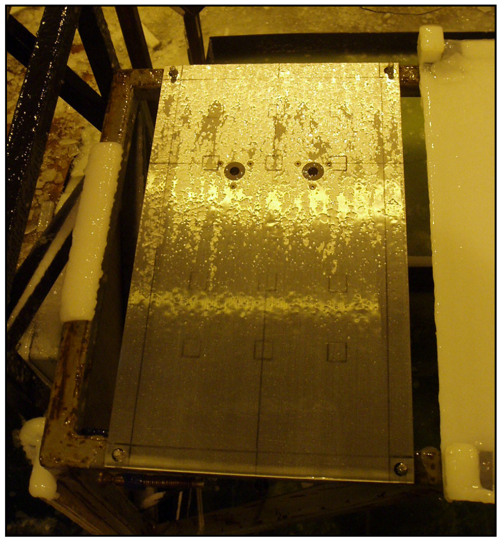
TP 14446E

A Sensor for Detecting Anti-Icing Fluid Failure: Phase II



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In cooperation with

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Transport Canada

Prepared by

APS Aviation Inc.

November 2005
Final Version 1.0

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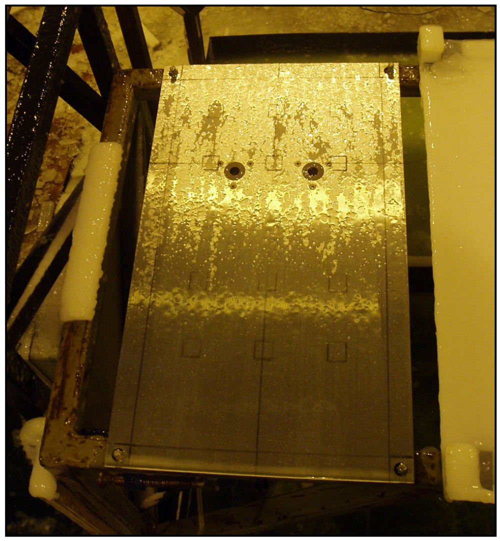

By:

Stephanie Bendickson

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The contents of this report reflect the views of APS Aviation Inc. and not necessarily the official view or opinions of the Transportation Development Centre of Transport Canada.

The Transportation Development Centre does not endorse products or manufacturers. Trade or manufacturers' names appear in this report only because they are essential to its objectives.

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Un sommaire français se trouve avant la table des matières.

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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;
- To conduct endurance time tests in frost on various test surfaces;
- To assist with the operational evaluation of Type III fluids;
- To finalize the laboratory snow test protocol with Type II, III and IV fluids;
- To evaluate weather data from previous winters to establish a range of conditions suitable for the evaluation of holdover time limits;
- To assist the SAE G-12 Ground Equipment Subcommittee in evaluating forced air-assist systems;
- To evaluate the possibility of using a fluid failure sensor in holdover time testing;
- To conduct endurance time tests on non-aluminum plates;
- To examine the effect of heat on Type II, III and IV fluid endurance times;
- To provide support for human factor tactile tests; and
- To conduct general and exploratory de/anti-icing research.

The research activities of the program conducted on behalf of Transport Canada during the winter of 2004-05 are documented in nine reports. The titles of the reports are as follows:

- TP 14443E Aircraft Ground De/Anti-Icing Fluid Holdover Time Development Program for the 2004-05 Winter;
- TP 14444E Winter Weather Impact on Holdover Time Table Format (1995-2005);
- TP 14445E Evaluation of Type IV Fluids Applied Using Forced Air Assist Equipment;
- TP 14446E A Sensor for Detecting Anti-Icing Fluid Failure: Phase II;
- TP 14447E Effect of Heat on Endurance Times of Anti-Icing Fluids;
- TP 14448E Aircraft Ground Deicing Fluid Endurance Times on Composite Surfaces;
- TP 14449E Development of Ice Samples for Visual and Tactile Ice Detection Capability Tests;
- TP 14450E Development of Ice Samples for Comparison Study of Human and Sensor Capability to Detect Ice on Aircraft; and
- TP 14451E Aircraft Ground Icing General Research Activities During the 2004-05 Winter.

In addition, the following interim report is being prepared:

- *Substantiation of Aircraft Ground Deicing Holdover Times in Frost Conditions.*

This report, TP 14446E, has the following objective:

- To evaluate the ability of a fluid failure sensor to replicate visual fluid failure determinations.

To satisfy this objective, a fluid failure sensor was acquired from Intertechnique and tested in natural snow and in simulated freezing rain, drizzle and fog.

This research project has been funded by the Civil Aviation Group, Transport Canada.

PROGRAM ACKNOWLEDGEMENTS

This multi-year research program has been funded by the Civil Aviation Group, 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: Stephanie Bendickson, Nicolas Blais, Michael Chaput, Sami Chebil, John D'Avirro, Peter Dawson, Stéphane Gosselin, Mark Mayodon, Chris McCormack, Nicoara Moc, Filomeno Pepe, Marco Ruggi, Joey Tiano, Kim Vepsa, and David Youssef.

Special thanks are extended to Barry Myers, Frank Eyre and Yagusha Bodnar, who on behalf of the Transportation Development Centre, have participated, contributed and provided guidance in the preparation of these documents.

PROJECT ACKNOWLEDGEMENTS

The author would like to acknowledge the significant contribution of Intertechnique to this project. In addition to providing a complete ice detection system, Intertechnique also provided training and guidance throughout the test season and duration of the project. In particular, the author would like to thank the contribution of Mr. François Larue of Intertechnique; without his support this project could not have been possible.

APS Aviation Inc. would also like to thank SPCA for providing fluid for testing.

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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. Nine reports (including this one) were produced as part of this winter's research program. Their subject matter is outlined in the preface.

16. Abstract

In recent years, research has been conducted to evaluate the variance in endurance times caused by individual variance in determination of fluid failure. In the winter of 2003-04, testing was conducted with the Intertechnique Ice Detection System (IDES) in an attempt to determine if it could replace the visual determination of fluid failure.

Results of testing in 2003-04 were promising, and it was recommended that if improvements could be made to the Intertechnique system, more tests be conducted in the winter of 2004-05. Intertechnique did make improvements to the system and provided the Wing Ice Detection System (WIDS) for testing in 2004-05.

Tests were conducted with the WIDS in snow, freezing rain, freezing drizzle and freezing fog in various temperatures from 0ºC to -16ºC. Type I PG, Type II PG, Type IV PG and Type IV EG fluids were tested in various dilutions.

It was found that:

- Compared to the 2003-04 system, the 2004-05 ice detection system had better results in snow but no significant improvement in simulated precipitation conditions;
- The WIDS was better able to replicate visual fluid failure with Type II and Type IV fluids than with Type I fluids, likely due to the mechanisms used to detect fluid failure;
- The WIDS was better able to replicate visual endurance times in snow than in freezing drizzle or freezing rain; and
- No significant relationship was found between the WIDS ability to replicate visual endurance times and Type II/IV fluid dilution or temperature.

Based on the limited number of tests that were conducted, it was concluded that the WIDS is currently not able to replicate a visual determination of failure. Although the Intertechnique ice detection system may be able to replicate visual endurance times in snow with Type II and Type IV fluids, significant resources would be required to get the system to be able to replicate visual endurance times with Type I fluids or in simulated precipitation conditions. It was therefore recommended that resources would be more effective in this area if they went towards training and education programs for test personnel rather than further developing an ice detection system.

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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. Neuf rapports (dont celui-ci) ont été rédigés dans le cadre du programme de recherche de cet hiver. Leur objet apparaît à l'avant-propos.

16. Résumé

Au cours des dernières années, des recherches ont été menées afin d'évaluer la variance dans les durées d'endurance causée par la variance individuelle observée dans la détermination de la défaillance d'un liquide. Des essais ont été effectués à l'aide du système d'évaluation de détection de givre d'Intertechnique (Intertechnique Ice Detection Evaluation System, ou IDES) durant l'hiver 2003-2004 dans le but d'établir si cette technologie pourrait remplacer la détermination visuelle de la défaillance d'un liquide.

Les résultats des essais menés en 2003-2004 s'étant avérés prometteurs, il avait été recommandé que si des améliorations pouvaient être apportées au système d'Intertechnique, d'autres tests soient effectués durant l'hiver 2004-2005. Intertechnique a apporté ces améliorations à son système, et a ainsi soumis aux fins d'évaluation le système de détection de givre sur les ailes (Wing Ice Detection System, ou WIDS) en 2004-2005.

Des essais ont été menés à l'aide du WIDS dans des conditions de neige, de pluie verglaçante, de bruine verglaçante et de brouillard verglaçant, à des températures variant de 0°C à -16°C. Des liquides de types I PG, II PG, IV PG et IV EG, dans diverses dilutions, ont été analysés.

Il a été constaté que :

- Comparativement au système de 2003-2004, le système de détection de givre de 2004-2005 a donné de meilleurs résultats dans des conditions de neige, mais n'a pas permis d'améliorations significatives dans des conditions de précipitations simulées ;
- Le WIDS a pu reproduire la détermination visuelle de la défaillance des liquides de types II et IV plus facilement que celle des liquides de type I, probablement en raison des mécanismes utilisés pour détecter la défaillance d'un liquide ;
- Le WIDS a pu reproduire les durées d'endurance déterminées visuellement dans des conditions de neige plus facilement que dans des conditions de bruine verglaçante ou de pluie verglaçante ; et
- Aucun lien significatif n'a été établi entre la capacité du WIDS à reproduire les durées d'endurance déterminées visuellement et la dilution ou la température des liquides de types II/IV.

Les essais menés, en nombre limité, ont permis de conclure que le WIDS n'est pas en mesure, à l'heure actuelle, de reproduire la détermination visuelle de la défaillance d'un liquide. Bien que le système de détection de givre d'Intertechnique puisse imiter les durées d'endurance déterminées visuellement dans des conditions de neige avec les liquides de types II et IV, des ressources importantes seraient requises pour l'amener à reproduire ces durées d'endurance déterminées visuellement avec les liquides de type I ou dans des conditions de précipitations simulées. Par conséquent, pour une utilisation plus efficace des ressources dans ce domaine, il a été recommandé que ces dernières soient allouées à des programmes de formation et d'éducation du personnel chargé des tests plutôt qu'à la poursuite du développement d'un système de détection de givre.

17. Mots clés Dégivrage, liquides de dégivrage et d'antigivrage, durées d'efficacité, temps d'endurance, défaillance d'un liquide, détecteurs, détection de givre	18. Diffusion Le Centre de développement des transports dispose d'un nombre limité d'exemplaires.

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EXECUTIVE SUMMARY

On behalf of the Transportation Development Centre (TDC) of Transport Canada (TC), APS Aviation Inc. (APS) has undertaken research activities to further advance aircraft ground de/anti-icing technology. In recent years, one of these research activities has been the evaluation of variance in endurance times caused by individual variance in determination of fluid failure.

Background

A small test program conducted in the winter of 2002-03 showed that a significant amount of variance in endurance times occurs when intermediate and novice individuals determine fluid failure. If these individuals conducted tests, this variance could significantly affect the holdover time guidelines. One way to eliminate some of this variance is to develop equipment to determine fluid failure. The Intertechnique ice detection system was seen as a possibility for this task and TC subsequently secured the Intertechnique Ice Detection Evaluation System (IDES) to test in the winter of 2003-04.

Results of testing in 2003-04 were promising, and it was recommended that more tests be conducted in the winter of 2004-05 if improvements could be made to the Intertechnique system. Intertechnique did make improvements to the system and provided the Wing Ice Detection System (WIDS) for testing in 2004-05.

Methodology

The Intertechnique system uses an ultrasonic technology based on acoustic impedance measurements to detect ice. Its components include ice sensors (for these tests the ice sensors were installed in a standard endurance time test plate), a remote unit, a power supply and interconnection box, and a laptop computer equipped with specialized software that monitors output from the sensors.

Standard endurance time test protocol, with several additional requirements, was used to conduct tests with the WIDS. The additional requirements were related to the specialized WIDS equipment and to the method of detecting fluid failure.

Tests were conducted with four fluids in natural snow, freezing drizzle, freezing rain and freezing fog.

Data

Due to limited funding being available, a limited number of tests were conducted. More tests were conducted in natural snow than in simulated freezing precipitation

conditions, and more tests were conducted with Type IV fluid than with other fluid types.

Analysis

The following observations were made based on testing with the WIDS:

- The variance between visual and WIDS endurance times was less than or equal to 10 percent in 41 percent of the tests (10 percent is the variance expected when a human observer determines fluid failure);
- The WIDS was better able to replicate visual fluid failure with Type II and Type IV fluids than with Type I fluids (the WIDS had difficulty detecting fluid failure with Type I fluids, likely due to the mechanisms used to detect fluid failure);
- The WIDS was better able to replicate visual endurance times in snow than in freezing drizzle or freezing rain;
- No significant relationship was found between the WIDS ability to replicate visual endurance times and Type II/IV fluid dilution or temperature; and
- The 2004-05 ice detection system showed improved results in snow compared to the 2003-04 system, but no significant improvement was seen in tests in simulated precipitation conditions.

Conclusions

Based on the limited number of tests that were conducted, it was concluded that the WIDS is currently not able to replicate a visual determination of failure.

Recommendations

The Intertechnique ice detection system may be able to accurately and consistently replicate visual endurance times in snow with Type II and Type IV fluids; further work would still be required to refine the system. However, significant resources would be required to enable the technology to accurately replicate visual endurance times with Type I fluids or in simulated precipitation conditions. Therefore, it is recommended that resources would be used more effectively in this area if they went towards training and education programs for test personnel rather than further developing an ice detection system.

SOMMAIRE

Au nom du Centre de développement des transports (CDT) de Transports Canada (TC), APS Aviation Inc. (APS) a entrepris des activités de recherche visant à faire progresser les technologies associées au dégivrage et à l'antigivrage d'aéronefs au sol. Au cours des dernières années, l'une de ces activités de recherche s'est concentrée sur l'évaluation de la variance dans les durées d'endurance causée par la variance individuelle observée dans la détermination de la défaillance d'un liquide.

Contexte

Un programme d'essai limité mis en place au cours de l'hiver 2002-2003 a démontré qu'une variance importante dans les durées d'endurance peut être observée lorsque des individus de niveau intermédiaire et des novices déterminent la défaillance d'un liquide. Cette variance, si ces individus devaient effectuer les tests, pourrait avoir une influence considérable sur les lignes directrices relatives aux durées d'efficacité. L'un des moyens d'éliminer en partie cette variance est de mettre au point des équipements permettant de déterminer la défaillance d'un liquide. Le système de détection de givre d'Intertechnique étant perçu comme susceptible d'accomplir cette tâche, TC s'est doté du système d'évaluation de détection de givre d'Intertechnique (Intertechnique Ice Detection Evaluation System, ou IDES) aux fins d'essai durant l'hiver 2003-2004.

Les résultats des essais menés en 2003-2004 s'étant avérés prometteurs, il avait été recommandé que si des améliorations pouvaient être apportées au système d'Intertechnique, d'autres tests soient effectués durant l'hiver 2004-2005. Intertechnique a apporté ces améliorations à son système, et a ainsi soumis aux fins d'évaluation le système de détection de givre sur les ailes (Wing Ice Detection System, ou WIDS) en 2004-2005.

Méthodologie

Le système d'Intertechnique a recours à une technologie ultrasonique basée sur des mesures d'impédance acoustique permettant de détecter le givre. Ses composants incluent des détecteurs de givre (dans le cadre de ces tests, les détecteurs de givre étaient installés sur une plaque servant aux essais d'endurance standards), une unité distante, un bloc d'alimentation et une boîte d'interconnexion, ainsi qu'un ordinateur portable équipé d'un logiciel spécialisé surveillant les données des détecteurs.

Pour mener les tests à l'aide du WIDS, le protocole relatif aux essais d'endurance standards a été utilisé, en y ajoutant de nombreuses exigences, liées à

l'équipement spécialisé du WIDS et à la méthode de détection de la défaillance d'un liquide.

Des tests ont été effectués avec quatre liquides sous neige naturelle et dans des conditions de bruine verglaçante, de pluie verglaçante et de brouillard verglaçant.

Données

En raison d'un financement limité, un nombre réduit d'essais ont été menés. Davantage de tests ont été menés sous neige naturelle que dans des conditions de précipitations verglaçantes simulées, et un plus grand nombre d'essais ont été effectués avec des liquides de type IV qu'avec d'autres types de liquides.

Analyse

Les observations suivantes ont été faites à la suite des essais menés à l'aide du WIDS :

- La variance observée entre les durées d'endurance déterminées visuellement et celles déterminées par le WIDS était égale ou inférieure à 10 pour cent dans 41 pour cent des essais menés. Ce taux de dix pour cent représente la variance attendue lorsqu'un observateur humain détermine la défaillance d'un liquide ;

- Le WIDS a pu reproduire la détermination visuelle de la défaillance des liquides de types II et IV plus facilement que celle des liquides de type I. Le WIDS a éprouvé des difficultés à détecter la défaillance des liquides de type I, probablement en raison des mécanismes utilisés pour détecter la défaillance d'un liquide ;

- Le WIDS a pu reproduire les durées d'endurance déterminées visuellement dans des conditions de neige plus facilement que dans des conditions de bruine verglaçante ou de pluie verglaçante ;

- Aucun lien significatif n'a été établi entre la capacité du WIDS à reproduire les durées d'endurance déterminées visuellement et la dilution ou la température des liquides de types II/IV ; et

- Comparativement au système de 2003-2004, le système de détection de givre de 2004-2005 a donné de meilleurs résultats dans des conditions de neige. Aucune amélioration significative n'a été observée dans le cadre des essais menés dans des conditions de précipitations simulées.

Conclusions

Les essais menés, en nombre limité, ont permis de conclure que le WIDS n'est pas en mesure, à l'heure actuelle, de reproduire la détermination visuelle de la défaillance d'un liquide.

Recommandations

Il est possible que le système de détection de givre d'Intertechnique soit en mesure d'imiter précisément et systématiquement les durées d'endurance déterminées visuellement dans des conditions de neige avec les liquides de types II et IV. Des efforts supplémentaires s'avéreraient encore nécessaires afin de le perfectionner. Par ailleurs, des ressources importantes seraient requises pour amener la technologie à reproduire précisément les durées d'endurance déterminées visuellement avec les liquides de type I ou dans des conditions de précipitations simulées. Par conséquent, pour une utilisation plus efficace des ressources dans ce domaine, il est recommandé que ces dernières soient allouées à des programmes de formation et d'éducation du personnel chargé des tests plutôt qu'à la poursuite du développement d'un système de détection de givre.

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GLOSSARY

APS	APS Aviation Inc.
FAA	Federal Aviation Administration
IDES	Ice Detection Evaluation System
IDRU	Ice Detection Remote Unit
ISIS	In-situ Ice Sensors
NRC	National Research Council Canada
PSIB	Power Supply and Interconnection Box
TC	Transport Canada
TDC	Transportation Development Centre
WIDS	Wing Ice Detection System

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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 of what can be done to reduce the risks posed by the operation of aircraft in winter precipitation conditions. This "winter operations contaminated aircraft – ground" program of research is aimed at overcoming this lack of knowledge.

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

On behalf of the TDC, APS Aviation Inc. (APS) has undertaken research activities to further advance aircraft ground de/anti-icing technology. In recent years, one of these research activities has been an attempt to standardize the determination of fluid failure.

1.1 Background

Initial work was conducted in the winter of 2001-02 and reported in the TC report, TP 13991E, *Aircraft Ground De/Anti-Icing Fluid Holdover Time and Endurance Time Testing Program for the 2001-02 Winter* (1).

In the winter of 2002-03, further work was undertaken to document the variance in endurance times attributable to the level of experience of the individual. This work is documented in the TC report, TP 14156E, *Variance in Endurance Times of De/Anti-Icing Fluids* (2). These tests were conducted to evaluate the influence of the level of training, knowledge and experience on an individual's ability to determine fluid failures. Results showed a significant amount of variance in the endurance times measured by intermediate (14 percent) and novice (22 percent) individuals. It was concluded there are three ways of obtaining consistent results during holdover time testing: to use the same experienced individual to conduct tests, to develop an intense training program, or to develop technology to detect fluid failures.

Over the past decade, several companies have developed technology in this area but none has successfully developed a technology to the level required by the industry. Based on recent developments and research, it was believed that the Intertechnique Ice Detection Evaluation System (IDES), which was developed for on-wing ice detection, could be suitable for detecting fluid failure during endurance time testing. In the fall of 2003, APS approached Intertechnique on behalf of TC to ascertain their interest in having TC evaluate the IDES for use in endurance time testing. Intertechnique agreed and provided an IDES for testing in the winter of 2003-04.

A limited number of tests were conducted with the IDES in the winter of 2003-04. These tests are documented in the TC report, TP 14382E, *A Sensor for Detecting Anti-Icing Fluid Failure: Phase I* (3). From these tests, it was concluded that in its current state the IDES was not able to replicate visual determination of fluid failure. It was theorized that this might have been a result of its inability to replicate a human observation rather than its inability to detect ice. In fact, in some cases it may have measured a fluid's ability to offer ice protection more accurately than a human observer.

However, the results of testing in 2003-04 were promising, and it was recommended that more tests be conducted in the winter of 2004-05 if improvements could be made to the Intertechnique system. It was also recommended Intertechnique personnel be present at the simulated precipitation conditions test session. This report documents the work completed in 2004-05.

1.2 Objective

The objective of this project was to evaluate the ability of the improved Intertechnique ice detection system to replicate visual fluid failure determinations. It should be noted that the objective was not to evaluate the system's ability to detect fluid failure. The scope of work for this project is outlined in an excerpt from the TDC work statement provided in Appendix A.

Limited funding was available for this project and testing was subsequently completed in conjunction with other projects and other testing. Limited data and observations were collected, and while detailed analyses of the system's performance in specific conditions and with specific fluids are not conclusive, the limited data does give an overall sense of the system's ability to replicate the visual determination of fluid failure.

1.3 Report Format

The remainder of this report is organized into the following sections:

a) Section 2 (Methodology) presents the procedure and methods used to conduct the tests;

b) Section 3 (Data Collected) presents the data collected including number of tests conducted by precipitation condition and fluid type;

c) Section 4 (Analysis) provides an analysis of the data, and of the ability of the ice detection system to replicate visual determination of fluid failure;

d) Section 5 (Conclusions) provides conclusions from 2004-05 testing; and

e) Section 6 (Recommendations) provides recommendations for future testing.

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2. METHODOLOGY

The equipment, procedure, training, fluids, personnel and test locations involved in conducting tests with the Intertechnique ice detection system are outlined in this section.

2.1 Equipment

Along with standard endurance time test equipment, the Intertechnique ice detection system was required. Intertechnique made improvements to the IDES tested in 2003-04. The improved system, called the Wing Ice Detection System (WIDS), was brought to Montreal by Intertechnique in January 2005.

2.1.1 WIDS Components

The WIDS has four components, as listed below.

1. In-situ Ice Sensors (ISIS): Point sensors flush mounted with the critical surface to monitor and sense the presence of fluids, slush or ice and measure the anti-icing fluid dilution. They also include a temperature sensor for surface temperature measurements. The ice sensors are normally installed on aircraft. The location of the ice sensor installation in the test plate is shown in Figure 2.1 and in Photo 2.1.

2. Ice Detection Remote Unit (IDRU): Connects a minimum of one and a maximum of four ice sensors. The IDRU provides warning messages to the appropriate systems through a digital data bus. The IDRU is also shown in Photo 2.1.

3. Power Supply and Interconnection Box (PSIB): provides power to the IDRU and connects the operator interface computer and the IDRU. The PSIB is shown in Photo 2.2.

4. WIDS Operator Interface PC: Used to control and monitor the WIDS and support some maintenance functions. Intertechnique provided a laptop for this purpose.

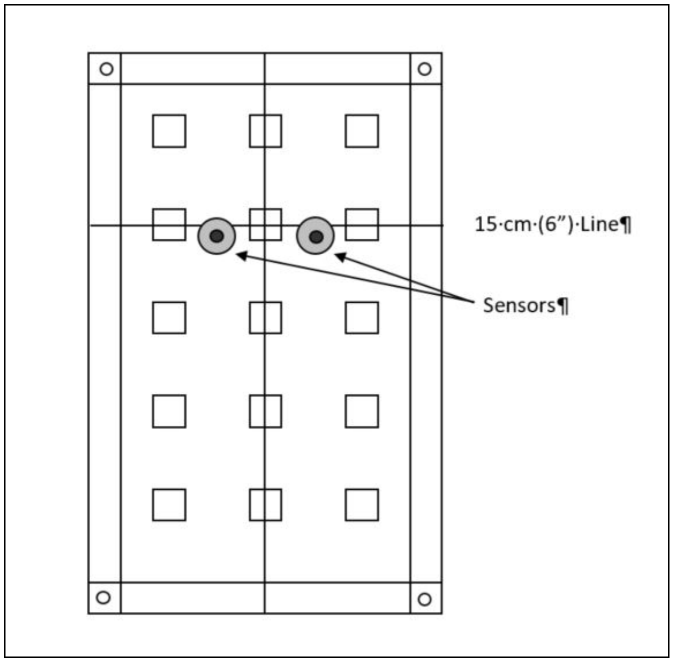

Figure 2.1: Standard Test Plate Equipped with IDES Sensors

2.1.2 WIDS Operating Principles

The WIDS operates using ultrasonic technology. The system's patented technology uses acoustic impedance measurements to measure the presence of de/anti-icing fluids on its ice sensors. Below the surfaces of the sensors, there are transmitters and receivers. The transmitters send out signals, and depending on the condition of the surface (fluid or ice) a different signal will be transmitted to the receiver. Based on the signals that are received and several other inputs, the system can determine if there is ice or fluid on the surface. If there is fluid on the surface, the WIDS gives an indication of the fluid's condition.

One of the other system inputs is the fluid freeze point curve for the fluid being tested. Fluid freeze point curves for each test fluid were therefore required. These curves were obtained from the fluid manufacturers by Intertechnique. The curves are included in Appendix B.

Other WIDS outputs include fluid dilution, fluid thickness and sensor/plate temperature.

2.1.3 WIDS Software Versions

Different software versions installed in the WIDS can have a significant impact on test results. An original software version was installed in the system when it was first brought to Montreal in January 2005. This version was used for all of the snow tests. Prior to the simulated precipitation test session, a second software version was installed. This version was used for all of the simulated precipitation tests. The data from the snow tests was subsequently re-run using this second version so that all test results could be reported using the same software version.

2.2 Procedure

The procedure used to conduct tests with the Intertechnique ice detection system is based on the standard endurance time testing procedure, which can be found in the TC report, TP 14443E, *Aircraft Ground De/Anti-Icing Fluid Holdover Time Development Program for the 2004-05 Winter (4)*. Several additional requirements were added to the standard endurance time test protocol in order to evaluate the ice detection system. These requirements are summarized in Subsections 2.1.1 to 2.1.3 and are described in detail in the sensor test procedure, which is included in Appendix C.

The test procedure used in 2004-05 is the same as the procedure used in 2003-04 with the following minor changes incorporated:

- A Type II fluid was tested in place of Octagon Max Flight;
- Only one test plate (instead of 2) was tested;
- The software user interface was slightly different;
- Some of the equipment components were set up differently; and
- The data form included space to record individual sensor failure and plate failure.

2.2.1 Test Plate

The first requirement added to the standard endurance time test procedure for testing with the sensor was that tests be conducted on standard endurance time test plates equipped with Intertechnique sensors. One test plate equipped with two sensors was provided by Intertechnique.

2.2.2 Equipment Monitoring

The second requirement added was that the ice detection system be monitored. The Intertechnique equipment was reset at the beginning of each test, following a thorough cleaning of the test plate. The computer equipment was monitored throughout the tests to ensure that it was functional and was recording data. At the end of the test session, all data had to be saved and downloaded.

2.2.3 Procedure for Determining Fluid Failure

The standard test protocol dictates that fluid failure be recorded when frozen precipitation is present on five crosshairs on a standard endurance time test plate. However, during tests with the ice detection system, the procedure required that the human observer record fluid failure when frozen precipitation was seen on each individual sensor. For interest, fluid failure was also recorded for the plate using the standard test protocol. Although two visual values were recorded for each test plate, only the value recorded for each sensor was used in the analysis.

It should be noted that in the majority of tests, the individual determining fluid failure did not observe the WIDS output during the test.

2.3 Personnel

Two individuals were required for testing. One individual set and monitored the WIDS, prepared fluids and filled out the test session log. The second individual recorded fluid failure. A requirement of the procedure was that the individuals recording fluid failure were experts as defined in TP 14156E (2):

Expert: These individuals have comprehensive knowledge of fluid failure and extensive experience determining fluid failures.

Three individuals classified as experts participated in the tests.

It was necessary to measure precipitation rates when testing in snow. During most test sessions, precipitation rates were already being measured for other projects and therefore it was not necessary for a third individual to measure precipitation rates. However, when precipitation rates were not being measured for other tests, a third individual was required to measure precipitation rates.

2.3.1 Training

Intertechnique provided training to APS researchers at a one day training session at the APS test site at the Montreal – Pierre Elliot Trudeau International Airport.

2.4 Fluids

Tests were conducted with Kilfrost ABC-S, UCAR Ultra+, SPCA Ecowing 26 and Clariant MP I 1938. Neat, 75/25 and 50/50 dilutions of the Type II and Type IV fluids were tested. The Type I fluid was mixed to a 10ºC buffer (fluid freezing point 10ºC lower that the outside air temperature) for testing. The Type II and Type IV fluids were tested with varying viscosities, depending on the availability of samples. The Ecowing 26 fluid was provided by SPCA. The other fluid samples were surplus test fluids from other projects. Test fluid details are given in Table 2.1.

Table 2.1: Test Fluids

Fluid	Fluid Type	Fluid Base
Dow/UCAR Ultra +	Type IV	Ethylene-Glycol
Kilfrost ABC-S	Type IV	Propylene-Glycol
SPCA Ecowing 26	Type II	Propylene-Glycol
Clariant MP I 1938	Type I	Propylene-Glycol

2.5 Test Locations

Tests were conducted in various winter precipitation conditions. Snow tests were conducted at the APS test site at the Montreal – Pierre Elliot Trudeau International Airport. Simulated precipitation tests were conducted at the NRC Climatic Engineering Facility in Ottawa.

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Photo 2.1: Test Plate Equipped with Ice Sensors, IDRU in Protective Housing

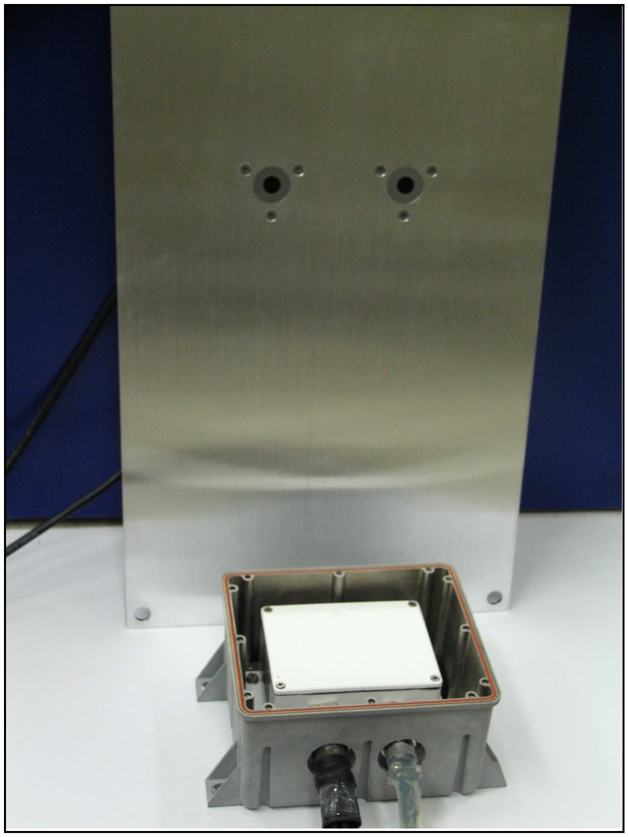

Photo 2.2: PSIB

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3. DATA COLLECTED

The data collected is described in this section.

3.1 Summary of Tests

As two sensors were installed on the test plate and visual fluid failure was recorded individually for each sensor, each test produced two test values. The number of tests conducted by precipitation condition is shown in Table 3.1. The majority of tests were conducted in snow. The number of tests conducted by fluid type is shown in Table 3.2. The majority of tests were conducted with Type IV fluid.

Table 3.1: Tests Conducted by Precipitation Condition

Precipitation Type	Tests Conducted	Test Values
Snow	40	80
Freezing Drizzle	12	24
Freezing Rain	9	18
Freezing Fog	1	2
Total	**62**	**124**

Table 3.2: Tests Conducted by Fluid Type

Fluid Type	Tests Conducted	Test Values
Type I PG	11	22
Type II PG	21	42
Type IV PG	21	42
Type IV EG	9	18
Total	**62**	**124**

3.2 Log of Tests

The log of tests is given at the end of this chapter in Table 3.3. The data in each column in the log is described in the following Subsections. Several columns, including the start time, end time and plate failure time, have been omitted from Table 3.3, but are included in the complete log of tests in Appendix D.

3.2.1 Test

This column gives the test number. The test numbers have been assigned chronologically.

3.2.2 Sensor

This column indicates if the test data is from Sensor 3 (installed on the left side of the plate) or Sensor 4 (installed on the right side of the plate). The sensors were numbered prior to delivery to Montreal: there was no Sensor 1 or Sensor 2.

3.2.3 Date

This column gives the date the test took place.

3.2.4 Fluid

This column gives the fluid brand tested.

3.2.5 Fluid Dilution

This column gives the fluid dilution tested, indicated as concentrate to water.

3.2.6 Precipitation Type

This column indicates the type of precipitation under which the test took place. Precipitation types include natural snow, simulated freezing fog, simulated freezing drizzle and simulated freezing rain.

3.2.7 Precipitation Rate

This column indicates the rate of precipitation, given in $g/dm^2/h$, under which the test took place.

3.2.8 Temperature

This column gives the outside air temperature for snow tests and the ambient air temperature for simulated precipitation tests. Temperatures are given in degrees Celsius.

3.2.9 Visual Endurance Time

This column gives the endurance time, in minutes, as determined by the human observer for the individual sensor.

3.2.10 WIDS Endurance Time

This column gives the endurance time, in minutes, as determined by the WIDS with version 2 of the software installed.

3.2.11 Visual WIDS Difference

The last column shows the difference between the visual and WIDS endurance times. This difference was calculated using the following formula:

$$\text{Difference} = \frac{\text{WIDS Endurance Time - Visual Endurance Time}}{\text{Visual Endurance Time}}$$

Negative values indicate the WIDS detected fluid failure sooner than the human observer and positive times indicate the WIDS detected fluid failure later than the human observer.

Table 3.3: Log of Tests

Test #	Sensor	Date	Fluid	Dilution	Precipitation		Temp. (°C)	Endurance Time		Visual WIDS Diff.
					Type	Rate (g/dm²/h)		Visual (min)	WIDS (min)	
1	3	26-Jan-05	UCAR Ultra+	100/0	Snow	5	-15.6	139	138	0%
1	4	26-Jan-05	UCAR Ultra+	100/0	Snow	5	-15.6	139	138	0%
2	3	26-Jan-05	Kilfrost ABC-S	100/0	Snow	5	-15.6	38	37	-1%
2	4	26-Jan-05	Kilfrost ABC-S	100/0	Snow	5	-15.6	38	37	-1%
3	3	10-Feb-05	SPCA Ecowing 26	100/0	Snow	6	-6.0	108	69	-37%
3	4	10-Feb-05	SPCA Ecowing 26	100/0	Snow	6	-6.0	108	93	-14%
4	3	10-Feb-05	Kilfrost ABC-S	100/0	Snow	5	-6.7	168	148	-12%
4	4	10-Feb-05	Kilfrost ABC-S	100/0	Snow	5	-6.7	168	148	-12%
5	3	10-Feb-05	SPCA Ecowing 26	75/25	Snow	10	-6.4	50	32	-36%
5	4	10-Feb-05	SPCA Ecowing 26	75/25	Snow	10	-6.4	50	41	-19%
6	3	10-Feb-05	Kilfrost ABC-S	75/25	Snow	8	-6.2	71	59	-17%
6	4	10-Feb-05	Kilfrost ABC-S	75/25	Snow	8	-6.2	71	65	-10%
7	3	10-Feb-05	Clariant MP I 1938	10ºC buffer	Snow	11	-6.2	7	5	-32%
7	4	10-Feb-05	Clariant MP I 1938	10ºC buffer	Snow	11	-6.2	7	9	21%
8	3	10-Feb-05	UCAR Ultra+	100/0	Snow	7	-6.0	86	84	-3%
8	4	10-Feb-05	UCAR Ultra+	100/0	Snow	7	-6.0	75	69	-8%
9	3	14-Feb-05	SPCA Ecowing 26	50/50	Snow	2	-0.5	88	88	0%
9	4	14-Feb-05	SPCA Ecowing 26	50/50	Snow	2	-0.5	72	88	22%
10	3	16-Feb-05	Clariant MP I 1938	10ºC buffer	Snow	23	0.0	6	8	41%
10	4	16-Feb-05	Clariant MP I 1938	10ºC buffer	Snow	23	0.0	6	8	50%
11	3	16-Feb-05	SPCA Ecowing 26	75/25	Snow	16	-0.2	25	21	-16%
11	4	16-Feb-05	SPCA Ecowing 26	75/25	Snow	16	-0.2	23	20	-12%
12	3	16-Feb-05	Kilfrost ABC-S	50/50	Snow	17	-0.1	9	9	-1%
12	4	16-Feb-05	Kilfrost ABC-S	50/50	Snow	17	-0.1	9	9	-2%
13	3	16-Feb-05	SPCA Ecowing 26	50/50	Snow	17	-0.1	9	8	-8%
13	4	16-Feb-05	SPCA Ecowing 26	50/50	Snow	17	-0.1	9	8	-8%
14	3	16-Feb-05	Kilfrost ABC-S	75/25	Snow	21	-0.1	28	25	-13%
14	4	16-Feb-05	Kilfrost ABC-S	75/25	Snow	21	-0.1	30	31	2%
15	3	16-Feb-05	SPCA Ecowing 26	100/0	Snow	16	0.0	43	42	-1%
15	4	16-Feb-05	SPCA Ecowing 26	100/0	Snow	16	0.0	43	43	1%
16	3	21-Feb-05	Kilfrost ABC-S	75/25	Snow	4	-14.7	46	22	-53%
16	4	21-Feb-05	Kilfrost ABC-S	75/25	Snow	4	-14.7	46	3	-93%
17	3	21-Feb-05	UCAR Ultra+	100/0	Snow	5	-14.9	42	25	-42%
17	4	21-Feb-05	UCAR Ultra+	100/0	Snow	5	-14.9	42	42	-1%
18	3	21-Feb-05	SPCA Ecowing 26	100/0	Snow	6	-14.8	52	24	-55%
18	4	21-Feb-05	SPCA Ecowing 26	100/0	Snow	6	-14.8	52	22	-57%
19	3	21-Feb-05	Kilfrost ABC-S	100/0	Snow	3	-8.2	167	153	-9%
19	4	21-Feb-05	Kilfrost ABC-S	100/0	Snow	3	-8.2	167	3	-98%
20	3	21-Feb-05	SPCA Ecowing 26	75/25	Snow	6	-7.4	28	24	-12%
20	4	21-Feb-05	SPCA Ecowing 26	75/25	Snow	6	-7.4	28	26	-4%
21	3	21-Feb-05	UCAR Ultra+	100/0	Snow	12	-6.0	66	66	0%
21	4	21-Feb-05	UCAR Ultra+	100/0	Snow	12	-6.0	54	56	3%

Table 3.3: Log of Tests (cont'd)

Test #	Sensor	Date	Fluid	Dilution	Precipitation		Temp. (°C)	Endurance Time		Visual WIDS Diff.
					Type	Rate (g/dm²/h)		Visual (min)	WIDS (min)	
22	3	21-Feb-05	Clariant MP I 1938	10ºC buffer	Snow	15	-6.9	4	6	49%
22	4	21-Feb-05	Clariant MP I 1938	10ºC buffer	Snow	15	-6.9	4	6	51%
23	3	21-Feb-05	Kilfrost ABC-S	75/25	Snow	16	-6.2	42	41	-4%
23	4	21-Feb-05	Kilfrost ABC-S	75/25	Snow	16	-6.2	42	41	-3%
24	3	21-Feb-05	Clariant MP I 1938	10ºC buffer	Snow	9	-6.3	8	8	-6%
24	4	21-Feb-05	Clariant MP I 1938	10ºC buffer	Snow	9	-6.3	8	7	-15%
25	3	01-Mar-05	SPCA Ecowing 26	75/25	Snow	11	-5.7	18	15	-16%
25	4	01-Mar-05	SPCA Ecowing 26	75/25	Snow	11	-5.7	14	13	-5%
26	3	01-Mar-05	SPCA Ecowing 26	100/0	Snow	16	-5.5	40	36	-11%
26	4	01-Mar-05	SPCA Ecowing 26	100/0	Snow	16	-5.5	40	35	-12%
27	3	01-Mar-05	Kilfrost ABC-S	100/0	Snow	7	-5.7	165	167	1%
27	4	01-Mar-05	Kilfrost ABC-S	100/0	Snow	7	-5.7	166	162	-3%
28	3	01-Mar-05	Clariant MP I 1938	10ºC buffer	Snow	14	-6.4	8	FND*	n/a
28	4	01-Mar-05	Clariant MP I 1938	10ºC buffer	Snow	14	-6.4	8	9	19%
29	3	01-Mar-05	UCAR Ultra+	100/0	Snow	15	-6.5	25	23	-10%
29	4	01-Mar-05	UCAR Ultra+	100/0	Snow	15	-6.5	25	24	-6%
30	3	01-Mar-05	Kilfrost ABC-S	75/25	Snow	18	-6.1	45	41	-9%
30	4	01-Mar-05	Kilfrost ABC-S	75/25	Snow	18	-6.1	45	38	-15%
31	3	01-Mar-05	Clariant MP I 1938	10ºC buffer	Snow	15	-6.1	7	7	15%
31	4	01-Mar-05	Clariant MP I 1938	10ºC buffer	Snow	15	-6.1	7	7	7%
32	3	01-Mar-05	SPCA Ecowing 26	75/25	Snow	11	-6.0	31	28	-7%
32	4	01-Mar-05	SPCA Ecowing 26	75/25	Snow	11	-6.0	31	30	-2%
33	3	01-Mar-05	SPCA Ecowing 26	100/0	Snow	8	-5.7	65	62	-5%
33	4	01-Mar-05	SPCA Ecowing 26	100/0	Snow	8	-5.7	65	61	-6%
34	3	07-Mar-05	Kilfrost ABC-S	100/0	Snow	6	-10.0	113	112	0%
34	4	07-Mar-05	Kilfrost ABC-S	100/0	Snow	6	-10.0	123	123	0%
35	3	11-Mar-05	SPCA Ecowing 26	50/50	Snow	2	-2.0	22	22	1%
35	4	11-Mar-05	SPCA Ecowing 26	50/50	Snow	2	-2.0	18	17	-1%
36	3	11-Mar-05	SPCA Ecowing 26	50/50	Snow	2	-3.4	14	15	2%
36	4	11-Mar-05	SPCA Ecowing 26	50/50	Snow	2	-3.4	23	23	0%
37	3	11-Mar-05	Kilfrost ABC-S	50/50	Snow	3	-3.4	11	12	4%
37	4	11-Mar-05	Kilfrost ABC-S	50/50	Snow	3	-3.4	11	11	0%
38	3	11-Mar-05	Kilfrost ABC-S	50/50	Snow	9	-3.4	9	9	4%
38	4	11-Mar-05	Kilfrost ABC-S	50/50	Snow	9	-3.4	10	10	0%
39	3	11-Mar-05	SPCA Ecowing 26	50/50	Snow	4	-3.6	18	18	0%
39	4	11-Mar-05	SPCA Ecowing 26	50/50	Snow	4	-3.6	17	17	1%
40	3	11-Mar-05	Kilfrost ABC-S	50/50	Snow	9	-3.5	9	10	9%
40	4	11-Mar-05	Kilfrost ABC-S	50/50	Snow	9	-3.5	10	9	-8%
41	3	05-Apr-05	Kilfrost ABC-S	75/25	Freezing Drizzle	5	-10.0	14	FND*	n/a
41	4	05-Apr-05	Kilfrost ABC-S	75/25	Freezing Drizzle	5	-10.0	14	FND*	n/a
42	3	05-Apr-05	SPCA Ecowing 26	75/25	Freezing Drizzle	5	-10.0	7	FND*	n/a
42	4	05-Apr-05	SPCA Ecowing 26	75/25	Freezing Drizzle	5	-10.0	8	FND*	n/a

Table 3.3: Log of Tests (cont'd)

Test #	Sensor	Date	Fluid	Dilution	Precipitation		Temp. (°C)	Endurance Time		Visual WIDS Diff.
					Type	Rate (g/dm²/h)		Visual (min)	WIDS (min)	
43	3	05-Apr-05	Clariant MP I 1938	10ºC buffer	Freezing Drizzle	5	-10.0	9	23	163%
43	4	05-Apr-05	Clariant MP I 1938	10ºC buffer	Freezing Drizzle	5	-10.0	9	19	116%
44	3	05-Apr-05	Clariant MP I 1938	10ºC buffer	Freezing Drizzle	13	-10.0	6	11	92%
44	4	05-Apr-05	Clariant MP I 1938	10ºC buffer	Freezing Drizzle	13	-10.0	6	9	69%
45	3	05-Apr-05	SPCA Ecowing 26	75/25	Freezing Drizzle	13	-10.0	29	FND*	n/a
45	4	05-Apr-05	SPCA Ecowing 26	75/25	Freezing Drizzle	13	-10.0	33	FND*	n/a
46	3	05-Apr-05	UCAR Ultra+	100/0	Freezing Drizzle	13	-10.0	16	14	-10%
46	4	05-Apr-05	UCAR Ultra+	100/0	Freezing Drizzle	13	-10.0	16	13	-16%
47	3	05-Apr-05	UCAR Ultra+	100/0	Freezing Rain	25	-10.0	53	63	19%
47	4	05-Apr-05	UCAR Ultra+	100/0	Freezing Rain	25	-10.0	54	51	-5%
48	3	06-Apr-05	Kilfrost ABC-S	100/0	Freezing Rain	13	-10.0	31	85	179%
48	4	06-Apr-05	Kilfrost ABC-S	100/0	Freezing Rain	13	-10.0	31	86	181%
49	3	06-Apr-05	Clariant MP I 1938	10ºC buffer	Freezing Rain	13	-10.0	6	12	118%
49	4	06-Apr-05	Clariant MP I 1938	10ºC buffer	Freezing Rain	13	-10.0	7	13	107%
50	3	06-Apr-05	SPCA Ecowing 26	50/50	Freezing Rain	13	-3.0	10	7	-25%
50	4	06-Apr-05	SPCA Ecowing 26	50/50	Freezing Rain	13	-3.0	11	8	-28%
51	3	06-Apr-05	SPCA Ecowing 26	100/0	Freezing Rain	13	-3.0	34	29	-14%
51	4	06-Apr-05	SPCA Ecowing 26	100/0	Freezing Rain	13	-3.0	38	32	-15%
52	3	06-Apr-05	Kilfrost ABC-S	75/25	Freezing Rain	13	-3.0	30	FND*	n/a
52	4	06-Apr-05	Kilfrost ABC-S	75/25	Freezing Rain	13	-3.0	30	FND*	n/a
53	3	06-Apr-05	UCAR Ultra+	100/0	Freezing Rain	13	-3.0	42	FND*	n/a
53	4	06-Apr-05	UCAR Ultra+	100/0	Freezing Rain	13	-3.0	44	FND*	n/a
54	3	06-Apr-05	Kilfrost ABC-S	100/0	Freezing Rain	25	-3.0	51	FND*	n/a
54	4	06-Apr-05	Kilfrost ABC-S	100/0	Freezing Rain	25	-3.0	55	FND*	n/a
55	3	06-Apr-05	UCAR Ultra+	100/0	Freezing Rain	25	-3.0	30	FND*	n/a
55	4	06-Apr-05	UCAR Ultra+	100/0	Freezing Rain	25	-3.0	31	FND*	n/a
56	3	07-Apr-05	SPCA Ecowing 26	50/50	Freezing Drizzle	5	-3.0	11	24	111%
56	4	07-Apr-05	SPCA Ecowing 26	50/50	Freezing Drizzle	5	-3.0	10	FND*	n/a
57	3	07-Apr-05	Clariant MP I 1938	10ºC buffer	Freezing Drizzle	5	-3.0	13	FND*	n/a
57	4	07-Apr-05	Clariant MP I 1938	10ºC buffer	Freezing Drizzle	5	-3.0	15	FND*	n/a
58	3	07-Apr-05	Kilfrost ABC-S	75/25	Freezing Drizzle	5	-3.0	62	FND*	n/a
58	4	07-Apr-05	Kilfrost ABC-S	75/25	Freezing Drizzle	5	-3.0	62	FND*	n/a
59	3	07-Apr-05	Kilfrost ABC-S	50/50	Freezing Drizzle	13	-3.0	14	8	-43%
59	4	07-Apr-05	Kilfrost ABC-S	50/50	Freezing Drizzle	13	-3.0	14	7	-45%
60	3	07-Apr-05	SPCA Ecowing 26	100/0	Freezing Drizzle	13	-3.0	38	FND*	n/a
60	4	07-Apr-05	SPCA Ecowing 26	100/0	Freezing Drizzle	13	-3.0	39	36	-9%
61	3	07-Apr-05	Kilfrost ABC-S	100/0	Freezing Drizzle	13	-3.0	82	75	-8%
61	4	07-Apr-05	Kilfrost ABC-S	100/0	Freezing Drizzle	13	-3.0	83	78	-6%
62	3	08-Apr-05	Clariant MP I 1938	10ºC buffer	Freezing Fog	2	-3.0	25	52	107%
62	4	08-Apr-05	Clariant MP I 1938	10ºC buffer	Freezing Fog	2	-3.0	24	44	84%

*FND = Failure not detected

4. ANALYSIS

The ability of the WIDS to replicate visual determination of fluid failure is examined in this section.

4.1 Preface

As discussed in the introduction, the number of tests conducted was determined in part by available funding. As funding was limited, fewer tests were conducted than would be required for a complete and thorough analysis. The data has been analysed by precipitation condition, fluid type/dilution and temperature; however, only general conclusions can be drawn from this analysis. The complete data set is given in Appendix D and can be used for future reference and/or analysis.

4.2 Comparison of WIDS and Visual Endurance Times

If the WIDS were able to replicate visual endurance time determination, the difference between the WIDS and visual endurance times should be less than 10 percent for each test. This value has previously been established as the amount of variance expected between tests when the same individual runs the tests with the same fluid in the same conditions.

In the 2004-05 tests, 41 percent of the WIDS endurance times were within 10 percent of the visual endurance time. 59 percent were within 20 percent of the visual endurance time. This is an improvement over the IDES tested the previous winter in which 23 percent were within 10 percent and 40 percent were within 20 percent of the visual endurance time.

Figure 4.1 shows the test values generated in snow. 59 percent of WIDS endurance times in snow were within 10 percent of the visual endurance time and 80 percent were within 20 percent. These percentages are about 15 percent higher than in 2003-04.

Figure 4.2 shows the test values generated in simulated precipitation. 9 percent of WIDS endurance times in simulated precipitation were within 10 percent of the visual endurance time and 20 percent were within 20 percent. This is about the same percentage as seen in 2003-04 testing.

The WIDS did not detect ice in almost half (45 percent) of the simulated precipitation tests. These tests can easily be seen in Figure 4.2, as they show up at various points on the x-axis, as the WIDS endurance time is zero.

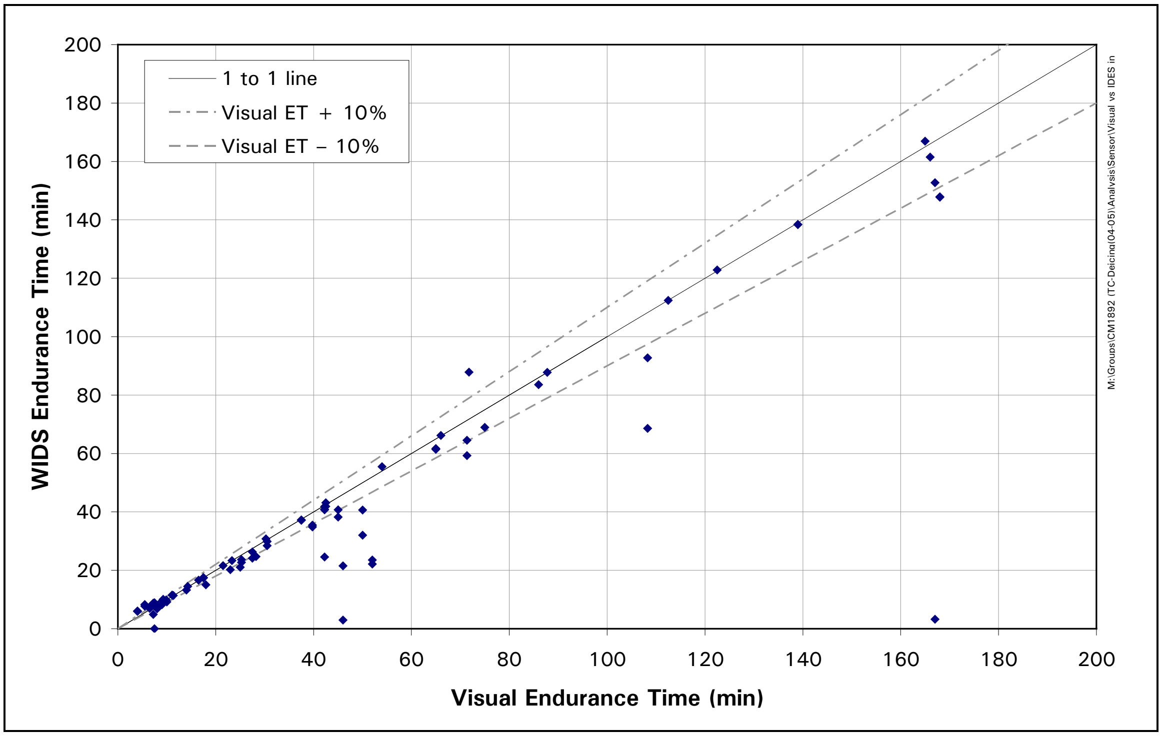

Figure 4.1: WIDS vs. Visual Endurance Times in Snow

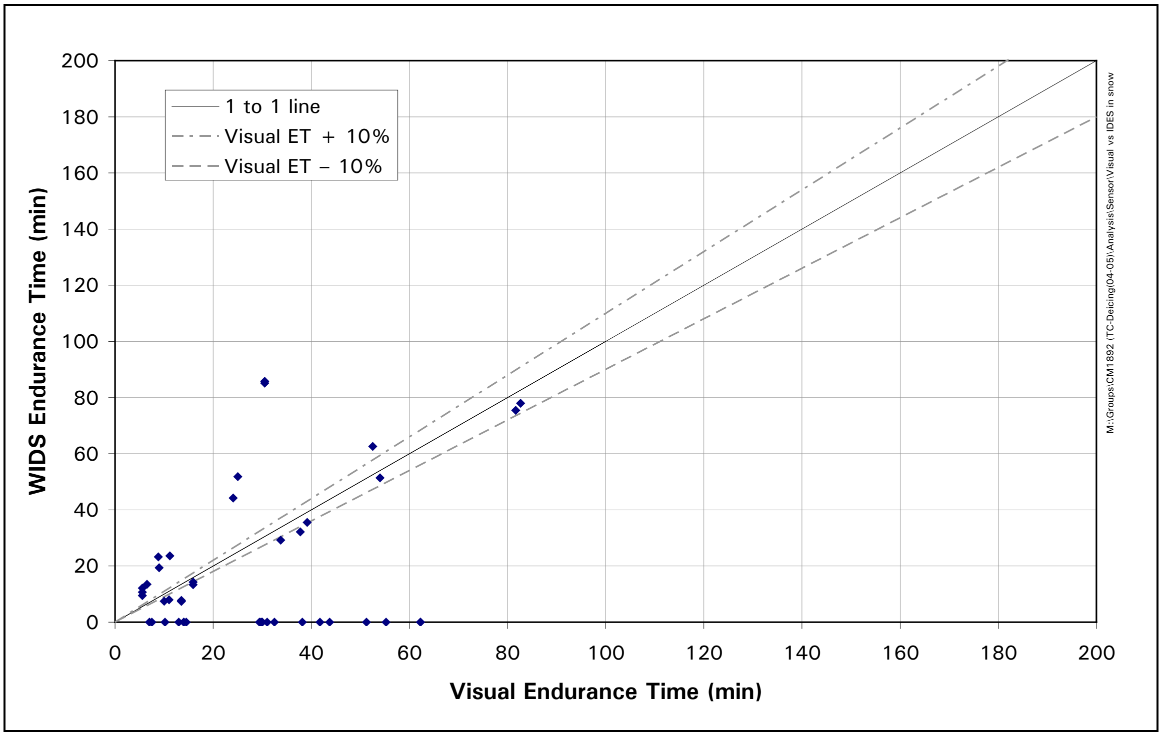

Figure 4.2: WIDS vs. Visual Endurance Times in Simulated Precipitation

4.3 Influence of Fluid Type and Dilution

All of the test results are plotted by fluid type and dilution in Figures 4.3 and 4.4. Points that fall below the x-axis are tests where the WIDS underestimated the endurance time; points above the x-axis are tests where the WIDS overestimated the endurance time.

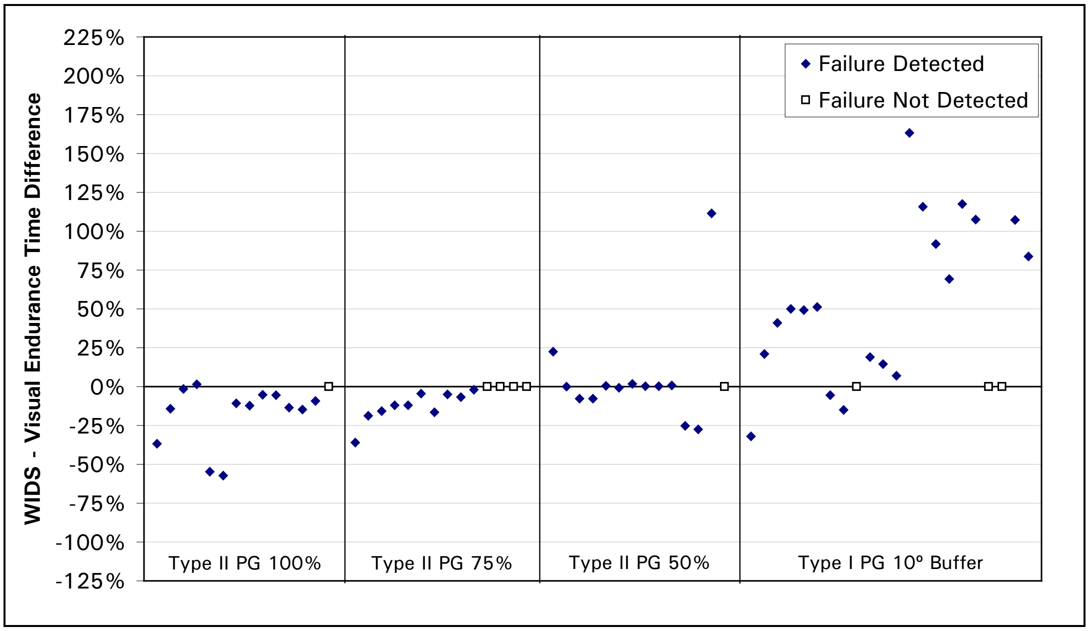

Figure 4.3: Test Results by Fluid Type and Dilution – Type I and II

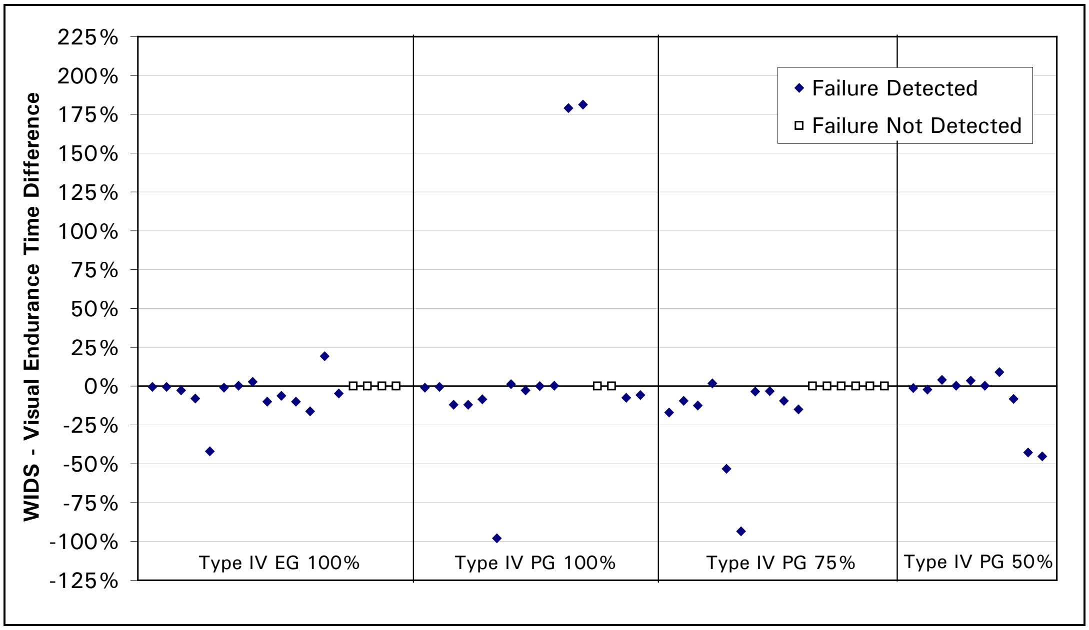

Figure 4.4: Test Results by Fluid Type and Dilution – Type IV

As was seen in the 2003-04 testing, the Intertechnique system accurately simulated visual determination of fluid failure in very few cases with Type I fluid. It appears that the WIDS was more accurate with Type II/IV 50/50 fluids than other dilutions, but this may be a result of the temperatures at which the tests were conducted – there is not enough data for a conclusive determination.

Figure 4.5 shows the percentage of tests with each fluid type/dilution where the WIDS accurately simulated visual endurance times. The black bar indicates the percentage of tests that were within 10 percent of the visual endurance time, the dark grey bar indicates tests that were from 10 to 20 percent, the light gray indicates test where fluid failure was detected, but was more than 20 percent later or earlier than the visual endurance time, and the top bar shows the percentage of tests where the WIDS did not detect fluid failure. Again, it is clear that the WIDS is not accurate with Type I fluids.

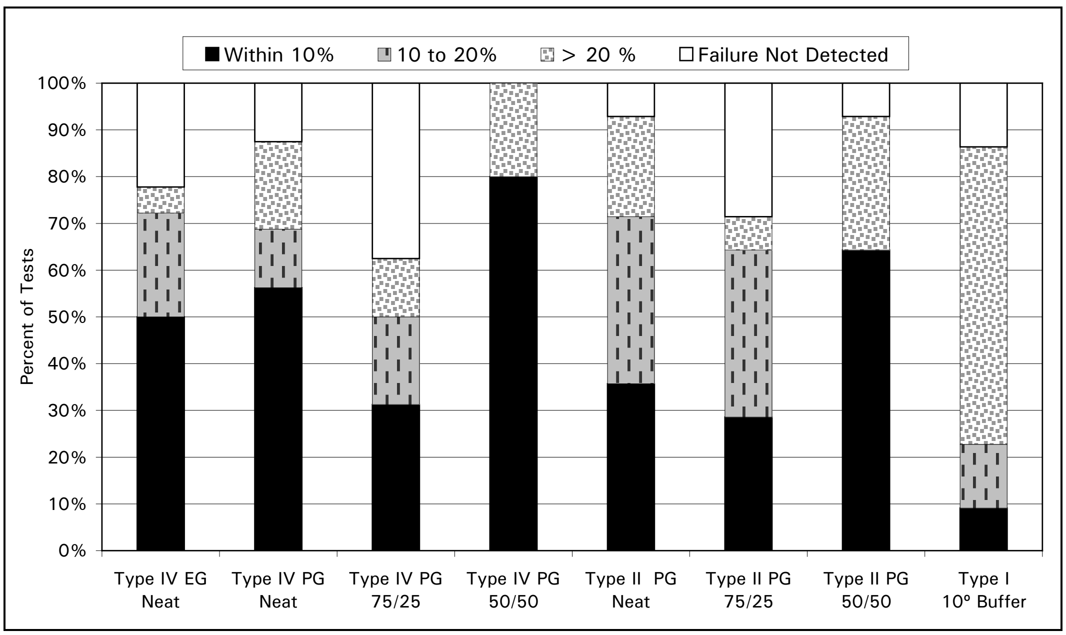

Figure 4.5: Distribution of Accuracy of WIDS Endurance Times relative to Visual Endurance Times by Fluid Type and Dilution

4.3.1 Type I Fluid

The Intertechnique ice detection system has difficulty detecting failure with Type I fluids. In 2003-04, the IDES did not detect fluid failure in three of the eight tests conducted with Type I fluid. In 2004-05 fluid failure was not detected in three of 22 tests. Although this is an improvement, in the tests where the WIDS did detect failure, it was significantly later than the human observer.

The difficulty had by the Intertechnique system with Type I fluids is likely a result of its mechanisms for detecting fluid failure. The system uses two different mechanisms for detecting fluid failure (descriptions provided by the manufacturer):

1. Fluid Failure: When a fluid layer with or without the presence of frozen elements is covering the sensor and the freezing point of that fluid has reached or is greater than the plate temperature and the plate temperature is lower than 0.5°C, fluid failure is detected.

2. Frozen Adhering Contamination: When the IDES/WIDS has detected the presence of frozen adhering contamination, fluid failure is detected. To identify frozen contamination, typically ice, the system may need a minimal thickness varying from approximately 0.1 mm to 0.2 mm depending on the contaminant structure.

Type I fluids are significantly thinner than other fluids, which causes difficulties for both failure detection mechanisms used by the IDES/WIDS. First, when Type I fluids freeze, the ice is initially too thin for the IDES/WIDS to detect frozen adhering contamination. Second, the IDES/WIDS cannot measure the freezing point of the fluid when the fluid is less than 0.1 mm thick and therefore the difference between the fluid freezing point and the plate temperature cannot be used to detect fluid failure until the ice thickness has reached 0.15 mm. This appears to explain the significant number of fluid failures not detected with Type I fluids.

4.4 Influence of Precipitation Type

The dates of the simulated precipitation test session were changed just prior to testing: most freezing fog conditions were postponed by one week. Intertechnique personnel were not able to change their travel plans and, as a result, the WIDS was not available for testing the second week. Thus, only a few Type I fluid tests were conducted in freezing fog, and no Type II or IV tests were conducted.

The test values are shown by precipitation type in Figure 4.6. The Type I test values have been eliminated from this analysis due to the large amount of variance in the results (see previous Subsection).

Based on the tests conducted, it appears the WIDS is better able to replicate visual determination of fluid failure in snow than in freezing precipitation conditions. There were a significant number of tests where failure was not detected in freezing precipitation, but none in snow. Figure 4.7 shows the percentage of tests where the WIDS accurately replicated visual fluid failure. Again, it is clear the WIDS is more accurate in snow.

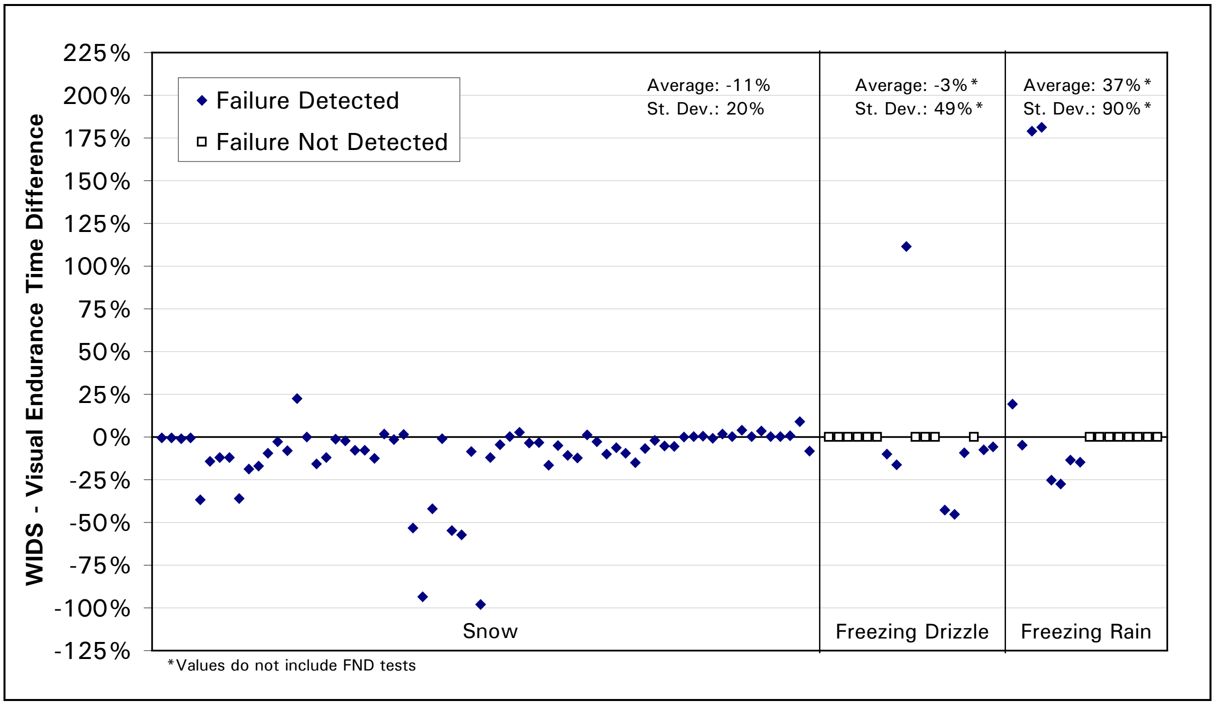

Figure 4.6: Type II/IV Test Results by Precipitation Type

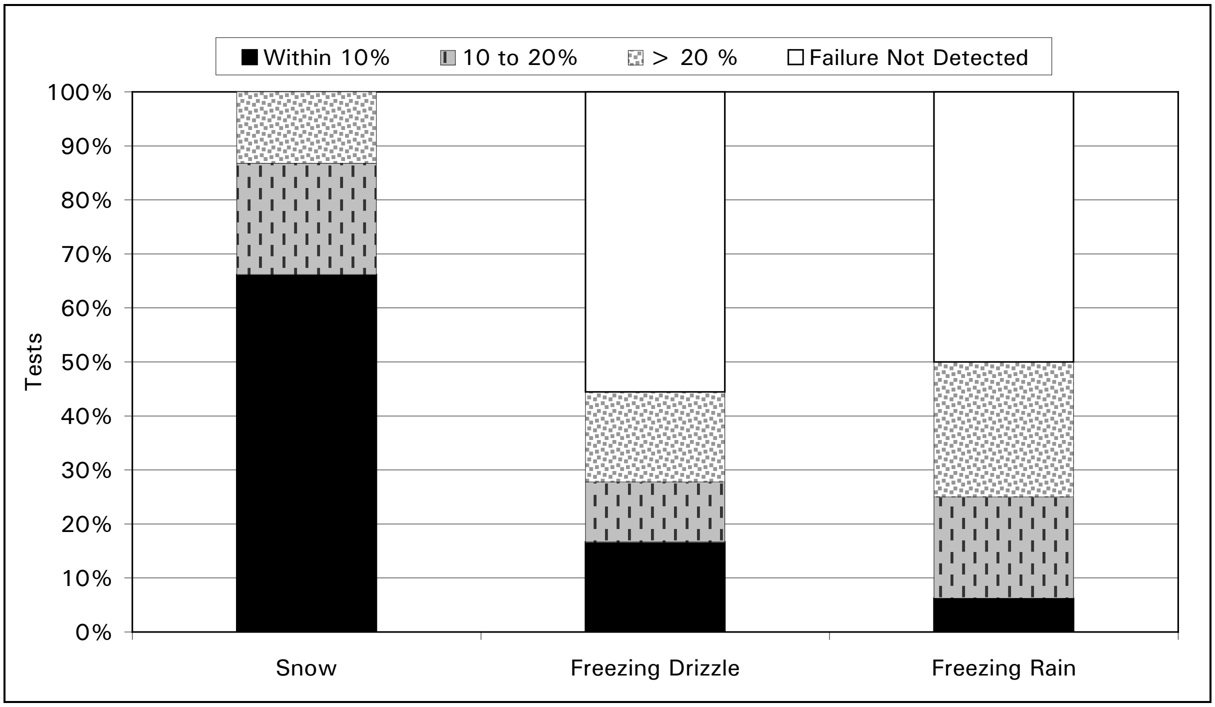

Figure 4.7: Distribution of Accuracy of WIDS Endurance Times relative to Visual Endurance Times by Precipitation Type

4.5 Influence of Temperature

The Type II and IV fluid test results are plotted in order of decreasing test temperature in Figure 4.8. There does not appear to be a relationship between test temperature and the WIDS ability to replicate visual failure determinations. In 2003-04 the IDES appeared to better replicate visual endurance times in warmer temperatures than in colder temperatures.

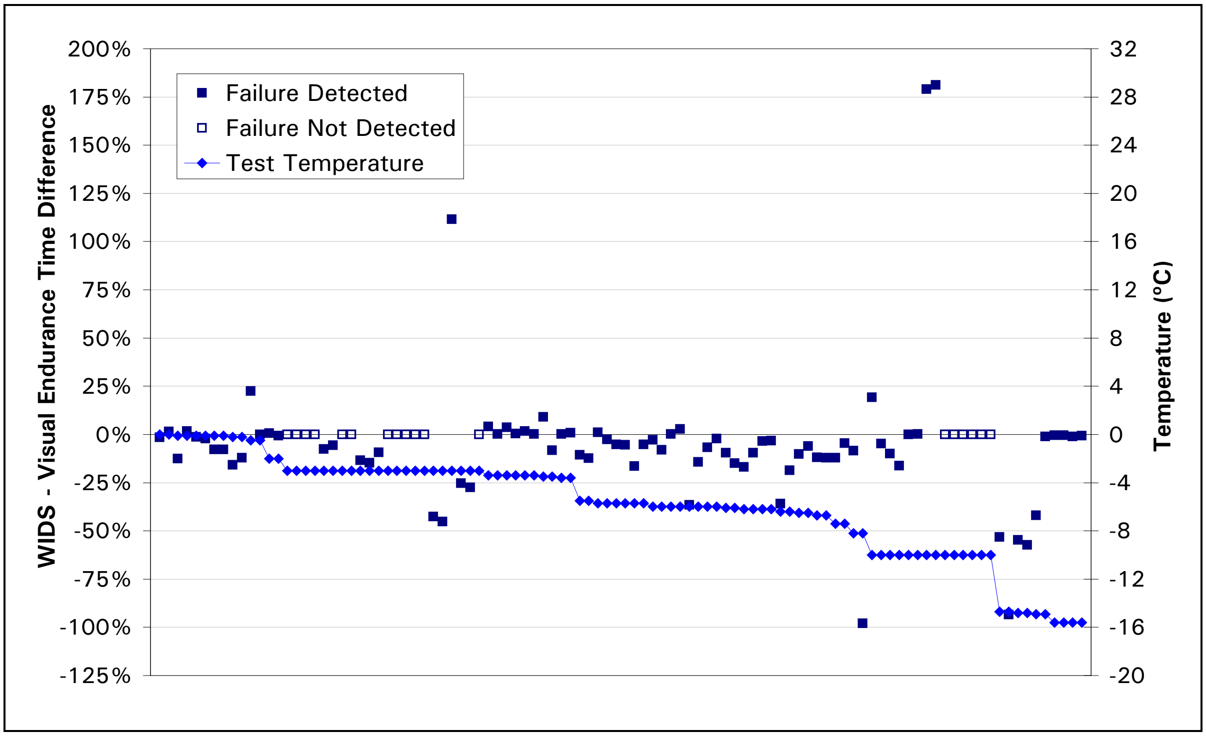

Figure 4.8: Type II/IV Results by Temperature

4.6 Ability to Detect Ice: WIDS vs. Human Observers

Although a significant amount of variance was observed between the endurance times measured by the WIDS and human observer, the possibility that some of this variance is the result of the inability of the human observer to properly detect ice should be mentioned. In fact, it is possible that in some cases, the WIDS more accurately measured a fluid's ability to offer ice protection. One possible scenario is that a layer of ice forms on the top of the fluid, but a thick layer of uncontaminated fluid remains between the ice and the plate. The human observer would declare that the fluid had failed based on the definition of fluid failure, but the WIDS could accurately indicate that the fluid still offers protection from frozen adhered contamination.

4.7 Influence of Software

The software program and algorithms within largely influence the outcome of the test results. If the WIDS endurance times are consistently higher or lower than the visual endurance times, the algorithms could be rewritten to detect fluid failure a set percentage sooner or later.

With the high standard deviation in freezing rain and freezing drizzle tests (see Figure 4.6), it is clear that simply increasing/decreasing the values by a set percentage would not improve the results. However, the Type II/IV snow tests varied considerably less: the standard deviation of those test results was only 20 percent, and the majority of WIDS endurance times were shorter than the visual endurance times. To evaluate whether a change in the software could significantly improve the test results, the WIDS endurance times were increased by 5 percent and the results were analysed.

The results are shown in Figure 4.9. As speculated, the overall accuracy of the WIDS increased, with 76 percent of the WIDS endurance times falling within 10 percent of the visual endurance time. This analysis illustrates that the software can significantly impact the test results. However, in this case the improvement is not large enough to change the overall conclusions of the ability of the WIDS to replicate visual endurance times.

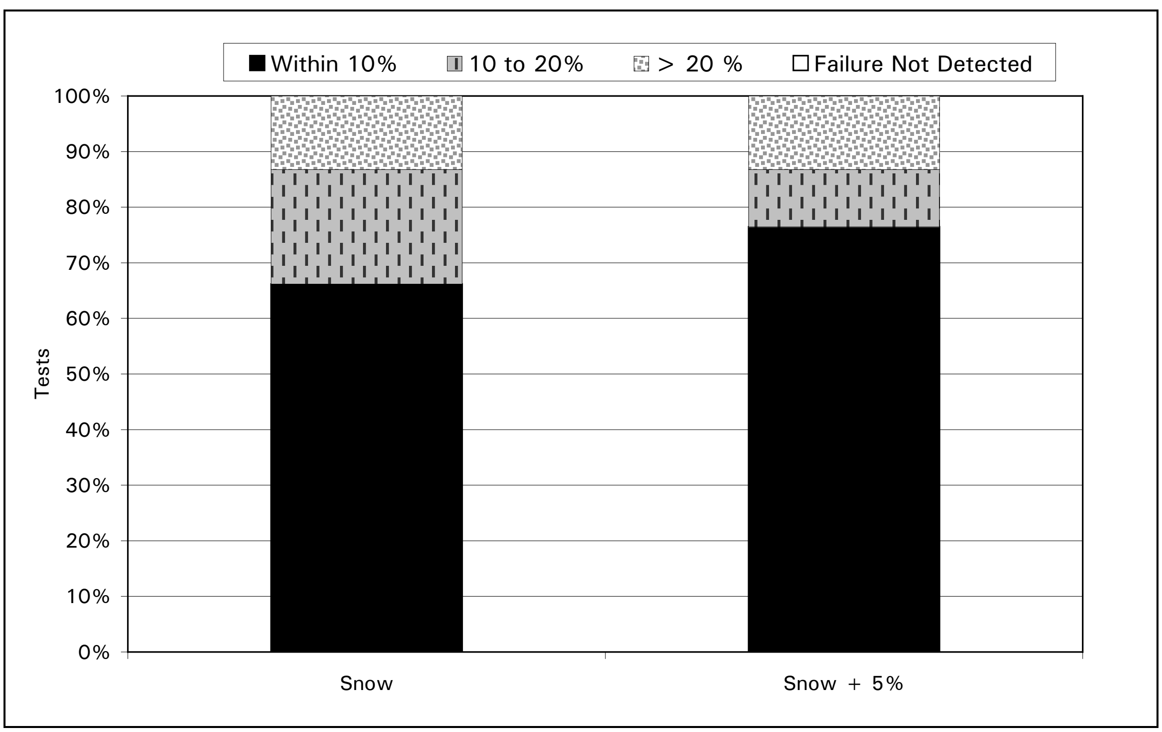

Figure 4.9: Distribution of Accuracy of WIDS Endurance Times relative to Visual Endurance Times in Snow

5. CONCLUSIONS

Several conclusions can be drawn from the limited tests conducted.

a) The Intertechnique ice detection system is currently not able to replicate a visual determination of failure. This may be partially a result of its inability to replicate a human observation, rather than its inability to detect ice. In fact, it is possible that in some cases the system more accurately measured a fluid's ability to offer ice protection.

   This is an important conclusion, as the sensor would need to be trained to determine the end condition as the human observer "sees" contamination.

b) The following relationships were seen between the WIDS and the test parameters:

   - The WIDS is better able to detect fluid failure with Type II and Type IV fluids than with Type I fluids, likely due to the methods the WIDS uses to detect failure;
   - No significant relationship was found between the WIDS ability to replicate visual endurance times and temperature;
   - The WIDS was better able to replicate visual endurance times in snow than in freezing drizzle or freezing rain (data was not available for freezing fog); and
   - No significant relationship was found between the WIDS ability to replicate visual endurance times and Type II/IV fluid dilution.

c) When the WIDS (2004-05 system) was compared to the IDES (2003-04 system), it was found that:

   - The WIDS was better at detecting fluid failure in snow than the IDES, but no significant improvement was seen testing in simulated precipitation conditions;
   - The WIDS detected fluid failure in a greater number of Type I tests in 2004-05 than the IDES did in 2003-04; however, in the majority of these tests the WIDS detected fluid failure significantly later than the human observer;

- Unlike the IDES, testing with the WIDS demonstrated no significant relationship between ability to replicate visual endurance times and temperature; and

d) As this technology is currently not at a stage of development to be used in endurance time testing, at this time the best way to obtain consistent results during endurance time testing is to maintain the current experts and/or to develop an intense training program.

6. RECOMMENDATIONS

The Intertechnique ice detection system may be able to accurately and consistently replicate visual endurance times in snow with Type II and Type IV fluids. Further work is still required to refine the system for these conditions.

Tests conducted in 2003-04 and 2004-05 indicate the technology is currently not able to accurately replicate visual endurance times with Type I fluids or in simulated precipitation conditions. A significant amount of resources would be required to possibly achieve this goal in the future.

It is therefore recommended that resources would be more used more effectively in this area if they went towards training and education programs for test personnel rather than further developing an ice detection system.

However, in its current state the technology may provide insight into research that is currently being carried out to determine when the true failure of a fluid occurs.

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REFERENCES

1. Campbell, R, Chaput, M., *Aircraft Ground De/Anti-Icing Fluid Holdover Time and Endurance Time Testing Program for the 2001-02 Winter*, APS Aviation Inc., Transportation Development Centre, Montreal, December 2002, TP 13991E, XX (to be published).

2. Bendickson, S., *Variance in Endurance Times of De/Anti-Icing Fluids,* APS Aviation Inc., Transportation Development Centre, Montreal, December 2003, TP 14156E, 38.

3. Bendickson, S., *A Sensor for Detecting Anti-Icing Fluid Failure: Phase I,* APS Aviation Inc., Transportation Development Centre, Montreal, December 2004, TP 14382E, XX (to be published).

4. Bendickson, S., *Aircraft Ground De/Anti-Icing Fluid Holdover Time Development Program for the 2004-05 Winter*, APS Aviation Inc., Transportation Development Centre, Montreal, October 2005, TP 14443E, 68.

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APPENDIX A

TRANSPORTATION DEVELOPMENT CENTRE
WORK STATEMENT EXCERPT –
AIRCRAFT & ANTI-ICING FLUID WINTER TESTING 2003-05

TRANSPORTATION DEVELOPMENT CENTRE
WORK STATEMENT EXCERPT –
AIRCRAFT & ANTI-ICING FLUID
WINTER TESTING 2003-05

6.14 Sensor Technology to Minimize Variance in HOT Failure

a) Create an internal fluid failure training manual for APS employees. The information contained in the training package will be taken from the report Characteristics of Aircraft Anti–icing Fluids Subjected to Precipitation 1998-99, TP 13484E. The document should be easily read and no longer than ten written pages; and

b) Test a fluid failure sensor and compare its ability to call failures relative to the actual failure call and to results of junior and intermediate fluid failure calls made in previous winters.

- Alter the test procedure to require that the individual make the failure call on individual sensors, rather than on the plate as a whole;
- Return and re-acquire the modified Intertechnique sensor and make it operational for testing;
- Collect data in various conditions, outdoor at the APS test site and indoor at the NRC facility. Emphasis shall be place in natural snow;
- Analyse data; and
- Prepare a report.

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APPENDIX B

FLUID FREEZE POINT CURVES

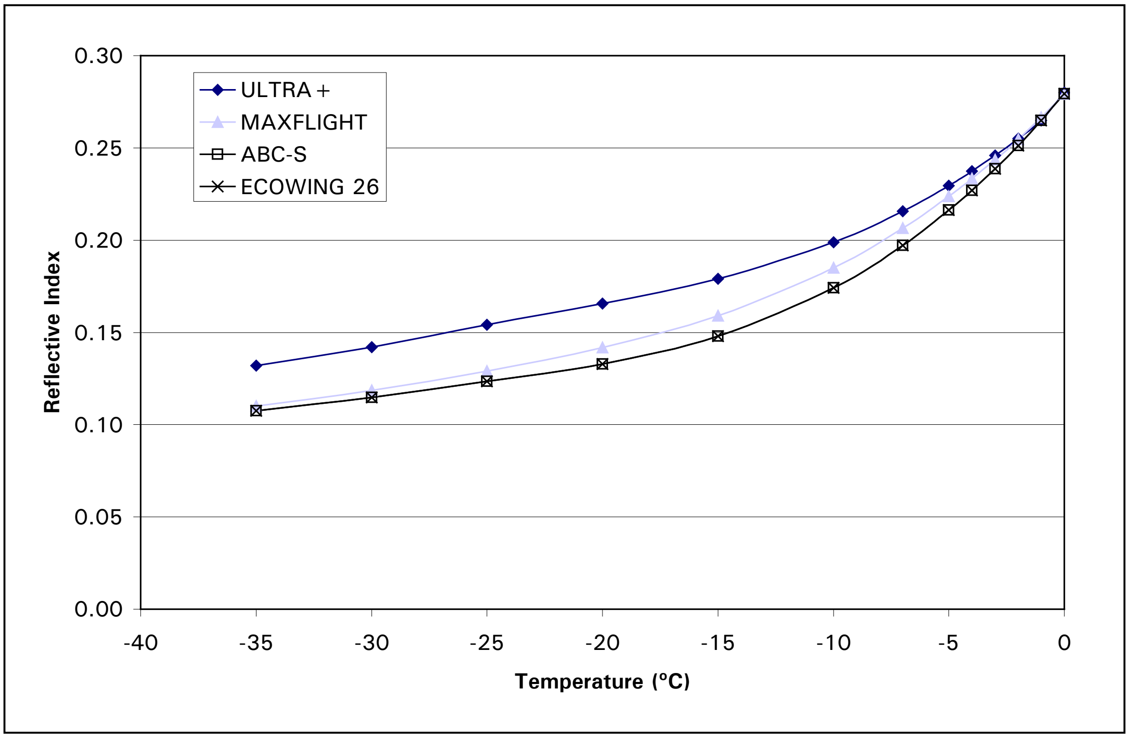

Figure B-1: Fluid Freeze Curves – All Fluids

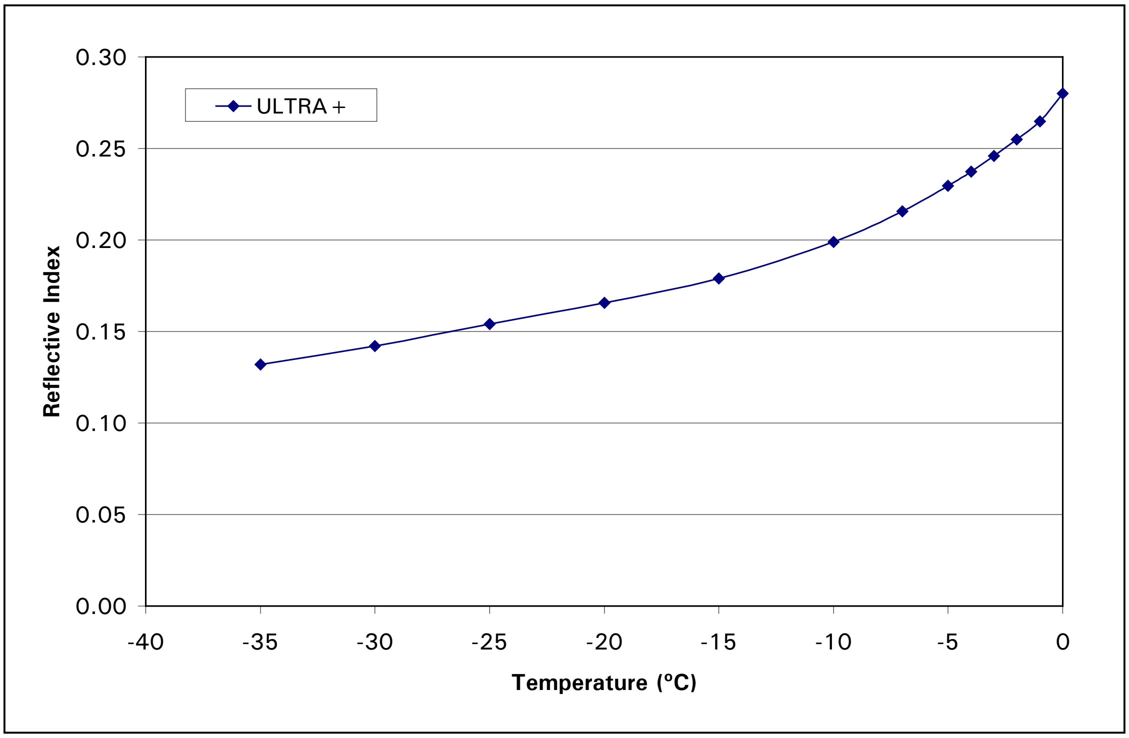

Figure B-2: Fluid Curve – UCAR Ultra+

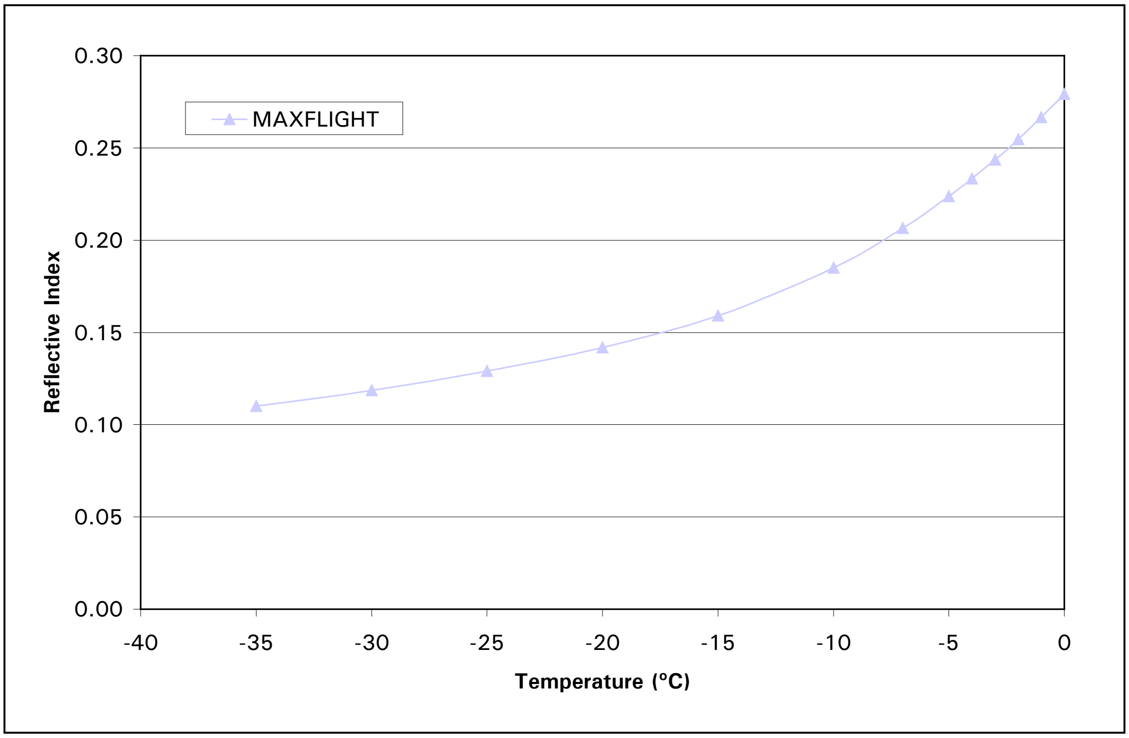

Figure B-3: Fluid Freeze Curve – Octagon MaxFlight

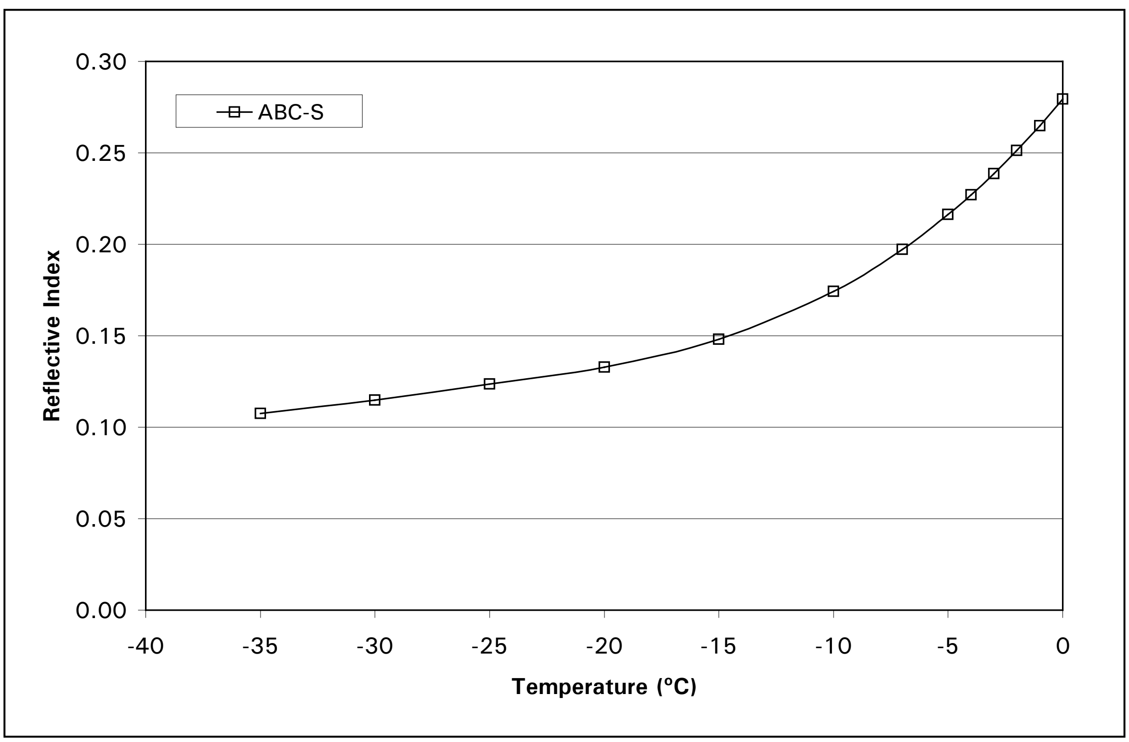

Figure B-4: Fluid Freeze Curve – Kilfrost ABC-S

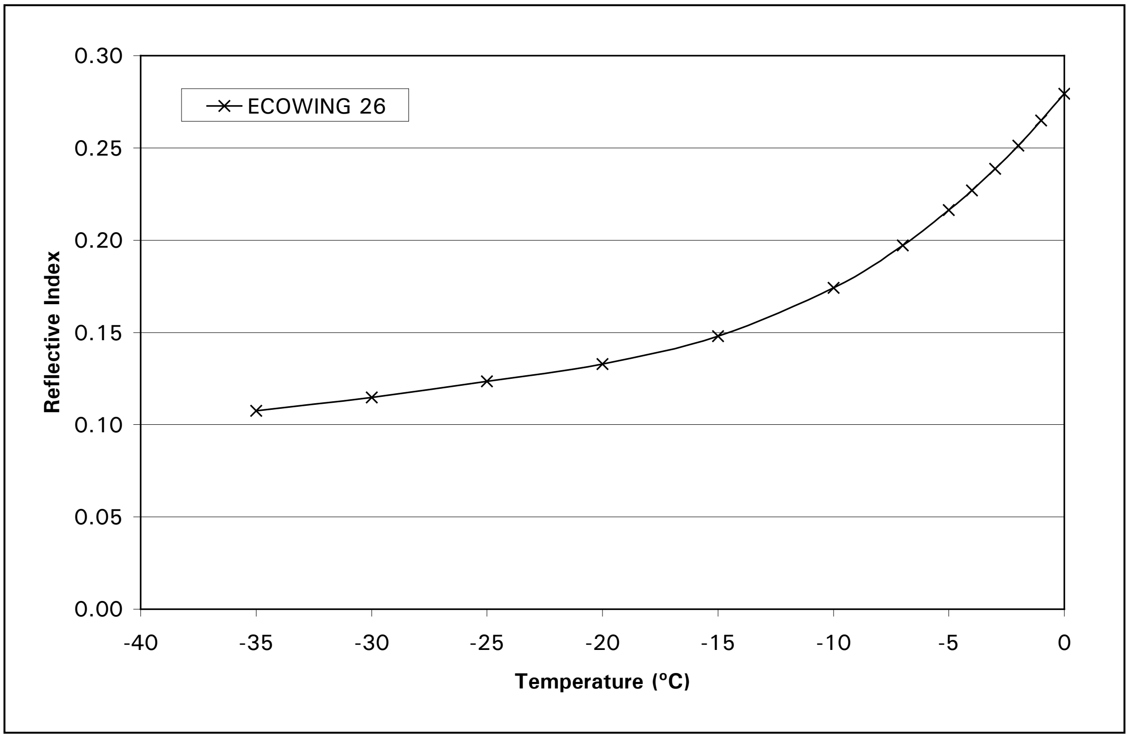

Figure B-5: Fluid Freeze Curve – SPCA Ecowing 26

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APPENDIX C

EXPERIMENTAL PROCEDURE
COMPARISON OF ENDURANCE TIMES MEASURED BY SENSOR AND BY TRAINED PERSONNEL

CM1892.001 (04-05)

EXPERIMENTAL PROCEDURE
COMPARISON OF ENDURANCE TIMES MEASURED BY SENSOR AND BY TRAINED PERSONNEL

Winter 2004-05

Prepared for

Transportation Development Centre
Transport Canada

Prepared by: Stephanie Bendickson

Reviewed by: John D'Avirro

APS Aviation Inc.

January 12, 2005
Version 1.0

EXPERIMENTAL PROCEDURE
COMPARISON OF ENDURANCE TIMES MEASURED BY SENSOR AND BY TRAINED PERSONNEL

Winter 2004-05

1. BACKGROUND

In the winter of 2002-03, tests were conducted to evaluate the influence of level of training, knowledge and experience on the ability to determine fluid failures. Results showed a significant amount of variance in the endurance times measured by intermediate and novice individuals. It was concluded there are two ways of obtaining consistent results during holdover time testing: to use the same experienced individual to conduct tests or alternately, to develop technology to detect fluid failures.

Over the past decade several companies have developed technology in this area. However, none has been developed to the level required by the industry. In the winter of 2003-04, Intertechnique provided their Ice Detection Evaluation System (IDES) to Transport Canada for test purposes. APS conducted a limited number of tests with the IDES in the winter of 2003-04 and concluded that at its current stage of development, it could not replicate visual endurance times. However, Intertechnique made adjustments to the system, and APS will test the new system in the winter of 2004-05.

It should be noted that this procedure is almost identical to the procedure of the same name that was issued in the winter of 2003-04.

2. OBJECTIVE

The objective of these tests is to evaluate the IDES ability to replicate visual endurance times, as measured by experienced individuals.

3. PROCEDURE

Standard endurance time tests will be run on a test plate equipped with two sensors. The procedure is as follows:

1. Turn on the PC and the power supply and interconnection box (PSIB).
2. Synchronize PC clock with test clocks.

3. Initiate data recording by following instructions given in IDES user guide. The test fluid must be selected.
4. Pour test fluid on plate.
5. Using the data form given in Figure 2, record visual fluid failure when it occurs on each individual sensor and for the plate.
6. Several minutes after the visual failure calls and sensor failure calls have been made, stop data recording and clean the test plates.
7. Repeat steps 3 to 6 for each test; and
8. At end of test session download data files to the data key and fill in a test session log (see Figure 2).

4. FLUIDS

UCAR Ultra+ (Type IV EG), Kilfrost ABC-S (Type IV PG), SPCA Ecowing 26 (Type II PG) and Clariant Safewing MP I 1938 ECO will be tested. Additional fluids may be added to the test plan if they become available.

5. PERSONNEL

Two individuals are required for these tests. One individual will be responsible for setting and monitoring the IDES computer, preparing fluids and recording when the sensor indicates fluid failure. The second individual will be responsible for determining and recording fluid failure as per standard holdover time testing procedure.

If precipitation rates are not being measured simultaneously for other projects, the first individual will be required to measure precipitation rates.

6. TEST PLAN

Tests will be conducted in various winter precipitation conditions. Natural snow tests will be conducted at the APS test site at Montreal – Pierre Elliot Trudeau International Airport. A session test plan for these tests is shown in Table 1. Simulated precipitation tests will be conducted at the National Research Centre Climatic Engineering Facility in Ottawa. A test plan for simulated precipitation tests will be included in the procedure *Overall Test Program at NRC 2004-05.* It is anticipated that a minimum of six test sessions will take place: three in natural snow and three in simulated precipitation conditions.

The goal for each test session is to complete all tests in the session test plan at least once; however this will be constrained by weather conditions and the duration of the snowstorm.

Table 1: Session Test Plan

Test #	Fluid	Dilution	Notes
1	UCAR Ultra+	100/0	
2	Kilfrost ABC-S	100/0	
3	Kilfrost ABC-S	75/25	If OAT is above -14°C
4	Kilfrost ABC-S	50/50	If OAT is above -3°C
5	SPCA Ecowing 26	100/0	
6	SPCA Ecowing 26	75/25	If OAT is above -14°C
7	SPCA Ecowing 26	50/50	If OAT is above -3°C
8	Clariant MP I 1938	10°C buffer	
9	Clariant MP I 1938	10°C buffer	

7. EQUIPMENT

Table 2 lists the equipment required. The equipment setup schematic is given in the IDES user guide.

Table 2: Equipment List

Equipment	Provided by
Maintenance PC	Intertechnique
Test plate	Intertechnique
Ice detectors (2)	Intertechnique
Power Supply and Interconnection Box (PSIB)	Intertechnique
Ice Detection Remote Unit (IDRU)	Intertechnique
Connection Cables	Intertechnique
Fluids	APS
Two-position test stand	APS

8. DATA FORMS

The form given in Figure 1 will be used to record visual fluid failure. Standard endurance time data forms may also be used to record fluid failure. A test session log, shown in Figure 2, will be filled out for each test session.

9. SAFETY PRECAUTIONS

The following precautions will be taken when executing tests to ensure the safety of all personnel:

- Pathways, stairs and test areas are to be cleared of snow regularly;
- Appropriate footwear is to be worn by all personnel at the test site to prevent slipping;
- Warm clothing is to be worn by all personnel to prevent frostbite;
- Electrical appliances (including computers) are to be unplugged before any wires or connections are altered. If necessary, the affected breaker is to be turned off;
- If fluid comes into contact with skin, rinse hands under running water;
- If fluid comes into contact with eyes, flush with the portable eye wash station located inside the main trailer; and
- When operating snow blower use ear protection.

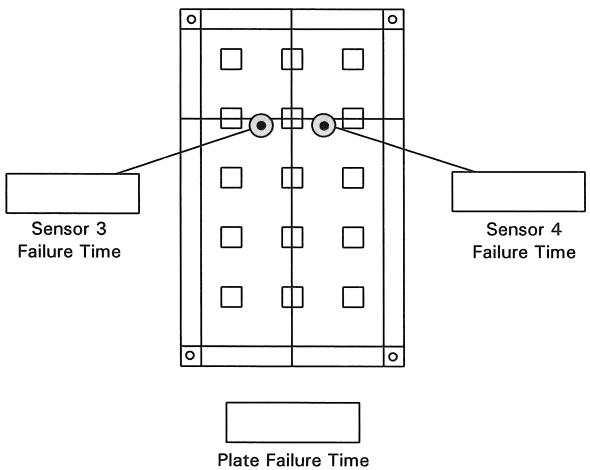
Figure 1: End Condition Data Form for IDES Tests

Run #: ______________________

Fluid: ______________________

Dilution: ______________________

Time of Fluid Application: ______________________

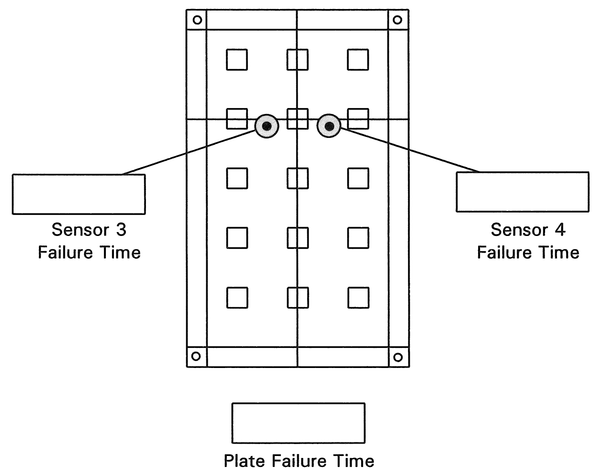


Run #: ______________________

Fluid: ______________________

Dilution: ______________________

Time of Fluid Application: ______________________



Date: ______________________ Written By: ______________________

Figure 2: Test Session Log

Date: ____________________

Precip. Type: ____________________ Test Manager: ____________________

Run #	Plate (A or B)	Fluid	Dilution	Start Time	OAT	Rates Location	Fluid Failure determined by	Failure Time (Sensor)

M:\Groups\CM1892 (TC-Deicing 03-04)\Procedures\Sensor\Test Session Log

Comments: ____________________

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APPENDIX D

COMPLETE LOG OF TESTS

TABLE D-1: COMPLETE LOG OF TESTS

Test #	Sensor	Date	Fluid	Dilution	Precipitation		Temp. (ºC)	Start Time	Failure Time			Endurance Time (min)			Test Value	Comments
					Type	Rate (g/dm²/h)			Visual (Sensor)	Visual (Plate)	WIDS	Visual (Sensor)	Visual (Plate)	WIDS		
1	3	26-Jan-05	UCAR Ultra+	100%	Snow	5	-16	0:50:00	3:09:00	3:14:00	3:08:26	139	144	138	0%	
1	4	26-Jan-05	UCAR Ultra+	100%	Snow	5	-16	0:50:00	3:09:00	3:14:00	3:08:21	139	144	138	0%	
2	3	26-Jan-05	Kilfrost ABC-S	100%	Snow	5	-16	3:26:00	4:03:30	4:07:30	4:03:06	38	42	37	-1%	
2	4	26-Jan-05	Kilfrost ABC-S	100%	Snow	5	-16	3:26:00	4:03:30	4:07:30	4:03:16	38	42	37	-1%	
3	3	10-Feb-05	SPCA Ecowing 26	100%	Snow	6	-6	6:11:45	8:00:00	7:55:00	7:20:21	108	103	69	-37%	Photo taken after IDES failure at 7:25
3	4	10-Feb-05	SPCA Ecowing 26	100%	Snow	6	-6	6:11:45	8:00:00	7:55:00	7:44:31	108	103	93	-14%	Photo taken after IDES failure at 7:50
4	3	10-Feb-05	Kilfrost ABC-S	100%	Snow	5	-7	8:10:00	10:58:00	10:54:00	10:37:54	168	164	148	-12%	Photo taken at 10:40 after IDES failure
4	4	10-Feb-05	Kilfrost ABC-S	100%	Snow	5	-7	8:10:00	10:58:00	10:54:00	10:37:44	168	164	148	-12%	Photo taken at 10:40 after IDES failure
5	3	10-Feb-05	SPCA Ecowing 26	75%	Snow	10	-6	11:07:00	11:57:00	11:54:00	11:39:00	50	47	32	-36%	
5	4	10-Feb-05	SPCA Ecowing 26	75%	Snow	10	-6	11:07:00	11:57:00	11:54:00	11:47:40	50	47	41	-19%	
6	3	10-Feb-05	Kilfrost ABC-S	75%	Snow	8	-6	12:13:40	13:25:00	13:22:00	13:12:56	71	68	59	-17%	
6	4	10-Feb-05	Kilfrost ABC-S	75%	Snow	8	-6	12:13:40	13:25:00	13:22:00	13:18:11	71	68	65	-10%	S4 had triggered failure prior to start of test
7	3	10-Feb-05	Clariant 1938	10º buffer	Snow	11	-6	13:48:45	13:56:00	13:56:00	13:53:41	7	7	5	-32%	Visual failure was estimated
7	4	10-Feb-05	Clariant 1938	10º buffer	Snow	11	-6	13:48:45	13:56:00	13:56:00	13:57:31	7	7	9	21%	Visual failure was estimated
8	3	10-Feb-05	UCAR Ultra+	100%	Snow	7	-6	14:24:00	15:50:00	15:56:00	15:47:33	86	92	84	-3%	Fluid initially poured at 14:21, but repoured at 14:24
8	4	10-Feb-05	UCAR Ultra+	100%	Snow	7	-6	14:24:00	15:39:00	15:56:00	15:32:58	75	92	69	-8%	(initial fluid was degraded)
9	3	14-Feb-05	SPCA Ecowing 26	50%	Snow	2	-1	17:37:15	19:05:00	19:05:00	19:05:01	88	88	88	0%	
9	4	14-Feb-05	SPCA Ecowing 26	50%	Snow	2	-1	17:37:15	18:49:00	19:05:00	19:05:07	72	88	88	22%	Photo taken at 18:50
10	3	16-Feb-05	Clariant 1938	10º buffer	Snow	23	0	10:15:00	10:20:30	10:20:30	10:22:45	6	6	8	41%	
10	4	16-Feb-05	Clariant 1938	10º buffer	Snow	23	0	10:15:00	10:20:30	10:20:30	10:23:15	6	6	8	50%	
11	3	16-Feb-05	SPCA Ecowing 26	75%	Snow	16	0	10:27:00	10:52:00	11:05:00	10:48:03	25	38	21	-16%	
11	4	16-Feb-05	SPCA Ecowing 26	75%	Snow	16	0	10:27:00	10:50:00	11:05:00	10:47:13	23	38	20	-12%	
12	3	16-Feb-05	Kilfrost ABC-S	50%	Snow	17	0	11:14:00	11:23:00	11:23:40	11:22:53	9	10	9	-1%	
12	4	16-Feb-05	Kilfrost ABC-S	50%	Snow	17	0	11:14:00	11:23:00	11:23:40	11:22:48	9	10	9	-2%	
13	3	16-Feb-05	SPCA Ecowing 26	50%	Snow	17	0	11:28:30	11:37:30	11:39:00	11:36:48	9	11	8	-8%	
13	4	16-Feb-05	SPCA Ecowing 26	50%	Snow	17	0	11:28:30	11:37:30	11:39:00	11:36:48	9	11	8	-8%	
14	3	16-Feb-05	Kilfrost ABC-S	75%	Snow	21	0	11:44:45	12:13:00	12:18:00	12:09:28	28	33	25	-13%	
14	4	16-Feb-05	Kilfrost ABC-S	75%	Snow	21	0	11:44:45	12:15:00	12:18:00	12:15:33	30	33	31	2%	
15	3	16-Feb-05	SPCA Ecowing 26	100%	Snow	16	0	12:35:30	13:18:00	13:22:00	13:17:22	43	47	42	-1%	
15	4	16-Feb-05	SPCA Ecowing 26	100%	Snow	16	0	12:35:30	13:18:00	13:22:00	13:18:37	43	47	43	1%	
16	3	21-Feb-05	Kilfrost ABC-S	75%	Snow	4	-15	5:54:00	6:40:00	6:40:00	6:15:30	46	46	22	-53%	Ice crystals, no data file, IDES times taken from on-
16	4	21-Feb-05	Kilfrost ABC-S	75%	Snow	4	-15	5:54:00	6:40:00	6:40:00	5:57:00	46	46	3	-93%	screen display
17	3	21-Feb-05	UCAR Ultra+	100%	Snow	5	-15	6:46:45	7:29:00	7:32:00	7:11:18	42	45	25	-42%	Dilution failure
17	4	21-Feb-05	UCAR Ultra+	100%	Snow	5	-15	6:46:45	7:29:00	7:32:00	7:28:33	42	45	42	-1%	Dilution failure
18	3	21-Feb-05	SPCA Ecowing 26	100%	Snow	6	-15	7:42:00	8:34:00	8:36:00	8:05:31	52	54	24	-55%	Ice crystals
18	4	21-Feb-05	SPCA Ecowing 26	100%	Snow	6	-15	7:42:00	8:34:00	8:36:00	8:04:11	52	54	22	-57%	Ice crystals
19	3	21-Feb-05	Kilfrost ABC-S	100%	Snow	3	-8	8:41:00	11:28:00	11:28:00	11:13:44	167	167	153	-9%	Ice crystals
19	4	21-Feb-05	Kilfrost ABC-S	100%	Snow	3	-8	8:41:00	11:28:00	11:28:00	8:44:14	167	167	3	-98%	Ice crystals
20	3	21-Feb-05	SPCA Ecowing 26	75%	Snow	6	-7	11:39:30	12:07:00	12:07:00	12:03:41	28	28	24	-12%	Ice crystals
20	4	21-Feb-05	SPCA Ecowing 26	75%	Snow	6	-7	11:39:30	12:07:00	12:07:00	12:05:46	28	28	26	-4%	Ice crystals
21	3	21-Feb-05	UCAR Ultra+	100%	Snow	12	-6	12:15:00	13:21:00	13:18:00	13:21:11	66	63	66	0%	
21	4	21-Feb-05	UCAR Ultra+	100%	Snow	12	-6	12:15:00	13:09:00	13:18:00	13:10:31	54	63	56	3%	At failure, fluid past freeze pt, but FND
22	3	21-Feb-05	Clariant 1938	10º buffer	Snow	15	-7	13:26:00	13:30:00	13:30:00	13:31:58	4	4	6	49%	
22	4	21-Feb-05	Clariant 1938	10º buffer	Snow	15	-7	13:26:00	13:30:00	13:30:00	13:32:03	4	4	6	51%	

TABLE D-1: COMPLETE LOG OF TESTS (cont'd)

Test #	Sensor	Date	Fluid	Dilution	Precipitation Type	Precipitation Rate (g/dm²/h)	Temp. (°C)	Start Time	Failure Time Visual (Sensor)	Failure Time Visual (Plate)	Failure Time WIDS	Endurance Time (min) Visual (Sensor)	Endurance Time (min) Visual (Plate)	Endurance Time (min) WIDS	Test Value	Comments
23	3	21-Feb-05	Kilfrost ABC-S	75%	Snow	16	-6	13:41:45	14:24:00	14:24:00	14:22:30	42	42	41	-4%	
23	4	21-Feb-05	Kilfrost ABC-S	75%	Snow	16	-6	13:41:45	14:24:00	14:24:00	14:22:35	42	42	41	-3%	
24	3	21-Feb-05	Clariant 1938	10° buffer	Snow	9	-6	14:30:30	14:38:30	14:38:30	14:38:03	8	8	8	-6%	
24	4	21-Feb-05	Clariant 1938	10° buffer	Snow	9	-6	14:30:30	14:38:30	14:38:30	14:37:18	8	8	7	-15%	
25	3	01-Mar-05	SPCA Ecowing 26	75%	Snow	11	-6	5:31:00	5:49:00	5:49:00	5:46:02	18	18	15	-16%	
25	4	01-Mar-05	SPCA Ecowing 26	75%	Snow	11	-6	5:31:00	5:45:00	5:49:00	5:44:17	14	18	13	-5%	
26	3	01-Mar-05	SPCA Ecowing 26	100%	Snow	16	-6	5:52:45	6:32:30	6:32:30	6:28:15	40	40	36	-11%	
26	4	01-Mar-05	SPCA Ecowing 26	100%	Snow	16	-6	5:52:45	6:32:30	6:32:30	6:27:35	40	40	35	-12%	
27	3	01-Mar-05	Kilfrost ABC-S	100%	Snow	7	-6	6:38:00	9:23:00	9:23:00	9:24:56	165	165	167	1%	Rate dropped to almost 0 g/dm²/h from 6:50 to 7:50,
27	4	01-Mar-05	Kilfrost ABC-S	100%	Snow	7	-6	6:38:00	9:24:00	9:23:00	9:19:31	166	165	162	-3%	and then picked up to 15 g/dm²/h
28	3	01-Mar-05	Clariant 1938	10° buffer	Snow	14	-6	9:29:30	9:37:00	9:37:00	FND	8	8	FND*	n/a	S3 did not detect failure for this test
28	4	01-Mar-05	Clariant 1938	10° buffer	Snow	14	-6	9:29:30	9:37:00	9:37:00	9:38:25	8	8	9	19%	
29	3	01-Mar-05	UCAR Ultra+	100%	Snow	15	-7	10:29:15	10:54:30	10:54:30	10:51:57	25	25	23	-10%	
29	4	01-Mar-05	UCAR Ultra+	100%	Snow	15	-7	10:29:15	10:54:30	10:54:30	10:52:57	25	25	24	-6%	
30	3	01-Mar-05	Kilfrost ABC-S	75%	Snow	18	-6	11:01:00	11:46:00	11:43:30	11:41:44	45	43	41	-9%	
30	4	01-Mar-05	Kilfrost ABC-S	75%	Snow	18	-6	11:01:00	11:46:00	11:43:30	11:39:14	45	43	38	-15%	
31	3	01-Mar-05	Clariant 1938	10° buffer	Snow	15	-6	11:52:15	11:58:45	11:58:45	11:59:42	7	7	7	15%	
31	4	01-Mar-05	Clariant 1938	10° buffer	Snow	15	-6	11:52:15	11:58:45	11:58:45	11:59:12	7	7	7	7%	
32	3	01-Mar-05	SPCA Ecowing 26	75%	Snow	11	-6	12:09:30	12:40:00	12:39:00	12:37:57	31	30	28	-7%	
32	4	01-Mar-05	SPCA Ecowing 26	75%	Snow	11	-6	12:09:30	12:40:00	12:39:00	12:39:22	31	30	30	-2%	
33	3	01-Mar-05	SPCA Ecowing 26	100%	Snow	8	-6	12:46:00	13:51:00	13:51:00	13:47:40	65	65	62	-5%	
33	4	01-Mar-05	SPCA Ecowing 26	100%	Snow	8	-6	12:46:00	13:51:00	13:51:00	13:47:25	65	65	61	-6%	
34	3	07-Mar-05	Kilfrost ABC-S	100%	Snow	6	-10	15:19:30	17:12:00	17:31:00	17:11:54	113	132	112	0%	
34	4	07-Mar-05	Kilfrost ABC-S	100%	Snow	6	-10	15:19:30	17:22:00	17:31:00	17:22:19	123	132	123	0%	
35	3	11-Mar-05	SPCA Ecowing 26	50%	Snow	2	-2	17:30:30	17:52:00	17:59:00	17:52:07	22	29	22	1%	
35	4	11-Mar-05	SPCA Ecowing 26	50%	Snow	2	-2	17:30:30	17:48:00	17:59:00	17:47:52	18	29	17	-1%	
36	3	11-Mar-05	SPCA Ecowing 26	50%	Snow	2	-3	18:40:45	18:55:00	18:56:00	18:55:15	14	15	15	2%	
36	4	11-Mar-05	SPCA Ecowing 26	50%	Snow	2	-3	18:40:45	19:04:03	18:56:00	19:04:05	23	15	23	0%	
37	3	11-Mar-05	Kilfrost ABC-S	50%	Snow	3	-3	19:08:00	19:19:05	19:23:00	19:19:32	11	15	12	4%	
37	4	11-Mar-05	Kilfrost ABC-S	50%	Snow	3	-3	19:08:00	19:19:20	19:23:00	19:19:22	11	15	11	0%	
38	3	11-Mar-05	Kilfrost ABC-S	50%	Snow	9	-3	19:25:30	19:34:15	19:37:00	19:34:34	9	12	9	4%	
38	4	11-Mar-05	Kilfrost ABC-S	50%	Snow	9	-3	19:25:30	19:35:22	19:37:00	19:35:24	10	12	10	0%	
39	3	11-Mar-05	SPCA Ecowing 26	50%	Snow	4	-4	19:39:30	19:57:00	19:59:00	19:57:03	18	20	18	0%	
39	4	11-Mar-05	SPCA Ecowing 26	50%	Snow	4	-4	19:39:30	19:56:00	19:59:00	19:56:08	17	20	17	1%	
40	3	11-Mar-05	Kilfrost ABC-S	50%	Snow	9	-4	20:02:00	20:11:15	20:14:00	20:12:05	9	12	10	9%	
40	4	11-Mar-05	Kilfrost ABC-S	50%	Snow	9	-4	20:02:00	20:12:00	20:14:00	20:11:10	10	12	9	-8%	
41	3	05-Apr-05	Kilfrost ABC-S	75%	ZD	5	-10	11:01:00	11:15:00	11:17:00	FND	14	16	FND*	n/a	
41	4	05-Apr-05	Kilfrost ABC-S	75%	ZD	5	-10	11:01:00	11:15:00	11:17:00	FND	14	16	FND*	n/a	
42	3	05-Apr-05	SPCA Ecowing 26	75%	ZD	5	-10	12:02:00	12:09:00	12:08:30	FND	7	7	FND*	n/a	
42	4	05-Apr-05	SPCA Ecowing 26	75%	ZD	5	-10	12:02:00	12:09:30	12:08:30	FND	8	7	FND*	n/a	
43	3	05-Apr-05	Clariant 1938	10° buffer	ZD	5	-10	13:51:00	13:59:50	13:59:20	14:14:15	9	8	23	163%	ice detected only after thickness reached 0.2mm
43	4	05-Apr-05	Clariant 1938	10° buffer	ZD	5	-10	13:51:00	14:00:00	13:59:20	14:10:25	9	8	19	116%	ice detected only after thickness reached 0.2mm
44	3	05-Apr-05	Clariant 1938	10° buffer	ZD	13	-10	15:38:15	15:43:50	15:43:40	15:48:57	6	5	11	92%	ice detected only after thickness reached 0.25mm
44	4	05-Apr-05	Clariant 1938	10° buffer	ZD	13	-10	15:38:15	15:43:50	15:43:40	15:47:42	6	5	9	69%	ice detected only after thickness reached 0.25mm

TABLE D-1: COMPLETE LOG OF TESTS (cont'd)

Test #	Sensor	Date	Fluid	Dilution	Precipitation		Temp. (°C)	Start Time	Failure Time			Endurance Time (min)			Test Value	Comments
					Type	Rate (g/dm²/h)			Visual (Sensor)	Visual (Plate)	WIDS	Visual (Sensor)	Visual (Plate)	WIDS		
45	3	05-Apr-05	SPCA Ecowing 26	75%	ZD	13	-10	16:11:15	16:40:40	16:40:10	FND	29	29	FND*	n/a	
45	4	05-Apr-05	SPCA Ecowing 26	75%	ZD	13	-10	16:11:15	16:43:45	16:40:10	FND	33	29	FND*	n/a	
46	3	05-Apr-05	UCAR Ultra+	100%	ZD	13	-10	16:57:00	17:12:55	17:12:00	17:11:19	16	15	14	-10%	flash freezing
46	4	05-Apr-05	UCAR Ultra+	100%	ZD	13	-10	16:57:00	17:12:55	17:12:00	17:10:19	16	15	13	-16%	flash freezing
47	3	05-Apr-05	UCAR Ultra+	100%	ZR	25	-10	18:46:00	19:38:30	19:13:00	19:48:35	53	27	63	19%	failed bottom up
47	4	05-Apr-05	UCAR Ultra+	100%	ZR	25	-10	18:46:00	19:40:00	19:13:00	19:37:25	54	27	51	-5%	failed bottom up
48	3	06-Apr-05	Kilfrost ABC-S	100%	ZR	13	-10	9:19:30	9:50:00	9:50:00	10:44:37	31	31	85	179%	ice floating on surface
48	4	06-Apr-05	Kilfrost ABC-S	100%	ZR	13	-10	9:19:30	9:50:00	9:50:00	10:45:17	31	31	86	181%	ice floating on surface
49	3	06-Apr-05	Clariant 1938	10° buffer	ZR	13	-10	10:54:40	11:00:15	11:00:15	11:06:49	6	6	12	118%	
49	4	06-Apr-05	Clariant 1938	10° buffer	ZR	13	-10	10:54:40	11:01:10	11:00:15	11:08:09	7	6	13	107%	
50	3	06-Apr-05	SPCA Ecowing 26	50%	ZR	13	-3	12:51:00	13:01:00	13:02:00	12:58:28	10	11	7	-25%	
50	4	06-Apr-05	SPCA Ecowing 26	50%	ZR	13	-3	12:51:00	13:02:00	13:02:00	12:58:58	11	11	8	-28%	
51	3	06-Apr-05	SPCA Ecowing 26	100%	ZR	13	-3	13:16:15	13:50:00	13:52:00	13:45:26	34	36	29	-14%	
51	4	06-Apr-05	SPCA Ecowing 26	100%	ZR	13	-3	13:16:15	13:54:00	13:52:00	13:48:26	38	36	32	-15%	
52	3	06-Apr-05	Kilfrost ABC-S	75%	ZR	13	-3	14:28:15	14:58:00	14:57:00	FND	30	29	FND*	n/a	ice too thin for detection
52	4	06-Apr-05	Kilfrost ABC-S	75%	ZR	13	-3	14:28:15	14:58:00	14:57:00	FND	30	29	FND*	n/a	ice too thin for detection
53	3	06-Apr-05	UCAR Ultra+	100%	ZR	13	-3	15:18:15	16:00:00	16:00:30	FND	42	42	FND*	n/a	test stopped
53	4	06-Apr-05	UCAR Ultra+	100%	ZR	13	-3	15:18:15	16:02:00	16:00:30	FND	44	42	FND*	n/a	test stopped
54	3	06-Apr-05	Kilfrost ABC-S	100%	ZR	25	-3	17:22:45	18:14:00	18:14:00	FND	51	51	FND*	n/a	
54	4	06-Apr-05	Kilfrost ABC-S	100%	ZR	25	-3	17:22:45	18:18:00	18:14:00	FND	55	51	FND*	n/a	
55	3	06-Apr-05	UCAR Ultra+	100%	ZR	25	-3	18:22:00	18:52:00	18:52:00	FND	30	30	FND*	n/a	
55	4	06-Apr-05	UCAR Ultra+	100%	ZR	25	-3	18:22:00	18:53:00	18:52:00	FND	31	30	FND*	n/a	
56	3	07-Apr-05	SPCA Ecowing 26	50%	ZD	5	-3	9:22:50	9:34:00	9:33:00	9:46:27	11	10	24	111%	
56	4	07-Apr-05	SPCA Ecowing 26	50%	ZD	5	-3	9:22:50	9:33:00	9:33:00	FND	10	10	FND*	n/a	
57	3	07-Apr-05	Clariant 1938	10° buffer	ZD	5	-3	9:54:00	10:07:00	10:07:00	FND	13	13	FND*	n/a	
57	4	07-Apr-05	Clariant 1938	10° buffer	ZD	5	-3	9:54:00	10:08:30	10:07:00	FND	15	13	FND*	n/a	
58	3	07-Apr-05	Kilfrost ABC-S	75%	ZD	5	-3	10:32:45	11:35:00	11:35:00	FND	62	62	FND*	n/a	
58	4	07-Apr-05	Kilfrost ABC-S	75%	ZD	5	-3	10:32:45	11:35:00	11:35:00	FND	62	62	FND*	n/a	
59	3	07-Apr-05	Kilfrost ABC-S	50%	ZD	13	-3	13:43:30	13:57:00	13:57:00	13:51:14	14	14	8	-43%	flash freezing?
59	4	07-Apr-05	Kilfrost ABC-S	50%	ZD	13	-3	13:43:30	13:57:00	13:57:00	13:50:54	14	14	7	-45%	flash freezing?
60	3	07-Apr-05	SPCA Ecowing 26	100%	ZD	13	-3	14:16:50	14:55:00	14:56:00	FND	38	39	FND*	n/a	
60	4	07-Apr-05	SPCA Ecowing 26	100%	ZD	13	-3	14:16:50	14:56:00	14:56:00	14:52:23	39	39	36	-9%	
61	3	07-Apr-05	Kilfrost ABC-S	100%	ZD	13	-3	15:27:20	16:49:00	16:49:00	16:42:49	82	82	75	-8%	
61	4	07-Apr-05	Kilfrost ABC-S	100%	ZD	13	-3	15:27:20	16:50:00	16:49:00	16:45:19	83	82	78	-6%	
62	3	08-Apr-05	Clariant 1938	10° buffer	ZF	2	-3	11:27:10	11:52:10	11:51:30	12:18:59	25	24	52	107%	
62	4	08-Apr-05	Clariant 1938	10° buffer	ZF	2	-3	11:27:10	11:51:15	11:51:30	12:11:24	24	24	44	84%	

*FND = Failure not detected

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