Effect of Heat on Endurance Times of Anti-Icing Fluids

Prepared by

APS Aviation Inc.

Prepared for
Transportation Development Centre

In cooperation with

Civil Aviation
Transport Canada

And

The Federal Aviation Administration
William J. Hughes Technical Center

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Effect of Heat on Endurance Times of Anti-Icing Fluids

by

Nicoara Moc
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. (APS) has undertaken a research program to advance aircraft ground de/anti-icing technology. The specific objectives of the APS test program are the following:

- To develop holdover time data for all newly-qualified de/anti-icing fluids;
- To conduct endurance time 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 Determining 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 Research General 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 14447E, has the following objective:

- To conduct endurance time tests with heated Type II, III and IV fluids and to compare these endurance times with endurance times obtained using the standard protocol.

The objective was met by conducting a series of tests under natural and simulated precipitation conditions. Tests were conducted always in pairs, with one fluid applied heated and the other fluid applied according to the standard protocol. The results were compared and the findings are presented in this report.

This research project has been funded by the Civil Aviation Group of Transport Canada with support from the Federal Aviation Administration (FAA).

**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 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 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.
Effect of Heat on Endurance Times of Anti-Icing Fluids

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 (TDC). Nine reports (including this one) were produced as part of this winter’s research program. Their subject matter is outlined in the preface. This research project has been funded by the Civil Aviation Group of Transport Canada with support from the Federal Aviation Administration (FAA).

APS Aviation Inc. (APS) undertook a study to conduct endurance time tests with heated Type II, III and IV fluids and to compare these endurance times with endurance times obtained using the standard test protocol. The objective was met by conducting a series of tests under natural and simulated precipitation conditions. Tests were conducted always in pairs, with one fluid applied heated and the other fluid applied according to the standard protocol.

Fluid endurance time testing during natural snow conditions was conducted at the APS test site located at the Montreal-Trudeau Airport, during the winter of 2004-05. To obtain the necessary fluid endurance time data for the freezing precipitation conditions, testing was carried out at the National Research Council Canada (NRC) Climatic Engineering Facility using a sprayer assembly to simulate the required freezing precipitation conditions. During the winter of 2004-05, 19 comparison tests (38 individual tests) were conducted in snow conditions and 20 comparison tests (40 individual tests) were conducted under freezing precipitation conditions. These tests were carried out with five fluid brands and three fluid types.

The comparative tests conducted during simulated freezing precipitation conditions indicated that fluids applied heated diluted faster than those applied at room temperature. Also, the test temperature played an important role in the results of the comparative tests. At -10°C, heat reduced the endurance time of the fluid, whereas at -3°C, it extended the fluid endurance time. Additionally, there seems to be a variation between the various fluid types tested, substantiating that perhaps the effect of heat is fluid dependent.

The comparative tests conducted during natural snow conditions indicated that, typically, heating the fluid prior to application resulted in shorter endurance times in the case of low dilution fluids, namely Type III fluids. The effect of heat seems to increase the endurance time of Type IV fluids. These findings match the results from similar tests conducted during the 2001-02 winter season.

Due to the limited number of tests conducted under both snow and freezing precipitation conditions, currently there is not sufficient data to enable a solid conclusion on the effect of heat on different fluid types and fluid brands. Therefore, it is recommended that the failure mechanisms be further evaluated and analysed by conducting a new series of comparative tests using different fluid types and dilutions at various temperatures and precipitation rates. Furthermore, a series of tests should be conducted on a wing in order to conclude on the validity of the fluid application protocol.

Hot Fluid, Cold Fluid, Natural Snow, Freezing Precipitation, Holdover Time, Heat

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Due to the limited number of tests conducted under both snow and freezing precipitation conditions, currently there is not sufficient data to enable a solid conclusion on the effect of heat on different fluid types and fluid brands. Therefore, it is recommended that the failure mechanisms be further evaluated and analysed by conducting a new series of comparative tests using different fluid types and dilutions at various temperatures and precipitation rates. Furthermore, a series of tests should be conducted on a wing in order to conclude on the validity of the fluid application protocol.
Effect of Heat on Endurance Times of Anti-Icing Fluids

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Effect of Heat on Endurance Times of Anti-Icing Fluids

Le Centre de développement des transports dispose d'un nombre limité d’exemplaires

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EXECUTIVE SUMMARY

Under contract to the Transportation Development Centre (TDC) of Transport Canada (TC), APS Aviation Inc. (APS) undertook a study to conduct endurance time tests with heated Type II, III and IV fluids and to compare these endurance times with endurance times obtained using the standard test protocol.

The objective was met by conducting a series of tests under natural and simulated precipitation conditions. Tests were conducted always in pairs, with one fluid applied heated and the other fluid applied according to the standard protocol. The results were compared and the findings are presented in this report.

Description and Processing of Data

Fluid endurance time testing during natural snow conditions was conducted at the APS test site located at the Montreal-Trudeau Airport, during the winter of 2004-05. To obtain the necessary fluid endurance time data for the freezing precipitation conditions, testing was carried out at the National Research Council Canada (NRC) Climatic Engineering Facility (CEF) using a sprayer assembly to simulate the required freezing precipitation conditions. Testing was conducted by APS personnel, under both natural snow and freezing precipitation conditions.

During the winter of 2004-05, 19 comparison tests (38 individual tests) were conducted in snow conditions and 20 comparison tests (40 individual tests) were conducted under freezing precipitation conditions. These tests were carried out with five fluid brands and three fluid types.

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

Results and Conclusions

The conclusions drawn from the tests performed during the winter of 2004-05 are described on the following page, per precipitation condition.
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1. Simulated Freezing Precipitation

The comparative tests conducted during simulated freezing precipitation conditions indicated that:

- Fluids applied heated diluted faster than those applied at ambient temperature;
- Data collected with two fluids illustrated a very consistent pattern. Independent of the precipitation condition (drizzle or rain) and the precipitation rate (high or low), the test temperature played an important role in the result of the comparative test. At -10°C, heat reduced the endurance time of the fluid, whereas at -3°C, it extended the fluid endurance time;
- The failure mechanisms described above were not entirely supported by the comparative endurance time testing run with two other fluids. Also, additional data from tests conducted during the 2001-02 winter season showed that the effect of heat did not reduce endurance times. In some cases, a significant improvement was observed; and
- There seems to be a variation among the various fluid types tested, suggesting that perhaps the effect of heat is fluid dependent.

2. Endurance Time Testing During Natural Snow

The comparative tests conducted during natural snow conditions indicated that:

- On average, the hot/cold ratio was 85 percent for Type III fluid and 131 percent for Type IV fluid. This indicated that, on average, heating the fluid prior to application resulted in shorter endurance times in the case of low dilution fluids, namely Type III fluids. Also, the effect of heat seems to increase the endurance time of Type IV fluids. These findings match the results from similar tests conducted during the 2001-02 winter season; and
- There also seems to be a difference among the various Type IV fluid types tested, suggesting that perhaps the effect of heat is fluid dependent.

Recommendations

Due to the limited number of tests conducted under both snow and freezing precipitation conditions, and the slightly contradictory results compared with 2001-02 testing, currently there is no sufficient data to enable a solid conclusion on the effect of heat on different fluid types or even fluid brands. Therefore, it is
EXECUTIVE SUMMARY

recommended that the failure mechanisms be further evaluated and analysed by conducting a new series of comparative tests using different fluid types and dilutions at various temperatures and precipitation rates.

Furthermore, for snow conditions, the application protocol used in 2004-05 was initially developed for Type I fluids. The protocol was empirically developed, by comparing temperature profiles from aircraft wings to those of various test surfaces. However, for these comparative tests, an assumption was made that the correspondence between the aircraft wing temperature profile and the profile of the test surface remains unchanged when Type IV is used. This assumption will have to be substantiated by conducting a series of comparative tests on the Jetstar wing. These tests should be conducted before further Type IV hot vs. cold tests are run under snow conditions.
SOMMAIRE

En vertu d’un contrat avec le Centre de développement des transports (CDT) de Transports Canada (TC), APS Aviation Inc. (APS) a entrepris une étude pour la tenue d’essais sur l’endurance de liquides chauffés de types II, III et IV et de les comparer à l’endurance obtenue avec le protocole standard d’essais.

L’objectif a été atteint en effectuant une série d’essais dans des conditions de précipitations naturelles et simulées. Les essais étaient toujours effectués simultanément, un liquide étant appliqué chauffé alors que l’autre liquide était appliqué selon le protocole standard. Les résultats ont été comparés et les conclusions sont présentées dans le présent rapport.

Description et traitement des données


Au cours de l’hiver 2004-2005, 19 essais comparatifs (38 essais individuels) ont été tenus dans des conditions de neige et 20 essais comparatifs (40 essais individuels) dans des conditions de précipitations verglaçantes. Ces essais ont été effectués avec cinq marques de liquides et trois types de liquides.

Plusieurs paramètres ont été documentés au cours de chaque essai tenu sur l’endurance des liquides. Les données recueillies sur la dilution des liquides (degré Brix) et sur l’épaisseur des liquides ont été mesurées à intervalles réguliers pour la durée des essais, alors que la température de la surface de la plaque était enregistrée de façon continue. Ces paramètres ont servi à la préparation de tableaux pour mieux illustrer les profils de température de la surface d’essais, ainsi que la désintégration de l’épaisseur du liquide et sa dilution.

Résultats et conclusions

Les conclusions tirées des essais effectués au cours de l’hiver 2004-2005 sont exposées à la page suivante, par type de précipitations.
1. Précipitation verglaçante simulée

Les essais comparatifs effectués dans des conditions de précipitations verglaçantes ont démontré que :

- Les liquides appliqués chaufés se diluaient plus rapidement que ceux qui sont appliqués à la température ambiante ;

- Les données recueillies sur deux liquides affichaient un modèle très constant. Peu importe la condition de précipitation (bruine ou pluie) et le taux de précipitation (élevé ou faible), la température des essais a joué un rôle important sur le résultat des essais comparatifs. À -10°C, la chaleur réduisait l’endurance du liquide, alors qu’à -3°C, elle en prolongeait l’endurance ;

- Les mécanismes de rupture décrits ci-dessus n’étaient pas entièrement corroborés par les essais comparatifs d’endurance effectués sur deux autres liquides. De plus, les données additionnelles issues d’essais effectués au cours de l’hiver 2001-2002 ont démontré que l’effet de la chaleur ne réduisait pas l’endurance. Dans certains cas, on a noté une amélioration significative ; et

- Il semble y avoir une variation parmi les différents types de liquides mis à l’essai, ce qui suggère que l’effet de la chaleur dépend peut-être du liquide.

2. Essais d’endurance dans la neige naturelle

Les essais comparatifs effectués dans des conditions de neige naturelle ont démontré que :

- En général, le ratio chaud/froid était de 85 pourcent dans le cas des liquides de type III et de 131 pourcent dans le cas des liquides de type IV. Ceci démontre qu’en moyenne, le chauffage du liquide avant son application réduit l’endurance des liquides de faible dilution, à savoir les liquides de type III. De plus, l’effet de la chaleur semble augmenter l’endurance des liquides de type IV. Ces résultats concordent avec ceux d’essais semblables effectués au cours de l’hiver 2001-2002 ; et

- Il semble également y avoir une différence parmi les différents liquides de type IV mis à l’essai, ce qui suggère que l’effet de la chaleur dépend peut-être du liquide.
Recommandations

En raison du nombre limité d’essais effectués dans des conditions de neige et de précipitations verglaçantes, ainsi que des résultats contradictoires comparativement aux essais de 2001-2002, il n’y a pas à l’heure actuelle suffisamment de données pour arriver à une conclusion solide sur l’effet de la chaleur sur les différents types et marques de liquides. En conséquence, il est recommandé d’évaluer et d’analyser davantage les mécanismes de rupture à l’aide d’une nouvelle série d’essais comparatifs, utilisant différents types et dilutions de liquides à des températures variées et à différents taux de précipitation.

En outre, dans des conditions de neige, le protocole d’application utilisé en 2004-2005 a été élaboré initialement pour les liquides de type I. Le protocole a été élaboré de façon expérimentale, en comparant les profils de température sur les ailes d’aéronefs à ceux des diverses surfaces d’essais. Dans le cas de ces essais comparatifs cependant, on a émis l’hypothèse que la correspondance entre le profil de température de l’aile d’aéronef et celui de la surface d’essais demeure inchangé pour l’application de liquide de type IV. Cette hypothèse devra être corroborée par la tenue d’une série d’essais comparatifs sur l’aile du Jetstar. Ces essais devraient être effectués avant la tenue d’autres essais chaud c. froid sur les liquides de type IV dans des conditions de neige.
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<td>OAT</td>
<td>Outside Air Temperature</td>
</tr>
<tr>
<td>SAE</td>
<td>Society of Automotive Engineers, Inc.</td>
</tr>
<tr>
<td>TC</td>
<td>Transport Canada</td>
</tr>
<tr>
<td>TDC</td>
<td>Transportation Development Centre</td>
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</table>
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1. INTRODUCTION

Under winter precipitation conditions, aircrafts 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 little 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.

Over the past several years, the Transportation Development Centre (TDC), 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 US Federal Aviation Administration (FAA), the National Research Council (NRC), Atmospheric Environment Services, several major airlines, and deicing fluid manufacturers. The TDC is continuing its research, development, testing and evaluation program.

Under contract to the TDC, APS Aviation Inc. (APS) undertook a test program to investigate the impact of anti-icing fluid application temperature on endurance time performance.

1.1 Background

At an SAE International (SAE) G-12 Holdover Time (HOT) Subcommittee meeting in November 2000, discussion focused on the need to recognize the contribution of heat in the endurance time test procedure for Type I fluids. Research was conducted and it was concluded that an empty aluminum box insulated on all sides except the top would be a suitable simulation of the wing leading edge. As a result, Type I fluids were tested outdoors with this wing leading edge thermal equivalent box, and holdover times were subsequently developed. Because heated Type II and IV fluids at 50/50 and 75/25 concentrations were sometimes being used in one-step deicing procedures, a motion was made to alter the test procedure for these fluids to recognize the contribution of heat and to use as a test surface, the same box that is used in tests with the Type I fluids.

In 2001-02, exploratory tests were conducted to investigate whether heat significantly influences the endurance times for Type II and Type IV fluids. Five different fluid brands were used for these exploratory tests. These tests indicated
that heat did not reduce endurance times. In some cases, a significant improvement was observed. However, further investigation was recommended.

1.2 Objective

The objective of this project was to further investigate the impact of the anti-icing fluid application temperature on the endurance time.

The following are the detailed objectives (also see Appendix A):

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

The objective was met by conducting a series of tests under natural and simulated precipitation conditions. Tests were conducted always in pairs, with one fluid applied heated and the other fluid applied according to the standard protocol. The results were compared and the findings are presented in this report.

1.3 Report Format

The following provides short descriptions of main sections of this report:

- Section 2 provides a description of the methodology used to carry out the tests;
- Section 3 presents the data that were collected during natural snow and simulated freezing precipitation conditions;
- Section 4 presents the data analysis of the tests;
- Section 5 presents the conclusions; and
- Section 6 presents the recommendations.
2. METHODOLOGY

This section describes the overall approach, test parameters and experimental procedures followed in this project.

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 International Organization for Standardization (ISO) 9001:2000 standards and developed internally by APS.

2.1 Test Site

Fluid endurance time testing during natural snow conditions was conducted at the APS test site located at the Montreal-Trudeau Airport, during the winter of 2004-05. Testing was conducted by APS personnel. The location of the test site is shown on the plan view of the airport in Figure 2.1. The APS test site is located near the Meteorological Service Canada (MSC) automated weather observation station. A view of the test site is shown in Photo 2.1.

![Plan View of APS Montreal-Trudeau Airport Test Site](image-url)

Figure 2.1: Plan View of APS Montreal-Trudeau Airport Test Site
2. METHODOLOGY

2.2 NRC Climatic Engineering Facility

Fluid endurance time testing in freezing precipitation conditions was carried out at the NRC Climatic Engineering Facility (CEF) (Photo 2.2) using a sprayer assembly to produce the required conditions. Testing was conducted by APS personnel, under freezing rain and freezing drizzle conditions.

2.3 Description of Test Procedures

Comparative endurance time tests were conducted using various fluids at the Montreal-Trudeau Airport test site and at the NRC facility. Standard fluid endurance time test procedures were applied. The tests were conducted simultaneously following the application methods described below.

In an attempt to increase efficiency, testing to determine the impact of fluid application temperature on endurance time was combined with another project related to non-aluminum plate endurance time tests. The test procedure in Appendix B refers to both heated fluid endurance time tests and non-aluminum plate endurance time tests. Photo 2.3 demonstrates the setup used to conduct simultaneous comparative testing for heated fluid endurance time and non-aluminum plate endurance time outdoors. Photo 2.4 demonstrates the setup used to conduct simultaneous comparative testing for heated fluid endurance time and non-aluminum plate endurance time indoors. Only the procedure describing heated fluid endurance time testing is of concern to this report. A complete description of the test procedure used is provided in Appendix B.

2.3.1 Indoor Tests Type II/III/IV Fluids

Position 1: Baseline Standard Test:

1 L of fluid at outside air temperature (OAT) poured (with no spreader) onto an aluminum plate.

Position 2: Heated Fluid Test:

1.0 L of fluid warmed to 60ºC and poured with the warm 12-hole spreader (if fluid is too viscous, then hand pour) onto a plate.

The summary of these application methods is shown in Figure 2.2.
2. METHODOLOGY

Position 1 (Baseline Standard Test)
- Plate
- 1 L of fluid
- Apply at OAT
- Poured

Position 2 (Heated Test)
- Plate
- 1 L of fluid
- Applied at 60 ºC
- Poured with the 12-hole spreader

Figure 2.2: Position on Stand – Indoor Tests with Type II/III/IV Fluids

2.3.2 Outdoor Tests with Type II/III/IV Fluids

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

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

The summary of these application methods is shown in Figure 2.3.

Position 1 (Baseline Standard Test)
- Plate
- 1 L of fluid
- Apply at OAT
- Poured

Position 2 (Heated Test)
- Box (empty) @ OAT
- 0.5 L of fluid
- Applied at 60 ºC
- Poured with the 12-hole spreader

Figure 2.3: Position on Stand – Outdoor Tests with Type II/III/IV Fluids

2.4 Data Forms

Two data forms were required for comparative heated fluid endurance time testing:
- Data form for documenting fluid endurance time; and
- Data form for documenting fluid thickness and Brix.

The data forms are provided in the procedure given in Appendix B.
2.5 Equipment

In order to conduct endurance time comparison testing, APS used various pieces of equipment. The key items employed are described below.

2.5.1 Test Surfaces

Baseline standard fluid endurance time testing, for both indoor and outdoor, was conducted using standard aluminum test plates. In the case of outdoor testing, the heated fluid was applied to an empty aluminum box insulated on all sides except the top, as per the Type I fluid application protocol. Testing conducted in 2000-01 to develop the Type I protocol had shown that the box provided a thermal equivalent to the wing leading edge.

2.5.2 Thermistor Probes

Each test plate had a thermistor probe installed at the 15 cm line, inset 1/3 of the width from the edge attached to the underside of the test surface. The box had two thermistors installed at the 15 cm line on the underside of the test surface. Surface temperature data collected was constantly monitored during the test event and was stored in a data logger.

2.5.3 Test Stand

The stand used for standard endurance time tests was used to position the test surfaces. The test plates were placed at a 10° inclination on the test stand and were oriented facing the oncoming wind.

2.5.4 Wet Film Thickness Gauge

Wet film fluid thickness measurements were recorded during endurance time tests. Figure 2.4 shows the schematic of the wet film thickness gauges. Photo 2.5 shows an APS employee conducting a fluid thickness measurement.
2. METHODOLOGY

2.5.5 Brixometer

Brix measurements provided data relevant to the fluid concentration; measuring Brix monitors fluid dilution. Photo 2.6 shows a handheld Brixometer. Photo 2.7 and Photo 2.8 show an APS employee obtaining a fluid sample from the test plate, and using the Brixometer to measure the fluid Brix.

2.5.6 Twelve Hole Fluid Spreader

For both the outdoor and indoor tests, Type II, Type III and Type IV fluids heated to 60°C were applied with the standard twelve-hole spreader (see Photo 2.9), which distributed the fluid evenly along the top of the test plate. The unheated Type II, Type III and Type IV fluids were applied at OAT by freely pouring (without the spreader) over the flat plate test surface (see Photo 2.10).

2.6 Fluids

This section provides information concerning the various fluids used in these tests. Type II, III and IV fluid endurance time testing was conducted using five fluid brands. Table 2.1 lists the fluids used for comparative endurance time testing in snow and freezing precipitation. The fluids were coded, as the interest of this project is to get a generic understanding of the effect of heat.
2. METHODOLOGY

Table 2.1: Fluids Used for Comparative Endurance Time Testing

<table>
<thead>
<tr>
<th>Fluid Brand</th>
<th>Fluid Type</th>
<th>Fluid Dilution</th>
<th>Commercial or Experimental Fluid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluid A</td>
<td>II</td>
<td>50%, 75%, 100%</td>
<td>Commercial</td>
</tr>
<tr>
<td>Fluid B</td>
<td>III</td>
<td>50%, 75%, 100%</td>
<td>Commercial</td>
</tr>
<tr>
<td>Fluid C</td>
<td>IV</td>
<td>75%, 100%</td>
<td>Experimental</td>
</tr>
<tr>
<td>Fluid D</td>
<td>IV</td>
<td>50%, 75%, 100%</td>
<td>Commercial</td>
</tr>
<tr>
<td>Fluid E</td>
<td>IV</td>
<td>100%</td>
<td>Commercial</td>
</tr>
</tbody>
</table>

2.7 Personnel

Three individuals were required to conduct these tests. The test manager measured endurance times. An assistant was required to prepare the fluids, assist with fluid application and collect fluid thickness and dilution measurements. A third person measured precipitation rates.
Photo 2.1: View of APS Test Site

Photo 2.2: Inside View of NRC Climate Engineering Facility
2. METHODOLOGY

Photo 2.3: Comparative Endurance Time Testing Setup – Outdoors

Photo 2.4: Comparative Endurance Time Testing Setup – Indoors
2. METHODOLOGY

Photo 2.5: Fluid Thickness Measurement Using Wet Film Thickness Gauge

Photo 2.6: Handheld Brixometer
2. METHODOLOGY

Photo 2.7: Obtaining Fluid Sample for Brix Measurement

Photo 2.8: Using Brixometer to Measure Fluid Brix
2. METHODOLOGY

Photo 2.9: Fluid Application Using Twelve Hole Spreader

Photo 2.10: Fluid Application by Pouring
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3. DESCRIPTION AND PROCESSING OF DATA

This section describes the data collected from the comparison tests conducted by APS under natural snow and simulated freezing precipitation conditions.

3.1 Log of Tests

During the winter of 2004-05, 19 comparison tests (38 individual tests) were conducted in snow conditions and 20 comparison tests (40 individual tests) were conducted under freezing precipitation conditions. These tests were carried out with five fluid brands and three fluid types. To facilitate the accessibility of the data collected, two logs were created for the series of tests, Table 3.1 lists the tests conducted at the NRC CEF and Table 3.2 lists the tests conducted at the Montreal-Trudeau test site. The logs provide relevant information for each test, as well as final values used for the data analysis. Each row contains data specific to one test. Test numbers are not sequential, as comparative tests using heated and non-heated fluids were conducted in conjunction with testing on non-aluminum surfaces; data that was not of concern to this report was removed from the data log. The following is a brief description of the column headings for the test logs:

- **Test No.**: Exclusive number identifying each test;
- **Date**: Date when the test was conducted;
- **Fluid Dilution**: Aircraft anti-icing fluid glycol concentration;
- **Fluid Name**: A unique code designating a fluid brand name;
- **Fluid Type**: Aircraft anti-icing fluid type;
- **Fluid Applic. Temp**: Aircraft anti-icing fluid application temperature;
- **Test Surface**: Surface used for testing: flat plate or box;
- **Fail Time**: Measured fluid endurance time;
- **Precipitation Rate**: Average precipitation rate (in g/dm²/h) collected by two precipitation pans at set intervals for the duration of the test session;
- **Average Test Temp**: (Table 3.1) The average ambient temperature of the CEF during the test;
- **Average OAT**: (Table 3.2) The average hourly outside ambient temperature (in degrees Celsius) provided by Environment Canada;
- **Average Wind Speed**: (Table 3.2) The average hourly wind speed, (in g/dm²/h), provided by Environment Canada; and
- **Chart**: Designates whether the data collected during the test was plotted and a chart was produced.
### Table 3.1: Simulated Freezing Precipitation Tests 2004-05

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Date</th>
<th>Fluid Dilution</th>
<th>Fluid Name</th>
<th>Fluid Type</th>
<th>Fluid Appl. Temp. (°C)</th>
<th>Test Surface</th>
<th>Fail Time (min.)</th>
<th>Precipitation Rate (g/dm²/h)</th>
<th>Avg. Test Temp. (°C)</th>
<th>Condition</th>
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<td></td>
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<td>Fluid C</td>
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ZD – Freezing Drizzle  
ZR – Freezing Rain
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3.2 Detailed Temperature Profiles

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

Figure 3.1 and Figure 3.2 present the detailed temperature, fluid dilution and fluid thickness profile charts constructed for a comparative natural snow endurance time test conducted using a Type IV fluid applied to a box and to a standard test plate, respectively.

Figure 3.1 and Figure 3.2 demonstrate the surface temperatures and freeze point mechanisms that influence fluid failure. The dilution of the fluid is indicated on the charts in negative Brix values “(-) Brix” as conversion charts of Brix values to fluid freeze point temperatures were not available for many of the fluids tested.

As seen on the charts, the surface temperature profile and the fluid dilution curve gradually approach an ultimate value, ambient temperature. The point where the two curves come closest is the expected endurance time. In other words, freezing is expected to occur when the fluid freeze point and the surface temperature match.

Similar charts were completed for each test conducted, and are included in Appendix C.

3.3 Distribution of 2004-05 Simulated Precipitation Conditions

During the 2004-05 season, 20 comparison tests (40 individual tests) were conducted under freezing precipitation conditions. These tests were carried out with four fluid brands and three fluid types, under freezing drizzle and freezing rain. For both conditions, tests were carried out at -3°C and -10°C under the low and high precipitation rate limits specific to each weather condition.

3.4 Distribution of 2004-05 Winter Weather

During the winter of 2004-05, comparative endurance time testing for aluminum test plates was conducted during 4 natural snow events. A total of 19 comparative tests were conducted; 38 individual tests were performed. A distribution of the manually measured precipitation rate and the recorded wind speed was tabulated for the entire data set. Figure 3.3 and Figure 3.4 present the results.
The distribution of manually measured precipitation rates showed that 47 percent of the tests were conducted during snow conditions with precipitation rates below 10 g/dm²/h. Very light and light snow conditions typically account for the majority of the deicing operations performed at the Montreal-Trudeau Airport. The distribution of recorded wind speeds showed that 68 percent of the tests were conducted during wind speeds greater than 27 km/h.

Figure 3.1: Type IV Fluid Endurance Time on Aluminum Box Surface

Figure 3.2: Type IV Fluid Endurance Time on Aluminum Test Plate Surface
3. DESCRIPTION AND PROCESSING OF DATA

**Figure 3.3: Distribution of Precipitation Rate – Natural Snow Tests 2004-05**

Total Number of Tests: 38  
Average Precipitation Rate: 12 g/dm²/h  
Min. = 3.5 g/dm²/h  
Max. = 37.3 g/dm²/h

**Figure 3.4: Distribution of Wind Speed – Natural Snow Tests 2004-05**

Total Number of Tests: 38  
Average Wind Speed: 28 km/h  
Min. = 17 km/h  
Max. = 37 km/h
4. ANALYSIS AND OBSERVATIONS

In this section, the data collected for each test is analysed and discussed. For each test, the fluid endurance time measured using heated fluid was compared to the fluid endurance time measured using standard application protocols.

4.1 General Observations

Comparative analysis of the recorded endurance times was performed both for tests conducted in simulated freezing precipitation and in natural snow. The results are charted in Figure 4.1 and Figure 4.2 respectively. Adjacent pairs of bars represent the endurance time (in minutes) measured with the hot and the cold fluids. Pertinent test information for each comparative test is labelled: fluid type, fluid dilution, rate of precipitation and temperature.

4.1.1 Freezing Precipitation

Forty comparative endurance time tests (20 pairs) were run in freezing precipitation conditions. Figure 4.1 demonstrates the results obtained. As seen on the graph, endurance time tests were run under eight distinct precipitation conditions:

1. Freezing Rain, Temperature -3°C, Precipitation Rate 13 g/dm²/h (ZR3L);
2. Freezing Rain, Temperature -3°C, Precipitation Rate 25 g/dm²/h (ZR3H);
3. Freezing Rain, Temperature -10°C, Precipitation Rate 13 g/dm²/h (ZR10L);
4. Freezing Rain, Temperature -10°C, Precipitation Rate 25 g/dm²/h (ZR10H);
5. Freezing Drizzle, Temperature -3°C, Precipitation Rate 5 g/dm²/h (ZD3L);
6. Freezing Drizzle, Temperature -3°C, Precipitation Rate 13 g/dm²/h (ZD3H);
7. Freezing Drizzle, Temperature -10°C, Precipitation Rate 5 g/dm²/h (ZD10L); and
8. Freezing Drizzle, Temperature -10°C, Precipitation Rate 13 g/dm²/h (ZD10H).
Figure 4.1: Failure Time Comparison – Freezing Precipitation
4. ANALYSIS AND OBSERVATIONS

**Procedure:**
- Box: 0.5 L, 60°C, Spreader
- Plate: 1L, OAT, Poured

**Figure 4.2: Failure Time Comparison – Natural Snow**

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<td>100%</td>
<td>75%</td>
<td>75%</td>
<td>100%</td>
<td>75%</td>
<td>100%</td>
<td>100%</td>
<td>75%</td>
<td>75%</td>
</tr>
<tr>
<td>27.2</td>
<td>5.7</td>
<td>13.3</td>
<td>7.5</td>
<td>30.9</td>
<td>37.3</td>
<td>9.7</td>
<td>13.4</td>
<td>5.2</td>
<td>10.1</td>
<td>13.0</td>
<td>7.3</td>
<td>3.8</td>
<td>11.9</td>
<td>5.6</td>
<td>4.4</td>
<td>4.3</td>
<td>7.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-12.2</td>
<td>-5.7</td>
<td>-6.3</td>
<td>-12.8</td>
<td>-11.3</td>
<td>-12.3</td>
<td>-5.1</td>
<td>-6.3</td>
<td>-12.2</td>
<td>-10.9</td>
<td>-5.9</td>
<td>-5.4</td>
<td>-13.5</td>
<td>-13.0</td>
<td>-14.3</td>
<td>-14.4</td>
<td>-9.6</td>
<td>-10.6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fluid Designation, Fluid Type, Dilution, Precipitation Rate (g/dm²/h), OAT (°C)
To correlate the test results from the heated-fluid test plate to the standard protocol test plate, the fluid endurance times were compared. The comparison is presented in Table 4.1.

Table 4.1 presents the results obtained for freezing precipitation tests. The percentage ratio between the endurance time of the heated test and that of the standard protocol test was calculated for each test; the average and standard deviation of the data set was also calculated.

On average, under simulated freezing precipitation conditions, the endurance times obtained with hot fluid were longer (by 24 percent) than those obtained using the standard application protocol. However, the standard deviation was high, at 53 percent.

As seen in Table 4.1, endurance testing conducted with Fluid A and Fluid B accounts for eighty percent of all tests.

<table>
<thead>
<tr>
<th>Fluid Code</th>
<th>Fluid Type</th>
<th>Endurance Time (Cold Fluid) min.</th>
<th>Endurance Time (Hot Fluid) min.</th>
<th>Endurance Time Ratio (Hot / Cold)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FLUID A</td>
<td>TYPE II</td>
<td>24.8</td>
<td>19.8</td>
<td>80%</td>
</tr>
<tr>
<td>FLUID A</td>
<td>TYPE II</td>
<td>26.3</td>
<td>21.6</td>
<td>82%</td>
</tr>
<tr>
<td>FLUID A</td>
<td>TYPE II</td>
<td>14.3</td>
<td>11.3</td>
<td>79%</td>
</tr>
<tr>
<td>FLUID A</td>
<td>TYPE II</td>
<td>14.2</td>
<td>16.3</td>
<td>115%</td>
</tr>
<tr>
<td>FLUID A</td>
<td>TYPE II</td>
<td>9.7</td>
<td>15.1</td>
<td>155%</td>
</tr>
<tr>
<td>FLUID A</td>
<td>TYPE II</td>
<td>11.8</td>
<td>16.8</td>
<td>142%</td>
</tr>
<tr>
<td>FLUID A</td>
<td>TYPE II</td>
<td>6.8</td>
<td>16.3</td>
<td>241%</td>
</tr>
<tr>
<td>FLUID B</td>
<td>TYPE III</td>
<td>21.1</td>
<td>15.8</td>
<td>75%</td>
</tr>
<tr>
<td>FLUID B</td>
<td>TYPE III</td>
<td>15.5</td>
<td>9.5</td>
<td>61%</td>
</tr>
<tr>
<td>FLUID B</td>
<td>TYPE III</td>
<td>10.5</td>
<td>13.8</td>
<td>132%</td>
</tr>
<tr>
<td>FLUID B</td>
<td>TYPE III</td>
<td>8.7</td>
<td>8.2</td>
<td>94%</td>
</tr>
<tr>
<td>FLUID B</td>
<td>TYPE III</td>
<td>10.8</td>
<td>9.0</td>
<td>84%</td>
</tr>
<tr>
<td>FLUID B</td>
<td>TYPE III</td>
<td>11.4</td>
<td>14.9</td>
<td>131%</td>
</tr>
<tr>
<td>FLUID B</td>
<td>TYPE III</td>
<td>8.8</td>
<td>16.6</td>
<td>189%</td>
</tr>
<tr>
<td>FLUID B</td>
<td>TYPE III</td>
<td>7.8</td>
<td>16.7</td>
<td>215%</td>
</tr>
<tr>
<td>FLUID B</td>
<td>TYPE III</td>
<td>9.1</td>
<td>16.1</td>
<td>177%</td>
</tr>
<tr>
<td>FLUID C</td>
<td>TYPE IV</td>
<td>14.5</td>
<td>10.5</td>
<td>72%</td>
</tr>
<tr>
<td>FLUID C</td>
<td>TYPE IV</td>
<td>32.5</td>
<td>22.0</td>
<td>68%</td>
</tr>
<tr>
<td>FLUID D</td>
<td>TYPE IV</td>
<td>29.3</td>
<td>32.0</td>
<td>109%</td>
</tr>
<tr>
<td>FLUID D</td>
<td>TYPE IV</td>
<td>9.2</td>
<td>16.2</td>
<td>176%</td>
</tr>
</tbody>
</table>

Average: 124%
Standard Deviation: 53%
A closer look at the data collected with Fluid A and Fluid B illustrates a very consistent pattern. Independent of the precipitation condition (drizzle or rain) and the precipitation rate (high or low), the ambient test temperature seems to play an important role in the results of the comparative test.

As a general observation, valid for all fluid types, fluids applied heated diluted faster than those applied at ambient temperature. A possible explanation of this effect is that, upon application, the hot fluid runs off the plate faster than the cold fluid, resulting in a thinner layer of fluid throughout the test. Under similar precipitation rates, the hot fluid will consequently dilute faster.

As mentioned above, the actual test temperature seems to control whether the hot fluid fails first. As can be found in the detailed charts presented in Appendix C, in the case of Fluid A and Fluid B, all tests conducted at a temperature of -10°C resulted in shorter endurance times for the fluids applied heated. Similarly, all tests conducted at -3°C yielded longer endurance times for the fluids applied heated. The explanation is that, even at constantly higher dilution rates compared to the cold fluid, heated fluids showed a longer endurance time at -3°C due to their heat capacity. In other words, the extended endurance time came as a result of the fluid temperature, which had to drop below 0°C in order for the fluid to fail. In the case of the -10°C test, the fluid temperature dropped much faster, and consequently the higher dilution rate of the heated fluid became prevalent and led to a shorter endurance time.

The failure mechanisms described above are not entirely supported by the comparative endurance time testing run with Fluid C and Fluid D. The temperature profiles for these two Type IV fluids do not clearly demonstrate this theory. In the case of Fluid C, the endurance time of the heated fluid was always shorter than that of the cold fluid. In the case of Fluid D, the endurance time of the heated fluid was always longer than that of the cold fluid. However, testing with these two fluids consisted of only 20 percent of all testing.

Additional data was available from tests conducted during the 2001-02 winter season. As presented in Section 5 of TC report, TP 13994E, *Generation of Holdover Times Using the New Type I Fluid Test Protocol* (1), a series of 24 comparative tests (12 pairs) were conducted using the same protocol applied in 2004-05. Tests were conducted with Type II and Type IV fluids at different dilutions. The tests showed that heat did not reduce endurance times. In some cases, a significant improvement was observed.
4.1.2 Natural Snow

Thirty-eight comparative endurance time tests (19 pairs) were run in conditions of natural snow. Figure 4.2 presents the results obtained.

To correlate the heated-fluid test plate to the standard protocol test plate, a comparison of the measured fluid endurance times was made to evaluate any existing relationship and is presented in Table 4.2.

The percentage ratio between the endurance time of the heated test and that of the standard protocol test was calculated for each test; the average and standard deviation of the data set was also calculated. Table 4.2 demonstrates the results obtained for natural snow.

<table>
<thead>
<tr>
<th>Fluid Code</th>
<th>Fluid Type</th>
<th>Endurance Time (Cold Fluid) min.</th>
<th>Endurance Time (Hot Fluid) min.</th>
<th>Endurance Time Ratio (Hot / Cold)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FLUID B</td>
<td>Type III</td>
<td>10.0</td>
<td>7.0</td>
<td>70%</td>
</tr>
<tr>
<td>FLUID B</td>
<td>Type III</td>
<td>36.0</td>
<td>36.8</td>
<td>102%</td>
</tr>
<tr>
<td>FLUID B</td>
<td>Type III</td>
<td>21.3</td>
<td>15.2</td>
<td>71%</td>
</tr>
<tr>
<td>FLUID B</td>
<td>Type III</td>
<td>31.1</td>
<td>30.0</td>
<td>96%</td>
</tr>
<tr>
<td>FLUID B</td>
<td>Type III</td>
<td>26.9</td>
<td>24.5</td>
<td>91%</td>
</tr>
<tr>
<td>FLUID B</td>
<td>Type III</td>
<td>8.0</td>
<td>5.0</td>
<td>63%</td>
</tr>
<tr>
<td>FLUID B</td>
<td>Type III</td>
<td>7.0</td>
<td>5.5</td>
<td>79%</td>
</tr>
<tr>
<td>FLUID B</td>
<td>Type III</td>
<td>17.8</td>
<td>18.8</td>
<td>106%</td>
</tr>
<tr>
<td>FLUID B</td>
<td>Type III</td>
<td>16.0</td>
<td>12.0</td>
<td>75%</td>
</tr>
<tr>
<td>FLUID B</td>
<td>Type III</td>
<td>23.2</td>
<td>20.7</td>
<td>89%</td>
</tr>
<tr>
<td>FLUID B</td>
<td>Type III</td>
<td>17.6</td>
<td>15.9</td>
<td>90%</td>
</tr>
<tr>
<td>FLUID C</td>
<td>Type IV</td>
<td>67.0</td>
<td>62.3</td>
<td>93%</td>
</tr>
<tr>
<td>FLUID C</td>
<td>Type IV</td>
<td>57.0</td>
<td>87.0</td>
<td>153%</td>
</tr>
<tr>
<td>FLUID C</td>
<td>Type IV</td>
<td>39.3</td>
<td>46.2</td>
<td>118%</td>
</tr>
<tr>
<td>FLUID C</td>
<td>Type IV</td>
<td>18.2</td>
<td>20.3</td>
<td>112%</td>
</tr>
<tr>
<td>FLUID D</td>
<td>Type IV</td>
<td>58.3</td>
<td>100.3</td>
<td>172%</td>
</tr>
<tr>
<td>FLUID D</td>
<td>Type IV</td>
<td>30.5</td>
<td>43.7</td>
<td>143%</td>
</tr>
<tr>
<td>FLUID E</td>
<td>Type IV</td>
<td>152.3</td>
<td>173.5</td>
<td>114%</td>
</tr>
<tr>
<td>FLUID E</td>
<td>Type IV</td>
<td>111.2</td>
<td>162.0</td>
<td>146%</td>
</tr>
</tbody>
</table>

Average: 104%
Standard Deviation: 31%
On average, under natural snow conditions, the endurance times obtained with hot fluid were slightly longer (by 4 percent) when compared with those obtained using the standard application protocol. However, the standard deviation was fairly high, at 31 percent. A closer look at the data also shows that the hot/cold ratio has an average of 85 percent for Type III fluid and an average of 131 percent for Type IV fluid. This indicated that, on average, heating the fluid prior to application resulted in shorter endurance times in the case of less viscous fluids, namely Type III fluids. By the same token, heat seems to have a beneficial effect on the endurance time of Type IV fluids, extending their endurance time by roughly, 31 percent. Moreover, there also seems to be a difference between the various Type IV fluid types tested, illustrating that perhaps the effect of heat is fluid dependent.

A more in-depth look at the detailed charts presented in Appendix C shows that for Type III fluid, heat, in most cases, leads to a reduced fluid layer thickness, and consequently, to an accelerated rate of fluid dilution (see tests No. 48, 50 in Appendix C). As a result, heat produced a diminished fluid endurance time. In most cases, at the time of fluid failure, both surfaces (heated and cold) are at the same temperature, indicating that the heat from the hot fluid does not seem to produce a long-lasting effect on the test surface.

In the case of Type IV fluids, the extended endurance times recorded when hot fluid is applied do not seem to be caused by an elevated surface temperature, at the time of fluid failure both surfaces (heated and cold) being at the same temperature. However, heat may have an influence on the fluid dilution rate. Both surfaces fail at similar glycol concentration values. As observed during these tests, the heated fluid typically dilutes at a slower rate than the cold fluid, generating a longer endurance. Also, heat leads to an increase in fluid thickness, an effect that is present throughout the duration of the experiment time (see tests No. 28, 30 in Appendix C).

These findings match the results from similar tests conducted during the 2001-02 winter season. As presented in Section 5 of TC report, TP 13994E, *Generation of Holdover Times Using the New Type I Fluid Test Protocol* (1), a series of 18 comparative tests (9 pairs) were conducted using a protocol fairly similar to that applied in 2004-05. Tests were conducted with Type IV fluids and two dilutions of Type II fluids. The hot/cold endurance time ratios recorded in 2001-02 decreased as the fluid dilution increased.

However, due to the limited number of tests conducted so far, there is not sufficient data to enable a solid conclusion on the effect of heat on different fluid types and even fluid brands. It is recommended that the failure mechanisms be further evaluated and analysed by conducting a new series of comparative tests using different fluid types and dilutions at various temperatures and precipitation rates.
Moreover, the application protocol used in 2004-05 was initially developed for Type I fluids. The protocol was empirically developed, by comparing temperature profiles from aircraft wings to those of various test surfaces. However, for these comparative tests, an assumption was made that the correspondence between the aircraft wing profile and the profile of the test surface remains valid when Type IV is used. This assumption will have to be substantiated by conducting a series of comparative tests on the Jetstar wing. These tests should be conducted before further Type IV hot vs. cold tests are run.

4.1.3 Summary of Results

In conclusion, by putting all of the information together, there seems to be a variation between the various fluid types tested, indicating that perhaps the effect of heat is fluid dependent.

However, due to the limited number of tests conducted, there is not sufficient data to enable a solid conclusion on the effect of heat on different fluid types and even fluid brands. It is recommended that the failure mechanisms be further evaluated and analysed by conducting a new series of comparative tests using different fluid types and dilutions under various precipitation conditions.
5. CONCLUSIONS

The conclusions drawn from the tests performed during the winter of 2004-05 are described in this section.

5.1 Endurance Time Testing During Simulated Freezing Precipitation

The comparative tests conducted during simulated freezing precipitation conditions indicated that:

- Fluids applied heated diluted faster than those applied at ambient temperature;
- Data collected with two fluids illustrated a very consistent pattern. Independent of the precipitation condition (drizzle or rain) and the precipitation rate (high or low), the test temperature played an important role in the result of the comparative test. At $-10^\circ$C, heat reduced the endurance time of the fluid, whereas at $-3^\circ$C, it extended the fluid endurance time. The extended endurance time came as a result of the fluid temperature, which had to drop below $0^\circ$C in order for the fluid to fail. In the case of the $-10^\circ$C test, the fluid temperature dropped at subzero temperatures much faster, and consequently the higher dilution rate of the heated fluid became prevalent and led to a shorter endurance time;
- The failure mechanisms described above were not entirely supported by the comparative endurance time testing run with two other fluids. Also, additional data from tests conducted during the 2001-02 winter season showed that the effect of heat did not reduce endurance times. In some cases, a significant improvement was observed; and
- In conclusion, there seems to be a variation among the various fluid types tested, suggesting that perhaps the effect of heat is fluid dependent.

5.2 Endurance Time Testing During Natural Snow

The comparative tests conducted during natural snow conditions indicated that:

- On average, the hot/cold ratio was 85 percent for Type III fluid and 131 percent for Type IV fluid. This indicated that, on average, heating the fluid prior to application resulted in shorter endurance times in the case of less viscous fluids, namely Type III fluids. Also, the effect of heat seems to increase the endurance time of Type IV fluids. These findings match the results from similar tests conducted during the 2001-02 winter season; and
- There also seems to be a difference between the various Type IV fluid types tested, suggesting that perhaps the effect of heat is fluid dependent.
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6. RECOMMENDATIONS

Due to the limited number of tests conducted under both snow and freezing precipitation conditions, and the slightly contradictory results compared with 2001-02 testing, currently there is insufficient data to enable a solid conclusion on the effect of heat on different fluid types and even fluid brands. Therefore, it is recommended that the failure mechanisms be further evaluated and analysed by conducting a new series of comparative tests using different fluid types and dilutions at various temperatures and precipitation rates.

Furthermore, for snow conditions, the application protocol used in 2004-05 was initially developed for Type I fluids. The protocol was empirically developed, by comparing temperature profiles from aircraft wings to those of various test surfaces. However, for these comparative tests, an assumption was made that the correspondence between the aircraft wing profile and the profile of the test surface remains valid when Type IV is used. This assumption will have to be substantiated by conducting a series of comparative tests on the Jetstar wing. These tests should be conducted before further Type IV hot vs. cold tests are run under snow conditions.
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REFERENCES

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APPENDIX A

TRANSPORTATION DEVELOPMENT CENTRE
WORK STATEMENT EXCERPT –
AIRCRAFT & ANTI-ICING FLUID
WINTER TESTING 2003-05
6.19 Effect of Heat on Neat/Diluted Type II/IV Endurance Times

a) Review previous preliminary research that was completed on selected diluted Type II/IV fluids;
b) Design a test protocol with the cooperation of the FAA and TC;
c) Develop a test procedure for testing both outdoors and indoors;
d) Analyse data and results;
e) Prepare a report; and
f) Prepare presentation material.
APPENDIX B

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

EFFECT OF HEAT ON ENDURANCE TIME OF ANTI-ICING FLUIDS

(Subproject: Endurance Time of Non-Aluminum Plates)

Winter 2004-05

Prepared for

Transportation Development Centre
Transport Canada

Prepared by: John D’Avirro/Nicoara Moc

Reviewed by: John D’Avirro

December 23, 2004
Version 1.0
EXPERIMENTAL PROGRAM: EFFECT OF HEAT ON ENDURANCE TIME OF ANTI-ICING FLUIDS

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

Winter 2004-05

1. BACKGROUND

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

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

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

Further investigation was recommended.

2. OBJECTIVE

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

The following are the detailed objectives:

- Effect of heat on Neat and Diluted Type II and Type IV fluid endurance times.

- Effect of heat on Type III fluid (Neat and Diluted) endurance times: currently some operators are considering the use of Type III fluid in the same manner as Type I fluid.
EXPERIMENTAL PROGRAM: EFFECT OF HEAT ON ENDURANCE TIME OF ANTI-ICING FLUIDS

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

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

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

3. PROCEDURE

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

3.1 Outdoor Tests with Type II/III/IV Fluids

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

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

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

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

---

![Diagram](image-url)  

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

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M:\Projects\PM1892 (TC Deicing 04-05)\Reports\Hot vs. Cold\Final Version 1.0\Report Components\Appendices\Appendices.docx  
Version 1.0, December 2004

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3.2 Indoor Tests Type II/III/IV Fluids

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

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

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

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

![Figure 2: Position on Stand – Indoor Tests with Type II/III/IV Fluids](image)

3.3 Outdoor Tests with Type I Fluid

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

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

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

The summary of these application methods is shown in Figure 3.
3.4 Indoor Tests with Type I Fluid

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

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

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

4. FLUIDS

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

- Type III Clariant 2031
- Type I Clariant 1938 PG
- Type IV Dow Ultra +
- Type I Dow EG ADF
- Type IV Kilfrost ABC-S
EXPERIMENTAL PROGRAM: EFFECT OF HEAT ON ENDURANCE TIME OF ANTI-ICE FLUIDS

5. EQUIPMENT

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

6. PERSONNEL

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

7. DATA FORM

The standard endurance time test data forms will be used. To measure fluid Brix and thickness on selected tests, use Table 4.
**TABLE 1: MATRIX OF OUTDOOR TESTS**

<table>
<thead>
<tr>
<th>Test #</th>
<th>Fluid Type</th>
<th>Field Site*</th>
<th>Dilution</th>
<th>Precy. Type</th>
<th>Test Type</th>
<th>Precy. Rand. Rates (g/day)</th>
<th>STD Test</th>
<th>Hazardous Fluids</th>
<th>Non-Aluminum**</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cold</td>
<td>Clarion 2003</td>
<td>75</td>
<td>Any</td>
<td>Outdoor Snow</td>
<td>0.0014</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td><strong>S3 tests were conducted with Type II metal indium, as opposed to Type III, which would be more expensive for temporary work on unpaved roads.</strong></td>
</tr>
<tr>
<td>2</td>
<td>Cold</td>
<td>Clarion 2003</td>
<td>100</td>
<td>Any</td>
<td>Outdoor Snow</td>
<td>0.0007</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Cold</td>
<td>Clarion 2003</td>
<td>100</td>
<td>Any</td>
<td>Outdoor Snow</td>
<td>0.0007</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Cold</td>
<td>Clarion 2003</td>
<td>100</td>
<td>Any</td>
<td>Outdoor Snow</td>
<td>0.0007</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Cold</td>
<td>Clarion 2003</td>
<td>75</td>
<td>Any</td>
<td>Outdoor Snow</td>
<td>0.0007</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Cold</td>
<td>Clarion 2003</td>
<td>75</td>
<td>Any</td>
<td>Outdoor Snow</td>
<td>0.0007</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Cold</td>
<td>Clarion 2003</td>
<td>75</td>
<td>Any</td>
<td>Outdoor Snow</td>
<td>0.0007</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Cold</td>
<td>Clarion 2003</td>
<td>75</td>
<td>Any</td>
<td>Outdoor Snow</td>
<td>0.0007</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Cold</td>
<td>Clarion 2003</td>
<td>75</td>
<td>Any</td>
<td>Outdoor Snow</td>
<td>0.0007</td>
<td>1</td>
<td>1</td>
<td>1</td>
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</tr>
<tr>
<td>10</td>
<td>Cold</td>
<td>Clarion 2003</td>
<td>75</td>
<td>Any</td>
<td>Outdoor Snow</td>
<td>0.0007</td>
<td>1</td>
<td>1</td>
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<tr>
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<td>Cold</td>
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<td>Any</td>
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<td>Cold</td>
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<td>75</td>
<td>Any</td>
<td>Outdoor Snow</td>
<td>0.0007</td>
<td>1</td>
<td>1</td>
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</tr>
<tr>
<td>13</td>
<td>Cold</td>
<td>Clarion 2003</td>
<td>75</td>
<td>Any</td>
<td>Outdoor Snow</td>
<td>0.0007</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

*Note that if a new product A, B, C or D is a Type II, then this could be used for testing for one of these sets of tests.

**Note that tests that do not have non-aluminum plates are lower priority.
## Experimental Program: Effect of Heat on Endurance Time of Anti-Ice Fluids

### Table 2: Matrix of Indoor Tests

<table>
<thead>
<tr>
<th>Test #</th>
<th>Fluid Type</th>
<th>Fluid Brand</th>
<th>Dilution</th>
<th>Property Type</th>
<th>Test Temp.</th>
<th>Property Rate [mg/m²]</th>
<th>STD Test</th>
<th>Non-Aluminum**</th>
<th>Heated Plate [Method]</th>
<th>Comments</th>
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<tbody>
<tr>
<td>101</td>
<td>III</td>
<td>Citation 2001</td>
<td>100</td>
<td>Z0</td>
<td>3</td>
<td>TDQ</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>TDQ after outdoor test</td>
</tr>
<tr>
<td>102</td>
<td>III</td>
<td>Citation 2001</td>
<td>75</td>
<td>Z0</td>
<td>3</td>
<td>TDQ</td>
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<td>1</td>
<td>TDQ after outdoor test</td>
</tr>
<tr>
<td>103</td>
<td>III</td>
<td>Citation 2001</td>
<td>50</td>
<td>Z0</td>
<td>3</td>
<td>TDQ</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>TDQ after outdoor test</td>
</tr>
<tr>
<td>104</td>
<td>III</td>
<td>Citation 2001</td>
<td>100</td>
<td>Z0</td>
<td>3</td>
<td>TDQ</td>
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<td>1</td>
<td>1</td>
<td>TDQ after outdoor test</td>
</tr>
<tr>
<td>105</td>
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<td>75</td>
<td>Z0</td>
<td>3</td>
<td>TDQ</td>
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<td>1</td>
<td>1</td>
<td>TDQ after outdoor test</td>
</tr>
<tr>
<td>106</td>
<td>III</td>
<td>Citation 2001</td>
<td>50</td>
<td>Z0</td>
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<td>TDQ</td>
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<td>1</td>
<td>1</td>
<td>TDQ after outdoor test</td>
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<tr>
<td>107</td>
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<td>Citation 2001</td>
<td>100</td>
<td>Z0</td>
<td>10</td>
<td>TDQ</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>TDQ after outdoor test</td>
</tr>
<tr>
<td>108</td>
<td>III</td>
<td>Citation 2001</td>
<td>75</td>
<td>Z0</td>
<td>10</td>
<td>TDQ</td>
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<td>1</td>
<td>1</td>
<td>TDQ after outdoor test</td>
</tr>
<tr>
<td>109</td>
<td>III</td>
<td>Citation 2001</td>
<td>50</td>
<td>Z0</td>
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<td>TDQ</td>
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</tr>
<tr>
<td>111</td>
<td>III</td>
<td>Citation 2001</td>
<td>75</td>
<td>Z0</td>
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<td>TDQ</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>TDQ after outdoor test</td>
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<tr>
<td>112</td>
<td>III</td>
<td>Citation 2001</td>
<td>50</td>
<td>Z0</td>
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<td>TDQ</td>
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<td>1</td>
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<td>TDQ after outdoor test</td>
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<tr>
<td>113</td>
<td>III</td>
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<td>TDQ after outdoor test</td>
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<tr>
<td>114</td>
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<td>75</td>
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<td>TDQ after outdoor test</td>
</tr>
<tr>
<td>115</td>
<td>III</td>
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<td>50</td>
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<td>10</td>
<td>TDQ</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>TDQ after outdoor test</td>
</tr>
</tbody>
</table>

*Note that if a row product A, B, C or D is a Type III, then this could be used for testing for one of these sorts of tests.

**Some of tests that do not have non-aluminum plates are lower priority.
## APPENDIX B

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

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

<table>
<thead>
<tr>
<th>Fluid</th>
<th>Dilution</th>
<th>Quantity Needed</th>
<th>Batch No. (Location)</th>
<th>Comments/Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clariant 2031</td>
<td>100</td>
<td>15 L</td>
<td>TV390 (25)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>75</td>
<td>20 L</td>
<td>TV390 (23)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>10 L</td>
<td>TV390 (24)</td>
<td></td>
</tr>
<tr>
<td>Ultra+</td>
<td>100</td>
<td>20 L</td>
<td>Q113555D2(23)</td>
<td>Barrel</td>
</tr>
<tr>
<td>Clariant 1938</td>
<td>9 L</td>
<td>TV363 (34)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type I</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UCAR EG</td>
<td>9 L</td>
<td>TV363 (34)</td>
<td></td>
<td>Need to locate</td>
</tr>
<tr>
<td>Type I</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ABC-S</td>
<td>100</td>
<td>9 L</td>
<td>13402 (30)</td>
<td>Shed</td>
</tr>
<tr>
<td></td>
<td>75</td>
<td>6 L</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>6 L</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
# TABLE 4: FLUID BRIX/THICKNESS DATA FORM

<table>
<thead>
<tr>
<th>Plate / BOX: Fluid</th>
<th>Plate / BOX: Fluid</th>
<th>Plate / BOX: Fluid</th>
</tr>
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<tbody>
<tr>
<td></td>
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</tr>
<tr>
<td>TIME</td>
<td>Brix at 15 cm Line</td>
<td>TIME</td>
</tr>
<tr>
<td></td>
<td>Thick at 15 cm Line</td>
<td></td>
</tr>
</tbody>
</table>

**EXPERIMENTAL PROGRAM: EFFECT OF HEAT ON ENDURANCE TIME OF ANTI-ICING FLUIDS**
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APPENDIX C

DETAILED CHARTS OF ENDURANCE TIME COMPARISON TESTS
Surface Temperature, Fluid Dilution and Thickness Profiles
FLUID B (Neat) on Aluminum Plate
February 10, 2005, Test No. 11, Natural Snow

Average Precipitation Rate: 5.6 g/dm²/h
Average OAT: -5.7 ºC

Fluid Failure Time: 36.0 min.

Average Precipitation Rate: 5.7 g/dm²/h
Average OAT: -5.7 ºC

Fluid Failure Time: 36.8 min.
Surface Temperature, Fluid Dilution and Thickness Profiles
FLUID B ECO (75%) on Aluminum Plate
February 10, 2005, Test No. 14, Natural Snow

Average Precipitation Rate: 9.6 g/dm²/h  
Average OAT: -5.1 ºC

Fluid Failure Time: 17.8 min.

Surface Temperature, Fluid Dilution and Thickness Profiles
FLUID B (75%) on Box
February 10, 2005, Test No. 15, Natural Snow

Average Precipitation Rate: 9.7 g/dm²/h  
Average OAT: -5.1 ºC

Fluid Failure Time: 18.8 min.
Surface Temperature, Fluid Dilution and Thickness Profiles
FLUID C (75%) on Aluminum Plate
February 10, 2005, Test No. 18, Natural Snow

- Fluid Failure Time: 87.0 min.

Average Precipitation Rate: 7.3 g/dm²/h
Average OAT: -5.4 ºC

Surface Temperature, Fluid Dilution and Thickness Profiles
FLUID C (75%) on Box
February 10, 2005, Test No. 17, Natural Snow

- Fluid Failure Time: 57.0 min.

Average Precipitation Rate: 8.8 g/dm²/h
Average OAT: -5.4 ºC
Surface Temperature, Fluid Dilution and Thickness Profiles
FLUID D (75%) on Box
February 21, 2005, Test No. 19, Natural Snow

Average Precipitation Rate: 4.4 g/dm²/h
Average OAT: -14.4 ºC

Fluid Failure Time: 43.7 min.

Surface Temperature, Fluid Dilution and Thickness Profiles
FLUID D (75%) on Aluminum Plate
February 21, 2005, Test No. 21, Natural Snow

Average Precipitation Rate: 4.1 g/dm²/h
Average OAT: -14.4 ºC

Fluid Failure Time: 30.5 min.
Surface Temperature, Fluid Dilution and Thickness Profiles
FLUID D (Neat) on Box
February 21, 2005, Test No. 22, Natural Snow

Average Precipitation Rate: 5.8 g/dm²/h
Average OAT: -14.3 ºC

Fluid Failure Time: 100.3 min.

Surface Temperature, Fluid Dilution and Thickness Profiles
FLUID D (Neat) on Aluminum Plate
February 21, 2005, Test No. 24, Natural Snow

Average Precipitation Rate: 6.0 g/dm²/h
Average OAT: -14.3 ºC

Fluid Failure Time: 58.3 min.
Surface Temperature, Fluid Dilution and Thickness Profiles
FLUID C (75%) on Box
February 21, 2005, Test No. 25, Natural Snow

Average Precipitation Rate: 3.8 g/dm²/h
Average OAT: -13.5 °C

Fluid Failure Time: 46.2 min.

Average Precipitation Rate: 3.9 g/dm²/h
Average OAT: -13.5 °C

Fluid Failure Time: 39.3 min.
Surface Temperature, Fluid Dilution and Thickness Profiles
FLUID E (Neat) on Box
February 21, 2005, Test No. 28, Natural Snow

Average Precipitation Rate: 4.3 g/dm²/h
Average OAT: -9.3 ºC

Fluid Failure Time: 173.5 min.

Surface Temperature, Fluid Dilution and Thickness Profiles
FLUID E (Neat) on Aluminum Plate
February 21, 2005, Test No. 30, Natural Snow

Average Precipitation Rate: 3.5 g/dm²/h
Average OAT: -9.9 ºC

Fluid Failure Time: 152.3 min.
Surface Temperature, Fluid Dilution and Thickness Profiles
FLUID B (75%) on Box
February 21, 2005, Test No. 31, Natural Snow

Average Precipitation Rate: 13.4 g/dm²/h
Average OAT: -6.3 ºC

Fluid Failure Time: 12.0 min.

Surface Temperature, Fluid Dilution and Thickness Profiles
FLUID B (75%) on Aluminum Plate
February 21, 2005, Test No. 33, Natural Snow

Average Precipitation Rate: 13.8 g/dm²/h
Average OAT: -6.3 ºC

Fluid Failure Time: 16.0 min.
Surface Temperature, Fluid Dilution and Thickness Profiles
FLUID B (Neat) on Box
February 21, 2005, Test No. 34, Natural Snow

Average Precipitation Rate: 13.3 g/dm²/h
Average OAT: -6.3 ºC

Fluid Failure Time: 15.2 min.

Surface Temperature, Fluid Dilution and Thickness Profiles
FLUID B (Neat) on Aluminum Plate
February 21, 2005, Test No. 36, Natural Snow

Average Precipitation Rate: 14.0 g/dm²/h
Average OAT: -6.2 ºC

Fluid Failure Time: 21.3 min.
Surface Temperature, Fluid Dilution and Thickness Profiles
FLUID C (Neat) on Aluminum Plate
February 21, 2005, Test No. 39, Natural Snow

Average Precipitation Rate: 12.6 g/dm²/h
Average OAT: -5.9 ºC
Fluid Failure Time: 67.0 min.

Average Precipitation Rate: 13.0 g/dm²/h
Average OAT: -5.9 ºC
Fluid Failure Time: 62.3 min.
Surface Temperature, Fluid Dilution and Thickness Profiles
FLUID C (75%) on Box
March 7, 2005, Test No. 42, Natural Snow

Temp. Profile
(-) Brix
Fluid Thickness

Average Precipitation Rate: 11.9 g/dm²/h
Average OAT: -13.0 ºC

Fluid Failure Time:
20.3 min.

Surface Temperature, Fluid Dilution and Thickness Profiles
FLUID C (75%) on Aluminum Plate
March 7, 2005, Test No. 44, Natural Snow

Temp. Profile
(-) Brix
Fluid Thickness

Average Precipitation Rate: 11.9 g/dm²/h
Average OAT: -13.0 ºC

Fluid Failure Time:
18.2 min.
C-12
Surface Temperature, Fluid Dilution and Thickness Profiles

FLUID B (75%) on Box
March 7, 2005, Test No. 48, Natural Snow

- Average Precipitation Rate: 5.2 g/dm²/h
- Average OAT: -12.2 ºC

Fluid Failure Time: 20.7 min.

Surface Temperature, Fluid Dilution and Thickness Profiles

FLUID B (75%) on Aluminum Plate
March 7, 2005, Test No. 50, Natural Snow

- Average Precipitation Rate: 4.5 g/dm²/h
- Average OAT: -12.2 ºC

Fluid Failure Time: 23.2 min.
Surface Temperature, Fluid Dilution and Thickness Profiles
FLUID E (100%) on Box
March 7, 2005, Test No. 51, Natural Snow

Average Precipitation Rate: 7.2 g/dm²/h
Average OAT: -10.6 ºC

Fluid Failure Time: 162.0 min.

Surface Temperature, Fluid Dilution and Thickness Profiles
FLUID E (100%) on Aluminum Plate
March 7, 2005, Test No. 53, Natural Snow

Average Precipitation Rate: 4.6 g/dm²/h
Average OAT: -10.5 ºC

Fluid Failure Time: 111.2 min.
Surface Temperature, Fluid Dilution and Thickness Profiles
FLUID B (100%) on Box
March 7, 2005, Test No. 54, Natural Snow

Average Precipitation Rate: 11.1 g/dm²/h
Average OAT: -11.3 ºC

Fluid Failure Time: 24.5 min.

Surface Temperature, Fluid Dilution and Thickness Profiles
FLUID B (100%) on Aluminum Plate
March 7, 2005, Test No. 56, Natural Snow

Average Precipitation Rate: 11.0 g/dm²/h
Average OAT: -11.3 ºC

Fluid Failure Time: 26.9 min.
Surface Temperature, Fluid Dilution and Thickness Profiles
FLUID B (75%) on Box
March 7, 2005, Test No. 57, Natural Snow

Temperature (°C) / (-) Brix

Fluid Failure Time: 15.9 min.

Temperature (°C) / (-) Brix

Average Precipitation Rate: 10.1 g/dm²/h
Average OAT: -10.9 °C

Fluid Failure Time: 17.6 min.

Average Precipitation Rate: 9.4 g/dm²/h
Average OAT: -10.9 °C

Fluid Failure Time: 15.9 min.

Fluid Failure Time: 17.6 min.
Surface Temperature, Fluid Dilution and Thickness Profiles
FLUID B (Neat) on Aluminum Plate
April 5, 2005, Test No. 1, Freezing Drizzle

- Fluid Failure Time: 21.1 min.

Surface Temperature, Fluid Dilution and Thickness Profiles
FLUID B (Neat) on Heated Aluminum Plate
April 5, 2005, Test No. 2, Freezing Drizzle

- Fluid Failure Time: 15.8 min.
Surface Temperature, Fluid Dilution and Thickness Profiles

FLUID C (75%) on Aluminum Plate

April 5, 2005, Test No. 3, Freezing Drizzle

-40
-30
-20
-10
0
10
20
30
40

-5 15 35 55 75 95 115 135 155 175 195

Fluid Failure Time: 14.5 min.

Average Precipitation Rate: 5.3 g/dm²/h
Average OAT: -10.0 ºC

Surface Temperature, Fluid Dilution and Thickness Profiles

FLUID C on Heated Aluminum Plate

April 5, 2005, Test No. 4, Freezing Drizzle

-40
-30
-20
-10
0
10
20
30
40

-5 15 35 55 75 95 115 135 155 175 195

Fluid Failure Time: 10.5 min.

Average Precipitation Rate: 5.3 g/dm²/h
Average OAT: -9.9 ºC
Surface Temperature, Fluid Dilution and Thickness Profiles
FLUID A (75%) on Aluminum Plate
April 5, 2005, Test No. 6, Freezing Drizzle

Average Precipitation Rate: 13.2 g/dm²/h
Average OAT: -10.5 ºC

Fluid Failure Time:
26.3 min.

Surface Temperature, Fluid Dilution and Thickness Profiles
FLUID A (75%) on Heated Aluminum Plate
April 5, 2005, Test No. 7, Freezing Drizzle

Average Precipitation Rate: 13.2 g/dm²/h
Average OAT: -10.4 ºC

Fluid Failure Time:
21.6 min.
Surface Temperature, Fluid Dilution and Thickness Profiles

FLUID B (75%) on Aluminum Plate
April 5, 2005, Test No. 8, Freezing Drizzle

Average Precipitation Rate: 13.2 g/dm²/h
Average OAT: -10.5 ºC

Fluid Failure Time: 8.7 min.

Surface Temperature, Fluid Dilution and Thickness Profiles

FLUID B (75%) on Heated Aluminum Plate
April 5, 2005, Test No. 9, Freezing Drizzle

Average Precipitation Rate: 13.2 g/dm²/h
Average OAT: -10.5 ºC

Fluid Failure Time: 8.2 min.
Surface Temperature, Fluid Dilution and Thickness Profiles

FLUID D (Neat) on Aluminum Plate
April 5, 2005, Test No. 10, Freezing Drizzle

Average Precipitation Rate: 13.2 g/dm²/h
Average OAT: -10.3 ºC

Fluid Failure Time:
29.3 min.

Surface Temperature, Fluid Dilution and Thickness Profiles

FLUID D (Neat) on Heated Aluminum Plate
April 5, 2005, Test No. 11, Freezing Drizzle

Average Precipitation Rate: 13.2 g/dm²/h
Average OAT: -10.3 ºC

Fluid Failure Time:
32.0 min.
Surface Temperature, Fluid Dilution and Thickness Profiles
FLUID A (Neat) on Aluminum Plate
April 5, 2005, Test No. 13, Freezing Rain

-40 -30 -20 -10 0 10 20 30 40
-40 -30 -20 -10 0 10 20 30 40

Temperature (°C) / (-) Brix

Thickness (mm)

Temp. Profile
(-) Brix
Fluid Thickness

Average Precipitation Rate: 25.2 g/dm²/h
Average OAT: -9.9 °C

Fluid Failure Time:
24.8 min.

Average Precipitation Rate: 25.2 g/dm²/h
Average OAT: -9.8 °C

Fluid Failure Time:
19.8 min.
Surface Temperature, Fluid Dilution and Thickness Profiles

FLUID A (75%) on Aluminum Plate
April 5, 2005, Test No. 15, Freezing Rain

- Average Precipitation Rate: 25.2 g/dm²/h
- Average OAT: -10.1 ºC

Fluid Failure Time: 14.3 min.

Average Precipitation Rate: 25.2 g/dm²/h
Average OAT: -10.1 ºC

Fluid Failure Time: 11.3 min.
Surface Temperature, Fluid Dilution and Thickness Profiles

FLUID B (Neat) on Aluminum Plate
April 6, 2005, Test No. 19, Freezing Rain

-40 -30 -20 -10 0 10 20 30 40
0 1 2 3

Fluid Failure Time: 15.5 min.

Average Precipitation Rate: 13.4 g/dm²/h
Average OAT: -10.9 ºC

Surface Temperature, Fluid Dilution and Thickness Profiles

FLUID B (Neat) on Heated Aluminum Plate
April 6, 2005, Test No. 20, Freezing Rain

-40 -30 -20 -10 0 10 20 30 40
0 1 2 3

Fluid Failure Time: 9.5 min.

Average Precipitation Rate: 13.4 g/dm²/h
Average OAT: -10.8 ºC
Surface Temperature, Fluid Dilution and Thickness Profiles
FLUID B (75%) on Aluminum Plate
April 6, 2005, Test No. 23, Freezing Rain

<table>
<thead>
<tr>
<th>Time (minutes)</th>
<th>Temperature (ºC)</th>
<th>(-) Brix</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>15</td>
<td>-5</td>
<td>0.5</td>
</tr>
<tr>
<td>30</td>
<td>-10</td>
<td>1</td>
</tr>
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</table>

Average Precipitation Rate: 13.4 g/dm²/h
Average OAT: -10.5 ºC

Fluid Failure Time: 10.8 min.

Average Precipitation Rate: 13.4 g/dm²/h
Average OAT: -10.5 ºC

Fluid Failure Time: 9.0 min.

Surface Temperature, Fluid Dilution and Thickness Profiles
FLUID B (75%) on Heated Aluminum Plate
April 6, 2005, Test No. 24, Freezing Rain

<table>
<thead>
<tr>
<th>Time (minutes)</th>
<th>Temperature (ºC)</th>
<th>(-) Brix</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>15</td>
<td>-5</td>
<td>0.5</td>
</tr>
<tr>
<td>30</td>
<td>-10</td>
<td>1</td>
</tr>
</tbody>
</table>

Average Precipitation Rate: 13.4 g/dm²/h
Average OAT: -10.5 ºC

Fluid Failure Time: 10.8 min.
Surface Temperature, Fluid Dilution and Thickness Profiles
FLUID B (75%) on Aluminum Plate
April 6, 2005, Test No. 26, Freezing Rain

Average Precipitation Rate: 13.3 g/dm²/h
Average OAT: -3.2 ºC

Fluid Failure Time:
11.4 min.

Temp. Profile
(-) Brix
Fluid Thickness

Temperature (ºC) / (-) Brix
Thickness (mm)

Surface Temperature, Fluid Dilution and Thickness Profiles
FLUID B (75%) on Heated Aluminum Plate
April 6, 2005, Test No. 27, Freezing Rain

Average Precipitation Rate: 13.3 g/dm²/h
Average OAT: -3.2 ºC

Fluid Failure Time:
14.9 min.

Temp. Profile
(-) Brix
Fluid Thickness

Temperature (ºC) / (-) Brix
Thickness (mm)
Surface Temperature, Fluid Dilution and Thickness Profiles
FLUID A (50%) on Aluminum Plate
April 6, 2005, Test No. 28, Freezing Rain

Average Precipitation Rate: 13.3 g/dm²/h
Average OAT: -3.2 ºC
Fluid Failure Time: 9.7 min.

Surface Temperature, Fluid Dilution and Thickness Profiles
FLUID A (50%) on Heated Aluminum Plate
April 6, 2005, Test No. 29, Freezing Rain

Average Precipitation Rate: 13.3 g/dm²/h
Average OAT: -3.2 ºC
Fluid Failure Time: 15.1 min.
Surface Temperature, Fluid Dilution and Thickness Profiles
FLUID B (50%) on Aluminum Plate
April 6, 2005, Test No. 30, Freezing Rain

Average Precipitation Rate: 13.3 g/dm²/h
Average OAT: -3.1 °C

Fluid Failure Time: 7.8 min.

Surface Temperature, Fluid Dilution and Thickness Profiles
FLUID B (50%) on Heated Aluminum Plate
April 6, 2005, Test No. 31, Freezing Rain

Average Precipitation Rate: 13.3 g/dm²/h
Average OAT: -3.1 °C

Fluid Failure Time: 16.7 min.
FLUID A (75%) on Aluminum Plate
April 6, 2005, Test No. 32, Freezing Rain

Average Precipitation Rate: 25.5 g/dm²/h
Average OAT: -3.1 ºC

Fluid Failure Time: 14.2 min.

FLUID A (75%) on Heated Aluminum Plate
April 6, 2005, Test No. 33, Freezing Rain

Average Precipitation Rate: 25.5 g/dm²/h
Average OAT: -3.1 ºC

Fluid Failure Time: 16.3 min.
Surface Temperature, Fluid Dilution and Thickness Profiles
FLUID B (Neat) on Aluminum Plate
April 6, 2005, Test No. 34, Freezing Rain

Average Precipitation Rate: 25.5 g/dm²/h
Average OAT: -3.1 ºC

Fluid Failure Time: 10.5 min.

Surface Temperature, Fluid Dilution and Thickness Profiles
FLUID B (Neat) on Heated Aluminum Plate
April 6, 2005, Test No. 35, Freezing Rain

Average Precipitation Rate: 25.5 g/dm²/h
Average OAT: -3.2 ºC

Fluid Failure Time: 13.8 min.
Surface Temperature, Fluid Dilution and Thickness Profiles
FLUID C (75%) on Aluminum Plate
April 6, 2005, Test No. 36, Freezing Rain

Average Precipitation Rate: 25.5 g/dm²/h
Average OAT: -3.1 ºC

Fluid Failure Time: 32.5 min.

Surface Temperature, Fluid Dilution and Thickness Profiles
FLUID C (75%) on Heated Aluminum Plate
April 6, 2005, Test No. 37, Freezing Rain

Average Precipitation Rate: 25.5 g/dm²/h
Average OAT: -3.1 ºC

Fluid Failure Time: 22.0 min.
Surface Temperature, Fluid Dilution and Thickness Profiles
FLUID A (50%) on Aluminum Plate
April 7, 2005, Test No. 41, Freezing Drizzle

- Average Precipitation Rate: 5.4 g/dm²/h
- Average OAT: -3.3 ºC

Fluid Failure Time: 11.8 min.

Temperature (ºC) / (-) Brix
Fluid Thickness

Surface Temperature, Fluid Dilution and Thickness Profiles
FLUID A (50%) on Heated Aluminum Plate
April 7, 2005, Test No. 42, Freezing Drizzle

- Average Precipitation Rate: 5.4 g/dm²/h
- Average OAT: -3.3 ºC

Fluid Failure Time: 16.8 min.
Surface Temperature, Fluid Dilution and Thickness Profiles
FLUID B (50%) on Aluminum Plate
April 7, 2005, Test No. 43, Freezing Drizzle

Average Precipitation Rate: 5.4 g/dm²/h
Average OAT: -3.2 °C

Fluid Failure Time: 9.1 min.

Surface Temperature, Fluid Dilution and Thickness Profiles
FLUID B (50%) on Heated Aluminum Plate
April 7, 2005, Test No. 44, Freezing Drizzle

Average Precipitation Rate: 5.4 g/dm²/h
Average OAT: -3.2 °C

Fluid Failure Time: 16.1 min.
Surface Temperature, Fluid Dilution and Thickness Profiles
FLUID B (75%) on Aluminum Plate
April 7, 2005, Test No. 45, Freezing Drizzle

-40 -30 -20 -10 0 10 20 30 40
0 15 35 55 75 95 115 135 155 175 195

Time (minutes)
Temperature (ºC) / (-) Brix
Thickness (mm)

Temp. Profile
(-) Brix
Fluid Thickness

Average Precipitation Rate: 13.4 g/dm²/h
Average OAT: -3.0 ºC

Fluid Failure Time: 8.8 min.

Surface Temperature, Fluid Dilution and Thickness Profiles
FLUID B (75%) on Heated Aluminum Plate
April 7, 2005, Test No. 46, Freezing Drizzle

-40 -30 -20 -10 0 10 20 30 40
0 15 35 55 75 95 115 135 155 175 195

Time (minutes)
Temperature (ºC) / (-) Brix
Thickness (mm)

Temp. Profile
(-) Brix
Fluid Thickness

Average Precipitation Rate: 13.4 g/dm²/h
Average OAT: -3.0 ºC

Fluid Failure Time: 16.6 min.
Surface Temperature, Fluid Dilution and Thickness Profiles

FLUID D (50%) on Aluminum Plate
April 7, 2005, Test No. 49, Freezing Drizzle

Temperature (ºC) / (-) Brix

Average Precipitation Rate: 13.4 g/dm²/h
Average OAT: -3.1 ºC

Fluid Failure Time: 9.2 min.

Surface Temperature, Fluid Dilution and Thickness Profiles

FLUID D (50%) on Heated Aluminum Plate
April 7, 2005, Test No. 50, Freezing Drizzle

Temperature (ºC) / (-) Brix

Average Precipitation Rate: 13.4 g/dm²/h
Average OAT: -3.1 ºC

Fluid Failure Time: 16.2 min.