TP 15052E

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

Volume 1 of 2: Primary Research (Conducted Winter 2009-10) and Analysis




Prepared for
Transportation Development Centre

In cooperation with

Civil Aviation
Transport Canada

and

The Federal Aviation Administration
William J. Hughes Technical Center

Prepared by:

APS Aviation Inc.

May 2011
Final Version 1.0

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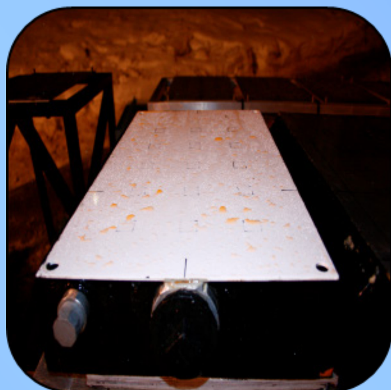


by:

Stephanie Bendickson and Marco Ruggi

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Final Version 1.0

APS Aviation Inc.

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DOCUMENT ORIGIN AND APPROVAL RECORD

Prepared by:

Aug 30, 2021

Stephanie Bendickson, BComm — Date
Project Leader

And by:

Aug 30, 2021

Marco Ruggi, Eng, M.B.A — Date
Project Leader

Reviewed by:

Aug 30, 2021

John D'Avirro, Eng., PBDM — Date
Director, Aviation Services

Approved by: **

John Detombe — Date
Chief Engineer
ADGA Group Consultant Inc.

Un sommaire français se trouve avant la table des matières.

This report was first provided to Transport Canada as Final Draft 1.0 in May 2011.
It has been published as Final Version 1.0 in August 2021.

***Final Draft 1.0 of this report was signed and provided to Transport Canada in May 2011. A Transport Canada technical and editorial review was subsequently completed and the report was finalized in August 2021; John Detombe was not available to participate in the final review or to sign the current version of the report.*

PREFACE

Under contract to the Transportation Development Centre of Transport Canada, APS Aviation Inc. has undertaken a research program to advance aircraft ground de/anti-icing technology. The specific objectives of the APS Aviation Inc. test program are the following:

- To develop holdover time data for all newly-qualified de/anti-icing fluids; and update and maintain the website for the holdover time guidelines;
- To evaluate weather data from previous winters that can have an impact on the format of the holdover time guidelines;
- To develop Type I holdover times for composite surfaces; and evaluate first-step rule for use with composite surfaces;
- To conduct general and exploratory de/anti-icing research;
- To conduct endurance time tests simulating vertical stabilizer anti-icing;
- To conduct endurance time tests in simulated snow pellet conditions;
- To conduct endurance time tests with a snow machine in an attempt to refine the current test protocol;
- To conduct endurance time tests in heavy snow conditions;
- To support Federal Aviation Administration and Transport Canada in the development of an advisory circular for the implementation of a holdover time determination system;
- To evaluate the use of sensors in determining active frost conditions;
- To initiate research for development of ice detection capabilities for departing aircraft at the runway threshold;
- To evaluate frost holdover times for use during cold-soaked wing frost conditions;
- To update the regression coefficient report with the newly-qualified de/anti-icing fluids;
- To conduct endurance time tests on surfaces treated with ice phobic products;
- To evaluate holdover times for anti-icing in a hangar;
- To conduct research at the National Research Council Canada wind tunnel to further develop and expand ice pellet allowance times; and
- To conduct various aerodynamic research activities at the National Research Council Canada wind tunnel.

The research activities of the program conducted on behalf of Transport Canada during the winter of 2009-10 are documented in eight reports. The titles of the reports are as follows:

- TP 15050E Aircraft Ground De/Anti-Icing Fluid Holdover Time Development Program for the 2009-10 Winter;
- TP 15051E Winter Weather Impact on Holdover Time Table Format (1995-2010);

- TP 15052E Development of Type I Fluid Holdover Times for Use on Aircraft with Composite Surfaces;
- TP 15053E Aircraft Ground Icing General Research Activities During the 2009-10 Winter;
- TP 15054E Regression Coefficients and Equations Used to Develop the Winter 2010-11 Aircraft Ground Deicing Holdover Time Tables;
- TP 15055E Emerging De/Anti-Icing Technology: Evaluation of Ice Phobic Products for Potential Use in Aircraft Operations;
- TP 15056E Holdover Times Related to Aircraft Hangar Operations; and
- TP 15057E Exploratory Wind Tunnel Aerodynamic Research Examination of Contaminated Anti-Icing Fluid Flow-Off Characteristics Winter 2009-10.

In addition, the following interim report is being prepared:

- *Wind Tunnel Research to Support the Development of Ice Pellet Allowance Time Tables, Winter 2009-10.*

This report, TP 15052E, has the following objective:

- To document the data collected and analysis completed in support of the development of new holdover times for Type I fluids on composite surfaces.

This objective was met by conducting comparative endurance time testing on composite and aluminum surfaces over a number of winters and completing extensive analysis of the data.

PROGRAM ACKNOWLEDGEMENTS

This multi-year research program has been funded by Transport Canada with support from the Federal Aviation Administration, William J. Hughes Technical Center, Atlantic City, NJ. This program could not have been accomplished without the participation of many organizations. APS Aviation Inc. would therefore like to thank the Transportation Development Centre of Transport Canada, the Federal Aviation Administration, National Research Council Canada, the Meteorological Service of Canada, and several fluid manufacturers.

APS Aviation Inc. would also like to acknowledge the dedication of the research team, whose performance was crucial to the acquisition of hard data. This includes the following people: Steven Baker, Stephanie Bendickson, Jeffrey Bourgerois, John D'Avirro, Jesse Dybka, Daniel Fata, Benjamin Guthrie, Dany Posteraro, Marco Ruggi, James Smyth, David Youssef, and Victoria Zoitakis.

Special thanks are extended to Howard Posluns, Yvan Chabot, Doug Ingold and Warren Underwood, who on behalf of the Transportation Development Centre and the Federal

Aviation Administration, have participated, contributed and provided guidance in the preparation of these documents.

PROJECT ACKNOWLEDGEMENTS

APS Aviation Inc. would like to acknowledge and thank Aviation Equipment, Inc., and Toray Composites (America) Inc. for their diligence and commitment in providing material samples to this project. Thanks are also extended to the fluid manufacturers who contributed fluid samples for testing.

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Transport Canada / Transports Canada

PUBLICATION DATA FORM

1. Transport Canada Publication No. TP 15052E	2. Project No. B14W	3. Recipient's Catalogue No.
4. Title and Subtitle Development of Type I Fluid Holdover Times for Use on Aircraft with Composite Surfaces		5. Publication Date May 2011 6. Performing Organization Document No. CM2169.002
7. Author(s) Stephanie Bendickson and Marco Ruggi		8. Transport Canada File No. 2450-BP-14
9. Performing Organization Name and Address APS Aviation Inc. 6700 Côte-de-Liesse Rd., Suite 105 Montreal, Quebec, H4T 2B5		10. PWGSC File No. MTB-8-25519 11. PWGSC or Transport Canada Contract No. T8200-088510/001/MTB
12. Sponsoring Agency Name and Address Transportation Development Centre Transport Canada 330 Sparks St., 26th Floor Ottawa, Ontario, K1A 0N5		13. Type of Publication and Period Covered Final 14. Project Officer Antoine Lacroix for Howard Posluns

15. Supplementary Notes (Funding programs, titles of related publications, etc.)

Several research reports for testing of de/anti-icing technologies were produced for previous winters on behalf of Transport Canada. These are available from the Transportation Development Centre. Several reports were produced as part of this winter's research program. Their subject matter is outlined in the preface. This project was co-sponsored by the Federal Aviation Administration.

16. Abstract

The increasing use of composite materials in the construction of aircraft necessitated that research be conducted to determine if published holdover times, which were developed for aluminum aircraft using aluminum test surfaces, are valid for composite aircraft surfaces. A multi-year test program was carried out by APS Aviation Inc. on behalf of Transport Canada and the Federal Aviation Administration (FAA) to collect data to make this determination. The research program started in the winter of 2004-05 and continued until the winter of 2009-10.

Exploratory research was carried out during the first five years of the program. The research looked at different composite materials and thicknesses, different fluid types, different fluid temperatures and various test surface configurations. The research concluded that Type II, III and IV fluid endurance times are similar on composite and aluminum surfaces, but Type I fluid endurance times are 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 composites: validating the observed reductions, determining appropriate test protocols, and collecting sufficient data to produce composite-specific Type I holdover times. Although the Type I reductions were initially observed using non-standard test protocols, additional testing carried out using standard protocols confirmed the results.

In the winter of 2009-10, an extensive test program was carried out with five representative Type I fluids. Testing was conducted under all conditions encompassed by the Type I holdover time guidelines. All testing was conducted using standard Type I holdover time testing protocol. This testing provided the data required to develop 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 Type I fluids on composite surfaces. The resulting composite holdover times were generally shorter than the existing aluminum holdover times.

Transport Canada and the FAA incorporated the derived Type I composite holdover times 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.

Several recommendations came out of the six-year research program. These include conduct further testing with Type III fluids to determine the validity of Type III holdover times for heated Type III fluid applications; conduct full-scale testing to validate the Type I endurance time reductions measured on standard test surfaces; and conduct aerodynamic testing in the wind tunnel to investigate the aerodynamic effects of the reduced Type I fluid endurance times observed on composite surfaces.

17. Key Words Anti-icing, deicing, deicing fluid, holdover times, composite, precipitation, endurance times, Type I, Type II, Type III, Type IV, aircraft, ground, test, winter	18. Distribution Statement Limited number of copies available from the Transportation Development Centre

19. Security Classification (of this publication)	20. Security Classification (of this page)	21. Declassification (date)	22. No. of Pages	23. Price
Unclassified	Unclassified	—	xlii, 218 apps	—

CDT/TDC 79-005
Rev. 96

Canada

Transports Canada | Transport Canada

FORMULE DE DONNÉES POUR PUBLICATION

1. Nº de la publication de Transports Canada TP 15052E	2. Nº de l'étude B14W	3. Nº de catalogue du destinataire
4. Titre et sous-titre Development of Type I Fluid Holdover Times for Use on Aircraft with Composite Surfaces		5. Date de la publication Mai 2011 6. Nº de document de l'organisme exécutant CM2169.002
7. Auteur(s) Stephanie Bendickson et Marco Ruggi		8. Nº de dossier - Transports Canada 2450-BP-14
9. Nom et adresse de l'organisme exécutant APS Aviation Inc. 6700, Chemin de la Côte-de-Liesse, Bureau 105 Montréal (Québec) H4T 2B5		10. Nº de dossier - TPSGC MTB-8-25519 11. Nº de contrat - TPSGC ou Transports Canada T8200-088510/001/MTB
12. Nom et adresse de l'organisme parrain Centre de développement des transports Transports Canada 330, rue Sparks, 26ième étage Ottawa (Ontario) K1A 0N5		13. Genre de publication et période visée Final 14. Agent de projet Antoine Lacroix pour Howard Posluns

15. Remarques additionnelles (programmes de financement, titres de publications connexes, etc.)

Plusieurs rapports de recherche sur des essais de technologies de dégivrage et d'antigivrage ont été produits au cours des hivers précédents pour le compte de Transports Canada. Ils sont disponibles au Centre de développement des transports. De nombreux rapports ont été rédigés dans le cadre du programme de recherche de cet hiver. Leur objet apparaît à l'avant-propos. Ce projet était coparrainé par la Federal Aviation Administration.

16. Résumé

Étant donné l'utilisation croissante de matériaux composites dans la construction d'aéronefs, des recherches ont dû être menées dans le but de déterminer si les durées d'efficacité publiées, lesquelles ont été établies pour les aéronefs en aluminium à partir de surfaces d'essai en aluminium, étaient valables pour les surfaces composites. APS Aviation Inc. a réalisé, pour le compte de Transports Canada et de la Federal Aviation Administration (FAA), un programme d'essai s'étalant sur plusieurs années afin de recueillir des données à cette fin. Le programme a débuté au cours de l'hiver 2004-2005 et s'est poursuivi jusqu'à l'hiver 2009-2010.

Une recherche exploratoire a été menée durant les cinq premières années du programme. Elle a permis d'étudier différents matériaux composites et différentes épaisseurs, différents types et différentes températures de liquide et différentes configurations de surface d'essai. Elle a permis de conclure que les durées d'endurance des liquides de type II, III et IV sont semblables tant pour les surfaces composites que pour les surfaces en aluminium, mais que celles des liquides de type I sont plus courtes sur les surfaces composites que sur celles en aluminium. L'objectif du projet a ensuite été revu afin de déterminer les durées d'efficacité appropriées pour les liquides de type I sur les matériaux composites, c'est-à-dire de valider les réductions observées, de déterminer les protocoles d'essai appropriés et de recueillir suffisamment de données pour établir les durées d'efficacité des liquides de type I applicables aux matériaux composites. Bien que la réduction des délais d'efficacité des liquides de type I ait initialement été observée au moyen de protocoles d'essai non standards, les résultats ont par la suite été confirmés par des protocoles standards.

À l'hiver 2009-2010, cinq liquides de type I représentatifs ont été soumis à un programme d'essai rigoureux. Les essais ont été réalisés au moyen du protocole d'essai standard dans toutes les conditions comprises dans les lignes directrices relatives aux durées d'efficacité pour les liquides de type I. Ils ont permis d'obtenir les données requises pour déterminer 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 des liquides de type I sur les surfaces composites 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 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 sur 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.

De nombreuses recommandations ont découlé du programme de recherche de six ans. Parmi celles-ci, notons la réalisation d'autres essais sur les liquides de type III afin de vérifier la validité de leurs durées d'efficacité lorsqu'ils sont appliqués chauffés, la réalisation d'essais en grandeur réelle afin de confirmer la réduction des durées d'endurance des liquides de type I mesurée sur des surfaces d'essai standards ainsi que la réalisation d'essais aérodynamiques en soufflerie afin d'étudier les effets aérodynamiques des durées d'efficacité réduites des liquides de type I observées sur les surfaces composites.

17. Mots clés Antigivrage, dégivrage, liquide de dégivrage, durées d'efficacité, composite, précipitation, temps d'endurance, type I, type II, type III, type IV, aéronef, sol, essai, hiver	18. Diffusion Le Centre de développement des transports dispose d'un nombre limité d'exemplaires.

19. Classification de sécurité (de cette publication)	20. Classification de sécurité (de cette page)	21. Déclassification (date)	22. Nombre de pages	23. Prix
Non classifiée	Non classifiée	—	xlii, 218 ann.	—

CDT/TDC 79-005
Rev. 96

Canada

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. 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. 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

AMIL	Anti-Icing Materials International Laboratory
APS	APS Aviation Inc.
ARP	Aerospace Recommended Practice
EG	Ethylene Glycol
FAA	Federal Aviation Administration
FP	Freezing Point
HOT	Holdover Time
LETE	Leading Edge Thermal Equivalent
MSC	Meteorological Service of Canada
NRC	National Research Council Canada
OAT	Outside Air Temperature
PG	Propylene Glycol
RH	Relative Humidity
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 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 (this volume) 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 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 Summary of Work Conducted

A summary of the composite research conducted in each winter of the research program is provided in this subsection. Table 1.1, at the end of the subsection, provides a further summary.

1.4.1 Winter 2004-05 Testing

During the winter of 2004-05, APS conducted testing to compare fluid endurance times on aluminum and composite flat plate surfaces. The detailed results of this testing were first published in the Transport Canada report, TP 14448E, *Aircraft Ground Deicing Fluid Endurance Times on Composite Surfaces* (1). The testing is reviewed in detail in Volume 2 (Section 3) of this report.

The testing found fluid endurance times (for Type I, II, III, IV fluids) were slightly longer on the composite surface than on the aluminum surface in both natural snow and simulated freezing precipitation. However, it was hypothesized that the results may have been affected by black body radiation heat transfer and experimental error caused by the difficulty in determining visual fluid failure on differing bare material colours. For this reason and because further work was required to verify the validity of the composite test surface, the results were considered preliminary and were in fact later determined to be invalid.

Testing with Type I fluids in natural frost showed reduced fluid endurance times on a white-painted insulated composite test plate compared to a white-painted insulated aluminum test plate. As the composite and aluminum test surfaces were both painted white, the data is considered valid and provided additional support to the frost testing conducted in subsequent winters.

1.4.2 Winter 2005-06 Testing

During the winter of 2005-06, APS conducted testing to evaluate the endurance times of fluids on four white-painted composite test surfaces. Comparative tests were used to assess the endurance time performance of fluids on a white-painted non-aluminum test surface relative to those on a white-painted standard aluminum test surface. For reference purposes, tests were also conducted on a standard unpainted aluminum test surface (the current standard for developing de/anti-icing fluid holdover times). The detailed results of this testing were first published in the Transport Canada report, TP 14720E, *Effect of Heat on Fluid Endurance Times Using Composite Surfaces* (2). The testing is reviewed in detail in Volume 2 (Section 4) of this report.

The testing showed similar endurance times on all four composite materials tested, despite differences in material composition, structure, and thickness. The test results showed that, on average, Type II, Type III, and Type IV fluids had similar endurance times on composite and aluminum test surfaces in natural snow and freezing precipitation. The test results also showed that Type I fluids had shorter endurance times on composite test surfaces than on aluminum test surfaces in natural snow, simulated freezing precipitation, and natural frost.

As a result of these findings, it was recommended that additional testing be conducted with Type I fluids using the current standard test protocols for evaluating holdover times for Type I fluids. In natural snow, this meant conducting tests on composite leading edge thermal equivalent (LETE) surfaces (2005-06 tests were conducted on flat plates). In freezing precipitation, this meant conducting tests with fluids heated to 20°C (2005-06 tests were conducted with fluids heated to 60°C).

1.4.3 Winter 2006-07 Testing

During the winter of 2006-07, APS conducted testing with Type I fluids in natural snow using white-painted composite LETE boxes. Comparative tests were conducted using composite LETE boxes and standard aluminum LETE boxes; the top exposed plates of both the composite and aluminum boxes were painted white to allow for equal radiation effects. For reference purposes, a baseline test was also conducted using an unpainted aluminum thermal equivalent box, which is the current standard for developing holdover times for Type I fluids in snow. The detailed results of this testing were first documented in an interim report, which was provided to Transport Canada and the FAA. They are published for the first time in Volume 2 (Section 5) of this report.

The endurance times measured using the white-painted composite LETE box were, on average, 31 percent shorter than the endurance times measured using the white-painted aluminum LETE box. The differences were less than four minutes for all tests conducted. Testing conducted with Type I fluid heated to either 20ºC or 60ºC generated similar reductions in endurance time. However, testing was conducted primarily in moderate and heavy snow conditions, which generated shorter fluid endurance times. Further testing was recommended to validate the endurance time reductions in light snow conditions.

1.4.4 Winter 2007-08 Testing

During the winter of 2007-08, APS repeated the testing that was conducted in 2006-07. The purpose of this testing was to acquire additional data in light snow conditions to support the findings from the testing conducted during the winter of 2006-07. The detailed results of this testing were first documented in an interim report, which was provided to Transport Canada and the FAA. They are published for the first time in Volume 2 (Section 5) of this report.

The test results confirmed the findings of the 2006-07 research.

1.4.5 Winter 2008-09 Testing

During the winter of 2008-09, APS conducted tests with Type I fluids on composite surfaces in simulated freezing precipitation. Similar testing had previously been conducted in the winter of 2005-06 primarily using fluids heated to 60°C. The 2008-09 testing was conducted with fluids heated to 20°C, which is the current protocol for measuring endurance times of Type I fluids in simulated freezing precipitation.

Comparative tests were conducted using white-painted composite and white-painted aluminum test surfaces. For reference purposes, baseline tests were also conducted using a standard unpainted aluminum test plate, which is the current standard for developing holdover times. The results of this testing were first documented in an interim report, which was provided to Transport Canada and the FAA. They are published for the first time in Volume 2 (Section 6) of this report.

The results showed that endurance times on composite test surfaces were on average 20 percent shorter than endurance times on aluminum test surfaces. The results were similar to those seen in the 2005-06 testing, which showed endurance times on average 24 percent shorter on composite surfaces than on aluminum surfaces.

As a result of the research conducted to this point, regulators published interim guidance on composite surfaces for the Winter 2009-10 operating season. Specifically, they added a note indicating that Type I fluid holdover times could be shorter by up to 30 percent compared to the current holdover times. The note was published by Transport Canada in an update to TP 14052 included in the 2009-10 holdover time guidelines and by the FAA in Notice N 8900.104, *Revised FAA-Approved Deicing Program Updates, Winter 2009-2010* (3).

1.4.6 Winter 2009-10 Testing

During the winter of 2009-10, APS conducted tests 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). This testing enabled the development of composite-specific holdover times for Type I fluids.

All testing was conducted using the current protocol for evaluating holdover times of Type I fluids, with the exception that testing was conducted on composite surfaces. Comparative tests were run concurrently on aluminum surfaces for reference and potential inclusion in the holdover time analysis.

The results of the 2009-10 testing are documented for the first time in this report, in Sections 2, 3, and 4 of Volume 1 (this volume).

Table 1.1: Summary of Composite Work Conducted by Winter

Winter	Conditions Tested	Fluid Types Tested	Composite Surface(s) Tested	Transport Canada Report	Comments
2004-05	• Frost • Snow • Freezing precipitation	• Type I • Type II/III/IV	• Unpainted composite plate	TP 14448E + TP 15052E (Vol 2, Section 3)	• Results were preliminary and supported work conducted the following winters. • Recommendation: Test different types of composite materials and test painted surfaces to eliminate radiative effects.
2005-06	• Frost • Snow • Freezing precipitation	• Type I • Type II/IV • Type III (ltd)	• White-painted composite plates (4 composite samples tested)	TP 14720E + TP 15052E (Vol 2, Section 4)	• No significant differences amongst different composite materials tested; no significant differences in endurance times for Type II/IV fluids; reductions observed with Type I fluids. • Recommendation: Test Type I fluids using current Type I protocol (leading edge thermal equivalent boxes) to validate results.
2006-07	• Snow	• Type I	• White-painted composite LETE box	Interim + TP 15052E (Vol 2, Section 5)	• Reduced Type I endurance times on composite surface observed. Data primarily collected in moderate and heavy snow conditions. • Recommendation: Collect additional data in light snow.
2007-08	• Snow	• Type I	• White-painted composite LETE box	Interim + TP 15052E (Vol 2, Section 5)	• Data collected to further substantiate 2006-07 results.
2008-09	• Freezing precipitation	• Type I	• White-painted composite plate	Interim + TP 15052E (Vol 2, Section 6)	• Limited indoor testing to substantiate 2005-06 Type I results. Testing conducted in accordance with indoor Type I protocol. • Recommendation: Collect additional data.
2009-10	• Frost • Snow • Freezing precipitation	• Type I	• White-painted composite plate • White-painted composite LETE Box	TP 15052E (Vol 1, Sections 2, 3, 4)	• Extensive testing conducted with Type I fluids in all conditions to develop holdover times for Type I fluids on composite surfaces.

1.5 Volume Format and Content

Volume 1 (this volume) includes 10 sections. A short description of the content of each section is listed below.

a) Section 1 contains an introduction and background to the project and provides a history of the composite research conducted since 2004-05.

b) Section 2 describes the test methodology used in the testing completed in the winter of 2009-10.

c) Section 3 documents the data collected in the winter of 2009-10 in natural snow, freezing precipitation, frost, and artificial snow.

d) Section 4 details the data and analysis used to determine holdover times for Type I fluids on composite surfaces in snow.

e) Section 5 details the data and analysis used to determine holdover times for Type I fluids on composite surfaces in freezing precipitation.

f) Section 6 details the data and analysis used to determine holdover times for Type I fluids on composite surfaces in frost.

g) Section 7 describes the process for incorporating the new composite holdover times into the Transport Canada and FAA holdover time guidelines and presents the revised guidelines.

h) Section 8 describes supplemental testing conducted in 2009-10 to examine the use of -3°C buffer Type I fluids in two-step de/anti-icing operations.

i) Section 9 presents conclusions.

j) Section 10 presents recommendations for future research.

1.6 Evolution of Type I Holdover Time Guidelines

As part of this project, the evolution of the Type I holdover time guidelines was researched and documented in a short report. The report, which documents the changes made to the Type I holdover time guidelines from the winter of 1990-91 to the winter of 2010-11, is provided in Appendix B.

2. 2009-10 TEST METHODOLOGY

The composite research carried out in 2009-10 consisted of a large number of comparative endurance time tests conducted on aluminum and composite test surfaces under various precipitation conditions and in various ambient temperatures. Tests were carried out using standard holdover time testing procedures with five Type I fluids.

This section describes the test methodology and experimental procedures used to conduct the composite research in the winter of 2009-10.

2.1 Test Sites

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

2.1.1 Outdoor Test Site

Natural snow and frost testing were conducted at the APS test site located at the Montreal–Pierre Elliott Trudeau International Airport (Photos 2.1 and 2.2). The location of the test site is shown on a plan view of the airport in Figure 2.1.

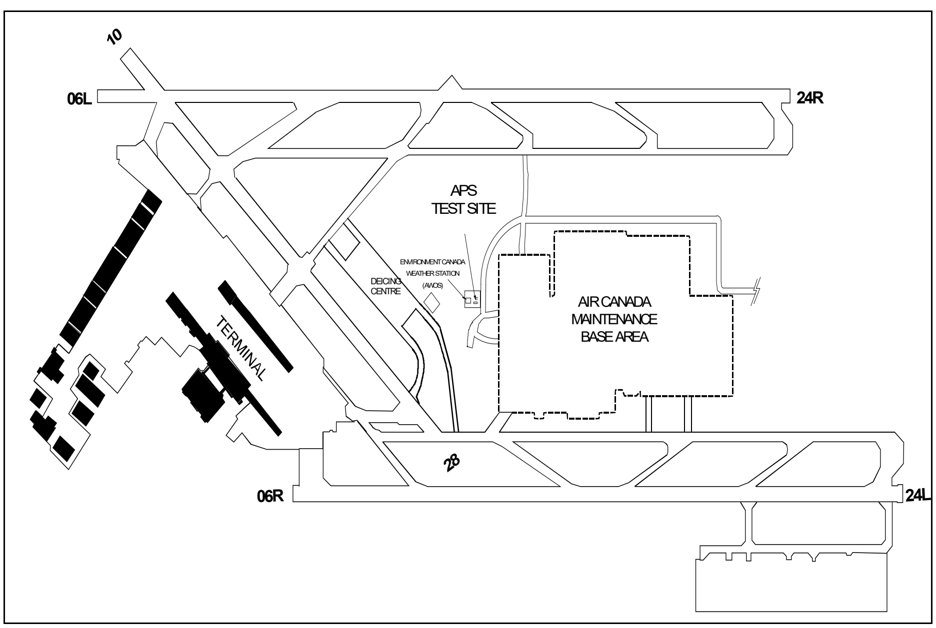

Figure 2.1: Plan View of APS Montreal–Trudeau Airport Test Site

2.1.2 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, light freezing rain, and rain on cold-soaked wing.

2.2 Test Surfaces

Testing was conducted on aluminum and composite surfaces. The test surface materials, configurations, and finishes are described below. Photos of several of the test surfaces are included at the end of this section, as listed below.

- Photo 2.5: Unpainted aluminum flat plate
- Photo 2.6: Unpainted composite (Comp 05) flat plate *(Note: testing was conducted on white-painted composite flat plates; this photo has been included to show the composite material, which can not readily be seen after paint has been applied)*
- Photo 2.7: Unpainted aluminum leading edge thermal equivalent box
- Photo 2.8: White-painted composite leading edge thermal equivalent box
- Photo 2.9: White-painted aluminum frosticator plate

2.2.1 Test Surface Materials

Two test surface materials were used.

1. **Aluminum:** The aluminum material tested was the standard aluminum material used in holdover time testing (0.32 cm thick Alclad 2024 T3 aluminum). See Photos 2.5, 2.7, and 2.9.

2. **Composite:** The composite material tested was a carbon fibre cross weave fabric (referred to as "Comp 05" from this point forward). It was also 0.32 cm thick. Testing in 2005-06 (see Volume 2, Section 4) determined endurance time tests conducted on Comp 05 produce results representative of many composite aircraft materials. See Photos 2.6 and 2.8.

2.2.2 Test Surface Finishes

Test surfaces were tested either painted or unpainted. Painted surfaces were primed and painted white using aircraft-grade paint. Painting the surfaces equalizes surface roughness and finish and reduces variability in radiation effects due to differing bare material colours. Photos 2.8 and 2.9 show painted surfaces.

As per standard holdover time testing protocol, aluminum surfaces were painted for frost testing but left unpainted for snow and freezing precipitation testing. Composite surfaces were painted for testing in all precipitation conditions.

2.2.3 Test Surface Configuration

Three different test surface configurations were used.

1. **Flat Plates:** In freezing fog, freezing drizzle, and light freezing rain, tests were conducted on standard flat plates. A schematic of a standard flat plate is shown in Figure 2.2, a photo of an unpainted aluminum flat plate is given in Photo 2.5, and a photo of an unpainted Comp 05 flat plate is given in Photo 2.6 (note the composite flat plate was painted white for testing). Both composite and aluminum flat plates were constructed in accordance with standard flat plate dimensions.

2. **Leading Edge Thermal Equivalent (LETE) Boxes:** In natural snow and simulated rain on a cold-soaked wing conditions, tests were conducted on LETE boxes. LETE boxes were developed many years ago to simulate the surface temperature profile of an aircraft wing leading edge when it is exposed to heated Type I fluid. The boxes are built by mounting a standard flat plate (Figure 2.3) onto an aluminum frame to create an empty box. Photo 2.7 shows an unpainted aluminum LETE box. Composite LETE boxes were built according to the standard LETE box dimensions; a composite flat plate was affixed to an aluminum frame (sides and bottom). Photo 2.8 shows a white-painted composite LETE box.

3. **Frosticator Plates:** In natural frost, tests were conducted on frosticator plates, which are the current standard test surface used in frost holdover time testing. The frosticator plates were constructed by attaching Styrofoam insulation backing to the test surface (either aluminum or composite). The insulation prevents heat exchange via the underside of the flat plate and allows for effective radiative cooling during active frost conditions. Photo 2.9 shows a white-painted aluminum frosticator plate.

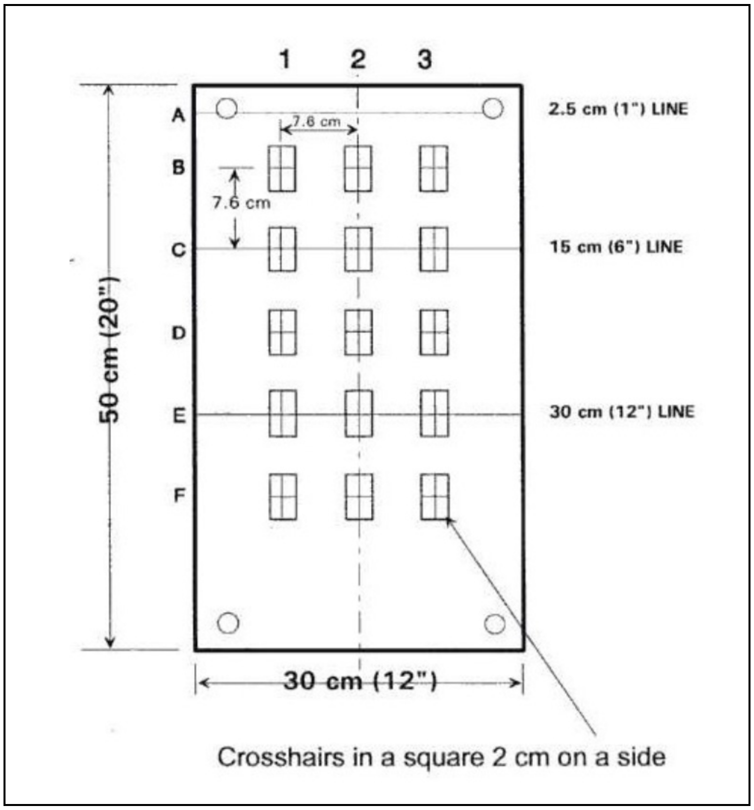

Figure 2.2: Schematic of Standard Holdover Time Testing Flat Plate

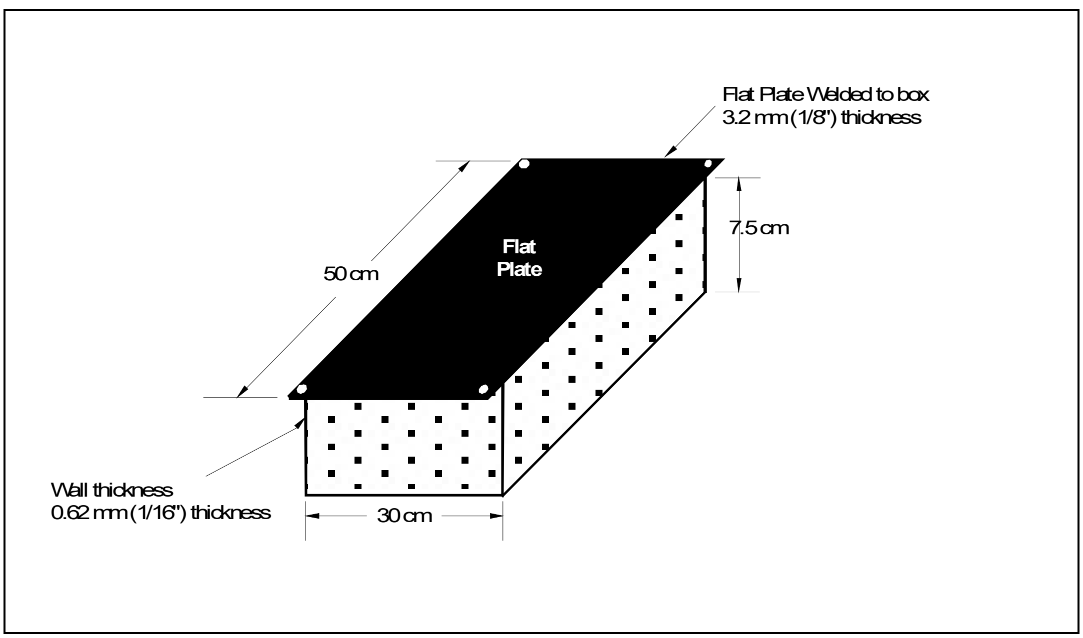

Figure 2.3: Schematic of Leading Edge Thermal Equivalent Box

2.2.4 Test Surface Summary

As noted in the previous subsections, the two test surface materials (composite and aluminum) were tested in different test surface configurations (flat plate, LETE box, frosticator plate) and with different finishes (painted or unpainted) in various precipitation conditions.

Table 2.1 summarizes the test surfaces used for each precipitation condition in 2009-10. It should be noted that the surfaces described in the aluminum column are the standard surfaces used to develop holdover times.

Table 2.1: Test Surfaces Used in 2009-10 Testing

Precipitation Condition	Aluminum Test Surface	Composite Test Surface
Natural Snow	Unpainted Aluminum LETE Box	Painted Composite LETE Box
Freezing Precipitation Freezing Fog, Freezing Drizzle, Light Freezing Rain	Unpainted Aluminum Flat Plate	Painted Composite Flat Plate
Freezing Precipitation Rain on Cold-Soaked Wing	Unpainted Aluminum LETE Box	Painted Composite LETE Box
Natural Frost	Painted Aluminum Frosticator Plate	Painted Composite Frosticator Plate

2.3 Test Procedures

Endurance time testing was carried out according to standard test protocol for Type I fluid endurance time testing, which is provided in SAE International (SAE) Aerospace Recommended Practice (ARP) 5945, *Endurance Time Tests for Aircraft Deicing/Anti-Icing Fluids: SAE Type I* (4).

Procedures were written in accordance with ARP5945 (4) to provide detailed guidance for testing in natural snow, simulated freezing precipitation, and natural frost. These procedures have been included as appendices to this report, as follows:

- Appendix C (Snow): Evaluation of Type I Endurance Times on Composite Surfaces, Natural Snow (Jan 2010);

- Appendix D (Freezing Precipitation): Evaluation of Type I Endurance Times on Composite Surfaces, Simulated Freezing Precipitation (Mar 2010); and
- Appendix E (Frost): Evaluation of Type I Endurance Times on Composite Surfaces, Natural Frost (Mar 2010).

The test procedures used in each type of testing are summarized in Table 2.2 and detailed further in the sections below.

Table 2.2: Summary of Test Procedures

Precipitation Condition	Test Surface Configuration	Test Surface Materials	Fluid Temp.	Fluid Quantity
Snow	LETE Box	• Unpainted Aluminum • Painted Composite (Comp 05)	60ºC	0.5 L
Freezing Precipitation	Flat Plate*	• Unpainted Aluminum • Painted Composite (Comp 05)	20ºC	1.0 L
Frost	Frosticator Plate	• Painted Aluminum • Painted Composite (Comp 05)	20ºC	0.5 L

* Rain on cold-soaked wing testing conducted on LETE boxes.

2.3.1 Natural Snow Test Procedures

In natural snow, each test run consisted of four tests: one aluminum surface test and three composite surface tests. The four tests were run simultaneously. Tests were conducted with fluids heated to 60°C. Testing was conducted on LETE boxes, as described in Subsection 2.2.3.

Figure 2.4 shows the test setup for each run, including test surfaces, fluids, fluid quantities, fluid temperatures, and application methods used.

It should be noted that, during each run, the fluid that was tested on the aluminum surface (position 1) was also tested on one of the composite surfaces (position 2). Different fluids were tested on positions 3 and 4. The fluids were rotated so that each of the five fluids tested (see Subsection 2.5) was tested on the aluminum surface several times.

2.3.2 Simulated Freezing Precipitation Test Procedures

In simulated freezing precipitation, two tests were conducted with each fluid (see Subsection 2.5) on composite surfaces in each condition. In addition, for each condition, two tests were conducted with one of the fluids (the same fluid) on aluminum surfaces. This resulted in 12 tests being run per condition. The tests were not necessarily run simultaneously as, unlike in natural conditions, the precipitation rate remained constant for the duration of the condition.

Tests were conducted with fluids heated to 20°C. Testing was conducted on flat plates (see Subsection 2.2.3) in freezing fog, freezing drizzle, and light freezing rain and on LETE boxes (see Subsection 2.2.3) in rain on a cold-soaked wing conditions.

2.3.3 Natural Frost Test Procedures

In natural frost, each test run consisted of four tests: one aluminum surface test and three composite surface tests. The four tests were run simultaneously. Tests were conducted with fluids heated to 20°C. Testing was conducted on frosticator plates, as described in Subsection 2.2.3.

Figure 2.6 shows the test setup for each run, including test surfaces, fluids, fluid quantities, fluid temperatures, and application methods used.

It should be noted that during each run the fluid that was tested on the aluminum surface (position 1) was also tested on one of the composite surfaces (position 2). Different fluids were tested on positions 3 and 4. The fluids were rotated so that each of the five fluids tested (see Subsection 2.5) was tested on the aluminum surface several times.

Position 1	Position 2	Position 3	Position 4
Aluminum LETE Box Fluid A 0.5 L of Fluid Apply at 60°C Spreader	Composite LETE Box Fluid A 0.5 L of Fluid Apply at 60°C Spreader	Composite LETE Box Fluid B 0.5 L of Fluid Apply at 60°C Spreader	Composite LETE Box Fluid C 0.5 L of Fluid Apply at 60°C Spreader

Figure 2.4: Test Setup – Natural Snow

Position 1	Position 2	Position 3	Position 4	Position 5	Position 6
Aluminum Flat Plate Fluid A 1 L of Fluid Apply at 20°C Spreader	Aluminum Flat Plate Fluid A 1 L of Fluid Apply at 20°C Spreader	Composite Flat Plate Fluid A 1 L of Fluid Apply at 20°C Spreader	Composite Flat Plate Fluid A 1 L of Fluid Apply at 20°C Spreader	Composite Flat Plate Fluid B 1 L of Fluid Apply at 20°C Spreader	Composite Flat Plate Fluid B 1 L of Fluid Apply at 20°C Spreader
Position 7	**Position 8**	**Position 9**	**Position 10**	**Position 11**	**Position 12**
Composite Flat Plate Fluid C 1 L of Fluid Apply at 20°C Spreader	Composite Flat Plate Fluid C 1 L of Fluid Apply at 20°C Spreader	Composite Flat Plate Fluid D 1 L of Fluid Apply at 20°C Spreader	Composite Flat Plate Fluid D 1 L of Fluid Apply at 20°C Spreader	Composite Flat Plate Fluid E 1 L of Fluid Apply at 20°C Spreader	Composite Flat Plate Fluid E 1 L of Fluid Apply at 20°C Spreader

Figure 2.5: Test Setup – Simulated Freezing Precipitation

Position 1	Position 2	Position 3	Position 4
Aluminum Frosticator Plate Fluid A 0.5 L of Fluid Apply at 20°C Spreader	Composite Frosticator Plate Fluid A 0.5 L of Fluid Apply at 20°C Spreader	Composite Frosticator Plate Fluid B 0.5 L of Fluid Apply at 20°C Spreader	Composite Frosticator Plate Fluid C 0.5 L of Fluid Apply at 20°C Spreader

Figure 2.6: Test Setup – Natural Frost

2.4 Equipment

Standard holdover time testing equipment was required to conduct the composite research. Several of the key pieces of equipment used in the testing are described below.

2.4.1 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.

2.4.2 Wet Film Thickness Gauge

Wet film fluid thickness measurements were recorded during select endurance time tests. Figure 2.7 shows a schematic of the wet film thickness gauges. Photo 2.10 shows the actual thickness gauges used for testing.

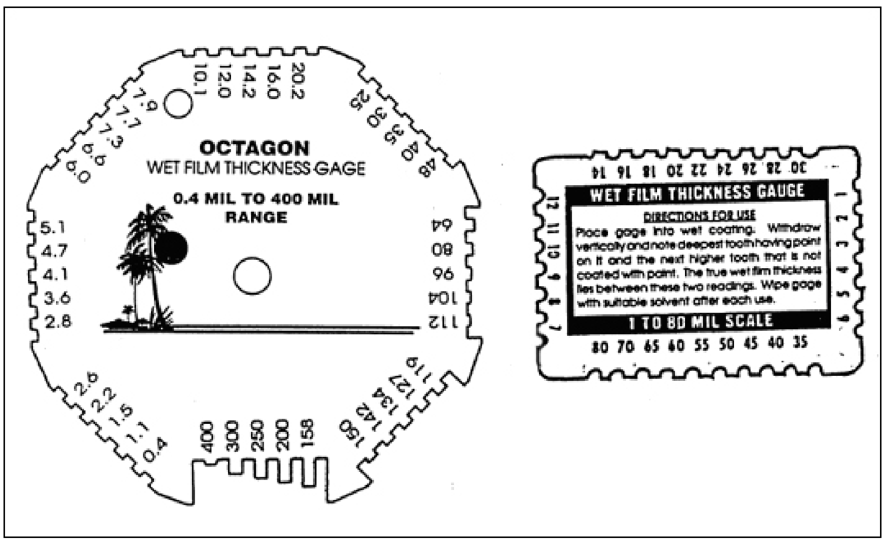

Figure 2.7: Wet Film Thickness Gauges

2.4.3 Brixometer

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

2.4.4 Twelve-Hole Fluid Spreader

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

2.4.5 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.

2.5 Fluids

Five representative Type I fluids were tested in the winter of 2009-10. This included four propylene-glycol (PG) based fluids and one ethylene-glycol (EG) based fluid. The specific fluid brands are detailed in Table 2.3.

All fluids were tested at a 10ºC buffer. To achieve this buffer, fluids were mixed to a freezing point 10°C below the ambient temperature prior to each test.

Table 2.3: Fluids Tested

Fluid	Fluid Base
Dow UCAR ADF	EG
Dow UCAR PG ADF	PG
Octagon Octaflo EF	PG
Clariant 1938	PG
Kilfrost DF^{sustain}	PG

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 the NRC Climate Engineering Facility

Photo 2.4: Sprayer Assembly Used to Produce Fine Droplets

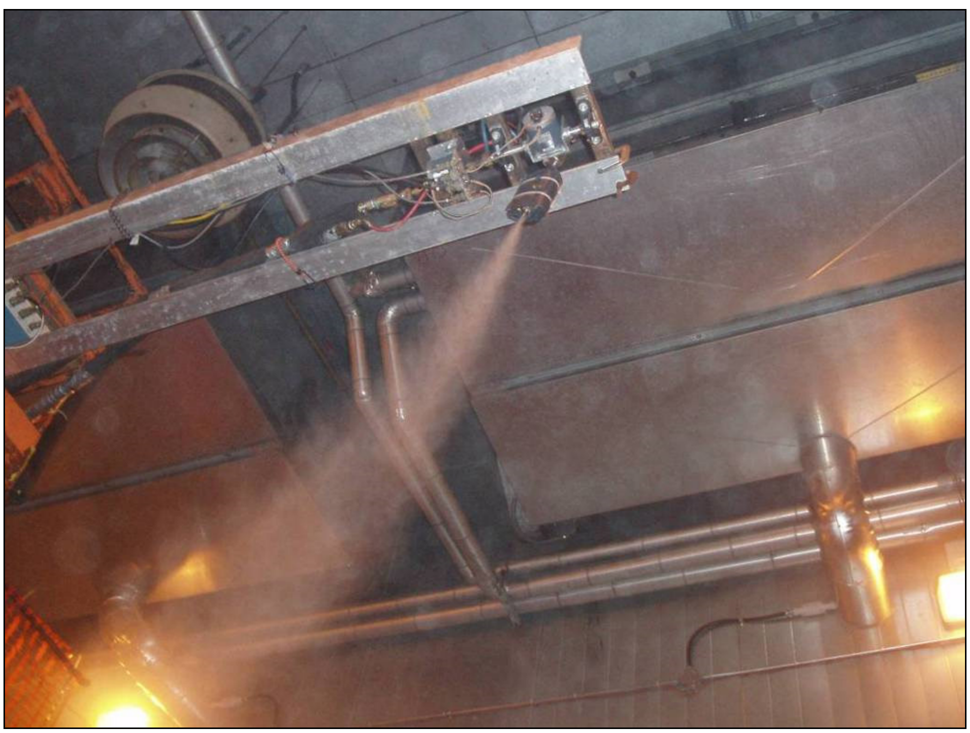

Photo 2.5: Unpainted Aluminum Flat Plate

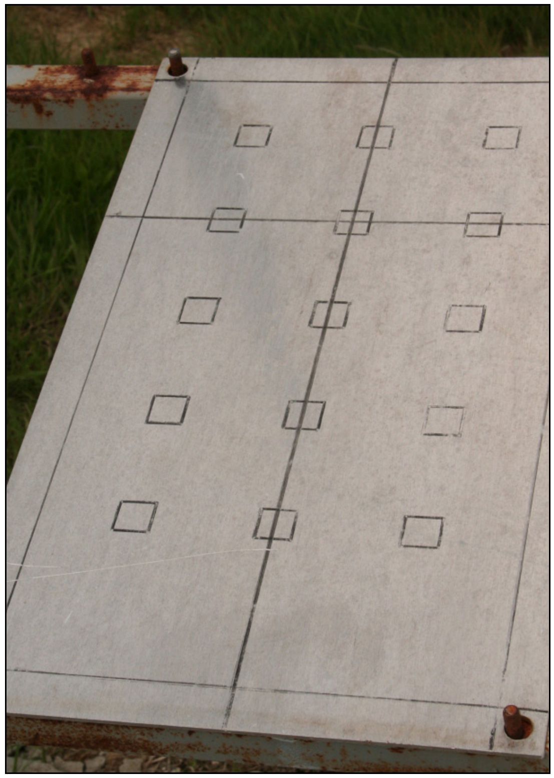

Photo 2.6: Unpainted Composite (Comp 05) Flat Plate

Photo 2.7: Unpainted Aluminum Leading Edge Thermal Equivalent Box

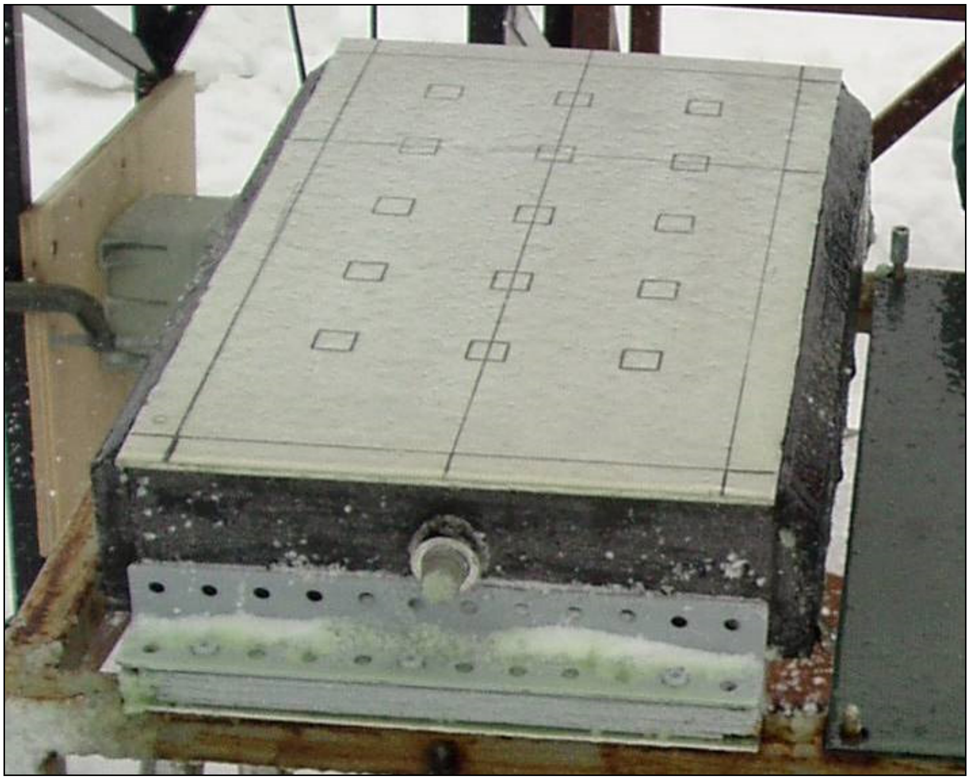

Photo 2.8: White-Painted Composite Leading Edge Thermal Equivalent Boxes

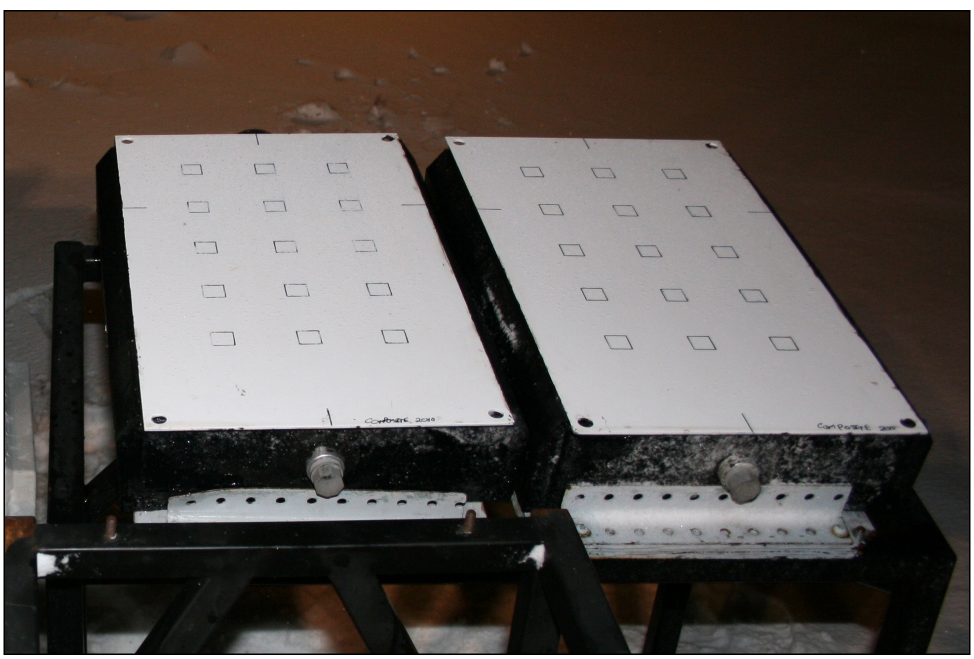

Photo 2.9: White-Painted Aluminum Frosticator Plate

Photo 2.10: Wet Film Thickness Gauges

Photo 2.11: Hand-Held Brixometer

Photo 2.12: Twelve-Hole Spreader Used for Fluid Application

3. DATA COLLECTED IN 2009-10

This section describes the composite surface data collected in the winter of 2009-10 in snow, freezing precipitation, and frost.

3.1 Summary of Tests Conducted

The total number of tests conducted in each precipitation condition is provided in Table 3.1 below. The total number of tests conducted in each condition on composite surfaces is shown; as is the number of tests conducted on aluminum surfaces. The aluminum surface tests were conducted for reference, as described further in Section 4.

Table 3.1: Summary of Tests Conducted in 2009-10

Precipitation Type	Composite Tests	Aluminum Tests	Total Tests
Snow	71	26	97
Freezing Fog	81	16	97
Freezing Drizzle	60	12	72
Light Freezing Rain	40	8	48
Rain on Cold-Soaked Wing	20	3	23
Frost	27	10	37
TOTAL	**299**	**75**	**374**

3.2 Log of Tests

A log of tests was created to document the results of testing carried out in 2009-10. The log was divided into three separate tables – one table 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 Temp.: Fluid temperature prior to application, measured in °C.

Test Surface: Test surface material (aluminum or composite) and configuration (in snow and freezing precipitation: plate or box; in frost: all tests conducted on frosticator plates).

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.

Endur. Time: Fluid endurance time, measured in minutes.

Precip. Rate: Average precipitation rate, measured in g/dm²/h, collected using standard holdover time precipitation measurement methods.

Ambient Temp.: Ambient temperature, measured in ºC. In snow and frost: the average of hourly outside air temperature (OAT) readings for the duration of the test, provided by Environment Canada. In freezing precipitation: desired 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 (snow and frost only).

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

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

Table 3.2: Log of Tests (2009-10) – Natural Snow

Test #	Date	Run #	Fluid Name	Fluid Dil.	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 (°)
1	3-Jan-10	1	Clariant 1938	10°B	60	Aluminum Box	Snow	3:15:15	3:18:40	3.4	21.8	-11.6	28	24.75	9.00
2	3-Jan-10	1	Clariant 1938	10°B	60	Composite Box	Snow	3:15:45	3:18:00	2.3	21.8	-11.6	28	24.75	10.00
3	3-Jan-10	1	Kilfrost DF^{sustain}	10°B	60	Composite Box	Snow	3:15:15	3:18:00	2.8	21.8	-11.6	28	30.25	13.00
4	3-Jan-10	1	Dow UCAR PG ADF	10°B	60	Composite Box	Snow	3:15:45	3:18:15	2.5	21.8	-11.6	28	30.25	15.00
5	3-Jan-10	2	Kilfrost DF^{sustain}	10°B	60	Aluminum Box	Snow	3:56:40	4:01:50	5.2	12.7	-11.8	30	31.50	15.00
6	3-Jan-10	2	Kilfrost DF^{sustain}	10°B	60	Composite Box	Snow	3:57:10	4:00:42	3.5	12.7	-11.8	30	31.50	19.00
7	3-Jan-10	2	Dow UCAR PG ADF	10°B	60	Composite Box	Snow	3:56:40	4:00:25	3.8	12.7	-11.8	30	29.50	19.00
8	3-Jan-10	2	Dow UCAR ADF	10°B	60	Composite Box	Snow	3:57:10	4:01:00	3.8	12.7	-11.8	30	23.75	16.00
9	28-Jan-10	1	Kilfrost DF^{sustain}	10°B	60	Aluminum Box	Snow	14:51:30	15:40:00	48.5	1.0	-4.2	11	27.50	8.00
10	28-Jan-10	1	Kilfrost DF^{sustain}	10°B	60	Composite Box	Snow	14:52:00	15:37:00	45.0	0.8	-4.2	11	23.00	6.00
11	28-Jan-10	1	Dow UCAR PG ADF	10°B	60	Composite Box	Snow	14:54:15	15:37:00	42.8	0.8	-4.2	11	27.00	6.00
12	28-Jan-10	1	Dow UCAR ADF	10°B	60	Composite Box	Snow	14:54:45	15:37:00	42.3	0.8	-4.2	11	24.00	5.00
13	18-Feb-10	1	Dow UCAR PG ADF	10°B	60	Aluminum Box	Snow	20:11:40	20:33:00	21.3	3.0	-2.2	26	20.50	4.50
14	18-Feb-10	1	Dow UCAR PG ADF	10°B	60	Composite Box	Snow	20:12:10	20:27:22	15.2	3.5	-2.2	26	20.50	7.00
15	18-Feb-10	1	Dow UCAR ADF	10°B	60	Composite Box	Snow	20:11:35	20:30:00	18.4	3.3	-2.2	26	15.00	5.00
16	18-Feb-10	1	Octagon Octaflo	10°B	60	Composite Box	Snow	20:12:15	20:30:30	18.3	3.1	-2.2	26	20.00	6.25
17	18-Feb-10	2	Clariant 1938	10°B	60	Aluminum Box	Snow	21:45:40	21:55:30	9.8	8.5	-2.9	24	22.50	5.50
18	18-Feb-10	2	Clariant 1938	10°B	60	Composite Box	Snow	21:46:20	21:53:30	7.2	8.5	-2.9	24	22.50	11.00
19	18-Feb-10	2	Kilfrost DF^{sustain}	10°B	60	Composite Box	Snow	21:45:40	21:53:15	7.6	8.5	-2.9	24	21.75	9.50
21	18-Feb-10	3	Dow UCAR ADF	10°B	60	Aluminum Box	Snow	22:33:50	22:42:45	8.9	8.6	-3.2	22	17.00	4.50
22	18-Feb-10	3	Dow UCAR ADF	10°B	60	Composite Box	Snow	22:34:20	22:41:50	7.5	8.6	-3.2	22	17.00	4.50
23	18-Feb-10	3	Octagon Octaflo	10°B	60	Composite Box	Snow	22:33:55	22:40:00	6.1	8.4	-3.2	22	21.25	9.00
24	18-Feb-10	3	Clariant 1938	10°B	60	Composite Box	Snow	22:34:20	22:41:30	7.2	8.6	-3.2	22	22.50	9.00
25	19-Feb-10	4	Clariant 1938	10°B	60	Aluminum Box	Snow	0:50:20	0:59:30	9.2	8.8	-3.4	30	23.50	6.50
26	19-Feb-10	4	Clariant 1938	10°B	60	Composite Box	Snow	0:50:55	0:57:30	6.6	9.4	-3.4	30	23.50	9.00
27	19-Feb-10	4	Kilfrost DF^{sustain}	10°B	60	Composite Box	Snow	0:50:20	0:56:20	6.0	10.0	-3.4	30	22.75	9.50
28	19-Feb-10	4	Dow UCAR PG ADF	10°B	60	Composite Box	Snow	0:50:55	0:58:00	7.1	9.2	-3.4	30	23.00	9.50
29	19-Feb-10	5	Kilfrost DF^{sustain}	10°B	60	Aluminum Box	Snow	1:31:05	1:58:00	26.9	4.1	-3.5	30	23.50	10.50
30	19-Feb-10	5	Kilfrost DF^{sustain}	10°B	60	Composite Box	Snow	1:31:30	1:52:50	21.3	3.1	-3.5	30	23.50	12.50
31	19-Feb-10	5	Dow UCAR PG ADF	10°B	60	Composite Box	Snow	1:31:05	1:49:10	18.1	2.9	-3.5	30	22.75	14.00
33	23-Feb-10	1	Octagon Octaflo	10°B	60	Aluminum Box	Snow	6:34:00	6:53:15	19.3	6.6	0.0	15	19.00	0.50
34	23-Feb-10	1	Octagon Octaflo	10°B	60	Composite Box	Snow	6:34:30	6:43:30	9.0	6.4	0.0	15	19.00	4.00
35	23-Feb-10	1	Clariant 1938	10°B	60	Composite Box	Snow	6:34:00	6:43:00	9.0	6.4	0.0	15	18.50	3.50
36	23-Feb-10	1	Kilfrost DF^{sustain}	10°B	60	Composite Box	Snow	6:34:30	6:42:30	8.0	6.3	0.0	15	18.50	3.25

Table 3.2: Log of Tests (2009-10) – Natural Snow (cont'd)

Test #	Date	Run #	Fluid Name	Fluid Dil.	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 (°)
37	23-Feb-10	2	Dow UCAR PG ADF	10°B	60	Aluminum Box	Snow	7:27:00	7:59:00	32.0	4.7	0.4	19	19.75	0.25
38	23-Feb-10	2	Dow UCAR PG ADF	10°B	60	Composite Box	Snow	7:27:30	7:37:00	9.5	4.2	0.4	19	19.75	3.50
39	23-Feb-10	2	Dow UCAR ADF	10°B	60	Composite Box	Snow	7:27:00	7:36:00	9.0	4.3	0.4	19	14.00	2.00
41	23-Feb-10	3	Dow UCAR ADF	10°B	60	Aluminum Box	Snow	8:17:30	8:47:00	29.5	8.3	0.4	17	14.00	0.00
42	23-Feb-10	3	Dow UCAR ADF	10°B	60	Composite Box	Snow	8:17:50	8:27:30	9.7	5.6	0.4	17	14.00	2.00
43	23-Feb-10	3	Octagon Octaflo	10°B	60	Composite Box	Snow	8:17:30	8:27:00	9.5	5.6	0.4	17	19.00	2.00
53	24-Feb-10	1A	Kilfrost DF^{sustain}	10°B	60	Aluminum Box	Snow	1:07:15	1:39:00	31.8	3.0	0.4	15	18.50	0.50
54	24-Feb-10	1A	Kilfrost DF^{sustain}	10°B	60	Composite Box	Snow	1:07:40	1:32:00	24.3	1.7	0.4	15	18.50	4.25
55	24-Feb-10	1A	Dow UCAR PG ADF	10°B	60	Composite Box	Snow	1:07:15	1:33:00	25.8	1.7	0.4	15	19.75	4.00
56	24-Feb-10	1A	Dow UCAR ADF	10°B	60	Composite Box	Snow	1:07:40	1:33:00	25.3	1.7	0.4	15	14.00	2.50
57	24-Feb-10	2	Octagon Octaflo	10°B	60	Aluminum Box	Snow	2:00:00	2:16:30	16.5	13.2	0.4	13	19.00	0.00
58	24-Feb-10	2	Octagon Octaflo	10°B	60	Composite Box	Snow	2:00:10	2:06:30	6.3	11.6	0.4	13	19.00	2.00
59	24-Feb-10	2	Clariant 1938	10°B	60	Composite Box	Snow	2:00:00	2:06:00	6.0	11.3	0.4	13	18.50	2.50
61	24-Feb-10	3	Dow UCAR PG ADF	10°B	60	Aluminum Box	Snow	2:27:45	2:58:00	30.3	7.7	0.5	13	19.75	0.25
62	24-Feb-10	3	Dow UCAR PG ADF	10°B	60	Composite Box	Snow	2:28:00	2:35:15	7.3	9.2	0.5	13	19.75	2.50
63	24-Feb-10	3	Dow UCAR ADF	10°B	60	Composite Box	Snow	2:27:45	2:35:00	7.3	9.2	0.5	13	14.00	2.00
64	24-Feb-10	3	Octagon Octaflo	10°B	60	Composite Box	Snow	2:28:00	2:36:00	8.0	9.2	0.5	13	19.00	2.50
65	24-Feb-10	4	Octagon Octaflo	10°B	60	Aluminum Box	Snow	3:16:00	4:13:00	57.0	3.3	0.6	13	19.00	0.50
66	24-Feb-10	4	Octagon Octaflo	10°B	60	Composite Box	Snow	3:16:30	3:27:00	10.5	6.1	0.6	13	19.00	2.00
67	24-Feb-10	4	Octagon Octaflo	10°B	60	Composite Box	Snow	3:16:00	3:26:30	10.5	6.2	0.6	13	18.50	2.50
68	24-Feb-10	4	Kilfrost DF^{sustain}	10°B	60	Composite Box	Snow	3:16:30	3:28:00	11.5	6.0	0.6	13	18.50	2.25
69	24-Feb-10	5	Dow UCAR PG ADF	10°B	60	Aluminum Box	Snow	5:10:15	5:36:00	25.8	6.9	0.5	15	19.75	0.00
70	24-Feb-10	5	Dow UCAR PG ADF	10°B	60	Composite Box	Snow	5:10:40	5:19:00	8.3	7.3	0.5	15	19.75	3.50
71	24-Feb-10	5	Dow UCAR ADF	10°B	60	Composite Box	Snow	5:10:15	5:20:00	9.8	7.4	0.5	15	14.00	2.00
73	24-Feb-10	6	Clariant 1938	10°B	60	Aluminum Box	Snow	6:04:45	6:42:00	37.3	4.4	0.5	15	18.50	0.25
74	24-Feb-10	6	Clariant 1938	10°B	60	Composite Box	Snow	6:05:20	6:17:00	11.7	4.6	0.5	15	18.50	4.00
75	24-Feb-10	6	Kilfrost DF^{sustain}	10°B	60	Composite Box	Snow	6:04:45	6:18:00	13.3	4.6	0.5	15	18.50	2.50
77	24-Feb-10	1	Dow UCAR ADF	10°B	60	Aluminum Box	Snow	17:29:10	17:43:30	14.3	13.9	0.7	17	14.00	0.00
78	24-Feb-10	1	Dow UCAR ADF	10°B	60	Composite Box	Snow	17:29:30	17:35:00	5.5	10.0	0.7	17	14.00	3.00
79	24-Feb-10	1	Octagon Octaflo	10°B	60	Composite Box	Snow	17:29:10	17:36:00	6.8	11.1	0.7	17	19.00	3.00
80	24-Feb-10	1	Clariant 1938	10°B	60	Composite Box	Snow	17:29:30	17:36:00	6.5	11.2	0.7	17	18.50	3.00
81	24-Feb-10	2	Kilfrost DF^{sustain}	10°B	60	Aluminum Box	Snow	18:17:10	19:00:00	42.8	6.7	0.8	19	18.50	0.00
82	24-Feb-10	2	Kilfrost DF^{sustain}	10°B	60	Composite Box	Snow	18:17:40	18:33:00	15.3	8.0	0.8	19	18.50	2.00
83	24-Feb-10	2	Dow UCAR PG ADF	10°B	60	Composite Box	Snow	18:17:10	18:33:00	15.8	7.9	0.8	19	19.75	1.00

Table 3.2: Log of Tests (2009-10) – Natural Snow (cont'd)

Test #	Date	Run #	Fluid Name	Fluid Dil.	Fluid Temp. (°C)	Test Surface	Precip. Type	Start Time	Fail Time	Endur. Time (min)	Precip. Rate ($g/dm^2/h$)	Ambient Temp. (°C)	Wind Speed (km/h)	Initial Brix (°)	Final Brix (°)
85	24-Feb-10	3	Clariant 1938	10°B	60	Aluminum Box	Snow	19:20:57	20:30:00	69.1	5.3	0.8	20	18.50	0.25
86	24-Feb-10	3	Clariant 1938	10°B	60	Composite Box	Snow	19:21:20	19:47:00	25.7	5.4	0.8	20	18.50	0.00
87	24-Feb-10	3	Kilfrost DF^{sustain}	10°B	60	Composite Box	Snow	19:20:55	19:47:30	26.6	5.4	0.8	20	18.50	0.00
88	24-Feb-10	3	Dow UCAR PG ADF	10°B	60	Composite Box	Snow	19:21:25	19:44:00	22.6	5.1	0.8	20	19.75	0.50
89	24-Feb-10	4	Dow UCAR ADF	10°B	60	Aluminum Box	Snow	20:51:00	21:09:00	18.0	9.6	0.9	20	14.00	0.25
90	24-Feb-10	4	Dow UCAR ADF	10°B	60	Composite Box	Snow	20:51:30	21:04:30	13.0	6.9	0.9	20	14.00	1.50
91	24-Feb-10	4	Octagon Octaflo	10°B	60	Composite Box	Snow	20:51:00	21:05:00	14.0	6.9	0.9	20	19.00	1.25
93	24-Feb-10	5	Kilfrost DF^{sustain}	10°B	60	Aluminum Box	Snow	21:37:20	22:52:00	74.7	6.0	0.8	22	18.50	1.00
94	24-Feb-10	5	Kilfrost DF^{sustain}	10°B	60	Composite Box	Snow	21:38:00	21:47:30	9.5	11.6	0.8	22	18.50	2.00
95	24-Feb-10	5	Dow UCAR PG ADF	10°B	60	Composite Box	Snow	21:37:20	21:46:00	8.7	11.8	0.8	22	19.75	1.75
96	24-Feb-10	5	Dow UCAR ADF	10°B	60	Composite Box	Snow	21:38:00	21:45:00	7.0	11.9	0.8	22	14.00	1.50
97	24-Feb-10	6	Octagon Octaflo	10°B	60	Aluminum Box	Snow	23:25:50	23:55:00	29.2	11.2	0.8	24	19.00	0.00
98	24-Feb-10	6	Octagon Octaflo	10°B	60	Composite Box	Snow	23:26:10	23:31:00	4.8	14.6	0.8	24	19.00	3.50
99	24-Feb-10	6	Clariant 1938	10°B	60	Composite Box	Snow	23:26:30	23:33:00	6.5	16.3	0.8	24	18.50	3.00
100	24-Feb-10	6	Kilfrost DF^{sustain}	10°B	60	Composite Box	Snow	23:26:50	23:32:00	5.2	16.3	0.8	24	18.50	3.00
102	24-Feb-10	7	Dow UCAR PG ADF	10°B	60	Composite Box	Snow	6:04:30	6:35:00	30.5	4.3	1.0	28	19.75	1.00
103	24-Feb-10	7	Dow UCAR ADF	10°B	60	Composite Box	Snow	6:04:15	6:35:00	30.8	4.4	1.0	28	14.00	0.50
105	25-Feb-10	1	Dow UCAR ADF	10°B	60	Aluminum Box	Snow	1:33:10	2:11:00	37.8	3.6	0.9	30	14.00	2.00
106	25-Feb-10	1	Dow UCAR ADF	10°B	60	Composite Box	Snow	1:33:30	1:45:00	11.5	3.0	0.9	30	14.00	4.00
107	25-Feb-10	1	Octagon Octaflo	10°B	60	Composite Box	Snow	1:33:10	2:01:30	28.3	2.4	0.9	30	19.00	5.50
109	25-Feb-10	2	Kilfrost DF^{sustain}	10°B	60	Aluminum Box	Snow	2:30:22	3:03:30	33.1	5.8	0.8	35	18.50	1.50
110	25-Feb-10	2	Kilfrost DF^{sustain}	10°B	60	Composite Box	Snow	2:30:52	2:37:30	6.6	9.4	0.8	35	18.50	6.00
111	25-Feb-10	2	Dow UCAR PG ADF	10°B	60	Composite Box	Snow	2:30:25	2:38:00	7.6	9.4	0.8	35	19.75	7.00
112	25-Feb-10	2	Dow UCAR ADF	10°B	60	Composite Box	Snow	2:30:50	2:36:40	5.8	9.7	0.8	35	14.00	5.00
113	25-Feb-10	3	Octagon Octaflo	10°B	60	Aluminum Box	Snow	3:24:25	3:44:00	19.6	12.1	0.7	32	19.00	0.50
114	25-Feb-10	3	Octagon Octaflo	10°B	60	Composite Box	Snow	3:24:45	3:29:30	4.8	12.2	0.7	32	19.00	8.00
115	25-Feb-10	3	Clariant 1938	10°B	60	Composite Box	Snow	3:24:25	3:30:00	5.6	12.3	0.7	32	18.50	7.00
118	25-Feb-10	4	Dow UCAR ADF	10°B	60	Composite Box	Snow	4:32:55	4:39:30	6.6	10.8	1.0	35	14.00	3.50
119	25-Feb-10	4	Octagon Octaflo	10°B	60	Composite Box	Snow	4:32:35	4:40:00	7.4	10.9	1.0	35	19.00	4.50

Table 3.3: Log of Tests (2009-10) – Freezing Precipitation

Test #	Date	Run #	Fluid Name	Fluid Dil.	Fluid Temp. (°C)	Test Surface	Precip. Type	Ambient Temp. (°C)	Start Time	Fail Time	Endur. Time (min)	Precip. Rate ($g/dm^2/h$)
C001	1-Apr-10	1	Kilfrost DF^{sustain}	10°B	20	Aluminum Plate	Freezing Fog	-3	20:01:10	20:13:40	12.5	5.2
C002	1-Apr-10	1	Kilfrost DF^{sustain}	10°B	20	Aluminum Plate	Freezing Fog	-3	19:55:50	20:06:55	11.1	5.2
C005	1-Apr-10	1	Kilfrost DF^{sustain}	10°B	20	Composite Plate	Freezing Fog	-3	17:55:43	18:07:00	11.3	4.8
C006	1-Apr-10	1	Kilfrost DF^{sustain}	10°B	20	Composite Plate	Freezing Fog	-3	19:56:40	20:05:20	8.7	5.3
C007	1-Apr-10	1	Octagon Octaflo	10°B	20	Composite Plate	Freezing Fog	-3	18:13:00	18:24:15	11.3	4.8
C008	1-Apr-10	1	Octagon Octaflo	10°B	20	Composite Plate	Freezing Fog	-3	19:38:10	19:48:10	10.0	4.9
C009	1-Apr-10	1	Clariant 1938	10°B	20	Composite Plate	Freezing Fog	-3	19:33:40	19:45:10	11.5	4.7
C010	1-Apr-10	1	Clariant 1938	10°B	20	Composite Plate	Freezing Fog	-3	20:11:20	20:21:50	10.5	4.9
C011	1-Apr-10	1	Dow UCAR ADF	10°B	20	Composite Plate	Freezing Fog	-3	19:18:50	19:29:30	10.7	4.7
C012	1-Apr-10	1	Dow UCAR ADF	10°B	20	Composite Plate	Freezing Fog	-3	20:08:10	20:17:00	8.8	5.3
C013	1-Apr-10	1	Dow UCAR PG ADF	10°B	20	Composite Plate	Freezing Fog	-3	18:27:30	18:38:30	11.0	4.8
C014	1-Apr-10	1	Dow UCAR PG ADF	10°B	20	Composite Plate	Freezing Fog	-3	20:00:20	20:10:25	10.1	4.9
C015	7-Apr-10	2	Kilfrost DF^{sustain}	10°B	20	Aluminum Plate	Freezing Fog	-3	17:08:50	17:30:30	21.7	1.9
C016	8-Apr-10	2	Kilfrost DF^{sustain}	10°B	20	Aluminum Plate	Freezing Fog	-3	12:50:12	13:08:40	18.5	2.0
C019	7-Apr-10	2	Kilfrost DF^{sustain}	10°B	20	Composite Plate	Freezing Fog	-3	17:41:20	17:58:30	17.2	1.9
C020	7-Apr-10	2	Kilfrost DF^{sustain}	10°B	20	Composite Plate	Freezing Fog	-3	17:41:00	17:58:05	17.1	2.3
C021	8-Apr-10	2	Octagon Octaflo	10°B	20	Composite Plate	Freezing Fog	-3	13:41:01	13:59:30	18.5	1.9
C022	7-Apr-10	2	Octagon Octaflo	10°B	20	Composite Plate	Freezing Fog	-3	17:40:14	17:59:30	19.3	1.8
C023	7-Apr-10	2	Clariant 1938	10°B	20	Composite Plate	Freezing Fog	-3	16:28:48	16:48:50	20.0	2.2
C024	7-Apr-10	2	Clariant 1938	10°B	20	Composite Plate	Freezing Fog	-3	16:29:08	16:48:40	19.5	2.0
C025	7-Apr-10	2	Dow UCAR ADF	10°B	20	Composite Plate	Freezing Fog	-3	16:53:15	17:11:36	18.4	1.9
C026	7-Apr-10	2	Dow UCAR ADF	10°B	20	Composite Plate	Freezing Fog	-3	16:54:50	17:10:55	16.1	2.0
C027	7-Apr-10	2	Dow UCAR PG ADF	10°B	20	Composite Plate	Freezing Fog	-3	16:27:58	16:48:40	20.7	1.9
C028	7-Apr-10	2	Dow UCAR PG ADF	10°B	20	Composite Plate	Freezing Fog	-3	16:54:11	17:12:36	18.4	2.2
C029	7-Apr-10	3	Kilfrost DF^{sustain}	10°B	20	Aluminum Plate	Freezing Fog	-6	9:49:24	9:58:45	9.3	5.3
C030	7-Apr-10	3	Kilfrost DF^{sustain}	10°B	20	Aluminum Plate	Freezing Fog	-6	9:48:28	9:59:00	10.5	5.1
C033	7-Apr-10	3	Kilfrost DF^{sustain}	10°B	20	Composite Plate	Freezing Fog	-6	10:00:55	10:08:30	7.6	4.8
C034	7-Apr-10	3	Kilfrost DF^{sustain}	10°B	20	Composite Plate	Freezing Fog	-6	10:04:20	10:11:25	7.1	4.9
C035	7-Apr-10	3	Octagon Octaflo	10°B	20	Composite Plate	Freezing Fog	-6	9:52:06	9:59:50	7.7	4.8
C036	7-Apr-10	3	Octagon Octaflo	10°B	20	Composite Plate	Freezing Fog	-6	9:50:30	9:57:00	6.5	5.2
C037	7-Apr-10	3	Clariant 1938	10°B	20	Composite Plate	Freezing Fog	-6	9:55:30	10:02:15	6.7	4.9
C038	7-Apr-10	3	Clariant 1938	10°B	20	Composite Plate	Freezing Fog	-6	9:58:13	10:05:30	7.3	5.2
C039	7-Apr-10	3	Dow UCAR ADF	10°B	20	Composite Plate	Freezing Fog	-6	9:57:12	10:03:45	6.5	5.4
C040	7-Apr-10	3	Dow UCAR ADF	10°B	20	Composite Plate	Freezing Fog	-6	9:57:42	10:04:35	6.9	5.3
C041	7-Apr-10	3	Dow UCAR PG ADF	10°B	20	Composite Plate	Freezing Fog	-6	9:47:06	9:54:45	7.7	5.4
C042	7-Apr-10	3	Dow UCAR PG ADF	10°B	20	Composite Plate	Freezing Fog	-6	9:47:52	9:55:00	7.1	5.3
C043	7-Apr-10	4	Kilfrost DF^{sustain}	10°B	20	Aluminum Plate	Freezing Fog	-6	14:37:04	14:50:30	13.4	2.0

Table 3.3: Log of Tests (2009-10) – Freezing Precipitation (cont'd)

Test #	Date	Run #	Fluid Name	Fluid Dil.	Fluid Temp. (°C)	Test Surface	Precip. Type	Ambient Temp. (°C)	Start Time	Fail Time	Endur. Time (min)	Precip. Rate (g/dm²/h)
C044	7-Apr-10	4	Kilfrost DF sustain	10°B	20	Aluminum Plate	Freezing Fog	-6	14:38:54	14:51:30	12.6	1.9
C047	7-Apr-10	4	Kilfrost DF sustain	10°B	20	Composite Plate	Freezing Fog	-6	14:39:27	14:49:00	9.6	1.9
C048	7-Apr-10	4	Kilfrost DF sustain	10°B	20	Composite Plate	Freezing Fog	-6	14:40:25	14:49:00	8.6	2.1
C049	7-Apr-10	4	Octagon Octaflo	10°B	20	Composite Plate	Freezing Fog	-6	14:47:17	14:57:30	10.2	1.9
C050	7-Apr-10	4	Octagon Octaflo	10°B	20	Composite Plate	Freezing Fog	-6	14:47:47	14:57:40	9.9	2.0
C051	7-Apr-10	4	Clariant 1938	10°B	20	Composite Plate	Freezing Fog	-6	14:52:41	15:02:15	9.6	2.0
C052	7-Apr-10	4	Clariant 1938	10°B	20	Composite Plate	Freezing Fog	-6	14:53:15	15:02:40	9.4	2.0
C053	7-Apr-10	4	Dow UCAR ADF	10°B	20	Composite Plate	Freezing Fog	-6	14:36:33	14:45:10	8.6	1.9
C054	7-Apr-10	4	Dow UCAR ADF	10°B	20	Composite Plate	Freezing Fog	-6	14:37:32	14:45:51	8.3	2.0
C055	7-Apr-10	4	Dow UCAR PG ADF	10°B	20	Composite Plate	Freezing Fog	-6	14:41:26	14:50:00	8.6	2.0
C056	7-Apr-10	4	Dow UCAR PG ADF	10°B	20	Composite Plate	Freezing Fog	-6	14:41:53	14:50:30	8.6	2.0
C057	7-Apr-10	5	Kilfrost DF sustain	10°B	20	Aluminum Plate	Freezing Fog	-10	10:37:07	10:43:55	6.8	5.3
C058	7-Apr-10	5	Kilfrost DF sustain	10°B	20	Aluminum Plate	Freezing Fog	-10	10:39:59	10:46:19	6.3	5.4
C061	7-Apr-10	5	Kilfrost DF sustain	10°B	20	Composite Plate	Freezing Fog	-10	10:38:02	10:43:30	5.5	4.8
C062	7-Apr-10	5	Kilfrost DF sustain	10°B	20	Composite Plate	Freezing Fog	-10	10:39:07	10:44:36	5.5	5.4
C063	7-Apr-10	5	Octagon Octaflo	10°B	20	Composite Plate	Freezing Fog	-10	10:43:27	10:48:25	5.0	5.1
C064	7-Apr-10	5	Octagon Octaflo	10°B	20	Composite Plate	Freezing Fog	-10	10:47:42	10:53:10	5.5	4.8
C065	7-Apr-10	5	Clariant 1938	10°B	20	Composite Plate	Freezing Fog	-10	10:58:11	11:02:31	4.3	4.8
C066	7-Apr-10	5	Clariant 1938	10°B	20	Composite Plate	Freezing Fog	-10	10:57:25	11:02:00	4.6	5.2
C067	7-Apr-10	5	Dow UCAR ADF	10°B	20	Composite Plate	Freezing Fog	-10	10:49:48	10:54:20	4.5	5.2
C068	7-Apr-10	5	Dow UCAR ADF	10°B	20	Composite Plate	Freezing Fog	-10	10:50:54	10:55:20	4.4	4.6
C069	7-Apr-10	5	Dow UCAR PG ADF	10°B	20	Composite Plate	Freezing Fog	-10	10:52:32	10:56:20	3.8	5.1
C070	7-Apr-10	5	Dow UCAR PG ADF	10°B	20	Composite Plate	Freezing Fog	-10	10:41:13	10:46:36	5.4	4.6
C070R	7-Apr-10	5	Dow UCAR PG ADF	10°B	20	Composite Plate	Freezing Fog	-10	11:59:40	12:04:40	5.0	4.4
C071	7-Apr-10	6	Kilfrost DF sustain	10°B	20	Aluminum Plate	Freezing Fog	-10	12:56:40	13:06:39	10.0	1.8
C072	7-Apr-10	6	Kilfrost DF sustain	10°B	20	Aluminum Plate	Freezing Fog	-10	12:57:57	13:08:05	10.1	1.9
C075	7-Apr-10	6	Kilfrost DF sustain	10°B	20	Composite Plate	Freezing Fog	-10	12:55:17	13:03:20	8.1	1.8
C076	7-Apr-10	6	Kilfrost DF sustain	10°B	20	Composite Plate	Freezing Fog	-10	12:55:55	13:04:30	8.6	1.7
C077	7-Apr-10	6	Octagon Octaflo	10°B	20	Composite Plate	Freezing Fog	-10	13:11:23	13:20:00	8.6	2.0
C078	7-Apr-10	6	Octagon Octaflo	10°B	20	Composite Plate	Freezing Fog	-10	13:11:56	13:21:00	9.1	2.1
C079	7-Apr-10	6	Clariant 1938	10°B	20	Composite Plate	Freezing Fog	-10	13:09:29	13:18:30	9.0	1.8
C080	7-Apr-10	6	Clariant 1938	10°B	20	Composite Plate	Freezing Fog	-10	13:10:07	13:19:00	8.9	1.7
C081	7-Apr-10	6	Dow UCAR ADF	10°B	20	Composite Plate	Freezing Fog	-10	13:02:20	13:10:35	8.3	2.0
C082	7-Apr-10	6	Dow UCAR ADF	10°B	20	Composite Plate	Freezing Fog	-10	13:12:52	13:20:55	8.0	2.0
C083	7-Apr-10	6	Dow UCAR PG ADF	10°B	20	Composite Plate	Freezing Fog	-10	12:58:41	13:07:10	8.5	2.0
C084	7-Apr-10	6	Dow UCAR PG ADF	10°B	20	Composite Plate	Freezing Fog	-10	12:59:25	13:08:25	9.0	2.1
C085	6-Apr-10	7	Kilfrost DF sustain	10°B	20	Aluminum Plate	Freezing Fog	-25	10:42:50	10:47:55	5.1	5.0

Table 3.3: Log of Tests (2009-10) – Freezing Precipitation (cont'd)

Test #	Date	Run #	Fluid Name	Fluid Dil.	Fluid Temp. (°C)	Test Surface	Precip. Type	Ambient Temp. (°C)	Start Time	Fail Time	Endur. Time (min)	Precip. Rate (g/dm²/h)
C086	6-Apr-10	7	Kilfrost DFsustain	10°B	20	Aluminum Plate	Freezing Fog	-25	11:01:20	11:06:30	5.2	5.1
C089	6-Apr-10	7	Kilfrost DFsustain	10°B	20	Composite Plate	Freezing Fog	-25	10:45:50	10:51:00	5.2	4.7
C090	6-Apr-10	7	Kilfrost DFsustain	10°B	20	Composite Plate	Freezing Fog	-25	10:47:56	10:53:15	5.3	5.3
C091	6-Apr-10	7	Octagon Octaflo	10°B	20	Composite Plate	Freezing Fog	-25	10:49:45	10:55:00	5.2	4.8
C092	6-Apr-10	7	Octagon Octaflo	10°B	20	Composite Plate	Freezing Fog	-25	10:44:28	10:49:44	5.3	5.2
C093	6-Apr-10	7	Clariant 1938	10°B	20	Composite Plate	Freezing Fog	-25	11:02:48	11:08:20	5.5	4.8
C094	6-Apr-10	7	Clariant 1938	10°B	20	Composite Plate	Freezing Fog	-25	11:03:39	11:09:00	5.4	5.2
C095	6-Apr-10	7	Dow UCAR ADF	10°B	20	Composite Plate	Freezing Fog	-25	11:14:05	11:18:20	4.3	4.8
C096	6-Apr-10	7	Dow UCAR ADF	10°B	20	Composite Plate	Freezing Fog	-25	11:14:43	11:18:40	4.0	5.2
C097	6-Apr-10	7	Dow UCAR PG ADF	10°B	20	Composite Plate	Freezing Fog	-25	11:13:27	11:18:00	4.6	5.2
C098	6-Apr-10	7	Dow UCAR PG ADF	10°B	20	Composite Plate	Freezing Fog	-25	11:02:05	11:06:40	4.6	5.2
C099	6-Apr-10	8	Kilfrost DFsustain	10°B	20	Aluminum Plate	Freezing Fog	-25	14:05:43	14:15:30	9.8	1.9
C100	6-Apr-10	8	Kilfrost DFsustain	10°B	20	Aluminum Plate	Freezing Fog	-25	14:11:42	14:21:40	10.0	1.7
C103	6-Apr-10	8	Kilfrost DFsustain	10°B	20	Composite Plate	Freezing Fog	-25	14:06:38	14:14:25	7.8	2.0
C104	6-Apr-10	8	Kilfrost DFsustain	10°B	20	Composite Plate	Freezing Fog	-25	14:07:42	14:15:00	7.3	2.0
C105	6-Apr-10	8	Octagon Octaflo	10°B	20	Composite Plate	Freezing Fog	-25	14:26:45	14:34:30	7.8	2.0
C106	6-Apr-10	8	Octagon Octaflo	10°B	20	Composite Plate	Freezing Fog	-25	14:28:35	14:39:00	10.4	1.8
C107	6-Apr-10	8	Clariant 1938	10°B	20	Composite Plate	Freezing Fog	-25	14:26:00	14:35:10	9.2	2.0
C108	6-Apr-10	8	Clariant 1938	10°B	20	Composite Plate	Freezing Fog	-25	14:27:40	14:37:30	9.8	1.7
C109	6-Apr-10	8	Dow UCAR ADF	10°B	20	Composite Plate	Freezing Fog	-25	14:08:38	14:16:30	7.9	1.7
C110	6-Apr-10	8	Dow UCAR ADF	10°B	20	Composite Plate	Freezing Fog	-25	14:18:45	14:25:00	6.3	1.9
C111	6-Apr-10	8	Dow UCAR PG ADF	10°B	20	Composite Plate	Freezing Fog	-25	14:12:48	14:20:50	8.0	1.9
C112	6-Apr-10	8	Dow UCAR PG ADF	10°B	20	Composite Plate	Freezing Fog	-25	14:13:43	14:22:00	8.3	1.8
C113	31-Mar-10	9	Kilfrost DFsustain	10°B	20	Aluminum Plate	Light Freezing Rain	-6	12:23:50	12:31:00	7.2	25.4
C114	31-Mar-10	9	Kilfrost DFsustain	10°B	20	Aluminum Plate	Light Freezing Rain	-6	12:26:15	12:33:00	6.8	25.3
C117	31-Mar-10	9	Kilfrost DFsustain	10°B	20	Composite Plate	Light Freezing Rain	-6	12:23:00	12:28:10	5.2	25.6
C118	31-Mar-10	9	Kilfrost DFsustain	10°B	20	Composite Plate	Light Freezing Rain	-6	12:25:30	12:31:00	5.5	25.6
C119	31-Mar-10	9	Octagon Octaflo	10°B	20	Composite Plate	Light Freezing Rain	-6	12:46:15	12:51:20	5.1	25.6
C120	31-Mar-10	9	Octagon Octaflo	10°B	20	Composite Plate	Light Freezing Rain	-6	12:45:25	12:50:50	5.4	24.8
C121	31-Mar-10	9	Clariant 1938	10°B	20	Composite Plate	Light Freezing Rain	-6	12:41:05	12:46:40	5.6	25.4
C122	31-Mar-10	9	Clariant 1938	10°B	20	Composite Plate	Light Freezing Rain	-6	12:41:40	12:47:00	5.3	24.7
C123	31-Mar-10	9	Dow UCAR ADF	10°B	20	Composite Plate	Light Freezing Rain	-6	12:28:45	12:33:00	4.3	26.1
C124	31-Mar-10	9	Dow UCAR ADF	10°B	20	Composite Plate	Light Freezing Rain	-6	12:29:45	12:34:50	5.1	24.7
C125	31-Mar-10	9	Dow UCAR PG ADF	10°B	20	Composite Plate	Light Freezing Rain	-6	12:33:30	12:38:50	5.3	24.8
C126	31-Mar-10	9	Dow UCAR PG ADF	10°B	20	Composite Plate	Light Freezing Rain	-6	12:32:20	12:37:20	5.0	25.6
C127	31-Mar-10	10	Kilfrost DFsustain	10°B	20	Aluminum Plate	Light Freezing Rain	-6	19:02:05	19:12:10	10.1	13.0
C128	31-Mar-10	10	Kilfrost DFsustain	10°B	20	Aluminum Plate	Light Freezing Rain	-6	19:04:55	19:13:10	8.3	13.0

Table 3.3: Log of Tests (2009-10) – Freezing Precipitation (cont'd)

Test #	Date	Run #	Fluid Name	Fluid Dil.	Fluid Temp. (°C)	Test Surface	Precip. Type	Ambient Temp. (°C)	Start Time	Fail Time	Endur. Time (min)	Precip. Rate (g/dm²/h)
C131	31-Mar-10	10	Kilfrost DF^sustain	10°B	20	Composite Plate	Light Freezing Rain	-6	19:01:15	19:09:30	8.3	13.2
C132	31-Mar-10	10	Kilfrost DF^sustain	10°B	20	Composite Plate	Light Freezing Rain	-6	19:04:00	19:12:30	8.5	13.2
C133	31-Mar-10	10	Octagon Octaflo	10°B	20	Composite Plate	Light Freezing Rain	-6	19:16:20	19:22:45	6.4	12.6
C134	31-Mar-10	10	Octagon Octaflo	10°B	20	Composite Plate	Light Freezing Rain	-6	19:18:45	19:26:45	8.0	13.2
C135	31-Mar-10	10	Clariant 1938	10°B	20	Composite Plate	Light Freezing Rain	-6	19:22:40	19:30:00	7.3	13.0
C136	31-Mar-10	10	Clariant 1938	10°B	20	Composite Plate	Light Freezing Rain	-6	19:25:35	19:32:15	6.7	12.6
C137	31-Mar-10	10	Dow UCAR ADF	10°B	20	Composite Plate	Light Freezing Rain	-6	19:06:15	19:12:30	6.2	13.2
C138	31-Mar-10	10	Dow UCAR ADF	10°B	20	Composite Plate	Light Freezing Rain	-6	19:07:05	19:15:00	7.9	13.0
C139	31-Mar-10	10	Dow UCAR PG ADF	10°B	20	Composite Plate	Light Freezing Rain	-6	19:17:20	19:24:15	6.9	13.2
C140	31-Mar-10	10	Dow UCAR PG ADF	10°B	20	Composite Plate	Light Freezing Rain	-6	19:08:15	19:15:50	7.6	13.0
C141	31-Mar-10	11	Kilfrost DF^sustain	10°B	20	Aluminum Plate	Light Freezing Rain	-10	10:19:15	10:23:35	4.3	25.0
C142	31-Mar-10	11	Kilfrost DF^sustain	10°B	20	Aluminum Plate	Light Freezing Rain	-10	10:27:35	10:32:25	4.8	24.6
C145	31-Mar-10	11	Kilfrost DF^sustain	10°B	20	Composite Plate	Light Freezing Rain	-10	9:27:18	9:31:38	4.3	25.1
C146	31-Mar-10	11	Kilfrost DF^sustain	10°B	20	Composite Plate	Light Freezing Rain	-10	9:27:42	9:32:14	4.5	24.9
C147	31-Mar-10	11	Octagon Octaflo	10°B	20	Composite Plate	Light Freezing Rain	-10	9:37:25	9:41:30	4.1	25.1
C148	31-Mar-10	11	Octagon Octaflo	10°B	20	Composite Plate	Light Freezing Rain	-10	9:37:50	9:42:15	4.4	24.9
C149	31-Mar-10	11	Clariant 1938	10°B	20	Composite Plate	Light Freezing Rain	-10	9:40:18	9:44:15	4.0	23.9
C150	31-Mar-10	11	Clariant 1938	10°B	20	Composite Plate	Light Freezing Rain	-10	9:40:50	9:44:15	3.4	24.2
C151	31-Mar-10	11	Dow UCAR ADF	10°B	20	Composite Plate	Light Freezing Rain	-10	9:49:15	9:53:00	3.8	24.4
C152	31-Mar-10	11	Dow UCAR ADF	10°B	20	Composite Plate	Light Freezing Rain	-10	9:49:30	9:53:30	4.0	23.9
C153	31-Mar-10	11	Dow UCAR PG ADF	10°B	20	Composite Plate	Light Freezing Rain	-10	9:29:36	9:33:30	3.9	23.9
C154	31-Mar-10	11	Dow UCAR PG ADF	10°B	20	Composite Plate	Light Freezing Rain	-10	9:30:03	9:33:40	3.6	24.2
C155	30-Mar-10	12	Kilfrost DF^sustain	10°B	20	Aluminum Plate	Light Freezing Rain	-10	13:11:57	13:18:40	6.7	13.8
C156	30-Mar-10	12	Kilfrost DF^sustain	10°B	20	Aluminum Plate	Light Freezing Rain	-10	13:14:50	13:21:20	6.5	13.0
C159	30-Mar-10	12	Kilfrost DF^sustain	10°B	20	Composite Plate	Light Freezing Rain	-10	12:11:15	12:17:00	5.7	12.9
C160	30-Mar-10	12	Kilfrost DF^sustain	10°B	20	Composite Plate	Light Freezing Rain	-10	12:13:50	12:20:00	6.2	13.3
C161	30-Mar-10	12	Octagon Octaflo	10°B	20	Composite Plate	Light Freezing Rain	-10	12:19:55	12:25:20	5.4	12.6
C162	30-Mar-10	12	Octagon Octaflo	10°B	20	Composite Plate	Light Freezing Rain	-10	12:26:30	12:31:15	4.8	12.6
C163	30-Mar-10	12	Clariant 1938	10°B	20	Composite Plate	Light Freezing Rain	-10	12:55:30	13:01:00	5.5	13.1
C164	30-Mar-10	12	Clariant 1938	10°B	20	Composite Plate	Light Freezing Rain	-10	12:56:06	13:02:00	5.9	13.5
C165	30-Mar-10	12	Dow UCAR ADF	10°B	20	Composite Plate	Light Freezing Rain	-10	12:35:58	12:41:05	5.1	12.6
C166	30-Mar-10	12	Dow UCAR ADF	10°B	20	Composite Plate	Light Freezing Rain	-10	12:36:53	12:41:30	4.6	12.6
C167	30-Mar-10	12	Dow UCAR PG ADF	10°B	20	Composite Plate	Light Freezing Rain	-10	12:28:12	12:33:45	5.5	12.9
C168	30-Mar-10	12	Dow UCAR PG ADF	10°B	20	Composite Plate	Light Freezing Rain	-10	12:28:55	12:34:30	5.6	13.3
C169	30-Mar-10	13	Kilfrost DF^sustain	10°B	20	Aluminum Plate	Freezing Drizzle	-3	19:51:55	20:05:30	13.6	13.0
C170	30-Mar-10	13	Kilfrost DF^sustain	10°B	20	Aluminum Plate	Freezing Drizzle	-3	19:52:58	20:06:00	13.0	13.8
C173	30-Mar-10	13	Kilfrost DF^sustain	10°B	20	Composite Plate	Freezing Drizzle	-3	18:30:50	18:40:30	9.7	13.4

Table 3.3: Log of Tests (2009-10) – Freezing Precipitation (cont'd)

Test #	Date	Run #	Fluid Name	Fluid Dil.	Fluid Temp. (°C)	Test Surface	Precip. Type	Ambient Temp. (°C)	Start Time	Fail Time	Endur. Time (min)	Precip. Rate (g/dm²/h)
C174	30-Mar-10	13	Kilfrost DF sustain	10°B	20	Composite Plate	Freezing Drizzle	-3	18:31:50	18:41:00	9.2	12.9
C175	30-Mar-10	13	Octagon Octaflo	10°B	20	Composite Plate	Freezing Drizzle	-3	19:21:00	19:31:00	10.0	13.1
C176	30-Mar-10	13	Octagon Octaflo	10°B	20	Composite Plate	Freezing Drizzle	-3	19:21:26	19:30:00	8.6	12.6
C177	30-Mar-10	13	Clariant 1938	10°B	20	Composite Plate	Freezing Drizzle	-3	18:44:45	18:53:30	8.7	12.9
C178	30-Mar-10	13	Clariant 1938	10°B	20	Composite Plate	Freezing Drizzle	-3	18:45:10	18:54:30	9.3	12.9
C179	30-Mar-10	13	Dow UCAR ADF	10°B	20	Composite Plate	Freezing Drizzle	-3	18:51:08	19:01:30	10.4	12.8
C180	30-Mar-10	13	Dow UCAR ADF	10°B	20	Composite Plate	Freezing Drizzle	-3	19:35:35	19:45:20	9.8	12.8
C181	30-Mar-10	13	Dow UCAR PG ADF	10°B	20	Composite Plate	Freezing Drizzle	-3	18:31:20	18:40:40	9.3	12.9
C182	30-Mar-10	13	Dow UCAR PG ADF	10°B	20	Composite Plate	Freezing Drizzle	-3	18:44:30	18:55:30	11.0	13.4
C183	29-Mar-10	14	Kilfrost DF sustain	10°B	20	Aluminum Plate	Freezing Drizzle	-3	17:20:31	17:33:00	12.5	4.9
C184	29-Mar-10	14	Kilfrost DF sustain	10°B	20	Aluminum Plate	Freezing Drizzle	-3	17:37:14	17:49:00	11.8	4.9
C187	29-Mar-10	14	Kilfrost DF sustain	10°B	20	Composite Plate	Freezing Drizzle	-3	15:36:26	15:48:30	12.1	5.4
C188	29-Mar-10	14	Kilfrost DF sustain	10°B	20	Composite Plate	Freezing Drizzle	-3	15:33:43	15:47:30	13.8	5.3
C189	29-Mar-10	14	Octagon Octaflo	10°B	20	Composite Plate	Freezing Drizzle	-3	15:38:40	15:53:30	14.8	4.8
C190	29-Mar-10	14	Octagon Octaflo	10°B	20	Composite Plate	Freezing Drizzle	-3	15:50:10	16:02:00	11.8	5.4
C191	29-Mar-10	14	Clariant 1938	10°B	20	Composite Plate	Freezing Drizzle	-3	15:51:00	16:04:50	13.8	5.3
C192	29-Mar-10	14	Clariant 1938	10°B	20	Composite Plate	Freezing Drizzle	-3	15:56:15	16:11:15	15.0	4.8
C193	29-Mar-10	14	Dow UCAR ADF	10°B	20	Composite Plate	Freezing Drizzle	-3	16:56:50	17:10:30	13.7	4.9
C194	29-Mar-10	14	Dow UCAR ADF	10°B	20	Composite Plate	Freezing Drizzle	-3	16:56:15	17:08:00	11.8	5.5
C195	29-Mar-10	14	Dow UCAR PG ADF	10°B	20	Composite Plate	Freezing Drizzle	-3	16:39:45	16:52:00	12.3	5.5
C196	29-Mar-10	14	Dow UCAR PG ADF	10°B	20	Composite Plate	Freezing Drizzle	-3	16:40:30	16:55:00	14.5	4.9
C197	30-Mar-10	15	Kilfrost DF sustain	10°B	20	Aluminum Plate	Freezing Drizzle	-6	16:38:00	16:45:40	7.7	13.1
C198	30-Mar-10	15	Kilfrost DF sustain	10°B	20	Aluminum Plate	Freezing Drizzle	-6	16:39:00	16:47:50	8.8	12.9
C201	30-Mar-10	15	Kilfrost DF sustain	10°B	20	Composite Plate	Freezing Drizzle	-6	16:38:30	16:44:40	6.2	12.6
C202	30-Mar-10	15	Kilfrost DF sustain	10°B	20	Composite Plate	Freezing Drizzle	-6	16:39:30	16:46:20	6.8	13.3
C203	30-Mar-10	15	Octagon Octaflo	10°B	20	Composite Plate	Freezing Drizzle	-6	16:43:00	16:50:20	7.3	13.4
C204	30-Mar-10	15	Octagon Octaflo	10°B	20	Composite Plate	Freezing Drizzle	-6	16:43:30	16:50:30	7.0	13.2
C205	30-Mar-10	15	Clariant 1938	10°B	20	Composite Plate	Freezing Drizzle	-6	16:44:00	16:50:20	6.3	13.0
C206	30-Mar-10	15	Clariant 1938	10°B	20	Composite Plate	Freezing Drizzle	-6	16:58:35	17:04:55	6.3	13.0
C207	30-Mar-10	15	Dow UCAR ADF	10°B	20	Composite Plate	Freezing Drizzle	-6	16:55:00	17:00:40	5.7	12.6
C208	30-Mar-10	15	Dow UCAR ADF	10°B	20	Composite Plate	Freezing Drizzle	-6	16:56:00	17:03:00	7.0	13.3
C209	30-Mar-10	15	Dow UCAR PG ADF	10°B	20	Composite Plate	Freezing Drizzle	-6	16:57:00	17:03:50	6.8	13.4
C210	30-Mar-10	15	Dow UCAR PG ADF	10°B	20	Composite Plate	Freezing Drizzle	-6	16:58:00	17:04:50	6.8	13.2
C211	29-Mar-10	16	Kilfrost DF sustain	10°B	20	Aluminum Plate	Freezing Drizzle	-6	12:53:50	13:05:00	11.2	5.3
C212	29-Mar-10	16	Kilfrost DF sustain	10°B	20	Aluminum Plate	Freezing Drizzle	-6	13:07:40	13:19:00	11.3	5.2
C215	29-Mar-10	16	Kilfrost DF sustain	10°B	20	Composite Plate	Freezing Drizzle	-6	12:44:45	12:55:00	10.3	4.6
C216	29-Mar-10	16	Kilfrost DF sustain	10°B	20	Composite Plate	Freezing Drizzle	-6	12:46:30	12:57:20	10.8	4.9

Table 3.3: Log of Tests (2009-10) – Freezing Precipitation (cont'd)

Test #	Date	Run #	Fluid Name	Fluid Dil.	Fluid Temp. (°C)	Test Surface	Precip. Type	Ambient Temp. (°C)	Start Time	Fail Time	Endur. Time (min)	Precip. Rate (g/dm²/h)
C217	29-Mar-10	16	Octagon Octaflo	10°B	20	Composite Plate	Freezing Drizzle	-6	12:45:30	12:55:30	10.0	5.2
C218	29-Mar-10	16	Octagon Octaflo	10°B	20	Composite Plate	Freezing Drizzle	-6	12:47:00	12:57:00	10.0	5.2
C219	29-Mar-10	16	Clariant 1938	10°B	20	Composite Plate	Freezing Drizzle	-6	13:02:20	13:12:45	10.4	4.6
C220	29-Mar-10	16	Clariant 1938	10°B	20	Composite Plate	Freezing Drizzle	-6	13:03:40	13:14:50	11.2	4.9
C221	29-Mar-10	16	Dow UCAR ADF	10°B	20	Composite Plate	Freezing Drizzle	-6	13:02:50	13:12:00	9.2	5.2
C222	29-Mar-10	16	Dow UCAR ADF	10°B	20	Composite Plate	Freezing Drizzle	-6	13:04:30	13:14:20	9.8	5.2
C223	29-Mar-10	16	Dow UCAR PG ADF	10°B	20	Composite Plate	Freezing Drizzle	-6	13:08:20	13:19:15	10.9	5.0
C224	29-Mar-10	16	Dow UCAR PG ADF	10°B	20	Composite Plate	Freezing Drizzle	-6	13:10:50	13:21:30	10.7	4.6
C225	30-Mar-10	17	Kilfrost DF^{sustain}	10°B	20	Aluminum Plate	Freezing Drizzle	-10	15:12:25	15:18:30	6.1	12.8
C226	30-Mar-10	17	Kilfrost DF^{sustain}	10°B	20	Aluminum Plate	Freezing Drizzle	-10	15:14:00	15:20:15	6.3	13.2
C229	30-Mar-10	17	Kilfrost DF^{sustain}	10°B	20	Composite Plate	Freezing Drizzle	-10	15:36:30	15:42:10	5.7	12.8
C230	30-Mar-10	17	Kilfrost DF^{sustain}	10°B	20	Composite Plate	Freezing Drizzle	-10	15:35:20	15:41:00	5.7	13.0
C231	30-Mar-10	17	Octagon Octaflo	10°B	20	Composite Plate	Freezing Drizzle	-10	14:36:15	14:41:45	5.5	12.9
C232	30-Mar-10	17	Octagon Octaflo	10°B	20	Composite Plate	Freezing Drizzle	-10	14:35:30	14:40:30	5.0	13.1
C233	30-Mar-10	17	Clariant 1938	10°B	20	Composite Plate	Freezing Drizzle	-10	14:34:55	14:40:00	5.1	12.9
C234	30-Mar-10	17	Clariant 1938	10°B	20	Composite Plate	Freezing Drizzle	-10	14:49:06	14:55:30	6.4	12.9
C235	30-Mar-10	17	Dow UCAR ADF	10°B	20	Composite Plate	Freezing Drizzle	-10	14:49:42	14:55:15	5.5	13.1
C236	30-Mar-10	17	Dow UCAR ADF	10°B	20	Composite Plate	Freezing Drizzle	-10	14:50:40	14:55:30	4.8	12.9
C237	30-Mar-10	17	Dow UCAR PG ADF	10°B	20	Composite Plate	Freezing Drizzle	-10	15:23:05	15:28:00	4.9	12.8
C238	30-Mar-10	17	Dow UCAR PG ADF	10°B	20	Composite Plate	Freezing Drizzle	-10	15:24:05	15:29:30	5.4	12.8
C239	29-Mar-10	18	Kilfrost DF^{sustain}	10°B	20	Aluminum Plate	Freezing Drizzle	-10	10:29:35	10:39:00	9.4	5.3
C240	29-Mar-10	18	Kilfrost DF^{sustain}	10°B	20	Aluminum Plate	Freezing Drizzle	-10	10:31:52	10:41:00	9.1	5.1
C243	29-Mar-10	18	Kilfrost DF^{sustain}	10°B	20	Composite Plate	Freezing Drizzle	-10	8:51:05	9:00:00	8.9	5.0
C244	29-Mar-10	18	Kilfrost DF^{sustain}	10°B	20	Composite Plate	Freezing Drizzle	-10	9:07:15	9:16:30	9.3	4.9
C245	29-Mar-10	18	Octagon Octaflo	10°B	20	Composite Plate	Freezing Drizzle	-10	9:12:20	9:21:30	9.2	5.4
C246	29-Mar-10	18	Octagon Octaflo	10°B	20	Composite Plate	Freezing Drizzle	-10	9:24:20	9:33:30	9.2	5.1
C247	29-Mar-10	18	Clariant 1938	10°B	20	Composite Plate	Freezing Drizzle	-10	9:36:35	9:46:45	10.2	4.9
C248	29-Mar-10	18	Clariant 1938	10°B	20	Composite Plate	Freezing Drizzle	-10	9:37:32	9:47:30	10.0	5.2
C249	29-Mar-10	18	Dow UCAR ADF	10°B	20	Composite Plate	Freezing Drizzle	-10	9:44:55	9:54:00	9.1	5.1
C250	29-Mar-10	18	Dow UCAR ADF	10°B	20	Composite Plate	Freezing Drizzle	-10	9:59:30	10:07:00	7.5	5.0
C251	29-Mar-10	18	Dow UCAR PG ADF	10°B	20	Composite Plate	Freezing Drizzle	-10	10:01:56	10:10:15	8.3	5.3
C252	29-Mar-10	18	Dow UCAR PG ADF	10°B	20	Composite Plate	Freezing Drizzle	-10	10:14:05	10:22:15	8.2	4.9
C253	1-Apr-10	19	Kilfrost DF^{sustain}	10°B	20	Aluminum Box	Cold Soak Box	1	14:16:30	14:18:36	2.1	77.2
C257	1-Apr-10	19	Kilfrost DF^{sustain}	10°B	20	Composite Box	Cold Soak Box	1	13:30:45	13:32:35	1.8	76.3
C258	1-Apr-10	19	Kilfrost DF^{sustain}	10°B	20	Composite Box	Cold Soak Box	1	13:32:38	13:34:25	1.8	76.4
C259	1-Apr-10	19	Octagon Octaflo	10°B	20	Composite Box	Cold Soak Box	1	13:42:11	13:43:52	1.7	76.4
C260	1-Apr-10	19	Octagon Octaflo	10°B	20	Composite Box	Cold Soak Box	1	13:55:24	13:57:04	1.7	74.3

Table 3.3: Log of Tests (2009-10) – Freezing Precipitation (cont'd)

Test #	Date	Run #	Fluid Name	Fluid Dil.	Fluid Temp. (°C)	Test Surface	Precip. Type	Ambient Temp. (°C)	Start Time	Fail Time	Endur. Time (min)	Precip. Rate (g/dm²/h)
C261	1-Apr-10	19	Clariant 1938	10°B	20	Composite Box	Cold Soak Box	1	13:35:35	13:37:19	1.7	76.3
C262	1-Apr-10	19	Clariant 1938	10°B	20	Composite Box	Cold Soak Box	1	13:35:42	13:37:34	1.9	76.4
C263	1-Apr-10	19	Dow UCAR ADF	10°B	20	Composite Box	Cold Soak Box	1	13:57:46	13:59:20	1.6	73.8
C264	1-Apr-10	19	Dow UCAR ADF	10°B	20	Composite Box	Cold Soak Box	1	14:08:24	14:10:05	1.7	76.5
C265	1-Apr-10	19	Dow UCAR PG ADF	10°B	20	Composite Box	Cold Soak Box	1	13:38:24	13:40:15	1.8	76.4
C266	1-Apr-10	19	Dow UCAR PG ADF	10°B	20	Composite Box	Cold Soak Box	1	13:59:52	14:02:01	2.2	74.3
C267	1-Apr-10	20	Kilfrost DF^{sustain}	10°B	20	Aluminum Box	Cold Soak Box	1	11:39:50	11:45:00	5.2	5.5
C268	1-Apr-10	20	Kilfrost DF^{sustain}	10°B	20	Aluminum Box	Cold Soak Box	1	11:49:12	11:53:50	4.6	5.5
C271	1-Apr-10	20	Kilfrost DF^{sustain}	10°B	20	Composite Box	Cold Soak Box	1	10:42:18	10:48:00	5.7	5.0
C272	1-Apr-10	20	Kilfrost DF^{sustain}	10°B	20	Composite Box	Cold Soak Box	1	11:07:55	11:14:30	6.6	5.7
C273	1-Apr-10	20	Octagon Octaflo	10°B	20	Composite Box	Cold Soak Box	1	12:00:41	12:07:45	7.1	5.0
C274	1-Apr-10	20	Octagon Octaflo	10°B	20	Composite Box	Cold Soak Box	1	12:15:21	12:23:30	8.2	5.5
C275	1-Apr-10	20	Clariant 1938	10°B	20	Composite Box	Cold Soak Box	1	11:25:33	11:32:15	6.7	5.3
C276	1-Apr-10	20	Clariant 1938	10°B	20	Composite Box	Cold Soak Box	1	11:24:20	11:31:10	6.8	4.9
C277	1-Apr-10	20	Dow UCAR ADF	10°B	20	Composite Box	Cold Soak Box	1	11:33:47	11:41:30	7.7	4.9
C278	1-Apr-10	20	Dow UCAR ADF	10°B	20	Composite Box	Cold Soak Box	1	11:34:46	11:41:40	6.9	5.3
C279	1-Apr-10	20	Dow UCAR PG ADF	10°B	20	Composite Box	Cold Soak Box	1	11:52:50	11:59:25	6.6	5.0
C280	1-Apr-10	20	Dow UCAR PG ADF	10°B	20	Composite Box	Cold Soak Box	1	12:07:08	12:14:00	6.9	5.5

Table 3.4: Log of Tests (2009-10) – Natural Frost

Test #	Date	Run #	Fluid Name	Fluid Dil.	Fluid Temp. (°C)	Test Surface	Precip. Type	Start Time	Fail Time	Endur. Time (min)	Precip. Rate (g/dm²/h)	Ambient Temp. (°C)	RH (%)	Wind Speed (km/h)	Initial Brix (°)	Final Brix (°)
1	21-Jan-10	1	Dow UCAR PG ADF	10°B	20	Aluminum	Frost	22:12:30	23:50:00	97.5	0.19	-7.8	88	9	27.50	16.00
2	21-Jan-10	1	Dow UCAR PG ADF	10°B	20	Composite	Frost	22:13:00	23:25:00	72.0	0.19	-7.8	88	9	27.50	16.00
3	21-Jan-10	1	Dow UCAR ADF	10°B	20	Composite	Frost	22:18:00	22:50:00	32.0	0.16	-7.8	88	9	21.75	15.50
4	21-Jan-10	1	Clariant 1938	10°B	20	Composite	Frost	22:21:30	23:20:00	58.5	0.19	-7.8	88	9	26.50	16.00
5	22-Jan-10	2	Clariant 1938	10°B	20	Aluminum	Frost	0:13:45	1:10:00	56.3	0.18	-8.3	87	14	26.50	18.00
6	22-Jan-10	2	Clariant 1938	10°B	20	Composite	Frost	0:14:00	1:10:00	56.0	0.18	-8.3	87	14	26.50	17.00
7	22-Jan-10	2	Kilfrost DF^{sustain}	10°B	20	Composite	Frost	0:16:45	1:05:00	48.3	0.18	-8.3	87	14	27.25	17.00
8	22-Jan-10	2	Clariant 1938	10°B	20	Composite	Frost	0:17:30	1:05:00	47.5	0.18	-8.3	87	14	21.50	15.00
9	23-Jan-10	1	Dow UCAR ADF	10°B	20	Aluminum	Frost	2:26:00	3:20:00	54.0	0.04	-10.0	67	4	21.75	12.00
10	23-Jan-10	1	Dow UCAR ADF	10°B	20	Composite	Frost	2:26:00	3:10:00	44.0	0.04	-10.0	67	4	21.75	13.00
11	23-Jan-10	1	Kilfrost DF^{sustain}	10°B	20	Composite	Frost	2:28:00	3:20:00	52.0	0.04	-10.0	67	4	27.25	15.00
12	23-Jan-10	1	Clariant 1938	10°B	20	Composite	Frost	2:28:30	3:25:00	56.5	0.04	-10.0	67	4	26.50	17.00
13	23-Jan-10	2	Kilfrost DF^{sustain}	10°B	20	Aluminum	Frost	4:49:45	6:20:00	90.3	0.06	-14.0	83	5	30.00	21.00
14	23-Jan-10	2	Kilfrost DF^{sustain}	10°B	20	Composite	Frost	4:49:45	6:13:00	83.3	0.06	-14.0	83	5	30.00	21.00
15	23-Jan-10	2	Dow UCAR PG ADF	10°B	20	Composite	Frost	4:54:50	6:20:00	85.2	0.06	-14.0	83	5	29.50	23.00
17	5-Mar-10	1	Octagon Octaflo	10°B	20	Aluminum	Frost	23:52:00	1:37:00	105.0	0.10	-2.9	63	0	20.50	19.00
18	5-Mar-10	1	Octagon Octaflo	10°B	20	Composite	Frost	23:52:35	1:01:00	68.4	0.09	-2.9	63	0	20.50	17.50
19	5-Mar-10	1	Clariant 1938	10°B	20	Composite	Frost	23:52:00	1:37:00	105.0	0.10	-2.9	63	0	21.50	20.00
20	5-Mar-10	1	Kilfrost DF^{sustain}	10°B	20	Composite	Frost	23:52:35	1:01:00	68.4	0.09	-2.9	63	0	20.75	18.00
21	6-Mar-10	2	Kilfrost DF^{sustain}	10°B	20	Aluminum	Frost	1:27:50	2:54:00	86.2	0.10	-4.6	68	5	20.75	17.50
22	6-Mar-10	2	Kilfrost DF^{sustain}	10°B	20	Composite	Frost	1:28:20	2:17:00	48.7	0.13	-4.6	68	5	20.75	18.50
23	6-Mar-10	2	Dow UCAR PG ADF	10°B	20	Composite	Frost	1:27:50	2:28:00	60.2	0.11	-4.6	68	5	21.50	18.50
25	6-Mar-10	3	Dow UCAR PG ADF	10°B	20	Aluminum	Frost	3:09:30	4:55:00	105.5	0.09	-4.0	68	7	24.25	14.50
26	6-Mar-10	3	Dow UCAR PG ADF	10°B	20	Composite	Frost	3:10:05	4:29:30	79.4	0.09	-4.0	68	7	24.25	15.25
27	6-Mar-10	3	Dow UCAR ADF	10°B	20	Composite	Frost	3:09:30	4:15:00	65.5	0.09	-4.0	68	7	19.00	12.00
28	6-Mar-10	3	Octagon Octaflo	10°B	20	Composite	Frost	3:10:05	4:17:00	66.9	0.09	-4.0	68	7	23.00	17.50
33	10-Mar-10	1	Octagon Octaflo	10°B	20	Aluminum	Frost	0:50:25	2:00:00	69.6	0.18	-4.2	73	5	21.25	16.00
34	10-Mar-10	1	Octagon Octaflo	10°B	20	Composite	Frost	0:51:10	1:44:00	52.8	0.18	-4.2	73	5	21.25	16.00
35	10-Mar-10	1	Clariant 1938	10°B	20	Composite	Frost	0:50:30	1:42:00	51.5	0.18	-4.2	73	5	22.50	16.50
36	10-Mar-10	1	Kilfrost DF^{sustain}	10°B	20	Composite	Frost	0:51:13	1:36:00	44.8	0.18	-4.2	73	5	21.75	16.75
37	10-Mar-10	2	Kilfrost DF^{sustain}	10°B	20	Aluminum	Frost	2:24:50	3:42:00	77.2	0.17	-3.8	73	4	22.75	15.25
38	10-Mar-10	2	Kilfrost DF^{sustain}	10°B	20	Composite	Frost	2:25:30	3:24:00	58.5	0.17	-3.8	73	4	22.75	15.50
39	10-Mar-10	2	Dow UCAR PG ADF	10°B	20	Composite	Frost	2:24:50	3:20:00	55.2	0.17	-3.8	73	4	22.75	15.50

Table 3.4: Log of Tests (2009-10) – Natural Frost (cont'd)

Test #	Date	Run #	Fluid Name	Fluid Dil.	Fluid Temp. (°C)	Test Surface	Precip. Type	Start Time	Fail Time	Endur. Time (min)	Precip. Rate (g/dm²/h)	Ambient Temp. (°C)	RH (%)	Wind Speed (km/h)	Initial Brix (°)	Final Brix (°)
41	10-Mar-10	3	Dow UCAR PG ADF	10°B	20	Aluminum	Frost	3:52:00	5:30:00	98.0	0.13	-4.0	72	7	22.75	15.00
42	10-Mar-10	3	Dow UCAR PG ADF	10°B	20	Composite	Frost	3:52:30	4:52:00	59.5	0.16	-4.0	72	7	22.75	14.00
43	10-Mar-10	3	Dow UCAR ADF	10°B	20	Composite	Frost	3:52:00	4:45:00	53.0	0.20	-4.0	72	7	17.50	10.50
44	10-Mar-10	3	Octagon Octaflo	10°B	20	Composite	Frost	3:52:30	4:55:00	62.5	0.16	-4.0	72	7	NR	16.00

NR = Not Recorded

3.3 Natural Snow Weather Conditions

A total of 71 composite tests were conducted in natural snow. Graphs showing the distribution of tests by precipitation rate, ambient temperature, and wind speed are shown in Figures 3.1, 3.2, and 3.3, respectively.

Figure 3.1 shows that 72 percent of the tests were conducted in light or very light snow (precipitation rates below 10 g/dm²/h). This is representative of typical snowfall rates in Montreal; light and very light snow typically account for the majority of the deicing operations performed at the Montreal–Pierre Elliott Trudeau International Airport.

Figure 3.2 shows that 69 percent of the tests were conducted at 0°C or above. These results are not typical; normally, Montreal experiences more snow events at colder temperatures, but the 2009-10 winter was unusually mild.

Figure 3.3 shows that 31 percent of the tests were conducted when wind speeds were greater than 26 km/h.

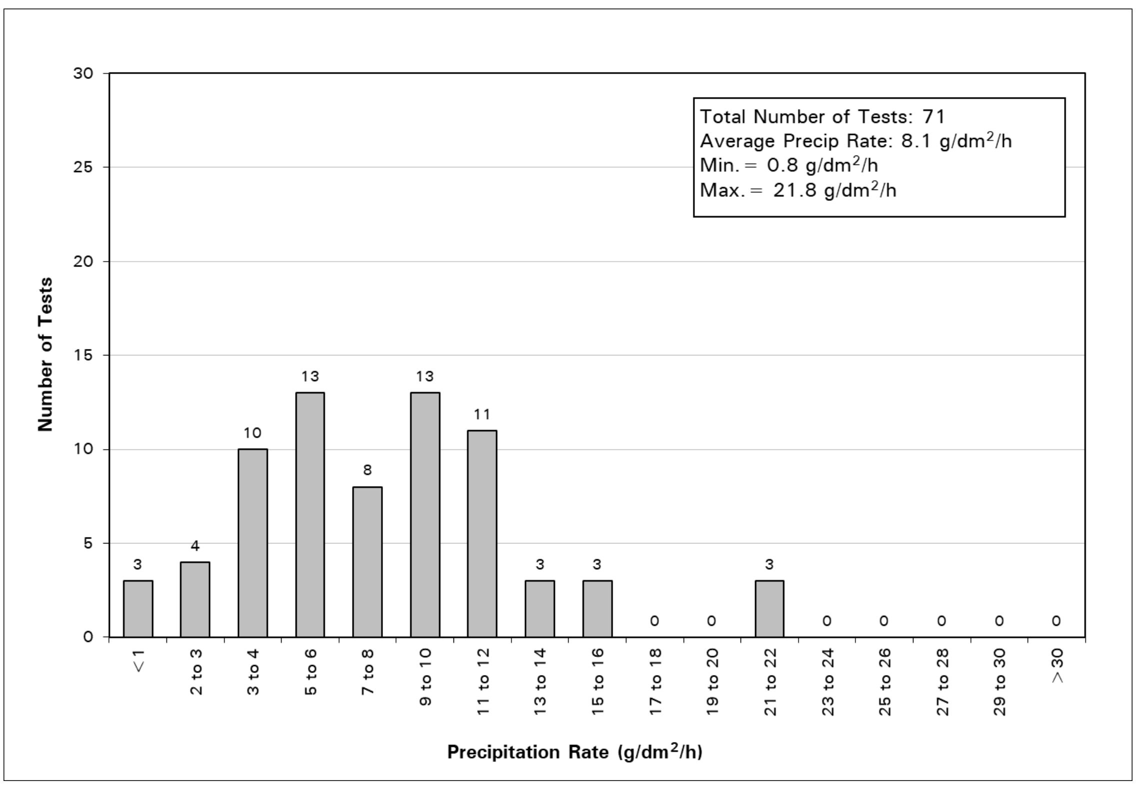

Figure 3.1: Distribution of 2009-10 Snow Tests by Precipitation Rate

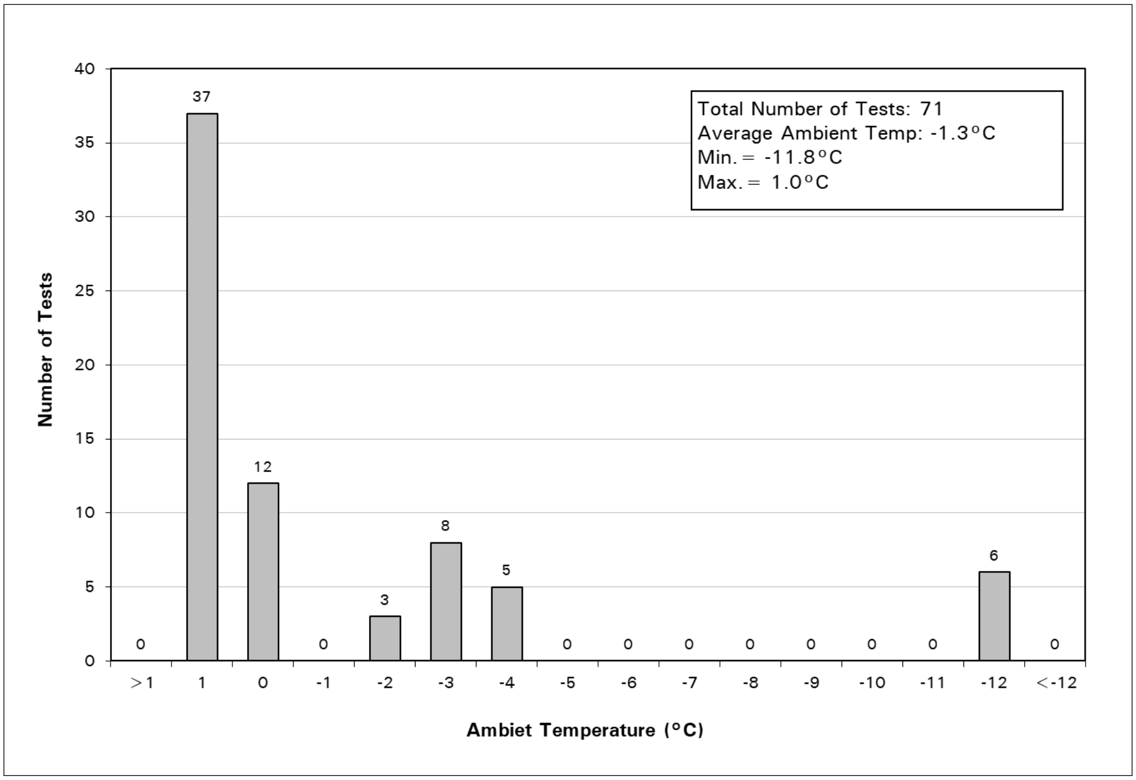

Figure 3.2: Distribution of 2009-10 Snow Tests by Ambient Temperature

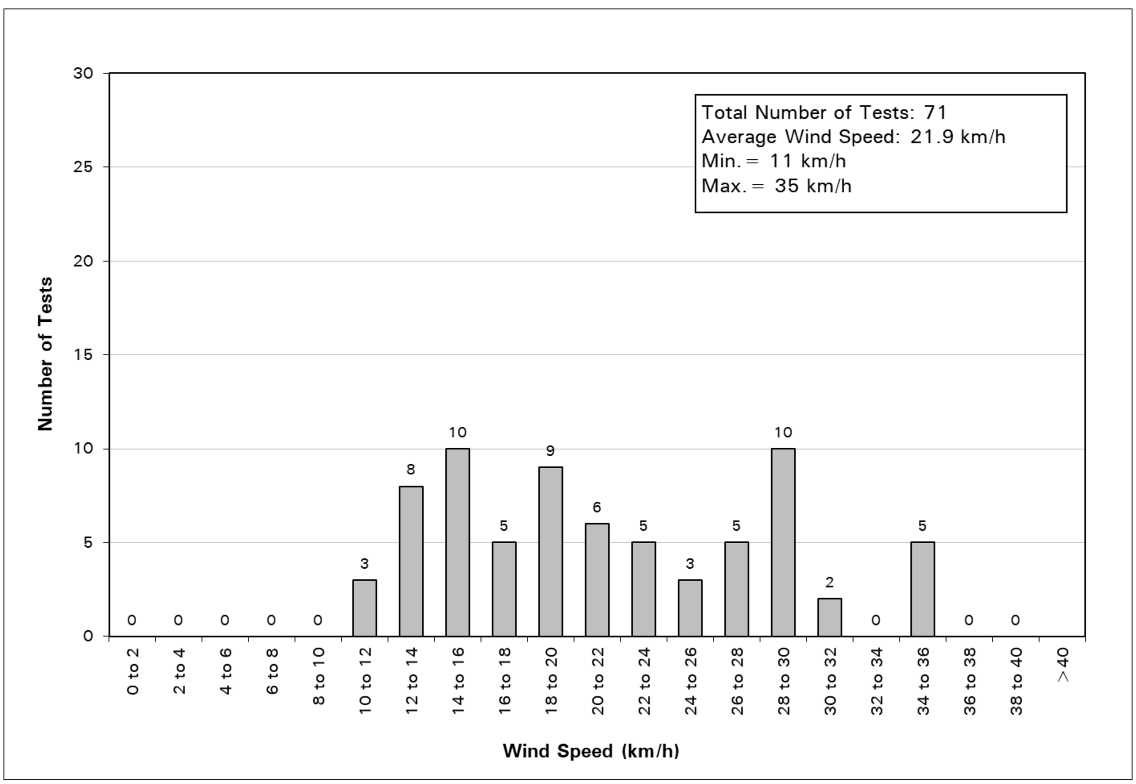

Figure 3.3: Distribution of 2009-10 Snow Tests by Wind Speed

3.4 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 throughout the test. The temperature data has been archived and is available; however, it has not been included in this report.

3.5 Artificial Snow

One comparative test run was conducted in artificial snow. This test was conducted for reference and was not included in the analysis to determine appropriate holdover times for composite surfaces. The test run included one composite test and one aluminum test. Both tests were conducted at an ambient temperature of -14°C and under a precipitation rate of 4 g/dm^2/h. The results are show in Table 3.5.

The results of the artificial snow test are similar to those seen in other Type I tests: the endurance time of the Type I fluid was shorter on the composite surface than on the aluminum surface.

Table 3.5: Log of Tests – Artificial Snow

Date	Run #	Test #	Fluid	Fluid Temp.	Test Surface	Ambient Temp. (°C)	Precip. Rate (g/dm^2/h)	Endurance Time (min)
29-Apr-10	1	1	Kilfrost DF^{sustain}	20°C	Aluminum	-14	4.0	8.2
29-Apr-10	1	2	Kilfrost DF^{sustain}	20°C	Composite	-14	4.0	7.2

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4. DETERMINATION OF HOTS: SNOW

This section describes the analysis methodology used to determine holdover times for Type I fluids on composite surfaces in snow, the data included in the analysis, and the results of the analysis.

4.1 Analysis Methodology

The holdover times that are published for Type I fluids on *aluminum* surfaces in snow conditions were determined using regression analysis. Specifically, regression analysis was performed on an endurance time data set that was collected in natural snow conditions in the winter of 2001-02. Testing was conducted that winter due to a new test protocol having been established for evaluating endurance times of Type I fluids in natural snow. APS and the Anti-Icing Materials International Laboratory (AMIL) collected data with six representative fluids under varying air temperatures, wind speeds, and precipitation rates.

The APS/AMIL data set was subjected to a multi-variable regression analysis which produces a formula in which holdover time is predicted by temperature and precipitation rate. Holdover times were determined by entering the temperature and precipitation rate limits associated with the Type I holdover time table into the regression equation.

1. Temperature: Holdover times were calculated for the lowest temperature associated with each temperature band, i.e., -3°C, -6°C, -10°C and -25°C.

2. Precipitation Rate: Holdover times were calculated for the lower and upper precipitation rate associated with each snowfall intensity column, i.e., 3, 4, 10 and 25 g/dm^2/h. The snowfall intensities limits used in the Transport Canada and FAA holdover time tables are:

    - Very Light Snow: 3 (FAA only) and 4 g/dm^2/h;
    - Light Snow: 4 and 10 g/dm^2/h; and
    - Moderate Snow: 10 and 25 g/dm^2/h.

This testing is documented in the Transport Canada report, TP 13994E, *Generation of Holdover Times Using the New Type I Fluid Test Protocol* (5).

The same methodology – multi-variable regression analysis – was used to determine holdover times for Type I fluids on *composite* surfaces. The analysis was completed using the data described in the next subsection.

4.2 Data Included in Determination of Type I HOTs in Snow

Testing was conducted with Type I fluids applied to composite surfaces over several winters. However, only data from three of these winters was collected using the standard test protocol: 2006-07, 2007-08, and 2009-10. The collection and processing of the 2009-10 data is described in Sections 2 and 3 in this document (Volume 1). The 2006-07 and 2007-08 data is described in Section 5 in Volume 2.

A total of 100 data points were collected with Type I fluids on composite surfaces in the three winters. The majority of data was collected in the winter of 2009-10:

- 2006-07: 16 data points;
- 2007-08: 13 data points; and
- 2009-10: 71 data points.

The 100 data points were collected using fluids heated to 60°C and applied to white-painted LETE boxes with composite (Comp 05) surfaces.

The complete data set is plotted in Figure 4.1, which shows the rate of precipitation and the failure time for each of the 100 tests. The data points are colour-coded by air temperature to illustrate the results obtained in each of the four temperature bands in the Type I holdover time table.

The data set includes data collected over a wide range of precipitation rates and air temperatures. As shown in Figure 4.2 and Figure 4.3, precipitation rates ranged from 0.8 to 120 $g/dm^2/h$ and air temperatures ranged from -13°C to +2°C.

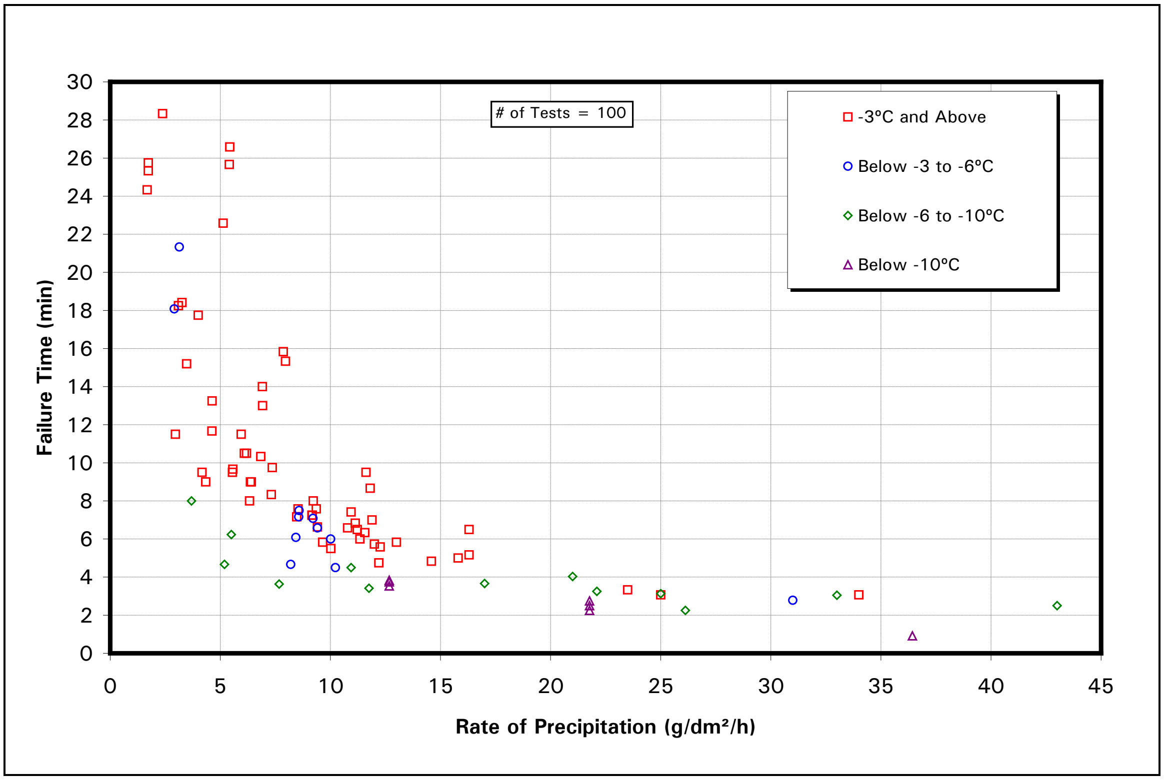

Figure 4.1: Data Included in Determination of Composite Snow HOTs

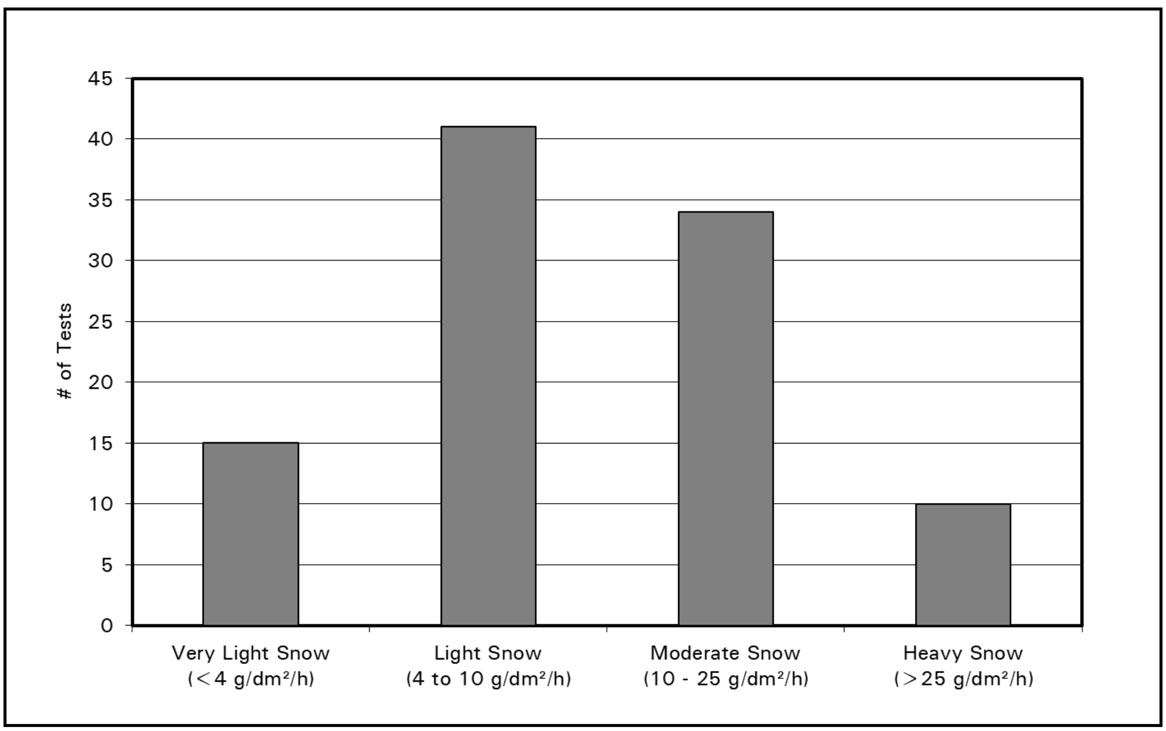

Figure 4.2: Distribution of Snow Data Set by Snow Type

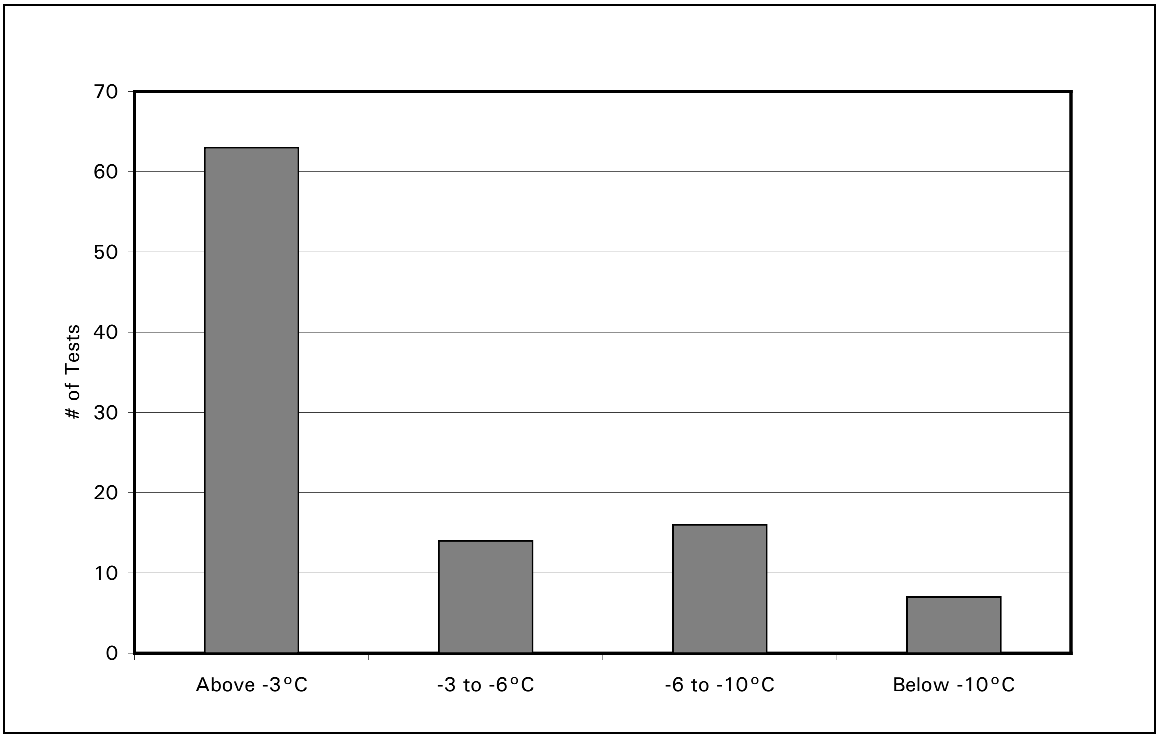

Figure 4.3: Distribution of Snow Data Set by Air Temperature

4.3 Application of Analysis Methodology (Raw HOTs)

As described in Subsection 4.1, the composite snow data set was subjected to multi-variable regression analysis to determine holdover times for composite surfaces for each cell of the Type I holdover time table.

The standard form of the regression equation for determining holdover times in snow is: $\mathbf{t = 10^I R^A (2\text{-}T)^B}$. The variables are:

- t = holdover time (minutes)
- R = rate of precipitation ($g/dm^2/h$)
- T = air temperature (°C)
- I, A, B = coefficients determined from the regression

Completion of the regression analysis resulted in the following coefficients and statistics:

- Intercept (I) = 1.6656
- Rate Coefficient (A) = -0.7424
- Temperature Coefficient (B) = -0.2094
- Coefficient of Determination (r^2) = 88 percent

Therefore, the equation for determining holdover times for composite surfaces in snow was derived to be: $\mathbf{t = 10^{(1.6656)}\, R^{(-0.7424)}\, (2\text{-}T)^{(-0.2094)}}$.

Regression values were calculated for each cell of the Type I holdover time table using this equation and the precipitation rate boundaries and minimum temperatures described in Subsection 4.1, resulting in the raw holdover times provided in Table 4.1.

Table 4.1: Raw Type I Composite Holdover Times in Snow

Outside Air Temperature		Holdover Times (minutes)		
°C	**°F**	**Very Light Snow**	**Light Snow**	**Moderate Snow**
-3 and above	27 and above	**11.8 – 14.6***	**6.0 – 11.8**	**3.0 – 6.0**
below -3 to -6	below 27 to 21	**10.7 – 13.3***	**5.4 – 10.7**	**2.7 – 5.4**
below -6 to -10	below 21 to 14	**9.8 – 12.2***	**5.0 – 9.8**	**2.5 – 5.0**
below -10	below 14	**8.3 – 10.3***	**4.2 – 8.3**	**2.1 – 4.2**

* Upper number applicable to FAA only

The results of the regression analysis are also shown graphically in Figure 4.4. In the figure, regression curves have been drawn for each of the four temperatures for which holdover times are calculated (-3°C, -6°C, -10°C, and -25°C). The precipitation rate boundaries used in the holdover time tables are indicated by thin vertical lines (at 3, 4, 10, and 25 g/dm^2/h). The raw holdover times produced by the regression analysis are the failure times at each intersection of the regression curves and the precipitation rate boundary lines.

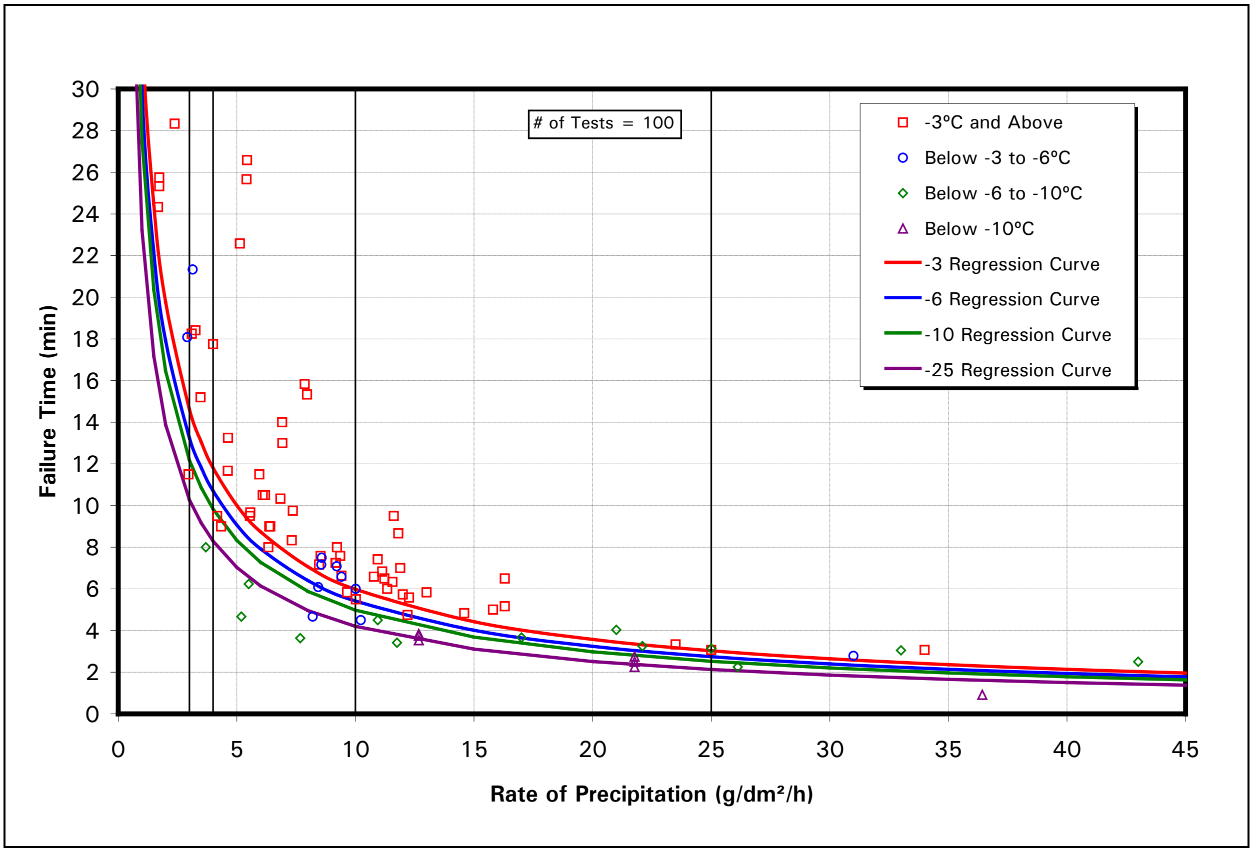

Figure 4.4: Regression Curves

4.4 Application of Rounding Rules (Final HOTs)

Rounding was applied to the raw holdover times. The rounding methodology employed was as follows:

- Raw holdover times above 10 minutes were rounded to the nearest whole number; and
- Raw holdover times below 10 minutes were rounded down to the nearest whole number.

As a final check, the rounded numbers were compared to the currently published (aluminum) holdover times. If the composite holdover time was greater than the current (aluminum) holdover time, the composite holdover time was reduced to the value of the aluminum holdover time.

This analysis resulted in the final holdover times for Type I fluids on composite surfaces in snow, as shown in Table 4.2.

Table 4.2: Final Type I Composite Holdover Times in Snow

Outside Air Temperature		Holdover Times (minutes)		
°C	°F	Very Light Snow	Light Snow	Moderate Snow
-3 and above	27 and above	**12 – 15***	**6 – 12**	**3 – 6**
below -3 to -6	below 27 to 21	**11 – 13***	**5 – 11**	**2 – 5**
below -6 to -10	below 21 to 14	**9 – 12***	**5 – 9**	**2 – 5**
below -10	below 14	**7 – 8***	**4 – 7**	**2 – 4**

* Upper number applicable to FAA only

4.5 Validation of Data – Comparison of Aluminum Data to Historical Aluminum Data

As described in Section 2, tests were conducted concurrently on aluminum surfaces during select composite tests in natural snow. In the three years of testing included in the composite data set, 54 comparative aluminum tests were conducted using the standard endurance time testing protocol. The aluminum data set was examined as a check on the validity of the data set.

Regression analysis was run on the aluminum data set. The results were compared to the existing published holdover times for aluminum surfaces. It was expected that the regression results would produce holdover times similar to the published holdover times.

The results are shown in Figure 4.5. The regression curves generated from the aluminum data set cross the precipitation boundary lines at or very near to the current holdover times. This validates the reproducibility of the aluminum holdover times using the data set collected in the three winters and indicates that the composite data set will generate reproducible results based on the number of tests conducted and the weather conditions under which testing took place.

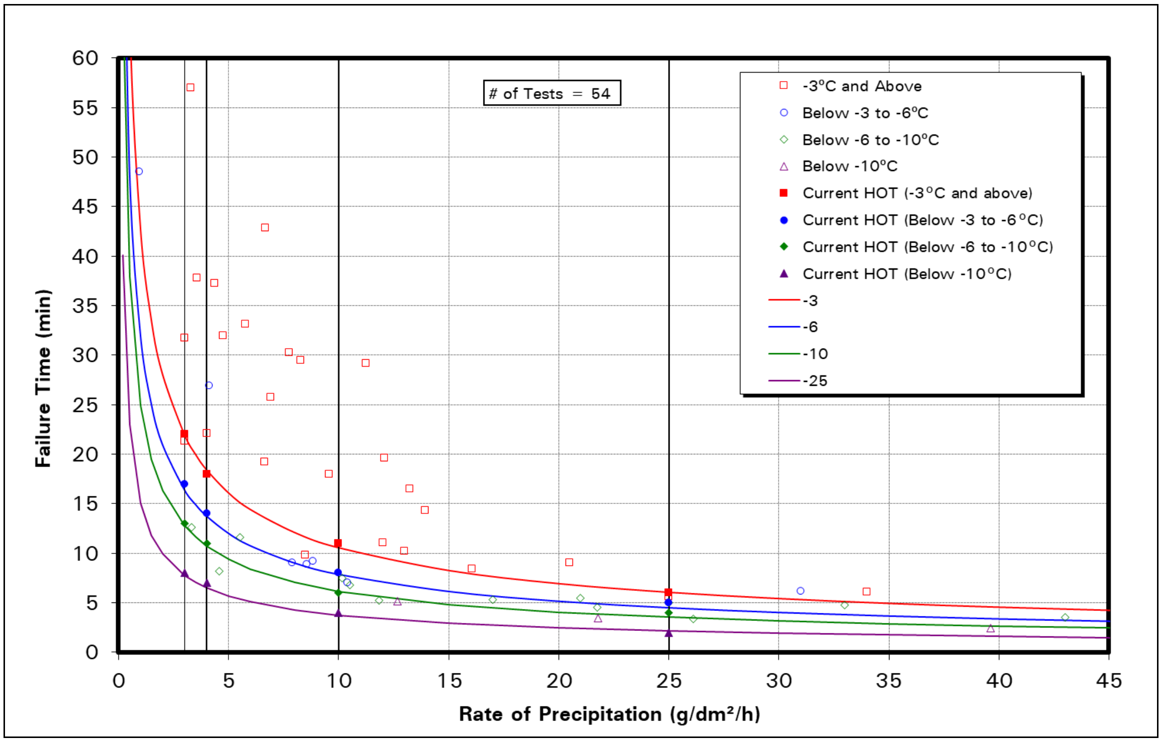

Figure 4.5: Aluminum Data Collected in 2006-07, 2007-08, 2009-10

4.6 Summary

Multi-variable regression analysis was used to derive appropriate holdover times for Type I fluids on composite surfaces in snow. The regression-derived values were rounded and compared to the existing aluminum holdover times before being finalized. These values were adopted by both Transport Canada and the FAA.

5. DETERMINATION OF HOTS: FREEZING PRECIPITATION

This section describes the analysis methodology used to determine holdover times for Type I fluids on composite surfaces in freezing precipitation, the data included in the analysis, and the results of the analysis.

5.1 Analysis Methodology

The holdover times published for Type I fluids on *aluminum* surfaces in freezing precipitation were selected by the SAE G-12 Holdover Time Committee based on the results of endurance time testing. The holdover times evolved over time as further data became available and test protocols were refined (refer to Appendix B for more information). A specific analysis methodology was not used to derive the holdover times from the data. Instead, visual examination of the plotted data resulted in holdover times that were agreed upon by the consensus of the SAE G-12 committee. The values selected were typically the lowest endurance times measured in each condition.

A more structured, analytical approach was taken to determine holdover times for Type I fluids on *composite* surfaces. The approach is based on regression analysis and is more objective, robust, and repeatable than the approach taken for aluminum holdover times and therefore allows for clearer documentation. The analysis methodology uses a weighted average of three statistics calculated from the regression analysis. The analysis included the following steps.

1. The data (see next subsection) was divided into surface and fluid-specific data sets. This resulted in five fluid-specific composite data sets and one fluid-specific aluminum data set.

2. Each data set was subjected to regression analysis. The regression results were then used to calculate a complete set of fluid-specific Type I endurance times for each data set (one endurance time per data set for each position in the Type I holdover time table).

3. Three statistics were calculated for each "position" in the Type I holdover time table. (Note: With the exception of the Transport Canada very light snow column, there are two "positions" in each cell of the Type I holdover time table: a lower and upper value.) The statistics and the reasons for including them in the analysis are listed below.

   i. **Minimum Composite Endurance Time**: Included because methodology for determining aluminum holdover times was based predominantly on the selection of minimum values.

ii. **Lower 1 σ of Composite Endurance Times**: Included to account for variability in the data. It should be noted that 84 percent of endurance times are above this value (lower 1 σ).

iii. **Aluminum-Composite Ratio Applied to Current Holdover Time**: Included to ensure the measured aluminum–composite endurance time difference is respected.

4. A weighted average was used to calculate raw holdover times from the three statistics.

5. The raw holdover times were subjected to rounding.

The analysis was completed using the data described in Subsection 5.2. The analysis is described in detail in Subsection 5.3.

5.2 Data Included in Determination of Type I HOTs in Freezing Precipitation

The data used to determine holdover times for composite surfaces in freezing precipitation was collected in the winter of 2009-10. The collection and processing of the 2009-10 data is described in Sections 2 and 3.

All data was collected using the same test protocol: fluids were heated to 20°C and then applied to either white-painted composite flat plates (in freezing drizzle, light freezing rain, and freezing fog) or white-painted composite LETE boxes (in rain on cold-soaked surface).

Testing was conducted with five representative fluids on composite surfaces and with one of the representative fluids on an aluminum surface. The number of tests conducted by precipitation type, test surface material, and ambient temperature is provided in Table 5.1.

Figures 5.1 to 5.10 show the data plotted on failure time versus rate of precipitation charts. There is one chart for each unique combination of precipitation type and ambient temperature. The fluids are coded in the charts as follows:

- Fluid A: Kilfrost DF^{sustain}
- Fluid B: Clariant Safewing 1938
- Fluid C: Dow UCAR ADF
- Fluid D: Dow UCAR PG ADF
- Fluid E: Octagon Octaflo

Table 5.1: Freezing Precipitation Data Points

Precip. Type	Test Surface	Ambient Temperature					
		+1°C	-3°C	-6°C	-10°C	-25°C	ALL
Freezing Fog	Composite	n/a	20	20	21	20	81
	Aluminum	n/a	4	4	4	4	16
Freezing Drizzle	Composite	n/a	20	20	20	n/a	60
	Aluminum	n/a	4	4	4	n/a	12
Light Freezing Rain	Composite	n/a	*	20	20	n/a	40
	Aluminum	n/a	*	4	4	n/a	8
Rain on Cold-Soaked Surface	Composite	20	n/a	n/a	n/a	n/a	20
	Aluminum	3	n/a	n/a	n/a	n/a	3

* *Type I fluids are not tested in freezing rain at -3°C because the latent heat of freezing in calm test conditions produces artificially long endurance times.*

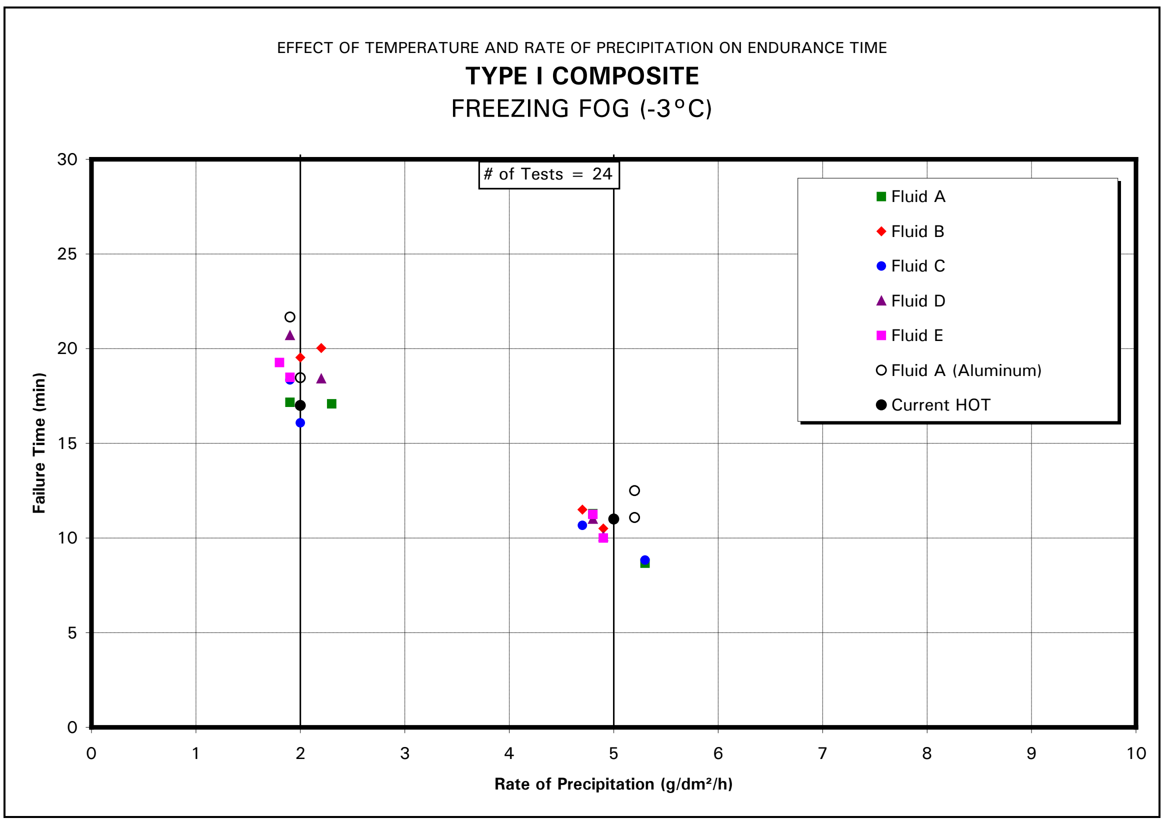

Figure 5.1: Freezing Fog, -3°C

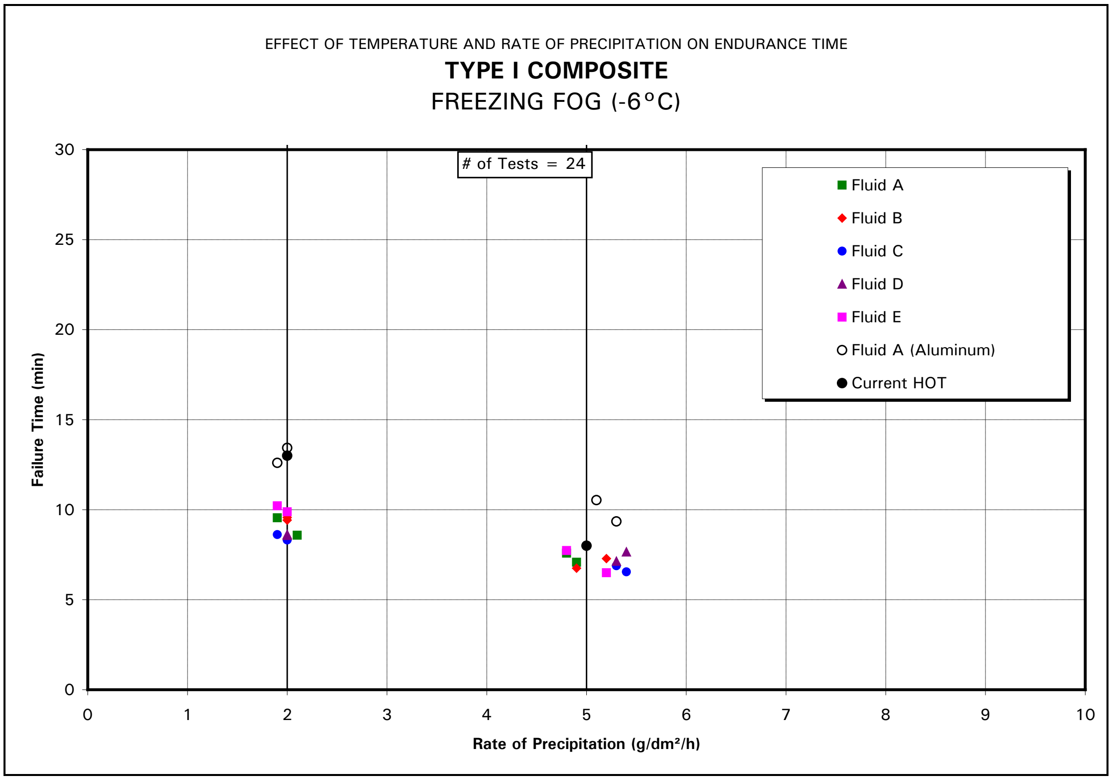

Figure 5.2: Freezing Fog, -6°C

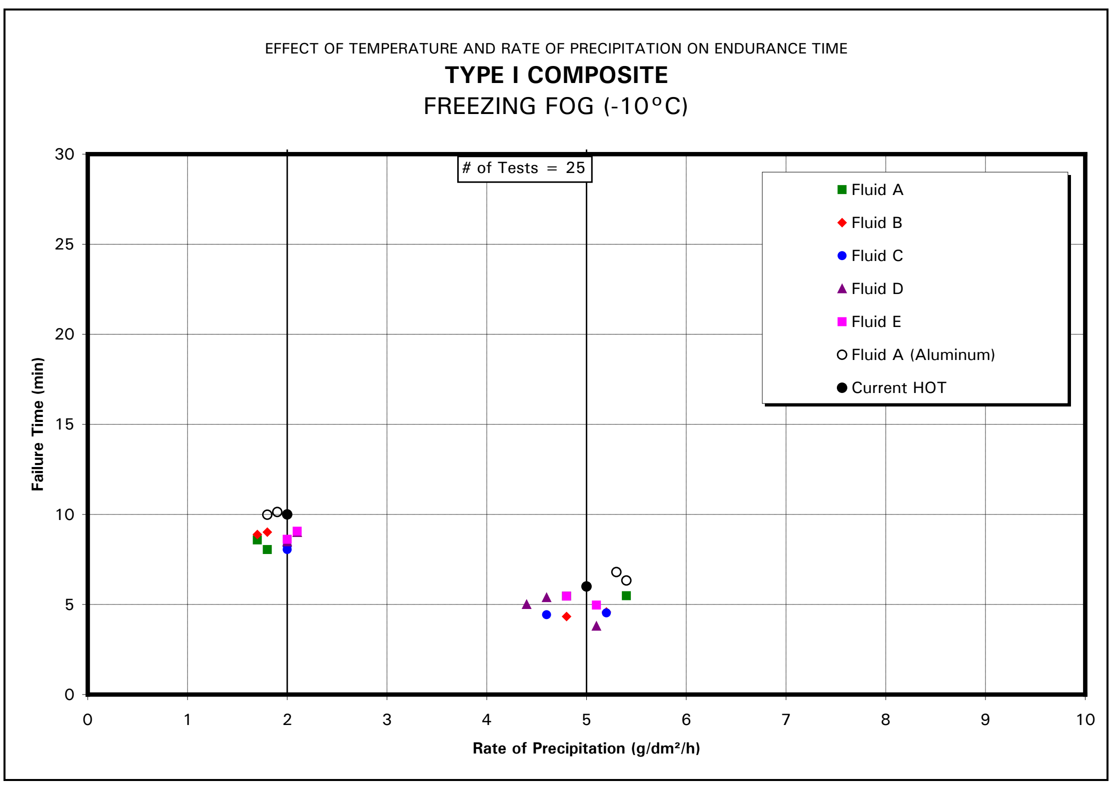

Figure 5.3: Freezing Fog, -10°C

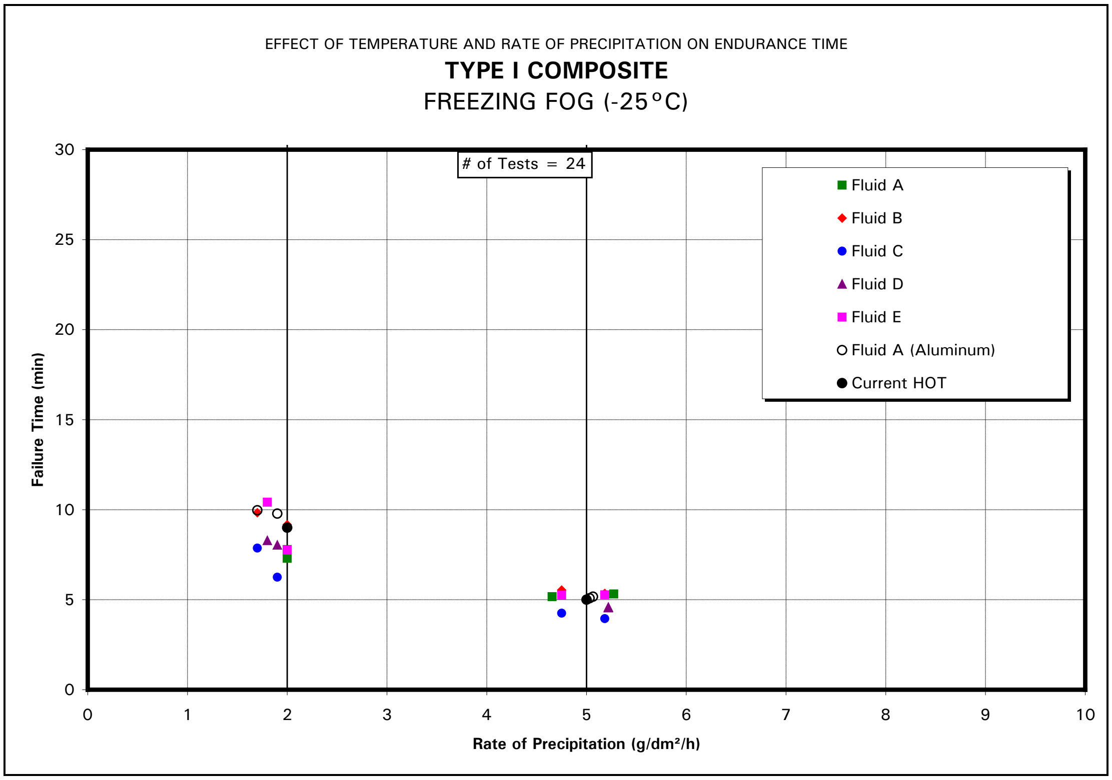

Figure 5.4: Freezing Fog, -25°C

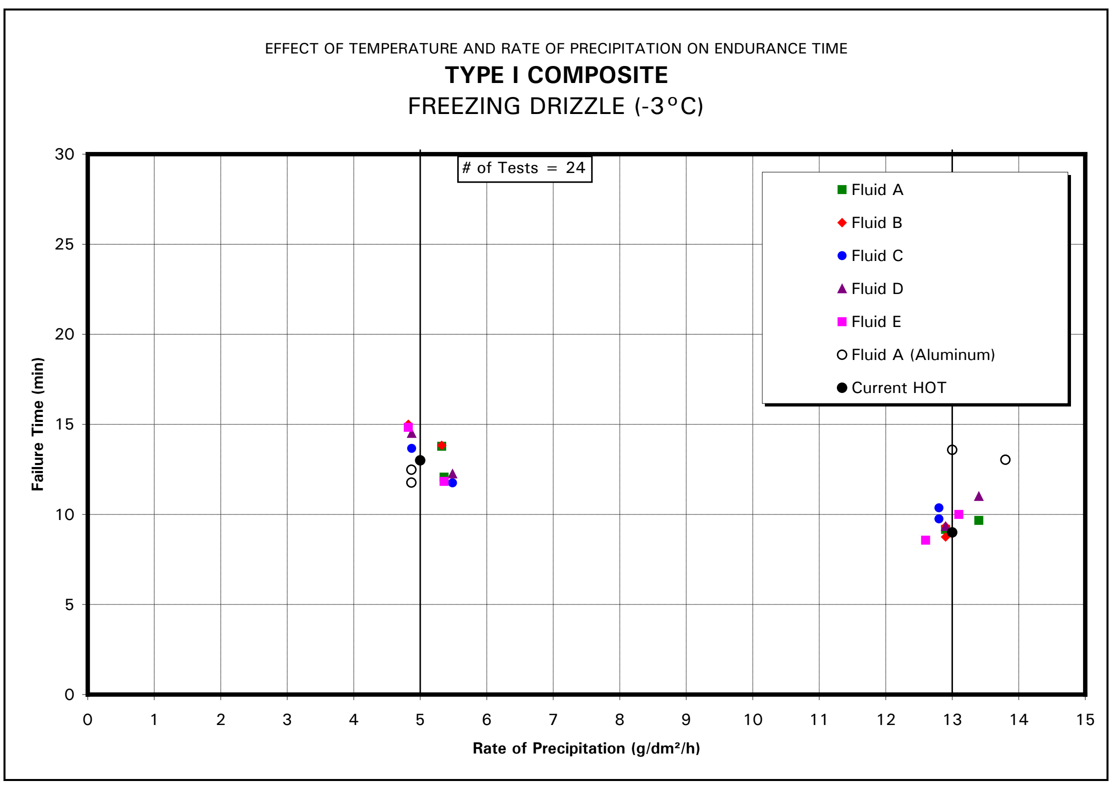

Figure 5.5: Freezing Drizzle, -3°C

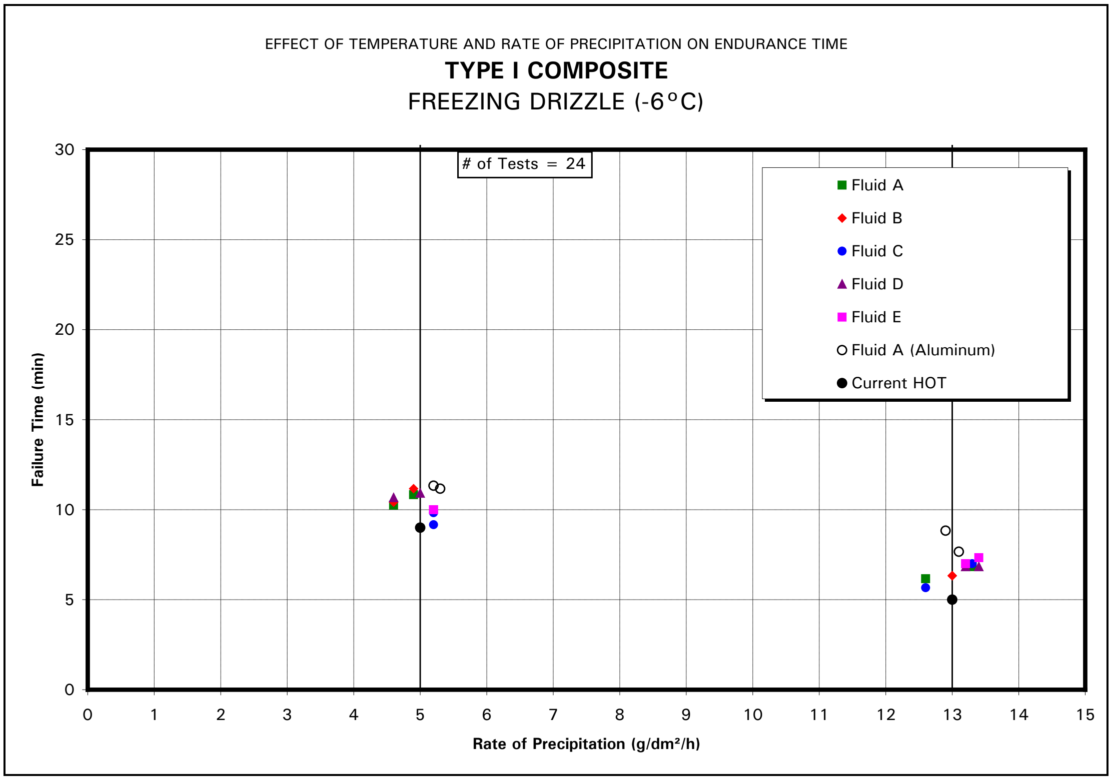

Figure 5.6: Freezing Drizzle, -6°C

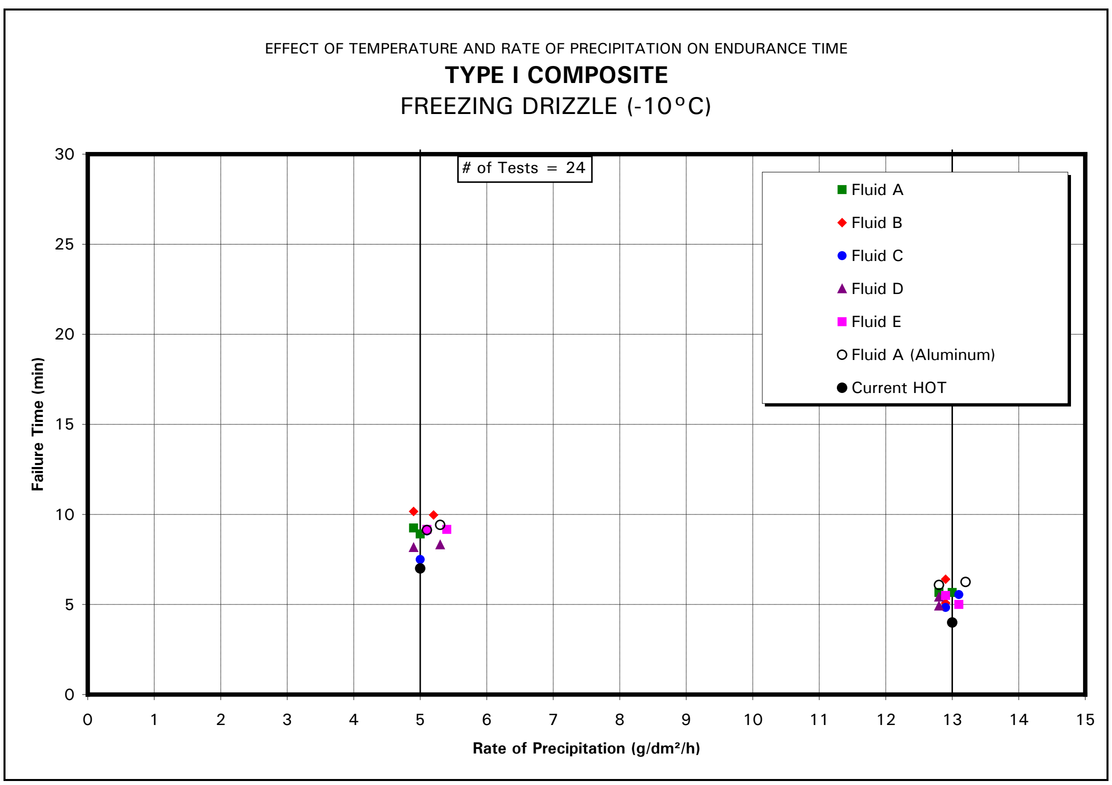

Figure 5.7: Freezing Drizzle, -10°C

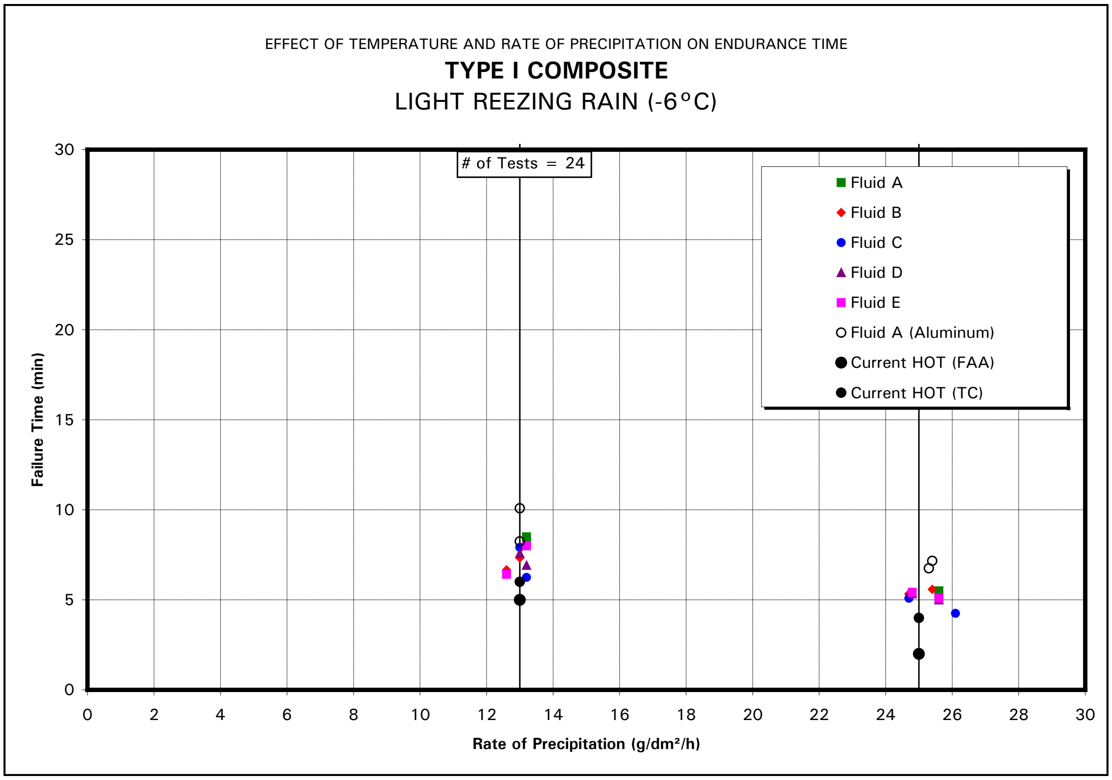

Figure 5.8: Light Freezing Rain, -6°C

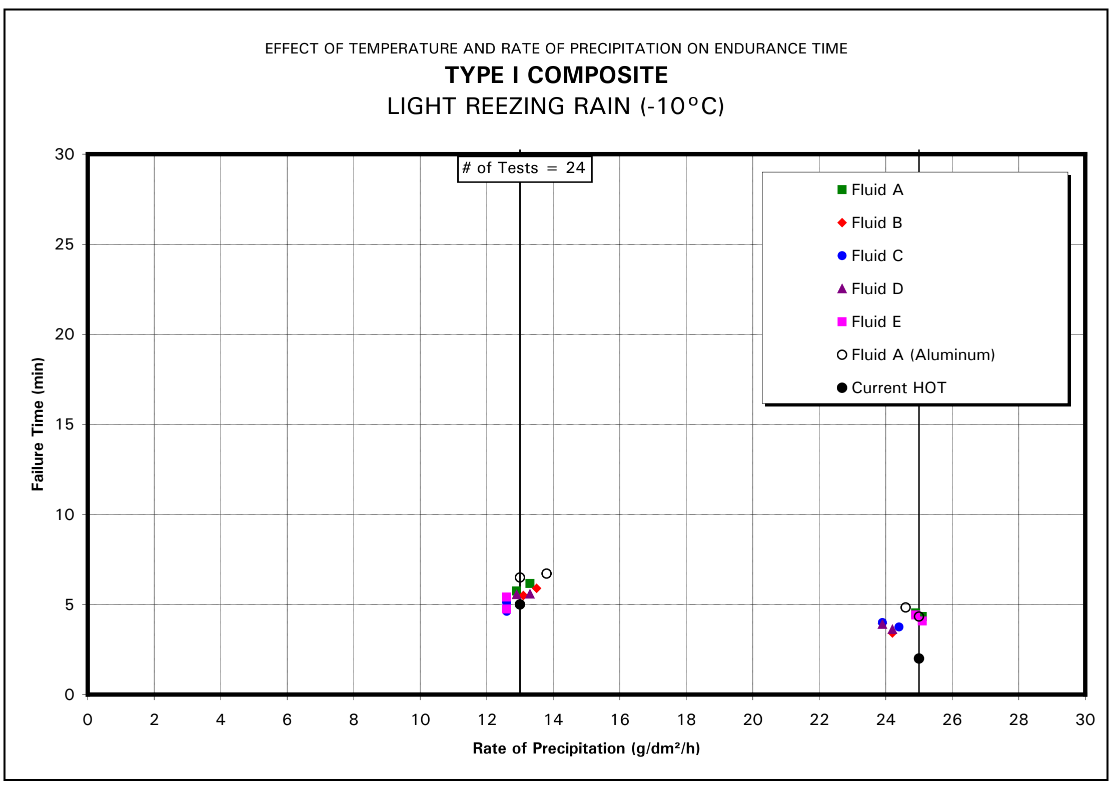

Figure 5.9: Light Freezing Rain, -10°C

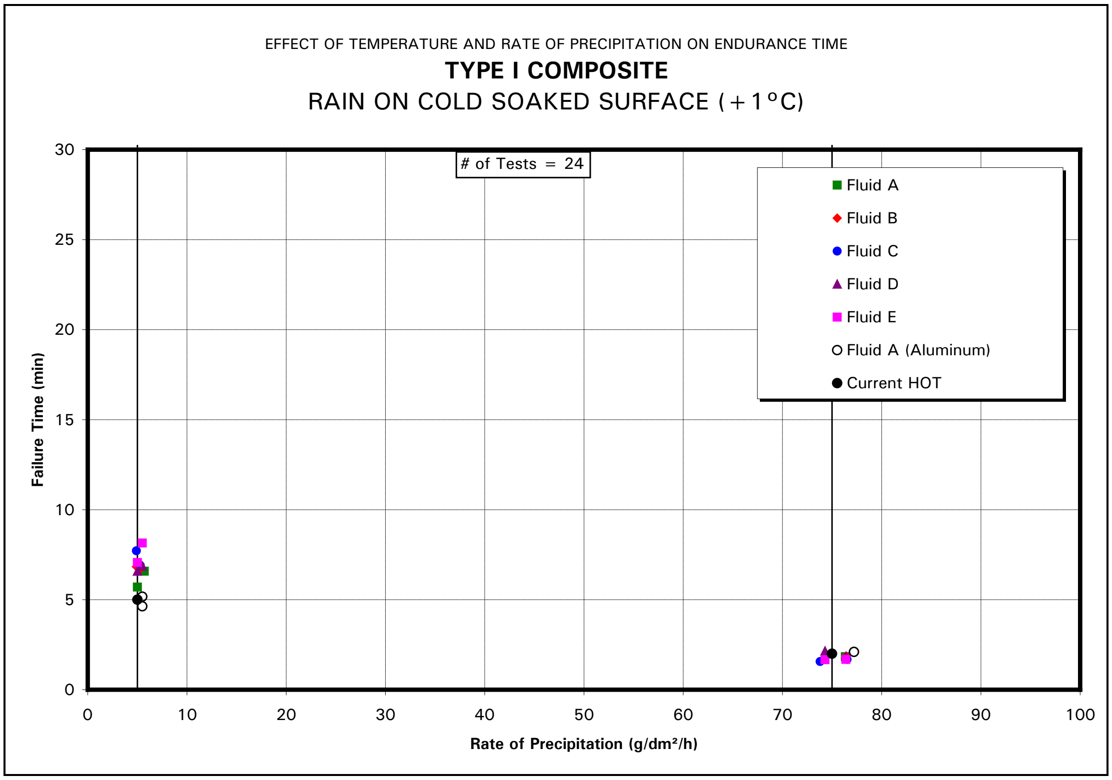

Figure 5.10: Rain on Cold-Soaked Surface, +1°C

5.3 Application of Analysis Methodology (Raw HOTs)

As described in Subsection 5.1, the first step in the analysis methodology was to separate the data by fluid and surface material. The results are provided in Figures 5.1 through 5.10.

The second step in the analysis methodology was to subject each of the data sets to regression analysis and then to calculate endurance times for each data set for each position in the Type I holdover time table. The results are shown in the first six rows in Table 5.2.

The third step in the analysis methodology was to calculate three statistics for each position in the Type I holdover time table, as described below. The calculated statistics are shown in rows 7, 8, and 9 (yellow shaded rows) in Table 5.2.

1. **Minimum Composite Endurance Time**: For each table position, the five fluid-specific regression-derived endurance times were compared. The minimum endurance time was selected.

2. **Lower 1 σ of Composite Endurance Times**: For each table position, the average and standard deviation of the five fluid-specific regression-derived

composite endurance times were calculated. The lower 1 σ was calculated from the average and standard deviation.

3. **Aluminum-Composite Ratio Applied to Current Holdover Time**: For each table position, the percent difference between the regression-derived endurance time for reference fluid 1 on composite and the same fluid on aluminum was calculated. This difference was then applied to the current aluminum holdover time.

Finally, the fourth step in the analysis methodology was to use a weighted average to determine a raw holdover time from the three statistics. The statistics were weighted as follows:

- Minimum Composite Endurance Time: 60 percent
- Lower 1 σ of Composite Endurance Times: 25 percent
- Aluminum-Composite Ratio Applied to Current Holdover Time: 15 percent

The raw holdover times derived from the weighted average calculation are shown in row 10 in Table 5.2.

5.4 Application of Rounding Rules (Final HOTs)

Rounding was applied to the raw holdover times. The rounding methodology employed was as follows:

- Raw holdover times with decimal place ≥.75 were rounded up to the nearest whole number (i.e., 12.8 rounded to 13); and
- Raw holdover times with decimal place <.75 were rounded down to the nearest whole number (i.e., 12.7 rounded to 12).

The rounded weighted average holdover times are shown in row 11 of Table 5.2.

As a final check, the rounded numbers were compared to the currently published (aluminum) holdover times. If the composite holdover time was greater than the current (aluminum) holdover time, the composite holdover time was reduced to the value of the aluminum holdover time. The current aluminum holdover times are shown in row 12 of Table 5.2. The final holdover times that resulted in this last step of the analysis are shown in the last row of Table 5.2 and also in Table 5.3.

The fluid and surface specific regression curves and the final holdover times for composite surfaces derived from the analysis have been added to the charts previously presented as Figures 5.1 to 5.10. The updated charts are included as Figures 5.11 to 5.20.

Table 5.2: Calculations for Deriving Freezing Precipitation Composite Holdover Times

	ZF, -3		ZF, -6		ZF, -10		ZF, -25		ZD, -3		ZD, -6		ZD, -10		ZR, -3		ZR, -6		ZR, -10		CS, +1	
Regression Determined ETs	Lower Limit	Upper Limit	Lower Limit	Upper Limit	Lower Limit	Upper Limit	Lower Limit	Upper Limit	Lower Limit	Upper Limit	Lower Limit	Upper Limit	Lower Limit	Upper Limit	Lower Limit	Upper Limit	Lower Limit	Upper Limit	Lower Limit	Upper Limit	Lower Limit	Upper Limit
Composite: Clariant 1938	10.7	20.4	7.0	9.5	4.5	8.2	5.4	9.1	9.0	14.5	6.3	10.5	5.7	10.1			5.5	6.9	3.6	5.8	1.8	6.8
Composite: Dow UCAR EG	9.6	17.0	6.8	8.4	4.4	8.1	4.1	6.7	10.0	12.8	6.3	9.6	5.2	8.3			4.7	7.1	3.8	4.8	1.6	7.4
Composite: Dow UCAR PG	10.3	19.9	7.5	8.6	4.4	9.0	4.7	7.8	10.1	13.5	6.9	10.6	5.1	8.3			5.2	7.3	3.7	5.6	2.0	6.9
Composite: Kilfrost DF^{sustain}	9.9	17.6	7.3	9.1	5.5	7.9	5.2	7.5	9.5	13.2	6.5	10.2	5.6	9.0			5.4	8.5	4.4	6.0	1.8	6.3
Composite: Octagon Octaflo	10.4	18.0	7.1	10.0	5.2	9.0	5.2	8.8	9.2	13.4	7.2	10.1	5.2	9.4			5.3	7.1	4.2	5.0	1.7	7.8
Aluminum: Kilfrost DF^{sustain}	12.0	19.8	10.0	12.9	6.7	9.7	5.2	9.2	13.3	12.2	8.2	11.4	6.2	9.4			7.0	9.1	4.6	6.7	2.1	5.0
Min Composite ET	9.6	17.0	6.8	8.4	4.4	7.9	4.1	6.7	9.0	12.8	6.3	9.6	5.1	8.3			4.7	6.9	3.6	4.8	1.6	6.3
1 σ Composite ET	9.8	17.1	6.9	8.5	4.3	7.9	4.4	7.0	9.1	12.9	6.3	9.8	5.1	8.3	SEE ZR, -6		4.9	6.8	3.6	4.9	1.6	6.5
Comp-Alum Ratio Applied to Current HOT	9.1	15.1	5.8	9.1	4.9	8.1	5.1	7.3	6.4	14.1	4.0	8.1	3.7	6.7			3.1	5.6	1.9	4.4	1.7	6.2
Wgt Avg HOT: Raw*	9.6	16.7	6.7	8.5	4.5	7.9	4.3	6.8	8.6	13.0	5.9	9.4	4.9	8.0			4.5	6.7	3.3	4.8	1.6	6.3
Wgt Avg HOT: Rounded**	9	16	6	8	4	8	4	7	8	13	6	9	5	8			4	6	3	5	1	6
Current Aluminum HOT	11	17	8	13	6	10	5	9	9	13	5	9	4	7			4	6	2	5	2	5
Final Composite HOT***	9	16	6	8	4	8	4	7	8	13	5	9	4	7			4	6	2	5	1	5

* Weighted average of min composite ET (60%), 1σ composite ET (25%), and comp/alum Δ applied to current HOT (15%)

** Rounding rules: Decimal > 0.75 then round up to nearest whole number; if decimal < 0.75 then round down to nearest whole number

*** If calculated composite HOT is > current aluminum HOT, the composite HOT is reduced in this cell

Table 5.3: Final Type I Composite Holdover Times in Freezing Precipitation

Outside Air Temperature		Holdover Times (minutes)			
°C	°F	Freezing Fog	Freezing Drizzle	Light Freezing Rain	Rain on Cold-Soaked Wing
-3 and above	27 and above	9 – 16	8 – 13	4[a] – 6[a] 2[b] – 5[b]	1 – 5
below -3 to -6	below 27 to 21	6 – 8	5 – 9	4[a] – 6[a] 2[b] – 5[b]	n/a
below -6 to -10	below 21 to 14	4 – 8	4 – 7	2 – 5	n/a
below -10	below 14	4 – 7	n/a	n/a	n/a

[a] Applicable to FAA only
[b] Applicable to Transport Canada only

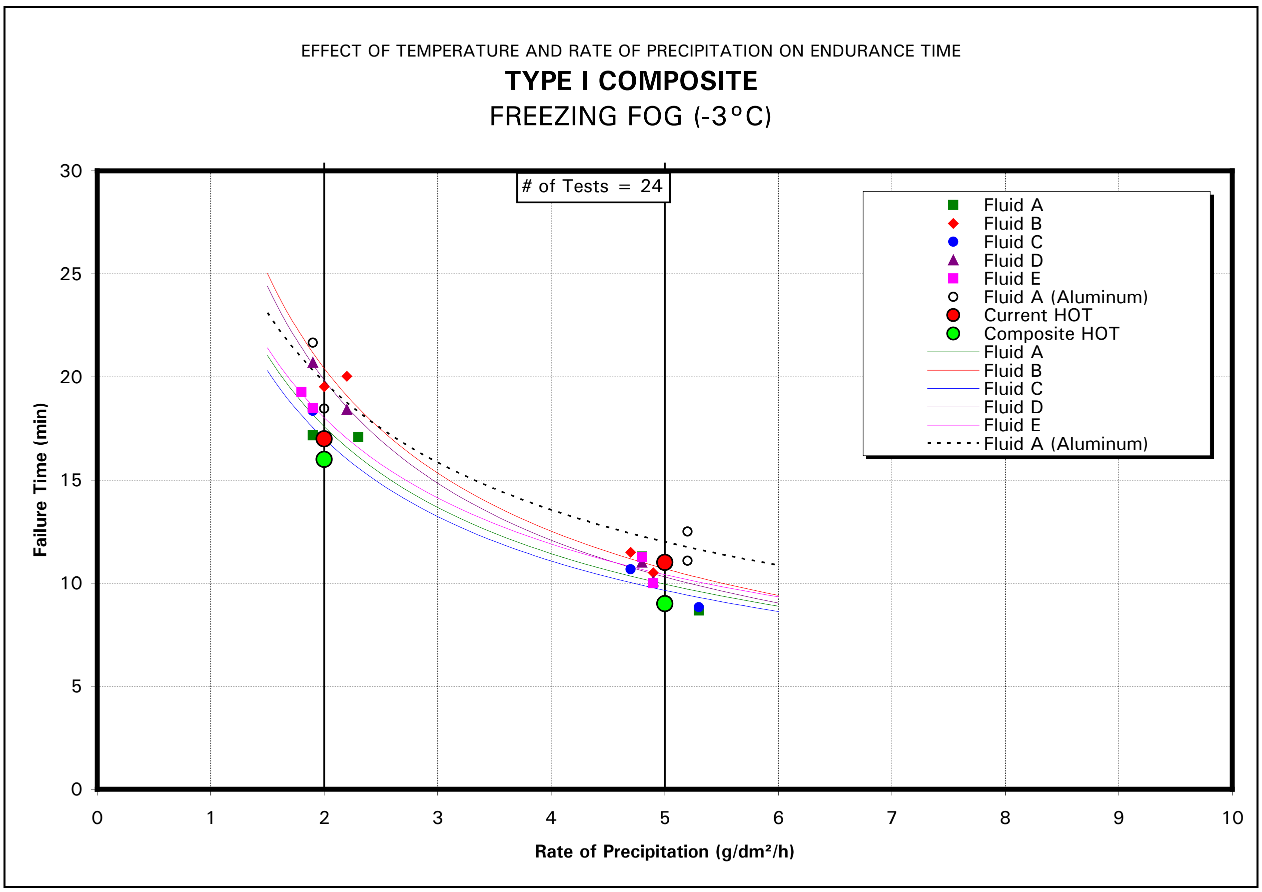

Figure 5.11: Freezing Fog, -3°C

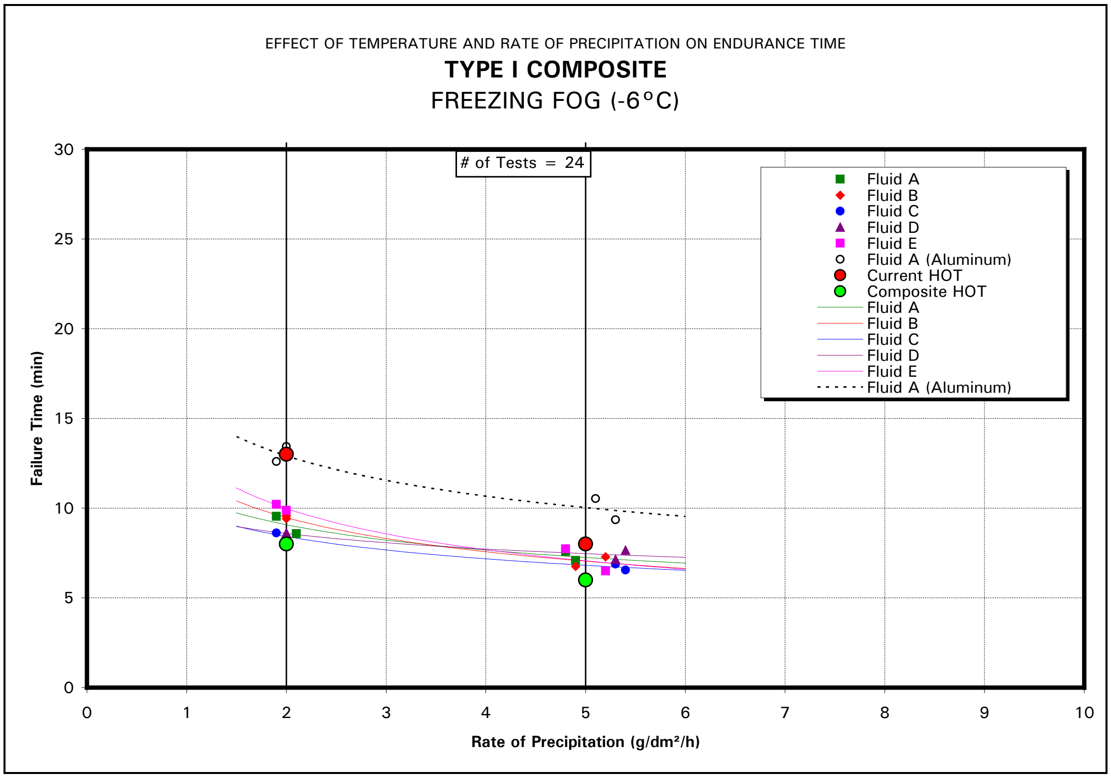

Figure 5.12: Freezing Fog, -6°C

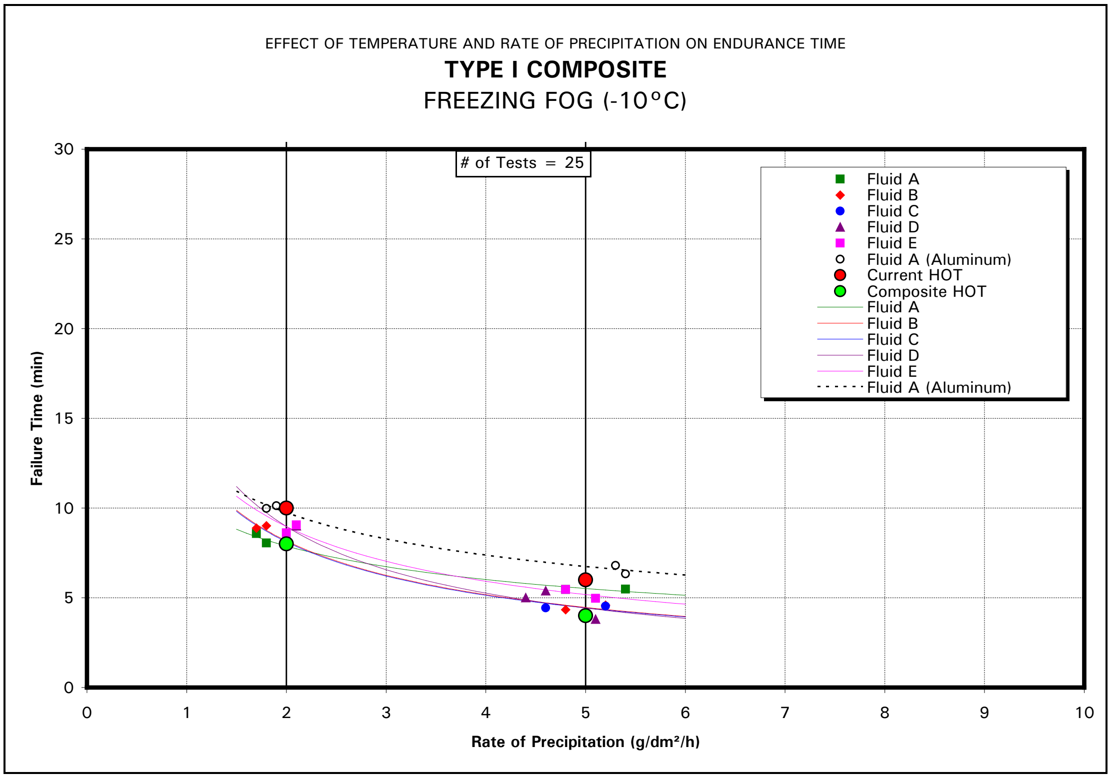

Figure 5.13: Freezing Fog, -10°C

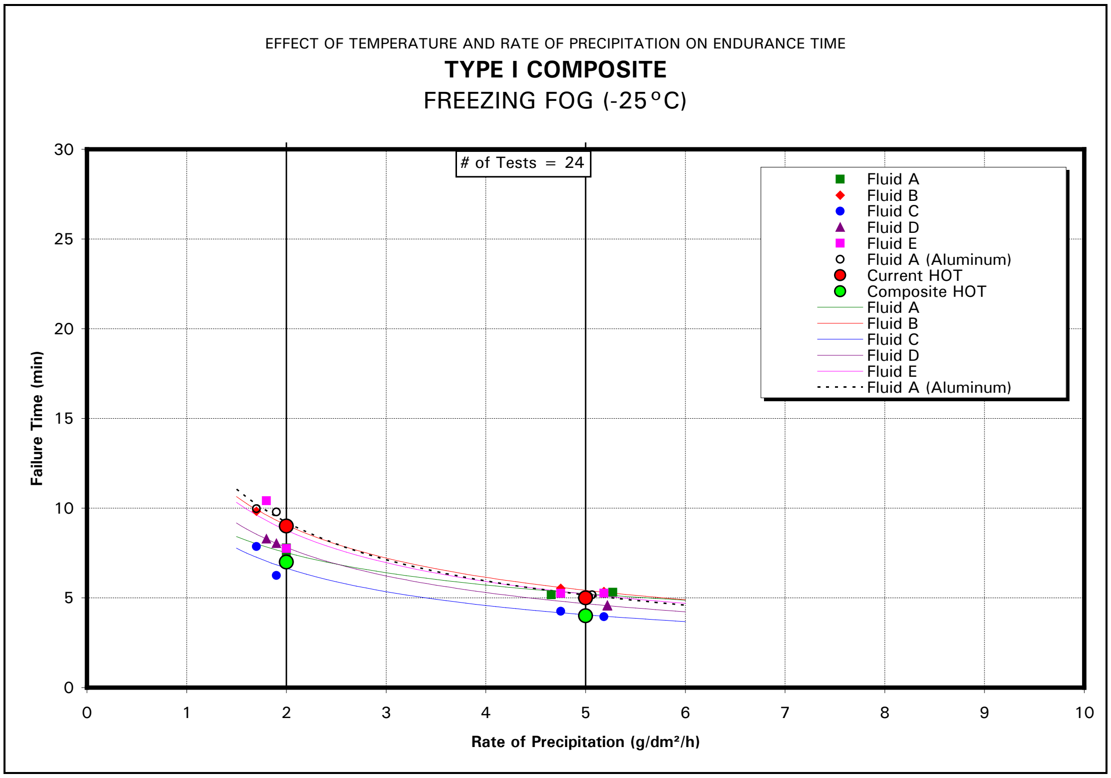

Figure 5.14: Freezing Fog, -25°C

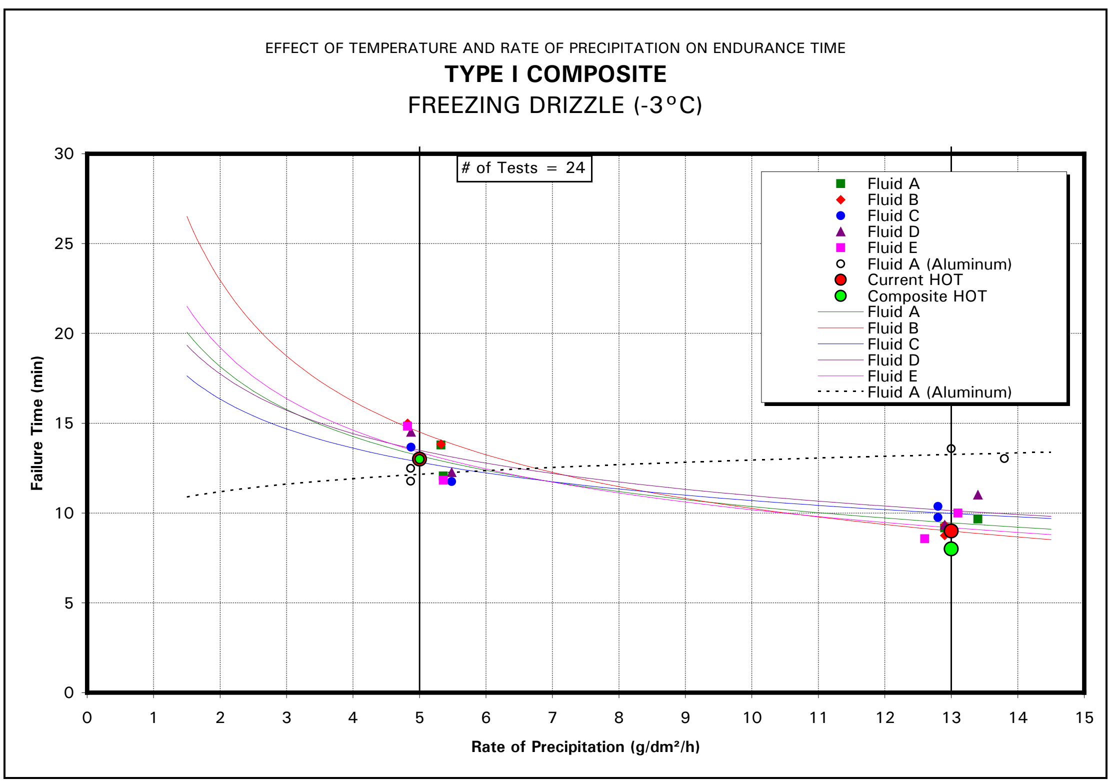

Figure 5.15: Freezing Drizzle, -3°C

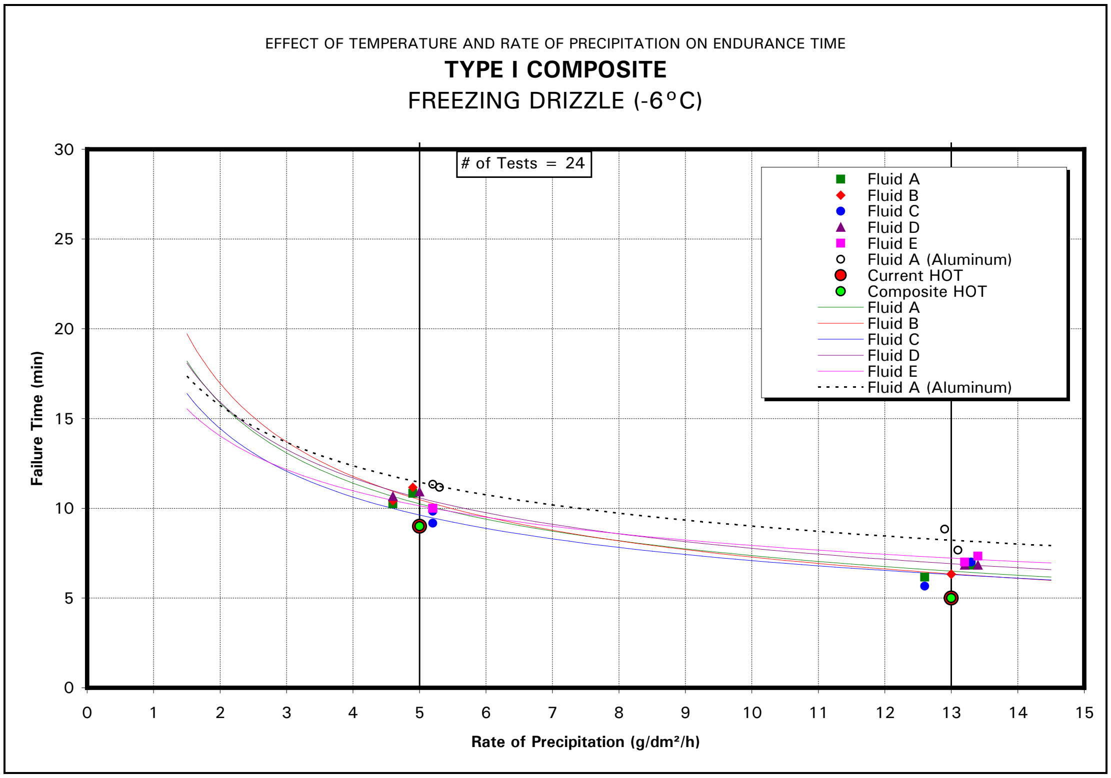

Figure 5.16: Freezing Drizzle, -6°C

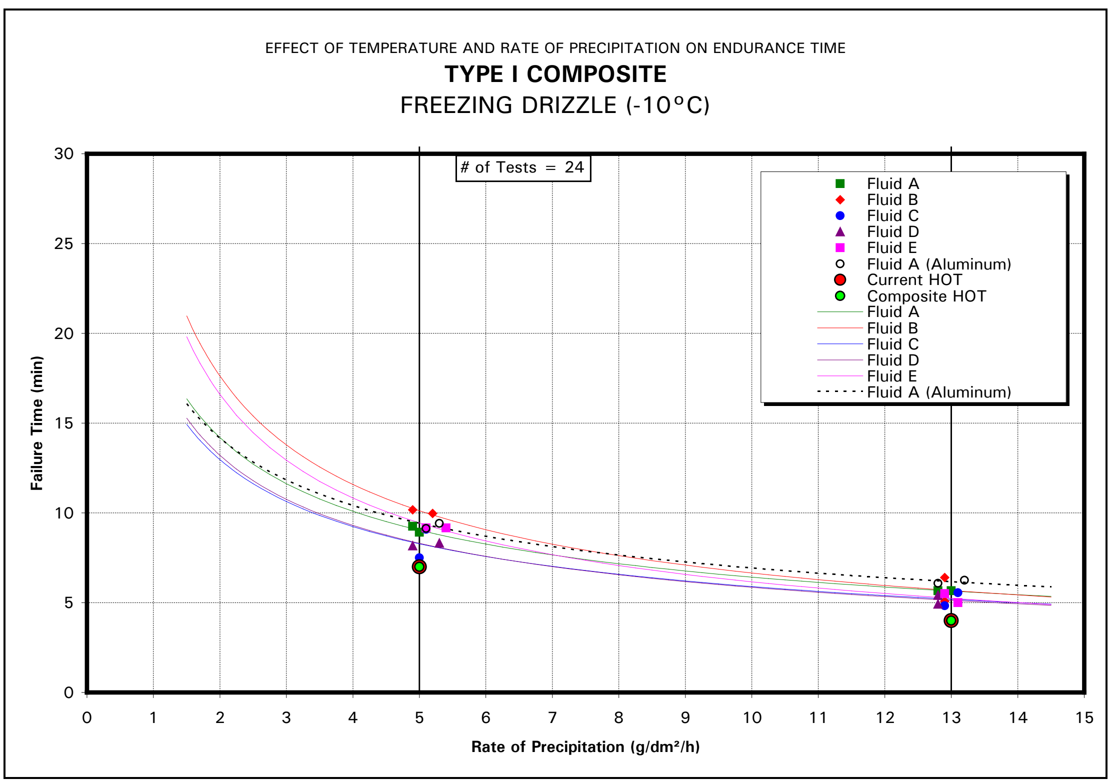

Figure 5.17: Freezing Drizzle, -10°C

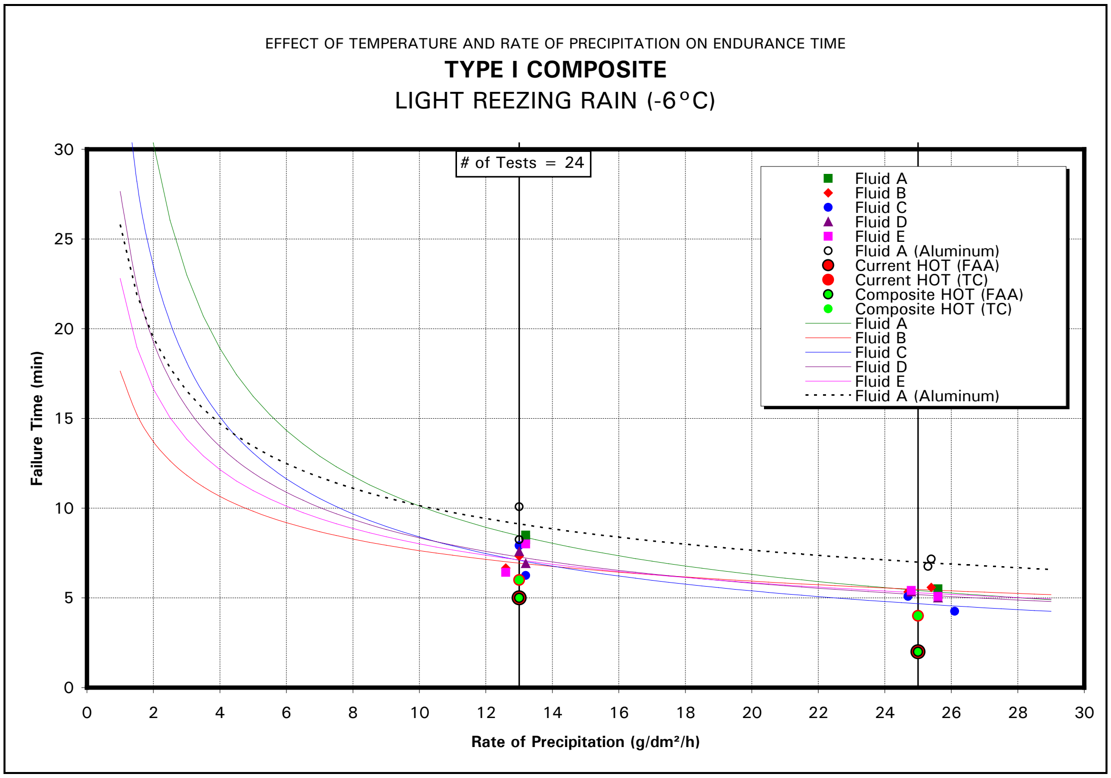

Figure 5.18: Light Freezing Rain, -6°C

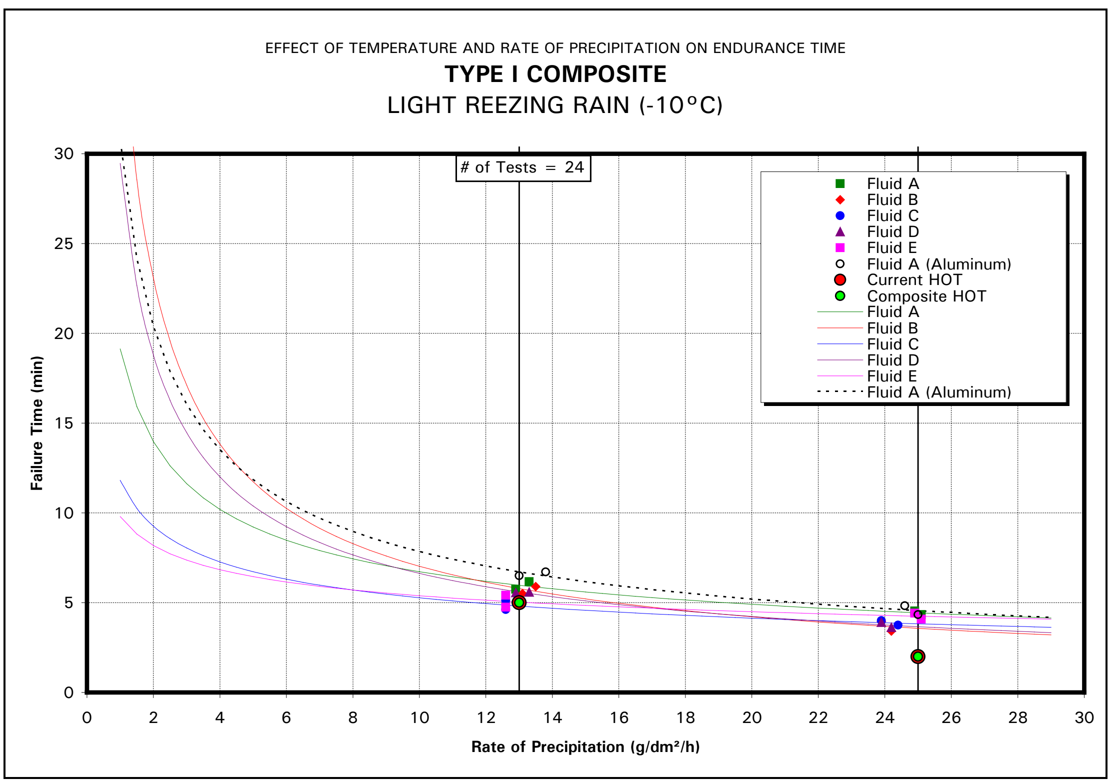

Figure 5.19: Light Freezing Rain, -10°C

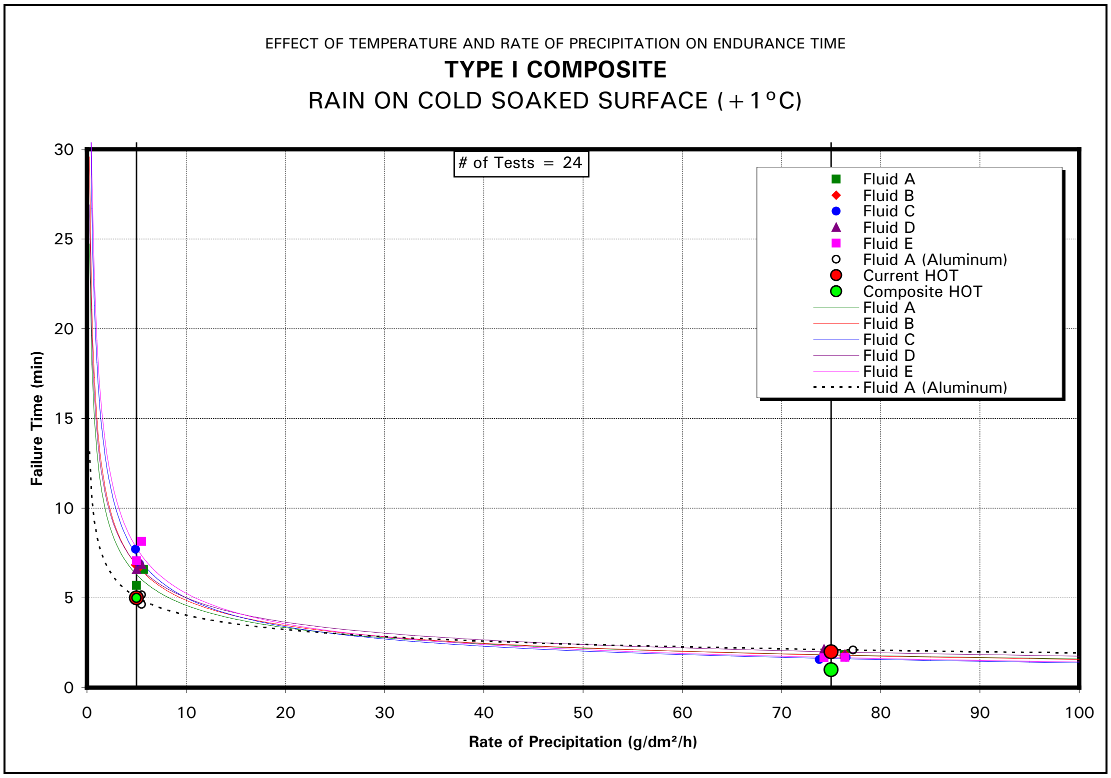

Figure 5.20: Rain on Cold-Soaked Surface, +1°C

5.5 Summary

Type I fluid holdover times for composite surfaces in freezing precipitation conditions were calculated from the weighted average of several statistics derived from regression analysis of fluid- and surface-specific data sets. The resulting values were rounded and compared to the existing aluminum holdover times before being finalized. These values were adopted by both Transport Canada and the FAA.

6. DETERMINATION OF HOTS: FROST

This section describes the analysis methodology used to determine a holdover time for Type I fluids on composite surfaces in frost, the data included in the analysis, and the results of the analysis.

6.1 Analysis Methodology

The holdover time for Type I fluids in active frost conditions was established several decades ago based primarily on high humidity endurance tests. It was later substantiated for *aluminum* surfaces with endurance time testing, which was conducted in natural frost with several representative Type I fluids (as well as other fluid types). In total, 47 data points were collected with Type I fluids as part of the substantiation research. The data is shown in Figure 6.1.

A "minimum values" analysis methodology was used to determine an appropriate holdover time from the data. Specifically, the shortest endurance times in the data set were identified, and a value near these endurance times was selected as an appropriate holdover time. The analysis resulted in a holdover time of 45 minutes. Since the historical holdover time was also 45 minutes, the existing published holdover time was substantiated (and retained). This research was documented in the Transport Canada report, TP 14938E, *Substantiation of Aircraft Ground Deicing Holdover Times in Frost Conditions* (6).

The same "minimum values" analysis methodology was used to determine the holdover time for *composite* surfaces in active frost conditions.

A second analysis methodology – ratio analysis – was used to substantiate the results of the minimum values analysis. This analysis involved applying the average ratio of composite endurance time to aluminum endurance time (measured during the comparative tests) to the current aluminum holdover time to determine an appropriate composite holdover time.

The minimum values analysis and ratio analysis were both completed using the data described in the next subsection.

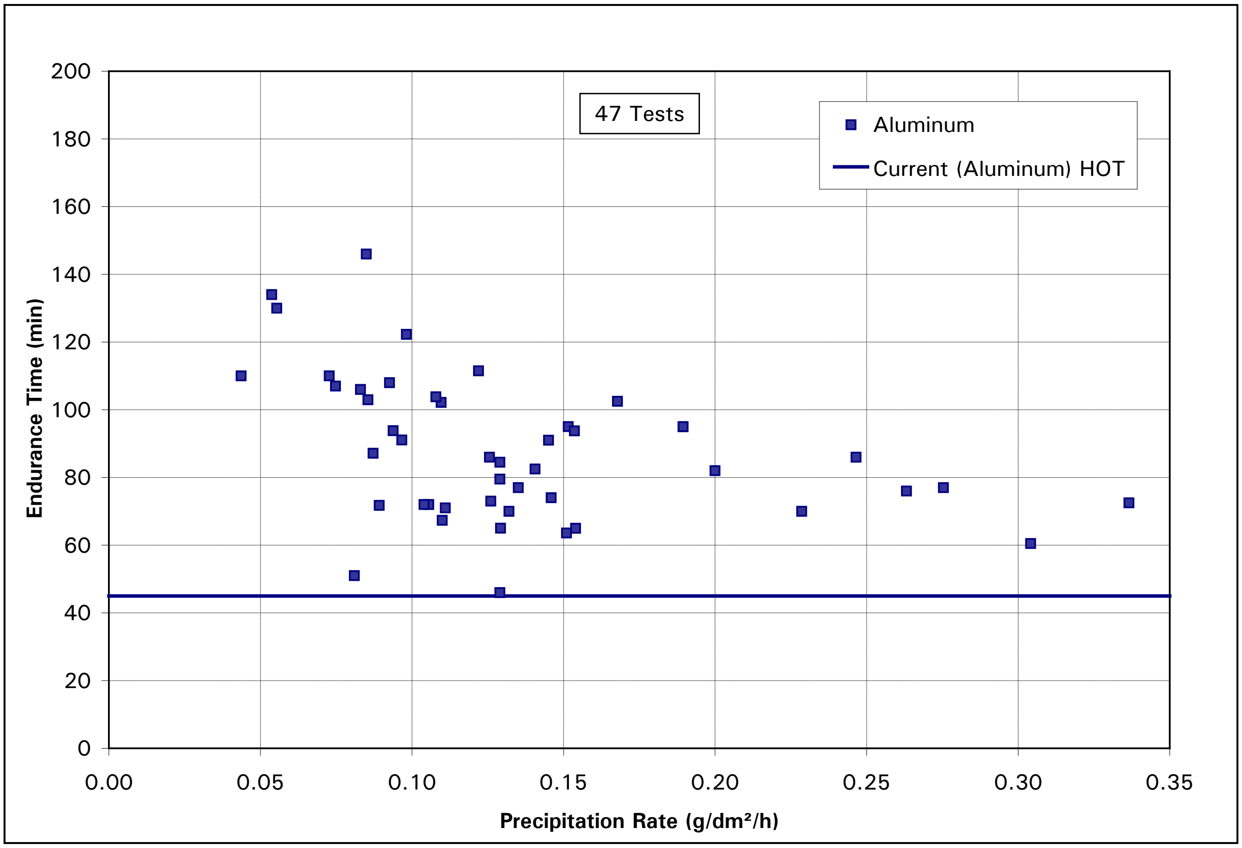

Figure 6.1: Data Used to Determine Type I Frost HOT on Aluminum Surfaces

6.2 Data Included in Determination of Type I HOTs in Frost

The data set used to determine the holdover time for Type I fluids on composite surfaces in frost included data collected in three winters of testing: 2004-05, 2005-06, and 2009-10. The collection and processing of the 2009-10 data is described in Sections 2 and 3 of this report (Volume 1). The 2004-05 data is documented in Section 3 of Volume 2 of this report and the 2005-06 data is documented in Section 4 of Volume 2 of this report.

The data set includes 39 composite data points. The majority of the data was collected in the winter of 2009-10, but data several data points were also collected in 2004-05 and 2005-06, as listed below.

- 2004-05: 6 data points
- 2005-06: 6 data points
- 2009-10: 27 data points

All tests included in the data set were conducted on white-painted Comp 05 frosticator plates; tests conducted on other composite surfaces and on unpainted surfaces were excluded from the data set. The data collected in the winters of 2004-05 and 2009-10 was collected with fluids applied at 20°C, as per standard test protocol. However, data collected in the winter of 2005-06 was collected with fluids applied at 60°C.

The frost data set is plotted in Figure 6.2, which shows the rate of precipitation and failure time for each of the 39 tests. The tests conducted with fluids applied at 20°C are shown as blue squares; tests conducted with fluids applied at 60°C are shown as magenta circles.

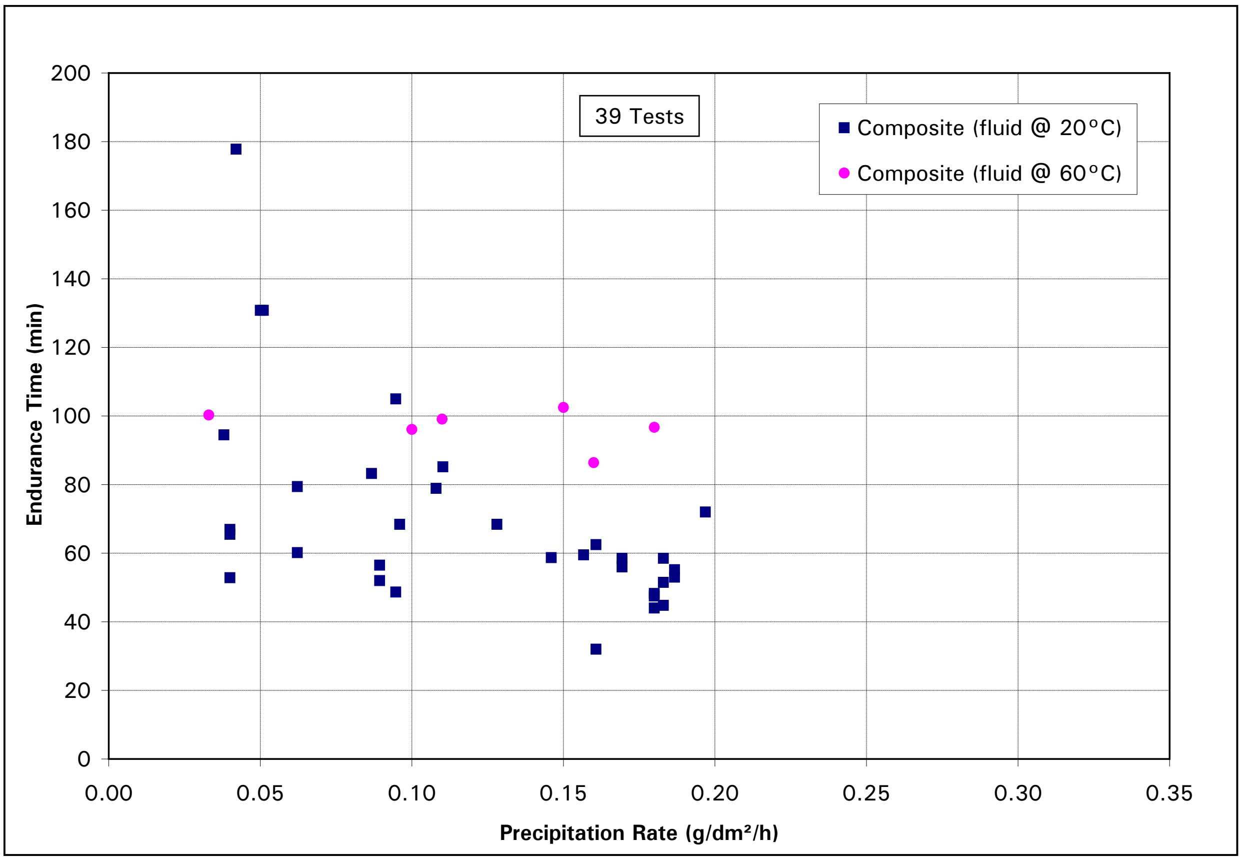

Figure 6.2: Data Included in Determination of Composite Frost HOTs

6.2.1 Distribution of Weather Conditions

The distribution of data points by outside air temperature, relative humidity, and wind speed is shown in Figures 6.3, 6.4, and 6.5, respectively.

The data was collected during five overnight events and encompasses testing conducted at air temperatures ranging from -22°C to 0°C, relative humidity ranging from 60 percent to 88 percent, and wind speeds ranging from 4 km/h to 16 km/h.

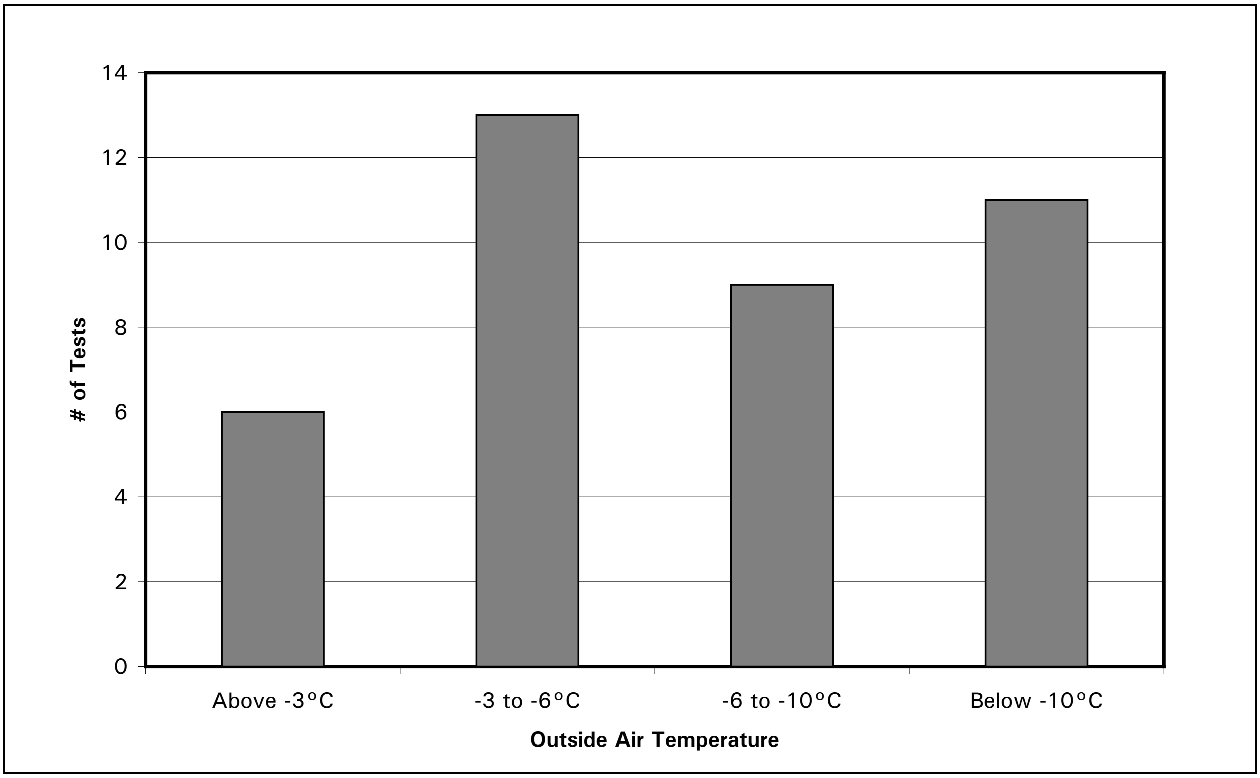

Figure 6.3: Distribution of Frost Data by OAT

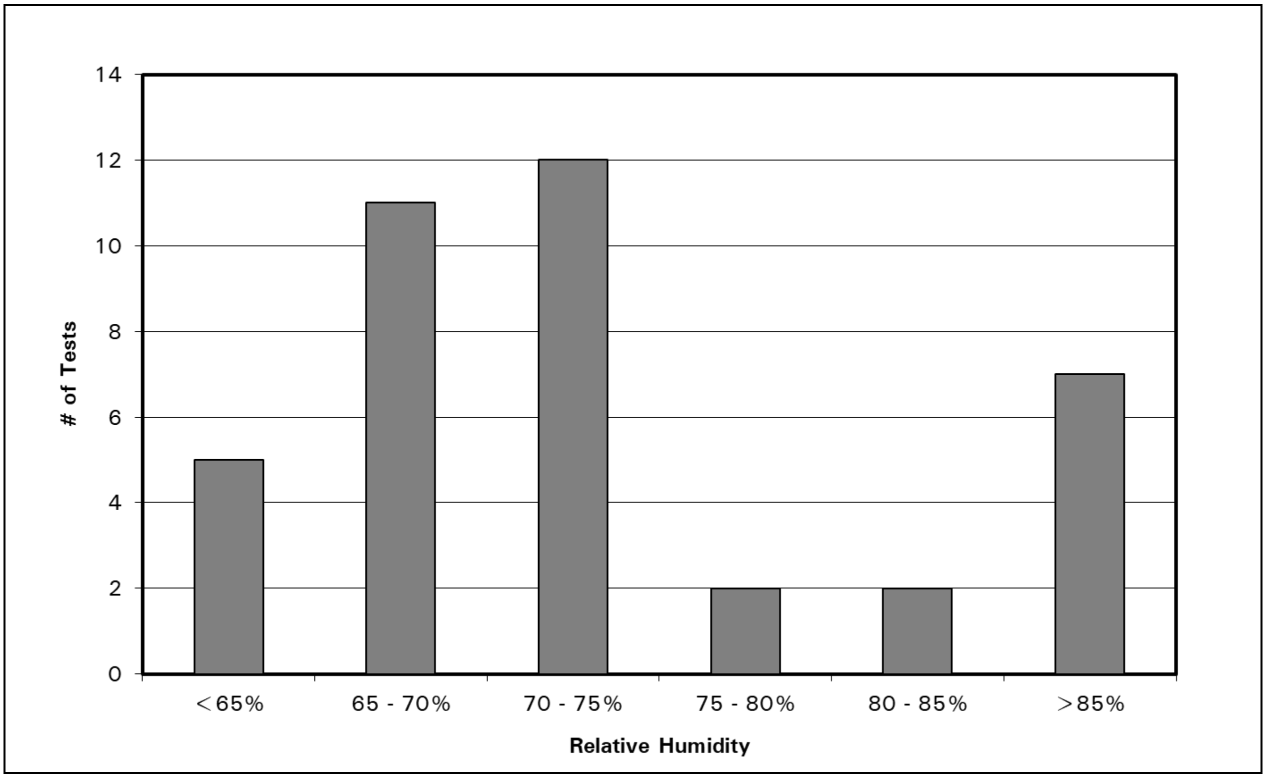

Figure 6.4: Distribution of Frost Data by Relative Humidity

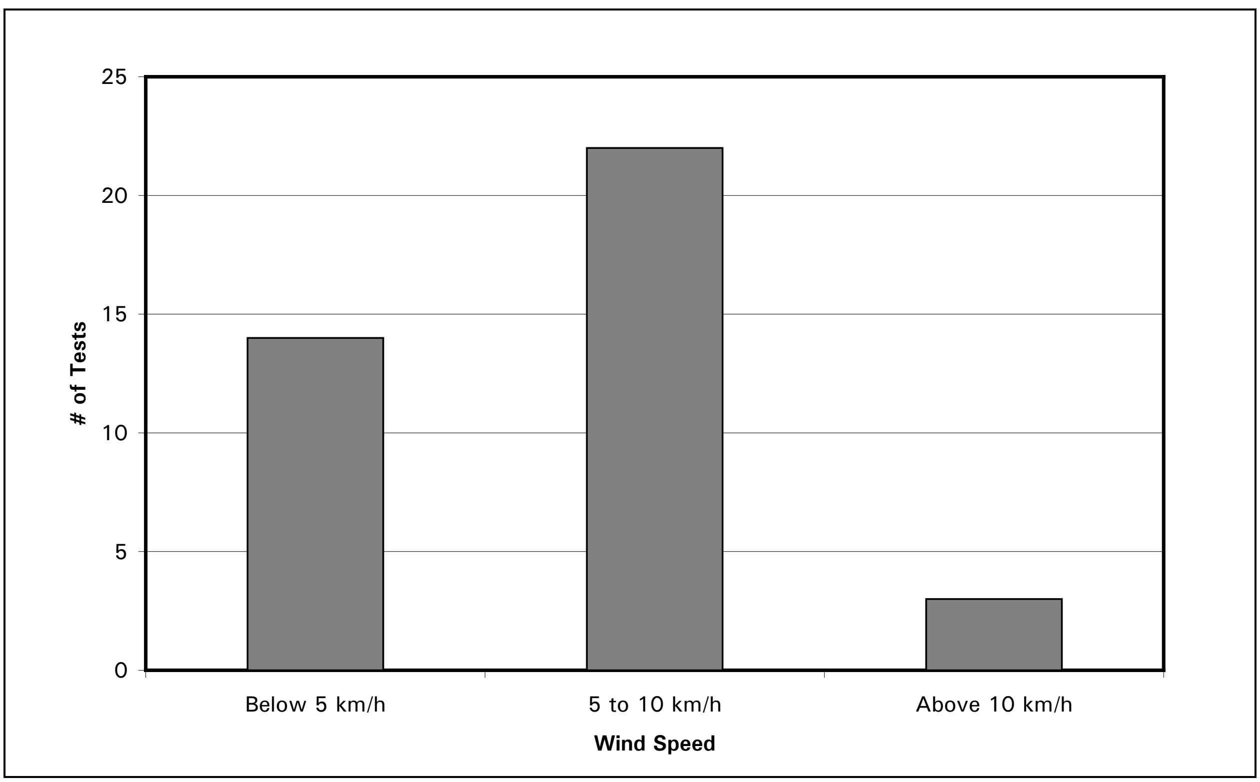

Figure 6.5: Distribution of Frost Data by Wind Speed

6.2.2 Comparative Data (Used for Ratio Analysis)

Of the 39 composite data points in the data set, 22 were conducted as comparative test runs. Each comparative test run included a test on a composite surface and a test run simultaneously with the same fluid on an aluminum surface. Therefore, for each of these 22 composite data points, there is a corresponding aluminum data point. The 22 comparative test run endurance times are plotted in Figure 6.6. This data was used in the ratio analysis.

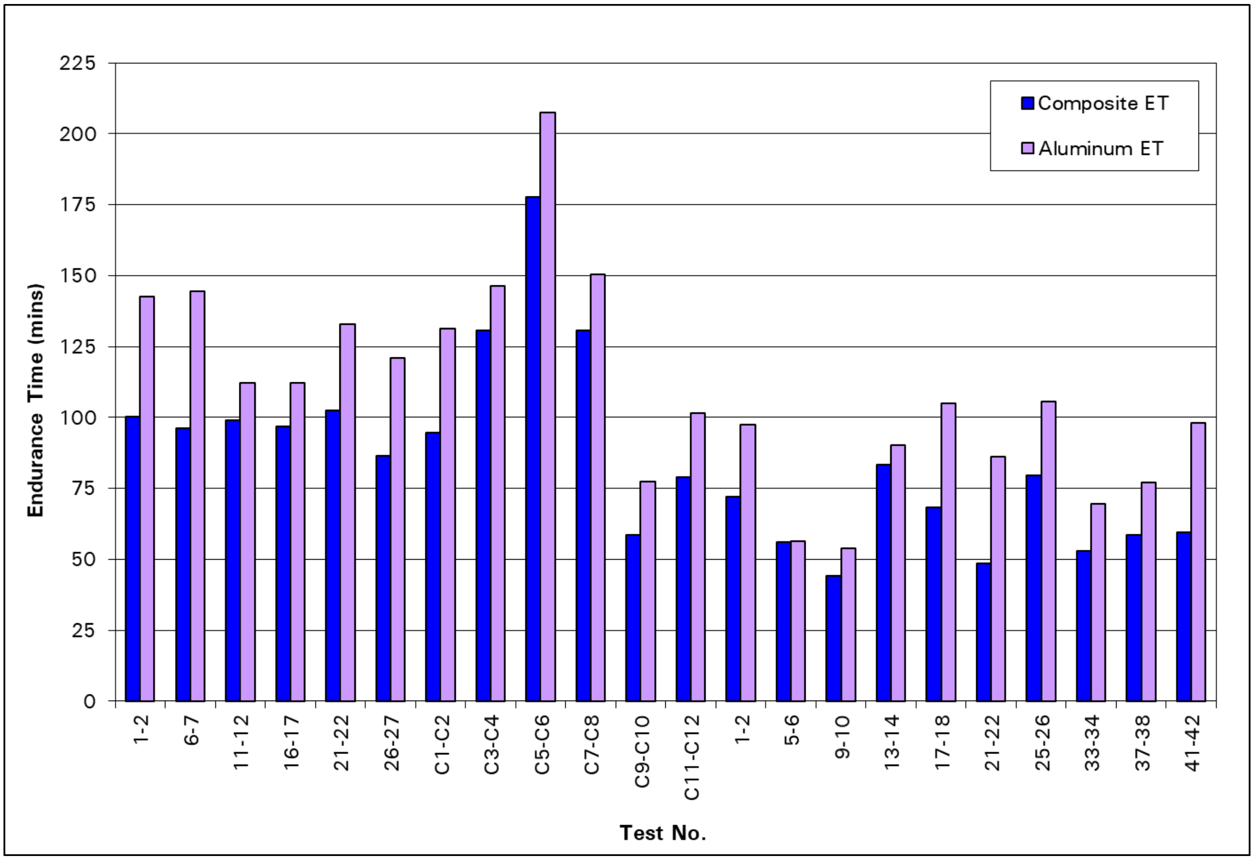

Figure 6.6: Comparative Frost Test Data

6.3 Application of Analysis Methodologies

The two analysis methodologies described in Subsection 6.1, minimum values analysis and ratio analysis, are applied below to the data set described in Subsection 6.2.

6.3.1 Minimum Values

To complete the minimum values analysis, the shortest endurance times in the data set (i.e., minimum values) were identified. The three shortest endurance times were identified as 32, 44, and 45 minutes. (It should be noted that none of the shortest endurance times were measured with fluids applied at 60°C. The shortest endurance time measured with a fluid heated to 60°C was 86 minutes, as can be seen in Figure 6.2.)

Using the same methodology employed to determine the aluminum Type I frost holdover time, 35 minutes was selected as an appropriate holdover time for composite surfaces in frost – it is below most data points and near the minimum endurance times measured.

The proposed composite holdover time is shown as a horizontal blue line on the composite data plot shown in Figure 6.7. The three minimum endurance time data points are shown in the chart as red triangles.

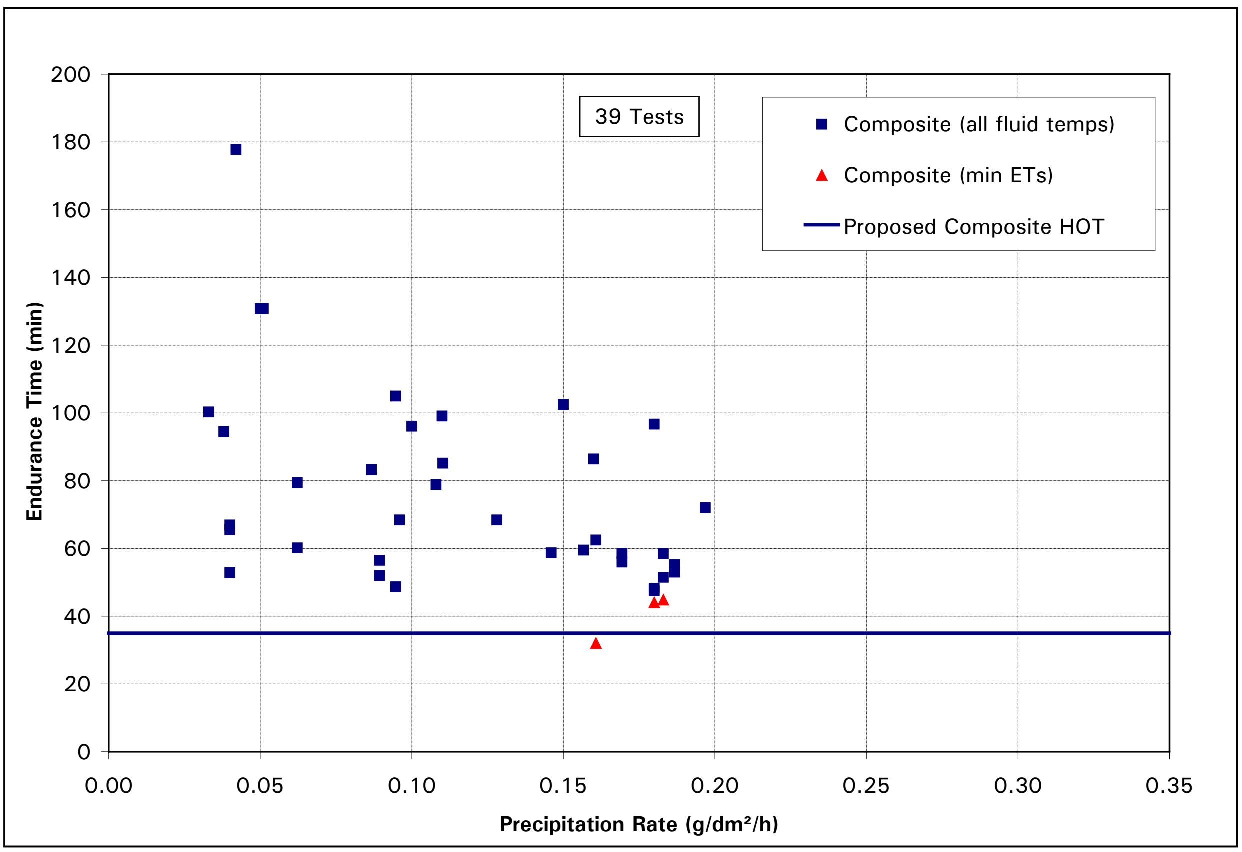

Figure 6.7: Data Used to Determine Type I Frost HOT on Composite Surfaces

6.3.2 Ratio Analysis

A ratio analysis was completed to validate the minimum values analysis. It was completed using the data from the 22 comparative test runs (see Figure 6.6). As described previously, each comparative test run included a composite test and an aluminum test conducted with the same fluid simultaneously. The endurance time ratio was calculated by dividing the composite endurance time by the aluminum endurance time.

The results are provided in Table 6.1. They show the average composite–aluminum endurance time ratio is 77 percent. When this ratio is applied to the current aluminum holdover time of 45 minutes, it provides a composite holdover time of 35 minutes. As this is the same holdover time derived from the minimum values analysis, the ratio analysis substantiates the result of the minimum values analysis.

Table 6.1: Frost Ratio Analysis

Test #	**Composite Endurance Time** (mins)	**Aluminum Endurance Time** (mins)	**Endurance Time % Ratio** (comp/alum)
1-2	72	97	74%
5-6	56	56	100%
9-10	44	54	81%
13-14	83	90	92%
17-18	68	105	65%
21-22	49	86	56%
25-26	79	106	75%
33-34	53	70	76%
37-38	59	77	76%
41-42	60	98	61%
1-2	100	143	70%
6-7	96	144	67%
11-12	99	112	88%
16-17	97	112	86%
21-22	103	133	77%
26-27	86	121	71%
C1-C2	95	131	72%
C3-C4	131	146	89%
C5-C6	178	208	86%
C7-C8	131	151	87%
C9-C10	59	77	76%
C11-C12	79	102	78%
		Average	77%
		Standard Deviation	11%

6.4 Summary

Both the minimum values analysis and the ratio analysis provided 35 minutes as an appropriate holdover time for Type I fluids on composite surfaces in active frost conditions. This value was adopted by both Transport Canada and the FAA.

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7. INCORPORATION OF TYPE I COMPOSITE HOTS INTO GUIDANCE MATERIALS

Transport Canada and the FAA incorporated the Type I fluid holdover times for composite surfaces developed over the winter of 2009-10 into their guidance materials for the Winter 2010-11 operating season. This section describes the process by which the information was incorporated into the Transport Canada and FAA guidance materials.

Interim guidance that was provided for the winter of 2009-10 is also summarized in this section.

7.1 Industry Feedback

On behalf of Transport Canada and the FAA, APS reported on the research, findings, and progress of the composite research program to the de/anti-icing industry on a regular basis over the duration of the six-year project. This reporting was provided through the SAE G-12 Holdover Time Committee. Presentations were provided to the committee at several of its annual meetings, including the following:

- Pittsburgh, May 2005;
- Lisbon, May 2006;
- Warsaw, May 2008;
- Charleston, May 2009; and
- Berlin, May 2010.

In later years, as it became clear that Type I fluids had shorter holdover times on composite surfaces than on aluminum surfaces (and therefore than published holdover times), meeting discussions centred on the best way to incorporate the reductions into the holdover time guidelines.

Three options were discussed. The first was to develop specific holdover times for composite surfaces for each published Type I holdover time. The second was to include a blanket statement indicating that Type I holdover times are a certain percentage (e.g., 30 percent) shorter on composite surfaces than on the aluminum surfaces. The third was to reduce Type I holdover times for all aircraft, both composite and aluminum.

Although opinions varied, the industry was generally in favour of developing specific holdover times for composite surfaces.

7.2 Interim Guidance Provided for Winter 2009-10

When regulators were preparing guidance materials for the winter of 2009-10, they were aware that Type I fluids had reductions in holdover time when applied to composite surfaces. It had been decided that the best way to incorporate these reductions into the holdover time guidelines was to publish composite-specific Type I holdover times. However, as the data had not yet been collected to produce the composite-specific holdover times, it was not possible to publish them in the Winter 2009-10 guidance materials.

As an interim measure, regulators provided general guidance for composite surfaces in Winter 2009-10 guidance materials.

7.2.1 Transport Canada

Transport Canada provided this guidance by adding a paragraph to its Aircraft Ground Icing Operations manual, TP 14052; the paragraph was published in the Transport Canada Holdover Time Guidelines for Winter 2009-10 (the document included a section on updates to TP 14052). 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.*

7.2.2 FAA

The FAA published the guidance in N 8900.104, *Revised FAA-Approved Deicing Program Updates, Winter 2009–2010* (3). 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.

7.3 2009-10 Test Program

An extensive test program was conducted with composites in the winter of 2009-10 with the purpose of collecting the data needed to develop composite-specific Type I holdover times. The outcome of the test program was the composite-specific holdover times for Type I fluids that were derived in Section 4 (snow), Section 5 (freezing precipitation), and Section 6 (frost).

Transport Canada and the FAA were highly involved in the determination of the composite-specific Type I holdover time values. They provided guidance and feedback on the test procedures and protocols, the selection of analysis methodologies, the determination of appropriate rounding protocols, and more.

7.4 Incorporation into Current HOT Tables

Transport Canada and the FAA considered two options for incorporating the composite-specific Type I holdover times into the Holdover Time Guidelines: incorporating the values directly into the existing holdover time tables or creating a new Type I holdover time table specifically for composite aircraft. They decided to incorporate the values directly into the existing tables.

Two holdover time tables were affected by this change: the Type I holdover time table and the frost holdover time table. The 2010-11 versions of these tables are shown in the following figures:

- Figure 7.1: Transport Canada 2010-11 Type I Holdover Time Table;
- Figure 7.2: Transport Canada 2010-11 Frost Holdover Time Table;
- Figure 7.3: FAA 2010-11 Type I Holdover Time Table; and
- Figure 7.4: FAA 2010-11 Frost Holdover Time Table.

7.5 Future Format Change

Following the publication of the 2010-11 Holdover Time Guidelines, feedback was received from the industry indicating that some operators would prefer the composite-specific holdover times be published in a separate table from the aluminum holdover times. These operators request that separation because they do not have composite aircraft in their fleets, so the numbers unnecessarily add confusion and clutter to the Type I holdover time table, making it more difficult for their pilots to use.

Transport Canada and the FAA are considering making this change for the winter 2011-12 guidance materials. If the change is made, the current Type I holdover time table would be split into two tables: one table with holdover times for aluminum aircraft and one table with holdover times for composite aircraft. The proposed tables are shown (in Transport Canada format) in Figure 7.5 and Figure 7.6.

Transport Canada Holdover Time Guidelines **Winter 2010-2011**

TABLE 1

SAE TYPE I FLUID HOLDOVER GUIDELINES FOR WINTER 2010-2011[1]

THE RESPONSIBILITY FOR THE APPLICATION OF THESE DATA REMAINS WITH THE USER

Outside Air Temperature[2]		Wing Surface	Approximate Holdover Times Under Various Weather Conditions (hours:minutes)							
Degrees Celsius	Degrees Fahrenheit		Freezing Fog	Snow, Snow Grains or Snow Pellets: Very Light[3]	Snow, Snow Grains or Snow Pellets: Light[3]	Snow, Snow Grains or Snow Pellets: Moderate	Freezing Drizzle[4]	Light Freezing Rain	Rain on Cold Soaked Wing[5]	Other[6]
-3 and above	27 and above	Aluminum	11 – 17	18	11 – 18	6 – 11	9 – 13	4 – 6	2 – 5	CAUTION: No holdover time guidelines exist
		Composite	9 – 16	12	6 – 12	3 – 6	8 – 13	4 – 6	1 – 5	
below -3 to -6	below 27 to 21	Aluminum	8 – 13	14	8 – 14	5 – 8	5 – 9	4 – 6		
		Composite	6 – 8	11	5 – 11	2 – 5	5 – 9	4 – 6		
below -6 to -10	below 21 to 14	Aluminum	6 – 10	11	6 – 11	4 – 6	4 – 7	2 – 5		
		Composite	4 – 8	9	5 – 9	2 – 5	4 – 7	2 – 5		
below -10	below 14	Aluminum	5 – 9	7	4 – 7	2 – 4				
		Composite	4 – 7	7	4 – 7	2 – 4				

NOTES

1 Type I Fluid / Water Mixture is selected so that the freezing point of the mixture is at least 10°C (18°F) below outside air temperature.
2 Ensure that the lowest operational use temperature (LOUT) is respected.
3 Use light freezing rain holdover times in conditions of very light or light snow mixed with light rain.
4 Use light freezing rain holdover times if positive identification of freezing drizzle is not possible.
5 No holdover time guidelines exist for this condition for 0°C (32°F) and below.
6 Heavy snow, ice pellets, moderate and heavy freezing rain, and hail.

CAUTIONS

- **The only acceptable decision-making criterion, for takeoff without a pre-takeoff contamination inspection, is the shorter time within the applicable holdover time table cell.**
- **The time of protection will be shortened in heavy weather conditions, heavy precipitation rates, or high moisture content.**
- **High wind velocity or jet blast may reduce holdover time.**
- **Holdover time may be reduced when aircraft skin temperature is lower than outside air temperature.**
- **Fluids used during ground deicing/anti-icing do not provide in-flight icing protection.**

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Figure 7.1: Transport Canada 2010-11 Type I Holdover Time Table

Transport Canada Holdover Time Guidelines **Winter 2010-2011**

TABLE 0

ACTIVE FROST HOLDOVER GUIDELINES FOR WINTER 2010-2011

THE RESPONSIBILITY FOR THE APPLICATION OF THESE DATA REMAINS WITH THE USER

Outside Air Temperature		Concentration Neat Fluid/Water (Volume %/Volume %)	Approximate Holdover Times (hours:minutes)			
			Active Frost			
Degrees Celsius	Degrees Fahrenheit		Type I[1,2]	Type II[3]	Type III[3]	Type IV[3]
-1 and above	30 and above	100/0	0:45 *(0:35)*[4]	8:00	2:00	12:00
		75/25		5:00	1:00	5:00
		50/50		3:00	0:30	3:00
below -1 to -3	below 30 to 27	100/0		8:00	2:00	12:00
		75/25		5:00	1:00	5:00
		50/50		1:30	0:30	3:00
below -3 to -10	below 27 to 14	100/0		8:00	2:00	10:00
		75/25		5:00	1:00	5:00
below -10 to -14	below 14 to 7	100/0		6:00	2:00	6:00
		75/25		1:00	1:00	1:00
below -14 to -21	below 7 to -6	100/0		6:00	2:00	6:00
below -21 to -25	below -6 to -13	100/0		2:00	2:00	4:00

NOTES
1 Type I Fluid / Water Mixture is selected so that the freezing point of the mixture is at least 10°C (18°F) below outside air temperature.
2 May be used below -25°C (-13°F) provided the lowest operational use temperature (LOUT) of the fluid is respected.
3 These fluids may not be used below -25°C (-13°F) in active frost conditions.
4 Value in parentheses is for composite surfaces.

CAUTIONS
- **Fluids used during ground deicing/anti-icing do not provide in-flight icing protection.**

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Figure 7.2: Transport Canada 2010-11 Frost Holdover Time Table

FAA TYPE I HOLDOVER TIME GUIDELINE

TABLE 1. FAA GUIDELINES FOR HOLDOVER TIMES SAE TYPE I FLUID MIXTURES AS A FUNCTION OF WEATHER CONDITIONS AND OUTSIDE AIR TEMPERATURE

CAUTION: THIS TABLE IS FOR DEPARTURE PLANNING ONLY AND SHOULD BE USED IN CONJUNCTION WITH PRETAKEOFF CHECK PROCEDURES.

Outside Air Temperature		Wing Surface	Approximate Holdover Times Under Various Weather Conditions (hours: minutes)							
Degrees Celsius	Degrees Fahrenheit		Freezing Fog	Snow, Snow Grains or Snow Pellets: Very Light	Light	Moderate	Freezing Drizzle*	Light Freezing Rain†	Rain on Cold Soaked Wing**	Other‡
-3 and above	27 and above	Aluminum	0:11-0:17	0:18-0:22	0:11-0:18	0:06-0:11	0:09-0:13	0:02-0:05	0:02-0:05	
		Composite	0:09-0:16	0:12-0:15	0:06-0:12	0:03-0:06	0:08-0:13	0:02-0:05	0:01-0:05	
below -3 to -6	below 27 to 21	Aluminum	0:08-0:13	0:14-0:17	0:08-0:14	0:05-0:08	0:05-0:09	0:02-0:05		
		Composite	0:06-0:08	0:11-0:13	0:05-0:11	0:02-0:05	0:05-0:09	0:02-0:05		
below -6 to -10	below 21 to 14	Aluminum	0:06-0:10	0:11-0:13	0:06-0:11	0:04-0:06	0:04-0:07	0:02-0:05	CAUTION: No holdover time guidelines exist	
		Composite	0:04-0:08	0:09-0:12	0:05-0:09	0:02-0:05	0:04-0:07	0:02-0:05		
Below -10	below 14	Aluminum	0:05-0:09	0:07-0:08	0:04-0:07	0:02-0:04				
		Composite	0:04-0:07	0:07-0:08	0:04-0:07	0:02-0:04				

THE RESPONSIBILITY FOR THE APPLICATION OF THESE DATA REMAINS WITH THE USER.

* Use light freezing rain holdover times if positive identification of freezing drizzle is not possible
** This column is for use at temperatures above 0 degrees Celsius (32 degrees Fahrenheit) only
‡ Heavy snow, ice pellets, moderate and heavy freezing rain, hail
† Use light freezing rain holdover times in conditions of light snow mixed with light rain.

SAE Type I fluid/water mixture is selected so that the freezing point of the mixture is at least 10 °C (18 °F) below OAT.

CAUTIONS:

- THE TIME OF PROTECTION WILL BE SHORTENED IN HEAVY WEATHER CONDITIONS. HEAVY PRECIPITATION RATES OR HIGH MOISTURE CONTENT, HIGH WIND VELOCITY, OR JET BLAST MAY REDUCE HOLDOVER TIME BELOW THE LOWEST TIME STATED IN THE RANGE. HOLDOVER TIME MAY BE REDUCED WHEN AIRCRAFT SKIN TEMPERATURE IS LOWER THAN OAT.
- **SAE TYPE I** FLUID USED DURING GROUND DEICING/ANTI-ICING IS NOT INTENDED FOR AND DOES NOT PROVIDE PROTECTION DURING FLIGHT.

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Figure 7.3: FAA 2010-11 Type I Holdover Time Table

TABLE 0. FAA GUIDELINES FOR HOLDOVER TIMES IN ACTIVE FROST, SAE TYPE I, TYPE II, TYPE III, AND TYPE IV FLUIDS

Outside Air Temperature		Concentration Neat Fluid/Water (Volume %/Volume %)	Approximate Holdover Times (hours: minutes) Active Frost			
Degrees Celsius	Degrees Fahrenheit		Type I[1,2]	Type II [3]	Type III [3]	Type IV [3]
-1 and above	30 and above	100/0		8:00	2:00	12:00
		75/25		5:00	1:00	5:00
		50/50		3:00	0:30	3:00
below -1 to -3	below 30 to 27	100/0		8:00	2:00	12:00
		75/25		5:00	1:00	5:00
		50/50		1:30	0:30	3:00
below -3 to -10	below 27 to 14	100/0	0:45 (0:35)[4]	8:00	2:00	10:00
		75/25		5:00	1:00	5:00
below -10 to -14	below 14 to 7	100/0		6:00	2:00	6:00
		75/25		1:00	1:00	1:00
below -14 to -21	below 7 to -6	100/0		6:00	2:00	6:00
below -21 to -25	below -6 to -13	100/0		2:00	2:00	4:00

THE RESPONSIBILITY FOR THE APPLICATION OF THESE DATA REMAINS WITH THE USER

NOTES

1 Type I Fluid / Water Mixture is selected so that the freezing point of the mixture is at least 10°C (18°F) below outside air temperature.

2 May be used below -25°C (-13°F) provided the lowest operational use temperature (LOUT) of the fluid is not exceeded.

3 These fluids may not be used below -25°C (-13°F) in active frost conditions.

4 Value in parenthesis is for composite aircraft.

CAUTIONS

Fluids used during ground deicing/anti-icing do not provide in-flight icing protection.

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Figure 7.4: FAA 2010-11 Frost Holdover Time Table

TABLE 1-A

SAE TYPE I FLUID HOLDOVER GUIDELINES ON ALUMINUM WING SURFACES FOR WINTER 2011-2012[1]

This table applies to aircraft already in service with critical surfaces constructed predominantly or entirely of aluminum materials that have demonstrated satisfactory use of these holdover times.
THE RESPONSIBILITY FOR THE APPLICATION OF THESE DATA REMAINS WITH THE USER

Outside Air Temperature[2]		Approximate Holdover Times Under Various Weather Conditions (minutes)							
Degrees Celsius	Degrees Fahrenheit	Freezing Fog	Snow, Snow Grains or Snow Pellets: Very Light[3]	Snow, Snow Grains or Snow Pellets: Light[3]	Snow, Snow Grains or Snow Pellets: Moderate	Freezing Drizzle[4]	Light Freezing Rain	Rain on Cold Soaked Wing[5]	Other[6]
-3 and above	27 and above	11 – 17	18	11 – 18	6 – 11	9 – 13	4 – 6	2 – 5	CAUTION: No holdover time guidelines exist
below -3 to -6	below 27 to 21	8 – 13	14	8 – 14	5 – 8	5 – 9	4 – 6	CAUTION: No holdover time guidelines exist	
below -6 to -10	below 21 to 14	6 – 10	11	6 – 11	4 – 6	4 – 7	2 – 5		
below -10	below 14	5 – 9	7	4 – 7	2 – 4				

NOTES

1 Type I Fluid / Water Mixture is selected so that the freezing point of the mixture is at least 10°C (18°F) below outside air temperature.
2 Ensure that the lowest operational use temperature (LOUT) is respected.
3 Use light freezing rain holdover times in conditions of very light or light snow mixed with light rain.
4 Use light freezing rain holdover times if positive identification of freezing drizzle is not possible.
5 No holdover time guidelines exist for this condition for 0°C (32°F) and below.
6 Heavy snow, ice pellets, moderate and heavy freezing rain, and hail.

CAUTIONS

- **The only acceptable decision-making criterion, for takeoff without a pre-takeoff contamination inspection, is the shorter time within the applicable holdover time table cell.**
- **The time of protection will be shortened in heavy weather conditions, heavy precipitation rates, or high moisture content.**
- **High wind velocity or jet blast may reduce holdover time.**
- **Holdover time may be reduced when aircraft skin temperature is lower than outside air temperature.**
- **Fluids used during ground deicing/anti-icing do not provide in-flight icing protection.**

Figure 7.5: Proposed Type I Aluminum HOT Table for 2011-12

TABLE 1-C

SAE TYPE I FLUID HOLDOVER GUIDELINES ON COMPOSITE WING SURFACES FOR WINTER 2011-2012[1]

These holdover times apply to newer aircraft with critical surfaces constructed predominantly or entirely of composite materials.
THE RESPONSIBILITY FOR THE APPLICATION OF THESE DATA REMAINS WITH THE USER

Outside Air Temperature[2]		Approximate Holdover Times Under Various Weather Conditions (minutes)							
			Snow, Snow Grains or Snow Pellets						
Degrees Celsius	**Degrees Fahrenheit**	**Freezing Fog**	**Very Light[3]**	**Light[3]**	**Moderate**	**Freezing Drizzle[4]**	**Light Freezing Rain**	**Rain on Cold Soaked Wing[5]**	**Other[6]**
-3 and above	27 and above	9 – 16	12	6 – 12	3 – 6	8 – 13	4 – 6	1 – 5	CAUTION: No holdover time guidelines exist
below -3 to -6	below 27 to 21	6 – 8	11	5 – 11	2 – 5	5 – 9	4 – 6		
below -6 to -10	below 21 to 14	4 – 8	9	5 – 9	2 – 5	4 – 7	2 – 5		
below -10	below 14	4 – 7	7	4 – 7	2 – 4				

NOTES
1 Type I Fluid / Water Mixture is selected so that the freezing point of the mixture is at least 10°C (18°F) below outside air temperature.
2 Ensure that the lowest operational use temperature (LOUT) is respected.
3 Use light freezing rain holdover times in conditions of very light or light snow mixed with light rain.
4 Use light freezing rain holdover times if positive identification of freezing drizzle is not possible.
5 No holdover time guidelines exist for this condition for 0°C (32°F) and below.
6 Heavy snow, ice pellets, moderate and heavy freezing rain, and hail.

CAUTIONS
- **The only acceptable decision-making criterion, for takeoff without a pre-takeoff contamination inspection, is the shorter time within the applicable holdover time table cell.**
- **The time of protection will be shortened in heavy weather conditions, heavy precipitation rates, or high moisture content.**
- **High wind velocity or jet blast may reduce holdover time.**
- **Holdover time may be reduced when aircraft skin temperature is lower than outside air temperature.**
- **Fluids used during ground deicing/anti-icing do not provide in-flight icing protection.**

Figure 7.6: Proposed Type I Composite HOT Table for 2011-12

8. SUPPLEMENTARY RESEARCH: EVALUATION OF USE OF -3°C BUFFER FLUID ON COMPOSITE SURFACES

Recent industry concerns about the use of -3°C buffer fluid in the first step of a two-step de/anti-icing operation led to a research program being conducted to examine endurance times of the Type I -3°C buffer on composite surfaces. The research is documented in this section.

8.1 Background

Aerospace Recommended Practice (ARP) 4737H, *Aircraft Deicing/Anti-Icing Methods* (7) provides industry standards for conducting de/anti-icing operations. It states that the freezing point (FP) of fluid used in the first step of a two-step operation can be up to 3°C above ambient temperature (i.e., -3°C buffer fluid). It implies that the first step will typically provide protection for at least 3 minutes. The relevant sections of ARP4737H (7) are excerpted below.

> *6.3.1.1 Temperature Limit*
>
> *When performing two step deicing/anti-icing, the FP of the fluid used for the first step shall not be more than 3°C (5°F) above ambient temperature.*
>
> *6.3.3.2 Two Step Deicing/Anti-icing*
>
> *When the first step is performed with deicing fluid (see 3.3.1). The correct deicing fluid mixture is chosen with regard to OAT. The second step is performed with anti-icing fluid (see 3.3.2). This fluid and its concentration are chosen with regard to desired holdover time, which is dictated by OAT and weather conditions. The second step shall be performed before first step fluid freezes* ***(typically within 3 min)****; if necessary area by area. Use a second step spraying technique to cover completely the first step fluid (for example using the method described in 6.2.4) in a sufficient amount of second step fluid. Where re-freezing occurs following the initial treatment, both first and second step must be repeated. When a fluid conforming to AMS1428 is used to perform step two in a two step deicing/anti-icing operation, and the fluid used in step one is a Type I fluid conforming to AMS1424, a test shall be made to confirm that the combination of these fluids does not significantly reduce the WSET performance of the AMS1428 fluid.*

Some concerns exist with the inclusion of this recommendation in ARP4737H (7). Specifically, it is thought that -3°C buffer fluid may provide less than 3 minutes of protection time under some weather conditions. These concerns have become more significant in recent years, as research has shown that Type I fluids typically freeze faster on composite surfaces than on aluminum surfaces. Like fluids mixed to higher freezing points (i.e., -3°C), composite surfaces have a negative impact on fluid protection time. The concern is that the combination of these two factors (composite surfaces, -3°C buffer fluid) will lead to conditions in which fluid protection times that are less than 3 minutes.

An examination of the current Type I holdover times indicates that these concerns are well founded. The holdover times provided for Type I fluids on aluminum surfaces are less than 3 minutes in five conditions in the FAA Type I table (see Table 8.1) and two conditions in the Transport Canada Type I table (see Table 8.2). This indicates that Type I fluids may provide as little as 2 minutes of protection time in some conditions, one minute less than the 3 minutes that ARP4737H (7) indicates is available.

Table 8.1: FAA Type I Holdover Time Table

Outside Air Temperature		Approximate Holdover Times Under Various Weather Conditions (hours: minutes)							
Degrees Celsius	Degrees Fahrenheit	Freezing Fog	Snow/Snow Grains: Very Light♦♦	Snow/Snow Grains: Light ♦♦	Snow/Snow Grains: Moderate♦♦	Freezing Drizzle*	Light Freezing Rain†	Rain on Cold Soaked Wing**	Other‡
-3 and above	27 and above	0:11-0:17	0:18-0:22	0:11-0:18	0:06-0:11	0:09-0:13	0:02-0:05	0:02-0:05	
below -3 to -6	below 27 to 21	0:08-0:13	0:14-0:17	0:08-0:14	0:05-0:08	0:05-0:09	0:02-0:05	CAUTION: No Holdover time guidelines exist	
below -6 to -10	below 21 to 14	0:06-0:10	0:11-0:13	0:06-0:11	0:04-0:06	0:04-0:07	0:02-0:05		
Below -10	below 14	0:05-0:09	0:07-0:08	0:04-0:07	0:02-0:04				

Table 8.2: Transport Canada Type I Holdover Time Table

Outside Air Temperature[5]		Approximate Holdover Times Under Various Weather Conditions (minutes)							
Degrees Celsius	Degrees Fahrenheit	Freezing Fog	Snow or Snow Grains[1]: Very Light[6]	Snow or Snow Grains[1]: Light[6]	Snow or Snow Grains[1]: Moderate	Freezing Drizzle[4]	Light Freezing Rain	Rain on Cold Soaked Wing	Other[2]
-3 and above	27 and above	11 – 17	18	11 – 18	6 – 11	9 – 13	4 – 6	2 – 5	
below -3 to -6	below 27 to 21	8 – 13	14	8 – 14	5 – 8	5 – 9	4 – 6	CAUTION: No holdover time guidelines exist	
below -6 to -10	below 21 to 14	6 – 10	11	6 – 11	4 – 6	4 – 7	2 – 5		
Below -10	below 14	5 – 9	7	4 – 7	2 – 4				

Because the Type I holdover times are based on testing with 10°C buffer fluids (fluids mixed to a freezing point 10°C *below* ambient temperature) on *aluminum* surfaces, it is reasonable to conjecture that endurance times of -3°C buffer fluids on composite surfaces will be shorter, possibly resulting in additional conditions in which Type I fluids provide less than 3 minutes of protection time.

8.2 Objective

Research was undertaken in the winter of 2009-10 to evaluate endurance times of Type I fluids mixed to a -3°C buffer applied to composite surfaces. The objective of the tests was to determine if -3°C buffer Type I fluids can provide protection for at least 3 minutes on composite surfaces. Testing was conducted under all conditions encompassed by the Type I holdover time guidelines.

8.3 Procedure and Data

Testing was conducted in natural snow and freezing precipitation according to the test protocol provided in ARP5945 (4). Testing was conducted on Comp 05 composite test surfaces with fluids mixed to a freezing point 3°C above the ambient temperature.

8.3.1 Natural Snow

Testing was conducted in natural snow with five representative fluids under varying conditions. Test data was collected in air temperatures ranging from -3.5°C to 1.0°C and in average precipitation rates ranging from 3 to 12 $g/dm^2/h$. A total of 13 tests were conducted. Due to abnormal winter weather in Montreal in 2009-10, data points at low temperatures and high precipitation rates were not collected. The distribution of tests by air temperature and precipitation rate is provided in Table 8.3. A log of tests conducted in natural snow is provided in Table 8.4. Descriptions of the column headings are provided in Subsection 3.2.

Table 8.3: Tests Conducted in Snow

Precipitation Type	**Precipitation Rate** ($g/dm^2/h$)	**Air Temperature**		
		<0°C	**>0°C**	**ALL**
Natural Snow	< 4	1	1	**2**
	4 - 10	1	8	**9**
	10 - 25	0	2	**2**
	> 25	0	0	**0**
	ALL	**2**	**11**	**13**

Table 8.4: Log of -3°C Buffer Tests – Snow

Test #	Date	Run #	Fluid Name	Fluid Dil.	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 (°)
20	18-Feb-10	2	Clariant 1938	-3°C Buf	60	Composite Box	Snow	21:46:20	21:49:30	3.2	8.7	-2.9	24	1.00	1.00
32	19-Feb-10	5	Kilfrost DFsustain	-3°C Buf	60	Composite Box	Snow	1:31:30	1:35:40	4.2	3.0	-3.5	30	2.00	2.00
40	23-Feb-10	2	Dow PG	-3°C Buf	60	Composite Box	Snow	7:27:30	7:35:00	7.5	4.4	0.4	19	1.00	0.25
44	23-Feb-10	3	Dow EG	-3°C Buf	60	Composite Box	Snow	8:17:50	8:33:30	15.7	5.8	0.4	17	1.00	0.00
60	24-Feb-10	2	Octaflo	-3°C Buf	60	Composite Box	Snow	2:00:10	2:06:00	5.8	11.4	0.4	13	1.00	0.00
72	24-Feb-10	5	Dow PG	-3°C Buf	60	Composite Box	Snow	5:10:40	5:17:45	7.1	7.4	0.5	15	1.00	0.25
76	24-Feb-10	6	Clariant 1938	-3°C Buf	60	Composite Box	Snow	6:05:20	6:12:30	7.2	4.4	0.5	15	1.00	0.00
84	24-Feb-10	2	Kilfrost DFsustain	-3°C Buf	60	Composite Box	Snow	18:17:40	18:23:00	5.3	7.3	0.8	19	1.00	0.00
92	24-Feb-10	4	Dow EG	-3°C Buf	60	Composite Box	Snow	20:51:30	21:00:45	9.2	6.4	0.9	20	1.00	0.25
104	24-Feb-10	7	Dow PG	-3°C Buf	60	Composite Box	Snow	6:04:30	6:12:00	7.5	9.4	1.0	28	1.00	0.50
108	25-Feb-10	1	Dow EG	-3°C Buf	60	Composite Box	Snow	1:33:30	1:46:00	12.5	3.0	0.9	30	1.00	0.75
116	25-Feb-10	3	Octaflo	-3°C Buf	60	Composite Box	Snow	3:24:52	3:28:30	3.6	12.1	0.7	32	1.00	0.50
120	25-Feb-10	4	Dow EG	-3°C Buf	60	Composite Box	Snow	4:33:01	4:37:17	4.3	8.9	1.0	35	1.00	0.75

8.3.2 Freezing Precipitation

Testing was conducted in freezing precipitation with one representative fluid. Testing was conducted under all freezing precipitation conditions encompassed in the Type I holdover table. A total of 40 tests were conducted. The distribution of tests by precipitation type, precipitation rate, and air temperature is provided in Table 8.5.

A log of tests conducted in freezing precipitation is provided in Table 8.6. Descriptions of the column headings are provided in Subsection 3.2.

Table 8.5: Tests Conducted in Freezing Precipitation

Precipitation Type	Precip. Rate (g/dm²/h)	Air Temperature					
		+1°C	-3°C	-6°C	-10°C	-25°C	ALL
Freezing Fog	2	n/a	2	2	2	2	16
	5	n/a	2	2	2	2	
Freezing Drizzle	5	n/a	2	2	2	n/a	12
	13	n/a	2	2	2	n/a	
Light Freezing Rain	13	n/a	*	2	2	n/a	8
	25	n/a	*	2	2	n/a	
Rain on Cold-Soaked Surface	5	2	n/a	n/a	n/a	n/a	4
	75	2	n/a	n/a	n/a	n/a	

* *Type I fluids are not tested in freezing rain at -3ºC because the latent heat of freezing in calm test conditions produces artificially long endurance times.*

Table 8.6: Log of -3°C Buffer Tests – Freezing Precipitation

Test #	Date	Fluid Name	Fluid Dil.	Fluid Temp. (°C)	Test Surface	Precip. Type	Ambient Temp. (°C)	Start Time	Fail Time	Endur. Time (min)	Precip. Rate (g/dm^2/h)
C003	1-Apr-10	Kilfrost DF^{sustain}	-3°C Buf	20	Composite Plate	Freezing Fog	-3	19:47:30	19:53:00	5.5	4.7
C004	1-Apr-10	Kilfrost DF^{sustain}	-3°C Buf	20	Composite Plate	Freezing Fog	-3	19:41:20	19:47:20	6.0	5.3
C017	8-Apr-10	Kilfrost DF^{sustain}	--3°C Buf	20	Composite Plate	Freezing Fog	-3	13:51:28	13:56:30	5.0	1.9
C018	8-Apr-10	Kilfrost DF^{sustain}	-3°C Buf	20	Composite Plate	Freezing Fog	-3	14:01:08	14:06:36	5.5	1.9
C031	7-Apr-10	Kilfrost DF^{sustain}	-3°C Buf	20	Composite Plate	Freezing Fog	-6	10:05:18	10:10:10	4.9	5.4
C032	7-Apr-10	Kilfrost DF^{sustain}	-3°C Buf	20	Composite Plate	Freezing Fog	-6	10:06:22	10:10:52	4.5	5.3
C045	7-Apr-10	Kilfrost DF^{sustain}	-3°C Buf	20	Composite Plate	Freezing Fog	-6	14:49:37	14:53:15	3.6	1.9
C046	7-Apr-10	Kilfrost DF^{sustain}	-3°C Buf	20	Composite Plate	Freezing Fog	-6	14:50:44	14:54:30	3.8	2.1
C059	7-Apr-10	Kilfrost DF^{sustain}	-3°C Buf	20	Composite Plate	Freezing Fog	-10	10:59:03	11:01:30	2.4	5.1
C060	7-Apr-10	Kilfrost DF^{sustain}	-3°C Buf	20	Composite Plate	Freezing Fog	-10	10:59:49	11:02:34	2.7	4.6
C073	7-Apr-10	Kilfrost DF^{sustain}	-3°C Buf	20	Composite Plate	Freezing Fog	-10	13:20:14	13:24:20	4.1	1.8
C074	7-Apr-10	Kilfrost DF^{sustain}	-3°C Buf	20	Composite Plate	Freezing Fog	-10	13:20:40	13:25:00	4.3	1.7
C087	6-Apr-10	Kilfrost DF^{sustain}	-3°C Buf	20	Composite Plate	Freezing Fog	-25	12:00:42	12:03:40	3.0	4.7
C088	6-Apr-10	Kilfrost DF^{sustain}	-3°C Buf	20	Composite Plate	Freezing Fog	-25	12:06:41	12:09:50	3.2	4.9
C101	6-Apr-10	Kilfrost DF^{sustain}	-3°C Buf	20	Composite Plate	Freezing Fog	-25	14:32:10	14:38:00	5.8	1.9
C102	6-Apr-10	Kilfrost DF^{sustain}	-3°C Buf	20	Composite Plate	Freezing Fog	-25	14:32:44	14:38:40	5.9	1.9
C115	31-Mar-10	Kilfrost DF^{sustain}	-3°C Buf	20	Composite Plate	Freezing Rain	-6	12:37:55	12:43:15	5.3	25.6
C116	31-Mar-10	Kilfrost DF^{sustain}	-3°C Buf	20	Composite Plate	Freezing Rain	-6	12:38:40	12:43:30	4.8	26.1
C129	31-Mar-10	Kilfrost DF^{sustain}	-3°C Buf	20	Composite Plate	Freezing Rain	-6	19:20:40	19:25:45	5.1	13.2
C130	31-Mar-10	Kilfrost DF^{sustain}	-3°C Buf	20	Composite Plate	Freezing Rain	-6	19:21:15	19:27:20	6.1	13.0
C143	31-Mar-10	Kilfrost DF^{sustain}	-3°C Buf	20	Composite Plate	Freezing Rain	-10	9:47:05	9:50:50	3.7	25.1
C144	31-Mar-10	Kilfrost DF^{sustain}	-3°C Buf	20	Composite Plate	Freezing Rain	-10	9:47:25	9:51:10	3.8	24.9
C157	30-Mar-10	Kilfrost DF^{sustain}	-3°C Buf	20	Composite Plate	Freezing Rain	-10	13:08:35	13:13:00	4.4	13.1
C158	30-Mar-10	Kilfrost DF^{sustain}	-3°C Buf	20	Composite Plate	Freezing Rain	-10	13:09:10	13:13:50	4.7	13.5
C171	30-Mar-10	Kilfrost DF^{sustain}	-3°C Buf	20	Composite Plate	Freezing Drizzle	-3	19:33:45	19:44:00	10.3	13.1
C172	30-Mar-10	Kilfrost DF^{sustain}	-3°C Buf	20	Composite Plate	Freezing Drizzle	-3	19:33:28	19:41:40	8.2	12.6
C185	29-Mar-10	Kilfrost DF^{sustain}	-3°C Buf	20	Composite Plate	Freezing Drizzle	-3	16:30:45	16:39:00	8.3	5.4
C186	29-Mar-10	Kilfrost DF^{sustain}	-3°C Buf	20	Composite Plate	Freezing Drizzle	-3	16:42:18	16:51:00	8.7	5.4

Table 8.6: Log of -3°C Buffer Tests – Freezing Precipitation (cont'd)

Test #	Date	Fluid Name	Fluid Dil.	Fluid Temp. (°C)	Test Surface	Precip. Type	Ambient Temp. (°C)	Start Time	Fail Time	Endur. Time (min)	Precip. Rate ($g/dm^2/h$)
C199	30-Mar-10	Kilfrost DF^{sustain}	-3°C Buf	20	Composite Plate	Freezing Drizzle	-6	17:07:00	17:13:05	6.1	12.6
C200	30-Mar-10	Kilfrost DF^{sustain}	-3°C Buf	20	Composite Plate	Freezing Drizzle	-6	17:07:30	17:13:40	6.2	13.3
C213	29-Mar-10	Kilfrost DF^{sustain}	-3°C Buf	20	Composite Plate	Freezing Drizzle	-6	13:18:20	13:24:00	5.7	4.6
C214	29-Mar-10	Kilfrost DF^{sustain}	-3°C Buf	20	Composite Plate	Freezing Drizzle	-6	13:18:50	13:24:00	5.2	5.2
C227	30-Mar-10	Kilfrost DF^{sustain}	-3°C Buf	20	Composite Plate	Freezing Drizzle	-10	15:22:22	15:27:10	4.8	13.0
C228	30-Mar-10	Kilfrost DF^{sustain}	-3°C Buf	20	Composite Plate	Freezing Drizzle	-10	15:35:55	15:39:50	3.9	12.8
C241	29-Mar-10	Kilfrost DF^{sustain}	-3°C Buf	20	Composite Plate	Freezing Drizzle	-10	9:02:40	9:08:00	5.3	4.7
C242	29-Mar-10	Kilfrost DF^{sustain}	-3°C Buf	20	Composite Plate	Freezing Drizzle	-10	9:03:10	9:10:00	6.8	4.8
C255	1-Apr-10	Kilfrost DF^{sustain}	-3°C Buf	20	Composite Box	Cold Soak Box	1	14:01:14	14:02:30	1.3	73.8
C256	1-Apr-10	Kilfrost DF^{sustain}	-3°C Buf	20	Composite Box	Cold Soak Box	1	14:11:30	14:13:11	1.7	76.5
C269	1-Apr-10	Kilfrost DF^{sustain}	-3°C Buf	20	Composite Box	Cold Soak Box	1	10:52:37	10:55:00	2.4	5.0
C270	1-Apr-10	Kilfrost DF^{sustain}	-3°C Buf	20	Composite Box	Cold Soak Box	1	11:15:30	11:16:55	1.4	5.7

8.4 Analysis and Observations – Snow

The endurance times measured in natural snow are summarized in Table 8.7. Notably, all tests had endurance times longer than 3 minutes. However, since no tests were conducted at ambient temperatures below -3.5°C and few were conducted at rates above 10 $g/dm^2/h$, these results are not representative of all operational conditions.

Table 8.7: Summary of Natural Snow Endurance Times

Test #	Rate ($g/dm^2/h$)	Ambient Temperature (°C)	Endurance Time (mins)
20	8.7	-2.9	3.2
32	3.0	-3.5	4.2
40	4.4	0.4	7.5
44	5.8	0.4	15.7
60	11.4	0.4	5.8
72	7.4	0.5	7.1
76	4.4	0.5	7.2
84	7.3	0.8	5.3
92	6.4	0.9	9.3
104	9.4	1.0	7.5
108	3.0	0.9	12.5
116	12.1	0.7	3.6
120	8.9	1.0	4.3
Minimum Endurance Time		**3.2 mins**	

Regression analysis was completed with the data set to predict endurance times from the data for colder temperatures and higher precipitation rates. Regression curves were drawn for temperatures of -3°C, -6°C, -10°C, and -25°C (see Figure 8.1). The curves were used to predict endurance times for Type I (-3°C buffer) fluids on composite surfaces in very light, light, and moderate snow. The endurance times are shown in Table 8.8.

The results indicate that when Type I (-3°C buffer) fluids are applied to a composite surface, in many cases they provide less than 3 minutes of protection time. Notably, protection is less than 3 minutes in most snowfall intensities at all temperatures below -6°C and at warmer temperatures in higher snowfall intensities.

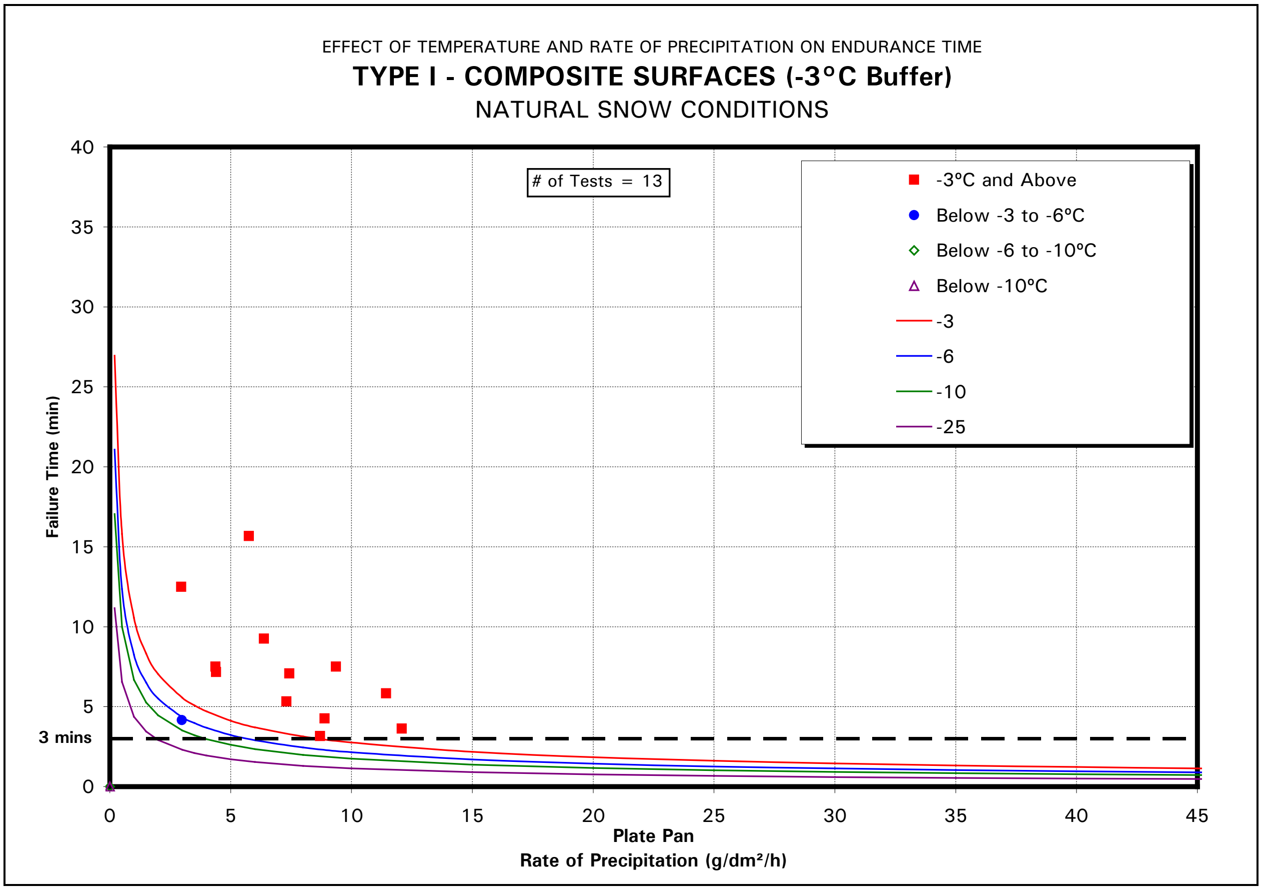

Figure 8.1: Regression Analysis – Type I (-3°C Buffer) on Composite in Snow

Table 8.8: Regression-Derived Snow Endurance Times on Composite Surfaces (-3°C Buffer)

Outside Air Temperature		Holdover Times (minutes)		
°C	°F	Very Light Snow	Light Snow	Moderate Snow
-3 and above	27 and above	4 – 6	4 – 4	2 – 4
below -3 to -6	below 27 to 21	4 – 5	3 – 4	2 – 3
below -6 to -10	below 21 to 14	2 – 3	2 – 2	1 – 2
below -10	below 14	1 – 2	1 – 1	1 – 1

8.5 Analysis and Observations – Freezing Precipitation

Each of the freezing precipitation data sets (e.g., freezing drizzle, -3°C) were subjected to regression analysis, resulting in the predicted freezing precipitation endurance times for Type I (-3°C buffer) fluids on composite surfaces shown in Table 8.9.

Of the 20 regression-derived endurance times, four were 3 minutes or less and three were between 3 and 4 minutes. Generally, the shorter endurance times were seen at lower temperatures and higher precipitation rates.

These results indicate that, in some freezing precipitation conditions, Type I (-3°C buffer) fluids applied to composite surfaces provide less than 3 minutes of protection time.

Table 8.9: Regression-Derived Freezing Precipitation Endurance Times on Composite Surfaces (-3°C Buffer)

Precipitation Type	Temp (°C)	Rate ($g/dm^2/h$)	Endurance Time (mins)
Freezing Fog	-3	2	5.8
		5	5.3
	-6	2	4.6
		5	***3.7***
	-10	2	***2.6***
		5	***4.0***
	-25	2	***3.0***
		5	5.7
Freezing Drizzle	-3	13	9.2
		5	8.4
	-6	13	6.1
		5	5.4
	-10	13	4.3
		5	5.9
Light Freezing Rain	-6	25	5.1
		13	5.6
	-10	25	***3.8***
		13	4.6
Cold Soak	+1	75	***1.5***
		5	***1.9***

8.6 Conclusions

The tests conducted in the winter of 2009-10 indicate that, in several conditions, Type I fluids mixed to a freezing point 3°C above ambient temperature and applied to a composite surface provide less than 3 minutes of protection time.

- Although limited data was collected in snow, the results of regression analysis indicate that protection time is likely to be less than 3 minutes in temperatures below -6°C and at higher precipitation rates in warmer temperatures.

- The data collected in freezing precipitation indicates that protection time is likely to be less than 3 minutes in lower temperatures (-10°C, -25°C) and at higher precipitation rates.

Although it is more likely for protection time to be less than 3 minutes when fluids are mixed to -3°C buffers and/or when fluids are applied to composite surfaces, it should also be noted that there are also conditions in which -10°C buffer fluids applied to aluminum surfaces may provide less than 3 minutes of protection time.

8.7 Recommendations

Based on the results of the research described in this section, it is recommended that changes be made to ARP4737H (7) to clearly indicate that 3 minutes of protection time may not always be provided by the first step of a two-step de/anti-icing operation.

Specifically, the following changes could be made to §6.3.3.2:

- Delete "(typically within 3 min)" from the middle of the paragraph; and

- Add the following caution note: "CAUTION: The second step shall be performed before the first step freezes. Freezing time of the first step will be dependent on weather conditions. Three minutes is a satisfactory time in most conditions. However, in heavy precipitation conditions, in cold temperatures, or for critical surfaces constructed of composite materials, this time may be less. In these situations, if necessary, the second step shall be applied area by area."

The suggested changes to ARP4737H (7) §6.3.3.2 are shown below in bolded text.

6.3.3.2 Two Step Deicing/Anti-icing

When the first step is performed with deicing fluid (see 3.3.1). The correct deicing fluid mixture is chosen with regard to OAT. The second step is performed with anti-icing fluid (see 3.3.2). This fluid and its concentration are chosen with regard to desired holdover time, which is dictated by OAT and weather conditions. The second step shall be performed before first step fluid freezes ~~***(typically within 3 min)***~~*; if necessary area by area. Use a second step spraying technique to cover completely the first step fluid (for example using the method described in 6.2.4) in a sufficient amount of second step fluid. Where re-freezing occurs following the initial treatment, both first and second step must be repeated. When a fluid conforming to AMS1428 is used to perform step two in a two step deicing/anti-icing operation, and the fluid used in step one is a Type I fluid conforming to AMS1424, a test shall be made to confirm that the combination of these fluids does not significantly reduce the WSET performance of the AMS1428 fluid.*

CAUTION: The second step shall be performed before the first step freezes. Freezing time of the first step will be dependent on weather conditions. Three minutes is a satisfactory time in most conditions. However, in heavy precipitation conditions, in cold temperatures, or for critical surfaces constructed of composite materials, this time may be less. In these situations, if necessary, the second step shall be applied area by area.

9. CONCLUSIONS

This section provides the conclusions of the composite surfaces research program drawn from testing conducted in the winters of 2004-05 through 2009-10.

9.1 Endurance Times of Type I Fluids on Composites

Testing with Type I fluids on composite surfaces over the winters of 2004-05 through 2008-09 demonstrated that endurance times of Type I fluids are shorter on composite surfaces compared to aluminum surfaces. Extensive testing conducted in the winter of 2009-10 enabled the development of composite-specific holdover times for Type I fluids. These holdover times were published by the FAA and Transport Canada for use in the winter of 2010-11.

9.2 Endurance Times of Type II/IV Fluids on Composites

Comparative tests conducted during the winter of 2005-06 in natural snow and freezing precipitation conditions indicated that, in general, endurance times of Type II, III, and IV fluids are similar on composite and aluminum surfaces. The differences in the recorded endurance times measured were not significant due to the longer fluid protection time provided by the more viscous fluids.

9.3 Endurance Times of Type III Fluids on Composites

Comparative tests were conducted with Type III fluid in the winter of 2005-06 in natural snow. The results showed Type III fluids had similar endurance times on composite and aluminum surfaces, and it was concluded that, like Type II and Type IV fluids, endurance times of Type III fluids were not affected by composite surfaces. However, research with Type I fluids in subsequent winters showed that heat plays a significant role in determining whether fluids are affected by composite surfaces. As Type III fluids are sometimes applied heated, it is felt that further research must be conducted to make a conclusion on the impact of composite surfaces on Type III endurance times.

9.4 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.

9.5 Use of -3°C Buffer Fluid on Composites

Testing in the winter of 2009-10 indicated that, in many conditions, Type I fluids mixed to a freezing point 3°C above ambient temperature and applied to a composite surface provide less than 3 minutes of protection time.

Although it is more likely for protection time to be less than 3 minutes when fluids are mixed to -3°C buffers and/or when fluids are applied to composite surfaces, it was also noted that there are conditions in which 10°C buffer fluids applied to aluminum surfaces may also provide less than 3 minutes of protection time.

10. RECOMMENDATIONS

The following recommendations were compiled following the testing conducted during the winters of 2005-06, 2006-07/2007-08, 2008-09, and 2009-10, as well as industry feedback regarding the results obtained.

10.1 Further Testing with Type III Fluids

Like Type I fluids, Type III fluids can be applied heated. Therefore, it is recommended that testing be conducted with heated Type III fluids on composite surfaces to ascertain the validity of the currently published Type III holdover times for use with Type III fluids applied heated to composite surfaces.

10.2 Full-Scale Validation of Type I Endurance Time Reduction

It is recommended that full-scale Type I endurance time testing be conducted with operational aircraft to validate the results observed on 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. Testing would investigate Type I endurance time reductions on the composite surfaces of the aircraft to validate the results obtained with the flat plate and LETE box tests. 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.

Another possibility is to conduct tests on an aircraft that has both composite and aluminum components and to observe if the composite components become contaminated prior to the aluminum components.

10.3 Aerodynamic Evaluation of Type I Endurance Time Reductions

It is 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.

10.4 Guidance for Protection Time of First-Step Fluids

It is recommended that changes be made to ARP4737H (7) to clearly indicate that 3 minutes of protection time may not always be provided by the first step of a two step de/anti-icing operation. It should be indicated that composite surfaces, fluids mixed to freezing point buffers less than 10°C, heavy precipitation rates, and cold temperatures may all contribute to shorter protection times provided by Type I fluids.

REFERENCES

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3. Federal Aviation Administration N 8900.104, *Revised FAA-Approved Deicing Program Updates, Winter 2009-2010*, November 2009.

4. Society of Automotive Engineers (SAE) Aerospace Recommended Practice 5945, *Endurance Time Tests for Aircraft Deicing/Anti-Icing Fluids: SAE Type I*, July 2007.

5. Alwaid, A., Dawson, P., Moc, N., *Generation of Holdover Times Using the New Type I Fluid Test Protocol,* APS Aviation Inc., Transportation Development Centre, Montreal, December 2002, TP 13994E, 106.

6. Ruggi, M., *Substantiation of Aircraft Ground Deicing Holdover Times in Frost Conditions,* APS Aviation Inc., Transportation Development Centre, Montreal, October 2009, TP 14938E, 120.

7. SAE International Aerospace Recommended Practice 4737H, *Aircraft Deicing/Anti-Icing Methods*, July 2008.

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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

REPORT:
EVOLUTION OF TYPE I HOLDOVER TIME GUIDELINES
1990-91 TO 2010-11

EVOLUTION OF TYPE I HOLDOVER TIME GUIDELINES 1990-91 TO 2010-11

Over the last twenty years, a significant amount of research has been carried out with Type I de/anti-icing fluids. This research has resulted in a better understanding of the capabilities and limitations of Type I fluids, especially in relation to holdover time performance.

As a result of this research, frequent changes have been made to the Type I holdover time (HOT) guidelines over the years to incorporate the research findings into operational guidance. The changes and related research have been documented in reports published almost annually by Transport Canada. However, because the information is spread over a large number of reports published over many years, until now the evolution of the Type I HOT guidelines has not been readily accessible.

This document was created in the winter of 2009-10 with the purpose of documenting the evolution of the Type I HOT guidelines (from 1990-91 to present) in a single report. This activity was spurred by the development of holdover times for Type I fluids on composite surfaces, as part of that activity was understanding the process by which the holdover times for Type I fluids on aluminum surfaces had been derived.

This report provides a summary of the changes made annually to the Type I HOT guidelines from 1990-91 to 2010-11. While it does not go into detail about the research conducted in support of the changes, it does provide references to the related Transport Canada reports in which the research is documented in detail. The reader is encouraged to refer to these reports for a more thorough understanding of the subject matter. A list of the reports referenced in this documented is provided at the end of the document.

1. Type I HOT Table for 1990-91

(Ref: Figure 1.1)

In the early 1990s, aircraft in North America were anti-iced with Type I fluids. Operators used the HOT table shown in Figure 1.1 to estimate the protection time the Type I fluids provided against winter weather contamination. The table was developed and published by the Association of European Airlines (AEA) and the International Standards Organization (ISO).

After serious air accidents in Dryden, Ontario and La Guardia, New York were both partially attributed to ground icing conditions, the Society of Automotive Engineers (SAE) took a more active role in the development of holdover times. Under its guidance, researchers began evaluating the validity of holdover times published for Type I fluids and also evaluating the potential use of European Type II fluids in North America.

OAT [°C]	WEATHER CONDITIONS				
	Frost	Freezing Fog	Steady Snow	Freezing Rain	Rain on Cold Soaked Wing
+ 0 and above	45 min.	30 min.	15 min.	5 min.	15 min.
- 0 to - 7	45 min.	15 min.	15 min.	3 min.	
- 8 and below	30 min.	15 min.	15 min.		

Figure 1.1: 1990-91 Type I Fluid Holdover Table (AEA/ISO)

2. Changes to Type I HOT Table for 1992-93

(Ref: Figure 2.1, TP 11836E)

Research conducted by APS, NRC, United Airlines and others in the early 1990s found that holdover times vary depending on precipitation intensity. The research also showed that in some cases the currently published holdover times were too long. Based on the testing, the SAE G-12 HOT Committee decided to replace the single holdover time in each cell of the Type I HOT table with a holdover time range to account for varying precipitation intensities.

The holdover time range was based on the existing single holdover time, which was kept as the upper value in the range. A reduction of 40% was applied to the existing holdover time to create the lower value in the range. This reduction was based on the research mentioned above. (It should be noted that in the early 1990s there was no documented SAE test protocol in place; the protocol was in development and therefore the holdover times were essentially "substantiated" based on the tests.)

The Type I HOT table published by SAE/ISO for use in the winter of 1992-93 is shown in Figure 2.1. It is dated September 30, 1992 and was taken from Transport Canada report, TP 11836E (1), which documents related research conducted by APS in the winter of 1992-93. The original source for the table is Federal Aviation Administration (FAA) Advisory Circular (AC) 120-58.

Table 2. Guidelines for Holdover Times Anticipated by SAE Type I and ISO Type I Fluid Mixtures as a Function of Weather Conditions and OAT.

CAUTION! THIS TABLE IS FOR USE IN DEPARTURE PLANNING ONLY AND IT SHOULD BE USED IN CONJUNCTION WITH PRETAKEOFF CHECK PROCEDURES.

Freezing Point of Type I fluid mixture used must be at least 10°C (18°F) below OAT.

OAT		Approximate Holdover Times Anticipated Under Various Weather Conditions (hours:minutes)				
°C	°F	FROST	FREEZING FOG	SNOW	FREEZING RAIN	RAIN ON COLD SOAKED WING
0 & above	32 & above	0:18-0:45	0:12-0:30	0:06-0:15	0:02-0:05	0:06-0:15
below 0 to -7	below 32 to 19	0:18-0:45	0:06-0:15	0:06-0:15	0:01-0:03	CAUTION! Clear ice may require touch for confirmation
below -7	below 19	0:12-0:30	0:06-0:15	0:06-0:15		

THIS TABLE DOES NOT APPLY TO OTHER THAN SAE OR ISO TYPE I FPD FLUIDS.

THE RESPONSIBILITY FOR THE APPLICATION OF THESE DATA REMAINS WITH THE USER.

Figure 2.1: 1992-93 Type I Fluid Holdover Table (SAE/ISO)

3. Changes to Type I HOT Guidelines for 1995-96

(Ref: Figure 3.1, TP 12654E)

Based on a search of available documentation, it appears that no changes were made to the Type I HOT guidelines for 1993-94 and 1994-95 operations and that the table shown in Figure 2.1 was used in those winters.

However, several changes were made to the Type I HOT guidelines for 1995-96 operations. The changes are listed below and are also documented in Transport Canada report, TP 12654E (2), which includes related supporting research.

- **Precipitation Columns / Holdover Times**: The *Freezing Rain* column was replaced with two new columns, *Freezing Drizzle* and *Light Freezing Rain*. These precipitation types are differentiated by their respective rates of precipitation and droplet sizes. The holdover times for freezing drizzle and light freezing rain were based on results from testing conducted in the winter of 1994-95. Holdover times were notably different:
    - Freezing Drizzle: 5-8 minutes; and
    - Light Freezing Rain: 2-5 minutes.
- **Notes**: Notes were added to the *Freezing Drizzle* and *Light Freezing Rain* below -7°C cells to indicate the approximate holdover times for temperatures between -7°C and -10°C:
    - Freezing Drizzle: 5-8 minutes; and
    - Light Freezing Rain: 2-5 minutes.
- **No changes** were made to temperature ranges or cautions.

The Type I HOT table published by SAE/ISO for use in the winter of 1995-96 is shown in Figure 3.1.

SAE/ISO HOLDOVER TIME TABLE FOR TYPE I FLUIDS USED IN 1995/96

CAUTION: THIS TABLE IS FOR USE IN DEPARTURE PLANNING ONLY AND IT SHOULD BE USED IN CONJUNCTION WITH PRETAKEOFF CHECK PROCEDURES.

TYPE I

Freezing Point of Type I Fluid Mixture used must be at least 10°C (18°F) below OAT.

OAT		Approximate Holdover Times Anticipated Under Various Weather Conditions (hours:minutes)					
					PROPOSED		
°C	°F	FROST	FREEZING FOG	SNOW	FREEZING DRIZZLE	LIGHT FRZ RAIN	RAIN ON COLD SOAKED WING
above 0	above 32	0:18-0:45 S	0:12-0:30 NS	0:06-0:15 S	0:05-0:08 S	0:02-0:05 S	0:06-0:15 NS
0 to -7	32 to 19	0:18-0:45 S	0:06-0:15 S	0:06-0:15 S	0:05-0:08 S	0:02-0:05 S	CAUTION! clear ice may require touch for confirmation
below -7	below 19	0:12-0:30 S	0:06-0:15 S	0:06-0:15 S	** S	*** S	

This table does not apply to other than SAE or ISO Type I FPD fluids.

The responsibility for the application of these data remains with the user.

**** Approximate Holdover Time for Freezing Drizzle is between 5 to 8 min below -7°C to -10°C.**

***** Approximate Holdover Time for Light Freezing Rain is between 2 to 5 min below -7°C to -10°C.**

S = Substantiated
NS = Not substantiated

Figure 3.1: 1995-96 Type I Fluid Holdover Table (SAE/ISO)

4. Changes to Type I HOT Guidelines for 1996-97

(Ref: Figure 4.1, TP 12896E)

Several changes were made to the Type I HOT guidelines for 1996-97 operations. The changes are listed below and are also documented in Transport Canada report, TP 12896E (3), which includes related supporting research.

- **Temperature Ranges**: The *0°C to -7°C* temperature row was modified to *0°C to -10°C* because of the -10°C cut-off for freezing drizzle and light freezing rain. The decision was based on SAE G-12 meetings in 1995.
- **Notes:** A note was added to the *Freezing Drizzle* column indicating that light freezing rain holdover times should be used if positive identification of freezing drizzle is not possible.
- **Cautions:** A caution note was added indicating that holdover times will be reduced during heavy precipitation.
- **Holdover Times**: The holdover times for rain on cold soaked wing were reduced to 2-5 minutes based on 1996 SAE G-12 meetings in Denver.
- **No changes** were made to the precipitation columns.

The Type I HOT guidelines published by SAE for use in the winter of 1996-97 are shown in Figure 4.1.

Guideline for Holdover Times Anticipated for SAE Type I and ISO Type I Fluid Mixtures as a Function of Weather Conditions and OAT.

The responsibility for the application of these data remains with the user.

SAE TYPE I

OAT		Approximate Holdover Times Under Various Weather Conditions (hours:minutes)					
°C	**°F**	***FROST**	**FREEZING FOG**	**SNOW**	****FREEZING DRIZZLE**	**LIGHT FRZ RAIN**	**RAIN ON COLD SOAKED WING**
above 0º	**above 32º**	0:45 **S**	0:12-0:30 **NS**	0:06-0:15 **S**	0:05-0:08 **S**	0:02-0:05 **S**	0:02-0:05 **NS**
0 to -10	**32 to 14**	0:45 **S**	0:06-0:15 **S**	0:06-0:15 **S**	0:05-0:08 **S**	0:02-0:05 **S**	
below -10	**below 14**	0:45 **S**	0:06-0:15 **S**	0:06-0:15 **S**			

ºC = Degrees Celsius
ºF = Degrees Fahrenheit
OAT = Outside Air Temperature
FP = Freezing Point

* During conditions that apply to aircraft protection for ACTIVE FROST
** Use light freezing rain holdover times if positive identification of freezing drizzle is not possible

SAE Type I Fluid / Water Mixture is selected so that the FP of the mixture is at least 10°C (18°F) below OAT.

CAUTION: THE TIME OF PROTECTION WILL BE SHORTENED IN HEAVY WEATHER CONDITIONS, HEAVY PRECIPITATION RATES OR HIGH MOISTURE CONTENT. HIGH WIND VELOCITY OR JET BLAST MAY REDUCE HOLDOVER TIME BELOW THE LOWEST TIME STATED IN THE RANGE. HOLDOVER TIME MAY ALSO BE REDUCED WHEN AIRCRAFT SKIN TEMPERATURE IS LOWER THAN OAT. THE ONLY ACCEPTABLE DECISION CRITERIA TIME IS THE SHORTEST TIME WITHIN THE APPLICABLE HOLDOVER TIMETABLE CELL.

S = **Substantiated**
NS = **Not Substantiated**

Figure 4.1: 1996-97 Type I Fluid Holdover Guidelines (SAE/ISO)

5. Changes to Type I HOT Guidelines for 1997-98

(Ref: Figure 5.1, TP 13131E)

Several changes were made to the Type I HOT guidelines for 1997-98 operations. The changes are listed below and are also documented in Transport Canada report, TP 13131E (4) which includes related supporting research.

- **Cautions**: At the Chicago 1997 SAE Holdover Time Subcommittee meeting, the Airline Pilot Association (ALPA) requested a caution statement be added to the bottom of all holdover time tables indicating that ground de/anti-icing fluids do not provide protection during flight. This caution statement was added.

- **No changes** were made to holdover times, precipitation columns, temperature ranges or notes.

The Type I HOT guidelines published by Transport Canada for use in the winter of 1997-98 are shown in Figure 5.1.

TABLE 1

SAE TYPE I FLUID HOLDOVER TABLE

Guideline for Holdover Times Anticipated for SAE Type I Fluid Mixture as a Function of Weather Conditions and OAT

THE RESPONSIBILITY FOR THE APPLICATION OF THESE DATA REMAINS WITH THE USER

OAT		Approximate Holdover Times Under Various Weather Conditions (hours : minutes)					
°C	°F	*FROST	FREEZING FOG	SNOW	**FREEZING DRIZZLE	LIGHT FREEZING RAIN	RAIN ON COLD SOAKED WING
above 0°	above 32°	0:45	0:12 - 0:30	0:06 - 0:15	0:05 - 0:08	0:02 - 0:05	0:02 - 0:05
0 to -10	32 to 14	0:45	0:06 - 0:15	0:06 - 0:15	0:05 - 0:08	0:02 - 0:05	
below -10	below 14	0:45	0:06 - 0:15	0:06 - 0:15			

°C = Degrees Celsius
°F = Degrees Fahrenheit
OAT = Outside Air Temperature
FP = Freezing Point

* During conditions that apply to aircraft protection for ACTIVE FROST
**Use light freezing rain holdover times if positive identification of freezing drizzle is not possible.

SAE Type I Fluid / Water Mixture is selected so that the FP of the mixture is at least 10° C(18° F) below OAT

CAUTION: THE TIME OF PROTECTION WILL BE SHORTENED IN HEAVY WEATHER CONDITIONS, HEAVY PRECIPITATION RATES OR HIGH MOISTURE CONTENT. HIGH WIND VELOCITY OR JET BLAST MAY REDUCE HOLDOVER TIME BELOW THE LOWEST TIME STATED IN THE RANGE. HOLDOVER TIME MAY ALSO BE REDUCED WHEN AIRCRAFT SKIN TEMPERATURE IS LOWER THAN OAT. THE ONLY ACCEPTABLE DECISION CRITERIA TIME IS THE SHORTEST TIME WITHIN THE APPLICABLE HOLDOVER TIMETABLE CELL.

FLUIDS USED DURING GROUND DEICING ARE NOT INTENDED FOR AND DO NOT PROVIDE ICE PROTECTION DURING FLIGHT.

TRANSPORT CANADA, JULY 1997

Figure 5.1: 1997-98 Type I Fluid Holdover Guidelines (Transport Canada)

6. Changes to Type I HOT Guidelines for 1998-99

(Ref: Figure 6.1, TP 13318E)

Although no changes were made to the Type I HOT guidelines for 1998-99, a new Type I HOT table was produced. The Type I HOT guidelines published by Transport Canada for use in the winter of 1998-99 are shown in Figure 6.1.

Holdover time research that was conducted in the related winter (1997-98) is documented in Transport Canada report, TP 13318E (5).

TABLE 1

SAE TYPE I FLUID HOLDOVER TABLE

Guideline for Holdover Times Anticipated for SAE Type I Fluid Mixture as a Function of Weather Conditions and OAT

THE RESPONSIBILITY FOR THE APPLICATION OF THESE DATA REMAINS WITH THE USER

OAT		Approximate Holdover Times Under Various Weather Conditions (hours : minutes)					
°C	°F	*FROST	FREEZING FOG	SNOW	**FREEZING DRIZZLE	LIGHT FREEZING RAIN	RAIN ON COLD SOAKED WING
above 0°	above 32°	0:45	0:12 - 0:30	0:06 - 0:15	0:05 - 0:08	0:02 - 0:05	0:02 - 0:05
0 to -10	32 to 14	0:45	0:06 - 0:15	0:06 - 0:15	0:05 - 0:08	0:02 - 0:05	
below -10	below 14	0:45	0:06 - 0:15	0:06 - 0:15			

°C = Degrees Celsius
°F = Degrees Farenheit
OAT = Outside Air Temperature
FP = Freezing Point

* During conditions that apply to aircraft protection for ACTIVE FROST
**Use light freezing rain holdover times if positive identification of freezing drizzle is not possible.

SAE Type I Fluid / Water Mixture is selected so that the FP of the mixture is at least 10° C(18° F) below OAT

CAUTION: THE TIME OF PROTECTION WILL BE SHORTENED IN HEAVY WEATHER CONDITIONS, HEAVY PRECIPITATION RATES OR HIGH MOISTURE CONTENT. HIGH WIND VELOCITY OR JET BLAST MAY REDUCE HOLDOVER TIME BELOW THE LOWEST TIME STATED IN THE RANGE. HOLDOVER TIME MAY ALSO BE REDUCED WHEN AIRCRAFT SKIN TEMPERATURE IS LOWER THAN OAT. THE ONLY ACCEPTABLE DECISION CRITERIA TIME IS THE SHORTEST TIME WITHIN THE APPLICABLE HOLDOVER TIME TABLE CELL.

FLUIDS USED DURING GROUND DEICING ARE NOT INTENDED FOR AND DO NOT PROVIDE ICE PROTECTION DURING FLIGHT

TRANSPORT CANADA : AUGUST 1998

Figure 6.1: 1998-99 Type I Fluid Holdover Guidelines (Transport Canada)

7. Changes to Type I HOT Guidelines for 1999-2000

(Ref: Figure 7.1, TP 13477E)

Several changes were made to the Type I HOT guidelines for 1999-2000 operations. The changes are listed below and are also documented in Transport Canada report, TP 13477E (6), which includes related supporting research.

- **Precipitation Columns / Notes**: An new column, *Other*, was added based on discussions at the SAE G-12 HOT Committee meeting in Toronto. A note was added to the other column to indicate "other" precipitation conditions include heavy snow, snow pellets, snow grains, ice pellets, moderate and heavy freezing rain, and hail.

- **Cautions**: A cautionary note was added stating that no holdover time guidelines currently exist for cells with no holdover times.

- **No changes** were made to holdover times or temperature ranges.

The Type I HOT guidelines published by Transport Canada for use in the winter of 1999-2000 are shown in Figure 7.1.

SAE TYPE I FLUID HOLDOVER TABLE

Guideline for Holdover Times Anticipated for SAE Type I Fluid Mixture as a Function of Weather Conditions and OAT

THE RESPONSIBILITY FOR THE APPLICATION OF THESE DATA REMAINS WITH THE USER

OAT		Approximate Holdover Times Under Various Weather Conditions (hours:minutes)						
°C	°F	Frost[1]	Freezing Fog	Moderate Snow	Freezing Drizzle[2]	Light Freezing Rain	Rain on Cold Soaked Wing	Other[3]
above 0°	above 32°	0:45	0:12 - 0:30	0:06 - 0:15	0:05 - 0:08	0:02 - 0:05	0:02 - 0:05	
0 to -10	32 to 14	0:45	0:06 - 0:15	0:06 - 0:15	0:05 - 0:08	0:02 - 0:05	CAUTION : No holdover time guidelines exist	
below -10	below 14	0:45	0:06 - 0:15	0:06 - 0:15				

°C = Degrees Celsius OAT = Outside Air Temperature
°F = Degrees Fahrenheit FP = Freezing Point

NOTES
1 During conditions that apply to aircraft protection for ACTIVE FROST.
2 Use light freezing rain holdover times if positive identification of freezing drizzle is not possible.
3 Heavy snow, snow pellets, snow grains, ice pellets, moderate and heavy freezing rain, and hail.

SAE Type I Fluid / Water Mixture is selected so that the FP of the mixture is at least 10°C (18°F) below OAT.

CAUTIONS:
THE TIME OF PROTECTION WILL BE SHORTENED IN HEAVY WEATHER CONDITIONS, HEAVY PRECIPITATION RATES OR HIGH MOISTURE CONTENT. HIGH WIND VELOCITY OR JET BLAST MAY REDUCE HOLDOVER TIME BELOW THE LOWEST TIME STATED IN THE RANGE. HOLDOVER TIME MAY ALSO BE REDUCED WHEN AIRCRAFT SKIN TEMPERATURE IS LOWER THAN OAT.
THE ONLY ACCEPTABLE DECISION CRITERIA TIME IS THE SHORTEST TIME WITHIN THE APPLICABLE HOLDOVER TIME TABLE CELL.

FLUIDS USED DURING GROUND DEICING ARE NOT INTENDED FOR AND DO NOT PROVIDE ICE PROTECTION DURING FLIGHT.

TRANSPORT CANADA, AUGUST 1999

Figure 7.1: 1999-2000 Type I Fluid Holdover Guidelines (Transport Canada)

8. Changes to Type I HOT Guidelines for 2000-01

(Ref: Figure 8.1, TP 13659E)

Several changes were made to the Type I HOT guidelines for 2000-01 operations. The changes are listed below and are also documented in Transport Canada report, TP 13659E (7), which includes related supporting research.

- **Notes**: At the SAE G-12 Holdover Time Subcommittee meeting in Toulouse May 2000, it was decided a note would be added to the snow column indicating it includes snow grains.
- **Holdover Times**: Changes were made to the upper freezing fog holdover times due to a specific precipitation rate of 2 g/dm²/h being used for the first time in 1999-2000 testing.
    - *0°C to -10°C*: At the SAE G-12 Holdover Time Committee meeting in Toulouse in May 2000, the holdover time range in this cell was reduced from 6-15 minutes to 6-11 minutes based on results from testing in July 1999; and
    - *Below -10°C:* At the same May 2000 meeting, the holdover time range in this cell was reduced from 6-15 minutes to 6-9 minutes based on results from testing in July 1999.
- **Holdover Times**: Changes were made to snow holdover times as a result of refined analysis protocols and data collected in the winter of 1999-2000 (by APS and AMIL in simulated and artificial snow; tests conducted on flat plates) that showed shorter holdover times than were currently published. This data was presented at the May 2000 SAE G-12 Holdover Time Committee meeting and resulted in several changes.
    - *Above 0°C:* 7-12 minutes;
    - *0°C to -10°C:* 3-6 minutes; and
    - *Below -10°C:* 2-4 minutes.
- **No changes** were made to temperature ranges, precipitation columns or cautions.

The Type I HOT guidelines published by Transport Canada for use in the winter of 2000-01 are shown in Figure 8.1.

TABLE 5.67

SAE TYPE I FLUID HOLDOVER TIME GUIDELINES

For Use in 2000-2001

OAT		Approximate Holdover Times Under Various Weather Conditions (hours:minutes)						
°C	°F	*FROST	FREEZING FOG	SNOW ◊	**FREEZING DRIZZLE	LIGHT FRZ RAIN	RAIN ON COLD SOAKED WING	OTHER***
above 0°	above 32°	0:45	0:12-0:30	0:07-0:12	0:05-0:08	0:02-0:05	0:02-0:05	
0 to -10	32 to 14	0:45	0:06-0:11	0:03-0:06	0:05-0:08	0:02-0:05	CAUTION No holdover time	
below -10	below 14	0:45	0:06-0:09	0:02-0:04			guidelines exist	

* During conditions that apply to aircraft protection for ACTIVE FROST.
** Use light freezing rain holdover times if positive identification of freezing drizzle is not possible.
*** Heavy snow, snow pellets, ice pellets, moderate and heavy freezing rain, and hail.
◊ Snow includes snow grains

Figure 8.1: 2000-01 Type I Fluid Holdover Guidelines

9. Changes to Type I HOT Guidelines for 2001-02

(Ref: Figure 9.1, TP 13826E)

Several changes were made to the Type I HOT guidelines for 2001-02 operations. The changes are listed below and are also documented in Transport Canada report, TP 13826E (8), which includes related supporting research.

- **Holdover Times**: There was discussion at the May 2001 SAE G-12 Committee about the validity of the test protocol for measuring holdover times of Type I fluids. Specifically, it was felt that fluids should be applied heated, as they are in operations. As a result, Transport Canada and the FAA elected to reinsert the previous Type I holdover times along with the newer 2000-01 holdover times on an "interim basis" until an appropriate Type I fluid protocol was developed to account for the affect of heat and data could be collected with the new protocol.
- **Notes**: A note was added to the snow and frost columns indicating that the "old" holdover times could be used if fluids were applied at 60°C and a minimum quantity of fluid was applied.
- **No changes** were made to temperature ranges, precipitation columns or cautions.

The Type I HOT guidelines published by Transport Canada for use in the winter of 2001-02 are shown in Figure 9.1.

SAE TYPE I[5] FLUID HOLDOVER GUIDELINES FOR WINTER 2001-2002

THE RESPONSIBILITY FOR THE APPLICATION OF THESE DATA REMAINS WITH THE USER

OAT		Approximate Holdover Times Under Various Weather Conditions (hours:minutes)						
°C	°F	Frost[2]	Freezing Fog	Snow	Freezing Drizzle[3]	Light Freezing Rain	Rain on Cold Soaked Wing	Other[4]
above 0	above 32	0:45	0:12 - 0:30	0:06 - 0:15[1] *0:07 - 0:12*	0:05 - 0:08	0:02 - 0:05	0:02 - 0:05	
0 to -10	32 to 14	0:45	0:06 - 0:15[1] *0:06 - 0:11*	0:06 - 0:15[1] *0:03 - 0:06*	0:05 - 0:08	0:02 - 0:05	CAUTION: No holdover time guidelines exist	
below -10	below 14	0:45	0:06 - 0:15[1] *0:06 - 0:09*	0:06 - 0:15[1] *0:02 - 0:04*				

°C = Degrees Celsius
°F = Degrees Fahrenheit
OAT = Outside Air Temperature
FP = Freezing Point

NOTES
1 To use these times, the fluid must be heated to a minimum temperature providing 60°C (140°F) at the nozzle and an average rate of at least 1 litre/m^2 (2 gals/100 ft^2) must be applied to deiced surfaces, OTHERWISE THE ITALICIZED TIMES MUST BE USED.
2 During conditions that apply to aircraft protection for ACTIVE FROST.
3 Use light freezing rain holdover times if positive identification of freezing drizzle is not possible.
4 Heavy snow, snow pellets, ice pellets, moderate and heavy freezing rain, and hail.
5 Type I Fluid / Water Mixture is selected so that the FP of the mixture is at least 10°C (18°F) below OAT.

CAUTIONS:
- The time of protection will be shortened in heavy weather conditions, heavy precipitation rates or high moisture content. High wind velocity or jet blast may reduce holdover time below the lowest time stated in the range. Holdover time may also be reduced when aircraft skin temperature is lower than OAT.
- The only acceptable decision criteria time is the shortest time within the applicable holdover time table cell.
- Fluids used during ground deicing do not provide ice protection during flight.

Figure 9.1: 2001-02 Type I Fluid Holdover Guidelines (Transport Canada)

10. Changes to Type I HOT Guidelines for 2002-03

(Ref: Figure 10.1, TP 13827E, TP 13994E, TP 13991E, TP 13993E)

Testing was conducted over the winter of 2001-02 using the new SAE test protocol for holdover time evaluation of Type I fluids. The new test protocol required tests be conducted with fluids heated to 60°C and applied to leading edge thermal equivalent boxes. Several Transport Canada reports document related research and development activities:

- TP 13827E (9): Documents the development of the new test protocol;
- TP 13994E (10): Documents testing conducted with the new protocol and analysis completed to determine holdover times from the data; and
- TP 13991E (11): Documents related holdover time testing conducted in the winter of 2001-02.

This test results were proposed and accepted at the SAE G-12 HOT Committee meeting in Frankfurt in May 2002. This resulted in several significant changes being made to the Type I HOT guidelines for 2001-02 operations. Additionally, research on the frequency of occurrence of weather conditions, documented in TP 13993E (12), resulted in additional changes being. All of the changes made to the Type I HOT guidelines for 2001-02 operations are listed below.

- **Temperature Ranges**: The temperature ranges were changed to increase the operational usability of Type I fluids (the existing *0°C to -10°C* row was found to incur significant operational penalties). The new temperature ranges were: *Above -3°C*; *-3°C to -10°C*; and *Below -10°C*.

- **Precipitation columns**: The *Snow* column was expanded into two columns, *Light Snow* and *Moderate Snow*, to increase the operational usability of Type I fluids. (As light snow was found to account for 73% of snow events, moderate for 24%, and heavy for 3%, using moderate snow as the basis for snow holdover times imposed frequent operational penalties). Light snow was defined as 3 to 10 g/dm^2/h; moderate snow as 10 to 25 g/dm^2/h.

- **Holdover Times**: New holdover times were added to account for the changes made to temperature ranges and precipitation columns noted above and to incorporate results of new testing. These included:
  - *Light Snow*, *Above -3°C*: 11-22 minutes;
  - *Light Snow*, *-3°C to -10°C*: 6-13 minutes;
  - *Light Snow*, *Below -10°C*: 4-8 minutes;
  - *Moderate Snow*, *Above -3°C*: 6-11 minutes;
  - *Moderate Snow*, *-3°C to -10°C*: 4-6 minutes;
  - *Moderate Snow*, *Below -10°C*: 2-4 minutes.

- *Freezing Fog, Above -3°C*: 11-17 minutes;
- *Freezing Fog, -3°C to -10°C*: 6-10 minutes;
- *Freezing Fog, Below -10°C*: 5-9 minutes; and
- *Freezing Drizzle, Above -3°C*: 9-13 minutes.

- **Notes**: A note was added to indicate the light snow range is based on precipitation rates of 1.0 to 0.3 mm/hr liquid water equivalent.

- **No changes** were made to cautions.

The Type I HOT guidelines published by Transport Canada for use in the winter of 2002-03 are shown in Figure 10.1. It should be noted the Type I HOT guidelines published by the FAA were slightly different than those published by Transport Canada. The differences included:

- **Temperature ranges**: In place of the *-3 to -10°C* row, the FAA included two rows, *-3 to -6°C* and *-7 to -10°C*. Holdover times were provided for all precipitation columns for the -6°C row.

- **Light Snow Precipitation Rate Boundaries**: FAA used a higher rate of precipitation as the lower limit for light snow (5 $g/dm^2/h$ compared to Transport Canada's 3 $g/dm^2/h$). This resulted in slightly shorter upper holdover time values in the light snow cells.

TRANSPORT CANADA HOLDOVER TIME GUIDELINES

TABLE 1S-3gm

SAE TYPE I[5] FLUID HOLDOVER GUIDELINES FOR WINTER 2002-2003

THE RESPONSIBILITY FOR THE APPLICATION OF THESE DATA REMAINS WITH THE USER

OAT		Approximate Holdover Times Under Various Weather Conditions (minutes)							
°C	°F	Frost[2]	Freezing Fog	Light Snow[1]	Moderate Snow[1]	Freezing Drizzle[3]	Light Freezing Rain	Rain on Cold Soaked Wing	Other[4]
above -3	above 27	45	11 - 17	11 - 22[6]	6 - 11	9 - 13	2 - 5	2 - 5	
-3 to -10	27 to 14	45	6 - 10	6 - 13[6]	4 - 6	5 - 8	2 - 5	CAUTION: No holdover time guidelines exist	
below -10	below 14	45	5 - 9	4 - 8[6]	2 - 4				

°C = Degrees Celsius °F = Degrees Fahrenheit OAT = Outside Air Temperature FP = Freezing Point

NOTES
1 To use these times, the fluid must be heated to a minimum temperature providing 60°C (140°F) at the nozzle and an average rate of at least 1 L/m² (2 gal./100 sq. ft.) must be applied to deiced surfaces, OTHERWISE TIMES WILL BE SHORTER.
2 During conditions that apply to aircraft protection for ACTIVE FROST.
3 Use light freezing rain holdover times if positive identification of freezing drizzle is not possible.
4 Heavy snow, snow pellets, ice pellets, moderate and heavy freezing rain, and hail.
5 Type I Fluid / Water Mixture is selected so that the FP of the mixture is at least 10°C (18°F) below OAT.
6 The light snow range is based on precipitation rates from 1.0 mm/hr to 0.3 mm/hr liquid water equivalent.

CAUTIONS
- **The time of protection will be shortened in heavy weather conditions, heavy precipitation rates, or high moisture content. High wind velocity or jet blast may reduce holdover time below the lowest time stated in the range. Holdover time may also be reduced when aircraft skin temperature is lower than OAT.**
- **The only acceptable decision criteria time is the shortest time within the applicable holdover time table cell.**
- **Fluids used during ground deicing do not provide ice protection during flight.**

Figure 10.1: 2002-03 Type I Fluid Holdover Guidelines

11. Changes to Type I HOT Guidelines for 2003-04

(Ref: Figure 11.1, TP 14144E, TP 14146E, and TP 14151E)

Several reports document research conducted in support of the 2003-04 Type I HOT guidelines:

- TP 14144E (13): Documents the changes made to the HOT guidelines and much of the supporting research, notably the testing conducted with Type I fluids at -6°C;
- TP 14146E (14): Documents research on the frequency of occurrence of weather conditions; and
- TP 14151E (15): Documents research on the relationship between snowfall intensity and visibility and changes made to the visibility table published in the HOT guidelines (the table is used in conjunction with the Type I guidelines and determines which snow column should be used).

The changes made to the Type I HOT guidelines for 2003-04 operations are listed below.

- **Temperature Ranges**: The temperature ranges were further expanded to increase the operational usability of Type I fluids and to harmonize the Transport Canada and FAA guidelines. The temperature ranges used by both organizations in 2003-04 were: *-3°C and Above*; *Below -3°C to -6°C*; *Below -6°C to -10°C* and *Below -10°C*.
- **Precipitation columns**: The *Light Snow* column was expanded into two columns, *Very Light Snow* and *Light Snow*, to further increase the operational usability of Type I fluids (research showed very light snow accounts for 53 percent of snow events). This was following a meeting of the SAE G-12 HOT Committee held in Vancouver in May 2003. The precipitation boundaries for light snow were changed to 4 to 10 $g/dm^2/h$. The very light snow column was given one boundary at 4 $g/dm^2/h$.
- **Holdover Times**: New holdover times were added for the new -6°C row, and the new *Very Light Snow* column. The upper values in the *Light Snow* cells were changed to account for the change in the precipitation rate boundary. The resulting holdover times were:
  - *Very Light Snow*, *-3°C and Above*: 18 minutes;
  - *Very Light Snow*, *Below -3°C to -6°C*: 14 minutes;
  - *Very Light Snow*, *Below -6°C to -10°C*: 11 minutes;
  - *Very Light Snow*, *Below -10°C*: 7 minutes;
  - *Light Snow*, *-3°C and Above*: 11-28 minutes;

- *Light Snow*, *Below -3°C to -6°C*: 8-14 minutes;
- *Light Snow*, *Below -6°C to -10°C*: 6-11 minutes;
- *Light Snow*, *Below -10°C*: 4-7 minutes;
- *Moderate Snow*, *Below -6°C to -10°C*: 5-8 minutes;
- *Freezing Fog*, *Below -6°C to -10°C*: 8-13 minutes;
- *Freezing Drizzle*, *Below -6°C to -10°C*: 5-9 minutes;
- *Light Freezing Rain*, *Below -6°C to -10°C*: 4-6 minutes;

- **Holdover Times**: Two other changes were made to holdover times.
  - *Freezing Drizzle*, *-6°C to -10°C*: Data for this cell was re-evaluated and proper rounding techniques employed to produce a new holdover time range of 4-7 minutes.
  - *Light Freezing Rain*, *-3°C and Above*: Tests can not be conducted in this condition due to the latent heat of freezing in calm test conditions. Previously, holdover times obtained from testing at -10°C were used were used in this cell; these were replaced with the holdover times obtained from testing at -6°C, i.e. 4-6 minutes.

- **Notes**: The note for precipitation rates for light snow was removed.

The Type I HOT guidelines published by Transport Canada for use in the winter of 2003-04 are shown in Figure 11.1. It should be noted the Type I HOT guidelines published by the FAA were slightly different than those published by Transport Canada. The differences included:

- **Temperature ranges**: In place of the *-3 to -10°C* row, the FAA included two rows, *-3 to -6°C* and *-7 to -10°C*. Holdover times were provided for all precipitation columns for the -6°C row.

- **Very Light Snow Holdover Times**: Whereas Transport Canada provided a single holdover time for *Very Light Snow* cells, the FAA provided a holdover time range, with the lower value being equivalent to the Transport Canada value and the upper value being calculated for a precipitation rate of 3 $g/dm^2/h$.

- **Light Freezing Rain Holdover Times**: The FAA elected to retain 2-5 minutes in all *Light Freezing Rain* cells, despite Transport Canada electing to incorporate new test data and using 4-6 minutes in the two warmer temperature ranges. This was likely a result of the five minute rule that the FAA allows operators to use in conjunction with a pre-takeoff contamination check.

SAE TYPE I[5] FLUID HOLDOVER GUIDELINES FOR WINTER 2003-2004

THE RESPONSIBILITY FOR THE APPLICATION OF THESE DATA REMAINS WITH THE USER

OAT		Approximate Holdover Times Under Various Weather Conditions (minutes)								
°C	°F	Frost[2]	Freezing Fog	Very Light Snow[1]	Light Snow[1]	Moderate Snow[1]	Freezing Drizzle[3]	Light Freezing Rain	Rain on Cold Soaked Wing	Other[4]
-3 and above	27 and above	45	11 – 17	18	11 – 18	6 – 11	9 – 13	4 – 6	2 – 5	
below -3 to -6	below 27 to 21	45	8 – 13	14	8 – 14	5 – 8	5 – 9	4 – 6		
below -6 to -10	below 21 to 14	45	6 – 10	11	6 – 11	4 – 6	4 – 7	2 – 5		CAUTION: No holdover time guidelines exist
below -10	below 14	45	5 – 9	7	4 – 7	2 – 4				

°C = Degrees Celsius °F = Degrees Fahrenheit OAT = Outside Air Temperature FP = Freezing Point

NOTES

1. To use these times, the fluid must be heated to a minimum temperature providing 60°C (140°F) at the nozzle and an average rate of at least 1 L/m² (2 gal./100 sq. ft.) must be applied to deiced surfaces, OTHERWISE TIMES WILL BE SHORTER.
2. During conditions that apply to aircraft protection for ACTIVE FROST.
3. Use light freezing rain holdover times if positive identification of freezing drizzle is not possible.
4. Heavy snow, snow pellets, ice pellets, moderate and heavy freezing rain, and hail.
5. Type I Fluid / Water Mixture is selected so that the FP of the mixture is at least 10°C (18°F) below OAT.

CAUTIONS

- **The time of protection will be shortened in heavy weather conditions, heavy precipitation rates, or high moisture content. High wind velocity or jet blast may reduce holdover time below the lowest time stated in the range. Holdover time may also be reduced when aircraft skin temperature is lower than OAT.**
- **The only acceptable decision criteria time is the shortest time within the applicable holdover time table cell.**
- **Fluids used during ground deicing do not provide ice protection during flight.**

Figure 11.1: 2003-04 Type I Fluid Holdover Guidelines

12. Changes to Type I HOT Guidelines for 2004-05

(Ref: Figure 12.1, TP 14374E)

No changes were made to the Type I HOT guidelines for 2004-05. The Type I HOT guidelines published by Transport Canada for use in the winter of 2007-08 are shown in Figure 12.1.

Holdover time research conducted in the related winter (2003-04) is documented in Transport Canada report, TP 14374E (16).

SAE TYPE I[5] FLUID HOLDOVER GUIDELINES FOR WINTER 2004-2005

THE RESPONSIBILITY FOR THE APPLICATION OF THESE DATA REMAINS WITH THE USER

OAT[6]		Approximate Holdover Times Under Various Weather Conditions (minutes)								
°C	°F	Frost[2]	Freezing Fog	Very Light Snow[1]	Light Snow[1]	Moderate Snow[1]	Freezing Drizzle[3]	Light Freezing Rain	Rain on Cold Soaked Wing	Other[4]
-3 and above	27 and above	45	11 – 17	18	11 – 18	6 – 11	9 – 13	4 – 6	2 – 5	
below -3 to -6	below 27 to 21	45	8 – 13	14	8 – 14	5 – 8	5 – 9	4 – 6	CAUTION: No holdover time guidelines exist	
below -6 to -10	below 21 to 14	45	6 – 10	11	6 – 11	4 – 6	4 – 7	2 – 5		
below -10	below 14	45	5 – 9	7	4 – 7	2 – 4				

°C = Degrees Celsius °F = Degrees Fahrenheit OAT = Outside Air Temperature FP = Freezing Point

NOTES

1. To use these times, the fluid must be heated to a minimum temperature providing 60°C (140°F) at the nozzle and an average rate of at least 1 litre/m^2 (2 gal./100 sq. ft.) must be applied to deiced surfaces, OTHERWISE TIMES WILL BE SHORTER.
2. During conditions that apply to aircraft protection for ACTIVE FROST.
3. Use light freezing rain holdover times if positive identification of freezing drizzle is not possible.
4. Heavy snow, snow pellets, ice pellets, moderate and heavy freezing rain, and hail.
5. Type I Fluid / Water Mixture is selected so that the FP of the mixture is at least 10°C (18°F) below OAT.
6. Ensure that the lowest operational use temperature (LOUT) is respected.

CAUTIONS

- **The time of protection will be shortened in heavy weather conditions, heavy precipitation rates, or high moisture content. High wind velocity or jet blast may reduce holdover time below the lowest time stated in the range. Holdover time may also be reduced when aircraft skin temperature is lower than OAT.**
- **The only acceptable decision criteria time is the shortest time within the applicable holdover time table cell.**
- **Fluids used during ground deicing do not provide ice protection during flight.**

Figure 12.1: 2004-05 Type I Fluid Holdover Guidelines

13. Changes to Type I HOT Guidelines for 2005-06

(Ref: Figure 13.1, TP 14443E)

Several changes were made to the Type I HOT guidelines for 2005-06 operations. The changes are listed below and are also documented in Transport Canada report, TP 14443E (17), which includes related supporting research.

- **Precipitation Columns**: Two changes were made to the precipitation column headings.
  - The *Frost* column was changed to *Active Frost*
  - The *Snow* column was changed to *Snow or Snow Grains*
- **Notes**: Two notes were removed as a result of the changes made to the precipitation columns.
  - Note pertaining to active frost was removed; and
  - Note pertaining to snow grains was removed.
- **Cautions**: Caution notes were expanded from three to five bullets; the content of the cautions did not change.
- **Misc**: Several abbreviations (OAT, °C, °F) were replaced with full spellings.
- **No changes** were made to temperature ranges.

The Type I HOT guidelines published by Transport Canada for use in the winter of 2005-06 are shown in Figure 13.1.

SAE TYPE I[3] FLUID HOLDOVER GUIDELINES FOR WINTER 2005-2006

THE RESPONSIBILITY FOR THE APPLICATION OF THESE DATA REMAINS WITH THE USER

Outside Air Temperature[5]		Approximate Holdover Times Under Various Weather Conditions (minutes)								
Degrees Celsius	Degrees Fahrenheit	Active Frost	Freezing Fog	Snow or Snow Grains[1] Very Light	Snow or Snow Grains[1] Light	Snow or Snow Grains[1] Moderate	Freezing Drizzle[4]	Light Freezing Rain	Rain on Cold Soaked Wing	Other[2]
-3 and above	27 and above	45	11 – 17	18	11 – 18	6 – 11	9 – 13	4 – 6	2 – 5	
below -3 to -6	below 27 to 21	45	8 – 13	14	8 – 14	5 – 8	5 – 9	4 – 6	CAUTION: No holdover time guidelines exist	
below -6 to -10	below 21 to 14	45	6 – 10	11	6 – 11	4 – 6	4 – 7	2 – 5		
below -10	below 14	45	5 – 9	7	4 – 7	2 – 4				

NOTES

1 To use these times, the fluid must be heated to a minimum temperature providing 60°C (140°F) at the nozzle and an average rate of at least 1 litre/m^2 (2 gal./100 sq. ft.) must be applied to deiced surfaces, OTHERWISE TIMES WILL BE SHORTER.
2 Heavy snow, snow pellets, ice pellets, moderate and heavy freezing rain, and hail.
3 Type I Fluid / Water Mixture is selected so that the freezing point of the mixture is at least 10°C (18°F) below outside air temperature.
4 Use light freezing rain holdover times if positive identification of freezing drizzle is not possible.
5 Ensure that the lowest operational use temperature (LOUT) is respected.

CAUTIONS

- **The only acceptable decision criteria time is the shortest time within the applicable holdover time table cell.**
- **The time of protection will be shortened in heavy weather conditions, heavy precipitation rates, or high moisture content.**
- **High wind velocity or jet blast may reduce holdover time.**
- **Holdover time may be reduced when aircraft skin temperature is lower than outside air temperature.**
- **Fluids used during ground deicing/anti-icing do not provide in-flight icing protection.**

Figure 13.1: 2005-06 Type I Fluid Holdover Guidelines

14. Changes to Type I HOT Guidelines for 2006-07

(Ref: Figure 14.1, TP 14712E)

No changes were made to the Type I HOT guidelines for 2006-07. The Type I HOT guidelines published by Transport Canada for use in the winter of 2007-08 are shown in Figure 14.1.

Holdover time research conducted in the related winter (2005-06) is documented in Transport Canada report, TP 14712E (18).

SAE TYPE I[3] FLUID HOLDOVER GUIDELINES FOR WINTER 2006-2007

THE RESPONSIBILITY FOR THE APPLICATION OF THESE DATA REMAINS WITH THE USER

Outside Air Temperature[5]		Approximate Holdover Times Under Various Weather Conditions (minutes)								
Degrees Celsius	Degrees Fahrenheit	Active Frost	Freezing Fog	Snow or Snow Grains[1] Very Light	Snow or Snow Grains[1] Light	Snow or Snow Grains[1] Moderate	Freezing Drizzle[4]	Light Freezing Rain	Rain on Cold Soaked Wing	Other[2]
-3 and above	27 and above	45	11 – 17	18	11 – 18	6 – 11	9 – 13	4 – 6	2 – 5	
below -3 to -6	below 27 to 21	45	8 – 13	14	8 – 14	5 – 8	5 – 9	4 – 6	CAUTION: No holdover time guidelines exist	
below -6 to -10	below 21 to 14	45	6 – 10	11	6 – 11	4 – 6	4 – 7	2 – 5		
below -10	below 14	45	5 – 9	7	4 – 7	2 – 4				

NOTES

1. To use these times, the fluid must be heated to a minimum temperature providing 60°C (140°F) at the nozzle and an average rate of at least 1 litre/m^2 (2 gal./100 sq. ft.) must be applied to deiced surfaces, OTHERWISE TIMES WILL BE SHORTER.
2. Heavy snow, snow pellets, ice pellets, moderate and heavy freezing rain, and hail.
3. Type I Fluid / Water Mixture is selected so that the freezing point of the mixture is at least 10°C (18°F) below outside air temperature.
4. Use light freezing rain holdover times if positive identification of freezing drizzle is not possible.
5. Ensure that the lowest operational use temperature (LOUT) is respected.

CAUTIONS

- **The only acceptable decision criteria time is the shortest time within the applicable holdover time table cell.**
- **The time of protection will be shortened in heavy weather conditions, heavy precipitation rates, or high moisture content.**
- **High wind velocity or jet blast may reduce holdover time.**
- **Holdover time may be reduced when aircraft skin temperature is lower than outside air temperature.**
- **Fluids used during ground deicing/anti-icing do not provide in-flight icing protection.**

Figure 14.1: 2006-07 Type I Fluid Holdover Guidelines

15. Changes to Type I HOT Guidelines for 2007-08

(Ref: Figure 15.1, TP 14776E)

No changes were made to the Type I HOT guidelines for 2007-08. The Type I HOT guidelines published by Transport Canada for use in the winter of 2007-08 are shown in Figure 15.1.

Holdover time research conducted in the related winter (2006-07) is documented in Transport Canada report, TP 14776E (19).

SAE TYPE I[3] FLUID HOLDOVER GUIDELINES FOR WINTER 2007-2008

THE RESPONSIBILITY FOR THE APPLICATION OF THESE DATA REMAINS WITH THE USER

Outside Air Temperature[5]		Approximate Holdover Times Under Various Weather Conditions (minutes)								
Degrees Celsius	Degrees Fahrenheit	Active Frost	Freezing Fog	Snow or Snow Grains[1]			Freezing Drizzle[4]	Light Freezing Rain	Rain on Cold Soaked Wing	Other[2]
				Very Light	Light	Moderate				
-3 and above	27 and above	45	11 – 17	18	11 – 18	6 – 11	9 – 13	4 – 6	2 – 5	
below -3 to -6	below 27 to 21	45	8 – 13	14	8 – 14	5 – 8	5 – 9	4 – 6	CAUTION: No holdover time guidelines exist	
below -6 to -10	below 21 to 14	45	6 – 10	11	6 – 11	4 – 6	4 – 7	2 – 5		
below -10	below 14	45	5 – 9	7	4 – 7	2 – 4				

NOTES

1 To use these times, the fluid must be heated to a minimum temperature providing 60°C (140°F) at the nozzle and an average rate of at least 1 litre/m² (2 gal./100 sq. ft.) must be applied to deiced surfaces. OTHERWISE TIMES WILL BE SHORTER.

2 Heavy snow, snow pellets, ice pellets, moderate and heavy freezing rain, and hail.

3 Type I Fluid / Water Mixture is selected so that the freezing point of the mixture is at least 10°C (18°F) below outside air temperature.

4 Use light freezing rain holdover times if positive identification of freezing drizzle is not possible.

5 Ensure that the lowest operational use temperature (LOUT) is respected.

CAUTIONS

- **The only acceptable decision-making criterion, for takeoff without a pre-takeoff contamination inspection, is the shorter time within the applicable holdover time table cell.**
- **The time of protection will be shortened in heavy weather conditions, heavy precipitation rates, or high moisture content.**
- **High wind velocity or jet blast may reduce holdover time.**
- **Holdover time may be reduced when aircraft skin temperature is lower than outside air temperature.**
- **Fluids used during ground deicing/anti-icing do not provide in-flight icing protection.**

Figure 15.1: 2007-08 Type I Fluid Holdover Guidelines

16. Changes to Type I HOT Guidelines for 2008-09

(Ref: Figure 16.1, TP 14869E)

No changes were made to the Type I HOT guidelines for 2008-09. The Type I HOT guidelines published by Transport Canada for use in the winter of 2007-08 are shown in Figure 16.1.

Holdover time research conducted in the related winter (2007-08) is documented in Transport Canada report, TP 14869E (20).

SAE TYPE I[3] FLUID HOLDOVER GUIDELINES FOR WINTER 2008-2009

THE RESPONSIBILITY FOR THE APPLICATION OF THESE DATA REMAINS WITH THE USER

Outside Air Temperature[5]		Approximate Holdover Times Under Various Weather Conditions (minutes)								
				Snow or Snow Grains[1]						
Degrees Celsius	Degrees Fahrenheit	Active Frost	Freezing Fog	Very Light	Light	Moderate	Freezing Drizzle[4]	Light Freezing Rain	Rain on Cold Soaked Wing	Other[2]
-3 and above	27 and above	45	11 – 17	18	11 – 18	6 – 11	9 – 13	4 – 6	2 – 5	
below -3 to -6	below 27 to 21	45	8 – 13	14	8 – 14	5 – 8	5 – 9	4 – 6	CAUTION: No holdover time guidelines exist	
below -6 to -10	below 21 to 14	45	6 – 10	11	6 – 11	4 – 6	4 – 7	2 – 5		
below -10	below 14	45	5 – 9	7	4 – 7	2 – 4				

NOTES
1 To use these times, the fluid must be heated to a minimum temperature providing 60°C (140°F) at the nozzle and an average rate of at least 1 litre/m^2 (2 gal./100 sq. ft.) must be applied to deiced surfaces, OTHERWISE TIMES WILL BE SHORTER.
2 Heavy snow, snow pellets, ice pellets, moderate and heavy freezing rain, and hail.
3 Type I Fluid / Water Mixture is selected so that the freezing point of the mixture is at least 10°C (18°F) below outside air temperature.
4 Use light freezing rain holdover times if positive identification of freezing drizzle is not possible.
5 Ensure that the lowest operational use temperature (LOUT) is respected.

CAUTIONS
- **The only acceptable decision-making criterion, for takeoff without a pre-takeoff contamination inspection, is the shorter time within the applicable holdover time table cell.**
- **The time of protection will be shortened in heavy weather conditions, heavy precipitation rates, or high moisture content.**
- **High wind velocity or jet blast may reduce holdover time.**
- **Holdover time may be reduced when aircraft skin temperature is lower than outside air temperature.**
- **Fluids used during ground deicing/anti-icing do not provide in-flight icing protection.**

Figure 16.1: 2008-09 Type I Fluid Holdover Guidelines

17. Changes to Type I HOT Guidelines for 2009-10

(Ref: Figure 17.1, TP 14933E)

Several changes were made to the Type I HOT guidelines for 2009-10 operations. The changes are listed below and also documented in Transport Canada report, TP 14933E (21), which includes related supporting research.

- **Precipitation Columns**: The *Active Frost* column was removed. The active frost holdover times were relocated to the newly created Frost HOT table.
- **Notes**: A note indicating light freezing rain holdover times can be used in conditions of light snow mixed with light rain was added.
- **No changes** were made to holdover times, temperature ranges or cautions.

The Type I HOT guidelines published by Transport Canada for use in the winter of 2009-10 are shown in Figure 17.1.

SAE TYPE I[3] FLUID HOLDOVER GUIDELINES FOR WINTER 2009-2010

THE RESPONSIBILITY FOR THE APPLICATION OF THESE DATA REMAINS WITH THE USER

Outside Air Temperature[5]		Approximate Holdover Times Under Various Weather Conditions (minutes)							
Degrees Celsius	Degrees Fahrenheit	Freezing Fog	Snow or Snow Grains[1] Very Light[6]	Snow or Snow Grains[1] Light[6]	Snow or Snow Grains[1] Moderate	Freezing Drizzle[4]	Light Freezing Rain	Rain on Cold Soaked Wing	Other[2]
-3 and above	27 and above	11 – 17	18	11 – 18	6 – 11	9 – 13	4 – 6	2 – 5	
below -3 to -6	below 27 to 21	8 – 13	14	8 – 14	5 – 8	5 – 9	4 – 6	CAUTION: No holdover time guidelines exist	
below -6 to -10	below 21 to 14	6 – 10	11	6 – 11	4 – 6	4 – 7	2 – 5		
Below -10	below 14	5 – 9	7	4 – 7	2 – 4				

NOTES
1 To use these times, the fluid must be heated to a minimum temperature providing 60°C (140°F) at the nozzle and an average rate of at least 1 litre/m^2 (2 gal./100 sq. ft.) must be applied to deiced surfaces, OTHERWISE TIMES WILL BE SHORTER.
2 Heavy snow, snow pellets, ice pellets, moderate and heavy freezing rain, and hail.
3 Type I Fluid / Water Mixture is selected so that the freezing point of the mixture is at least 10°C (18°F) below outside air temperature.
4 Use light freezing rain holdover times if positive identification of freezing drizzle is not possible.
5 Ensure that the lowest operational use temperature (LOUT) is respected.
6 Use light freezing rain holdover times in conditions of light snow mixed with light rain.

CAUTIONS
- **The only acceptable decision-making criterion, for takeoff without a pre-takeoff contamination inspection, is the shorter time within the applicable holdover time table cell.**
- **The time of protection will be shortened in heavy weather conditions, heavy precipitation rates, or high moisture content.**
- **High wind velocity or jet blast may reduce holdover time.**
- **Holdover time may be reduced when aircraft skin temperature is lower than outside air temperature.**
- **Fluids used during ground deicing/anti-icing do not provide in-flight icing protection.**

Figure 17.1: 2009-10 Type I Fluid Holdover Guidelines

18. Changes to Type I HOT Guidelines for 2010-11

(Ref: Figure 18.1, TP 15050E, TP 15052E)

Several changes were made to the Type I HOT guidelines for 2010-11 operations. The changes are listed below.

Holdover time research conducted in the related winter (2009-10) is documented in Transport Canada report TP 15050E (22). The research conducted in support of the new composite Type I holdover times is documented in the Transport Canada report, TP 15052E (23).

- **Holdover Times / Wing Surface Column**: A new column was added for wing surface. Rows for composite and aluminum were added to the column. New holdover times now included in HOT table.
- **Precipitation Columns**: The snow column was modified to include snow pellets.
- **Notes**: Several changes were made to the notes and the notes were reorganized.
  - The note pertaining to fluid application temperature (60°C) and quantity (1 litre/m²) was removed, as it already exists in the Type I fluid application procedure table;
  - Very light snow condition included in note 3; and
  - A note was added to indicate no holdover times exist for *Rain on Cold Soaked Wing* for 0°C (32°F) and below.
- **No changes** were made to temperature ranges, or cautions.

The Type I HOT guidelines published by Transport Canada for use in the winter of 2010-11 are shown in Figure 18.1.

TABLE 1

SAE TYPE I FLUID HOLDOVER GUIDELINES FOR WINTER 2010-2011[1]

THE RESPONSIBILITY FOR THE APPLICATION OF THESE DATA REMAINS WITH THE USER

Outside Air Temperature[2]		Wing Surface	Approximate Holdover Times Under Various Weather Conditions (hours:minutes)							
Degrees Celsius	Degrees Fahrenheit		Freezing Fog	Snow, Snow Grains or Snow Pellets: Very Light[3]	Light[3]	Moderate	Freezing Drizzle[4]	Light Freezing Rain	Rain on Cold Soaked Wing[5]	Other[6]
-3 and above	27 and above	Aluminum	11 – 17	18	11 – 18	6 – 11	9 – 13	4 – 6	2 – 5	
		Composite	9 – 16	12	6 – 12	3 – 6	8 – 13	4 – 6	1 – 5	
below -3 to -6	below 27 to 21	Aluminum	8 – 13	14	8 – 14	5 – 8	5 – 9	4 – 6	CAUTION: No holdover time guidelines exist	
		Composite	6 – 8	11	5 – 11	2 – 5	5 – 9	4 – 6		
below -6 to -10	below 21 to 14	Aluminum	6 – 10	11	6 – 11	4 – 6	4 – 7	2 – 5		
		Composite	4 – 8	9	5 – 9	2 – 5	4 – 7	2 – 5		
below -10	below 14	Aluminum	5 – 9	7	4 – 7	2 – 4				
		Composite	4 – 7	7	4 – 7	2 – 4				

NOTES

1. Type I Fluid / Water Mixture is selected so that the freezing point of the mixture is at least 10°C (18°F) below outside air temperature.
2. Ensure that the lowest operational use temperature (LOUT) is respected.
3. Use light freezing rain holdover times in conditions of very light or light snow mixed with light rain.
4. Use light freezing rain holdover times if positive identification of freezing drizzle is not possible.
5. No holdover time guidelines exist for this condition for 0°C (32°F) and below.
6. Heavy snow, ice pellets, moderate and heavy freezing rain, and hail.

CAUTIONS

- **The only acceptable decision-making criterion, for takeoff without a pre-takeoff contamination inspection, is the shorter time within the applicable holdover time table cell.**
- **The time of protection will be shortened in heavy weather conditions, heavy precipitation rates, or high moisture content.**
- **High wind velocity or jet blast may reduce holdover time.**
- **Holdover time may be reduced when aircraft skin temperature is lower than outside air temperature.**
- **Fluids used during ground deicing/anti-icing do not provide in-flight icing protection.**

Figure 18.1: 2010-11 Type I Fluid Holdover Guidelines

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18. Bendickson, S., *Aircraft Ground De/Anti-Icing Fluid Holdover Time Development Program for the 2005-06 Winter*, APS Aviation Inc., Transportation Development Centre, Montreal, October 2006, TP 14712E, 62.

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APPENDIX C

PROCEDURE:
EVALUATION OF TYPE I ENDURANCE TIMES ON COMPOSITE SURFACES

NATURAL SNOW (JAN 2010)

CM2169.002

PROCEDURE:
EVALUATION OF TYPE I ENDURANCE TIMES ON COMPOSITE SURFACES

NATURAL SNOW

Winter 2009-10

Prepared for

Transportation Development Centre
Transport Canada

Prepared by: For Victoria Zoitakis

Reviewed by: John D'Avirro

APS Aviation Inc.

January 18, 2010
Final Version 1.1

EVALUATION OF TYPE I ENDURANCE TIMES ON COMPOSITE SURFACES

NATURAL SNOW

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 preliminary work has demonstrated that Type I fluid endurance times are reduced when applied to composite surfaces. Depending on the condition, there is a 20 to 30 percent reduction in endurance time. The following reductions were noted:

- For natural snow conditions, the endurance time measured using the composite leading edge thermal equivalent box was 31 percent ± 10 percent less than the endurance time measured using the white painted aluminum leading edge thermal equivalent box;
- For natural frost conditions, the endurance time measured using the white painted composite test plate was 23 percent ± 9 percent less than the endurance time measured using the white painted aluminum test plate; and
- For simulated freezing conditions, the endurance time measured using the white painted composite test plate was 23 percent ± 9 percent less than the endurance time measured using the white painted aluminum test plate.

It was recommended that comprehensive Type I fluid endurance time testing be conducted to develop HOT's for use with composite materials. Testing should be conducted in all the HOT conditions: freezing fog, snow, freezing drizzle, light freezing rain, rain on a cold soaked wing, and frost. Testing should be conducted with several representative fluids and be performed in accordance with ARP 5945.

2. OBJECTIVE

The objective of this project is to develop Type I HOT's for use with composite materials. Comparative testing will be conducted in all the HOT conditions: freezing fog, snow, freezing drizzle, light freezing rain, rain on a cold soaked wing, and frost. This procedure describes the outdoor natural snow tests. For better understanding on the conduct of tests, separate procedures will be prepared for the natural frost and indoor tests. Figure 2.1 shows the list of procedures for the composite project.

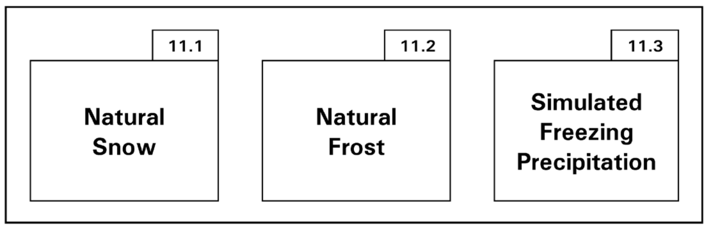

Figure 2.1: Procedures Used for Composite Testing – Winter 2009-10

3. METHODOLOGY USED TO DETERMINE COMPOSITE TYPE I HOLDOVER TIMES

Research was conducted in Winter 2000-01 to develop Type I holdover times for natural snow. A total of 193 data points were collected with various fluids. The data points collected were used to develop the current Type I holdover times; which were developed using a regression analysis, see TP 14994E.

For this project, a total of approximately 160 data points in natural snow are required for the regression analysis and development of Type I holdover times for composite surfaces. A total of 5 different fluids will be used.

4. PROCEDURE

Endurance time tests will be conducted with various Type I fluids at the Montreal-Trudeau airport test site. Standard fluid endurance time test procedures will apply. Four tests will be conducted simultaneously using leading edge thermal equivalent boxes. A six-position test stand will be required for testing. The following describes the test surfaces used.

Figure 3.1 demonstrates the setup required.

- Position 1: Rate Pan
- Position 2: Baseline Type I Endurance Time Test
  - Material: Aluminum Box
  - Unpainted
- Position 3: Composite Type I Endurance Time Test
  - Material: Composite
  - Painted white with aircraft grade paint
- Position 4: Composite Type I Endurance Time Test
  - Material: Composite
  - Painted white with aircraft grade paint
- Position 5: Composite Type I Endurance Time Test
  - Material: Composite
  - Painted white with aircraft grade paint
- Position 6: Empty

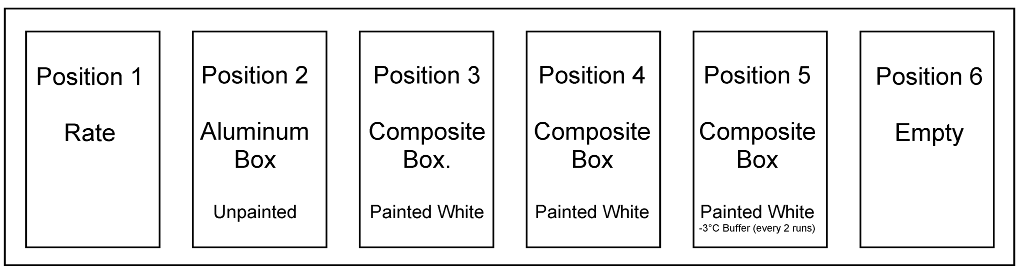

Figure 3.1: Test Stand Setup

4.1 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 2 to 5 with a warm 12-hole spreader. Fluid is to be diluted to a 10°C buffer and be applied to each test surface. Rate measurements should be taken every 5 minutes depending on the intensity of precipitation.

It should be noted that for some tests, fluid is to be diluted to a -3°C buffer. During a two-step application process, ARP 4737 states the second step, anti-icing, is to be applied before the fluid applied in the first step freezes, typically within 3 minutes. A select number of tests are to be conducted to validate the 3 minute allowance time used during a two-step application process with composite surfaces.

5. TEST SURFACES

Four 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);
- Composite Box (Painted White);
- Composite Box (Painted White); and
- Composite Box (Painted White).

6. TEST PLAN

Testing is to be conducted in every cell of the Type I holdover table. Two tests are planned for each condition. A total of approximately 32 data points is to be collected per fluid; which makes a total of approximately 160 data points, collected with the five different fluids, will be used for the regression analysis. For the -3°C buffer tests, a total of approximately 20 points will be collected. One test will be conducted for every two runs. A test plan is included in Attachment I.

7. MEASUREMENTS

7.1 Brix

Brix measurements are to be taken at the 15 cm line at the start and end of every test.

7.2 Surface Temperature

Surface temperature measurements are to be recorded one minute after fluid application and are only required for a selected number of runs, these are listed with a star in Attachment I.

8. FLUIDS

The fluids in Table 8.1 will be used for the comparative endurance time testing. Fluid dilution information is also included in Attachment II.

Table 8.1: List of Fluids Required for Testing

Fluid	Quantity Needed
Dow UCAR EF ADP	10 L Concentrate
Dow UCAR EG	10 L Concentrate
Octagon Octaflo EF	10 L Concentrate
Clariant 1938	10 L Concentrate
Kilfrost DF^{sustain}	10 L Concentrate

9. EQUIPMENT

- Standard HOT equipment will be used;
- Logging of temperatures will be required for these tests; and
- Brix 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.

10. PERSONNEL

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

11. DATA FORMS

The following data form will be used to document fluid endurance time, precipitation and Brix data:

- Attachment III: End Condition Form for Endurance Time Testing;

For the -3°Buffer tests, two failure times are to be recorded. The sign of first failure is to be recorded and failure is to be recorded when one third of the plate is covered, therefore visually failed.

ATTACHMENT I: MATRIX OF OUTDOOR TESTS

Run	Test	Fluid #	Fluid Name	Dilution	Brix	OAT	Rate (g/dm²/h)	Test Surface	Status
1	1	Fluid 1	Dow PG	10° Buffer		above -3	< 10	Standard Aluminum Box	
	2	Fluid 1	Dow PG	10° Buffer		above -3	< 10	Composite Box	
	3	Fluid 2	Dow EG	10° Buffer		above -3	< 10	Composite Box	
	4	Fluid 3	Octaflo	10° Buffer		above -3	< 10	Composite Box	
2*	5	Fluid 4	Clar 1938	10° Buffer		above -3	< 10	Standard Aluminum Box	
	6	Fluid 4	Clar 1938	10° Buffer		above -3	< 10	Composite Box	
	7	Fluid 5	Kil Dfsus	10° Buffer		above -3	< 10	Composite Box	
	8	**Fluid 4**	**Clar 1938**	**3° Buffer**		**above -3**	**< 10**	**Composite Box**	
3	9	Fluid 2	Dow EG	10° Buffer		above -3	< 10	Standard Aluminum Box	
	10	Fluid 2	Dow EG	10° Buffer		above -3	< 10	Composite Box	
	11	Fluid 3	Octaflo	10° Buffer		above -3	< 10	Composite Box	
	12	Fluid 4	Clar 1938	10° Buffer		above -3	< 10	Composite Box	
4	13	Fluid 5	Kil Dfsus	10° Buffer		above -3	< 10	Standard Aluminum Box	
	14	Fluid 5	Kil Dfsus	10° Buffer		above -3	< 10	Composite Box	
	15	Fluid 1	Dow PG	10° Buffer		above -3	< 10	Composite Box	
	16	**Fluid 5**	**Kil Dfsus**	**3° Buffer**		**above -3**	**< 10**	**Composite Box**	
5	17	Fluid 3	Octaflo	10° Buffer		above -3	> 10	Standard Aluminum Box	
	18	Fluid 3	Octaflo	10° Buffer		above -3	> 10	Composite Box	
	19	Fluid 4	Clar 1938	10° Buffer		above -3	> 10	Composite Box	
	20	Fluid 5	Kil Dfsus	10° Buffer		above -3	> 10	Composite Box	
6*	21	Fluid 1	Dow PG	10° Buffer		above -3	> 10	Standard Aluminum Box	
	22	Fluid 1	Dow PG	10° Buffer		above -3	> 10	Composite Box	
	23	Fluid 2	Dow EG	10° Buffer		above -3	> 10	Composite Box	
	24	**Fluid 1**	**Dow PG**	**3° Buffer**		**above -3**	**> 10**	**Composite Box**	
7	25	Fluid 4	Clar 1938	10° Buffer		above -3	> 10	Standard Aluminum Box	
	26	Fluid 4	Clar 1938	10° Buffer		above -3	> 10	Composite Box	
	27	Fluid 5	Kil Dfsus	10° Buffer		above -3	> 10	Composite Box	
	28	Fluid 1	Dow PG	10° Buffer		above -3	> 10	Composite Box	
8	29	Fluid 2	Dow EG	10° Buffer		above -3	> 10	Standard Aluminum Box	
	30	Fluid 2	Dow EG	10° Buffer		above -3	> 10	Composite Box	
	31	Fluid 3	Octaflo	10° Buffer		above -3	> 10	Composite Box	
	32	**Fluid 2**	**Dow EG**	**3° Buffer**		**above -3**	**> 10**	**Composite Box**	
9	33	Fluid 5	Kil Dfsus	10° Buffer		below -3 to -10	< 10	Standard Aluminum Box	
	34	Fluid 5	Kil Dfsus	10° Buffer		below -3 to -10	< 10	Composite Box	
	35	Fluid 1	Dow PG	10° Buffer		below -3 to -10	< 10	Composite Box	
	36	Fluid 2	Dow EG	10° Buffer		below -3 to -10	< 10	Composite Box	

* Temperature measurements should be taking one minute after application.

ATTACHMENT I (cont'd): MATRIX OF OUTDOOR TESTS

Run	Test	Fluid #	Fluid Name	Dilution	Brix	OAT	Rate (g/dm²/h)	Test Surface	Status
10*	37	Fluid 3	Octaflo	10º Buffer		below -3 to -10	< 10	Standard Aluminum Box	
	38	Fluid 3	Octaflo	10º Buffer		below -3 to -10	< 10	Composite Box	
	39	Fluid 4	Clar 1938	10º Buffer		below -3 to -10	< 10	Composite Box	
	40	**Fluid 3**	**Octaflo**	**3º Buffer**		**below -3 to -10**	**< 10**	**Composite Box**	
11	41	Fluid 1	Dow PG	10º Buffer		below -3 to -10	< 10	Standard Aluminum Box	
	42	Fluid 1	Dow PG	10º Buffer		below -3 to -10	< 10	Composite Box	
	43	Fluid 2	Dow EG	10º Buffer		below -3 to -10	< 10	Composite Box	
	44	Fluid 3	Octaflo	10º Buffer		below -3 to -10	< 10	Composite Box	
12	45	Fluid 4	Clar 1938	10º Buffer		below -3 to -10	< 10	Standard Aluminum Box	
	46	Fluid 4	Clar 1938	10º Buffer		below -3 to -10	< 10	Composite Box	
	47	Fluid 5	Kil Dfsus	10º Buffer		below -3 to -10	< 10	Composite Box	
	48	**Fluid 4**	**Clar 1938**	**3º Buffer**		**below -3 to -10**	**< 10**	**Composite Box**	
13	49	Fluid 2	Dow EG	10º Buffer		below -3 to -10	> 10	Standard Aluminum Box	
	50	Fluid 2	Dow EG	10º Buffer		below -3 to -10	> 10	Composite Box	
	51	Fluid 3	Octaflo	10º Buffer		below -3 to -10	> 10	Composite Box	
	52	Fluid 4	Clar 1938	10º Buffer		below -3 to -10	> 10	Composite Box	
14*	53	Fluid 5	Kil Dfsus	10º Buffer		below -3 to -10	> 10	Standard Aluminum Box	
	54	Fluid 5	Kil Dfsus	10º Buffer		below -3 to -10	> 10	Composite Box	
	55	Fluid 1	Dow PG	10º Buffer		below -3 to -10	> 10	Composite Box	
	56	**Fluid 5**	**Kil Dfsus**	**3º Buffer**		**below -3 to -10**	**> 10**	**Composite Box**	
15	57	Fluid 3	Octaflo	10º Buffer		below -3 to -10	> 10	Standard Aluminum Box	
	58	Fluid 3	Octaflo	10º Buffer		below -3 to -10	> 10	Composite Box	
	59	Fluid 4	Clar 1938	10º Buffer		below -3 to -10	> 10	Composite Box	
	60	Fluid 5	Kil Dfsus	10º Buffer		below -3 to -10	> 10	Composite Box	
16	61	Fluid 1	Dow PG	10º Buffer		below -3 to -10	> 10	Standard Aluminum Box	
	62	Fluid 1	Dow PG	10º Buffer		below -3 to -10	> 10	Composite Box	
	63	Fluid 2	Dow EG	10º Buffer		below -3 to -10	> 10	Composite Box	
	64	**Fluid 1**	**Dow PG**	**3º Buffer**		**below -3 to -10**	**> 10**	**Composite Box**	
17	65	Fluid 4	Clar 1938	10º Buffer		below -10	< 10	Standard Aluminum Box	
	66	Fluid 4	Clar 1938	10º Buffer		below -10	< 10	Composite Box	
	67	Fluid 5	Kil Dfsus	10º Buffer		below -10	< 10	Composite Box	
	68	Fluid 1	Dow PG	10º Buffer		below -10	< 10	Composite Box	
18*	69	Fluid 2	Dow EG	10º Buffer		below -10	< 10	Standard Aluminum Box	
	70	Fluid 2	Dow EG	10º Buffer		below -10	< 10	Composite Box	
	71	Fluid 3	Octaflo	10º Buffer		below -10	< 10	Composite Box	
	72	**Fluid 2**	**Dow EG**	**3º Buffer**		**below -10**	**< 10**	**Composite Box**	

* Temperature measurements should be taking one minute after application.

ATTACHMENT I (cont'd): MATRIX OF OUTDOOR TESTS

Run	Test	Fluid #	Fluid Name	Dilution	Brix	OAT	Rate (g/dm²/h)	Test Surface	Status
19	73	Fluid 5	Kil Dfsus	10° Buffer		below -10	< 10	Standard Aluminum Box	
	74	Fluid 5	Kil Dfsus	10° Buffer		below -10	< 10	Composite Box	
	75	Fluid 1	Dow PG	10° Buffer		below -10	< 10	Composite Box	
	76	Fluid 2	Dow EG	10° Buffer		below -10	< 10	Composite Box	
20	77	Fluid 3	Octaflo	10° Buffer		below -10	< 10	Standard Aluminum Box	
	78	Fluid 3	Octaflo	10° Buffer		below -10	< 10	Composite Box	
	79	Fluid 4	Clar 1938	10° Buffer		below -10	< 10	Composite Box	
	80	**Fluid 3**	**Octaflo**	**3° Buffer**		**below -10**	**< 10**	**Composite Box**	
21	81	Fluid 1	Dow PG	10° Buffer		below -10	> 10	Standard Aluminum Box	
	82	Fluid 1	Dow PG	10° Buffer		below -10	> 10	Composite Box	
	83	Fluid 2	Dow EG	10° Buffer		below -10	> 10	Composite Box	
	84	Fluid 3	Octaflo	10° Buffer		below -10	> 10	Composite Box	
22*	85	Fluid 4	Clar 1938	10° Buffer		below -10	> 10	Standard Aluminum Box	
	86	Fluid 4	Clar 1938	10° Buffer		below -10	> 10	Composite Box	
	87	Fluid 5	Kil Dfsus	10° Buffer		below -10	> 10	Composite Box	
	88	**Fluid 4**	**Clar 1938**	**3° Buffer**		**below -10**	**> 10**	**Composite Box**	
23	89	Fluid 2	Dow EG	10° Buffer		below -10	> 10	Standard Aluminum Box	
	90	Fluid 2	Dow EG	10° Buffer		below -10	> 10	Composite Box	
	91	Fluid 3	Octaflo	10° Buffer		below -10	> 10	Composite Box	
	92	Fluid 4	Clar 1938	10° Buffer		below -10	> 10	Composite Box	
24	93	Fluid 5	Kil Dfsus	10° Buffer		below -10	> 10	Standard Aluminum Box	
	94	Fluid 5	Kil Dfsus	10° Buffer		below -10	> 10	Composite Box	
	95	Fluid 1	Dow PG	10° Buffer		below -10	> 10	Composite Box	
	96	**Fluid 5**	**Kil Dfsus**	**3° Buffer**		**below -10**	**> 10**	**Composite Box**	
25	97	Fluid 3	Octaflo	10° Buffer		OAT	any	Standard Aluminum Box	
	98	Fluid 3	Octaflo	10° Buffer		OAT	any	Composite Box	
	99	Fluid 4	Clar 1938	10° Buffer		OAT	any	Composite Box	
	100	Fluid 5	Kil Dfsus	10° Buffer		OAT	any	Composite Box	
26	101	Fluid 1	Dow PG	10° Buffer		OAT	any	Standard Aluminum Box	
	102	Fluid 1	Dow PG	10° Buffer		OAT	any	Composite Box	
	103	Fluid 2	Dow EG	10° Buffer		OAT	any	Composite Box	
	104	**Fluid 1**	**Dow PG**	**3° Buffer**		**OAT**	**any**	**Composite Box**	
27	105	Fluid 4	Clar 1938	10° Buffer		OAT	any	Standard Aluminum Box	
	106	Fluid 4	Clar 1938	10° Buffer		OAT	any	Composite Box	
	107	Fluid 5	Kil Dfsus	10° Buffer		OAT	any	Composite Box	
	108	Fluid 1	Dow PG	10° Buffer		OAT	any	Composite Box	

* Temperature measurements should be taking one minute after application.

ATTACHMENT I (cont'd): MATRIX OF OUTDOOR TESTS

Run	Test	Fluid #	Fluid Name	Dilution	Brix	OAT	Rate (g/dm²/h)	Test Surface	Status
28	109	Fluid 2	Dow EG	10° Buffer		OAT	any	Standard Aluminum Box	
	110	Fluid 2	Dow EG	10° Buffer		OAT	any	Composite Box	
	111	Fluid 3	Octaflo	10° Buffer		OAT	any	Composite Box	
	112	**Fluid 2**	**Dow EG**	**3° Buffer**		**OAT**	**any**	**Composite Box**	
29	113	Fluid 5	Kil Dfsus	10° Buffer		OAT	any	Standard Aluminum Box	
	114	Fluid 5	Kil Dfsus	10° Buffer		OAT	any	Composite Box	
	115	Fluid 1	Dow PG	10° Buffer		OAT	any	Composite Box	
	116	Fluid 2	Dow EG	10° Buffer		OAT	any	Composite Box	
30	117	Fluid 3	Octaflo	10° Buffer		OAT	any	Standard Aluminum Box	
	118	Fluid 3	Octaflo	10° Buffer		OAT	any	Composite Box	
	119	Fluid 4	Clar 1938	10° Buffer		OAT	any	Composite Box	
	120	**Fluid 3**	**Octaflo**	**3° Buffer**		**OAT**	**any**	**Composite Box**	
31	121	Fluid 1	Dow PG	10° Buffer		OAT	any	Standard Aluminum Box	
	122	Fluid 1	Dow PG	10° Buffer		OAT	any	Composite Box	
	123	Fluid 2	Dow EG	10° Buffer		OAT	any	Composite Box	
	124	Fluid 3	Octaflo	10° Buffer		OAT	any	Composite Box	
32	125	Fluid 4	Clar 1938	10° Buffer		OAT	any	Standard Aluminum Box	
	126	Fluid 4	Clar 1938	10° Buffer		OAT	any	Composite Box	
	127	Fluid 5	Kil Dfsus	10° Buffer		OAT	any	Composite Box	
	128	**Fluid 4**	**Clar 1938**	**3° Buffer**		**OAT**	**any**	**Composite Box**	
33	129	Fluid 2	Dow EG	10° Buffer		OAT	any	Standard Aluminum Box	
	130	Fluid 2	Dow EG	10° Buffer		OAT	any	Composite Box	
	131	Fluid 3	Octaflo	10° Buffer		OAT	any	Composite Box	
	132	Fluid 4	Clar 1938	10° Buffer		OAT	any	Composite Box	
34	133	Fluid 5	Kil Dfsus	10° Buffer		OAT	any	Standard Aluminum Box	
	134	Fluid 5	Kil Dfsus	10° Buffer		OAT	any	Composite Box	
	135	Fluid 1	Dow PG	10° Buffer		OAT	any	Composite Box	
	136	**Fluid 5**	**Kil Dfsus**	**3° Buffer**		**OAT**	**any**	**Composite Box**	
35	137	Fluid 3	Octaflo	10° Buffer		OAT	any	Standard Aluminum Box	
	138	Fluid 3	Octaflo	10° Buffer		OAT	any	Composite Box	
	139	Fluid 4	Clar 1938	10° Buffer		OAT	any	Composite Box	
	140	Fluid 5	Kil Dfsus	10° Buffer		OAT	any	Composite Box	
36	141	Fluid 1	Dow PG	10° Buffer		OAT	any	Standard Aluminum Box	
	142	Fluid 1	Dow PG	10° Buffer		OAT	any	Composite Box	
	143	Fluid 2	Dow EG	10° Buffer		OAT	any	Composite Box	
	144	**Fluid 1**	**Dow PG**	**3° Buffer**		**OAT**	**any**	**Composite Box**	

* Temperature measurements should be taking one minute after application.

ATTACHMENT I (cont'd): MATRIX OF OUTDOOR TESTS

Run	Test	Fluid #	Fluid Name	Dilution	Brix	OAT	Rate (g/dm²/h)	Test Surface	Status
37	145	Fluid 4	Clar 1938	10° Buffer		OAT	any	Standard Aluminum Box	
	146	Fluid 4	Clar 1938	10° Buffer		OAT	any	Composite Box	
	147	Fluid 5	Kil Dfsus	10° Buffer		OAT	any	Composite Box	
	148	Fluid 1	Dow PG	10° Buffer		OAT	any	Composite Box	
38	149	Fluid 2	Dow EG	10° Buffer		OAT	any	Standard Aluminum Box	
	150	Fluid 2	Dow EG	10° Buffer		OAT	any	Composite Box	
	151	Fluid 3	Octaflo	10° Buffer		OAT	any	Composite Box	
	152	**Fluid 2**	**Dow EG**	**3° Buffer**		**OAT**	**any**	**Composite Box**	
39	153	Fluid 5	Kil Dfsus	10° Buffer		OAT	any	Standard Aluminum Box	
	154	Fluid 5	Kil Dfsus	10° Buffer		OAT	any	Composite Box	
	155	Fluid 1	Dow PG	10° Buffer		OAT	any	Composite Box	
	156	Fluid 2	Dow EG	10° Buffer		OAT	any	Composite Box	
40	157	Fluid 3	Octaflo	10° Buffer		OAT	any	Standard Aluminum Box	
	158	Fluid 3	Octaflo	10° Buffer		OAT	any	Composite Box	
	159	Fluid 4	Clar 1938	10° Buffer		OAT	any	Composite Box	
	160	**Fluid 3**	**Octaflo**	**3° Buffer**		**OAT**	**any**	**Composite Box**	

* Temperature measurements should be taking one minute after application.

EVALUATION OF TYPE I ENDURANCE TIMES ON COMPOSITE SURFACES NATURAL SNOW

ATTACHMENT II: FLUID DILUTIONS

OAT (°C)	FFP (°C)	UCAR EF ADF (PG)				UCAR ADF (EG)				Octagon Octaflo / EF				Clariant 1938				Kilfrost DF[sustain]			
		% Glycol	Brix	Glycol for 8 Litres	Water for 8 Litres	% Glycol	Brix	Glycol for 8 Litres	Water for 8 Litres	% Glycol	Brix	Glycol for 8 Litres	Water for 8 Litres	% Glycol	Brix	Glycol for 8 Litres	Water for 8 Litres	% Glycol	Brix	Glycol for 8 Litres	Water for 8 Litres
5	-5	26.0	17.3	2.1	5.9					15	9.75	12.0	6.8								
1	-9	27.7	18.4	2.2	5.8	21.5	13.5	1.7	6.3	27.5	18.5	2.2	5.8	28.5	16.5	2.3	5.7	27	17.25	2.2	5.8
0	-10	30.0	19.8	2.4	5.6	22	14	1.8	6.2	29	19	2.3	5.7	31.5	18.5	2.5	5.5	29	18.50	2.3	5.7
-1	-11	30.9	20.5	2.5	5.5	23	15	1.8	6.2	30	20	2.4	5.6	34	19.75	2.7	5.3	31	19.50	2.5	5.5
-2	-12	32.4	21.5	2.6	5.4	24.5	16	2.0	6.0	31	20.5	2.5	5.5	37.5	21.5	3.0	5.0	33	20.75	2.6	5.4
-3	-13	33.9	22.3	2.7	5.3	26	17	2.1	5.9	32	21.25	2.6	5.4	39.25	22.5	3.1	4.9	35	21.75	2.8	5.2
-4	-14	35.0	22.8	2.8	5.2	28	18	2.2	5.8	34	22.5	2.7	5.3	40.5	23.5	3.2	4.8	36.5	22.75	2.9	5.1
-5	-15	36.7	24.2	2.9	5.1	30	19	2.4	5.6	35	23	2.8	5.2	42	24.25	3.4	4.6	38.5	23.75	3.1	4.9
-6	-16	38.1	25.0	3.0	5.0	31	19.75	2.5	5.5	36	23.5	2.9	5.1	43	24.75	3.4	4.6	40	24.50	3.2	4.8
-7	-17	39.4	25.8	3.1	4.9	32	20.5	2.6	5.4	37	24	3.0	5.0	44.25	25.5	3.5	4.5	41.5	25.50	3.3	4.7
-8	-18	40.0	27.2	3.2	4.8	33.5	21.25	2.7	5.3	38.5	25	3.1	4.9	45.5	26	3.6	4.4	43	26.25	3.4	4.6
-9	-19	41.9	27.5	3.4	4.6	34.5	21.75	2.8	5.2	40	26	3.2	4.8	46.5	26.5	3.7	4.3	45	27.25	3.6	4.4
-10	-20	43.1	27.8	3.4	4.6	36	22.5	2.9	5.1	42	27	3.4	4.6	47.75	27.5	3.8	4.2	46	28.00	3.7	4.3
-11	-21	45.0	28.6	3.6	4.4	37	23	3.0	5.0	44	28	3.5	4.5	49	28	3.9	4.1	47.5	28.75	3.8	4.2
-12	-22	45.4	29.0	3.6	4.4	38	23.75	3.0	5.0	45	28.5	3.6	4.4	50	28.75	4.0	4.0	49	29.50	3.9	4.1
-13	-23	46.4	29.5	3.7	4.3	39	24.5	3.1	4.9	46	29	3.7	4.3	51	29.25	4.1	3.9	50	30.00	4.0	4.0
-14	-24	47.5	30.0	3.8	4.2	40	25	3.2	4.8	47	29.5	3.8	4.2	52.25	29.75	4.2	3.8	51.5	30.75	4.1	3.9
-15	-25	48.5	30.5	3.9	4.1	41	25.5	3.3	4.7	47.5	30	3.8	4.2	53.5	30.25	4.3	3.7	52.5	31.25	4.2	3.8
-16	-26	49.5	31.0	4.0	4.0	42	26	3.4	4.6	48.5	30.5	3.9	4.1	54.5	30.75	4.4	3.6	53.5	32.00	4.3	3.7
-17	-27	50.0	31.4	4.0	4.0	43	26.5	3.4	4.6	49	31	3.9	4.1	55.5	31.25	4.4	3.6	54.5	32.50	4.4	3.6
-18	-28	51.3	31.8	4.1	3.9	44	27	3.5	4.5	50	31.5	4.0	4.0	56.5	31.75	4.5	3.5	55.5	33.00	4.4	3.6
-19	-29	52.2	32.1	4.2	3.8	45	27.5	3.6	4.4	51	32	4.1	3.9	57.75	32.25	4.6	3.4	56.5	33.50	4.5	3.5
-20	-30	53.9	32.8	4.3	3.7	45.75	28	3.7	4.3	52	32.5	4.2	3.8	58.75	32.75	4.7	3.3	57.5	34.00	4.6	3.4
-22	-32	56.1	34.0	4.5	3.5	47	28.75	3.8	4.2	53.5	33.5	4.3	3.7	61	33.75	4.9	3.1	59	34.75	4.7	3.3
-25	-35	60.0	36.3	4.8	3.2	49	30	3.9	4.1	56	34.5	4.5	3.5	64.5	35.25	5.2	2.8	60.5	35.50	4.8	3.2
-30	-40	55.0	33.8	4.4	3.6	53	32	4.2	3.8	60	37	4.8	3.2	70	37.75	5.6	2.4	62.5	36.50	5.0	3.0
Standard Mix		26.0	17.3	2.1	5.9	57	33.5	4.6	3.4	63	38.25	5	3.0								

EVALUATION OF TYPE I ENDURANCE TIMES ON COMPOSITE SURFACES NATURAL SNOW

ATTACHMENT III: END CONDITION FORM FOR ENDURANCE TIME TESTING

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

FLUID NAME	______	______	______	______
PLATE POSITION	______	______	______	______
	ALUMINUM BOX	**COMPOSITE BOX #1**	**COMPOSITE BOX #2**	**COMPOSITE BOX #3**

	1	2	3
B	○	○	○
C	○	○	○
D	○	○	○
E	○	○	○
F	○	○	○

TIME OF FLUID APPLICATION		______	______	______	______
TIME OF FLUID FAILURE		______	______	______	______
TIME OF FIRST SIGN OF FLUID FAILURE		______	______	______	______
TEMPERATURE AT 15 CM LINE AT 1 MIN		______	______	______	______
BRIX MEASUREMENTS TIME / BRIX	INITIAL	0 min /	0 min /	0 min /	0 min /
	END	/	/	/	/
FAILURES CALLED BY:		______			

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APPENDIX D

PROCEDURE:
EVALUATION OF TYPE I ENDURANCE TIMES ON COMPOSITE SURFACES

SIMULATED FREEZING PRECIPITATION (MAR 2010)

CM2169.002

PROCEDURE: EVALUATION OF TYPE I ENDURANCE TIMES ON COMPOSITE SURFACES

SIMULATED FREEZING PRECIPITATION

Winter 2009-10

Prepared for

Transportation Development Centre
Transport Canada

Prepared by: Victoria Zoitakis

Reviewed by: John D'Avirro

APS Aviation Inc.

March 26, 2010
Final Version 1.0

EVALUATION OF TYPE I ENDURANCE TIMES ON COMPOSITE SURFACES SIMULATED FREEZING PRECIPITATION

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 preliminary work has demonstrated that Type I fluid endurance times are reduced when applied to composite surfaces. Depending on the condition, there is a 20 to 30 percent reduction in endurance time. The following reductions were noted:

- For natural snow conditions, the endurance time measured using the composite leading edge thermal equivalent box was 31 percent ± 10 percent less than the endurance time measured using the white painted aluminum leading edge thermal equivalent box;
- For natural frost conditions, the endurance time measured using the white painted composite test plate was 23 percent ± 9 percent less than the endurance time measured using the white painted aluminum test plate; and
- For simulated freezing conditions, the endurance time measured using the white painted composite test plate was 23 percent ± 9 percent less than the endurance time measured using the white painted aluminum test plate.

It was recommended that comprehensive Type I fluid endurance time testing be conducted to develop HOT's for use with composite materials. Testing should be conducted in all the HOT conditions: freezing fog, snow, freezing drizzle, light freezing rain, rain on a cold soaked wing, and frost. Testing should be conducted with several representative fluids and be performed in accordance with ARP 5945.

2. OBJECTIVE

The objective of this project is to develop Type I HOT's for use with composite materials. Comparative testing will be conducted in all the HOT conditions: freezing fog, snow, freezing drizzle, light freezing rain, rain on a cold soaked wing, and frost. This procedure describes the simulated freezing precipitation tests. For better understanding on the conduct of tests, separate procedures will be prepared for the natural frost and natural snow tests. Figure 2.1 shows the list of procedures for the composite project.

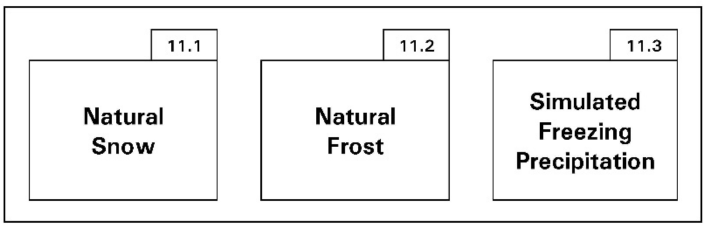

Figure 2.1: Procedures Used for Composite Testing – Winter 2009-10

3. METHODOLOGY USED TO DETERMINE COMPOSITE TYPE I HOLDOVER TIMES

Research was conducted in Winter 2001-02 with Type I fluids in freezing precipitation. Holdover time ranges were made based on a visual inspection of the data collected with various fluids, see TP 13991E. A similar approach will be used for the development of holdover times with composite surfaces.

For this project, a total of approximately 280 data points in freezing precipitation are required for the development of Type I holdover times for composite surfaces. A total of 5 different fluids will be used.

4. PROCEDURE

Endurance time tests will be conducted with various fluids at the National Research Council (NRC) Climatic Engineering Facility (CEF) in Ottawa. Tests will be done on white painted composite plates. Baseline endurance time test will be conducted in accordance with standard endurance time testing.

4.1 Indoor Tests with Type I Fluids Heated to 20°C

1 L of fluid heated to 20 °C should be poured onto a test plate. Fluid is to be diluted to a 10°C buffer and be applied to each test surface.

It should be noted that for some tests, fluid is to be diluted to a -3°C buffer. During a two-step application process, ARP 4737 states the second step, anti-icing, is to be applied before the fluid applied in the first step freezes, typically within 3 minutes. A select number of tests are to be conducted to evaluate or to validate the 3 minute allowance time used during a two-step application process with composite surfaces.

5. TEST SURFACES

5.1 Freezing Precipitation

Testing is to be conducted on white painted composite plate during freezing rain, freezing drizzle and freezing fog conditions. The baseline tests will also be conducted using the standard unpainted aluminium test plates.

5.2 Coal Soak Wing

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 procedure for conducting these tests can be found in the document entitled *Overall Program of Tests at NRC, March-April 2010* (1). Details are provided in the separate procedure.

6. TEST PLAN

Testing is to be conducted in every cell of the Type I holdover table. Two tests are planned for each condition. A total of approximately 40 data points is to be collected per fluid in exception of the Kilfrost $DF^{sustain}$ which will have 120 points. A total of approximately 280 data points will be collected with the five different fluids, which will be used for the analysis. For the -3°C buffer tests, a total of approximately 40 points will be collected. Two tests will be conducted for every condition with one fluid (Kilfrost $DF^{sustain}$). A test plan is included in Attachment I.

The Type I Composite project requires that testing be conducted all standard holdover time conditions and in some additional conditions. This is due to differences between the format of the Type I table and the Type II/IV tables, i.e. an additional row for -6°C and freezing fog at -10°C rather than -14°C.

7. MEASUREMENTS

No measurements are required for these tests.

8. FLUIDS

The fluids in Table 8.1 will be used for the comparative endurance time testing. Fluid dilution information is also included in Attachment II.

Table 8.1: List of Fluids Required for Testing

Fluid	Quantity Needed
Dow UCAR EF ADP	20 L Concentrate
Dow UCAR EG	20 L Concentrate
Octagon Octaflo EF	20 L Concentrate
Clariant 1938	20 L Concentrate
Kilfrost DF^{sustain}	40 L Concentrate

9. EQUIPMENT

- Standard HOT equipment will be used; and
- Logging of temperatures will be required for these tests.

10. PERSONNEL

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

11. DATA FORMS

The following data form will be used to document fluid endurance time:

- Attachment III: Freezing Precipitation Endurance Time Data Form; and
- Attachment IV: Cold-Soak Wing Endurance Time Data Form.

For the -3°Buffer tests, two failure times are to be recorded. The sign of first failure is to be recorded and failure is to be recorded when one third of the plate is covered, therefore visually failed.

12. REFERENCES

1. Procedure: Overall Program of Tests at NRC, March - April 2010, Final Version 1.0, March 25, 2010.

ATTACHMENT I: TYPE I COMPOSITE TEST PLAN

Test #	Precipitation Type	Temp (°C)	Precip. Rate (g/dm²/h)	Fluid	Dilution (%)	Test Surface	Comments
C1	Freezing Fog	-3	5	Kilfrost DFsustain	10°B (B=21.75)	Aluminum Plate	Pour 1 L fluid @ 20°C
C2	Freezing Fog	-3	5	Kilfrost DFsustain	10°B (B=21.75)	Aluminum Plate	Pour 1 L fluid @ 20°C
C3	Freezing Fog	-3	5	Kilfrost DFsustain	-3°B (WATER)	Composite Plate	Pour 1 L fluid @ 20°C
C4	Freezing Fog	-3	5	Kilfrost DFsustain	-3°B (WATER)	Composite Plate	Pour 1 L fluid @ 20°C
C5	Freezing Fog	-3	5	Kilfrost DFsustain	10°B (B=21.75)	Composite Plate	Pour 1 L fluid @ 20°C
C6	Freezing Fog	-3	5	Kilfrost DFsustain	10°B (B=21.75)	Composite Plate	Pour 1 L fluid @ 20°C
C7	Freezing Fog	-3	5	Octagon Octaflo	10°B (B=21.25)	Composite Plate	Pour 1 L fluid @ 20°C
C8	Freezing Fog	-3	5	Octagon Octaflo	10°B (B=21.25)	Composite Plate	Pour 1 L fluid @ 20°C
C9	Freezing Fog	-3	5	Clariant 1938	10°B (B=21.75)	Composite Plate	Pour 1 L fluid @ 20°C
C10	Freezing Fog	-3	5	Clariant 1938	10°B (B=21.75)	Composite Plate	Pour 1 L fluid @ 20°C
C11	Freezing Fog	-3	5	Dow UCAR EG	10°B (B=17.0)	Composite Plate	Pour 1 L fluid @ 20°C
C12	Freezing Fog	-3	5	Dow UCAR EG	10°B (B=17.0)	Composite Plate	Pour 1 L fluid @ 20°C
C13	Freezing Fog	-3	5	Dow UCAR PG	10°B (B=21.5)	Composite Plate	Pour 1 L fluid @ 20°C
C14	Freezing Fog	-3	5	Dow UCAR PG	10°B (B=21.5)	Composite Plate	Pour 1 L fluid @ 20°C
C15	Freezing Fog	-3	2	Kilfrost DFsustain	10°B (B=21.75)	Aluminum Plate	Pour 1 L fluid @ 20°C
C16	Freezing Fog	-3	2	Kilfrost DFsustain	10°B (B=21.75)	Aluminum Plate	Pour 1 L fluid @ 20°C
C17	Freezing Fog	-3	2	Kilfrost DFsustain	-3°B (WATER)	Composite Plate	Pour 1 L fluid @ 20°C
C18	Freezing Fog	-3	2	Kilfrost DFsustain	-3°B (WATER)	Composite Plate	Pour 1 L fluid @ 20°C
C19	Freezing Fog	-3	2	Kilfrost DFsustain	10°B (B=21.75)	Composite Plate	Pour 1 L fluid @ 20°C
C20	Freezing Fog	-3	2	Kilfrost DFsustain	10°B (B=21.75)	Composite Plate	Pour 1 L fluid @ 20°C
C21	Freezing Fog	-3	2	Octagon Octaflo	10°B (B=21.25)	Composite Plate	Pour 1 L fluid @ 20°C
C22	Freezing Fog	-3	2	Octagon Octaflo	10°B (B=21.25)	Composite Plate	Pour 1 L fluid @ 20°C
C23	Freezing Fog	-3	2	Clariant 1938	10°B (B=21.75)	Composite Plate	Pour 1 L fluid @ 20°C
C24	Freezing Fog	-3	2	Clariant 1938	10°B (B=21.75)	Composite Plate	Pour 1 L fluid @ 20°C
C25	Freezing Fog	-3	2	Dow UCAR EG	10°B (B=17.0)	Composite Plate	Pour 1 L fluid @ 20°C
C26	Freezing Fog	-3	2	Dow UCAR EG	10°B (B=17.0)	Composite Plate	Pour 1 L fluid @ 20°C
C27	Freezing Fog	-3	2	Dow UCAR PG	10°B (B=21.5)	Composite Plate	Pour 1 L fluid @ 20°C
C28	Freezing Fog	-3	2	Dow UCAR PG	10°B (B=21.5)	Composite Plate	Pour 1 L fluid @ 20°C
C29	Freezing Fog	-6	5	Kilfrost DFsustain	10°B (B=24.5)	Aluminum Plate	Pour 1 L fluid @ 20°C
C30	Freezing Fog	-6	5	Kilfrost DFsustain	10°B (B=24.5)	Aluminum Plate	Pour 1 L fluid @ 20°C
C31	Freezing Fog	-6	5	Kilfrost DFsustain	-3°B (B=8.0)	Composite Plate	Pour 1 L fluid @ 20°C
C32	Freezing Fog	-6	5	Kilfrost DFsustain	-3°B (B=8.0)	Composite Plate	Pour 1 L fluid @ 20°C
C33	Freezing Fog	-6	5	Kilfrost DFsustain	10°B (B=24.5)	Composite Plate	Pour 1 L fluid @ 20°C
C34	Freezing Fog	-6	5	Kilfrost DFsustain	10°B (B=24.5)	Composite Plate	Pour 1 L fluid @ 20°C
C35	Freezing Fog	-6	5	Octagon Octaflo	10°B (B=23.5)	Composite Plate	Pour 1 L fluid @ 20°C
C36	Freezing Fog	-6	5	Octagon Octaflo	10°B (B=23.5)	Composite Plate	Pour 1 L fluid @ 20°C
C37	Freezing Fog	-6	5	Clariant 1938	10°B (B=24.5)	Composite Plate	Pour 1 L fluid @ 20°C
C38	Freezing Fog	-6	5	Clariant 1938	10°B (B=24.5)	Composite Plate	Pour 1 L fluid @ 20°C
C39	Freezing Fog	-6	5	Dow UCAR EG	10°B (B=19.75)	Composite Plate	Pour 1 L fluid @ 20°C
C40	Freezing Fog	-6	5	Dow UCAR EG	10°B (B=19.75)	Composite Plate	Pour 1 L fluid @ 20°C
C41	Freezing Fog	-6	5	Dow UCAR PG	10°B (B=24.25)	Composite Plate	Pour 1 L fluid @ 20°C
C42	Freezing Fog	-6	5	Dow UCAR PG	10°B (B=24.25)	Composite Plate	Pour 1 L fluid @ 20°C
C43	Freezing Fog	-6	2	Kilfrost DFsustain	10°B (B=24.5)	Aluminum Plate	Pour 1 L fluid @ 20°C
C44	Freezing Fog	-6	2	Kilfrost DFsustain	10°B (B=24.5)	Aluminum Plate	Pour 1 L fluid @ 20°C
C45	Freezing Fog	-6	2	Kilfrost DFsustain	-3°B (B=8.0)	Composite Plate	Pour 1 L fluid @ 20°C
C46	Freezing Fog	-6	2	Kilfrost DFsustain	-3°B (B=8.0)	Composite Plate	Pour 1 L fluid @ 20°C
C47	Freezing Fog	-6	2	Kilfrost DFsustain	10°B (B=24.5)	Composite Plate	Pour 1 L fluid @ 20°C
C48	Freezing Fog	-6	2	Kilfrost DFsustain	10°B (B=24.5)	Composite Plate	Pour 1 L fluid @ 20°C
C49	Freezing Fog	-6	2	Octagon Octaflo	10°B (B=23.5)	Composite Plate	Pour 1 L fluid @ 20°C
C50	Freezing Fog	-6	2	Octagon Octaflo	10°B (B=23.5)	Composite Plate	Pour 1 L fluid @ 20°C
C51	Freezing Fog	-6	2	Clariant 1938	10°B (B=24.5)	Composite Plate	Pour 1 L fluid @ 20°C
C52	Freezing Fog	-6	2	Clariant 1938	10°B (B=24.5)	Composite Plate	Pour 1 L fluid @ 20°C
C53	Freezing Fog	-6	2	Dow UCAR EG	10°B (B=19.75)	Composite Plate	Pour 1 L fluid @ 20°C
C54	Freezing Fog	-6	2	Dow UCAR EG	10°B (B=19.75)	Composite Plate	Pour 1 L fluid @ 20°C
C55	Freezing Fog	-6	2	Dow UCAR PG	10°B (B=24.25)	Composite Plate	Pour 1 L fluid @ 20°C
C56	Freezing Fog	-6	2	Dow UCAR PG	10°B (B=24.25)	Composite Plate	Pour 1 L fluid @ 20°C

ATTACHMENT I: TYPE I COMPOSITE TEST PLAN (cont'd)

Test #	Precipitation Type	Temp (°C)	Precip. Rate (g/dm²/h)	Fluid	Dilution (%)	Test Surface	Comments
C57	Freezing Fog	-10	5	Kilfrost DFsustain	10°B (B=28.0)	Aluminum Plate	Pour 1 L fluid @ 20°C
C58	Freezing Fog	-10	5	Kilfrost DFsustain	10°B (B=28.0)	Aluminum Plate	Pour 1 L fluid @ 20°C
C59	Freezing Fog	-10	5	Kilfrost DFsustain	-3°B (B=15.0)	Composite Plate	Pour 1 L fluid @ 20°C
C60	Freezing Fog	-10	5	Kilfrost DFsustain	-3°B (B=15.0)	Composite Plate	Pour 1 L fluid @ 20°C
C61	Freezing Fog	-10	5	Kilfrost DFsustain	10°B (B=28.0)	Composite Plate	Pour 1 L fluid @ 20°C
C62	Freezing Fog	-10	5	Kilfrost DFsustain	10°B (B=28.0)	Composite Plate	Pour 1 L fluid @ 20°C
C63	Freezing Fog	-10	5	Octagon Octaflo	10°B (B=27.0)	Composite Plate	Pour 1 L fluid @ 20°C
C64	Freezing Fog	-10	5	Octagon Octaflo	10°B (B=27.0)	Composite Plate	Pour 1 L fluid @ 20°C
C65	Freezing Fog	-10	5	Clariant 1938	10°B (B=27.5)	Composite Plate	Pour 1 L fluid @ 20°C
C66	Freezing Fog	-10	5	Clariant 1938	10°B (B=27.5)	Composite Plate	Pour 1 L fluid @ 20°C
C67	Freezing Fog	-10	5	Dow UCAR EG	10°B (B=22.5)	Composite Plate	Pour 1 L fluid @ 20°C
C68	Freezing Fog	-10	5	Dow UCAR EG	10°B (B=22.5)	Composite Plate	Pour 1 L fluid @ 20°C
C69	Freezing Fog	-10	5	Dow UCAR PG	10°B (B=27.5)	Composite Plate	Pour 1 L fluid @ 20°C
C70	Freezing Fog	-10	5	Dow UCAR PG	10°B (B=27.5)	Composite Plate	Pour 1 L fluid @ 20°C
C71	Freezing Fog	-10	2	Kilfrost DFsustain	10°B (B=28.0)	Aluminum Plate	Pour 1 L fluid @ 20°C
C72	Freezing Fog	-10	2	Kilfrost DFsustain	10°B (B=28.0)	Aluminum Plate	Pour 1 L fluid @ 20°C
C73	Freezing Fog	-10	2	Kilfrost DFsustain	-3°B (B=15.0)	Composite Plate	Pour 1 L fluid @ 20°C
C74	Freezing Fog	-10	2	Kilfrost DFsustain	-3°B (B=15.0)	Composite Plate	Pour 1 L fluid @ 20°C
C75	Freezing Fog	-10	2	Kilfrost DFsustain	10°B (B=28.0)	Composite Plate	Pour 1 L fluid @ 20°C
C76	Freezing Fog	-10	2	Kilfrost DFsustain	10°B (B=28.0)	Composite Plate	Pour 1 L fluid @ 20°C
C77	Freezing Fog	-10	2	Octagon Octaflo	10°B (B=27.0)	Composite Plate	Pour 1 L fluid @ 20°C
C78	Freezing Fog	-10	2	Octagon Octaflo	10°B (B=27.0)	Composite Plate	Pour 1 L fluid @ 20°C
C79	Freezing Fog	-10	2	Clariant 1938	10°B (B=27.5)	Composite Plate	Pour 1 L fluid @ 20°C
C80	Freezing Fog	-10	2	Clariant 1938	10°B (B=27.5)	Composite Plate	Pour 1 L fluid @ 20°C
C81	Freezing Fog	-10	2	Dow UCAR EG	10°B (B=22.5)	Composite Plate	Pour 1 L fluid @ 20°C
C82	Freezing Fog	-10	2	Dow UCAR EG	10°B (B=22.5)	Composite Plate	Pour 1 L fluid @ 20°C
C83	Freezing Fog	-10	2	Dow UCAR PG	10°B (B=27.5)	Composite Plate	Pour 1 L fluid @ 20°C
C84	Freezing Fog	-10	2	Dow UCAR PG	10°B (B=27.5)	Composite Plate	Pour 1 L fluid @ 20°C
C85	Freezing Fog	-25	5	Kilfrost DFsustain	10°B (B=35.5)	Aluminum Plate	Pour 1 L fluid @ 20°C
C86	Freezing Fog	-25	5	Kilfrost DFsustain	10°B (B=35.5)	Aluminum Plate	Pour 1 L fluid @ 20°C
C87	Freezing Fog	-25	5	Kilfrost DFsustain	-3°B (B=29.5)	Composite Plate	Pour 1 L fluid @ 20°C
C88	Freezing Fog	-25	5	Kilfrost DFsustain	-3°B (B=29.5)	Composite Plate	Pour 1 L fluid @ 20°C
C89	Freezing Fog	-25	5	Kilfrost DFsustain	10°B (B=35.5)	Composite Plate	Pour 1 L fluid @ 20°C
C90	Freezing Fog	-25	5	Kilfrost DFsustain	10°B (B=35.5)	Composite Plate	Pour 1 L fluid @ 20°C
C91	Freezing Fog	-25	5	Octagon Octaflo	10°B (B=34.5)	Composite Plate	Pour 1 L fluid @ 20°C
C92	Freezing Fog	-25	5	Octagon Octaflo	10°B (B=34.5)	Composite Plate	Pour 1 L fluid @ 20°C
C93	Freezing Fog	-25	5	Clariant 1938	10°B (B=35.75)	Composite Plate	Pour 1 L fluid @ 20°C
C94	Freezing Fog	-25	5	Clariant 1938	10°B (B=35.75)	Composite Plate	Pour 1 L fluid @ 20°C
C95	Freezing Fog	-25	5	Dow UCAR EG	10°B (B=30.0)	Composite Plate	Pour 1 L fluid @ 20°C
C96	Freezing Fog	-25	5	Dow UCAR EG	10°B (B=30.0)	Composite Plate	Pour 1 L fluid @ 20°C
C97	Freezing Fog	-25	5	Dow UCAR PG	10°B (B=34.0)	Composite Plate	Pour 1 L fluid @ 20°C
C98	Freezing Fog	-25	5	Dow UCAR PG	10°B (B=34.0)	Composite Plate	Pour 1 L fluid @ 20°C
C99	Freezing Fog	-25	2	Kilfrost DFsustain	10°B (B=35.5)	Aluminum Plate	Pour 1 L fluid @ 20°C
C100	Freezing Fog	-25	2	Kilfrost DFsustain	10°B (B=35.5)	Aluminum Plate	Pour 1 L fluid @ 20°C
C101	Freezing Fog	-25	2	Kilfrost DFsustain	-3°B (B=29.5)	Composite Plate	Pour 1 L fluid @ 20°C
C102	Freezing Fog	-25	2	Kilfrost DFsustain	-3°B (B=29.5)	Composite Plate	Pour 1 L fluid @ 20°C
C103	Freezing Fog	-25	2	Kilfrost DFsustain	10°B (B=35.5)	Composite Plate	Pour 1 L fluid @ 20°C
C104	Freezing Fog	-25	2	Kilfrost DFsustain	10°B (B=35.5)	Composite Plate	Pour 1 L fluid @ 20°C
C105	Freezing Fog	-25	2	Octagon Octaflo	10°B (B=34.5)	Composite Plate	Pour 1 L fluid @ 20°C
C106	Freezing Fog	-25	2	Octagon Octaflo	10°B (B=34.5)	Composite Plate	Pour 1 L fluid @ 20°C
C107	Freezing Fog	-25	2	Clariant 1938	10°B (B=35.75)	Composite Plate	Pour 1 L fluid @ 20°C
C108	Freezing Fog	-25	2	Clariant 1938	10°B (B=35.75)	Composite Plate	Pour 1 L fluid @ 20°C
C109	Freezing Fog	-25	2	Dow UCAR EG	10°B (B=30.0)	Composite Plate	Pour 1 L fluid @ 20°C
C110	Freezing Fog	-25	2	Dow UCAR EG	10°B (B=30.0)	Composite Plate	Pour 1 L fluid @ 20°C
C111	Freezing Fog	-25	2	Dow UCAR PG	10°B (B=34.0)	Composite Plate	Pour 1 L fluid @ 20°C
C112	Freezing Fog	-25	2	Dow UCAR PG	10°B (B=34.0)	Composite Plate	Pour 1 L fluid @ 20°C

ATTACHMENT I: TYPE I COMPOSITE TEST PLAN (cont'd)

Test #	Precipitation Type	Temp (°C)	Precip. Rate ($g/dm^2/h$)	Fluid	Dilution (%)	Test Surface	Comments
C113	Light Freezing Rain	-6	25	Kilfrost DFsustain	10°B (B=24.5)	Aluminum Plate	Pour 1 L fluid @ 20°C
C114	Light Freezing Rain	-6	25	Kilfrost DFsustain	10°B (B=24.5)	Aluminum Plate	Pour 1 L fluid @ 20°C
C115	Light Freezing Rain	-6	25	Kilfrost DFsustain	-3°B (B=8.0)	Composite Plate	Pour 1 L fluid @ 20°C
C116	Light Freezing Rain	-6	25	Kilfrost DFsustain	-3°B (B=8.0)	Composite Plate	Pour 1 L fluid @ 20°C
C117	Light Freezing Rain	-6	25	Kilfrost DFsustain	10°B (B=24.5)	Composite Plate	Pour 1 L fluid @ 20°C
C118	Light Freezing Rain	-6	25	Kilfrost DFsustain	10°B (B=24.5)	Composite Plate	Pour 1 L fluid @ 20°C
C119	Light Freezing Rain	-6	25	Octagon Octaflo	10°B (B=23.5)	Composite Plate	Pour 1 L fluid @ 20°C
C120	Light Freezing Rain	-6	25	Octagon Octaflo	10°B (B=23.5)	Composite Plate	Pour 1 L fluid @ 20°C
C121	Light Freezing Rain	-6	25	Clariant 1938	10°B (B=24.5)	Composite Plate	Pour 1 L fluid @ 20°C
C122	Light Freezing Rain	-6	25	Clariant 1938	10°B (B=24.5)	Composite Plate	Pour 1 L fluid @ 20°C
C123	Light Freezing Rain	-6	25	Dow UCAR EG	10°B (B=19.75)	Composite Plate	Pour 1 L fluid @ 20°C
C124	Light Freezing Rain	-6	25	Dow UCAR EG	10°B (B=19.75)	Composite Plate	Pour 1 L fluid @ 20°C
C125	Light Freezing Rain	-6	25	Dow UCAR PG	10°B (B=24.25)	Composite Plate	Pour 1 L fluid @ 20°C
C126	Light Freezing Rain	-6	25	Dow UCAR PG	10°B (B=24.25)	Composite Plate	Pour 1 L fluid @ 20°C
C127	Light Freezing Rain	-6	13	Kilfrost DFsustain	10°B (B=24.5)	Aluminum Plate	Pour 1 L fluid @ 20°C
C128	Light Freezing Rain	-6	13	Kilfrost DFsustain	10°B (B=24.5)	Aluminum Plate	Pour 1 L fluid @ 20°C
C129	Light Freezing Rain	-6	13	Kilfrost DFsustain	-3°B (B=8.0)	Composite Plate	Pour 1 L fluid @ 20°C
C130	Light Freezing Rain	-6	13	Kilfrost DFsustain	-3°B (B=8.0)	Composite Plate	Pour 1 L fluid @ 20°C
C131	Light Freezing Rain	-6	13	Kilfrost DFsustain	10°B (B=24.5)	Composite Plate	Pour 1 L fluid @ 20°C
C132	Light Freezing Rain	-6	13	Kilfrost DFsustain	10°B (B=24.5)	Composite Plate	Pour 1 L fluid @ 20°C
C133	Light Freezing Rain	-6	13	Octagon Octaflo	10°B (B=23.5)	Composite Plate	Pour 1 L fluid @ 20°C
C134	Light Freezing Rain	-6	13	Octagon Octaflo	10°B (B=23.5)	Composite Plate	Pour 1 L fluid @ 20°C
C135	Light Freezing Rain	-6	13	Clariant 1938	10°B (B=24.5)	Composite Plate	Pour 1 L fluid @ 20°C
C136	Light Freezing Rain	-6	13	Clariant 1938	10°B (B=24.5)	Composite Plate	Pour 1 L fluid @ 20°C
C137	Light Freezing Rain	-6	13	Dow UCAR EG	10°B (B=19.75)	Composite Plate	Pour 1 L fluid @ 20°C
C138	Light Freezing Rain	-6	13	Dow UCAR EG	10°B (B=19.75)	Composite Plate	Pour 1 L fluid @ 20°C
C139	Light Freezing Rain	-6	13	Dow UCAR PG	10°B (B=24.25)	Composite Plate	Pour 1 L fluid @ 20°C
C140	Light Freezing Rain	-6	13	Dow UCAR PG	10°B (B=24.25)	Composite Plate	Pour 1 L fluid @ 20°C
C141	Light Freezing Rain	-10	25	Kilfrost DFsustain	10°B (B=28.0)	Aluminum Plate	Pour 1 L fluid @ 20°C
C142	Light Freezing Rain	-10	25	Kilfrost DFsustain	10°B (B=28.0)	Aluminum Plate	Pour 1 L fluid @ 20°C
C143	Light Freezing Rain	-10	25	Kilfrost DFsustain	-3°B (B=15.0)	Composite Plate	Pour 1 L fluid @ 20°C
C144	Light Freezing Rain	-10	25	Kilfrost DFsustain	-3°B (B=15.0)	Composite Plate	Pour 1 L fluid @ 20°C
C145	Light Freezing Rain	-10	25	Kilfrost DFsustain	10°B (B=28.0)	Composite Plate	Pour 1 L fluid @ 20°C
C146	Light Freezing Rain	-10	25	Kilfrost DFsustain	10°B (B=28.0)	Composite Plate	Pour 1 L fluid @ 20°C
C147	Light Freezing Rain	-10	25	Octagon Octaflo	10°B (B=27.0)	Composite Plate	Pour 1 L fluid @ 20°C
C148	Light Freezing Rain	-10	25	Octagon Octaflo	10°B (B=27.0)	Composite Plate	Pour 1 L fluid @ 20°C
C149	Light Freezing Rain	-10	25	Clariant 1938	10°B (B=27.5)	Composite Plate	Pour 1 L fluid @ 20°C
C150	Light Freezing Rain	-10	25	Clariant 1938	10°B (B=27.5)	Composite Plate	Pour 1 L fluid @ 20°C
C151	Light Freezing Rain	-10	25	Dow UCAR EG	10°B (B=22.5)	Composite Plate	Pour 1 L fluid @ 20°C
C152	Light Freezing Rain	-10	25	Dow UCAR EG	10°B (B=22.5)	Composite Plate	Pour 1 L fluid @ 20°C
C153	Light Freezing Rain	-10	25	Dow UCAR PG	10°B (B=27.5)	Composite Plate	Pour 1 L fluid @ 20°C
C154	Light Freezing Rain	-10	25	Dow UCAR PG	10°B (B=27.5)	Composite Plate	Pour 1 L fluid @ 20°C
C155	Light Freezing Rain	-10	13	Kilfrost DFsustain	10°B (B=28.0)	Aluminum Plate	Pour 1 L fluid @ 20°C
C156	Light Freezing Rain	-10	13	Kilfrost DFsustain	10°B (B=28.0)	Aluminum Plate	Pour 1 L fluid @ 20°C
C157	Light Freezing Rain	-10	13	Kilfrost DFsustain	-3°B (B=15.0)	Composite Plate	Pour 1 L fluid @ 20°C
C158	Light Freezing Rain	-10	13	Kilfrost DFsustain	-3°B (B=15.0)	Composite Plate	Pour 1 L fluid @ 20°C
C159	Light Freezing Rain	-10	13	Kilfrost DFsustain	10°B (B=28.0)	Composite Plate	Pour 1 L fluid @ 20°C
C160	Light Freezing Rain	-10	13	Kilfrost DFsustain	10°B (B=28.0)	Composite Plate	Pour 1 L fluid @ 20°C
C161	Light Freezing Rain	-10	13	Octagon Octaflo	10°B (B=27.0)	Composite Plate	Pour 1 L fluid @ 20°C
C162	Light Freezing Rain	-10	13	Octagon Octaflo	10°B (B=27.0)	Composite Plate	Pour 1 L fluid @ 20°C
C163	Light Freezing Rain	-10	13	Clariant 1938	10°B (B=27.5)	Composite Plate	Pour 1 L fluid @ 20°C
C164	Light Freezing Rain	-10	13	Clariant 1938	10°B (B=27.5)	Composite Plate	Pour 1 L fluid @ 20°C
C165	Light Freezing Rain	-10	13	Dow UCAR EG	10°B (B=22.5)	Composite Plate	Pour 1 L fluid @ 20°C
C166	Light Freezing Rain	-10	13	Dow UCAR EG	10°B (B=22.5)	Composite Plate	Pour 1 L fluid @ 20°C
C167	Light Freezing Rain	-10	13	Dow UCAR PG	10°B (B=27.5)	Composite Plate	Pour 1 L fluid @ 20°C
C168	Light Freezing Rain	-10	13	Dow UCAR PG	10°B (B=27.5)	Composite Plate	Pour 1 L fluid @ 20°C

ATTACHMENT I: TYPE I COMPOSITE TEST PLAN (cont'd)

Test #	Precipitation Type	Temp (°C)	Precip. Rate (g/dm²/h)	Fluid	Dilution (%)	Test Surface	Comments
C169	Freezing Drizzle	-3	13	Kilfrost DFsustain	10°B (B=21.75)	Aluminum Plate	Pour 1 L fluid @ 20°C
C170	Freezing Drizzle	-3	13	Kilfrost DFsustain	10°B (B=21.75)	Aluminum Plate	Pour 1 L fluid @ 20°C
C171	Freezing Drizzle	-3	13	Kilfrost DFsustain	-3°B (WATER)	Composite Plate	Pour 1 L fluid @ 20°C
C172	Freezing Drizzle	-3	13	Kilfrost DFsustain	-3°B (WATER)	Composite Plate	Pour 1 L fluid @ 20°C
C173	Freezing Drizzle	-3	13	Kilfrost DFsustain	10°B (B=21.75)	Composite Plate	Pour 1 L fluid @ 20°C
C174	Freezing Drizzle	-3	13	Kilfrost DFsustain	10°B (B=21.75)	Composite Plate	Pour 1 L fluid @ 20°C
C175	Freezing Drizzle	-3	13	Octagon Octaflo	10°B (B=21.25)	Composite Plate	Pour 1 L fluid @ 20°C
C176	Freezing Drizzle	-3	13	Octagon Octaflo	10°B (B=21.25)	Composite Plate	Pour 1 L fluid @ 20°C
C177	Freezing Drizzle	-3	13	Clariant 1938	10°B (B=21.75)	Composite Plate	Pour 1 L fluid @ 20°C
C178	Freezing Drizzle	-3	13	Clariant 1938	10°B (B=21.75)	Composite Plate	Pour 1 L fluid @ 20°C
C179	Freezing Drizzle	-3	13	Dow UCAR EG	10°B (B=17.0)	Composite Plate	Pour 1 L fluid @ 20°C
C180	Freezing Drizzle	-3	13	Dow UCAR EG	10°B (B=17.0)	Composite Plate	Pour 1 L fluid @ 20°C
C181	Freezing Drizzle	-3	13	Dow UCAR PG	10°B (B=21.5)	Composite Plate	Pour 1 L fluid @ 20°C
C182	Freezing Drizzle	-3	13	Dow UCAR PG	10°B (B=21.5)	Composite Plate	Pour 1 L fluid @ 20°C
C183	Freezing Drizzle	-3	5	Kilfrost DFsustain	10°B (B=21.75)	Aluminum Plate	Pour 1 L fluid @ 20°C
C184	Freezing Drizzle	-3	5	Kilfrost DFsustain	10°B (B=21.75)	Aluminum Plate	Pour 1 L fluid @ 20°C
C185	Freezing Drizzle	-3	5	Kilfrost DFsustain	-3°B (WATER)	Composite Plate	Pour 1 L fluid @ 20°C
C186	Freezing Drizzle	-3	5	Kilfrost DFsustain	-3°B (WATER)	Composite Plate	Pour 1 L fluid @ 20°C
C187	Freezing Drizzle	-3	5	Kilfrost DFsustain	10°B (B=21.75)	Composite Plate	Pour 1 L fluid @ 20°C
C188	Freezing Drizzle	-3	5	Kilfrost DFsustain	10°B (B=21.75)	Composite Plate	Pour 1 L fluid @ 20°C
C189	Freezing Drizzle	-3	5	Octagon Octaflo	10°B (B=21.25)	Composite Plate	Pour 1 L fluid @ 20°C
C190	Freezing Drizzle	-3	5	Octagon Octaflo	10°B (B=21.25)	Composite Plate	Pour 1 L fluid @ 20°C
C191	Freezing Drizzle	-3	5	Clariant 1938	10°B (B=21.75)	Composite Plate	Pour 1 L fluid @ 20°C
C192	Freezing Drizzle	-3	5	Clariant 1938	10°B (B=21.75)	Composite Plate	Pour 1 L fluid @ 20°C
C193	Freezing Drizzle	-3	5	Dow UCAR EG	10°B (B=17.0)	Composite Plate	Pour 1 L fluid @ 20°C
C194	Freezing Drizzle	-3	5	Dow UCAR EG	10°B (B=17.0)	Composite Plate	Pour 1 L fluid @ 20°C
C195	Freezing Drizzle	-3	5	Dow UCAR PG	10°B (B=21.5)	Composite Plate	Pour 1 L fluid @ 20°C
C196	Freezing Drizzle	-3	5	Dow UCAR PG	10°B (B=21.5)	Composite Plate	Pour 1 L fluid @ 20°C
C197	Freezing Drizzle	-6	13	Kilfrost DFsustain	10°B (B=24.5)	Aluminum Plate	Pour 1 L fluid @ 20°C
C198	Freezing Drizzle	-6	13	Kilfrost DFsustain	10°B (B=24.5)	Aluminum Plate	Pour 1 L fluid @ 20°C
C199	Freezing Drizzle	-6	13	Kilfrost DFsustain	-3°B (B=8.0)	Composite Plate	Pour 1 L fluid @ 20°C
C200	Freezing Drizzle	-6	13	Kilfrost DFsustain	-3°B (B=8.0)	Composite Plate	Pour 1 L fluid @ 20°C
C201	Freezing Drizzle	-6	13	Kilfrost DFsustain	10°B (B=24.5)	Composite Plate	Pour 1 L fluid @ 20°C
C202	Freezing Drizzle	-6	13	Kilfrost DFsustain	10°B (B=24.5)	Composite Plate	Pour 1 L fluid @ 20°C
C203	Freezing Drizzle	-6	13	Octagon Octaflo	10°B (B=23.5)	Composite Plate	Pour 1 L fluid @ 20°C
C204	Freezing Drizzle	-6	13	Octagon Octaflo	10°B (B=23.5)	Composite Plate	Pour 1 L fluid @ 20°C
C205	Freezing Drizzle	-6	13	Clariant 1938	10°B (B=24.5)	Composite Plate	Pour 1 L fluid @ 20°C
C206	Freezing Drizzle	-6	13	Clariant 1938	10°B (B=24.5)	Composite Plate	Pour 1 L fluid @ 20°C
C207	Freezing Drizzle	-6	13	Dow UCAR EG	10°B (B=19.75)	Composite Plate	Pour 1 L fluid @ 20°C
C208	Freezing Drizzle	-6	13	Dow UCAR EG	10°B (B=19.75)	Composite Plate	Pour 1 L fluid @ 20°C
C209	Freezing Drizzle	-6	13	Dow UCAR PG	10°B (B=24.25)	Composite Plate	Pour 1 L fluid @ 20°C
C210	Freezing Drizzle	-6	13	Dow UCAR PG	10°B (B=24.25)	Composite Plate	Pour 1 L fluid @ 20°C
C211	Freezing Drizzle	-6	5	Kilfrost DFsustain	10°B (B=24.5)	Aluminum Plate	Pour 1 L fluid @ 20°C
C212	Freezing Drizzle	-6	5	Kilfrost DFsustain	10°B (B=24.5)	Aluminum Plate	Pour 1 L fluid @ 20°C
C213	Freezing Drizzle	-6	5	Kilfrost DFsustain	-3°B (B=8.0)	Composite Plate	Pour 1 L fluid @ 20°C
C214	Freezing Drizzle	-6	5	Kilfrost DFsustain	-3°B (B=8.0)	Composite Plate	Pour 1 L fluid @ 20°C
C215	Freezing Drizzle	-6	5	Kilfrost DFsustain	10°B (B=24.5)	Composite Plate	Pour 1 L fluid @ 20°C
C216	Freezing Drizzle	-6	5	Kilfrost DFsustain	10°B (B=24.5)	Composite Plate	Pour 1 L fluid @ 20°C
C217	Freezing Drizzle	-6	5	Octagon Octaflo	10°B (B=23.5)	Composite Plate	Pour 1 L fluid @ 20°C
C218	Freezing Drizzle	-6	5	Octagon Octaflo	10°B (B=23.5)	Composite Plate	Pour 1 L fluid @ 20°C
C219	Freezing Drizzle	-6	5	Clariant 1938	10°B (B=24.5)	Composite Plate	Pour 1 L fluid @ 20°C
C220	Freezing Drizzle	-6	5	Clariant 1938	10°B (B=24.5)	Composite Plate	Pour 1 L fluid @ 20°C
C221	Freezing Drizzle	-6	5	Dow UCAR EG	10°B (B=19.75)	Composite Plate	Pour 1 L fluid @ 20°C
C222	Freezing Drizzle	-6	5	Dow UCAR EG	10°B (B=19.75)	Composite Plate	Pour 1 L fluid @ 20°C
C223	Freezing Drizzle	-6	5	Dow UCAR PG	10°B (B=24.25)	Composite Plate	Pour 1 L fluid @ 20°C
C224	Freezing Drizzle	-6	5	Dow UCAR PG	10°B (B=24.25)	Composite Plate	Pour 1 L fluid @ 20°C

ATTACHMENT I: TYPE I COMPOSITE TEST PLAN (cont'd)

Test #	Precipitation Type	Temp (°C)	Precip. Rate (g/dm²/h)	Fluid	Dilution (%)	Test Surface	Comments
C225	Freezing Drizzle	-10	13	Kilfrost DFsustain	10°B (B=28.0)	Aluminum Plate	Pour 1 L fluid @ 20°C
C226	Freezing Drizzle	-10	13	Kilfrost DFsustain	10°B (B=28.0)	Aluminum Plate	Pour 1 L fluid @ 20°C
C227	Freezing Drizzle	-10	13	Kilfrost DFsustain	-3°B (B=15.0)	Composite Plate	Pour 1 L fluid @ 20°C
C228	Freezing Drizzle	-10	13	Kilfrost DFsustain	-3°B (B=15.0)	Composite Plate	Pour 1 L fluid @ 20°C
C229	Freezing Drizzle	-10	13	Kilfrost DFsustain	10°B (B=28.0)	Composite Plate	Pour 1 L fluid @ 20°C
C230	Freezing Drizzle	-10	13	Kilfrost DFsustain	10°B (B=28.0)	Composite Plate	Pour 1 L fluid @ 20°C
C231	Freezing Drizzle	-10	13	Octagon Octaflo	10°B (B=27.0)	Composite Plate	Pour 1 L fluid @ 20°C
C232	Freezing Drizzle	-10	13	Octagon Octaflo	10°B (B=27.0)	Composite Plate	Pour 1 L fluid @ 20°C
C233	Freezing Drizzle	-10	13	Clariant 1938	10°B (B=27.5)	Composite Plate	Pour 1 L fluid @ 20°C
C234	Freezing Drizzle	-10	13	Clariant 1938	10°B (B=27.5)	Composite Plate	Pour 1 L fluid @ 20°C
C235	Freezing Drizzle	-10	13	Dow UCAR EG	10°B (B=22.5)	Composite Plate	Pour 1 L fluid @ 20°C
C236	Freezing Drizzle	-10	13	Dow UCAR EG	10°B (B=22.5)	Composite Plate	Pour 1 L fluid @ 20°C
C237	Freezing Drizzle	-10	13	Dow UCAR PG	10°B (B=27.5)	Composite Plate	Pour 1 L fluid @ 20°C
C238	Freezing Drizzle	-10	13	Dow UCAR PG	10°B (B=27.5)	Composite Plate	Pour 1 L fluid @ 20°C
C239	Freezing Drizzle	-10	5	Kilfrost DFsustain	10°B (B=28.0)	Aluminum Plate	Pour 1 L fluid @ 20°C
C240	Freezing Drizzle	-10	5	Kilfrost DFsustain	10°B (B=28.0)	Aluminum Plate	Pour 1 L fluid @ 20°C
C241	Freezing Drizzle	-10	5	Kilfrost DFsustain	-3°B (B=15.0)	Composite Plate	Pour 1 L fluid @ 20°C
C242	Freezing Drizzle	-10	5	Kilfrost DFsustain	-3°B (B=15.0)	Composite Plate	Pour 1 L fluid @ 20°C
C243	Freezing Drizzle	-10	5	Kilfrost DFsustain	10°B (B=28.0)	Composite Plate	Pour 1 L fluid @ 20°C
C244	Freezing Drizzle	-10	5	Kilfrost DFsustain	10°B (B=28.0)	Composite Plate	Pour 1 L fluid @ 20°C
C245	Freezing Drizzle	-10	5	Octagon Octaflo	10°B (B=27.0)	Composite Plate	Pour 1 L fluid @ 20°C
C246	Freezing Drizzle	-10	5	Octagon Octaflo	10°B (B=27.0)	Composite Plate	Pour 1 L fluid @ 20°C
C247	Freezing Drizzle	-10	5	Clariant 1938	10°B (B=27.5)	Composite Plate	Pour 1 L fluid @ 20°C
C248	Freezing Drizzle	-10	5	Clariant 1938	10°B (B=27.5)	Composite Plate	Pour 1 L fluid @ 20°C
C249	Freezing Drizzle	-10	5	Dow UCAR EG	10°B (B=22.5)	Composite Plate	Pour 1 L fluid @ 20°C
C250	Freezing Drizzle	-10	5	Dow UCAR EG	10°B (B=22.5)	Composite Plate	Pour 1 L fluid @ 20°C
C251	Freezing Drizzle	-10	5	Dow UCAR PG	10°B (B=27.5)	Composite Plate	Pour 1 L fluid @ 20°C
C252	Freezing Drizzle	-10	5	Dow UCAR PG	10°B (B=27.5)	Composite Plate	Pour 1 L fluid @ 20°C
C253	Cold Soak Box	1	75	Kilfrost DFsustain	10°B (B=17.25)	Aluminum Box	Pour 1 L fluid @ 20°C
C254	Cold Soak Box	1	75	Kilfrost DFsustain	10°B (B=17.25)	Aluminum Box	Pour 1 L fluid @ 20°C
C255	Cold Soak Box	1	75	Kilfrost DFsustain	-3°B (WATER)	Composite Box	Pour 1 L fluid @ 20°C
C256	Cold Soak Box	1	75	Kilfrost DFsustain	-3°B (WATER)	Composite Box	Pour 1 L fluid @ 20°C
C257	Cold Soak Box	1	75	Kilfrost DFsustain	10°B (B=17.25)	Composite Box	Pour 1 L fluid @ 20°C
C258	Cold Soak Box	1	75	Kilfrost DFsustain	10°B (B=17.25)	Composite Box	Pour 1 L fluid @ 20°C
C259	Cold Soak Box	1	75	Octagon Octaflo	10°B (B=18.5)	Composite Box	Pour 1 L fluid @ 20°C
C260	Cold Soak Box	1	75	Octagon Octaflo	10°B (B=18.5)	Composite Box	Pour 1 L fluid @ 20°C
C261	Cold Soak Box	1	75	Clariant 1938	10°B (B=16.75)	Composite Box	Pour 1 L fluid @ 20°C
C262	Cold Soak Box	1	75	Clariant 1938	10°B (B=16.75)	Composite Box	Pour 1 L fluid @ 20°C
C263	Cold Soak Box	1	75	Dow UCAR EG	10°B (B=13.5)	Composite Box	Pour 1 L fluid @ 20°C
C264	Cold Soak Box	1	75	Dow UCAR EG	10°B (B=13.5)	Composite Box	Pour 1 L fluid @ 20°C
C265	Cold Soak Box	1	75	Dow UCAR PG	10°B (B=17.25)	Composite Box	Pour 1 L fluid @ 20°C
C266	Cold Soak Box	1	75	Dow UCAR PG	10°B (B=17.25)	Composite Box	Pour 1 L fluid @ 20°C
C267	Cold Soak Box	1	5	Kilfrost DFsustain	10°B (B=17.25)	Aluminum Box	Pour 1 L fluid @ 20°C
C268	Cold Soak Box	1	5	Kilfrost DFsustain	10°B (B=17.25)	Aluminum Box	Pour 1 L fluid @ 20°C
C269	Cold Soak Box	1	5	Kilfrost DFsustain	-3°B (WATER)	Composite Box	Pour 1 L fluid @ 20°C
C270	Cold Soak Box	1	5	Kilfrost DFsustain	-3°B (WATER)	Composite Box	Pour 1 L fluid @ 20°C
C271	Cold Soak Box	1	5	Kilfrost DFsustain	10°B (B=17.25)	Composite Box	Pour 1 L fluid @ 20°C
C272	Cold Soak Box	1	5	Kilfrost DFsustain	10°B (B=17.25)	Composite Box	Pour 1 L fluid @ 20°C
C273	Cold Soak Box	1	5	Octagon Octaflo	10°B (B=18.5)	Composite Box	Pour 1 L fluid @ 20°C
C274	Cold Soak Box	1	5	Octagon Octaflo	10°B (B=18.5)	Composite Box	Pour 1 L fluid @ 20°C
C275	Cold Soak Box	1	5	Clariant 1938	10°B (B=16.75)	Composite Box	Pour 1 L fluid @ 20°C
C276	Cold Soak Box	1	5	Clariant 1938	10°B (B=16.75)	Composite Box	Pour 1 L fluid @ 20°C
C277	Cold Soak Box	1	5	Dow UCAR EG	10°B (B=13.5)	Composite Box	Pour 1 L fluid @ 20°C
C278	Cold Soak Box	1	5	Dow UCAR EG	10°B (B=13.5)	Composite Box	Pour 1 L fluid @ 20°C
C279	Cold Soak Box	1	5	Dow UCAR PG	10°B (B=17.25)	Composite Box	Pour 1 L fluid @ 20°C
C280	Cold Soak Box	1	5	Dow UCAR PG	10°B (B=17.25)	Composite Box	Pour 1 L fluid @ 20°C

ATTACHMENT II: FLUID DILUTIONS

Dow UCAR PG ADF					
FFP (°C)	Test Temp (10°B)	% Glycol	Brix	Glycol for 4 L	Water for 4 L
-9	1	26.0	17.25	1.0	3.0
-13	-3	32.4	21.50	1.3	2.7
-16	-6	36.7	24.25	1.5	2.5
-20	-10	41.9	27.50	1.7	2.3
-35	-25	56.1	34.00	2.2	1.8

Dow UCAR ADF (EG)					
FFP (°C)	Test Temp (10°B)	% Glycol	Brix	Glycol for 4 L	Water for 4 L
-9	1	21.5	13.50	0.9	3.1
-13	-3	26.0	17.00	1.0	3.0
-16	-6	31.0	19.75	1.2	2.8
-20	-10	36.0	22.50	1.4	2.6
-35	-25	49.0	30.00	2.0	2.0

Octagon Octaflo EF					
FFP (°C)	Test Temp (10°B)	% Glycol	Brix	Glycol for 4 L	Water for 4 L
-9	1	27.5	18.50	1.1	2.9
-13	-3	32.0	21.25	1.3	2.7
-16	-6	36.0	23.50	1.4	2.6
-20	-10	42.0	27.00	1.7	2.3
-35	-25	56.0	34.50	2.2	1.8

Clariant Safewing MP I 1938 ECO					
FFP (°C)	Test Temp (10°B)	% Glycol	Brix	Glycol for 4 L	Water for 4 L
-9	1	26.0	16.75	1.0	3.0
-13	-3	33.9	21.75	1.4	2.6
-16	-6	38.7	24.50	1.5	2.5
-20	-10	44.0	27.50	1.8	2.2
-35	-25	58.9	35.75	2.4	1.6

Kilfrost DF^{sustain}						
FFP (°C)	Test Temp (10°B)	Test Temp (-3°B)	% Glycol	Brix	Glycol for 4 L	Water for 4 L
-3	n/a	-6	12.0	8.00	0.5	3.5
-7	n/a	-10	23.0	15.00	0.9	3.1
-9	1	n/a	27.0	17.25	1.1	2.9
-13	-3	n/a	35.0	21.75	1.4	2.6
-16	-6	n/a	40.0	24.50	1.6	2.4
-20	-10	n/a	46.0	28.00	1.8	2.2
-22	n/a	-25	49.0	29.50	2.0	2.0
-35	-25	n/a	60.5	35.50	2.4	1.6

ATTACHMENT III: FREEZING PRECIPITATION ENDURANCE TIME DATA FORM

REMEMBER TO SYNCHRONIZE TIME

LOCATION: CEF (Ottawa)	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 0.5°C OF AIR TEMP)						
Initial Fluid Temperature (°C) (NEEDS TO BE WITHIN 3°C OF AIR TEMP)						
FLUID NAME/BATCH						
B1 B2 B3						
C1 C2 C3						
D1 D2 D3						
E1 E2 E3						
F1 F2 F3						
TIME TO FIRST PLATE FAILURE WITHIN WORK AREA						
FAILURE CALL (circle)	V. Difficult Difficult. Easy	V. Difficult Difficult. Easy	V. Difficult Difficult. Easy	V. Difficult Difficult. Easy	V. Difficult Difficult. Easy	V. Difficult Difficult. Easy
HRZ. AIR VELOCITY * (circle)	A B C	A B C	A B C	A B C	A B C	A B C

	Plate 7	Plate 8	Plate 9	Plate 10	Plate 11	Plate 12
Time of Fluid Application:						
Initial Plate Temperature (°C) (NEEDS TO BE WITHIN 0.5°C OF AIR TEMP)						
Initial Fluid Temperature (°C) (NEEDS TO BE WITHIN 3°C OF AIR TEMP)						
FLUID NAME/BATCH						
B1 B2 B3						
C1 C2 C3						
D1 D2 D3						
E1 E2 E3						
F1 F2 F3						
TIME TO FIRST PLATE FAILURE WITHIN WORK AREA						
FAILURE CALL (circle)	V. Difficult Difficult. Easy	V. Difficult Difficult. Easy	V. Difficult Difficult. Easy	V. Difficult Difficult. Easy	V. Difficult Difficult. Easy	V. Difficult Difficult. Easy
HRZ. AIR VELOCITY * (circle)	A B C	A B C	A B C	A B C	A B C	A B C

PRECIP (circle): ZF , ZD , ZR-, MOD

AMBIENT TEMPERATURE: ________ °C

COMMENTS: ______________________________

NOTE:
* A: HORIZONTAL AIR VELOCITY ≤ 0.4 m/s
B: 0.4 m/s < HORIZONTAL AIR VELOCITY ≤ 1.0 m/s
C: HORIZONTAL AIR VELOCITY > 1.0 m/s

LEADER / MANAGER: ______________________

ATTACHMENT IV: COLD-SOAK WING ENDURANCE TIME DATA FORM

REMEMBER TO SYNCHRONIZE TIME

LOCATION:	CEF (Ottawa)	DATE:	RUN NUMBER:	STAND # :

TIME TO FAILURE FOR INDIVIDUAL CROSSHAIRS (real time)

Time of Fluid Application	______	______	______	______	______
Initial BOX Temperature (°C) (NEEDS TO BE -10 ± 1)	______	______	______	______	______
Initial Fluid Temperature (°C) (NEEDS TO BE WITHIN 3°C OF AIR TEMP)	______	______	______	______	______
Enter Box Number	**Box #**	**Box #**	**Box #**	**Box #**	**Box #**
FLUID NAME/BATCH					
B1 B2 B3					
C1 C2 C3					
D1 D2 D3					
E1 E2 E3					
F1 F2 F3					
TIME TO FIRST PLATE FAILURE WITHIN WORK AREA					
FAILURE CALL (circle)	V. Difficult Difficult. Easy	V. Difficult Difficult. Easy	V. Difficult Difficult. Easy	V. Difficult Difficult. Easy	V. Difficult Difficult. Easy
HRZ. AIR VELOCITY * (circle)	A B	A B	A B	A B	A B

Time of Fluid Application	______	______	______	______	______
Initial BOX Temperature (°C) (NEEDS TO BE -10 ± 1)	______	______	______	______	______
Initial Fluid Temperature (°C) (NEEDS TO BE WITHIN 3°C OF AIR TEMP)	______	______	______	______	______
Enter Box Number	**Box #**	**Box #**	**Box #**	**Box #**	**Box #**
FLUID NAME/BATCH					
B1 B2 B3					
C1 C2 C3					
D1 D2 D3					
E1 E2 E3					
F1 F2 F3					
TIME TO FIRST PLATE FAILURE WITHIN WORK AREA					
FAILURE CALL (circle)	V. Difficult Difficult. Easy	V. Difficult Difficult. Easy	V. Difficult Difficult. Easy	V. Difficult Difficult. Easy	V. Difficult Difficult. Easy
HRZ. AIR VELOCITY * (circle)	A B	A B	A B	A B	A B

AMBIENT TEMPERATURE: ________ **°C**

PRE-START COOLANT TEMPERATURE: ________ **°C**
(Code requirements are -12 ± 1 °C)

COMMENTS: ______________________________

NOTE:
* **A: HORIZONTAL AIR VELOCITY ≤ 1.0 m/s**
B: HORIZONTAL AIR VELOCITY > 1.0 m/s

LEADER / MANAGER: ________________

APPENDIX E

PROCEDURE: EVALUATION OF TYPE I ENDURANCE TIMES ON COMPOSITE SURFACES

NATURAL FROST (MAR 2010)

CM2169.002

PROCEDURE:
EVALUATION OF TYPE I ENDURANCE TIMES ON COMPOSITE SURFACES

NATURAL FROST

Winter 2009-10

Prepared for

Transportation Development Centre
Transport Canada

Prepared by: For Victoria Zoitakis

Reviewed by: John D'Avirro

APS Aviation Inc.

March 5, 2010
Final Version 1.2

EVALUATION OF TYPE I ENDURANCE TIMES ON COMPOSITE SURFACES

NATURAL FROST

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 preliminary work has demonstrated that Type I fluid endurance times are reduced when applied to composite surfaces. Depending on the condition, there is a 20 to 30 percent reduction in endurance time. The following reductions were noted:

- For natural snow conditions, the endurance time measured using the composite leading edge thermal equivalent box was 31 percent ± 10 percent less than the endurance time measured using the white painted aluminum leading edge thermal equivalent box;
- For natural frost conditions, the endurance time measured using the white painted composite test plate was 23 percent ± 9 percent less than the endurance time measured using the white painted aluminum test plate; and
- For simulated freezing conditions, the endurance time measured using the white painted composite test plate was 23 percent ± 9 percent less than the endurance time measured using the white painted aluminum test plate.

It was recommended that comprehensive Type I fluid endurance time testing be conducted to develop HOT's for use with composite materials. Testing should be conducted in all the HOT conditions: freezing fog, snow, freezing drizzle, light freezing rain, rain on a cold soaked wing, and frost. Testing should be conducted with several representative fluids and be performed in accordance with ARP 5945.

2. PREVIOUS TESTING

Comparative endurance time testing was conducted in natural frost conditions in Winters 2004-05 and 2005-06.

During Winter 2004-05, comparative testing was conducted using 0.5 L of Type I fluid heated to 20°C. Results indicated that on average, the measured endurance time using the white painted composite test plate was 19 percent ± 7 percent shorter than the endurance time measured using the white painted aluminum test plate (reference TP 14448E).

During Winter 2005-06, comparative testing was conducted using 0.5 L of Type I fluid heated to 60°C. Results indicated that on average, the measured endurance time using the white painted composite test plate was 23 percent ± 9 percent shorter than the endurance time measured using the white painted aluminum test plate (reference TP 14720E).

3. OBJECTIVE

The objective of this project is to develop Type I HOT's for use with composite materials. Comparative testing will be conducted in all the HOT conditions: freezing fog, snow, freezing drizzle, light freezing rain, rain on a cold soaked wing, and frost. This procedure describes the outdoor natural frost tests. For better understanding on the conduct of tests, separate procedures will be prepared for the natural snow and indoor tests. Figure 3.1 shows the list of procedures for the composite project.

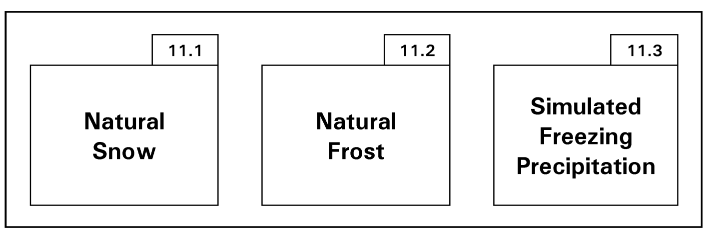

Figure 3.1: Procedures Used for Composite Testing – Winter 2009-10

4. METHODOLOGY USED TO DETERMINE COMPOSITE TYPE I HOLDOVER TIMES

A current holdover time of 45 minutes is available for Type I fluids in natural frost conditions. Data is to be collected and analyzed using ratio comparison (baseline vs. composite) to develop Type I holdover times with composite surfaces.

5. PROCEDURE

Endurance time tests will be conducted with various Type I fluids at the Montreal-Trudeau airport test site. The standard procedure for frost rate data collection and frost fluid endurance tests will be followed; see procedure *"Endurance Time Testing in Frost with Type I, II, III, and IV Fluids – 2003-04".* The tests will be conducted simultaneously using multiple test surfaces. All test plates will be prepared according to the frosticator setup used for endurance time testing in frost; plates will be painted white and will have an insulation backing.

A six position test stand will be required for testing. The first position will be reserved for a rate frosticator plate. Test stand positions two through five will include a aluminum test surface which will be the baseline endurance time test, and four composite material test surfaces representative of aircraft construction material; the same materials tested in 2005-06. Figure 4.1 demonstrates the setup required.

Previous work indicated that similar endurance times were produced using the various composite surfaces tested. If initial results indicate that endurance times measured on the various composite surfaces produce similar results. Testing will be done by using only one representative composite surface; Comp 05 test plates.

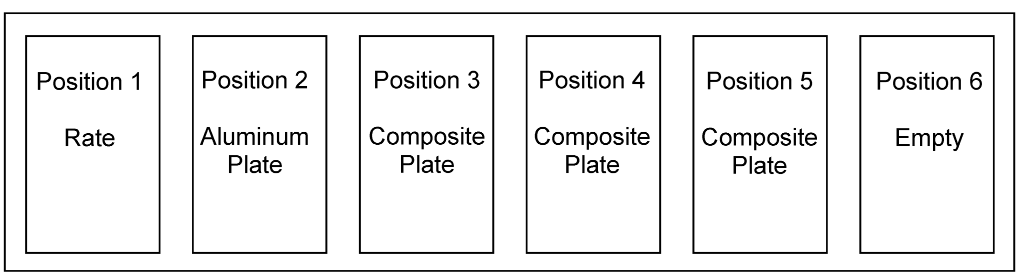

Figure 4.1: Test Stand Setup

5.1 Outdoor Tests with Type I Fluids Heated to 20ºC

0.5 L of Type I fluid heated to 20ºC should be poured simultaneously onto test positions 2 to 5 with a warm 12-hole spreader. Fluid is to be diluted to a 10ºC buffer and be applied to each test surface. Rate measurements should be taken at the beginning and at the end of every test.

It should be noted that for some tests, fluid is to be diluted to a -3°C buffer. During a two-step application process, ARP 4737 states the second step, anti-icing, is to be applied before the fluid applied in the first step freezes, typically within 3 minutes. A select number of tests are to be conducted to validate the 3 minute allowance time used during a two-step application process with composite surfaces.

6. TEST SURFACES

The following materials will be used for comparative endurance time testing and will be painted white using aircraft grade paint:

- ***Aluminum***
  (will be referred to as ***White Alum.***)
  - Material: Alclad 2024 T3;
  - Thickness: 0.32 cm; and
  - Test plate previously used during the winter of 2004-05 by APS; it was painted for testing in 2005-06.

- ***Carbon Fiber Plain Weave Fabric***
  (will be referred to as **Comp 05**)
  - Material: Carbon fiber;
  - Structure: Cross weave;
  - Thickness: 0.32 cm; and
  - Test plate previously used during the winter of 2004-05 by APS; it was painted for testing in 2005-06.

7. TEST PLAN

Testing is to be conducted in over two natural frost events. A total of approximately 24 data points is to be collected with the five different fluids; 12 tests are anticipated in temperatures above -10°C and 12 tests in temperatures below -10°C. For the -3°C buffer tests, a total of approximately 3 points will be collected. One test will be conducted for every two runs. A test plan is included in Attachment I.

8. MEASUREMENTS

8.1 Brix

Brix measurements are to be taken at the 15 cm line at the start and end of every test.

8.2 Surface Temperature

Surface temperature measurements are to be recorded one minute after fluid application and are only required for a selected number of runs, these are listed with a star in Attachment I.

9. FLUIDS

The fluids in Table 8.1 will be used for the comparative endurance time testing. Fluid dilution information is also included in Attachment II.

Table 8.1: List of Fluids Required for Testing

Fluid	Quantity Needed
Dow UCAR EF ADP	6 L Concentrate
Dow UCAR EG	6 L Concentrate
Octagon Octaflo EF	6 L Concentrate
Clariant 1938	6 L Concentrate
Kilfrost DF^{sustain}	6 L Concentrate

10. EQUIPMENT

The equipment required to collect frost rates includes:

a) An electronic balance;

b) One white-painted aluminum test plates with one thermistor probe installed at the 15 cm line, linked to the thermistor logger.

c) Three screened thermistor probes to measure air temperature linked to the thermistor logger;

Standard equipment used for Type I and Type II/III/IV fluid endurance tests outdoors will be used, with the exception that the test surface will be the white-painted insulated aluminum and composite surfaces. The surfaces will be instrumented with a thermistor probe installed at the 15 cm line, linked to the logger.

11. PERSONNEL

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

Brix 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.

12. DATA FORMS

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

- Attachment III: End Condition Form for Endurance Time Testing; and
- Attachment IV: Frost Rates on Test Surfaces.

For the -3°Buffer tests, two failure times are to be recorded. The sign of first failure is to be recorded and failure is to be recorded when one third of the plate is covered, therefore visually failed.

ATTACHMENT I: MATRIX OF OUTDOOR TESTS

Run	Test	Fluid #	Fluid Name	Dilution	OAT	Rate (g/dm^2/h)	Test Surface	Status
1	1	Fluid 1	Dow PG	10° Buffer	above -10	any	Standard Aluminum Plate	
	2	Fluid 1	Dow PG	10° Buffer	above -10	any	Composite Plate	
	3	Fluid 2	Dow EG	10° Buffer	above -10	any	Composite Plate	
	4	Fluid 3	Octaflo	10° Buffer	above -10	any	Composite Plate	
2*	5	Fluid 4	Clar 1938	10° Buffer	above -10	any	Standard Aluminum Plate	
	6	Fluid 4	Clar 1938	10° Buffer	above -10	any	Composite Plate	
	7	Fluid 5	Kil Dfsus	10° Buffer	above -10	any	Composite Plate	
	8	**Fluid 4**	**Clar 1938**	**-3° Buffer**	**above -10**	**any**	**Composite Plate**	
3	9	Fluid 2	Dow EG	10° Buffer	above -10	any	Standard Aluminum Plate	
	10	Fluid 2	Dow EG	10° Buffer	above -10	any	Composite Plate	
	11	Fluid 3	Octaflo	10° Buffer	above -10	any	Composite Plate	
	12	Fluid 4	Clar 1938	10° Buffer	above -10	any	Composite Plate	
4*	13	Fluid 5	Kil Dfsus	10° Buffer	below -10	any	Standard Aluminum Plate	
	14	Fluid 5	Kil Dfsus	10° Buffer	below -10	any	Composite Plate	
	15	Fluid 1	Dow PG	10° Buffer	below -10	any	Composite Plate	
	16	**Fluid 5**	**Kil Dfsus**	**-3° Buffer**	**below -10**	**any**	**Composite Plate**	
5	17	Fluid 3	Octaflo	10° Buffer	below -10	any	Standard Aluminum Plate	
	18	Fluid 3	Octaflo	10° Buffer	below -10	any	Composite Plate	
	19	Fluid 4	Clar 1938	10° Buffer	below -10	any	Composite Plate	
	20	Fluid 5	Kil Dfsus	10° Buffer	below -10	any	Composite Plate	
6*	21	Fluid 1	Dow PG	10° Buffer	below -10	any	Standard Aluminum Plate	
	22	Fluid 1	Dow PG	10° Buffer	below -10	any	Composite Plate	
	23	Fluid 2	Dow EG	10° Buffer	below -10	any	Composite Plate	
	24	**Fluid 1**	**Dow PG**	**-3° Buffer**	**below -10**	**any**	**Composite Plate**	

* Temperature measurements should be taking one minute after application.

ATTACHMENT II: FLUID DILUTIONS

OAT (°C)	FFP (°C)	UCAR EF ADF (PG)				UCAR ADF (EG)				Octagon Octaflo / EF				Clariant 1938				Kilfrost DF[sustain]			
		% Glycol	Brix	Glycol for 8 Litres	Water for 8 Litres	% Glycol	Brix	Glycol for 8 Litres	Water for 8 Litres	% Glycol	Brix	Glycol for 8 Litres	Water for 8 Litres	% Glycol	Brix	Glycol for 8 Litres	Water for 8 Litres	% Glycol	Brix	Glycol for 8 Litres	Water for 8 Litres
5	-5	26.0	17.3	2.1	5.9					15	9.75	12.0	6.8								
1	-9	27.7	18.4	2.2	5.8	21.5	13.5	1.7	6.3	27.5	18.5	2.2	5.8	28.5	16.5	2.3	5.7	27	17.25	2.2	5.8
0	-10	30.0	19.8	2.4	5.6	22	14	1.8	6.2	29	19	2.3	5.7	31.5	18.5	2.5	5.5	29	18.50	2.3	5.7
-1	-11	30.9	20.5	2.5	5.5	23	15	1.8	6.2	30	20	2.4	5.6	34	19.75	2.7	5.3	31	19.50	2.5	5.5
-2	-12	32.4	21.5	2.6	5.4	24.5	16	2.0	6.0	31	20.5	2.5	5.5	37.5	21.5	3.0	5.0	33	20.75	2.6	5.4
-3	-13	33.9	22.3	2.7	5.3	26	17	2.1	5.9	32	21.25	2.6	5.4	39.25	22.5	3.1	4.9	35	21.75	2.8	5.2
-4	-14	35.0	22.8	2.8	5.2	28	18	2.2	5.8	34	22.5	2.7	5.3	40.5	23.5	3.2	4.8	36.5	22.75	2.9	5.1
-5	-15	36.7	24.2	2.9	5.1	30	19	2.4	5.6	35	23	2.8	5.2	42	24.25	3.4	4.6	38.5	23.75	3.1	4.9
-6	-16	38.1	25.0	3.0	5.0	31	19.75	2.5	5.5	36	23.5	2.9	5.1	43	24.75	3.4	4.6	40	24.50	3.2	4.8
-7	-17	39.4	25.8	3.1	4.9	32	20.5	2.6	5.4	37	24	3.0	5.0	44.25	25.5	3.5	4.5	41.5	25.50	3.3	4.7
-8	-18	40.0	27.2	3.2	4.8	33.5	21.25	2.7	5.3	38.5	25	3.1	4.9	45.5	26	3.6	4.4	43	26.25	3.4	4.6
-9	-19	41.9	27.5	3.4	4.6	34.5	21.75	2.8	5.2	40	26	3.2	4.8	46.5	26.5	3.7	4.3	45	27.25	3.6	4.4
-10	-20	43.1	27.8	3.4	4.6	36	22.5	2.9	5.1	42	27	3.4	4.6	47.75	27.5	3.8	4.2	46	28.00	3.7	4.3
-11	-21	45.0	28.6	3.6	4.4	37	23	3.0	5.0	44	28	3.5	4.5	49	28	3.9	4.1	47.5	28.75	3.8	4.2
-12	-22	45.4	29.0	3.6	4.4	38	23.75	3.0	5.0	45	28.5	3.6	4.4	50	28.75	4.0	4.0	49	29.50	3.9	4.1
-13	-23	46.4	29.5	3.7	4.3	39	24.5	3.1	4.9	46	29	3.7	4.3	51	29.25	4.1	3.9	50	30.00	4.0	4.0
-14	-24	47.5	30.0	3.8	4.2	40	25	3.2	4.8	47	29.5	3.8	4.2	52.25	29.75	4.2	3.8	51.5	30.75	4.1	3.9
-15	-25	48.5	30.5	3.9	4.1	41	25.5	3.3	4.7	47.5	30	3.8	4.2	53.5	30.25	4.3	3.7	52.5	31.25	4.2	3.8
-16	-26	49.5	31.0	4.0	4.0	42	26	3.4	4.6	48.5	30.5	3.9	4.1	54.5	30.75	4.4	3.6	53.5	32.00	4.3	3.7
-17	-27	50.0	31.4	4.0	4.0	43	26.5	3.4	4.6	49	31	3.9	4.1	55.5	31.25	4.4	3.6	54.5	32.50	4.4	3.6
-18	-28	51.3	31.8	4.1	3.9	44	27	3.5	4.5	50	31.5	4.0	4.0	56.5	31.75	4.5	3.5	55.5	33.00	4.4	3.6
-19	-29	52.2	32.1	4.2	3.8	45	27.5	3.6	4.4	51	32	4.1	3.9	57.75	32.25	4.6	3.4	56.5	33.50	4.5	3.5
-20	-30	53.9	32.8	4.3	3.7	45.75	28	3.7	4.3	52	32.5	4.2	3.8	58.75	32.75	4.7	3.3	57.5	34.00	4.6	3.4
-22	-32	56.1	34.0	4.5	3.5	47	28.75	3.8	4.2	53.5	33.5	4.3	3.7	61	33.75	4.9	3.1	59	34.75	4.7	3.3
-25	-35	60.0	36.3	4.8	3.2	49	30	3.9	4.1	56	34.5	4.5	3.5	64.5	35.25	5.2	2.8	60.5	35.50	4.8	3.2
-30	-40	55.0	33.8	4.4	3.6	53	32	4.2	3.8	60	37	4.8	3.2	70	37.75	5.6	2.4	62.5	36.50	5.0	3.0
Standard Mix		26.0	17.3	2.1	5.9	57	33.5	4.6	3.4	63	38.25	5	3.0								

EVALUATION OF TYPE I ENDURANCE TIMES ON COMPOSITE SURFACES NATURAL FROST

ATTACHMENT III: END CONDITION FORM FOR COMPOSITE ENDURANCE TIME TESTING

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

FLUID NAME ______ ______ ______ ______

PLATE POSITION ______ ______ ______ ______

	ALUMINUM BOX			COMPOSITE BOX #1			COMPOSITE BOX #2			COMPOSITE BOX #3		
	1	2	3	1	2	3	1	2	3	1	2	3
B	○	○	○	○	○	○	○	○	○	○	○	○
C	○	○	○	○	○	○	○	○	○	○	○	○
D	○	○	○	○	○	○	○	○	○	○	○	○
E	○	○	○	○	○	○	○	○	○	○	○	○
F	○	○	○	○	○	○	○	○	○	○	○	○

TIME OF FLUID APPLICATION		______	______	______	______
TIME OF FLUID FAILURE		______	______	______	______
TIME OF FIRST SIGN OF FLUID FAILURE		______	______	______	______
TEMPERATURE AT 15 CM LINE AT 1 MIN		______	______	______	______
BRIX MEASUREMENTS TIME / BRIX	INITIAL	0 min /	0 min /	0 min /	0 min /
	END	/	/	/	/
FAILURES CALLED BY:		______			

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Final Version 1.2, March 10

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ATTACHMENT IV
DATA FORM
FROST RATES ON TEST SURFACES

Date ________________ Location __________________

Recorded by ___________ Signature _________________

Logger Start Time______________ Weather Trend Printed at (time)_________

Logger Save Time______________

Surface	Time (Hr:min)	Weight (g)
1		
2		
1		
2		
1		
2		
1		
2		
1		
2		
1		
2		
1		
2		
1		
2		
1		
2		
1		
2		

Surface	Time (Hr:min)	Weight (g)
1		
2		
1		
2		
1		
2		
1		
2		
1		
2		
1		
2		
1		
2		
1		
2		
1		
2		
1		
2		

Surface	Time (Hr:min)	Weight (g)
1		
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INSTRUCTIONS:

1. Confirm test surface temperature and OAT logging throughout the testing session by checking the real time readings displayed on the computer screen;
2. Check online the availability of Environment Canada weather summary every hour. If unavailable, fill in the form in ATTACHMENT B1; and
3. Weigh one plate at a time.

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