P1792 (Type II)*	75/25	Plate	Do not run, see ET Test 103***
C6a	Freezing Drizzle	-10	5	Batelle D3 ADF**	10°buf (34.75)	White Al.	1 L, 12-hole spreader, 20°C
C6b	Freezing Drizzle	-10	5	Batelle D3 ADF**	10°buf (34.75)	Comp 05	1 L, 12-hole spreader, 20°C
C6c	Freezing Drizzle	-10	5	Batelle D3 ADF**	10°buf (34.75)	Plate	Do not run, see ET Test 87***
C7a	Freezing Drizzle	-10	13	Kilfrost P1792 (Type II)*	75/25	White Al.	1 L, 12-hole spreader, 60°C
C7b	Freezing Drizzle	-10	13	Kilfrost P1792 (Type II)*	75/25	Comp 05	1 L, 12-hole spreader, 60°C
C7c	Freezing Drizzle	-10	13	Kilfrost P1792 (Type II)*	75/25	Plate	Do not run, see ET Test 81***
C8a	Freezing Drizzle	-10	13	Batelle D3 ADF**	10°buf (34.75)	White Al.	1 L, 12-hole spreader, 20°C
C8b	Freezing Drizzle	-10	13	Batelle D3 ADF**	10°buf (34.75)	Comp 05	1 L, 12-hole spreader, 20°C
C8c	Freezing Drizzle	-10	13	Batelle D3 ADF**	10°buf (34.75)	Plate	Do not run, see ET Test 65***
C9a	Light Freezing Rain	-3	13	Clariant Safewing MPIV Launch 2	75/25	White Al.	1 L, 12-hole spreader, 60°C
C9b	Light Freezing Rain	-3	13	Clariant Safewing MPIV Launch 2	75/25	Comp 05	1 L, 12-hole spreader, 60°C
C9c	Light Freezing Rain	-3	13	Clariant Safewing MPIV Launch 2	75/25	Plate	Do not run, see ET Test 147***
C10a	Light Freezing Rain	-3	25	Clariant Safewing MPIV Launch 2	75/25	White Al.	1 L, 12-hole spreader, 60°C
C10b	Light Freezing Rain	-3	25	Clariant Safewing MPIV Launch 2	75/25	Comp 05	1 L, 12-hole spreader, 60°C
C10c	Light Freezing Rain	-3	25	Clariant Safewing MPIV Launch 2	75/25	Plate	Do not run, see ET Test 117***
C11a	Light Freezing Rain	-10	13	Clariant Safewing MPIV Launch 2	100/0	White Al.	1 L, 12-hole spreader, 60°C
C11b	Light Freezing Rain	-10	13	Clariant Safewing MPIV Launch 2	100/0	Comp 05	1 L, 12-hole spreader, 60°C
C11c	Light Freezing Rain	-10	13	Clariant Safewing MPIV Launch 2	100/0	Plate	Do not run, see ET Test 197***
C12a	Light Freezing Rain	-10	13	Batelle D3 ADF**	10°buf (34.75)	White Al.	1 L, 12-hole spreader, 20°C
C12b	Light Freezing Rain	-10	13	Batelle D3 ADF**	10°buf (34.75)	Comp 05	1 L, 12-hole spreader, 20°C
C12c	Light Freezing Rain	-10	13	Batelle D3 ADF**	10°buf (34.75)	Plate	Do not run, see ET Test 191***
C13a	Light Freezing Rain	-10	25	Clariant Safewing MPIV Launch 2	100/0	White Al.	1 L, 12-hole spreader, 60°C
C13b	Light Freezing Rain	-10	25	Clariant Safewing MPIV Launch 2	100/0	Comp 05	1 L, 12-hole spreader, 60°C
C13c	Light Freezing Rain	-10	25	Clariant Safewing MPIV Launch 2	100/0	Plate	Do not run, see ET Test 175***
C14a	Light Freezing Rain	-10	25	Batelle D3 ADF**	10°buf (34.75)	White Al.	1 L, 12-hole spreader, 20°C
C14b	Light Freezing Rain	-10	25	Batelle D3 ADF**	10°buf (34.75)	Comp 05	1 L, 12-hole spreader, 20°C
C14c	Light Freezing Rain	-10	25	Batelle D3 ADF**	10°buf (34.75)	Plate	Do not run, see ET Test 169***

* If Kilfrost Type II fluid is not available, replace with Clariant Launch 2
** If Battelle Type I is not available, replace with UCAR EG ADF and omit standard HOT test
*** Standard HOT tests will be used in place of test "c"s and can be conducted independently from the composite tests

ATTACHMENT II: END CONDITION FORM FOR ENDURANCE TIME TESTING

REMEMBER TO SYNCHRONIZE TIME WITH MSC – USE LOCAL TIME

LOCATION: DATE: RUN NUMBER: STAND # :

TIME TO FAILURE FOR INDIVIDUAL CROSSHAIRS (real time)

	Plate 1	Plate 2	Plate 3	Plate 4	Plate 5	Plate 6
Time of Fluid Application:						
Initial Plate Temperature (°C) (NEEDS TO BE WITHIN 2°C OF AIR TEMP)						
Initial Fluid Temperature (°C) (NEEDS TO BE WITHIN 3°C OF AIR TEMP)						
FLUID NAME/DILUTION						
B1 B2 B3						
C1 C2 C3						
D1 D2 D3						
E1 E2 E3						
F1 F2 F3						
TIME TO FIRST PLATE FAILURE WITHIN WORK AREA						

	Plate 7	Plate 8	Plate 9	Plate 10	Plate 11	Plate 12
Time of Fluid Application:						
Initial Plate Temperature (°C) (NEEDS TO BE WITHIN 2°C OF AIR TEMP)						
Initial Fluid Temperature (°C) (NEEDS TO BE WITHIN 3°C OF AIR TEMP)						
FLUID NAME/DILUTION						
B1 B2 B3						
C1 C2 C3						
D1 D2 D3						
E1 E2 E3						
F1 F2 F3						
TIME TO FIRST PLATE FAILURE WITHIN WORK AREA						

AMBIENT TEMPERATURE: ________ °C

COMMENTS:

NOTE: PLEASE ENSURE CORRECT FUNCTIONING OF PLATE TEMPERATURE LOGGING SYSTEM AT START OF TEST. AT THE END OF TEST SESSION, SAVE THE ELECTRONIC LOGGER FILE ON A FLOPPY DISK AND ALSO E-MAIL IT TO THE OFFICE. LABEL THE DISKETTE AND PLACE IT WITHIN THE DATA FORM ENVELOPE.

FAILURES CALLED BY: ____________________

LEADER / MANAGER: ____________________

ATTACHMENT III: FLUID BRIX/THICKNESS DATA FORM

DATE: ______________ PERFORMED BY: ______________

RUN #: ______________ WRITTEN BY: ______________

STAND: ______________ LOCATION: ______________

Plate / BOX: Fluid:			Plate / BOX: Fluid:			Plate / BOX: Fluid:			Plate / BOX: Fluid:		
TIME	Brix at 15 cm Line	Thick. at 15 cm Line	TIME	Brix at 15 cm Line	Thick. at 15 cm Line	TIME	Brix at 15 cm Line	Thick. at 15 cm Line	TIME	Brix at 15 cm Line	Thick. at 15 cm Line

APPENDIX E

EXPERIMENTAL PROGRAM:
TYPE I ENDURANCE TIME TESTING ON NON-ALUMINUM LEADING EDGE THERMAL EQUIVALENT BOXES – NATURAL SNOW
(NOV 2006)

CM2020.002 (06-07)

EXPERIMENTAL PROGRAM
TYPE I ENDURANCE TIME TESTING ON NON-ALUMINUM LEADING EDGE THERMAL EQUIVALENT BOXES – NATURAL SNOW

Winter 2006-07

Prepared for

Transportation Development Centre
Transport Canada

Prepared by: Marco Ruggi

Reviewed by: John D'Avirro

APS Aviation Inc.

November 17, 2006
Final Version 1.0

EXPERIMENTAL PROGRAM
TYPE I ENDURANCE TIME TESTING ON NON-ALUMINUM LEADING EDGE THERMAL EQUIVALENT BOXES – NATURAL SNOW

Winter 2006-07

1. BACKGROUND

In recent years there has been an increase in the manufacturing of aircraft wings with non-aluminum materials. The trend has not slowed. In fact, a significant amount of the materials being used for the construction of the Airbus A 380 and the Boeing 787 are composite. The benefits of using composite materials in the construction of critical aircraft components include reduced aircraft weight, increased fuel efficiency, and improved maintainability.

As a result of the recent trend towards the use of composite materials in the construction of aircraft, a validation of the current holdover time values is required. The correlation between fluid endurance times measured on aluminum and non-aluminum surfaces is required to ensure that the guidelines for the use of deicing fluids on aircraft using composite materials is adequate.

Previous work has demonstrated that a reduction in endurance time may occur when conducting Type I fluid endurance time tests on composite plates. Testing with non-aluminum leading edge thermal equivalent boxes is required to validate the possible reduction in Type I endurance times measured using composite surfaces.

2. OBJECTIVE

The objective of this project is to investigate the impact of non-aluminum leading edge thermal equivalent boxes on Type I fluid endurance time. Comparative testing will be conducted during natural snow conditions to evaluate the differences in fluid endurance time. This procedure describes the outdoor natural snow tests. A separate procedure will be prepared at a later date for the indoor tests; this will be based on the results of the outdoor tests.

3. PROCEDURE

Endurance time tests will be conducted with various Type I fluids at the P. E. Trudeau airport test site. Standard fluid endurance time test procedures will apply. Three tests will be conducted simultaneously using leading edge thermal equivalent boxes. A three-position test stand will be required for testing. The following describes the test surfaces used. Figure 3.1 demonstrates the setup required.

- Position 1: Standard HOT Type I Endurance Time Test
    - Material: Aluminum
    - Unpainted
- Position 2: Baseline Type I Endurance Time Test
    - Material: Aluminum
    - Painted white with aircraft grade paint
- Position 3: Composite Type I Endurance Time Test
    - Material: Aluminum
    - Painted white with aircraft grade paint

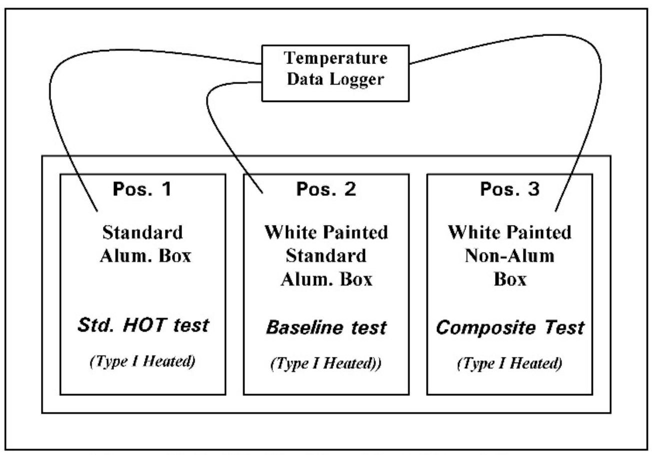

Figure 3.1: Six Position Test Stand Setup

3.1 Outdoor Tests with Type I Fluids Heated to 60°C

0.5 L of Type I fluid heated to 60°C should be poured simultaneously onto test positions 1 to 3 with a warm 12-hole spreader. The same fluid and dilution (to a 10°C buffer) should be applied to each test surface. Rate measurements should be taken every 5 minutes depending on the intensity of precipitation.

3.2 Outdoor Tests with Type I Fluids Heated to 20°C

A limited number of tests will be conducted with Type I fluid heated to 20°C.

0.5 L of Type I fluid heated to 20°C should be poured simultaneously onto test positions 1 to 3 with a warm 12-hole spreader. The same fluid and dilution (to a 10°C buffer) should be applied to each test surface. Rate measurements should be taken every 5 minutes depending on the intensity of precipitation.

4. TEST SURFACES

Three leading edge thermal equivalent boxes will be used for testing. All boxes will be constructed and prepared according to the specification used for constructing standard cold soak boxes for HOT testing. The following are the leading edge thermal equivalent boxes to be used for this years testing.

- Standard Aluminum Box (Unpainted)
- Standard Aluminum Box (Painted White)
- Non-Aluminum Box (Painted White)

It is important that the boxes (excluding the standard HOT test surface) be painted white with aircraft grade paint, to ensure that the test surfaces will be experiencing the same radiation during testing.

5. TEST PLAN

A test plan was compiled based on the results from previous testing. This years testing will be conducted using heated Type I application. The test plan is included in Attachment I.

6. FLUIDS

The fluids in Table 6.1 will be used for the comparative endurance time testing:

Table 6.1: List of Fluids Required for Testing

Fluid	Fluid Type	Dilution	Quantity Needed
UCAR EG ADF	I	10°C Buffer	25 L
Type I PG	I	10°C Buffer	5L

7. EQUIPMENT

- Logging of temperatures will be required for these tests; and
- Brix measurements and thickness measurements will be documented at the beginning and the end of each test. Additional measurements will be taken during the test for a select number of tests.

8. PERSONNEL

Two individuals will be required to conduct these tests. The test manager will measure endurance times. An assistant is required to collect rates, prepare fluids, and assist with fluid application.

9. DATA FORMS

The following data forms will be used to document fluid endurance time, rate of precipitation, and Brix and thickness data:

- Attachment II: End Condition Form for Endurance Time Testing;
- Attachment III: Meteorological and Precipitation Rate Data Form; and
- Attachment IV: Fluid Brix/Thickness Data Form

TYPE I ENDURANCE TIME TESTING ON NON-ALUMINUM LEADING EDGE THERMAL EQUIVALENT BOXES – NATURAL SNOW

ATTACHMENT I: MATRIX OF OUTDOOR TESTS

Run #	Test #	Fluid Type	Fluid Brand	Dilution	Precip Type	OAT [°C]	Fluid Temp. [°C]	Precip Rate [g/dm²/h]	Test Surface
1	1	I	Type I EG	10°C Buffer	Outdoor Snow	>-3	60	Any	Std. HOT
	2	I	Type I EG	10°C Buffer	Outdoor Snow	>-3	60	Any	Alum.
	3	I	Type I EG	10°C Buffer	Outdoor Snow	>-3	60	Any	Comp
2	4	I	Type I EG	10°C Buffer	Outdoor Snow	>-3	60	Any	Std. HOT
	5	I	Type I EG	10°C Buffer	Outdoor Snow	>-3	60	Any	Alum.
	6	I	Type I EG	10°C Buffer	Outdoor Snow	>-3	60	Any	Comp
3	7	I	Type I EG	10°C Buffer	Outdoor Snow	>-3	20	Any	Std. HOT
	8	I	Type I EG	10°C Buffer	Outdoor Snow	>-3	20	Any	Alum.
	9	I	Type I EG	10°C Buffer	Outdoor Snow	>-3	20	Any	Comp
4	10	I	Type I PG	10°C Buffer	Outdoor Snow	>-3	60	Any	Std. HOT
	11	I	Type I PG	10°C Buffer	Outdoor Snow	>-3	60	Any	Alum.
	12	I	Type I PG	10°C Buffer	Outdoor Snow	>-3	60	Any	Comp
5	13	I	Type I EG	10°C Buffer	Outdoor Snow	-3 to -14	60	Any	Std. HOT
	14	I	Type I EG	10°C Buffer	Outdoor Snow	-3 to -14	60	Any	Alum.
	15	I	Type I EG	10°C Buffer	Outdoor Snow	-3 to -14	60	Any	Comp
6	16	I	Type I EG	10°C Buffer	Outdoor Snow	-3 to -14	60	Any	Std. HOT
	17	I	Type I EG	10°C Buffer	Outdoor Snow	-3 to -14	60	Any	Alum.
	18	I	Type I EG	10°C Buffer	Outdoor Snow	-3 to -14	60	Any	Comp
7	19	I	Type I EG	10°C Buffer	Outdoor Snow	-3 to -14	20	Any	Std. HOT
	20	I	Type I EG	10°C Buffer	Outdoor Snow	-3 to -14	20	Any	Alum.
	21	I	Type I EG	10°C Buffer	Outdoor Snow	-3 to -14	20	Any	Comp
8	22	I	Type I EG	10°C Buffer	Outdoor Snow	< -14	60	Any	Std. HOT
	23	I	Type I EG	10°C Buffer	Outdoor Snow	< -14	60	Any	Alum.
	24	I	Type I EG	10°C Buffer	Outdoor Snow	< -14	60	Any	Comp
9	25	I	Type I EG	10°C Buffer	Outdoor Snow	< -14	60	Any	Std. HOT
	26	I	Type I EG	10°C Buffer	Outdoor Snow	< -14	60	Any	Alum.
	27	I	Type I EG	10°C Buffer	Outdoor Snow	< -14	60	Any	Comp

TYPE I ENDURANCE TIME TESTING ON NON-ALUMINUM LEADING EDGE THERMAL EQUIVALENT BOXES – NATURAL SNOW

ATTACHMENT II: END CONDITION FORM FOR ENDURANCE TIME TESTING

REMEMBER TO SYNCHRONIZE TIME WITH ATOMIC CLOCK - USE REAL TIME

VERSION 1.0 Winter 2006/2007

LOCATION: DORVAL TEST SITE	DATE:	RUN #:	STAND # :

OTHER COMMENTS (Fluid Batch, etc):

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

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

	BOX			BOX			BOX		
FLUID NAME									
B1 B2 B3									
C1 C2 C3									
D1 D2 D3									
E1 E2 E3									
F1 F2 F3									
TIME TO FIRST PLATE FAILURE WITHIN WORK AREA									
CALCULATED FAILURE TIME (MINUTES)									
BRIX START / END	/			/			/		
THICKNESS START / END	/			/			/		

PRINT SIGN

FAILURES CALLED BY : ____________ ____________

M:\Groups\PM2020 (TC Deicing 06-07)\Procedures\Composite\Outdoor Composite Final Version 1.0.doc
Final Version 1.0, November 06

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ATTACHMENT III: Meteorological and Precipitation Rate Data Form

REMEMBER TO SYNCHRONIZE TIME WITH MSC - USE LOCAL TIME

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

HAND HELD VIDEO CASSETTE #:

PLATE PAN WEIGHT MEASUREMENTS *

PAN #	t TIME BEFORE (h:min:s)	BUFFER TIME (s)	t TIME AFTER (h:min:s)	BUFFER TIME (s)	w WEIGHT BEFORE (g)	w WEIGHT AFTER (g)	COMPUTE RATE (△ w*4.7/ △t) ($g/dm^2/h$)	WIND SPEED** (km/h)	WIND DIR*** (°)

* Measurements every 10 min. and at failure time of each test panel.
** Wind speed measurements required every time the precipitation rate is measured and only if data not available from MSC.
*** Wind direction shall be recorder at least every 15 minutes.

METEO OBSERVATIONS ****

TIME (h:min)	TYPE (Table 1) ZR, ZL,S, SG IP, IC, BS	CLASSIF. (See snow classification diagram.)	If SNOW, WET or DRY

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

AIR TEMPERATURE AT START OF TEST ________ °C

WIND DIRECTION AT START OF TEST ________ °

TEST STAND ORIENTATION
(measured along long axes of the test panels) ________

COMMENTS : ______________________________

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

ATTACHMENT IV: FLUID BRIX/THICKNESS DATA FORM

DATE: ______________ PERFORMED BY: ______________

RUN #: ______________ WRITTEN BY: ______________

STAND: ______________ LOCATION: ______________

Plate / BOX: Fluid:			Plate / BOX: Fluid:			Plate / BOX: Fluid:		
TIME	Brix at 15 cm Line	Thick. at 15 cm Line	TIME	Brix at 15 cm Line	Thick. at 15 cm Line	TIME	Brix at 15 cm Line	Thick. at 15 cm Line

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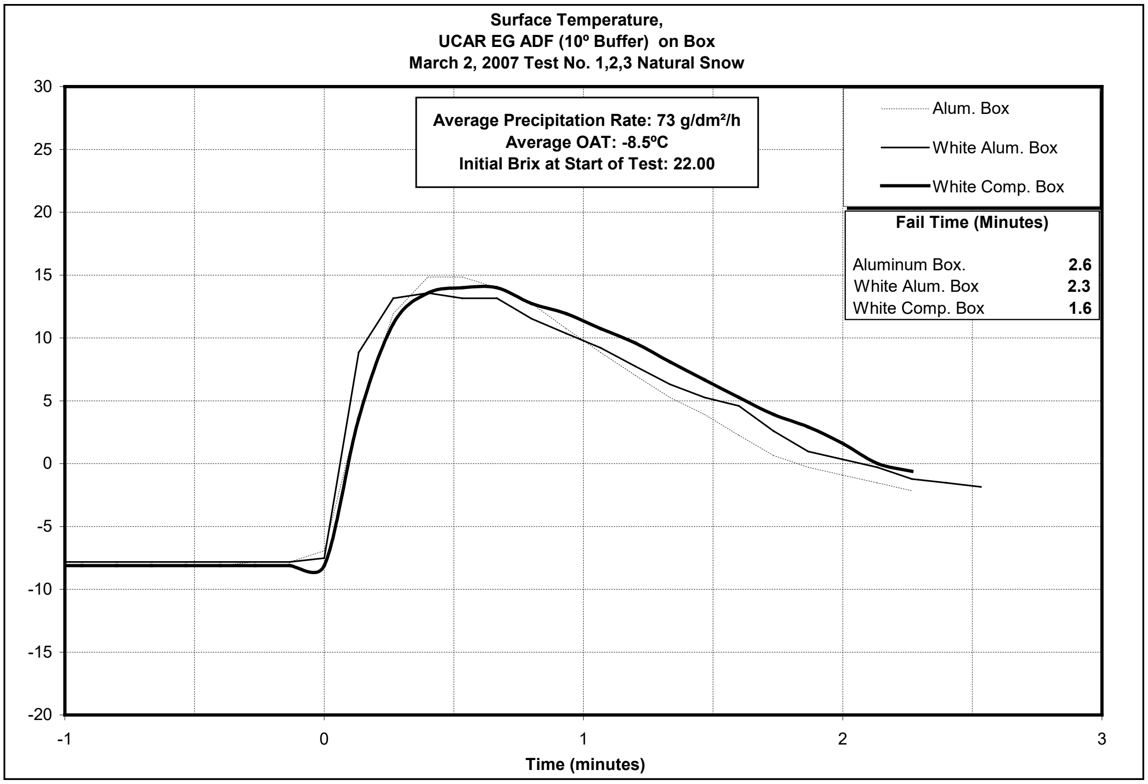
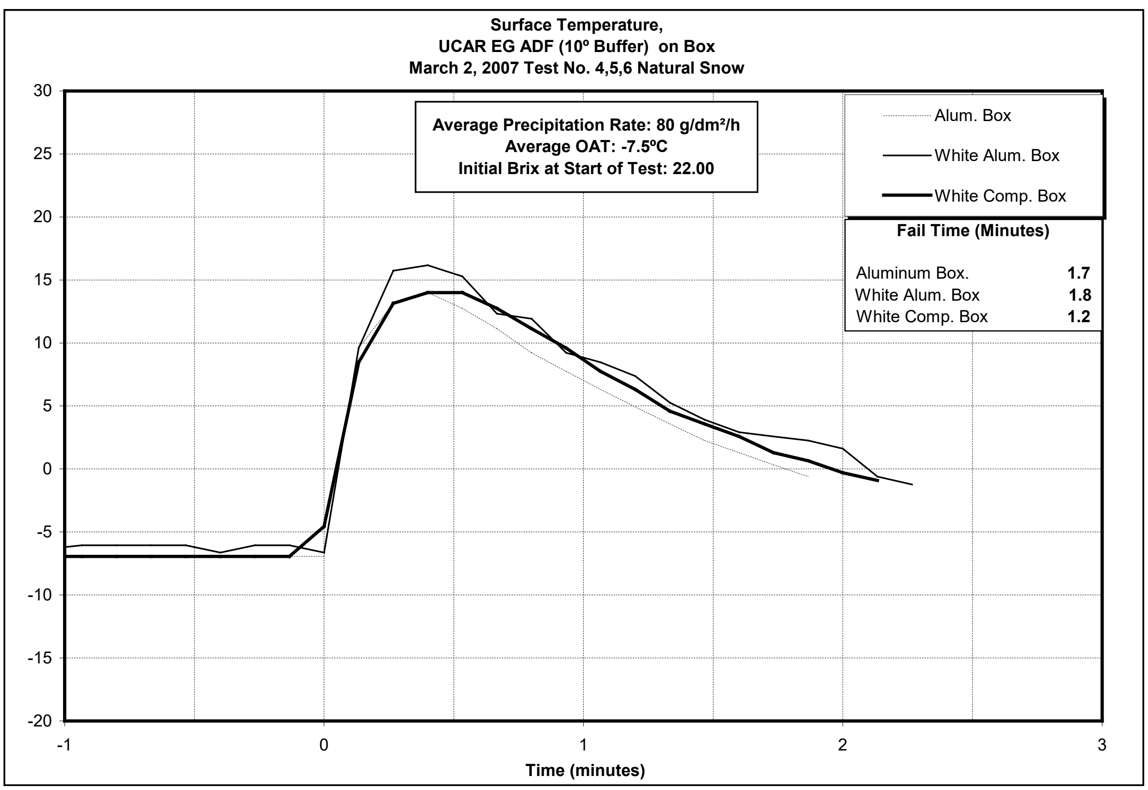
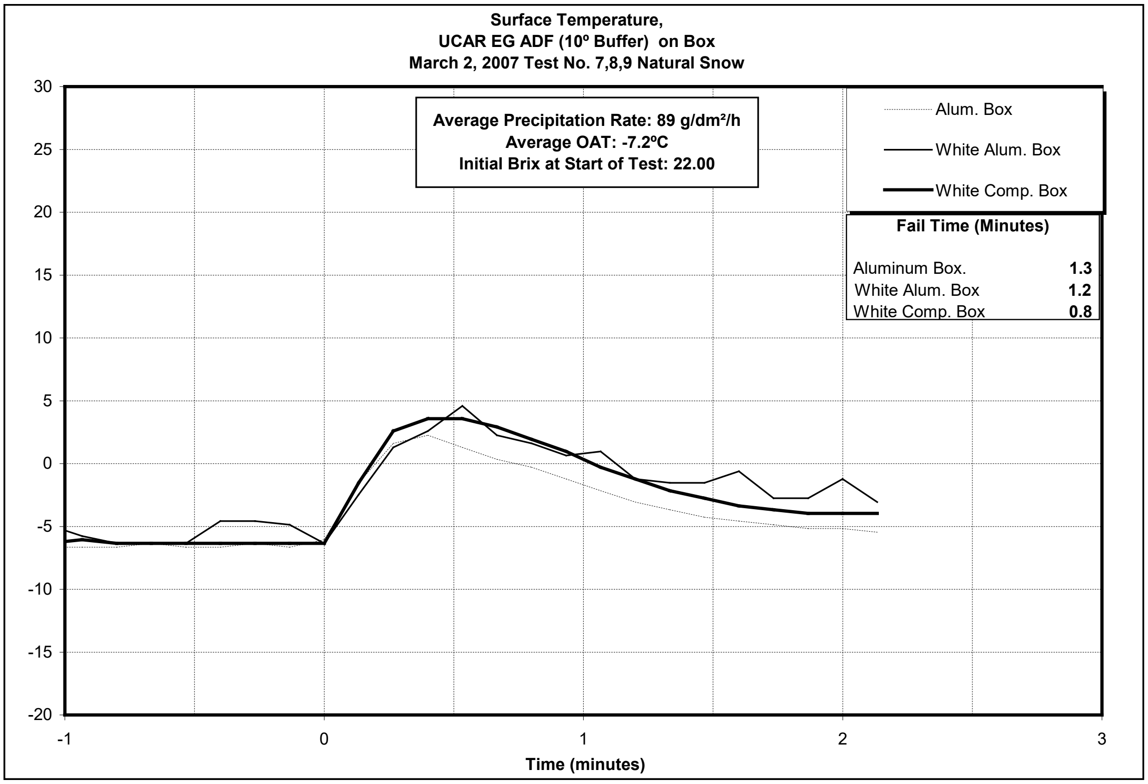
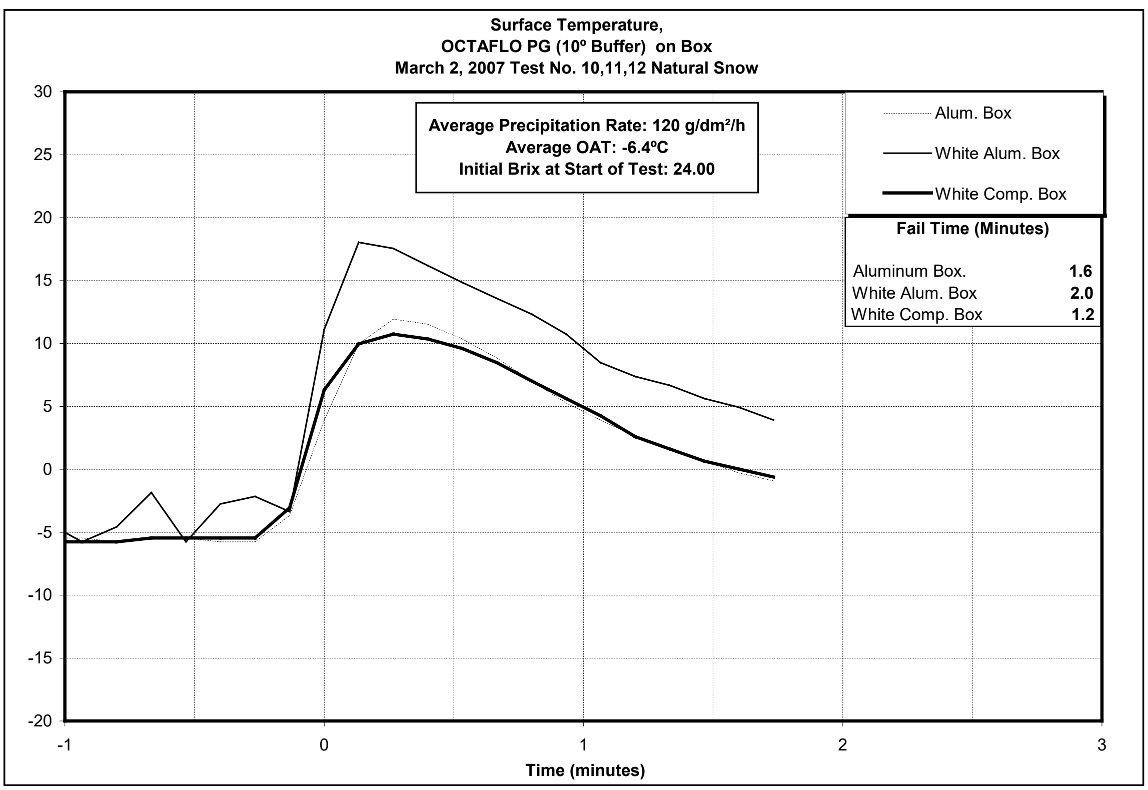
APPENDIX F

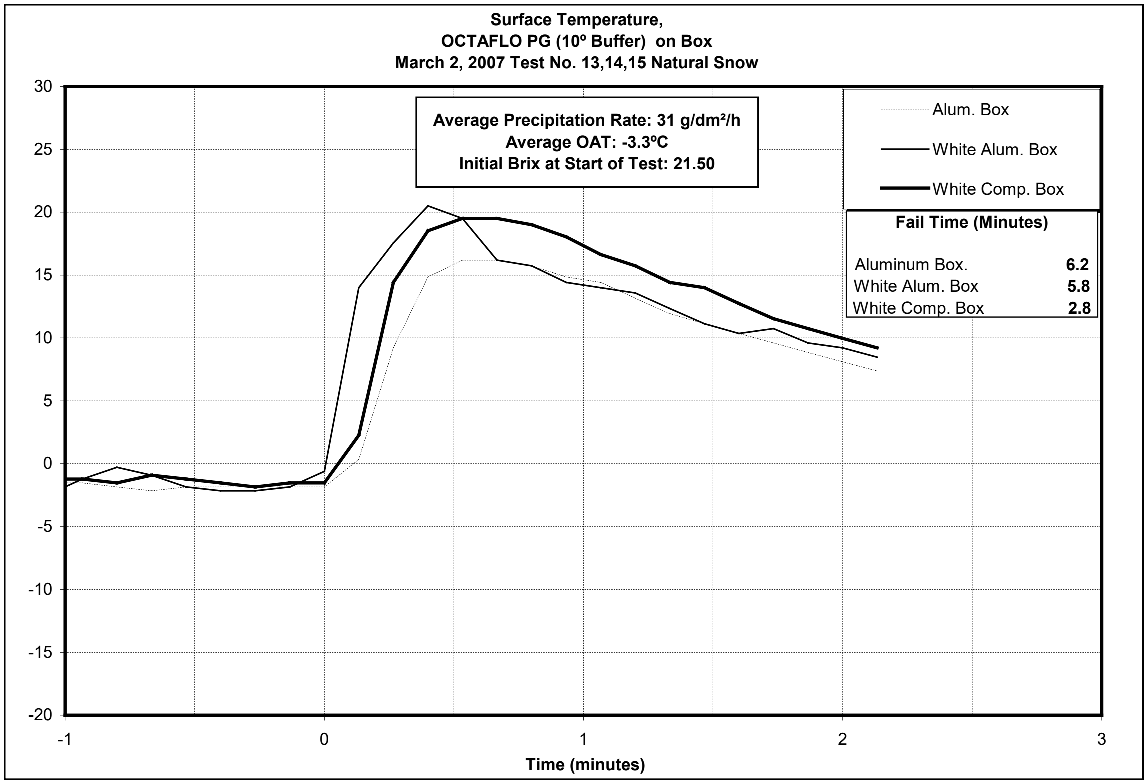
DETAILED TEMPERATURE PROFILES: TESTS CONDUCTED DURING NATURAL SNOW PRECIPITATION CONDITIONS IN 2006-07 AND 2007-08

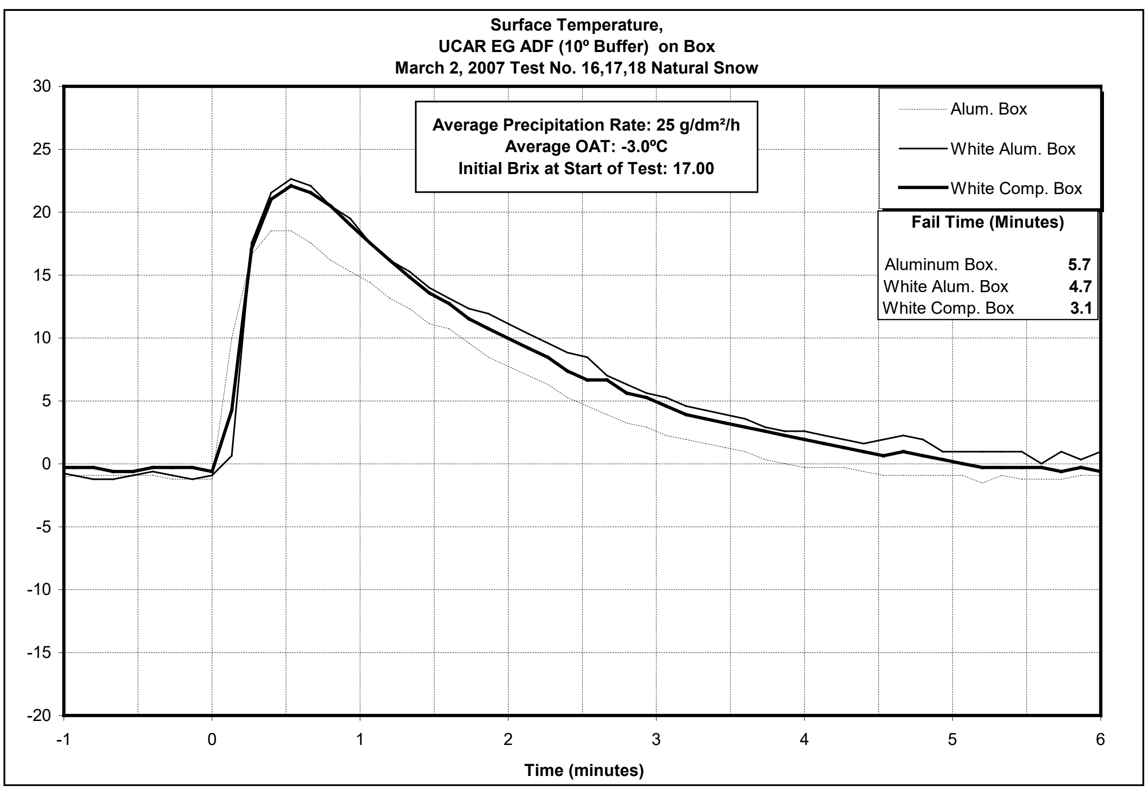

Surface Temperature,
UCAR EG ADF (10º Buffer) on Box
March 2, 2007 Test No. 1,2,3 Natural Snow
Average Precipitation Rate: 73 g/dm²/h
Average OAT: -8.5ºC
Initial Brix at Start of Test: 22.00
Alum. Box
White Alum. Box
White Comp. Box
Fail Time (Minutes)
Aluminum Box. 2.6
White Alum. Box 2.3
White Comp. Box 1.6
30
25
20
15
10
5
0
-5
-10
-15
-20
-1
0
1
2
3
Time (minutes)

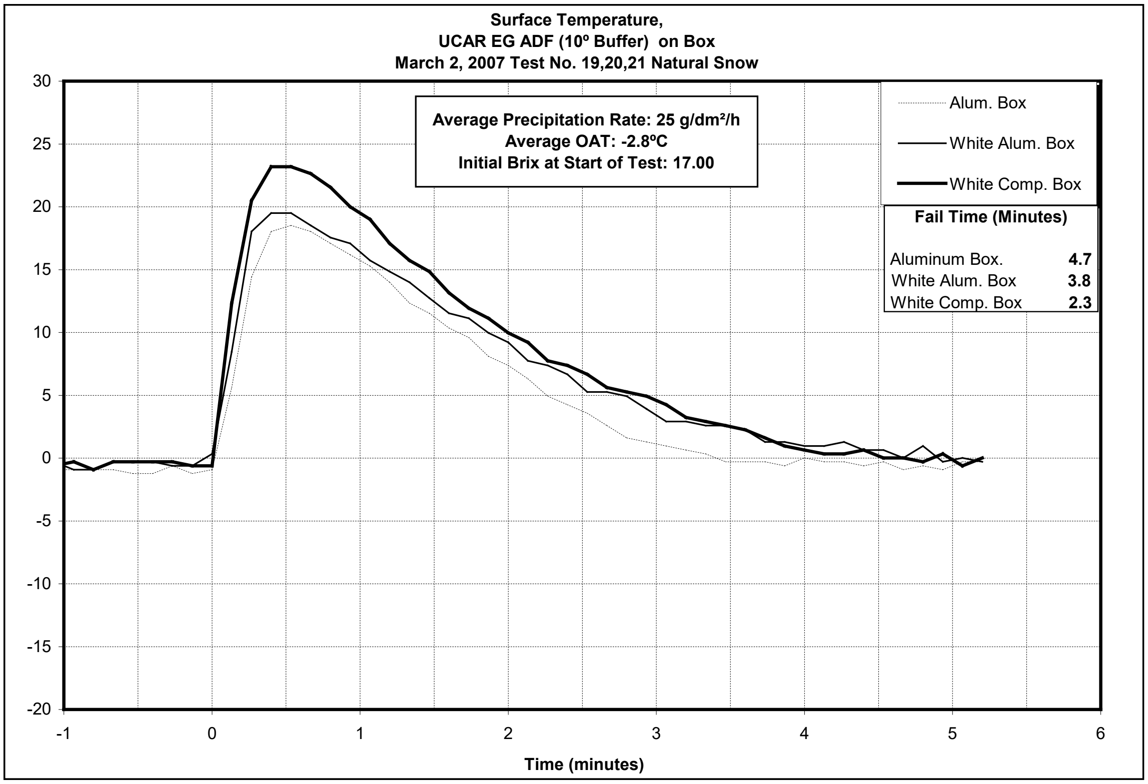

Surface Temperature,
UCAR EG ADF (10º Buffer) on Box
March 2, 2007 Test No. 4,5,6 Natural Snow
Average Precipitation Rate: 80 g/dm²/h
Average OAT: -7.5ºC
Initial Brix at Start of Test: 22.00
Alum. Box
White Alum. Box
White Comp. Box
Fail Time (Minutes)
Aluminum Box. 1.7
White Alum. Box 1.8
White Comp. Box 1.2
30
25
20
15
10
5
0
-5
-10
-15
-20
-1
0
1
2
3
Time (minutes)

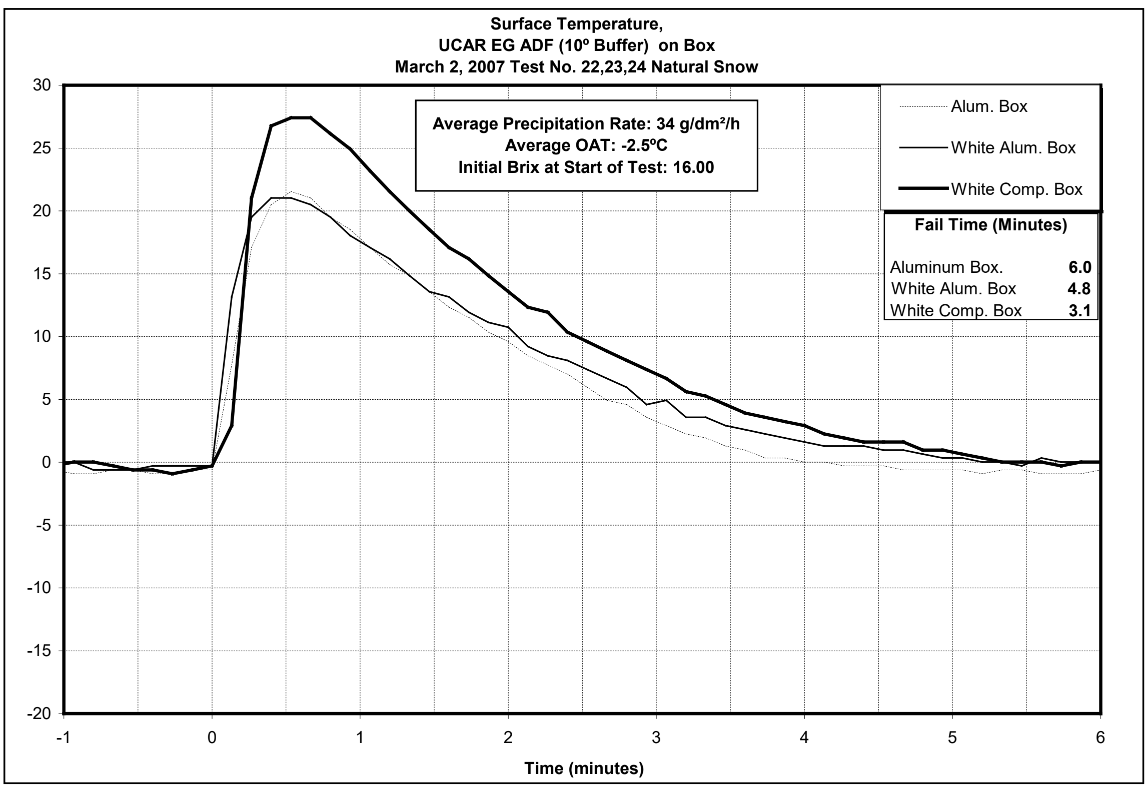

Surface Temperature,
UCAR EG ADF (10º Buffer) on Box
March 2, 2007 Test No. 7,8,9 Natural Snow
Average Precipitation Rate: 89 g/dm²/h
Average OAT: -7.2ºC
Initial Brix at Start of Test: 22.00
Alum. Box
White Alum. Box
White Comp. Box
Fail Time (Minutes)
Aluminum Box. 1.3
White Alum. Box 1.2
White Comp. Box 0.8
30
25
20
15
10
5
0
-5
-10
-15
-20
-1
0
1
2
3
Time (minutes)

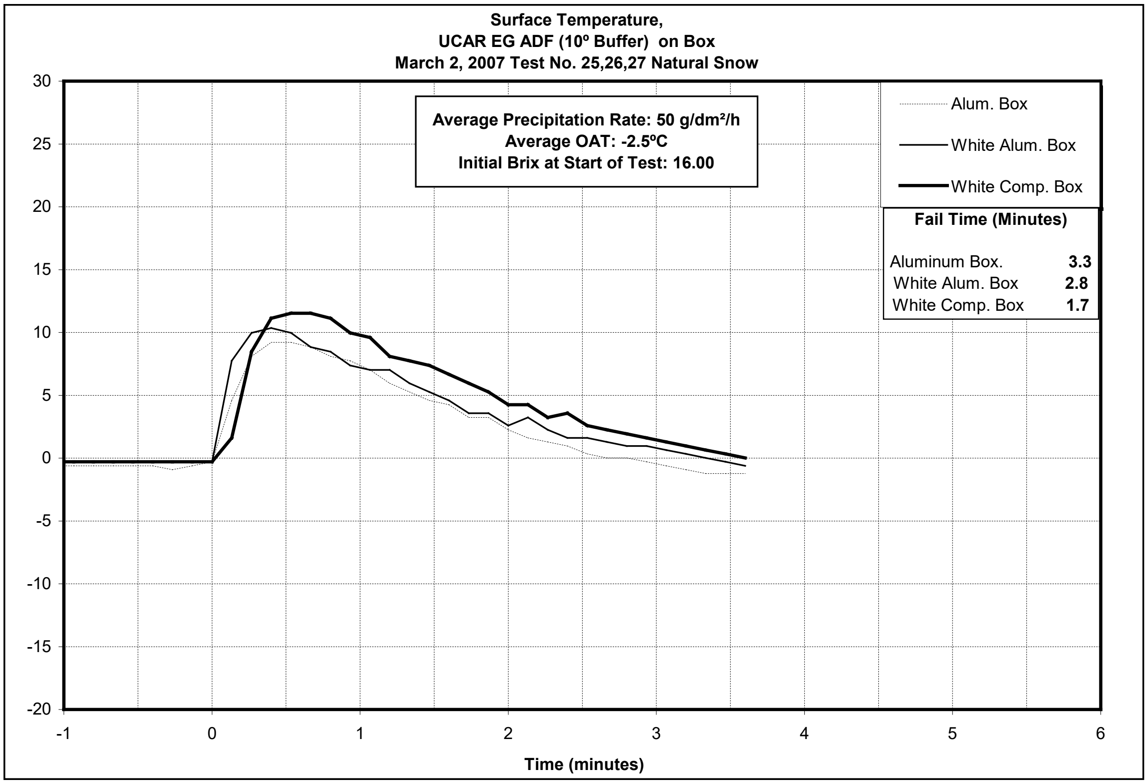

Surface Temperature,
OCTAFLO PG (10º Buffer) on Box
March 2, 2007 Test No. 10,11,12 Natural Snow
Average Precipitation Rate: 120 g/dm²/h
Average OAT: -6.4ºC
Initial Brix at Start of Test: 24.00
Alum. Box
White Alum. Box
White Comp. Box
Fail Time (Minutes)
Aluminum Box. 1.6
White Alum. Box 2.0
White Comp. Box 1.2
30
25
20
15
10
5
0
-5
-10
-15
-20
-1
0
1
2
3
Time (minutes)

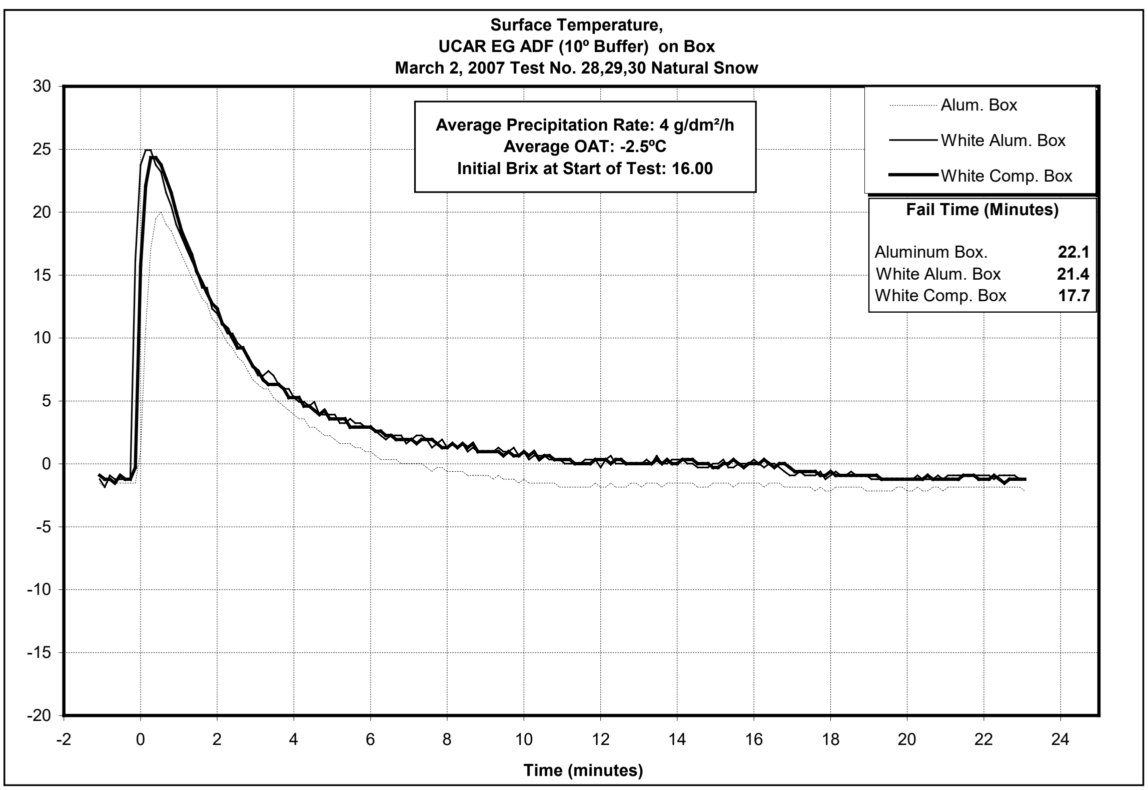

Surface Temperature,
OCTAFLO PG (10º Buffer) on Box
March 2, 2007 Test No. 13,14,15 Natural Snow
Average Precipitation Rate: 31 g/dm²/h
Average OAT: -3.3ºC
Initial Brix at Start of Test: 21.50
Alum. Box
White Alum. Box
White Comp. Box
Fail Time (Minutes)
Aluminum Box. 6.2
White Alum. Box 5.8
White Comp. Box 2.8
30
25
20
15
10
5
0
-5
-10
-15
-20
-1
0
1
2
3
Time (minutes)

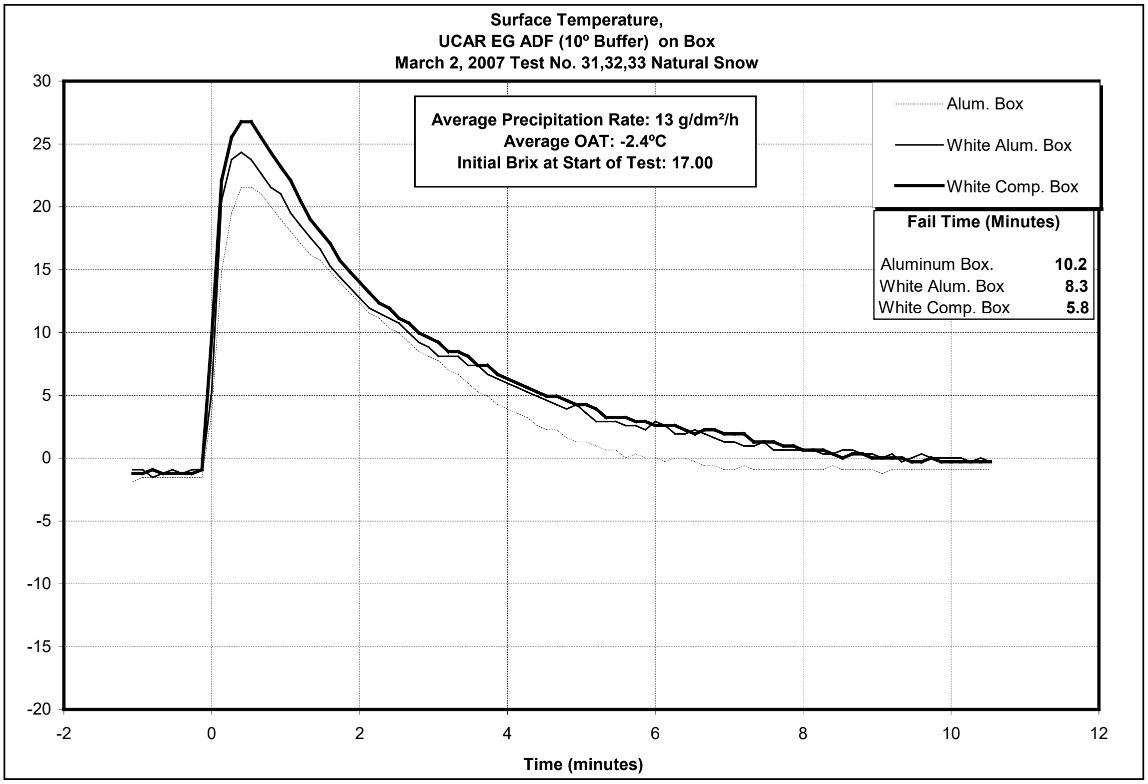

Surface Temperature,
UCAR EG ADF (10º Buffer) on Box
March 2, 2007 Test No. 16,17,18 Natural Snow
Average Precipitation Rate: 25 g/dm²/h
Average OAT: -3.0ºC
Initial Brix at Start of Test: 17.00
Alum. Box
White Alum. Box
White Comp. Box
Fail Time (Minutes)
Aluminum Box. 5.7
White Alum. Box 4.7
White Comp. Box 3.1
30
25
20
15
10
5
0
-5
-10
-15
-20
-1
0
1
2
3
4
5
6
Time (minutes)

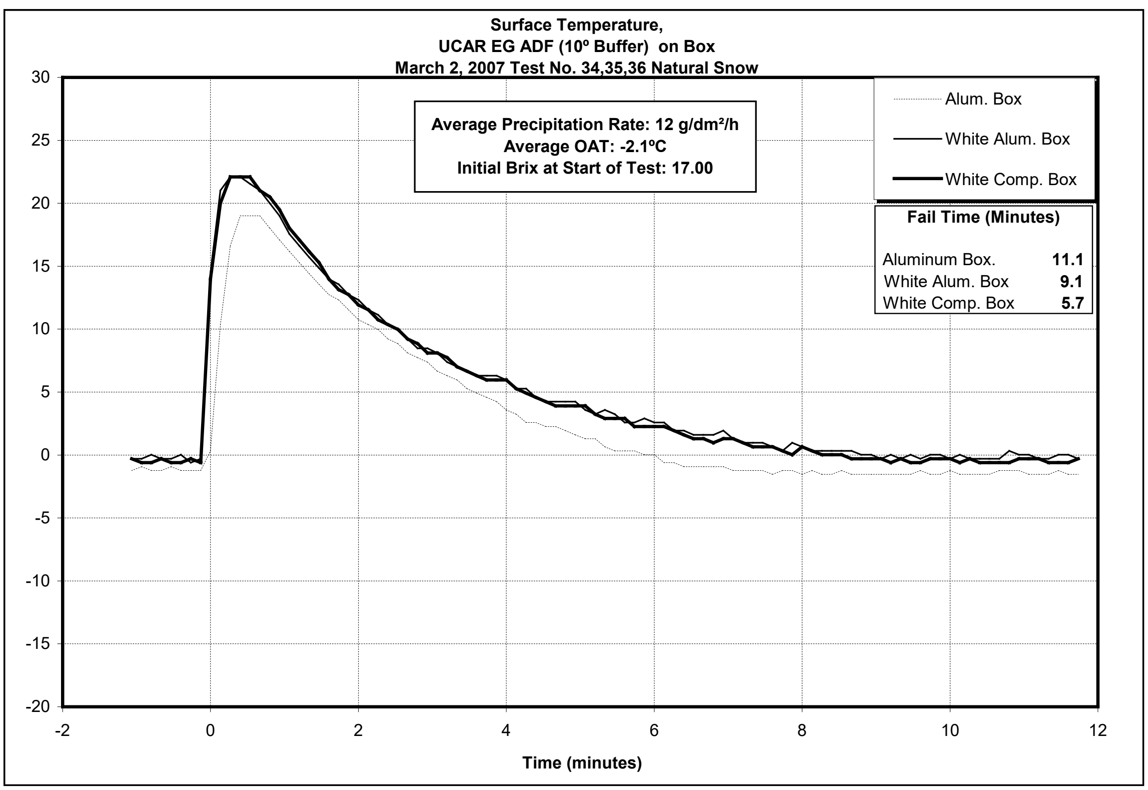

Surface Temperature,
UCAR EG ADF (10º Buffer) on Box
March 2, 2007 Test No. 19,20,21 Natural Snow
Average Precipitation Rate: 25 g/dm²/h
Average OAT: -2.8ºC
Initial Brix at Start of Test: 17.00
Alum. Box
White Alum. Box
White Comp. Box
Fail Time (Minutes)
Aluminum Box. 4.7
White Alum. Box 3.8
White Comp. Box 2.3
Time (minutes)

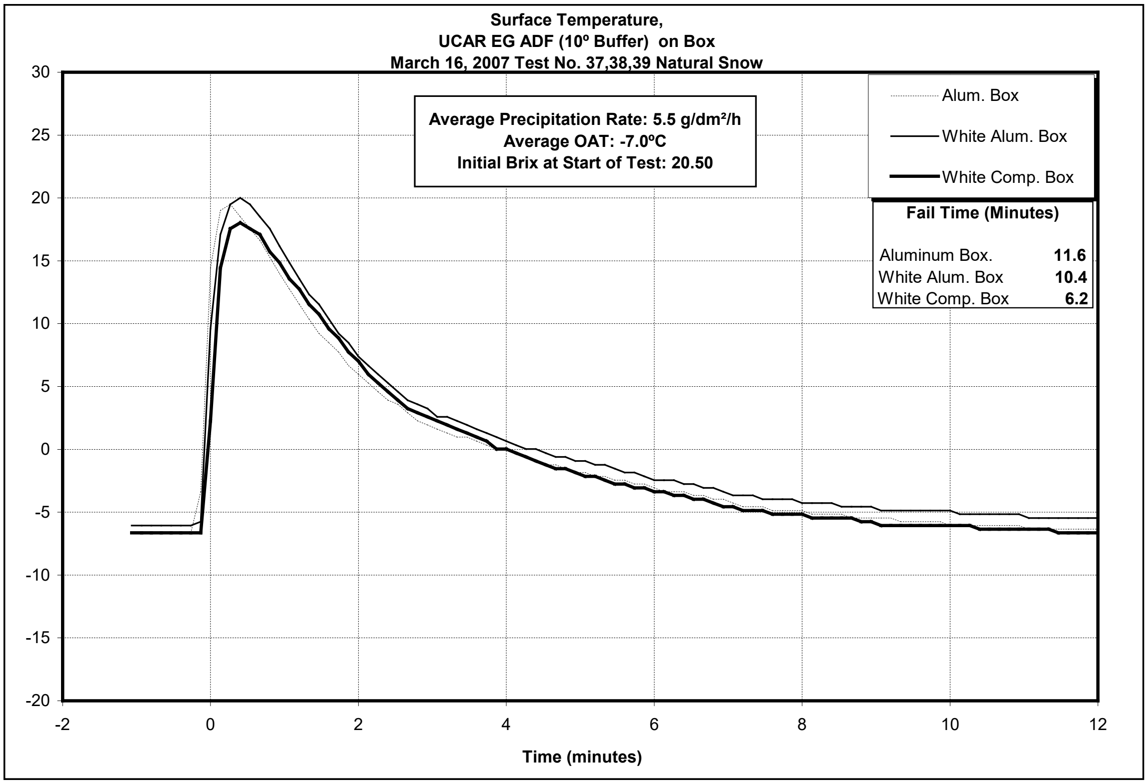

Surface Temperature,
UCAR EG ADF (10º Buffer) on Box
March 2, 2007 Test No. 22,23,24 Natural Snow
Average Precipitation Rate: 34 g/dm²/h
Average OAT: -2.5ºC
Initial Brix at Start of Test: 16.00
Alum. Box
White Alum. Box
White Comp. Box
Fail Time (Minutes)
Aluminum Box. 6.0
White Alum. Box 4.8
White Comp. Box 3.1
Time (minutes)

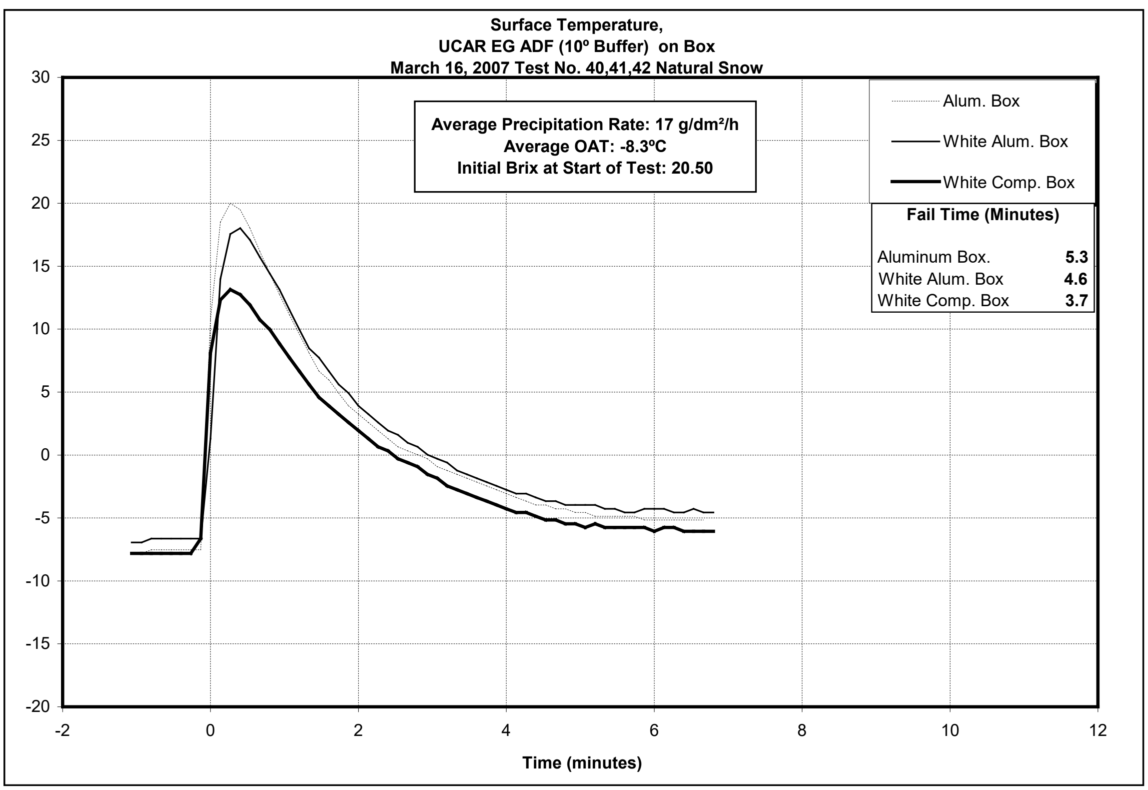

Surface Temperature,
UCAR EG ADF (10º Buffer) on Box
March 2, 2007 Test No. 25,26,27 Natural Snow
Average Precipitation Rate: 50 g/dm²/h
Average OAT: -2.5ºC
Initial Brix at Start of Test: 16.00
Alum. Box
White Alum. Box
White Comp. Box
Fail Time (Minutes)
Aluminum Box. 3.3
White Alum. Box 2.8
White Comp. Box 1.7
30
25
20
15
10
5
0
-5
-10
-15
-20
-1
0
1
2
3
4
5
6
Time (minutes)

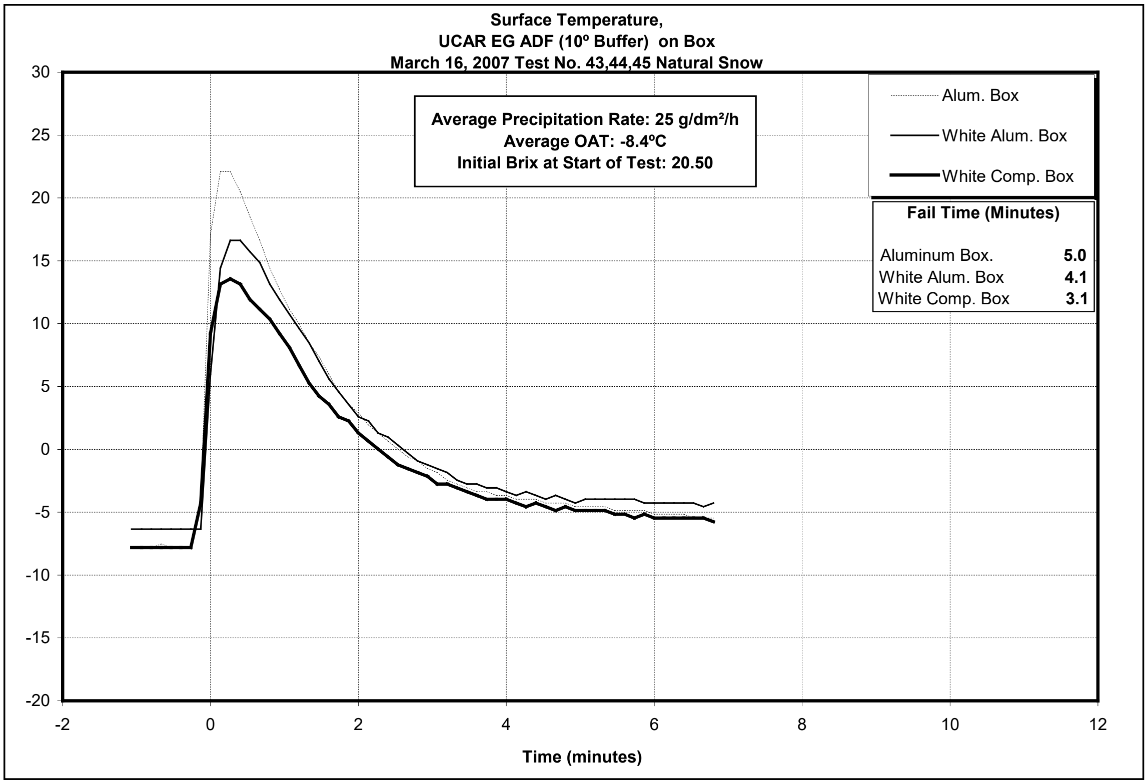

Surface Temperature,
UCAR EG ADF (10º Buffer) on Box
March 2, 2007 Test No. 28,29,30 Natural Snow
Average Precipitation Rate: 4 g/dm²/h
Average OAT: -2.5ºC
Initial Brix at Start of Test: 16.00
Alum. Box
White Alum. Box
White Comp. Box
Fail Time (Minutes)
Aluminum Box. 22.1
White Alum. Box 21.4
White Comp. Box 17.7
30
25
20
15
10
5
0
-5
-10
-15
-20
-2
0
2
4
6
8
10
12
14
16
18
20
22
24
Time (minutes)


Surface Temperature,
UCAR EG ADF (10º Buffer) on Box
March 2, 2007 Test No. 31,32,33 Natural Snow
Average Precipitation Rate: 13 g/dm²/h
Average OAT: -2.4ºC
Initial Brix at Start of Test: 17.00
Alum. Box
White Alum. Box
White Comp. Box
Fail Time (Minutes)
Aluminum Box. 10.2
White Alum. Box 8.3
White Comp. Box 5.8
30
25
20
15
10
5
0
-5
-10
-15
-20
-2
0
2
4
6
8
10
12
Time (minutes)

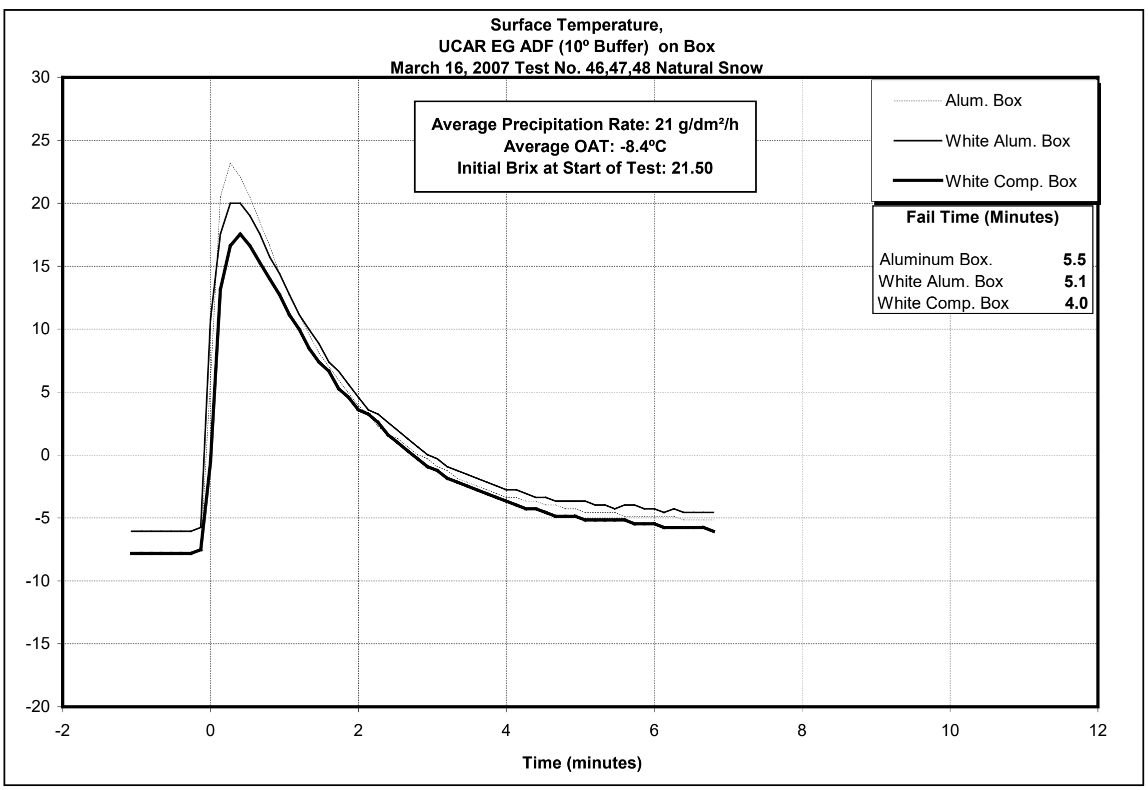

Surface Temperature,
UCAR EG ADF (10º Buffer) on Box
March 2, 2007 Test No. 34,35,36 Natural Snow
Average Precipitation Rate: 12 g/dm²/h
Average OAT: -2.1ºC
Initial Brix at Start of Test: 17.00
Alum. Box
White Alum. Box
White Comp. Box
Fail Time (Minutes)
Aluminum Box. 11.1
White Alum. Box 9.1
White Comp. Box 5.7
30
25
20
15
10
5
0
-5
-10
-15
-20
-2
0
2
4
6
8
10
12
Time (minutes)


Surface Temperature,
UCAR EG ADF (10º Buffer) on Box
March 16, 2007 Test No. 37,38,39 Natural Snow
Average Precipitation Rate: 5.5 g/dm²/h
Average OAT: -7.0ºC
Initial Brix at Start of Test: 20.50
Alum. Box
White Alum. Box
White Comp. Box
Fail Time (Minutes)
Aluminum Box. 11.6
White Alum. Box 10.4
White Comp. Box 6.2
30
25
20
15
10
5
0
-5
-10
-15
-20
-2
0
2
4
6
8
10
12
Time (minutes)

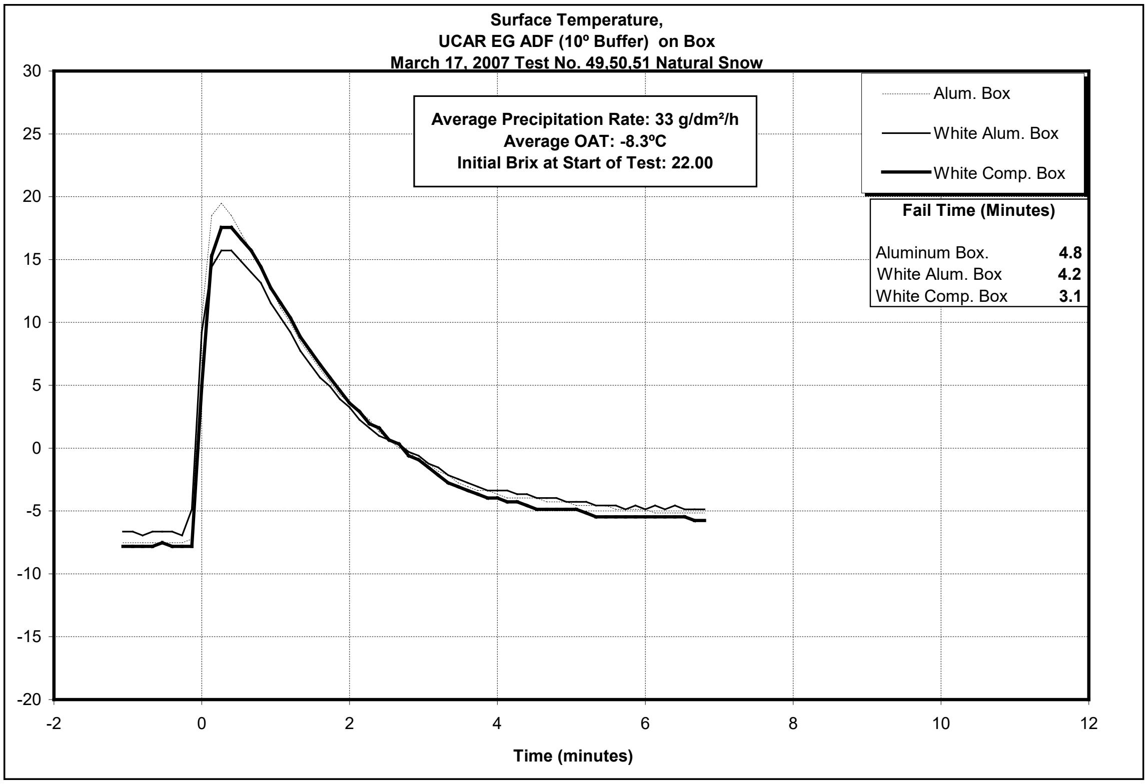

Surface Temperature,
UCAR EG ADF (10º Buffer) on Box
March 16, 2007 Test No. 40,41,42 Natural Snow
Average Precipitation Rate: 17 g/dm²/h
Average OAT: -8.3ºC
Initial Brix at Start of Test: 20.50
Alum. Box
White Alum. Box
White Comp. Box
Fail Time (Minutes)
Aluminum Box. 5.3
White Alum. Box 4.6
White Comp. Box 3.7
30
25
20
15
10
5
0
-5
-10
-15
-20
-2
0
2
4
6
8
10
12
Time (minutes)

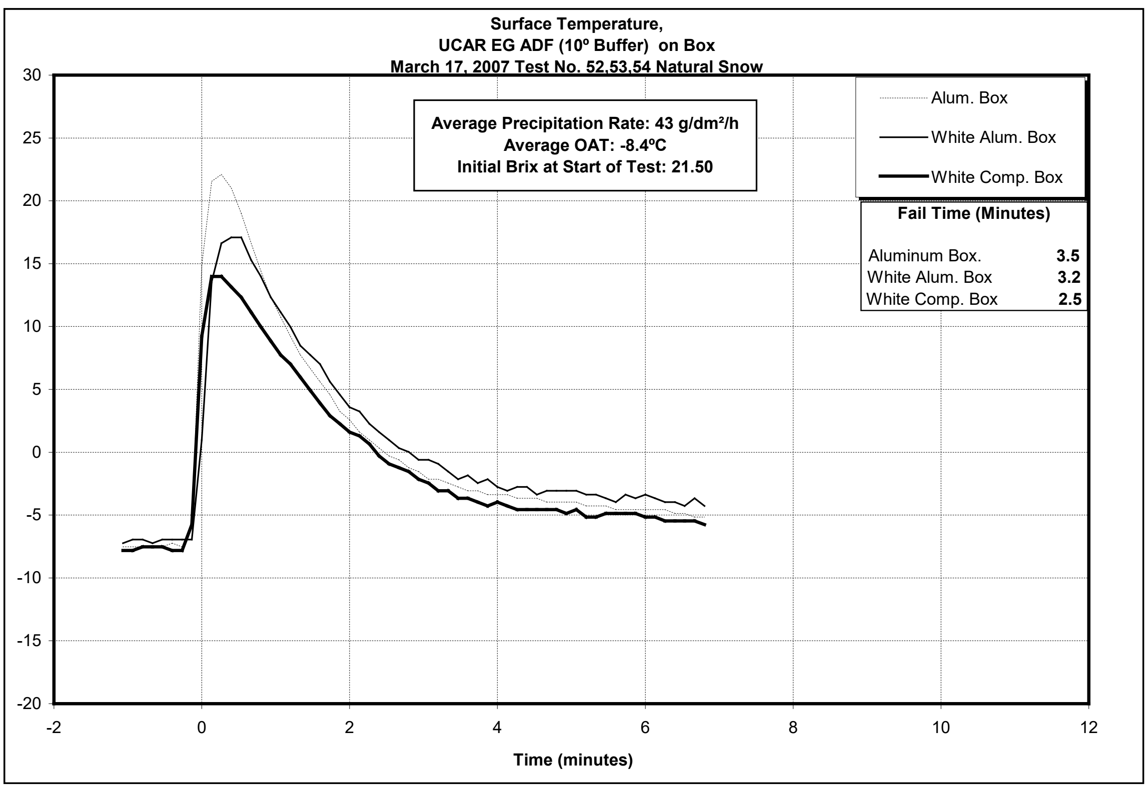


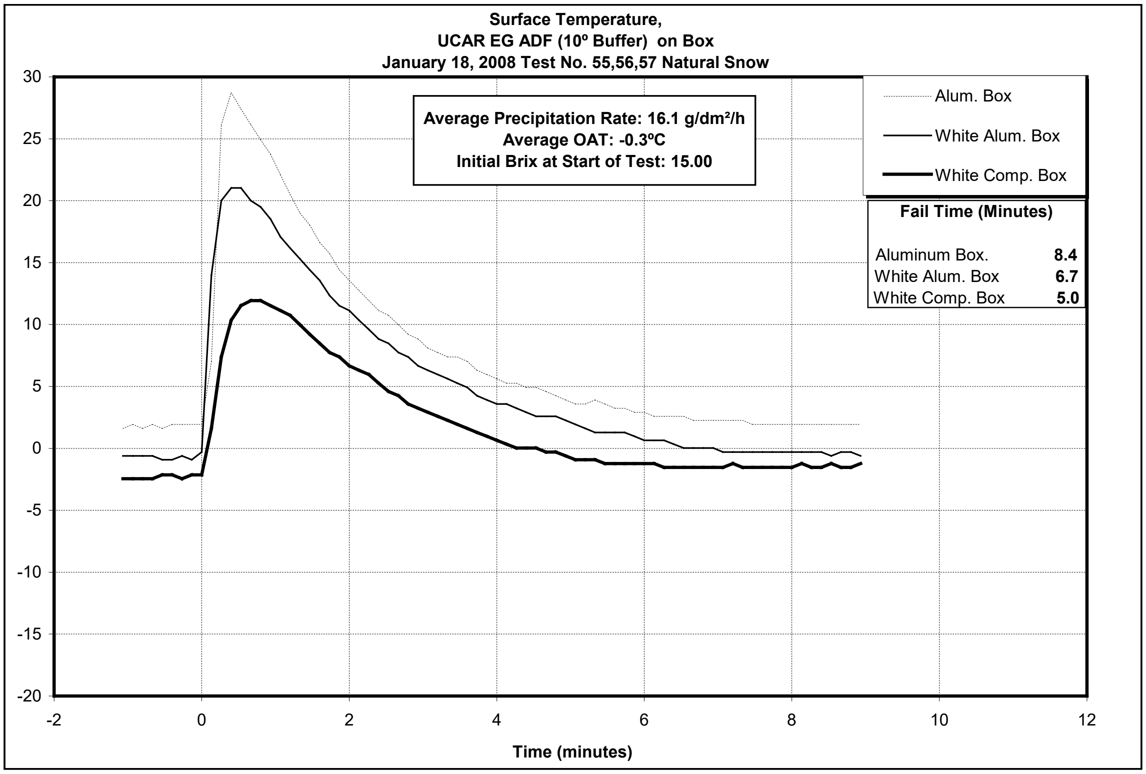
Surface Temperature,
UCAR EG ADF (10º Buffer) on Box
March 16, 2007 Test No. 43,44,45 Natural Snow
Average Precipitation Rate: 25 g/dm²/h
Average OAT: -8.4ºC
Initial Brix at Start of Test: 20.50
Alum. Box
White Alum. Box
White Comp. Box
Fail Time (Minutes)
Aluminum Box. 5.0
White Alum. Box 4.1
White Comp. Box 3.1
Time (minutes)



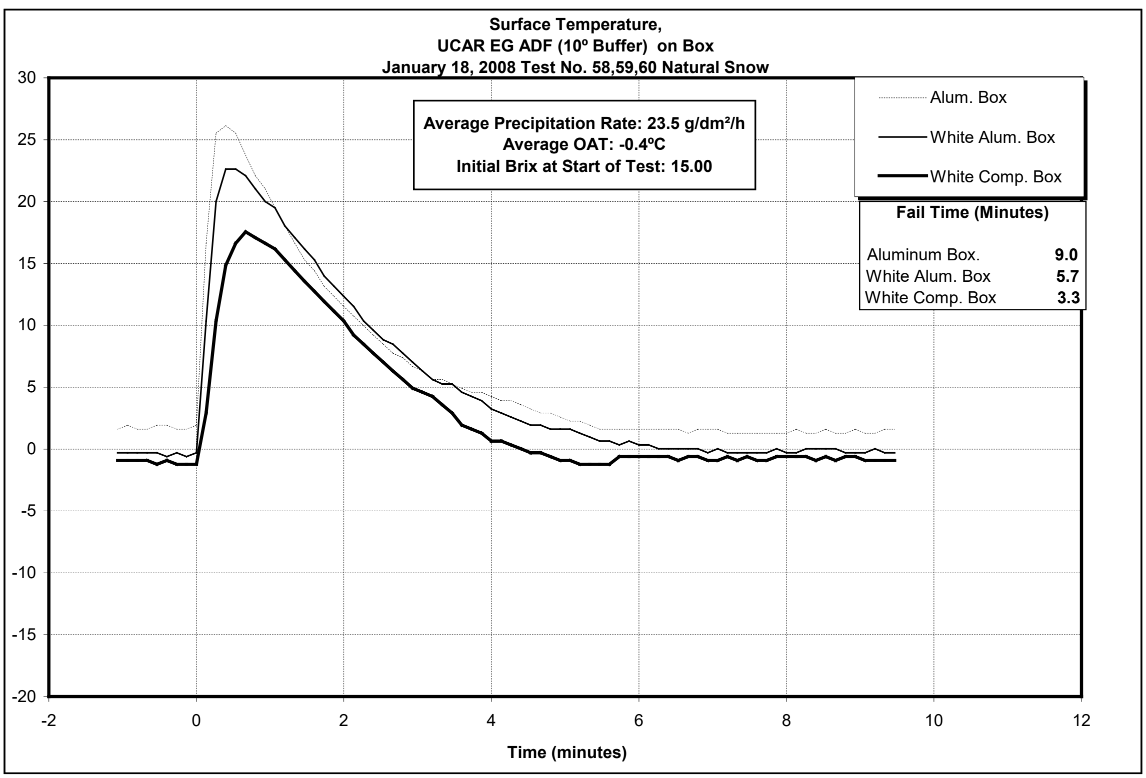
Surface Temperature,
UCAR EG ADF (10º Buffer) on Box
March 16, 2007 Test No. 46,47,48 Natural Snow
Average Precipitation Rate: 21 g/dm²/h
Average OAT: -8.4ºC
Initial Brix at Start of Test: 21.50
Alum. Box
White Alum. Box
White Comp. Box
Fail Time (Minutes)
Aluminum Box. 5.5
White Alum. Box 5.1
White Comp. Box 4.0
Time (minutes)


Surface Temperature,
UCAR EG ADF (10º Buffer) on Box
March 17, 2007 Test No. 49,50,51 Natural Snow
Average Precipitation Rate: 33 g/dm²/h
Average OAT: -8.3ºC
Initial Brix at Start of Test: 22.00
Alum. Box
White Alum. Box
White Comp. Box
Fail Time (Minutes)
Aluminum Box. 4.8
White Alum. Box 4.2
White Comp. Box 3.1
Time (minutes)
30
25
20
15
10
5
0
-5
-10
-15
-20
-2
0
2
4
6
8
10
12

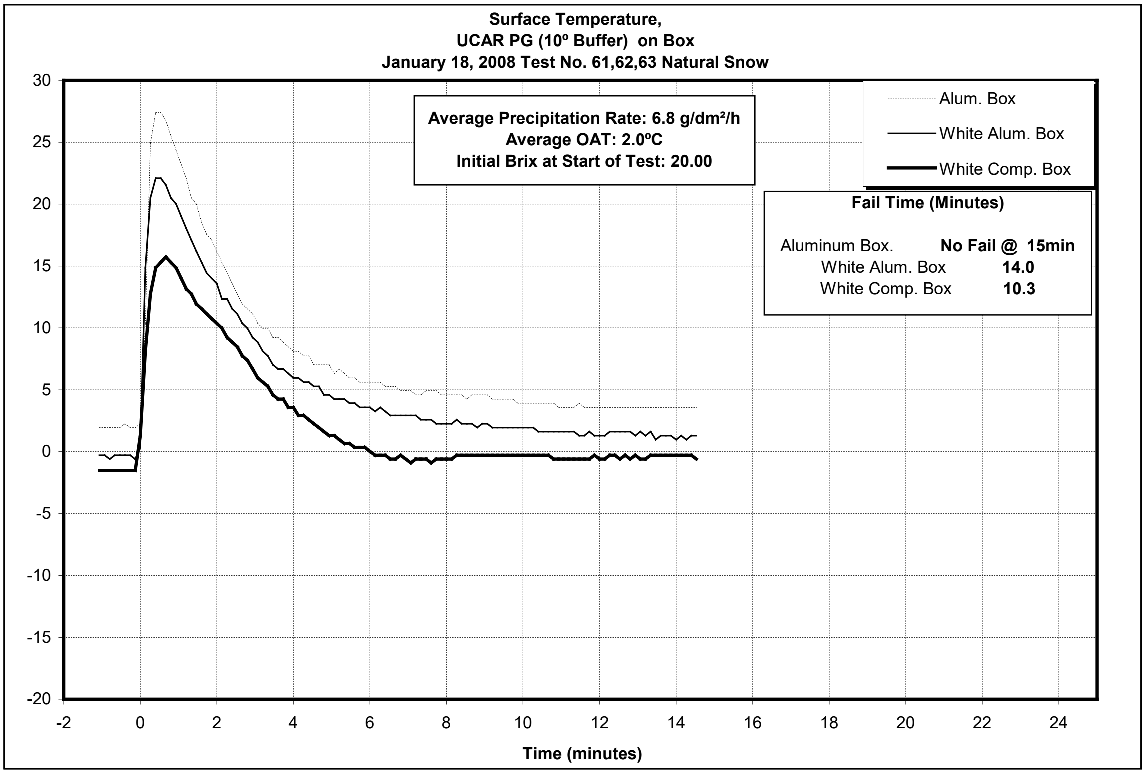

Surface Temperature,
UCAR EG ADF (10º Buffer) on Box
March 17, 2007 Test No. 52,53,54 Natural Snow
Average Precipitation Rate: 43 g/dm²/h
Average OAT: -8.4ºC
Initial Brix at Start of Test: 21.50
Alum. Box
White Alum. Box
White Comp. Box
Fail Time (Minutes)
Aluminum Box. 3.5
White Alum. Box 3.2
White Comp. Box 2.5
Time (minutes)
30
25
20
15
10
5
0
-5
-10
-15
-20
-2
0
2
4
6
8
10
12

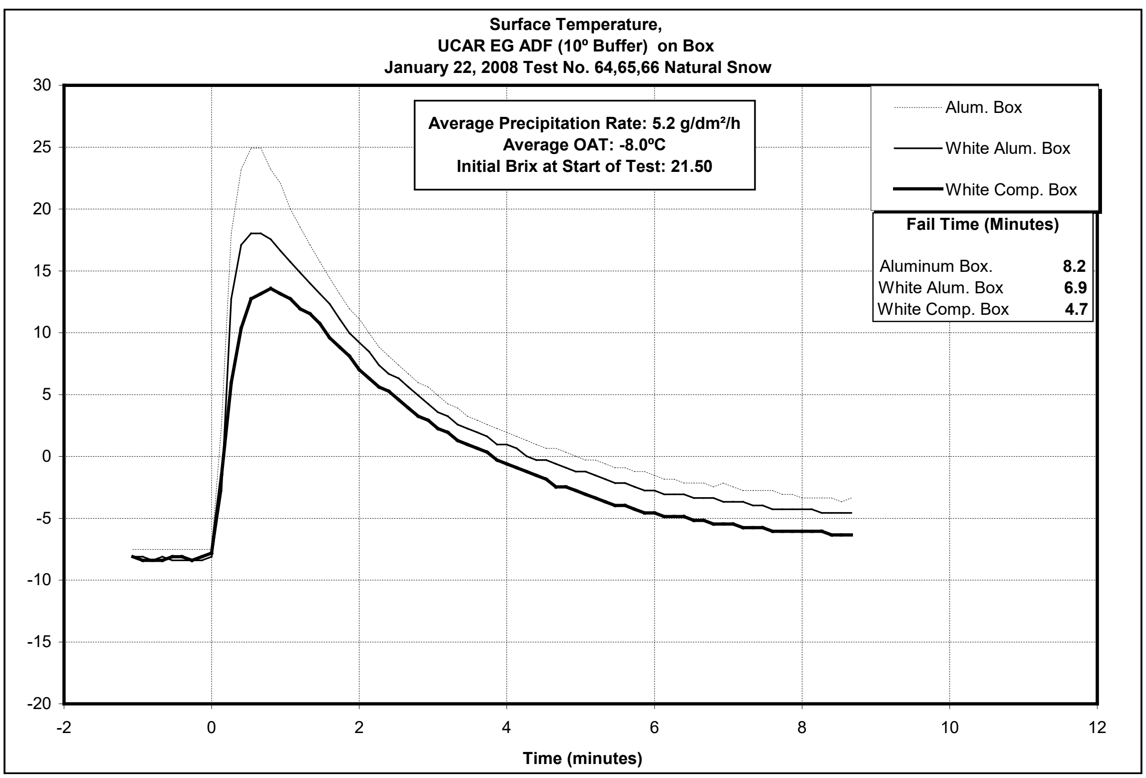


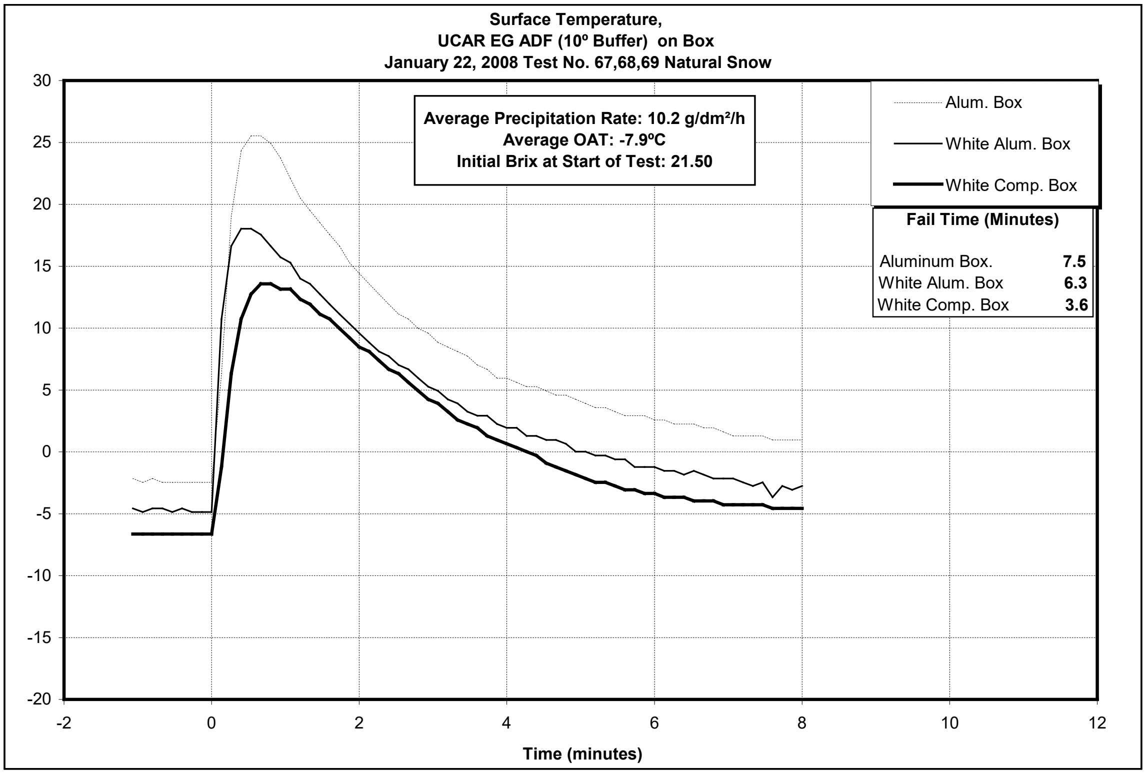
Surface Temperature,
UCAR EG ADF (10º Buffer) on Box
January 18, 2008 Test No. 55,56,57 Natural Snow
Average Precipitation Rate: 16.1 g/dm²/h
Average OAT: -0.3ºC
Initial Brix at Start of Test: 15.00
Alum. Box
White Alum. Box
White Comp. Box
Fail Time (Minutes)
Aluminum Box. 8.4
White Alum. Box 6.7
White Comp. Box 5.0
Time (minutes)

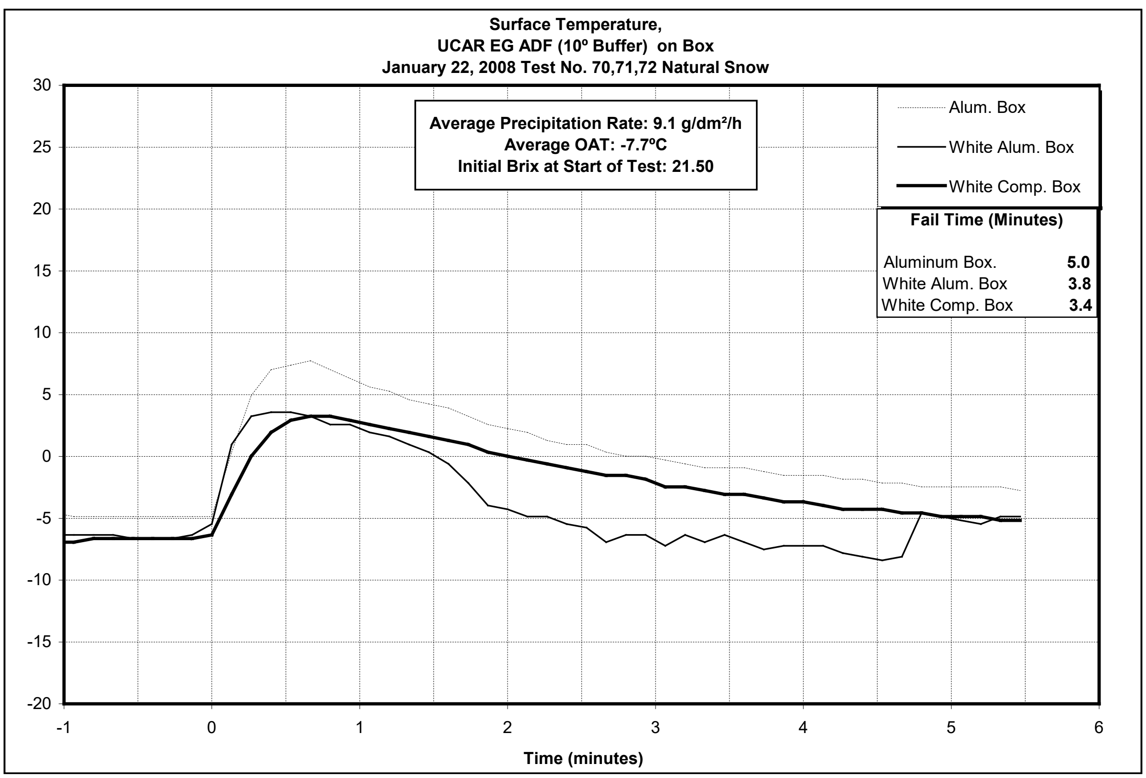


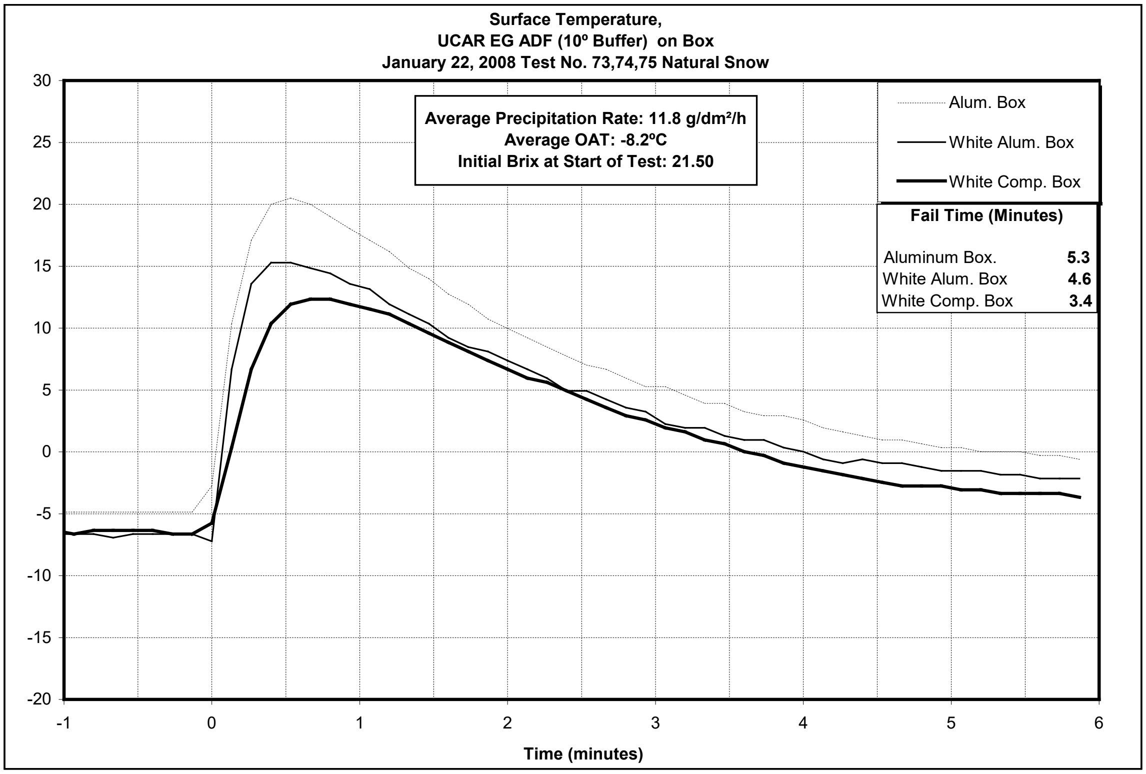
Surface Temperature,
UCAR EG ADF (10º Buffer) on Box
January 18, 2008 Test No. 58,59,60 Natural Snow
Average Precipitation Rate: 23.5 g/dm²/h
Average OAT: -0.4ºC
Initial Brix at Start of Test: 15.00
Alum. Box
White Alum. Box
White Comp. Box
Fail Time (Minutes)
Aluminum Box. 9.0
White Alum. Box 5.7
White Comp. Box 3.3
Time (minutes)

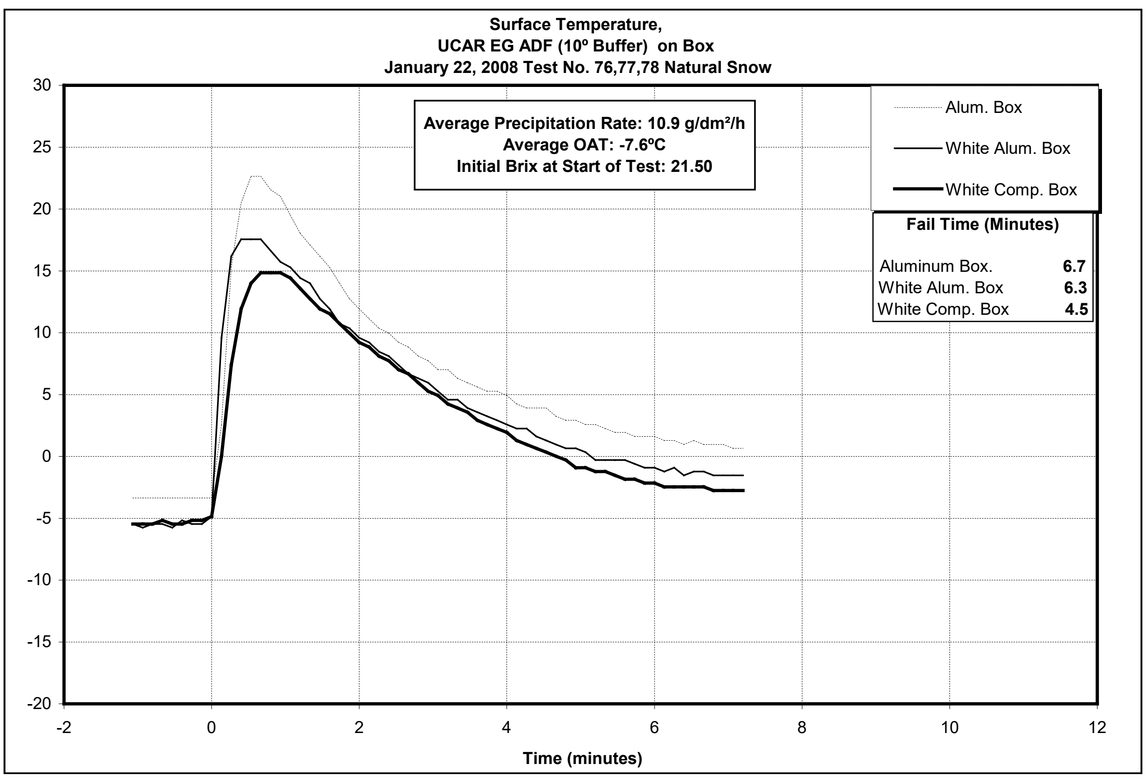

Surface Temperature,
UCAR PG (10º Buffer) on Box
January 18, 2008 Test No. 61,62,63 Natural Snow
Average Precipitation Rate: 6.8 g/dm²/h
Average OAT: 2.0ºC
Initial Brix at Start of Test: 20.00
Alum. Box
White Alum. Box
White Comp. Box
Fail Time (Minutes)
Aluminum Box. No Fail @ 15min
White Alum. Box 14.0
White Comp. Box 10.3
30
25
20
15
10
5
0
-5
-10
-15
-20
-2
0
2
4
6
8
10
12
14
16
18
20
22
24
Time (minutes)

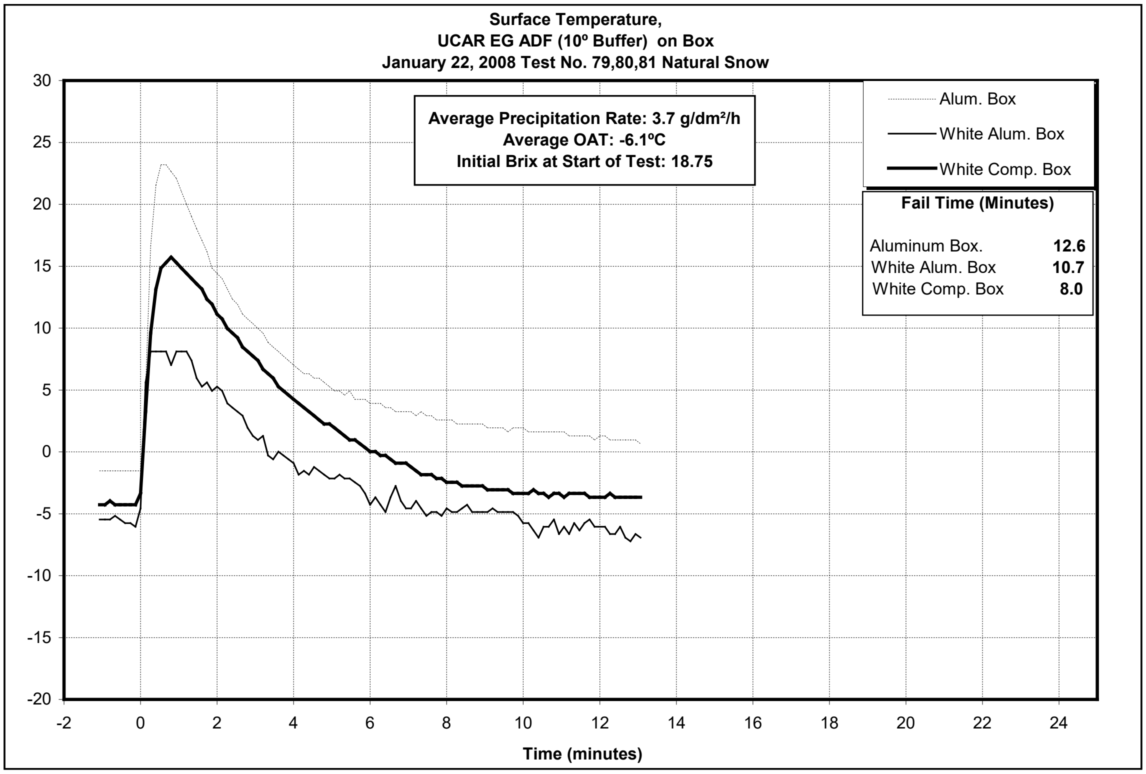

Surface Temperature,
UCAR EG ADF (10º Buffer) on Box
January 22, 2008 Test No. 64,65,66 Natural Snow
Average Precipitation Rate: 5.2 g/dm²/h
Average OAT: -8.0ºC
Initial Brix at Start of Test: 21.50
Alum. Box
White Alum. Box
White Comp. Box
Fail Time (Minutes)
Aluminum Box. 8.2
White Alum. Box 6.9
White Comp. Box 4.7
30
25
20
15
10
5
0
-5
-10
-15
-20
-2
0
2
4
6
8
10
12
Time (minutes)

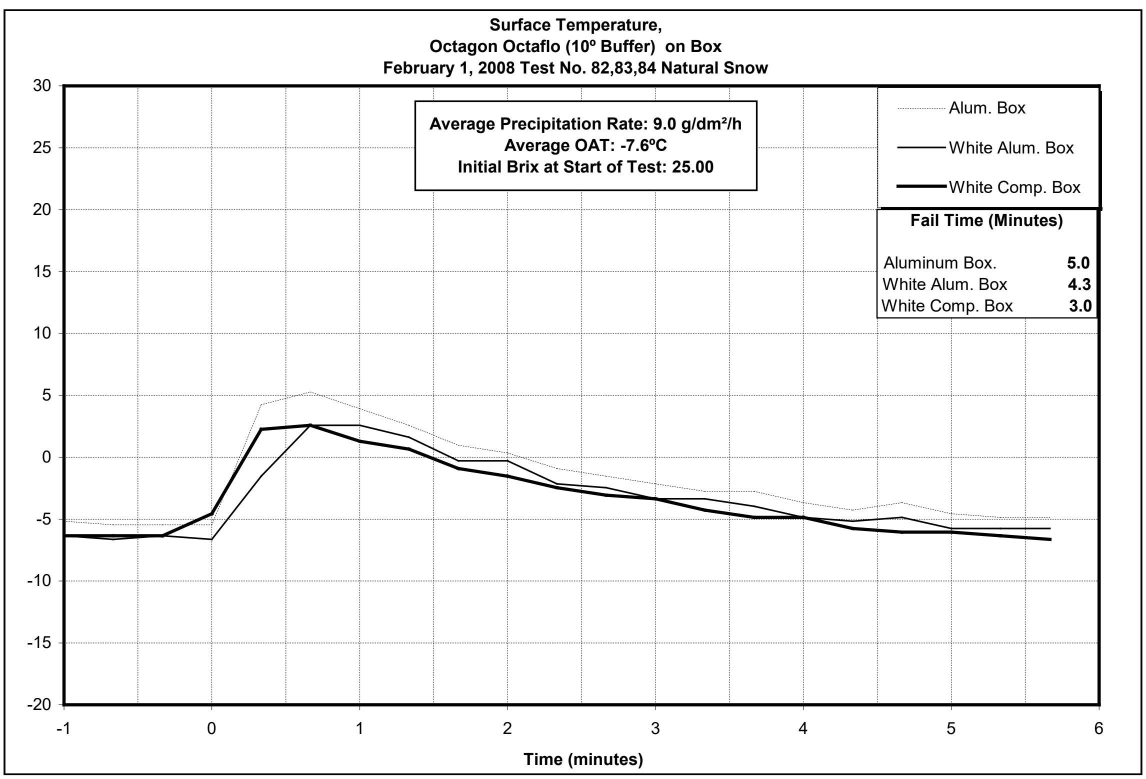

Surface Temperature,
UCAR EG ADF (10º Buffer) on Box
January 22, 2008 Test No. 67,68,69 Natural Snow
Average Precipitation Rate: 10.2 g/dm²/h
Average OAT: -7.9ºC
Initial Brix at Start of Test: 21.50
Alum. Box
White Alum. Box
White Comp. Box
Fail Time (Minutes)
Aluminum Box. 7.5
White Alum. Box 6.3
White Comp. Box 3.6
30
25
20
15
10
5
0
-5
-10
-15
-20
-2
0
2
4
6
8
10
12
Time (minutes)

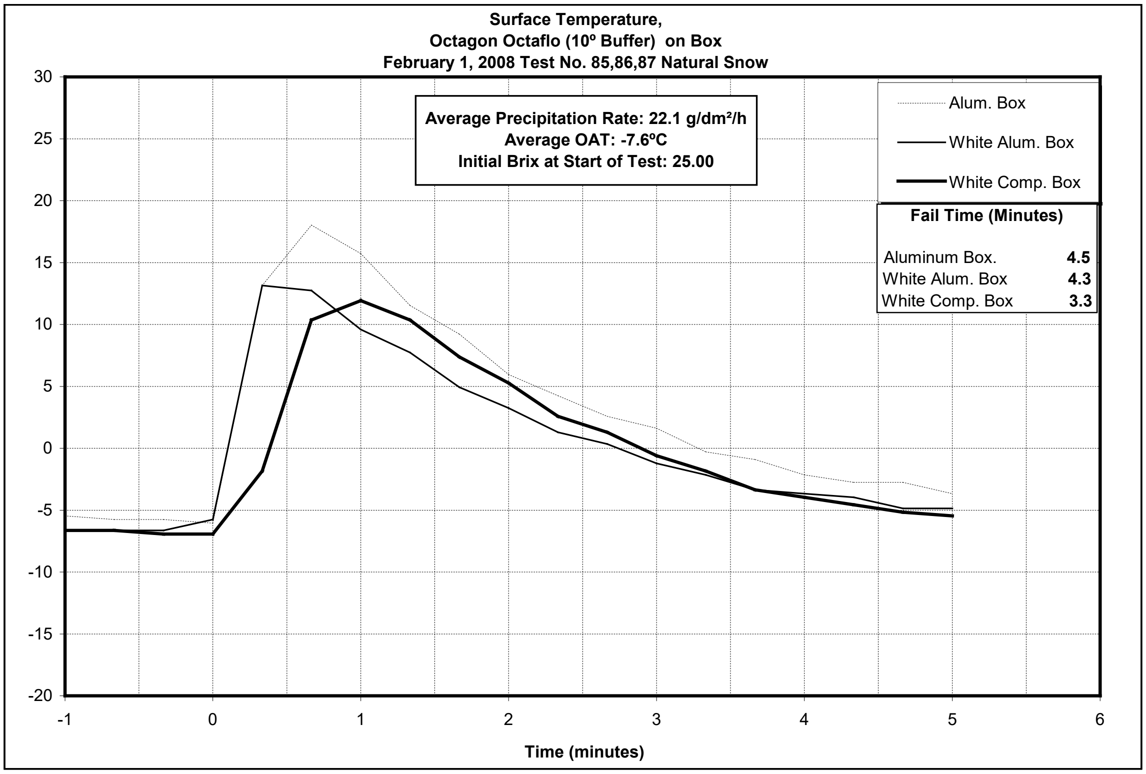

Surface Temperature,
UCAR EG ADF (10º Buffer) on Box
January 22, 2008 Test No. 70,71,72 Natural Snow
Average Precipitation Rate: 9.1 g/dm²/h
Average OAT: -7.7ºC
Initial Brix at Start of Test: 21.50
Alum. Box
White Alum. Box
White Comp. Box
Fail Time (Minutes)
Aluminum Box. 5.0
White Alum. Box 3.8
White Comp. Box 3.4
30
25
20
15
10
5
0
-5
-10
-15
-20
-1
0
1
2
3
4
5
6
Time (minutes)

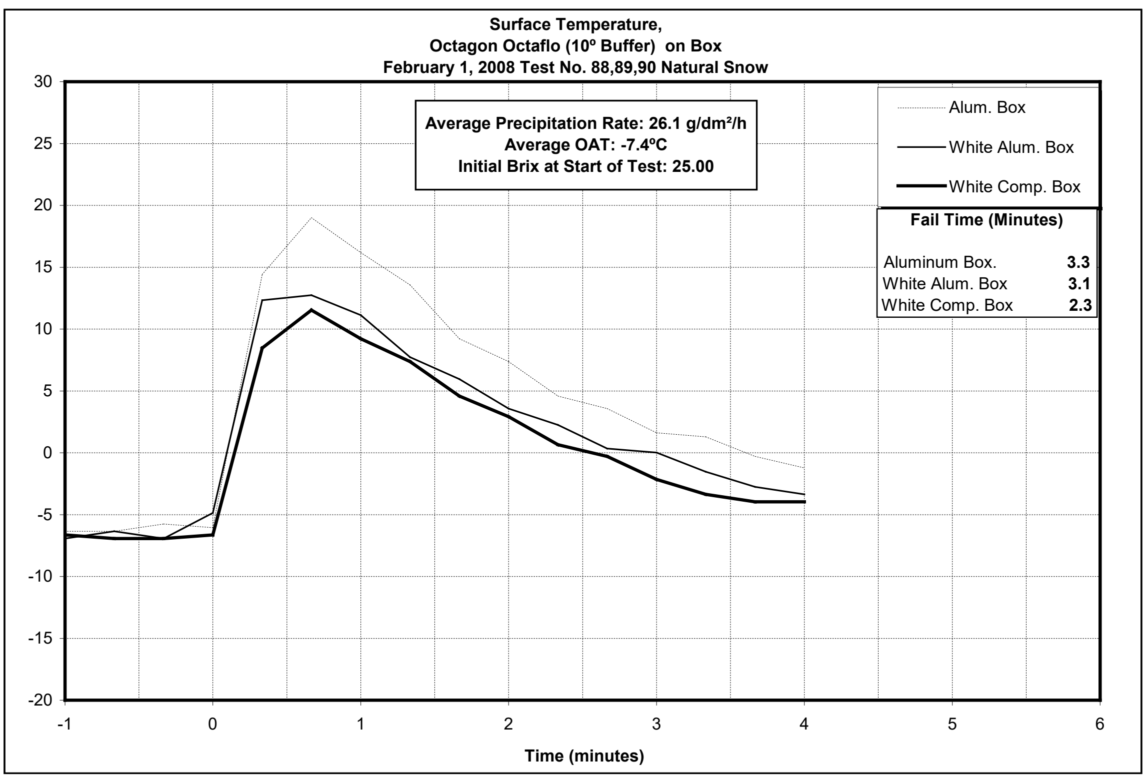

Surface Temperature,
UCAR EG ADF (10º Buffer) on Box
January 22, 2008 Test No. 73,74,75 Natural Snow
Average Precipitation Rate: 11.8 g/dm²/h
Average OAT: -8.2ºC
Initial Brix at Start of Test: 21.50
Alum. Box
White Alum. Box
White Comp. Box
Fail Time (Minutes)
Aluminum Box. 5.3
White Alum. Box 4.6
White Comp. Box 3.4
Time (minutes)

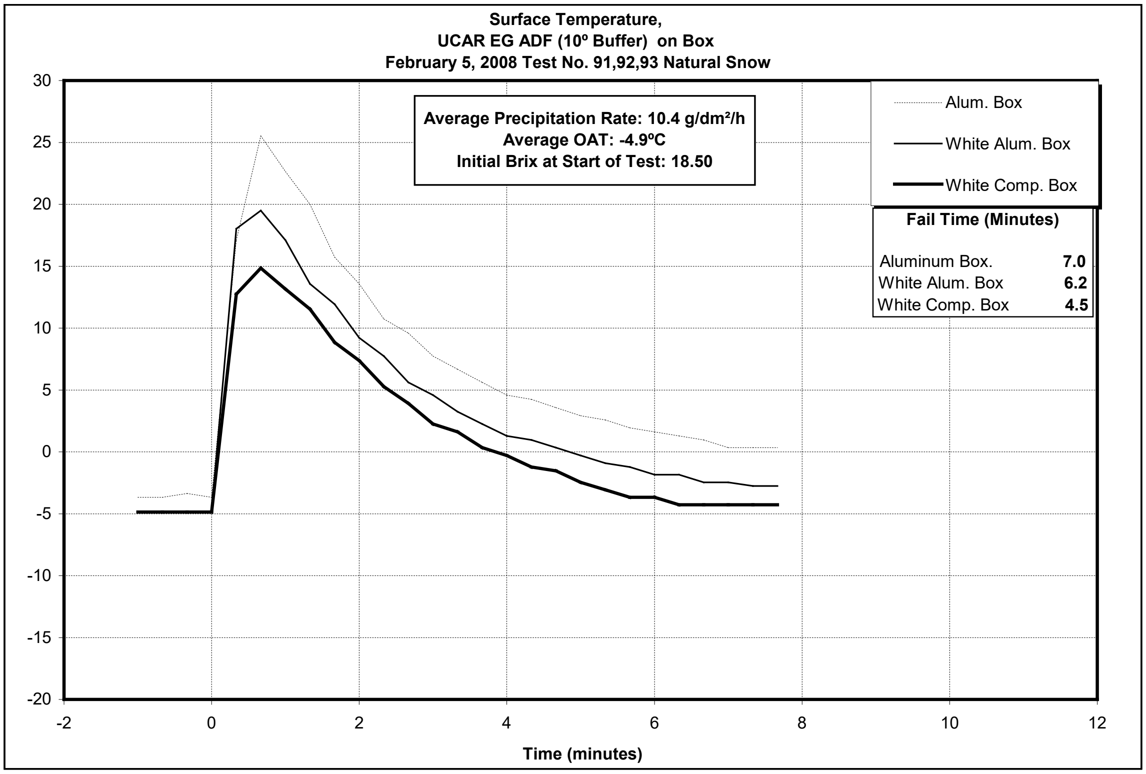

Surface Temperature,
UCAR EG ADF (10º Buffer) on Box
January 22, 2008 Test No. 76,77,78 Natural Snow
Average Precipitation Rate: 10.9 g/dm²/h
Average OAT: -7.6ºC
Initial Brix at Start of Test: 21.50
Alum. Box
White Alum. Box
White Comp. Box
Fail Time (Minutes)
Aluminum Box. 6.7
White Alum. Box 6.3
White Comp. Box 4.5
Time (minutes)

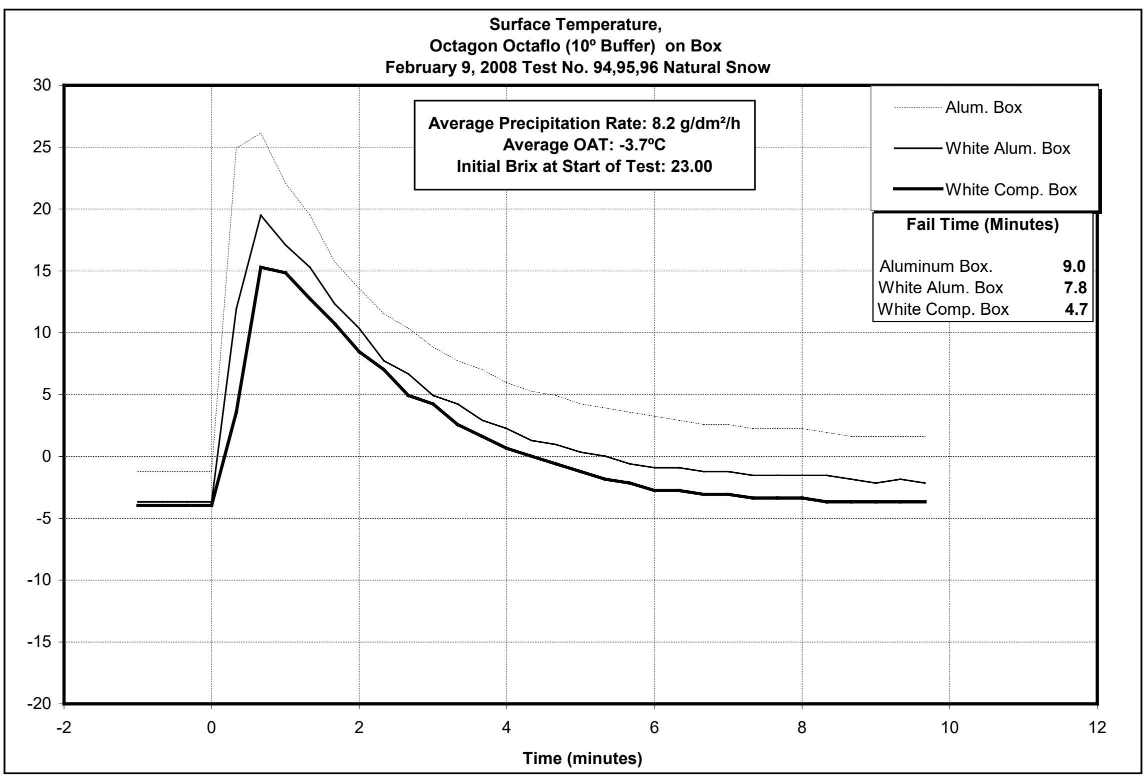

Surface Temperature,
UCAR EG ADF (10º Buffer) on Box
January 22, 2008 Test No. 79,80,81 Natural Snow
Average Precipitation Rate: 3.7 g/dm²/h
Average OAT: -6.1ºC
Initial Brix at Start of Test: 18.75
Alum. Box
White Alum. Box
White Comp. Box
Fail Time (Minutes)
Aluminum Box. 12.6
White Alum. Box 10.7
White Comp. Box 8.0
30
25
20
15
10
5
0
-5
-10
-15
-20
-2
0
2
4
6
8
10
12
14
16
18
20
22
24
Time (minutes)

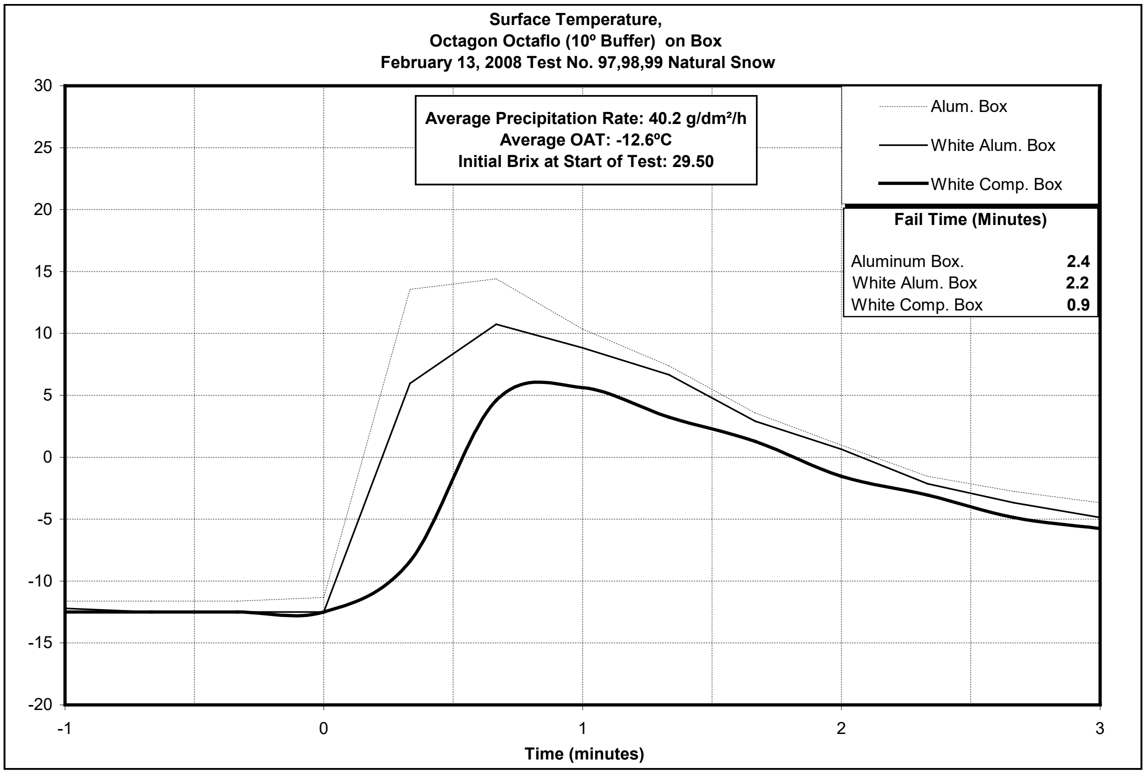

Surface Temperature,
Octagon Octaflo (10º Buffer) on Box
February 1, 2008 Test No. 82,83,84 Natural Snow
Average Precipitation Rate: 9.0 g/dm²/h
Average OAT: -7.6ºC
Initial Brix at Start of Test: 25.00
Alum. Box
White Alum. Box
White Comp. Box
Fail Time (Minutes)
Aluminum Box. 5.0
White Alum. Box 4.3
White Comp. Box 3.0
30
25
20
15
10
5
0
-5
-10
-15
-20
-1
0
1
2
3
4
5
6
Time (minutes)


Surface Temperature,
Octagon Octaflo (10º Buffer) on Box
February 1, 2008 Test No. 85,86,87 Natural Snow
Average Precipitation Rate: 22.1 g/dm²/h
Average OAT: -7.6ºC
Initial Brix at Start of Test: 25.00
Alum. Box
White Alum. Box
White Comp. Box
Fail Time (Minutes)
Aluminum Box. 4.5
White Alum. Box 4.3
White Comp. Box 3.3
30
25
20
15
10
5
0
-5
-10
-15
-20
-1
0
1
2
3
4
5
6
Time (minutes)


Surface Temperature,
Octagon Octaflo (10º Buffer) on Box
February 1, 2008 Test No. 88,89,90 Natural Snow
Average Precipitation Rate: 26.1 g/dm²/h
Average OAT: -7.4ºC
Initial Brix at Start of Test: 25.00
Alum. Box
White Alum. Box
White Comp. Box
Fail Time (Minutes)
Aluminum Box. 3.3
White Alum. Box 3.1
White Comp. Box 2.3
30
25
20
15
10
5
0
-5
-10
-15
-20
-1
0
1
2
3
4
5
6
Time (minutes)


Surface Temperature,
UCAR EG ADF (10º Buffer) on Box
February 5, 2008 Test No. 91,92,93 Natural Snow
Average Precipitation Rate: 10.4 g/dm²/h
Average OAT: -4.9ºC
Initial Brix at Start of Test: 18.50
Alum. Box
White Alum. Box
White Comp. Box
Fail Time (Minutes)
Aluminum Box. 7.0
White Alum. Box 6.2
White Comp. Box 4.5
30
25
20
15
10
5
0
-5
-10
-15
-20
-2
0
2
4
6
8
10
12
Time (minutes)


Surface Temperature,
Octagon Octaflo (10º Buffer) on Box
February 9, 2008 Test No. 94,95,96 Natural Snow
Average Precipitation Rate: 8.2 g/dm²/h
Average OAT: -3.7ºC
Initial Brix at Start of Test: 23.00
Alum. Box
White Alum. Box
White Comp. Box
Fail Time (Minutes)
Aluminum Box. 9.0
White Alum. Box 7.8
White Comp. Box 4.7
30
25
20
15
10
5
0
-5
-10
-15
-20
-2
0
2
4
6
8
10
12
Time (minutes)


Surface Temperature,
Octagon Octaflo (10º Buffer) on Box
February 13, 2008 Test No. 97,98,99 Natural Snow
Average Precipitation Rate: 40.2 g/dm²/h
Average OAT: -12.6ºC
Initial Brix at Start of Test: 29.50
Alum. Box
White Alum. Box
White Comp. Box
Fail Time (Minutes)
Aluminum Box. 2.4
White Alum. Box 2.2
White Comp. Box 0.9
30
25
20
15
10
5
0
-5
-10
-15
-20
-1
0
1
2
3
Time (minutes)

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