TP 13483E

Hot Water Deicing of Aircraft

Prepared for

Transportation Development Centre
On behalf of
Civil Aviation
Safety and Security
Transport Canada

and

The Federal Aviation Administration
William J. Hughes Technical Center

APS AVIATION INC.

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TP 13483E

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by

Peter Dawson and
Medhat Hanna

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Un sommaire français se trouve avant la table des matières.

PREFACE

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

- To develop holdover time tables for new anti-icing fluids, and to validate fluid-specific and SAE holdover time tables;
- To gather enough supplemental experimental data to support the development of a deicing-only table as an industry guideline;
- To examine conditions for which contamination due to anti-icing fluid failure in freezing precipitation fails to flow from the wing of a jet transport aircraft when subjected to speeds up to and including rotation;
- To measure the jet-blast wind speeds developed by commercial airliners in order to generate air-velocity distribution profiles (to predict the forces that could be experienced by deicing vehicles), and to develop a method of evaluating the stability of deicing vehicles during live deicing operations;
- To determine the feasibility of examining the surface conditions on wings before takeoff through the use of ice-contamination sensor systems, and to evaluate the sensitivity of one ice-detection sensor system;
- To evaluate the use of warm fuel as an alternative approach to ground deicing of aircraft;
- To evaluate hot water deicing to determine safe and practicable limits for wind and outside ambient temperature;
- To document the appearance of fluid failure, to measure its characteristics at the point of failure, and to compare the failures of various fluids in freezing precipitation;
- To determine the influence of fluid type, precipitation (type and rate), and wind (speed and relative direction) on both the locations and times to fluid failure initiation, with special attention to failure progression on the Bombardier Canadair Regional Jet and on high-wing turboprop commuter aircraft;
- To evaluate snow weather data from previous winters to identify a range of snow-precipitation suitable for the evaluation of holdover time limits;
- To compare the holdover times from natural and artificial snow trials and to evaluate the functionality of NCAR's prototype simulated snowmaking system; and
- To develop a plan for implementing a full-scale wing test facility that would enable the current testing of deicing and anti-icing fluids in natural and artificial freezing precipitation on a real aircraft wing.

The research activities of the program conducted on behalf of Transport Canada during the 1998-99 winter season are documented in twelve reports. The titles of these reports are as follows:

- TP 13477E Aircraft Ground De/Anti-Icing Fluid Holdover Time Field Testing Program for the 1998-99 Winter;

- TP 13478E Aircraft Deicing Fluid Freeze Point Buffer Requirements for *Deicing Only* Conditions;
- TP 13479E Contaminated Aircraft Takeoff Test for the 1998-99 Winter;
- TP 13480E Air Velocity Distribution Behind Wing-Mounted Aircraft Engines;
- TP 13481E Feasibility of Use of Ice Detection Sensors for End-of-Runway Wing Checks;
- TP 13482E Evaluation of Warm Fuel as an Alternative Approach to Deicing;
- TP 13483E Hot Water Deicing of Aircraft;
- TP 13484E Characteristics of Failure of Aircraft Anti-Icing Fluids Subjected to Precipitation;
- TP 13485E Aircraft Full-Scale Test Program for the 1998-99 Winter;
- TP 13486E Evaluation of Snow Weather Data for Aircraft Anti-Icing Holdover Times;
- TP 13487E Development of a Plan to Implement a Full-Scale Test Site; and
- TP 13488E A Snow Generation System – Prototype Testing.

This report, TP 13483E, has the following objective:

- To evaluate hot water deicing to determine safe and practicable limits for wind and outside ambient temperature.

This objective was met in part by conducting a series of tests on flat plates in a cold chamber laboratory. Test parameters included temperature, wind and active precipitation (rate and type). Test surfaces included contaminated plates fabricated from typical aircraft construction composite materials as well as from aircraft aluminum. The most critical data measured in these trials was the time interval between fluid application (spray) and first appearance of ice on test surface.

ACKNOWLEDGEMENTS

This research has been funded by the Civil Aviation Group, Transport Canada, and with support from the Federal Aviation Administration. This program could not have been accomplished without the participation of many organizations. APS would like to thank, therefore, the Transportation Development Centre of Transport Canada, the Federal Aviation Administration, the National Research Council Canada, Atmospheric Environment Services Canada, Transport Canada, and several fluid manufacturers. Special thanks are extended to US Airways Inc., Delta Air Lines, Royal Airlines, Air Canada, the National Research Council Canada, Canadian Airlines International, AéroMag 2000, Aéroport de Montreal, the Greater Toronto Airport Authority, Hudson General Aviation Services Inc., Union Carbide, RVSI, Cox and Company Inc., the Department of National Defence, and Shell Aviation, for provision of personnel and facilities and for their co-operation on the test program. APS would like also to acknowledge the dedication of the research team, whose performance was crucial to the acquisition of hard data.

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16. Abstract

A research program was undertaken to further examine environmental limits for the application of hot water as the first-step fluid in a two-step deicing procedure.

Results from several previous, related studies were used to determine an approach to current testing, and as sources of related data.

Tests on flat plates were conducted at the National Research Council Canada Climatic Engineering Facility in Ottawa. Test parameters included temperature, wind, active precipitation (type and rate), and substrate material. (Standard test plates were fabricated from typical aircraft composite materials as well as from aircraft aluminum.) A controlled level of contamination was allowed to collect on the plates prior to each test run by exposing the plate to precipitation for a predetermined time interval. The resulting layer of ice contamination was then removed by spraying as much fluid as was required to produce a clean plate. Fluids tested included water, diluted SAE Type I fluid, and full-strength SAE Type I fluid.

The most critical data measured in these trials were the time intervals between fluid application (spray) and first appearance of ice on test surfaces. An interval of at least three minutes was the key indicator of acceptable temperature and wind limits.

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16. Résumé

Une étude a été lancée dans le but d'examiner plus avant les conditions environnementales limites autorisant l'emploi d'eau chaude pour la première étape d'une procédure de dégivrage à deux étapes.

Les résultats des multiples études apparentées menées antérieurement ont servi d'inspiration pour définir la démarche des présents essais et de sources de données connexes.

Des essais sur plaques planes ont été menés à l'Installation de génie climatique du Conseil national de recherches du Canada à Ottawa. Parmi les variables étudiées figuraient la température, le vent, le type et le taux de précipitations actives, et le matériau constituant la surface. (Des plaques planes standard ont été fabriquées à partir de matériaux composites types pour aéronefs et d'aluminium aéronautique.) Les essais consistaient à laisser une quantité donnée de contaminants se déposer sur les plaques en exposant celles-ci à des précipitations pendant un laps de temps prédéterminé. La couche de contamination solide ainsi produite était ensuite enlevée par la pulvérisation d'autant de liquide que nécessaire pour nettoyer complètement la plaque. Les liquides mis à l'essai comprenaient de l'eau et un liquide de dégivrage SAE de type I dilué et non dilué.

Les données les plus importantes recueillies au cours de ces essais ont trait à l'intervalle de temps entre l'application (pulvérisation) du liquide et le début de la formation de glace sur les surfaces d'essai. Un intervalle d'au moins trois minutes constituait l'indicateur clé de conditions de température et de vent acceptables.

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EXECUTIVE SUMMARY

At the request of the Transportation Development Centre (TDC) of Transport Canada and the Federal Aviation Administration, APS Aviation has undertaken a research program to further examine environmental limits for the application of hot water as the first-step fluid in a two-step deicing procedure.

Hot water has been authorized and used as an aircraft ground-deicing agent for many years. Its use offers significant benefits to the operator, primarily reduced impact on the environment and reduced operating costs. Despite these potential benefits, hot water is not used as commonly as it had been in the past. One reason is its restrictive temperature limitation.

In the past, when hot water deicing enjoyed greater popularity, the allowed temperature range was greater than that now authorized. Consequently, the procedure was applied to a greater segment of the deicing operation.

The standard method for deicing with hot water involves removal of the contaminant with a hot water spray having a temperature at the nozzle of at least 60°C, followed by an over-spray of anti-icing fluid. The SAE Aerospace Recommended Practice ARP4737 that defines this methodology states that the anti-icing fluid is to be applied before the first-step fluid freezes, typically within three minutes. It also establishes limitations on ambient weather conditions for use of hot water as a first-step fluid, wherein the outside air temperature (OAT) must be no lower than –3°C. There is no reference to wind as a limiting factor.

The intent of this OAT limitation is to provide to the deicing operator a minimum three-minute window for application of the second-step or anti-icing fluid before freezing occurs. In operational practice, the spray operator must monitor his own progress to ensure that no surface area refreezes before the anti-icing fluid is applied. As no freeze point depressant is present when water is used as a first-step fluid, the delay in refreezing is due only to the heat that has been transferred to the aircraft surface from the hot water.

Previous related studies include *Hot Water Deicing Trials for the 1994-1995 Winter, TP 12653E* (1), and a study carried out during the winter 1997-98 season, *Aircraft Deicing Fluid Freeze Point Buffer Requirements Deicing Only and First Step of Two-step Deicing, TP 13315E* (2). Further investigation of deicing only fluid application was conducted during the 1998-1999 winter season. Results from these studies were used to determine a current testing approach, and were also used as sources of related data.

Tests on flat plates were conducted at the National Research Council Canada Climatic Engineering Facility in Ottawa. Test parameters included temperature, wind, active precipitation, and substrate materials. Standard test plates were fabricated from typical aircraft composite materials as well as from aircraft

aluminum. Because heat transfer to the test surface was a key element of the study, the thermal impact that accompanies removal of a surface contaminant was also examined. A controlled contamination level was allowed to collect on the plates prior to each test run, by exposing the plate to precipitation for a predetermined time interval. The resulting layer of ice contamination was then removed by spraying as much fluid as was required to produce a clean plate.

The most critical data measured in these trials were the time intervals between fluid application (spray) and first appearance of ice on test surfaces. An interval of at least three minutes was the key indicator of acceptable temperature and wind limits.

Results and Conclusions

The principal conclusion was that hot water provides a period of protection equal to or better than Type I fluid mixed to the approved freeze point, in ambient temperatures down to –6°C and in winds up to 10 km/h.

At –9°C, with winds of 10 km/h, diluted Type I fluid performs slightly better than hot water.

At –3°C, with winds of 20 and 30 km/h, hot water provided a three-minute period of protection before freezing.

In repeated tests in calm conditions, elapsed times until the onset of freezing showed some variability. This variability was reduced greatly for wind condition tests. As test results during wind conditions are more severe and conservative, they should provide the basis for establishing the lowest temperature at which hot water should be used.

Values for elapsed time until freezing were significantly lower in these tests than during previous “first-step fluid” trials because of the differences in test procedures (1,2). In the previous trials, 500 ml of the fluid was applied onto a clean test surface. This series of trials required spraying a contaminated plate until it was clean. A much smaller quantity of fluid was applied, which resulted in shorter periods of protection.

These protection periods were also considerably shorter than those obtained from field trials on operational aircraft in March/April 1995. Those trials involved spray application of hot water onto the aircraft by operators experienced in hot water deicing. Those trials, however, were conducted in dry conditions. A review of the test record revealed that operators sprayed varying amounts of hot water, ranging from 20 to 40 gal. (90 to 180 L), on each DC-9 wing. This is equivalent to 300 to 600 ml on each test plate area, for an average of 450 ml per application.

Thus, test quantities in the current series of trials were conservative, ranging from 200 to 300 ml per test plate.

The fluid quantities needed to produce clean surfaces on painted composite substrates were significantly smaller than those required to produce clean surfaces on bare aircraft aluminum substrates. Elapsed times to the onset of freezing for the glass fibre, carbon fibre, and kevlar composite surfaces were shorter than for the standard aluminum test plate, but equal to or greater than the times on the aluminum on honeycomb core test surface. The shorter times recorded for composites are at least partly due to the lower fluid quantities necessary to achieve a clean surface.

In an operational setting, any composite surfaces in a wing structure would receive the same amount of fluid as the aluminum surface. Therefore, the protection period would be similar.

Aluminum on honeycomb core appears to be the most critical type of surface, giving the lowest rate of increase in period of protection per additional unit of fluid quantity.

The quantity of fluid applied on aluminum substrates influenced the duration of the period of protection. Tests to investigate the influence of fluid quantity were not conducted on composite surfaces, but it is expected that a similar trend would result.

The degree of contamination does not significantly influence the elapsed time to freezing under the test procedures followed in this study. The fluid heat loss and the heat absorbed by the surface while cleaning away the heavier contamination are compensated for by the application of more fluid.

References

1. Dawson, P., D'Avirro, J., *Hot Water De-Icing Trials for the 1994-95 Winter,* APS Aviation Inc., Montreal, December 1995, Transport Canada – Dryden Commission Implementation Project, TP 12653E.

2. Dawson, P., Hanna, M., Chaput, M., *Aircraft Deicing Fluid Freeze Point Buffer Requirements Deicing Only and First Step of Two-Step Deicing,* APS Aviation Inc., Montreal, December 1998, Transportation Development Centre report, TP 13315E.

SOMMAIRE

À la demande du Centre de développement des transports (CDT) de Transports Canada et de la Federal Aviation Administration, APS Aviation a lancé une étude visant à examiner plus avant les conditions environnementales limites autorisant l'utilisation d'eau chaude pour la première étape d'une procédure à deux étapes de dégivrage des avions.

L'eau chaude est autorisée et utilisée depuis de nombreuses années en tant qu'agent de dégivrage au sol des aéronefs. Son utilisation comporte des avantages certains pour le transporteur, en particulier des impacts minimes sur l'environnement et des coûts réduits. Mais en dépit de ces avantages, l'eau chaude n'est plus utilisée aussi couramment que par le passé, en raison notamment des contraintes reliées à la température.

Autrefois, lorsque le dégivrage à l'eau chaude était plus populaire, la plage de températures autorisant le recours à cette méthode était plus étendue qu'elle l'est aujourd'hui. Elle était donc utilisée pour une plus grande proportion des opérations de dégivrage.

La méthode standard de dégivrage à l'eau chaude consiste à ôter la contamination avec de l'eau dont la température à la sortie de la buse est d'au moins 60 °C et à pulvériser ensuite un liquide antigivrage. La pratique recommandée en l'occurrence par SAE Aerospace, portant le numéro ARP4737, indique que le temps ouvert à la pulvérisation d'antigivre avant que l'eau gèle est normalement de trois minutes. Elle établit également des conditions météorologiques limites pour l'utilisation d'eau chaude, dont une température de l'air extérieur (OAT) d'au moins -3 °C. Mais elle ne fait aucune référence au vent en tant que facteur contraignant.

Cette limitation de l'OAT vise à donner au préposé au dégivrage un créneau d'au moins trois minutes pour l'application du deuxième liquide (antigivrage), avant que l'eau gèle. Dans la pratique, le préposé doit surveiller sa progression et s'assurer d'appliquer le liquide antigivrage avant que les surfaces gèlent de nouveau. Comme l'eau utilisée pour le dégivrage ne contient pas d'abaisseur du point de congélation, le délai de protection contre le gel est fonction uniquement de la chaleur transférée de l'eau à la voilure.

Au nombre des études antérieures portant sur le dégivrage à l'eau chaude figurent *Hot Water Deicing Trials for the 1994-1995 Winter, TP 12653E* (1), et une étude menée au cours de l'hiver 1997-1998, *Aircraft Deicing Fluid Freeze Point Buffer Requirements Deicing Only and First Step of Two-step Deicing, TP 13315E* (2). D'autres recherches sur la procédure de dégivrage simple ont été réalisées au cours de la saison hivernale 1998-1999. Les résultats de ces études ont servi d'inspiration pour définir l'approche des présents essais et de sources de données connexes.

Des essais sur plaques planes ont été menés à l’Installation de génie climatique du Conseil national de recherches du Canada à Ottawa. Parmi les variables étudiées figuraient la température, le vent, les précipitations actives et les matériaux constituant la surface. Des plaques planes standard ont été fabriquées à partir de matériaux composites types pour aéronefs et d’aluminium aéronautique. Comme le transfert de chaleur entre le liquide et la surface d’essai représentait un élément clé de l’étude, les phénomènes thermiques associés à l’enlèvement de contaminants sur les surfaces ont également été examinés. Les essais consistaient à laisser une quantité donnée de contaminants se déposer sur les plaques en exposant celles-ci aux précipitations pendant un laps de temps prédéterminé. La couche de contamination solide ainsi produite était ensuite enlevée par la pulvérisation d’autant de liquide que nécessaire pour nettoyer complètement la plaque.

Les données les plus importantes obtenues au cours de ces essais ont trait à l’intervalle de temps entre l’application (pulvérisation) du liquide et les premiers signes de givrage des surfaces d’essai. Un intervalle égal ou supérieur à trois minutes était l’indicateur clé de conditions de température et de vent acceptables.

Résultats et conclusions

La grande conclusion qui se dégage de l’étude est que l’eau chaude procure une période de protection égale ou supérieure à celle offerte par un liquide de type I préparé pour afficher le point de congélation approuvé, à des températures ambiantes allant jusqu’à -6 °C et sous des vents soufflant jusqu’à 10 km/h.

À -9 °C, sous des vents de 10 km/h, le liquide de type I dilué affiche une performance légèrement supérieure à celle de l’eau chaude.

À -3 °C, sous des vents de 20 et 30 km/h, l’eau chaude assure une protection de trois minutes contre le gel.

Des essais répétés menés en l’absence de vent ont révélé une certaine variabilité des délais de protection contre le gel. Mais ces délais étaient beaucoup plus constants en présence de vent. Comme les résultats des essais réalisés en présence de vent sont plus rigoureux et plus prudents, ils devraient servir de base pour déterminer la température la plus basse autorisant l’emploi d’eau chaude pour le dégivrage.

Les délais de protection contre le gel obtenus au terme des présents essais sont beaucoup plus courts que ceux découlant des essais antérieurs de liquides de «première étape», en raison de protocoles d’essai différents (1,2). En effet, les essais antérieurs consistaient à déposer 500 ml de liquide sur une surface propre, contrairement aux présents essais, qui consistaient à pulvériser une plaque contaminée jusqu'à ce qu'elle soit complètement propre. La quantité de liquide utilisée était alors beaucoup moindre, ce qui avait pour effet de réduire le délai de protection.

De plus, les délais de protection étaient beaucoup plus courts que ceux obtenus lors des essais en vraie grandeur menés en mars/avril 1995, auxquels participaient des préposés rompus au dégivrage à l'eau chaude. Ces essais ont toutefois été menés en l'absence de précipitations. Un examen du dossier des essais indique que les préposés pulvérisaient sur chaque aile de DC-9 des quantités d'eau chaude variant de 20 à 40 gallons (90 à 180 l). Cela équivaut à un volume de 300 à 600 ml sur chaque plaque d'essai, pour une moyenne de 450 ml par application. Ainsi, les quantités pulvérisées lors des présents essais étaient modérées, variant de 200 à 300 ml par plaque d'essai.

Les quantités de liquide nécessaires pour nettoyer les surfaces étaient beaucoup plus faibles lorsque celles-ci étaient en matériau composite peint que lorsqu'elles étaient en aluminium aéronautique nu. Les délais de protection contre le gel étaient plus courts pour les surfaces en matériau composite à base de fibre de verre, de fibres de carbone et de Kevlar que pour les plaques d'essai standard en aluminium, mais égaux ou plus longs que pour les surfaces d'essai en aluminium à âme alvéolaire. Les délais de protection relativement courts obtenus pour les surfaces en matériaux composites s'expliquent au moins partiellement par les quantités moindres de liquide nécessaires pour nettoyer la surface.

En contexte opérationnel, les surfaces en matériau composite qui constituent la structure de l'aile recevraient la même quantité de liquide que les surfaces en aluminium. Le délai de protection serait donc similaire sur toute la voilure.

Une surface en aluminium à âme alvéolaire est la surface la plus critique, car elle affiche le plus faible taux d'augmentation du délai de protection par unité additionnelle de liquide appliqué.

La quantité de liquide appliqué sur les surfaces en aluminium a influé sur le délai de protection. L'effet de la quantité de liquide sur le délai de protection des surfaces en matériau composite n'a pas été l'objet d'essais, mais tout porte à croire que de tels essais révéleraient une tendance similaire.

Le degré de contamination a peu d'effet sur le délai de protection contre le gel, selon les méthodes d'essai utilisées pour la présente étude. L'application d'une plus grande quantité de liquide compense pour la perte de chaleur du liquide et l'absorption de chaleur par la surface, lors de l'enlèvement d'une plus grande quantité de contaminants.

Références

1. Dawson, P., D'Avirro, J., *Hot Water De-Icing Trials for the 1994-95 Winter,* APS Aviation Inc., Montreal, December 1995, Transport Canada – Dryden Commission Implementation Project, TP 12653E.

2. Dawson, P., Hanna, M., Chaput, M., *Aircraft Deicing Fluid Freeze Point Buffer Requirements Deicing Only and First Step of Two-Step Deicing,* APS Aviation Inc., Montreal, December 1998, Transportation Development Centre report, TP 13315E.

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GLOSSARY

APS	APS Aviation Inc.
CEF	Climatic Engineering Facility
FAA	Federal Aviation Administration
FPD	Freezing Point Depression
NRC	National Research Council Canada
OAT	Outside Air Temperature
RVSI	Robotic Vision System Inc.
SAE	Society of Automotive Engineers
TDC	Transportation Development Centre
UCAR	Union Carbide Corporation

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1. INTRODUCTION

At the request of the Transportation Development Centre (TDC) of Transport Canada and the Federal Aviation Administration, APS Aviation undertook a research program to further examine environmental limits for the application of hot water as the first-step fluid in a two-step deicing procedure.

1.1 Background

Hot water has been authorized and used as a ground-deicing agent for aircraft for many years. Its use offers significant benefits to the operator, chief of which are reduced impact on the environment and reduced operating costs. Despite these potential benefits, hot water is not used as commonly as it had been in the past.

At least one reason for the lack of use is the narrowness of the temperature range under which hot water is approved for use as a deicing agent. The use of hot water for deicing requires maintenance of strict management disciplines in the deicing operation, and support of these disciplines inherently implies an increase in operating cost overhead (increased training, supervision, etc.). Pragmatically, only when the benefits far outweigh the additional overhead costs and increased complexities in the operation will operators choose to implement hot water deicing.

In the past, when hot water deicing enjoyed greater popularity, the allowed temperature range was greater than that now authorized. Consequently, the procedure applied to a greater segment of the deicing operation.

The standard method for deicing with hot water involves removal of the contaminant with a hot water spray having a temperature at the nozzle of at least 60°C, followed by an over-spray of anti-icing fluid. The SAE Aerospace Recommended Practice ARP4737 that defines this methodology (shown in Appendix D), states that the anti-icing fluid is to be applied before the first step fluid freezes, typically within three minutes. It also establishes limitations on ambient weather conditions for use of hot water as a first step fluid, wherein the current outside air temperature (OAT) must be no lower than –3°C. There is no reference to wind as a limiting factor.

The intent of this OAT limitation is to provide a minimum three-minute window to the deicing operator. The three-minute window allows the application of the second-step or anti-icing fluid before freezing occurs. In operational practice, the spray operator must monitor his own progress to ensure that no surface area refreezes before the anti-icing fluid is applied.

As there is no freeze point depressant in pure water, the delay in refreezing is due only to the heat that has been transferred to the aircraft surface from the hot water. In the past when hot water was used more widely and before the advent of the modern SAE Type IV fluids, the follow-on anti-icing spray generally consisted of a heated Type I fluid. In current day operations, Type IV fluids are applied unheated. This change in operational environment is an important topical consideration as a heated second-step fluid could be viewed to serve a natural corrective function for any early freezing of the water application not noted by the operator.

Previous related studies include *Hot Water Deicing Trials for the 1994-1995 Winter* TP 12653E (1) and a study during the Winter 1997-98 season *Aircraft Deicing Fluid Freeze Point Buffer Requirements Deicing Only and First Step of Two-Step Deicing* TP 13315E (2). Further investigation of the *deicing only* application was conducted during the 1998-1999-winter season. Results from both of these studies are valuable for determining an approach to current testing, and as sources of related data for the subject.

1.2 Work Statement

Appendix A presents the work statement for the APS Aviation Winter 1998-99 research program. Section 5.11 of Appendix A, Evaluation of Hot (and Cold) Water Deicing, describes this project. The project was to include tests in an environmental chamber and on operational aircraft. This report addresses results from laboratory tests. A correlation of results with test on aircraft was not conducted because of the late winter season.

1.3 Objective

The objective of this project was to evaluate environmental limitations (OAT, wind) for the use of hot water as the first-step fluid in a two-step deicing operation.

To satisfy this objective, tests on flat plates were conducted at the National Research Council Canada (NRC) Climatic Engineering Facility (CEF) in Ottawa. Findings from previous studies were considered in the design of the experiment. Test parameters included temperature, wind, active precipitation, and testing on plates fabricated from typical aircraft composite materials as well as from aluminum. Because heat transfer to the test surface was a key element of the study, the thermal impact that accompanies removal of a surface contamination was also considered. The most critical data measured in these trials were the time intervals between fluid application (spray) and first appearance of ice on test surfaces. An interval of at least three minutes was the key indicator of acceptable temperature and wind limits.

2. PREVIOUS RELATED STUDIES

2.1 Hot Water Deicing Trials for the 1994-95 Winter

This study, TP 12653, was commissioned to generate the scientific data necessary to support a rational determination of the lower OAT limit for application of hot water as a first-step deicing fluid (1). At the time the report was commissioned, the lower OAT limit had only recently been modified from –7°C to –3°C. This reduction was based solely on operator comments. This study examined whether the OAT limitation for the application of hot water could safely be lowered beyond -3°C. The study, conducted primarily on aircraft, indicated that hot water deicing is feasible at temperatures below -3°C, depending on wind speed and operator disciplines. The earliest occurrence of freezing occurred on flight control surfaces at the rear of the wing, not on the main wing surface.

Tests carried out in a controlled environment laboratory confirmed that high winds exert a major influence on shortening the time interval in which the earliest freezing occurs. During field trials, deicing personnel experienced in hot water deicing commented that a cautious approach is necessary even at moderate temperatures during conditions of high wind. The study recommended that any further tests should consider the impact of winds. As well, an examination of the effect of the more modern aviation composite materials, which are frequently used in the fabrication of aircraft lift surfaces, was also recommended.

Figure 2.1 plots results from three field tests performed on a McDonnell Douglas DC-9 aircraft. The tests were conducted in dry conditions. These tests included the removal from the wing of contamination that had formed in previous trials. The data points indicate the time interval (lag time) until the initiation of freezing following spray application of hot water, for various OAT's. The wind speed at the time of testing is also shown. The data points shown are the most severe (shortest times to freezing) of several locations measured on the wing, and were generally located on flight control surfaces. The box in the lower right hand corner indicates the extent of currently approved limits.

Figure 2.2 adds results from laboratory tests to the previous chart. In these trials, 0.5 L of heated water was poured on a clean plate. The laboratory data points illustrate the influence of wind on the time interval that elapsed before the onset of freezing. The chart also shows a data point generated in an independent field study (Transportation Development Centre report, TP 12735E (2), *Aircraft Ground Operations in Canadian Winter Weather*).

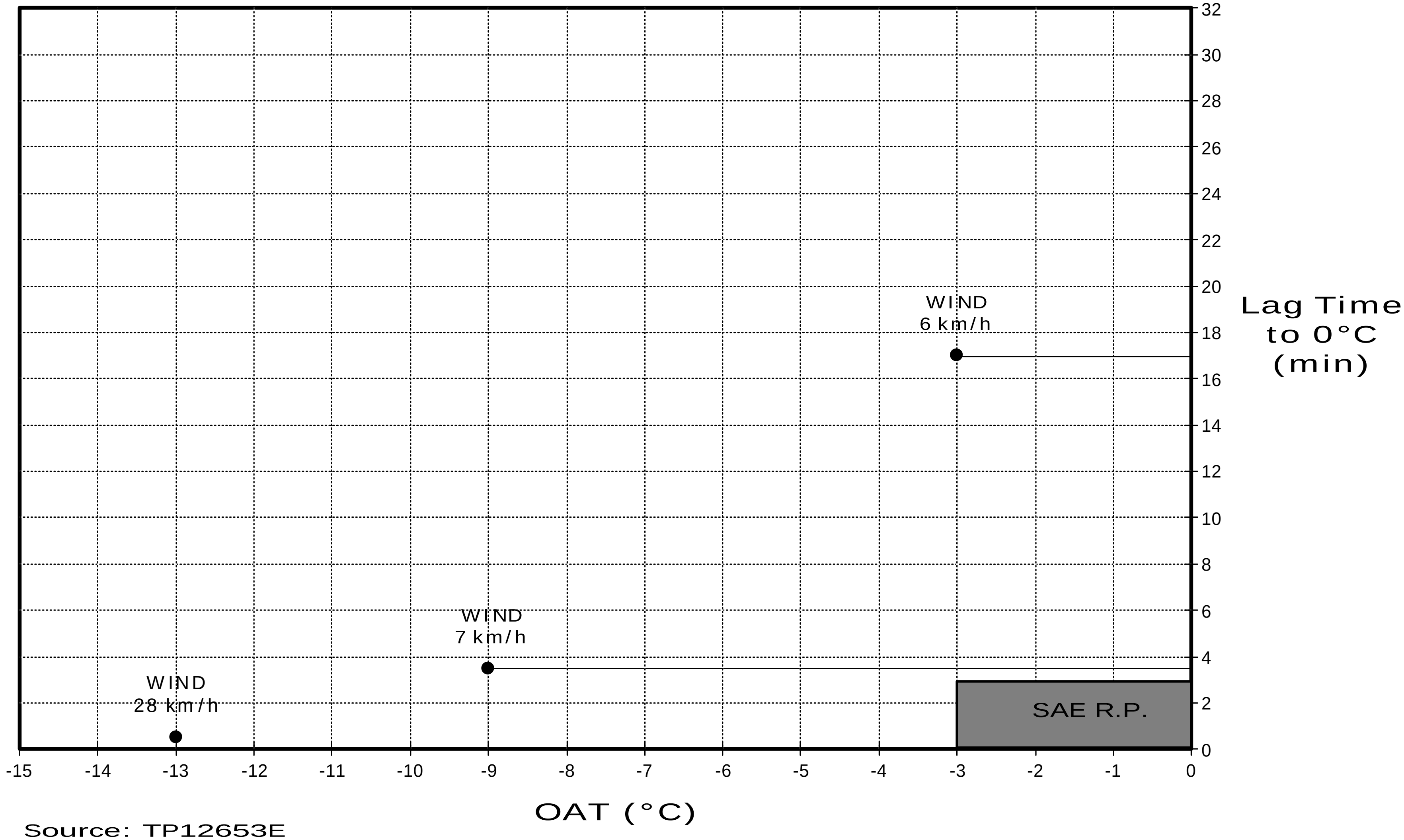
Figure 2.3 proposes a model to assist determination of operational limits for the combination of OAT and wind. A family of hypothetical curves is proposed, that could potentially define the relationship between lag time and OAT for various incremental wind speeds.

FIGURE 2.1

HOT WATER DEICING TRIALS - AIRCRAFT

NO PRECIPITATION

March - April 1995



C1514/report/hotwater/LAG_AC.GRF

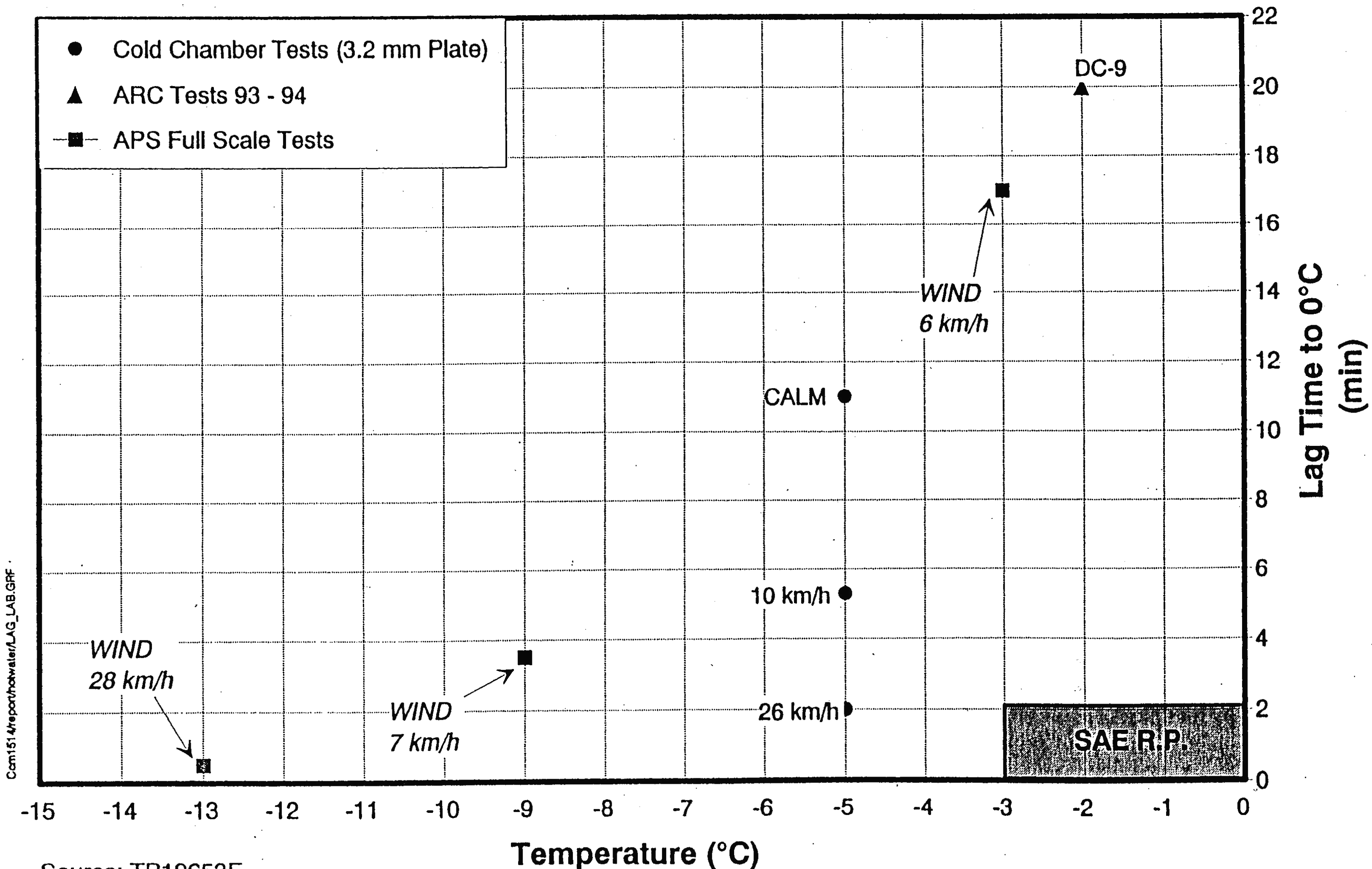
Source: TP12653E

FIGURE 2.2

HOT WATER DEICING TRIALS - AIRCRAFT AND LABORATORY

NO PRECIPITATION

March - April 1995



Source: TP12653E

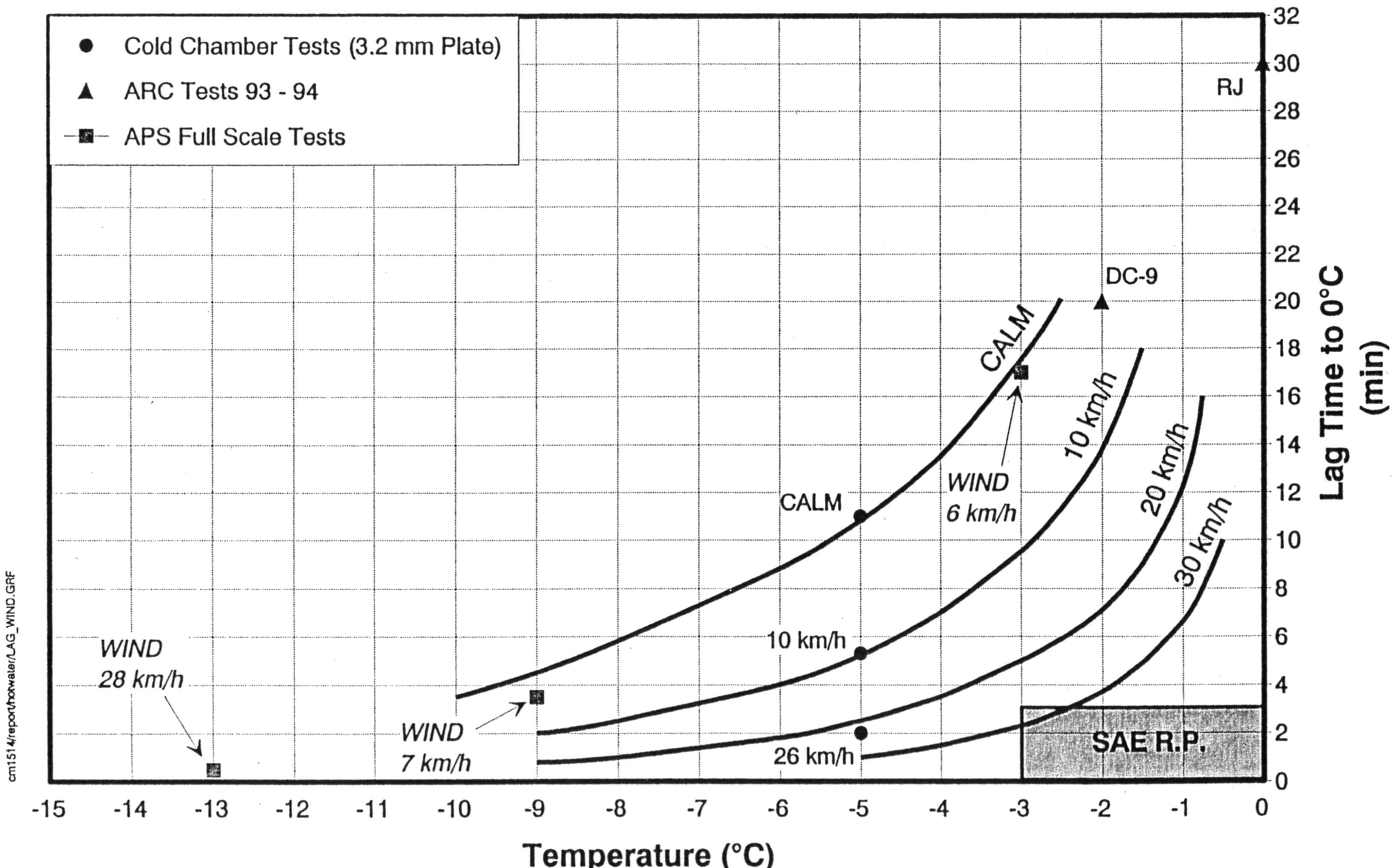
FIGURE 2.3

HYPOTHETICAL CURVES - RELATING LAG TIME TO FREEZING WITH OAT FOR INCREMENTAL WIND SPEED

HOT WATER DEICING TRIALS

NO PRECIPITATION

March - April 1995



Source: TP12653E

2.2 1997-98 Study on Fluid Freeze Point Buffer Requirements for First Step Fluids

This study, TP 13315E, examined the use of very dilute Type I fluids (as well as water), as first-step deicing fluids, and determined the resultant interval until freezing began (3). These trials differed from the previous hot water trials in that these tests were conducted in precipitation conditions. Again, 0.5 L of heated fluid was poured onto a clean test plate. Trials were conducted at a range of temperatures, under freezing rain and freezing drizzle precipitation. Later, during the progress of the study, a test procedure for combining wind and precipitation conditions was devised, and a small number of trials at one temperature but with several wind speeds were conducted. Figure 2.4 is a chart of test results for hot water. The chart plots *lagtimes* (time until the onset of freezing) versus OAT. Data for different wind speeds were generated at only one OAT.

This study (1997-98) also included an examination of the rate of dilution of the applied Type I fluids under the test levels of precipitation. Figure 2.5 is a plot of surface temperature and fluid freeze point over time. The surface cools after the application of hot water, and the fluid is diluted under ongoing precipitation. In the test reported in this figure, the Type I fluid was mixed to the currently approved limit for first step fluids wherein the fluid freeze point may be 3 degrees warmer than OAT. Figure 2.6 plots the same data for a neat Type I fluid, and demonstrates how quickly a fluid, which is initially in its standard concentration, is diluted to the point where its freeze point is at the OAT.

In Figure 2.5, it is seen that the fluid diluted to zero concentration in about 4 minutes. Test results demonstrated that heat transfer to the test surface from the first step fluid was the major contributor to the span of the time interval until freezing initiated:

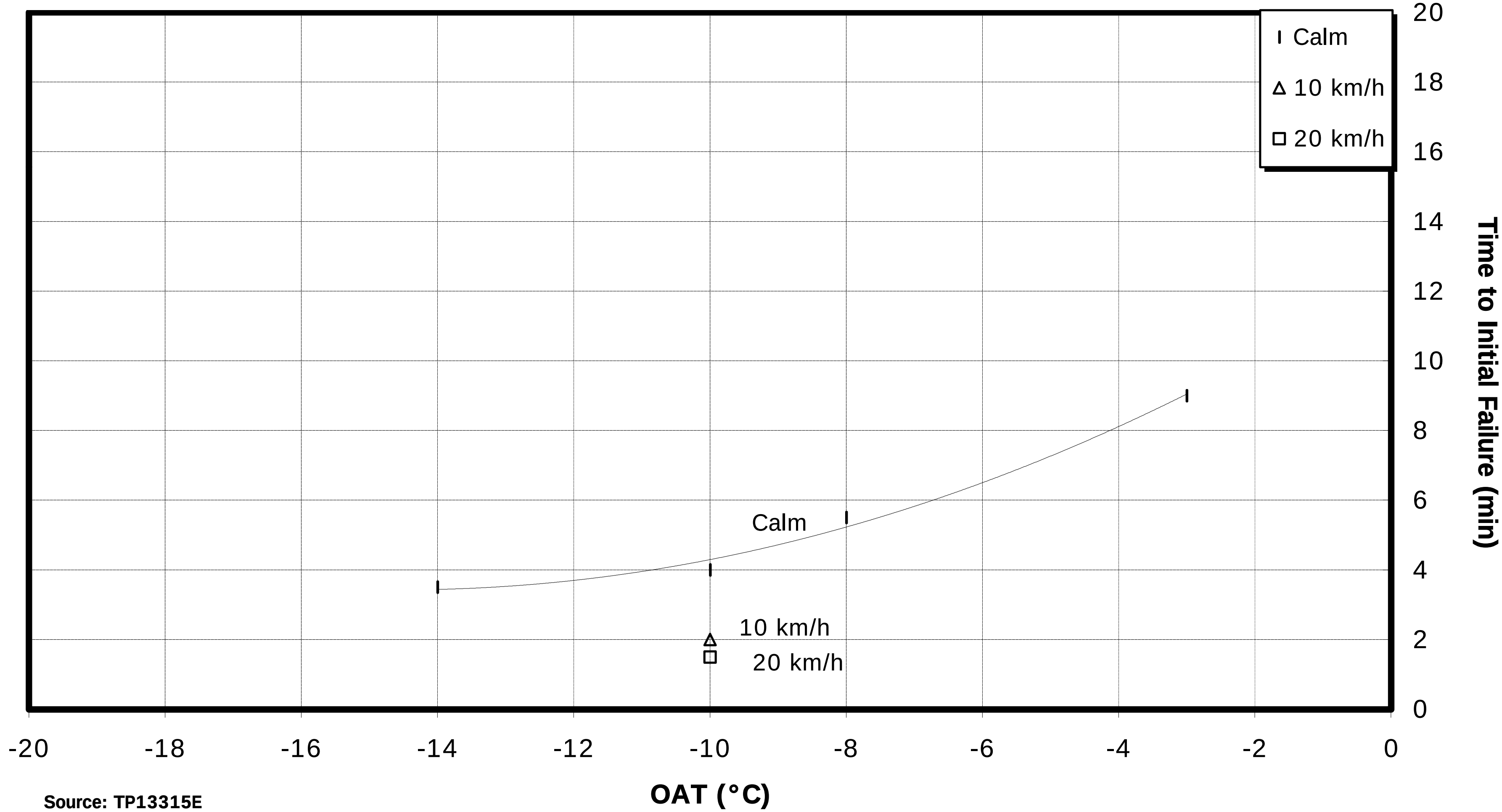
- In calm conditions, the surface cooled to 0°C in 4.5 minutes. In this case, the fluid freeze point curve indicates that at the point of freezing initiation, the fluid was already diluted to an insignificant glycol concentration. Therefore, freezing point depression provided no contribution to the elapsed time until onset of freezing.
- At a wind speed of 10 km/h, the fluid freeze point curve intersected the surface temperature curve slightly after the temperature curve crossed 0°C. At this wind speed, the Type I fluid could be said to perform equivalently to hot water.
- At a wind speed of 20 km/h, the fluid freeze point curve intersected the surface temperature curve about 0.5 minutes after the temperature curve crossed 0°C. At this wind speed, the surface heat provided protection for 1.5 minutes and the FPD action added a further 0.5 minutes of protection.

FIGURE 2.4

FIRST STEP FLUID TRIALS IN 1997/98

TIME TO ONSET OF FREEZING - HOT WATER

LIGHT FREEZING RAIN (25g/dm^2/hr)



Source: TP13315E

cm1514/report/hotwater/Fsp_978.xls
At: 1
Printed: 5/21/02, 9:20 AM

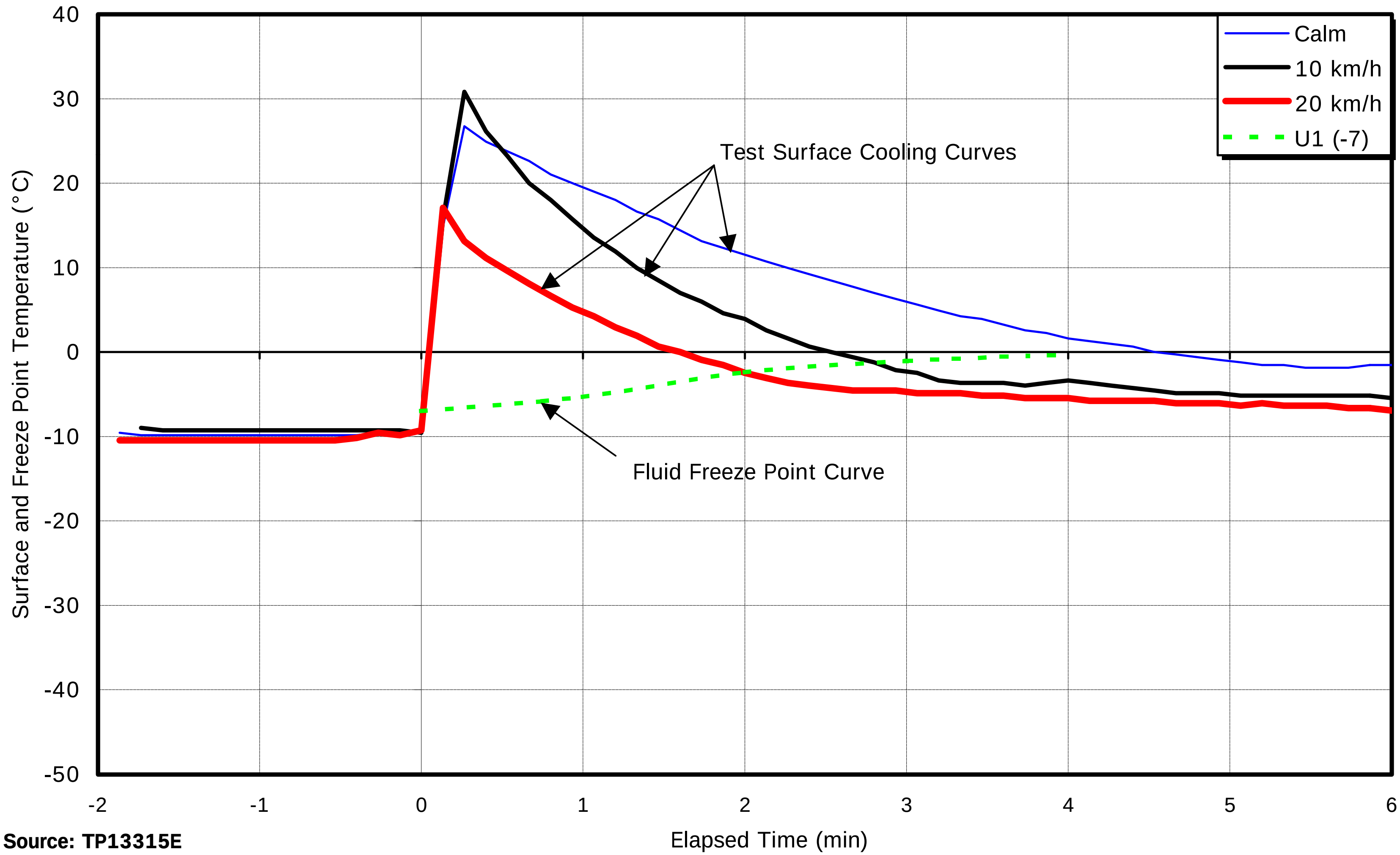
FIGURE 2.5

FIRST STEP FLUID TRIALS IN 1997/98

TEMPERATURE PROFILES OF TEST SURFACE AND FLUID FREEZE POINT

LIGHT FREEZING RAIN (25 g/dm²/hr), OAT = -10°C

Type I Fluid at Freeze Point of -7°C



Source: TP13315E

cm1514\report\hotwater\Adf7_-10.xls
At: 25g
5/21/02, 9:21 AM

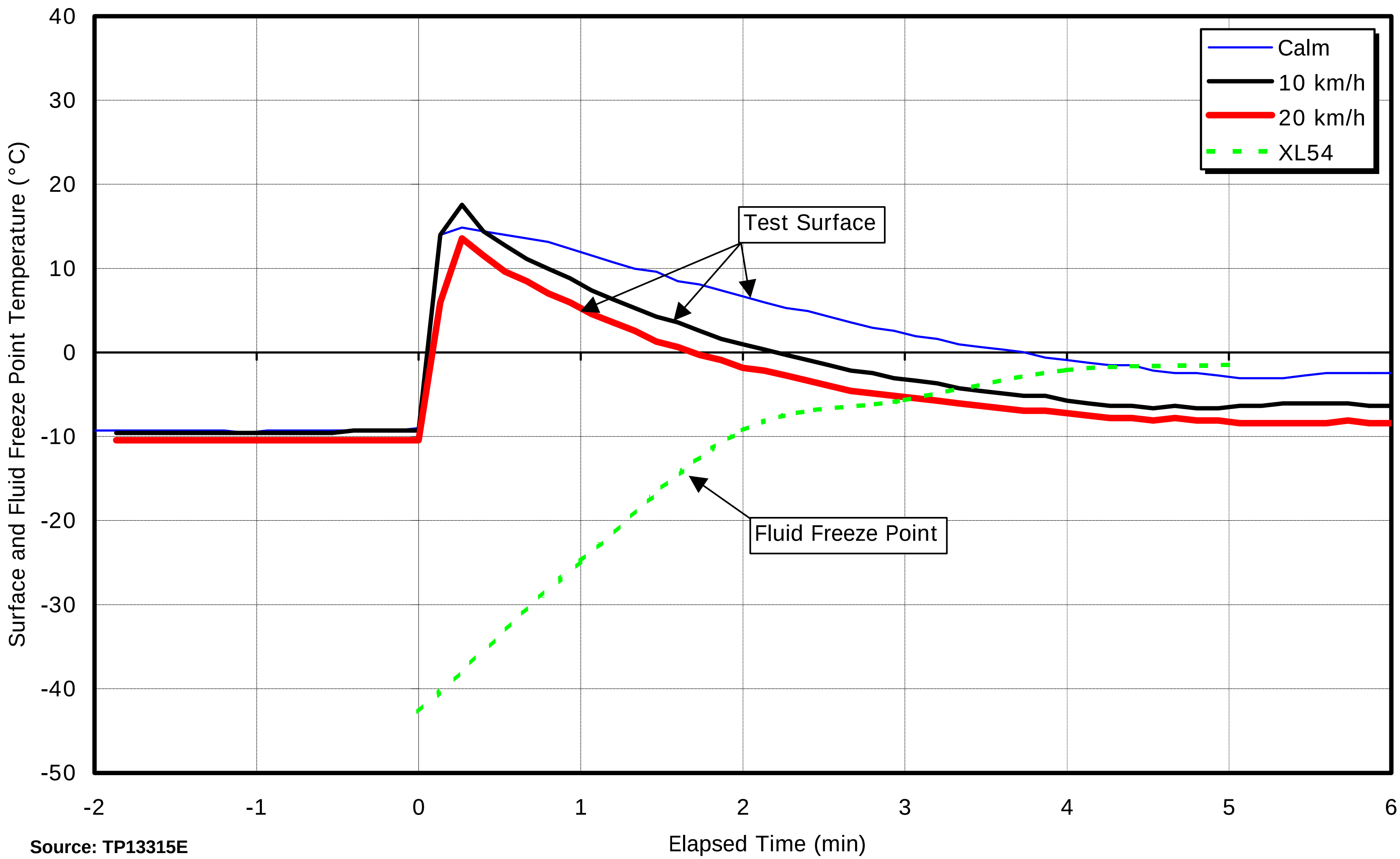
FIGURE 2.6

FIRST STEP TRIALS 1997-1998

TEMPERTURE PROFILES OF TEST SURFACE AND FLUID FREEZE POINT

LIGHT FREEZING RAIN (25 g/dm²/hr), OAT = -10°C

FULL STRENGTH TYPE I FLUID



Source: TP13315E

cm1514\report\hotwater\Xl54-10c.xls
At: 25 g
5/21/02, 9:24 AM

Figure 2.6 provides similar information for an application of full-strength Type I fluid.

Note: the *elapsed times until freezing* inferred from the intersection of the curves in Figure 2.5 are slightly longer than *time to onset of freezing* reported in Figure 2.4. This is a result of the method used to measure surface temperature wherein surface temperature (reported in Figure 2.5) was obtained by contact measurement instrumentation at only one point, near the geometrical center of the test plate. Time to onset of freezing (reported in Figure 2.4) was based on visual observation of the first sign of freezing. This usually occurred near the edge of the test plate where the surface temperature is generally cooler than at the point of surface temperature measurement.

2.3 1997-98 Deicing Only Study

This study, TP 13315E, examined the use of very dilute fluids to remove any contamination following termination of precipitation, when ongoing protection as provided by anti-icing fluid is not required (3). The study included measurement of the rate of cooling of the test surface for different wind and OAT combinations in non-precipitation conditions. This information is useful for providing an indication of the time interval following application of the deicing fluid until the surface temperature reaches 0°C, for various OAT/wind combinations.

Figure 2.7 is a chart of results obtained from trials using hot water. Here, the time interval (at various wind speeds) until the plate temperature drops to 0°C, is plotted versus OAT. Again in these trials, 0.5 L of water at 60°C was applied to each clean plate, marking the beginning of each test.

2.4 Further Evaluation of Deicing Only 1998-99

The results from the 1997-1998 studies on deicing only, and the results from fluid freeze point buffer requirements for first step fluids, were discussed in detail at the annual 1998 SAE G-12 Committee Aircraft Ground Deicing meeting, and also at a special meeting convened for that purpose and held in August 1998 at the FAA William J. Hughes Technical Center in Atlantic City.

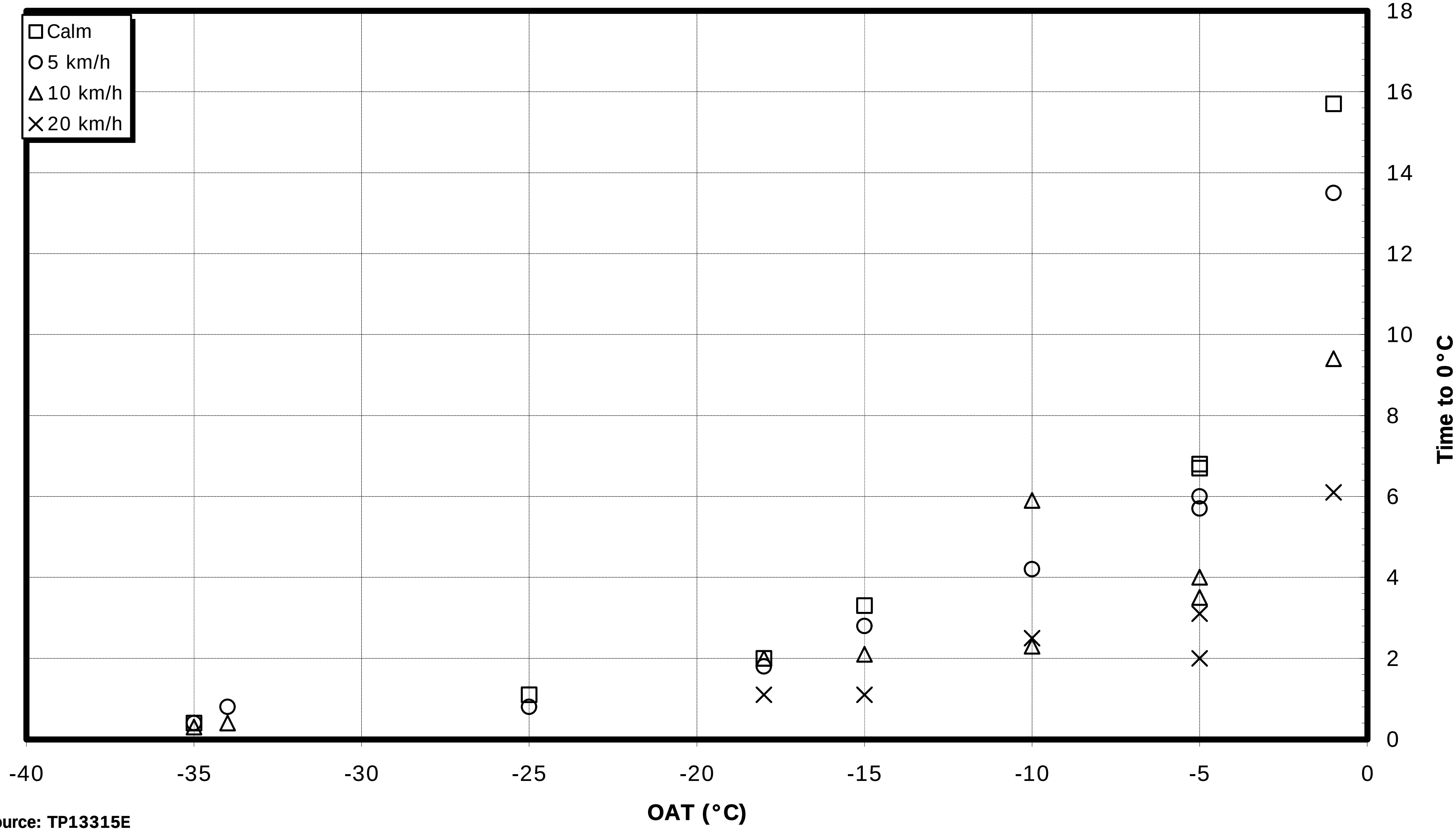
As a result of discussions at those meetings, further investigation of the *deicing only* application was conducted in order to examine the effects of varying several test parameters. One variable examined was the removal of snow contamination from the test surface, to ascertain whether the act of removing snow diminished the final transfer of heat to the surface. This factor was examined both in the laboratory and in the field on an aircraft

FIGURE 2.7

INFLUENCE OF OAT AND WIND ON PLATE COOLING RATE

DEICING ONLY TRIALS - HOT WATER

NO PRECIPITATION



Source: TP13315E

cm1514/report/hotwater/Tme_o°c.xls
At: 97-98
5/21/02, 9:25 AM

wing. The test methodology was based on actual operations, and allowed the spray operator to continue spraying until the surface was clean.

In general, it was concluded that the greater the amount of contamination, the greater was the quantity of fluid that was applied by the operator, and the greater quantity of fluid compensated for any loss of heat in the snow removal process.

2.5 Implications for Current Tests

All previous studies confirmed that in addition to OAT, wind plays a very significant role in determining the time interval following application of spray until onset of freezing. This was evident from tests conducted in both dry (non-precipitation) and in active precipitation conditions.

Tests under freezing precipitation (first-step fluid study) appeared to produce values for elapsed time until onset of freezing that were somewhat shorter than in dry conditions.

These observations indicate that the test design should include controlled combinations of wind and precipitation.

Previous studies indicate that when the OAT is lower than –12ºC, the time interval from spray application until onset of freezing is too short for operational practice. It was decided that a test design based on OAT values of -3, -6, -9 and -12°C would offer sufficient data for chart construction.

During industry discussions on the results of the *deicing only* study, several points of interest were raised that could be realistically addressed in the test design:

- *Impact of actual removal of contaminant from the surface*. Based on current year trials to supplement deicing only data, the process of removal of contamination by spraying appears to be self-compensating in the sense that the additional quantity of fluid required to remove the contaminant compensates for any heat loss to the contaminant.
- *Test surfaces composed of composite materials*. Trials could be conducted on test surfaces composed of composite materials developed for the deicing only study.
- *Tests on fluids mixed to currently authorized freeze point limits to serve as a reference when examining test results*. Type I fluid mixed to a fluid freeze point 3ºC above OAT (first step fluid limitation) should be tested in addition to hot water.

The industry transition from heated Type I fluid to unheated non-Newtonian fluid as the second-step anti-icing fluid has brought about a particular concern. When hot water deicing was practiced in the past, before the advent of the modern SAE Type IV fluids, the second-step anti-icing spray generally consisted of a heated Type I fluid. The heat from the second-step fluid served to correct any early freezing of the applied water not noted by the operator.

The loss of this inherent corrective function with the use of unheated anti-icing fluids is not addressed in this test program, other than designing the test around rigorous parameters. Any procedures and guidelines that emerge from this study must have as a goal the provision of a clean surface that remains unfrozen for a reasonable period after the first step fluid application.

It should be added that an investigation into the use of warmed anti-icing fluids led to significantly reduced holdover times due to reduced fluid viscosity and associated thinner stabilized fluid film thickness (4).

3. METHODOLOGY

This section describes the conditions and methodologies used in these tests, as well as the test equipment and personnel requirements.

3.1 Test Site

These tests were conducted at the National Research Council Canada (NRC) Climatic Engineering Facility (CEF) located near Ottawa International Airport.

Experimental trials for the winter 1997-98 study on aircraft deicing fluid freeze point buffer requirements for first step fluids (2) were also conducted in this facility. During the 1997-98 trials, an approach to providing a controlled combination of wind and precipitation for test purposes was developed. In that approach, the entire facility, encompassing both the large and the small chambers, was utilised.

The previous approach was enhanced for the 1998-99 trials by relocating the precipitation spray head to a location in the large chamber. This allowed placement of fans for wind production in the same chamber, thereby avoiding the excessive turbulence experienced previously from the structure dividing the two chambers. The freezing rain sprayer head is shown in Photo 3.1.

3.2 Description of Test Procedures

Tests were scheduled over a three-day period at the NRC CEF facility.

The test variables included air temperature and wind speed. A precipitation condition of freezing rain at a rate of 25 g/dm^2/hr was established. Precipitation rates were measured over the entire stand at the beginning and at the end of each test session, as well as on a continuing basis every 20 minutes. This methodology is based on the standard procedure established in the experimental methodology for determining fluid holdover times. Photo 3.2 shows collection pans being weighed as part of this procedure. The distribution of raindrops over the plate surface is shown in Photo 3.3. In this photograph, the bare plate, which had been cooled to ambient temperature (-12°C), was subjected to freezing rain precipitation at the test rate (25 g/dm^2/hr) for a one-minute interval. The drops froze immediately upon striking the bare plate surface. The resulting pattern of frozen rain droplets reflects an even distribution over the plate surface.

Aluminum plate test surfaces (300 x 500 x 3.2 mm) were prepared in advance. Plates were buffed, removing all traces of markings. Each was marked with an identification label. No grid marks were allowed to remain on plate surfaces in order to avoid damming of fluid runoff. A single thermistor probe was installed on each test plate at the 22.5 cm (9") line. Photo 3.4 shows probes being installed on the plates on the upper row. Plates were mounted on a standard flat plate test stand at slope of 10º, as shown in the general test set-up Photo 3.5. In general, plate positions on the upper row of the stand were preferred to facilitate fluid application and observation of surface conditions.

Testing on Type I deicing fluids was included to provide a reference to current operational practices. Type I fluid was tested both at full strength and diluted to currently approved levels (freeze point = 3ºC above OAT).

Fluid mixes were prepared in advance. For tests involving Type I fluid, a duplicate test plate was conducted to enable sampling for measurement of fluid dilution rates, without disturbing the test plate used to record observations.

Industry discussions of results from a similar study involving heat transfer from a heated fluid to the test surface (the 1997-1998 study on fluid freeze point buffer requirements for deicing only conditions[2]) raised a concern regarding testing on bare surfaces. The concern was that some of the fluid's heat might be dissipated by the actual removal of solid contamination, thereby decreasing the amount of heat transferred to the surface. To address that concern, these trials were designed to incorporate the removal of contamination from the test surface as part of the test procedure.

A controlled level of contamination was allowed to collect on the plates prior to each test run by exposing the plate to precipitation for a predetermined time interval. This exposure time interval was evaluated for each temperature condition, with the objective of standardizing the degree of plate contamination for all conditions as much as possible. This resulted in a standard exposure time of one minute for all temperatures tested. The exposure time was varied to study the effect of increased levels of contamination.

The resulting layer of ice contamination was then removed by spraying as much fluid as was required to provide a clean plate. Photos 3.6 and 3.7 show fluid being applied by spraying. Photo 3.6 clearly shows the ice contaminant being removed, resulting in a clean plate surface as the spray operator works his way down the plate from top to bottom. The distance from nozzle to surface was generally as shown in the photos, and typically in the range of 10 to 15 cm.

The time of spray application was recorded, as was the time interval until the initiation of freezing. The elapsed time to the onset of freezing was the key element being measured in these trials.

Fluid sprayers were constructed specifically to simulate spraying in field operations. These sprayers were pre-calibrated to enable calculation of the fluid quantity sprayed. The fluid quantities were based on records of spray duration.

In some of the trials that demonstrated times until freezing shorter than three minutes, the test was re-run with additional fluid sprayed, to determine how much additional fluid would be necessary to achieve a three-minute time to freezing.

Fluids were heated to 60ºC at the time of application. Temperature and Brix values of fluids were measured prior to fluid application.

The time interval until the initial appearance of freezing was the most critical data recorded.

Plate temperatures were monitored throughout the tests by means of thermistor probes, which were installed on plate surfaces, and data loggers were used to automatically record these temperatures. Test surface temperatures were allowed to return to the ambient laboratory temperature prior to proceeding with the next test.

Fluid strength was measured on an ongoing basis on duplicate plates throughout the test run. Measurements were taken at a frequency sufficient to construct a fluid freeze point temperature profile over time. The procedure for lifting samples for fluid strength measurement attempted to collect a representative mix of fluid by running the fluid sampler the full length of the plate, from bottom to top, but avoiding picking up fluid from the drip line. Fluid strength was measured on an ongoing basis using Brix-scale refractometers (Photo 3.8).

A video and photographic record of the test set-up was maintained.

Table 3.1 presents an overview of test parameters for these trials. The plan called for four OAT conditions with four values of wind speeds at each. Both water and SAE Type I fluids (mixed to a freeze point (FP) 3ºC above OAT) were tested. In addition to the standard aluminum test surfaces, surfaces fabricated from composite materials typically used in aircraft manufacture were also tested.

Table 3.2 provides the detailed test plan and defines the specific test parameter(s) varied in each run.

TABLE 3.1

TEST PLAN FOR HOT WATER TRIALS

OAT (°C)	FLUID	WIND (km/h)	TEST SURFACE
-3	Water	Calm	Standard Aluminum test plate for all conditions. Composite surface for selected conditions.
		10	
		20	
		30	
-6	Water Type I ADF, Freeze Point -3°C	Calm	
		10	
		20	
		30	
-9	Water Type I ADF, Freeze Point -6°C	Calm	
		10	
		20	
		30	
-12	Water Type I ADF, Freeze Point -9°C	Calm	
		10	
		20	
		30	

NOTES:

Precipitation rate - light freezing rain 25 g/dm²/hr

Fluid heated to 60°C

Fluid applied by spraying

TABLE 3.2 (Pg. 1/2)

HOT WATER TRIALS

TEST SCHEDULING AND CONTROL SHEET

PRECIPITATION: Light Freezing Rain at 25 g/dm²/hr

FLUID TEMPERATURE: 60°C at the Nozzle

<u>TEST SURFACE TYPES:</u>

Aluminum	Al
Aluminum Honeycomb	C1
Carbon Fibre on Honeycomb	C3
Glass Fibre on Honeycomb	C4
Kevlar on Honeycomb	C5

Note: for selected tests where time to freezing is less than 3 minutes, the test will be rerun with additional spray quantity to determine whether 3-minute lag can be delivered with additional spray quantity. These repetitions will be decided during the course of testing.

Proposed Test Period	Time Fluid Needed	Test Team	Run #	Test Objective	OAT (°C)	Fluid Type	Wind (km/h)	Surface Type	Plate Exposure Time
			1	Initial Ice	-3	Water	Calm	Al	
			2	Initial Ice	-3	Water	10	Al	
			3	Initial Ice	-3	Water	10	C1	
			4	Initial Ice	-3	Water	10	C3	
			5	Initial Ice	-3	Water	10	C4	
			6	Initial Ice	-3	Water	10	C5	
			7	Initial Ice	-3	Water	20	Al	
			8	Initial Ice	-3	Water	30	Al	
			9	Initial Ice	-6	Water	Calm	Al	
			10	Initial Ice	-6	T1E -3	Calm	Al	
			11	Brix	-6	T1E -3	Calm	Al	
			12	Initial Ice	-6	Water	10	Al	
			13	Initial Ice	-6	Water	10	C1	
			14	Initial Ice	-6	Water	10	C3	
			15	Initial Ice	-6	Water	10	C4	
			16	Initial Ice	-6	Water	10	C5	
			17	Initial Ice	-6	T1E -3	10	Al	
			18	Initial Ice	-6	T1E -3	10	C1	
			19	Initial Ice	-6	T1E -3	10	C3	
			20	Initial Ice	-6	T1E -3	10	C4	
			21	Initial Ice	-6	T1E -3	10	C5	
			22	Brix	-6	T1E -3	10	Al	
			23	Initial Ice	-6	Water	20	Al	
			24	Initial Ice	-6	T1E -3	20	Al	
			25	Brix	-6	T1E -3	20	Al	
			26	Initial Ice	-6	Water	30	Al	
			27	Initial Ice	-6	T1E -3	30	Al	
			28	Brix	-6	T1E -3	30	Al	
			29	Initial Ice	-9	Water	Calm	Al	
			30	Initial Ice	-9	T1E -6	Calm	Al	
			31	Brix	-9	T1E -6	Calm	Al	
			32	Initial Ice	-9	Water	10	Al	
			33	Initial Ice	-9	Water	10	C1	
			34	Initial Ice	-9	Water	10	C3	
			35	Initial Ice	-9	Water	10	C4	
			36	Initial Ice	-9	Water	10	C5	
			37	Initial Ice	-9	T1E -6	10	Al	
			38	Initial Ice	-9	T1E -6	10	C1	
			39	Initial Ice	-9	T1E -6	10	C3	

HOT WATER TRIALS

TEST SCHEDULING AND CONTROL SHEET

PRECIPITATION:	Light Freezing Rain at 25 g/dm²/hr	
FLUID TEMPERATURE:	60°C at the Nozzle	
<u>TEST SURFACE TYPES:</u>	Aluminum	Al
	Aluminum Honeycomb	C1
	Carbon Fibre on Honeycomb	C3
	Glass Fibre on Honeycomb	C4
	Kevlar on Honeycomb	C5

<u>Note</u>: for selected tests where time to freezing is less than 3 minutes, the test will be rerun with additional spray quantity to determine whether 3-minute lag can be delivered with additional spray quantity. These repetitions will be decided during the course of testing.

Proposed Test Period	Time Fluid Needed	Test Team	Run #	Test Objective	OAT (°C)	Fluid Type	Wind (km/h)	Surface Type	Plate Exposure Time
			40	Initial Ice	-9	T1E -6	10	C4	
			41	Initial Ice	-9	T1E -6	10	C5	
			42	Brix	-9	T1E -6	10	Al	
			43	Initial Ice	-9	Water	20	Al	
			44	Initial Ice	-9	T1E -6	20	Al	
			45	Brix	-9	T1E -6	20	Al	
			46	Initial Ice	-9	Water	30	Al	
			47	Initial Ice	-9	T1E -6	30	Al	
			48	Brix	-9	T1E -6	30	Al	
			49	Initial Ice	-12	Water	Calm	Al	
			50	Initial Ice	-12	T1E -9	Calm	Al	
			51	Brix	-12	T1E -9	Calm	Al	
			52	Initial Ice	-12	Water	10	Al	
			53	Initial Ice	-12	Water	10	C1	
			54	Initial Ice	-12	Water	10	C3	
			55	Initial Ice	-12	Water	10	C4	
			56	Initial Ice	-12	Water	10	C5	
			57	Initial Ice	-12	T1E -9	10	Al	
			58	Initial Ice	-12	T1E -9	10	C1	
			59	Initial Ice	-12	T1E -9	10	C3	
			60	Initial Ice	-12	T1E -9	10	C4	
			61	Initial Ice	-12	T1E -9	10	C5	
			62	Brix	-12	T1E -9	10	Al	
			63	Initial Ice	-12	Water	20	Al	
			64	Initial Ice	-12	T1E -9	20	Al	
			65	Brix	-12	T1E -9	20	Al	
			66	Initial Ice	-12	Water	30	Al	
			67	Initial Ice	-12	T1E -9	30	Al	
			68	Brix	-12	T1E -9	30	Al	

TABLE 3.3

Repeat Hot Water Tests at -9°C, March 25, 1999

OAT (°C)	WIND	FLUID	RUN	TEST TYPE
-9	CALM	Water	901	Pour 0.5 L clean plate
			902	Pour 0.5 L contaminated plate
			903	Regular spray
			904	Regular spray
			905	20 sec spray
			906	40 sec spray
		Type I ADF Freeze Point -6°C	907	Regular spray
			908	Regular spray
	10 km/h	Water	909	Pour 0.5 L clean plate
			910	Pour 0.5 L contaminated plate
			911	Regular spray
			912	Regular spray
			913	20 sec spray
			914	40 sec spray
		Type I ADF Freeze Point -6°C	915	Regular spray
			916	Regular spray
	20 km/h	Water	917	Regular spray
			918	Regular spray
		Type I ADF Freeze Point -6°C	919	Regular spray
			920	Regular spray

During the course of the trials, certain anomalies were observed in the test results. These were explored further through a complementary set of tests, listed in Table 3.3. This series of tests examined the impact of the duration of spray application, and also examined the impact of the method of fluid application (spraying versus pouring).

The experimental program is provided in Appendix B.

3.3 Data Forms

Forms for gathering test data included:

- Data form for Hot Water Trials (Figure 3.1);
- Brix Progression form for Hot Water Trials (Figure 3.2);
- Precipitation Rate Measurement Form (Figure 3.3); and
- Continuous Precipitation Rate Measurement Form (Figure 3.4).

Copies of these forms are also included in the test procedure (Appendix B).

3.4 Equipment

Some special equipment was needed to support these trials. Certain pieces were developed specifically for the project.

Large electric fans (Photo 3.9) were provided by NRC. These fans, mounted on castor wheels, were located at a fixed position and speed was controlled by means of a rheostat on the power supply. This was a major improvement over previous trials, which required the fans to be repositioned between runs to provide different wind speeds. The accuracy in reproducing specific wind speeds for subsequent tests was enhanced by this feature.

Various concentrations of Type I fluid were needed. These fluid samples were heated using 5-litre aluminum pots (Photo 3.10), hot plates, and a microwave oven (Photo 3.11) for small fluid quantities.

To satisfy the large demand for heated water (for the various hot water tests) a small water heater tank, mounted on a trolley for portability, was devised (Photo 3.12). The tank was specially instrumented to provide an accurate reading of water temperature and fill level. The tank, pressurised with compressed air from the building supply, was incorporated into a self-

FIGURE 3.1

DATA FORM FOR HOT WATER TRIALS (LIGHT FREEZING RAIN)

REMEMBER TO SYNCHRONIZE TIME 1998/99

LOCATION: CEF (Ottawa) **DATE: March ,1999** **AMBIENT TEMPERATURE: °C**

	RH	Wind Speed (km/h)			
	(%)	Top Left	Top Right	Bottom Left	Bottom Right
Start					
End					

Run #:	________	________	________
Surface Type:	______________	______________	______________
Fluid Type:	______________	______________	______________
Fluid Brix:	________ °	________ °	________ °
Fluid Temperature:	________ °C	________ °C	________ °C
Plate Exposure Start Time:	______________ (hh:mm:ss:)	______________ (hh:mm:ss:)	______________ (hh:mm:ss:)
Spray Start Time:	______________ (hh:mm:ss:)	______________ (hh:mm:ss:)	______________ (hh:mm:ss:)
Spray Finish Time:	______________ (hh:mm:ss:)	______________ (hh:mm:ss:)	______________ (hh:mm:ss:)

Plate #

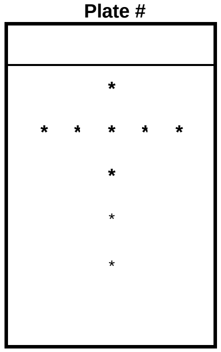


Plate #

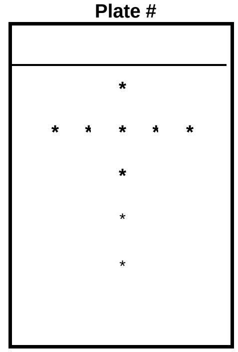
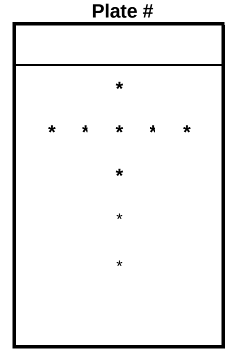


Plate #



Time to 1st Freezing:	______________	______________	______________
Time to Failure (6" Line):	______________	______________	______________
Time to complete Failure (15" Line):	______________	______________	______________

COMMENTS: ____

HAND WRITTEN BY : ______________

LEADER: ______________

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FIGURE 3.2

HOT WATER TRIALS

BRIX PROGRESSION

DATE: March , 1999

OAT: ________ **°C**

	RH (%)	Wind Speed (kph)			
		Top Left	Top Right	Bottom Left	Bottom Right
Start					
End					

Plate Position: ________ o **Fluid Temperature:** ________ o

Run #: ________ **Plate Exposure Start Time:** ________ (hh:mm:ss)

Surface Type: ________ **Spray Start Time** ________ (hh:mm:ss)

Fluid Type: ________ **Spray Finish time** ________ (hh:mm:ss)

Fluid Brix: ________ o

Time (min) / Brix	1	2	3	4	5	6	7	8	9	10
Time (min) / Brix	11	12	13	14	15	16	17	18	19	20

Comments on Final Plate Condition: ________

Plate Position: ________ o **Fluid Temperature:** ________ o

Run #: ________ **Plate Exposure Start Time:** ________ (hh:mm:ss)

Surface Type: ________ **Spray Start Time** ________ (hh:mm:ss)

Fluid Type: ________ **Spray Finish time** ________ (hh:mm:ss)

Fluid Brix: ________ o

Time (min) / Brix	1	2	3	4	5	6	7	8	9	10
Time (min) / Brix	11	12	13	14	15	16	17	18	19	20

Comments on Final Plate Condition: ________

MEASUREMENTS BY: ________ **HAND WRITTEN BY:** ________

FIGURE 3.3

PRECIPITATION RATE MEASUREMENT AT CEF IN OTTAWA

Date: ____________________

Start Time: ____________________ am/pm

Run # : ____________________

Precip Type: ____________________ (ZD, ZR-)

Pan Location:

1	**2**	**3**	**4**	**5**	**6**
7	**8**	**9**	**10**	**11**	**12**

Collection Pan:

Pan/ Cup #	Area of Pan (dm^2)	Location		Weight of Pan (g) Before	After	Collection Time (min) Start	End
1		1	=				
2		2	=				
3		3	=				
4		4	=				
5		5	=				
6		6	=				
7		7	=				
8		8	=				
9		9	=				
10		10	=				
11		11	=				
12		12	=				

Comments: ____

____

____

____

Handwritten by: ____________________

Measured by: ____________________

Precipitation Rate = $\Delta g/\text{area}\ (dm^2)/hr$

h:/cm1514/report/hotwater/Rate_frm.xls
5/21/02, RATE_FRM

FIGURE 3.4

CONTINUOUS PRECIPITATION RATE MEASUREMENT AT CEF IN OTTAWA

Date: ____________________

Start Time: ____________________

Run # : ____________________

Precip Type: ____________________ (ZD, ZR-)

Pan Location:

1	**2**	**3**	**4**	**5**	**6**
7	**8**	**9**	**10**	**11**	**12**

Collection Pan:

Pan/ Cup #	Area of Pan (dm²)	Location	Weight of Pan (g) Before	After	Collection Time Start	End	Rate
1							
2							
1							
2							
1							
2							
1							
2							
1							
2							
1							
2							
1							
2							
1							
2							

Comments:

Handwritten by: ____________________

Measured by: ____________________

Precipitation Rate = Δg/area (dm²)/hr

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Printed:5/21/02, 10:21 AM

contained water spray system. The water outlet from the tank was directed via a flexible hose to a spray nozzle, and thereby provided the heated water spray for the tests. The nozzle flow rate was calibrated to allow calculation of applied quantities of water based on the duration of spray. The flow rate was determined to be 25.5 ml/sec or 255 ml for 10-second spray duration. The external air supply provided a constant pressure in the tank thereby maintaining a constant application rate of the fluid mix or water regardless of change in liquid volume as it was expelled. A fluid temperature of 80°C in the tank supplied a temperature of 60°C at the nozzle (Photo 3.13). The water heater tank was not suited for the application of Type I fluids due to the smaller total quantities of the various mixes required.

The Type I fluid was applied using a separate sprayer that had been developed for supplementary trials in the deicing only study, conducted earlier in the 1998-1999 season. The Type I fluid sprayer (Photo 3.14) was based on a fire extinguisher tank, fitted with an air pressure supply fitting and a hose and nozzle assembly identical to the above-mentioned hot water tank. The tank was wrapped in insulation to maintain fluid temperatures. Prior to the tests, the two types of sprayers were tested and compared to ensure that they delivered common rates and patterns of spray.

Wind speeds were measured with a hand-held anemometer (Photo 3.15).

A video camera mounted on a tripod (Photo 3.16) and trained on the test stand was operated continuously to provide an ongoing record of the conduct of the tests. A monitor and VCR recorder (Photo 3.17) were linked to the video camera.

In addition to standard aluminum test plates, plates fabricated from composite materials as used in new aircraft construction were tested. They included:

- Aluminum on honeycomb backing;
- Carbon Fibre on honeycomb backing;
- Glass Fibre on honeycomb backing;
- Kevlar on honeycomb backing.

The aluminum honeycomb plate is shown in Photo 3.18. The plates fabricated from carbon fibre, glass fibre, and Kevlar were painted with a grey polyurethane paint and consequently looked alike. Photo 3.19 shows a typical painted composite surface plate.

Each test plate was outfitted with a temperature thermistor probe and linked to data loggers.

A complete list of equipment is contained in the test procedures (Appendix B).

3.5 Fluids

Fluids used in these trials were heated water and heated SAE Type I fluid mixed to various concentrations. Type I fluid strength for testing was specified to provide a fluid freeze point 3 degrees above test OAT. In the report, a fluid code such as TIE –3 is used, meaning Type I fluid, ethylene glycol-base, freeze point of –3ºC. A full strength Type I fluid was used in some tests, shown as XL54 (std).

UCAR Type I ADF fluid was used as the test fluid.

3.6 Personnel and Participation

The NRC Climatic Engineering Facility staff provided technical support during trials at that facility.

A representative from the Federal Aviation Administration participated as observer at the trials.

APS Aviation designed, co-ordinated and conducted trials. Data were gathered and analysed by APS Aviation staff.

Photo 3.1
Freezing Rain Sprayer

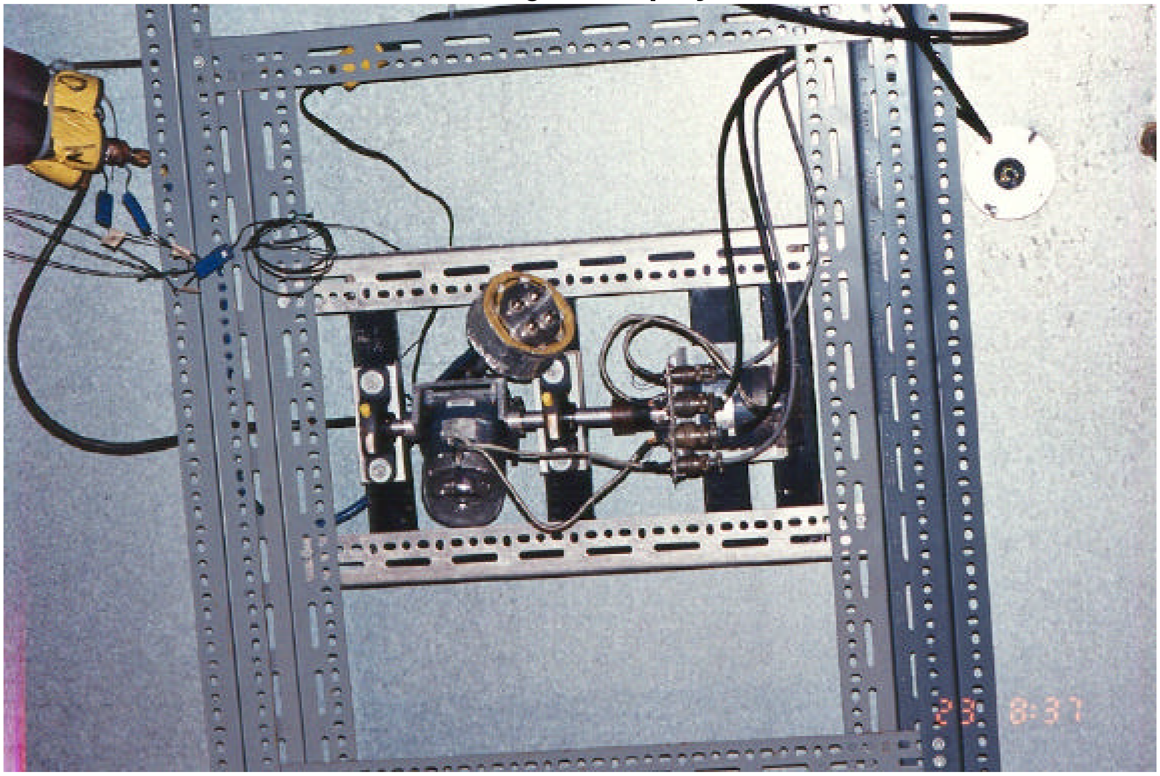


Photo 3.2
Weighing Plate Pans in Measuring Precipitation Plate

Photo 3.3
Distribution of Rain Droplets over Plate Surface

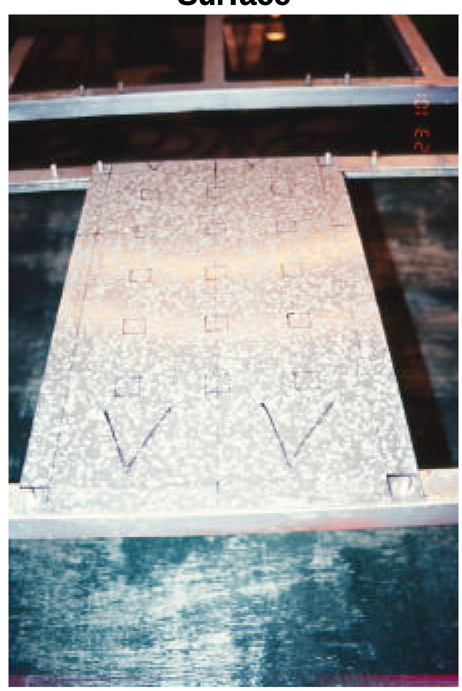


Photo 3.4
Thermistor Probes on Aluminum Plates

Photo 3.5
General Test Set-up

Photo 3.6
Cleaning Ice from Plate with Sprayed Fluid

Photo 3.7
Spray Application

Photo 3.8
Brix Refractometer

Photo 3.9
Electric Fans

Photo 3.10
Type I Fluid Heating Apparatus

Photo 3.11
Microwave Oven for Heating Small Quantities of Type I Fluid

Photo 3.12
Hot Water Tank

Photo 3.13
Measuring Water Temperature at Spray Nozzle

Photo 3.14
Type I Fluid Sprayer

Photo 3.15
Measuring Wind Speed With Anemometer

Photo 3.16
Continuous Recording with Video Camera

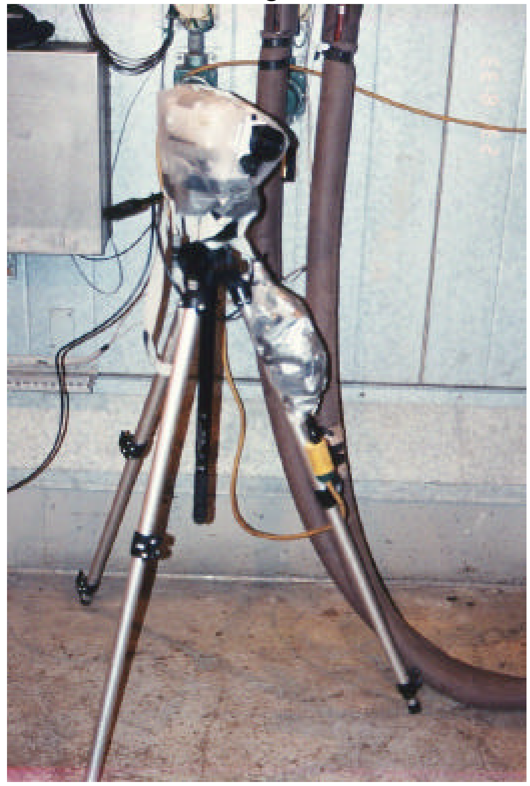


Photo 3.17
Video Monitor and VCR

Photo 3.18
Test Plate – Aluminum on Honeycomb Backing

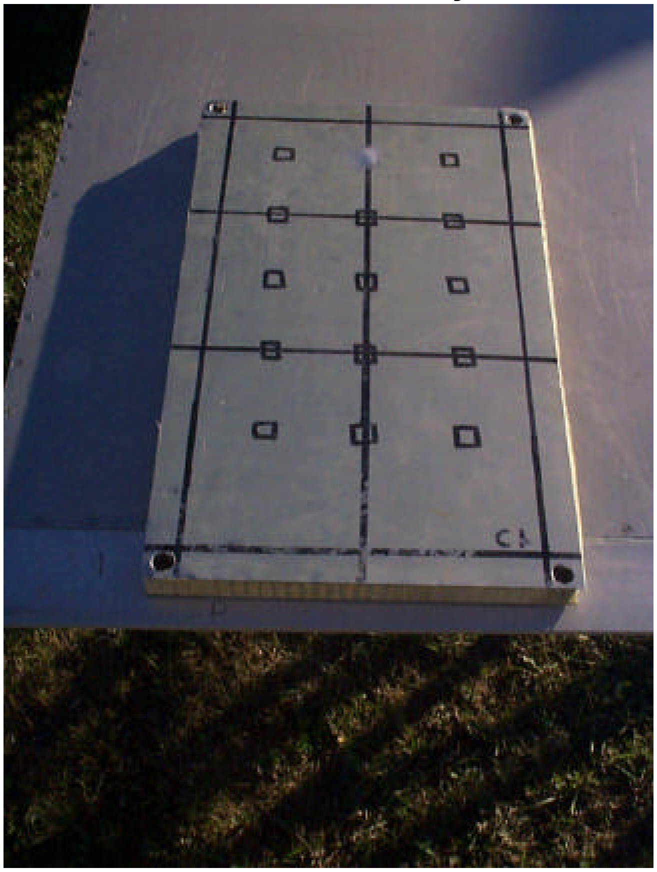
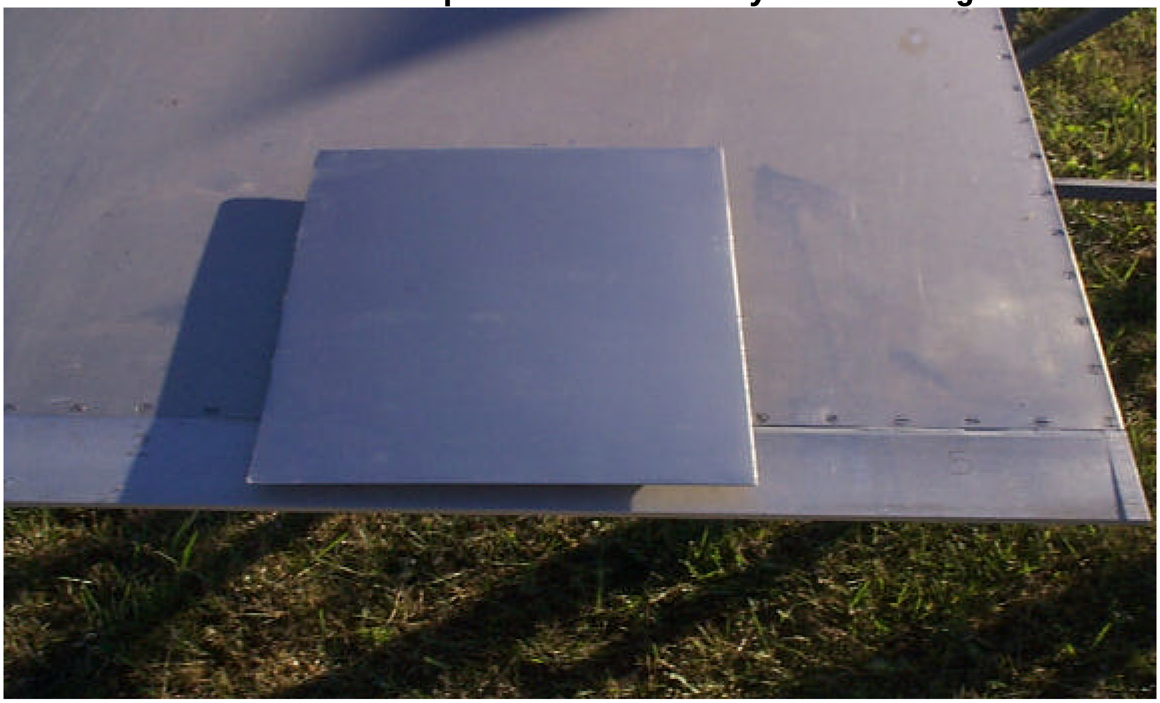


Photo 3.19
Test Plate – Composite Fibre on Honeycomb Backing



4. DESCRIPTION AND PROCESSING OF DATA

4.1 Overview of Tests

Tests were conducted from March 23 to 25, 1999. The initial test conditions were at the cold extreme (-12°C) of the range of test temperatures. Test condition temperatures were progressively increased over the three-day period.

During the first series of tests (at the coldest test temperatures), it was noted that the time interval until first freezing occurred was less than the three-minute target. To explore the causes of this shortfall, a number of tests were conducted with changes to various parameters. These included varying the amount of fluid sprayed, spraying with a different nozzle setting to produce a different spray pattern, and applying the fluid by pouring using fluid spreaders as used in the Deicing Only and First Step Fluid (2) study. Results of these variations are discussed in detail in the following chapter.

Further variations in parameters were tested during the next two days of trials at progressively warmer temperatures and are discussed in the next chapter.

A log of all trials conducted, including the special repeat trials conducted to explore test result anomalies, is presented in Table 4.1. Some of the columns in this log require explanation:

- ID # – is the sequential number of each test as it was run;
- Form # – up to three tests could be recorded on a single data form. The data forms were numbered sequentially from the start of testing;
- Run # – corresponds to the original run number in the detailed test plan (Figure 3.2). Some of the runs were conducted more than once to provide a level of confidence in the results or to explore unexpected results. Also, some runs (where no number is assigned) were ad hoc trials conducted to explore the effect of changes in parameter values;
- Plate # – is the number recorded on the plate, and on the thermistor probe. It serves to link the correct plate temperature data in the file to specific test runs;
- Plate exposure time – is the time that the plate was uncovered and exposed to precipitation to collect a layer of contamination;

TABLE 4.1 (Pg. 1/3)

HOT WATER DEICING AT NRC - WINTER 1999

ID #	Form #	Date	Run #	Plate #	Surface Type	Fluid Type	Fluid Temp. (°C)	Ambient Temp (Design) (°C)	Ambient Temp (Actual) (°C)	Wind Speed km/h	Plate Expos. Time	Spray Start Time	Spray Finish Time	Time of 1st Freeze	Time of Failure	Fluid Qty. (ml)	Exposure Interval (min)	Interval to 1st Freeze (min)	Interval to Complete Failure (min)	Comments
1	1	23-Mar-99	49	1	Aluminum	Water	60	-12	-11.5	0	11:21:54	11:22:53	11:23:04	11:25:35	11:26:40	281	1.0	2.5	3.6	
2	1	23-Mar-99	49	3	Aluminum	Water	60	-12	-11.6	0	11:28:03	11:29:03	11:29:15	11:31:13	11:33:00	306	1.0	2.0	3.8	
3	1	23-Mar-99	49	2	Aluminum	Water	60	-12	-11.6	0	11:34:45	11:35:54	11:36:07	11:39:20	11:40:05	332	1.2	3.2	4.0	
4	2	23-Mar-99	49	1	Aluminum	Water	60	-12	-11.7	0	11:52:44	11:53:44	11:53:57	11:56:13	11:57:22	332	1.0	2.3	3.4	
5	2	23-Mar-99	49	3	Aluminum	Water	60	-12	-11.7	0	11:56:32	11:57:32	11:57:52	11:59:50	12:02:27	500	1.0	2.0	4.6	1/2 liter with sprayer
6	2	23-Mar-99	49	2	Aluminum	Water	60	-12	-11.8	0	12:11:40	12:12:40	12:12:50	12:17:20	12:18:14	500	1.0	4.5	5.4	1/2 liter wih spreader
7	3	23-Mar-99	50	1	Aluminum	T1E-9	60	-12	-11.9	0	12:18:56	12:19:58	12:20:10	12:22:20	12:23:41	306	1.0	2.2	3.5	
8	3	23-Mar-99	50	2	Aluminum	T1E-9	60	-12	-11.9	0	12:24:27	12:25:27	12:25:38	12:28:40	12:29:40	281	1.0	3.0	4.0	
9	4	23-Mar-99	57	2	Aluminum	T1E-9	60	-12	-12.1	10	13:53:19	13:54:19	13:54:30	13:55:40	13:56:45	281	1.0	1.2	2.3	
10	4	23-Mar-99	57	3	Aluminum	T1E-9	60	-12	-12.1	10	13:57:00	13:58:00	13:58:11	13:59:00	14:00:40	281	1.0	0.8	2.5	
11	4	23-Mar-99	57	1	Aluminum	T1E-9	60	-12	-12.1	10	14:00:30	14:01:30	14:01:50	14:03:17	14:04:50	510	1.0	1.5	3.0	double fluid quantity sprayed
12	5	23-Mar-99	58	C1	C1	T1E-9	60	-12	-12.1	10	14:05:48	14:06:46	14:07:02	14:08:00	14:08:50	408	1.0	1.0	1.8	
13	6	23-Mar-99	58	C1	C1	T1E-9	60	-12	-12.0	10	15:00:10	15:01:10	15:01:22	15:02:30	15:03:10	306	1.0	1.1	1.8	
14	6	23-Mar-99	59	C3	C3	T1E-9	60	-12	-12.0	10	15:02:10	15:03:10	15:03:20	15:05:10	15:06:30	255	1.0	1.8	3.2	
15	6	23-Mar-99	61	C5	C5	T1E-9	60	-12	-12.0	10	15:05:35	15:06:40	15:06:53	15:08:00	15:09:50	332	1.1	1.1	3.0	
16	7	23-Mar-99	57	1	Aluminum	T1E-9	60	-12	-12.0	10	15:10:50	15:11:49	15:12:05	15:14:00	15:14:50	408	1.0	1.9	2.8	
17	7	23-Mar-99	60	C4	C4	T1E-9	60	-12	-12.0	10	15:08:20	15:09:22	15:09:27	15:11:15	15:12:20	128	1.0	1.8	2.9	
18	8	23-Mar-99	52	2	Aluminum	Water	60	-12	-12.0	10	14:13:38	14:14:38	14:14:58	14:16:15	14:17:48	510	1.0	1.3	2.8	double quantity
19	8	23-Mar-99	53	C1	C1	Water	60	-12	-11.9	10	14:16:05	14:17:03	14:17:11	14:18:15	14:18:45	204	1.0	1.1	1.6	
20	8	23-Mar-99	52	3	Aluminum	Water	60	-12	-11.9	10	14:18:05	14:19:10	14:19:22	14:20:37	14:21:45	306	1.1	1.3	2.4	
21	9	23-Mar-99	55	C4	C4	Water	60	-12	-11.9	10	14:24:00	14:25:03	14:25:16	14:26:00	14:28:00	332	1.1	0.7	2.7	
22	9	23-Mar-99	56	C5	C5	Water	60	-12	-11.9	10	14:32:25	14:33:25	14:33:31	14:34:30	14:36:05	153	1.0	1.0	2.6	short spray time
23	9	23-Mar-99	53	C1	C1	Water	60	-12	-11.9	10	14:35:50	14:36:50	14:37:01	14:38:00	14:38:55	281	1.0	1.0	1.9	
24	10	23-Mar-99	54	C3	C3	Water	60	-12	-11.9	10	14:37:30	14:38:30	14:38:41	14:39:40	14:41:05	281	1.0	1.0	2.4	
25	11	23-Mar-99	extra	1	Aluminum	Water	60	-12	-12.3	10	16:39:57	16:40:57	16:41:18	16:42:10	16:42:45	284	1.0	0.9	1.5	10sec--135mL Special test with different nozzle
26	11	23-Mar-99	extra	2	Aluminum	Water	60	-12	-12.3	10	16:43:30	16:44:11	16:44:25	16:45:10	16:46:10	386	0.7	0.8	1.8	10sec--275mL;special test different nozzle
27	12	23-Mar-99		1	Aluminum	Water	60	-12	-12.2	10	16:10:53	16:11:52	16:12:12	16:14:02	16:14:45	510	1.0	1.8	2.6	double quantity;spray start 20 sec
28	12	23-Mar-99		2	Aluminum	Water	60	-12	-12.2	10	16:12:47	16:13:20	16:14:00	16:16:40	16:17:10	1020	0.6	2.7	3.2	spray start 40 sec
29	13	23-Mar-99		1	Aluminum	XL54(std)	60	-12	-12.2	10	15:46:20	15:47:26	15:47:44	15:50:13	15:51:30	459	1.1	2.5	3.8	sprayed;special test
30	13	23-Mar-99		3	Aluminum	XL54(std)	60	-12	-12.1	10	16:02:06		16:02:06	16:05:10	16:06:20	500	0.0	3.1	4.2	poured(bare plate);special test
31	13	23-Mar-99		1	Aluminum	XL54(std)	60	-12	-12.2	10	16:25:40	16:27:50	16:28:03	16:30:22	16:31:37	332	2.2	2.3	3.6	sprayed;spray finish-13sec;special test
32	14	24-Mar-99	36	C5	C5	Water	60	-9	-8.8	10	9:51:42	9:52:42	9:52:49	9:53:30	9:55:20	179	1.0	0.7	2.5	
33	14	24-Mar-99	35	C4	C4	Water	60	-9	-8.7	10	9:55:46	9:55:59	9:56:08	9:57:07	9:59:00	230	0.2	1.0	2.9	
34	15	24-Mar-99	32	2	Aluminum	Water	60	-9	-8.7	10	9:53:05	9:54:03	9:54:14	9:54:55	9:56:25	281	1.0	0.7	2.2	
35	15	24-Mar-99	33	C1	C1	Water	60	-9	-8.6	10	9:54:38	9:55:38	9:55:49	9:56:55	9:57:50	281	1.0	1.1	2.0	
36	15	24-Mar-99	32	1	Aluminum	Water	60	-9	-9.1	10	9:58:08	9:59:06	9:59:16	10:00:40	10:01:30	255	1.0	1.4	2.2	
37	16	24-Mar-99	34	C3	C3	Water	60	-9	-9.3	10	10:00:20	10:01:20	10:01:30	10:03:10	10:04:35	255	1.0	1.7	3.1	
38	16	24-Mar-99	33	C1	C1	Water	60	-9	-9.4	10	10:14:36	10:15:36	10:15:47	10:17:06	10:17:46	281	1.0	1.3	2.0	
39	16	24-Mar-99	34	C3	C3	Water	60	-9	-9.4	10	10:18:43	10:19:43	10:19:54	10:21:10	10:22:30	281	1.0	1.3	2.6	
40	17	24-Mar-99		1	Aluminum	Water	60	-9	-9.4	10		10:15:37	10:15:37	10:17:15	10:18:15	500	0.0	1.6	2.6	No contamination;1/2 liter poured
41	18	24-Mar-99	36	C5	C5	Water	60	-9	-9.4	10	10:15:45	10:16:45	10:16:58	10:18:56	10:19:28	332	1.0	2.0	2.5	
42	18	24-Mar-99	35	C4	C4	Water	60	-9	-9.4	10	10:17:19	10:18:26	10:18:36	10:19:45	10:20:58	255	1.1	1.2	2.4	
43	19	24-Mar-99	32	1	Aluminum	Water	60	-9	-9.4	10	10:21:30	10:22:28	10:22:48	10:25:03	10:25:46	510	1.0	2.3	3.0	20 sec spray
44	20	24-Mar-99	41	6	C5	T1E-6	60	-9	-9.5	10	11:22:45	11:23:45	11:23:56	11:25:11	11:26:17	281	1.0	1.3	2.4	
45	20	24-Mar-99	40	4	C4	T1E-6	60	-9	-9.5	10	11:24:35	11:25:35	11:25:45	11:27:29	11:28:00	255	1.0	1.7	2.3	
46	21	24-Mar-99	37	1	Aluminum	T1E-6	60	-9	-9.3	10	11:29:40	11:30:38	11:30:53	11:32:53	11:33:30	383	1.0	2.0	2.6	
47	21	24-Mar-99	38	C1	C1	T1E-6	60	-9	-9.4	10	11:27:32	11:28:32	11:28:33	11:30:01	11:31:05	26	1.0	1.5	2.5	Low fluid quantity
48	21	24-Mar-99	39	C3	C3	T1E-6	60	-9	-9.4	10	11:31:40	11:32:39	11:32:54	11:34:25	11:35:25	383	1.0	1.5	2.5	
49	22	24-Mar-99	37	2	Aluminum	T1E-6	60	-9	-9.4	10	11:57:17	11:58:27	11:58:43	12:00:31	12:01:34	408	1.2	1.8	2.9	
50	22	24-Mar-99	38	C1	C1	T1E-6	60	-9	-9.6	10	11:50:57	11:51:58	11:52:11	11:53:16	11:54:20	332	1.0	1.1	2.2	
51	22	24-Mar-99	39	C3	C3	T1E-6	60	-9	-9.4	10	11:53:35	11:54:32	11:54:44	11:56:20	11:57:35	306	1.0	1.6	2.9	

TABLE 4.1 (Pg. 2/3)

HOT WATER DEICING AT NRC - WINTER 1999

ID #	Form #	Date	Run #	Plate #	Surface Type	Fluid Type	Fluid Temp. (°C)	Ambient Temp (Design) (°C)	Ambient Temp (Actual) (°C)	Wind Speed km/h	Plate Expos. Time	Spray Start Time	Spray Finish Time	Time of 1st Freeze	Time of Failure	Fluid Qty. (ml)	Exposure Interval (min)	Interval to 1st Freeze (min)	Interval to Complete Failure (min)	Comments
52	23	24-Mar-99	40	C4	C4	T1E-6	60	-9	-9.4	10	11:57:11	11:58:11	11:58:26	11:59:48	12:00:56	383	1.0	1.4	2.5	
53	23	24-Mar-99	41	C5	C5	T1E-6	60	-9	-9.4	10	11:59:32	12:00:32	12:00:49	12:01:59	12:02:47	434	1.0	1.2	2.0	
54	24	24-Mar-99		3	Aluminum	T1E-6	60	-9	-9.5	10	12:10:16	12:15:16	12:15:37	12:16:58	12:18:22	536	5.0	1.4	2.8	5 MIN EXPOSURE TIME FOR PLATE
55	24	24-Mar-99		2	Aluminum	XL54(std)	60	-9	-9.4	10	12:21:55	12:22:55	12:22:55	12:25:41	12:26:41	500	1.0	2.8	3.8	poured
56	25	24-Mar-99		1	Aluminum	XL54(std)	60	-9	-9.6	10	12:35:15	12:36:15	12:36:30	12:38:45	12:40:20	383	1.0	2.3	3.8	
57	25	24-Mar-99		3	Aluminum	XL54(std)	60	-9	-9.5	10	12:38:21	12:39:21	12:39:41	12:42:45	12:43:38	510	1.0	3.1	4.0	
58	25	24-Mar-99		2	Aluminum	XL54(std)	60	-9	-9.5	10	12:40:16	12:41:16	12:41:56	12:45:30	12:47:10	1020	1.0	3.6	5.2	
59	26	24-Mar-99	29	1	Aluminum	Water	60	-9	-9.6	0	12:59:39	13:00:39	13:00:47	13:02:12	13:04:05	204	1.0	1.4	3.3	
60	26	24-Mar-99	30	2	Aluminum	T1E-6	60	-9	-9.9	0	13:11:25	13:12:25	13:12:39	13:14:48	13:16:21	357	1.0	2.2	3.7	
61	26	24-Mar-99	29	3	Aluminum	Water	60	-9	-9.6	0	13:01:12	13:02:12	13:02:25	13:03:21	13:06:08	332	1.0	0.9	3.7	
62	27	24-Mar-99	30	1	Aluminum	T1E-6	60	-9	-10.0	0	13:21:24	13:22:24	13:22:41	13:24:30	13:26:10	434	1.0	1.8	3.5	
63	28	24-Mar-99	9	2	Aluminum	Water	60	-6	-6.0	0	14:05:40	14:06:39	14:06:50	14:10:20	14:11:35	281	1.0	3.5	4.8	
64	28	24-Mar-99	10	2	Aluminum	T1E-3	60	-6	-6.3	0	14:24:30	14:25:30	14:25:44	14:28:51	14:30:15	357	1.0	3.1	4.5	
65	29	24-Mar-99	9	1	Aluminum	Water	60	-6	-6.3	0	14:07:00	14:08:00	14:08:09	14:10:49	14:12:20	230	1.0	2.7	4.2	
66	29	24-Mar-99	10	1	Aluminum	T1E-3	60	-6	-6.3	0	14:26:10	14:27:10	14:27:21	14:29:40	14:31:27	281	1.0	2.3	4.1	
67	30	24-Mar-99	17	2	Aluminum	T1E-3	60	-6	-6.0	10	14:55:50	14:56:53	14:57:07	14:59:07	15:00:30	357	1.1	2.0	3.4	
68	30	24-Mar-99	18	C1	C1	T1E-3	60	-6	-6.0	10	14:58:27	14:59:25	14:59:36	15:01:10	15:02:10	281	1.0	1.6	2.6	
69	30	24-Mar-99	19	C3	C3	T1E-3	60	-6	-6.0	10	14:59:55	15:00:57	15:01:07	15:02:52	15:03:50	255	1.0	1.8	2.7	
70	31	24-Mar-99	17	3	Aluminum	T1E-3	60	-6	-6.0	10	15:05:00	15:06:01	15:06:12	15:07:57	15:09:12	281	1.0	1.8	3.0	
71	31	24-Mar-99	18	C1	C1	T1E-3	60	-6	-6.1	10	15:39:15	15:40:15	15:40:25	15:42:00	15:43:07	255	1.0	1.6	2.7	
72	31	24-Mar-99	19	C3	C3	T1E-3	60	-6	-6.0	10	15:41:45	15:42:46	15:42:54	15:44:28	15:45:22	204	1.0	1.6	2.5	
73	32	24-Mar-99	12	1	Aluminum	Water	60	-6	-5.9	10	15:16:27	15:17:25	15:17:37	15:19:45	15:20:45	306	1.0	2.1	3.1	
74	32	24-Mar-99	13	C1	C1	Water	60	-6	-6.0	10	15:28:00	15:29:00	15:29:11	15:30:45	15:31:57	281	1.0	1.6	2.8	
75	32	24-Mar-99	14	C3	C3	Water	60	-6	-6.0	10	15:29:25	15:30:21	15:30:30	15:32:25	15:34:07	230	0.9	1.9	3.6	
76	33	24-Mar-99	20	3	C4	T1E-3	60	-6	-6.0	10	15:46:10	15:47:10	15:47:18	15:48:56	15:49:57	204	1.0	1.6	2.7	
77	33	24-Mar-99	21	2	C5	T1E-3	60	-6	-6.0	10	15:45:40	15:46:40	15:46:42	15:48:20	15:49:24	51	1.0	1.6	2.7	Low fluid quantity
78	34	24-Mar-99	20	C4	C4	T1E-3	60	-6	-6.0	10	14:57:14	14:58:15	14:58:22	15:00:42	15:01:10	179	1.0	2.3	2.8	
79	34	24-Mar-99	21	2	C5	T1E-3	60	-6	-6.0	10	15:03:30	15:04:30	15:04:38	15:06:08	15:07:12	204	1.0	1.5	2.6	
80	35	24-Mar-99	12	2	Aluminum	Water	60	-6	-5.9	10	15:10:46	15:11:53	15:12:06	15:14:27	15:15:15	332	1.1	2.4	3.2	
81	35	24-Mar-99	13	C1	C1	Water	60	-6	-5.9	10	15:14:11	15:15:10	15:15:20	15:16:56	15:18:05	255	1.0	1.6	2.8	
82	35	24-Mar-99	14	C3	C3	Water	60	-6	-6.0	10	16:02:25	16:03:25	16:03:37	16:05:43	16:07:12	306	1.0	2.1	3.6	
83	36	24-Mar-99	15	C4	C4	Water	60	-6	-6.0	10	15:29:30	15:30:32	15:30:41	15:31:47	15:33:25	230	1.0	1.1	2.7	
84	36	24-Mar-99	16	C5	C5	Water	60	-6	-6.0	10	15:28:11	15:29:11	15:29:18	15:30:15	15:32:08	179	1.0	1.0	2.8	
85	37	24-Mar-99		3	Aluminum	T1E-3	60	-6	-6.0	10	15:47:30	15:48:30	15:48:50	15:51:18	15:52:27	510	1.0	2.5	3.6	special test 20 sec spray
86	37	24-Mar-99		2	Aluminum	Water	60	-6	-6.0	10	15:51:34	15:52:33	15:52:53	15:55:35	15:56:21	510	1.0	2.7	3.5	special test 20 sec spray
87	38	24-Mar-99	15	C4	C4	Water	60	-6	-6.0	10	16:04:15	16:05:15	16:05:22	16:06:02	16:08:28	179	1.0	0.7	3.1	
88	38	24-Mar-99	16	C5	C5	Water	60	-6	-6.0	10	16:02:58	16:03:58	16:04:07	16:05:40	16:07:26	230	1.0	1.6	3.3	
89	39	24-Mar-99		3	Aluminum	XL54(std)	60	-6	-6.0	10	16:30:00	16:31:01	16:31:13	16:33:56	16:36:00	306	1.0	2.7	4.8	
90	40	24-Mar-99		1	Aluminum	XL54(std)	60	-6	-6.0	10	16:27:20	16:28:20	16:28:38	16:31:40	16:33:18	459	1.0	3.0	4.7	spray
91	40	24-Mar-99		2	Aluminum	XL54(std)	60	-6	-5.9	10		16:42:20	16:42:29	16:46:49	16:47:25	500	0.0	4.3	4.9	poured, bare plate
92	41	24-Mar-99	24	3	Aluminum	T1E-3	60	-6	-5.9	20	17:24:07	17:25:18	17:25:29	17:26:57	17:28:09	281	1.2	1.5	2.7	
93	41	24-Mar-99	23	1	Aluminum	Water	60	-6	-5.9	20	17:26:22	17:27:29	17:27:39	17:29:09	17:30:00	255	1.1	1.5	2.4	
94	42	24-Mar-99	24	2	Aluminum	T1E-3	60	-6	-5.9	20	17:24:06	17:25:08	17:25:16	17:27:04	17:28:01	204	1.0	1.8	2.8	
95	42	24-Mar-99	23	2	Aluminum	Water	60	-6	-5.9	20	17:33:10	17:34:10	17:34:21	17:36:05	17:36:59	281	1.0	1.7	2.6	
96	43	25-Mar-99	1	2	Aluminum	Water	60	-3	-2.9	0	9:16:30	9:17:30	9:17:42	9:24:04	9:25:27	306	1.0	6.4	7.8	
97	43	25-Mar-99	1	1	Aluminum	Water	60	-3	-3.0	0	9:29:50	9:30:50	9:31:01	9:35:40	9:37:16	281	1.0	4.7	6.3	
98	44	25-Mar-99	1	3	Aluminum	Water	60	-3	-2.9	0	9:16:30	9:17:53	9:18:04	9:24:22	9:25:40	281	1.4	6.3	7.6	
99	44	25-Mar-99		2	Aluminum	Water	60	-3	-3.0	0	9:32:00	9:37:25	9:37:37	9:43:18	9:44:15	306	5.4	5.7	6.6	exposed for 5 min
100	44	25-Mar-99		3	Aluminum	Water	60	-3	-3.0	0	9:41:50	10:09:12	10:09:30	10:15:03	10:17:04	459	10.0	5.6	7.6	plate exposed till 9:51:50; 10 min
101	45	25-Mar-99		2	Aluminum	Water	60	-3	-2.9	0	10:22:07	10:23:12	10:23:20	10:30:55	10:32:30	500	1.1	7.6	9.2	poured;special test-- contamination 1 1/2 min
102	46	25-Mar-99	1	1	Aluminum	Water	60	-3	-3.0	0	10:07:07	10:07:07	10:07:13	10:15:21	10:17:03	500	0.0	8.1	9.8	poured, bare plate

TABLE 4.1 (Pg. 3/3)

HOT WATER DEICING AT NRC - WINTER 1999

ID #	Form #	Date	Run #	Plate #	Surface Type	Fluid Type	Fluid Temp. (°C)	Ambient Temp (Design) (°C)	Ambient Temp (Actual) (°C)	Wind Speed km/h	Plate Expos. Time	Spray Start Time	Spray Finish Time	Time of 1st Freeze	Time of Failure	Fluid Qty. (ml)	Exposure Interval (min)	Interval to 1st Freeze (min)	Interval to Complete Failure (min)	Comments
103	47	25-Mar-99	2	2	Aluminum	Water	60	-3	-2.6	10	10:58:35	10:59:35	10:59:43	11:02:39	11:03:30	204	1.0	2.9	3.8	
104	47	25-Mar-99	4	C3	C3	Water	60	-3	-2.6	10	10:59:57	11:00:58	11:01:05	11:03:52	11:06:00	179	1.0	2.8	4.9	
105	47	25-Mar-99	3	C1	C1	Water	60	-3	-2.5	10	11:05:45	11:06:44	11:06:56	11:09:28	11:10:30	306	1.0	2.5	3.6	
106	48	25-Mar-99	5	C4	C4	Water	60	-3	-2.6	10	10:58:45	10:59:45	10:59:52	11:03:28	11:04:16	179	1.0	3.6	4.4	
107	48	25-Mar-99	6	C5	C5	Water	60	-3	-2.5	10	11:00:10	11:01:10	11:01:15	11:03:42	11:05:34	128	1.0	2.5	4.3	
108	49	25-Mar-99		2	Aluminum	Water	60	-3	-2.5	10	11:33:06	11:34:08	11:34:15	11:37:45	11:39:40	500	1.0	3.5	5.4	poured contaminated 1/2 liter
109	50	25-Mar-99	5	C4	C4	Water	60	-3	-2.4	10	11:52:25	11:53:25	11:53:32	11:56:11	11:57:58	179	1.0	2.7	4.4	
110	50	25-Mar-99	6	C5	C5	Water	60	-3	-2.4	10	11:50:09	11:51:09	11:51:14	11:53:41	11:56:05	128	1.0	2.5	4.9	
111	50	25-Mar-99		3	Aluminum	Water	60	-3	-2.4	10		11:47:20	11:47:28	11:51:48	11:53:11	500	0.0	4.3	5.7	poured, bare plate
112	51	25-Mar-99	2	3	Aluminum	Water	60	-3	-2.5	10	11:08:20	11:09:20	11:09:30	11:12:50	11:14:10	255	1.0	3.3	4.7	
113	51	25-Mar-99	3	C1	C1	Water	60	-3	-2.4	10	11:48:10	11:49:10	11:49:11	11:51:55	11:52:55	26	1.0	2.7	3.7	
114	51	25-Mar-99	4	C3	C3	Water	60	-3	-2.5	10	12:04:10	12:05:10	12:05:16	12:08:20	12:10:20	153	1.0	3.1	5.1	
115	52	25-Mar-99	7	2	Aluminum	Water	60	-3	-2.4	20	12:40:11	12:41:11	12:41:21	12:44:36	12:45:11	255	1.0	3.3	3.8	
116	52	25-Mar-99	7	3	Aluminum	Water	60	-3	-2.4	20	12:40:41	12:41:41	12:41:48	12:44:42	12:45:58	179	1.0	2.9	4.2	
117	53	25-Mar-99	8	2	Aluminum	Water	60	-3	-2.3	30	14:08:07	14:09:06	14:09:17	14:12:35	14:13:35	281	1.0	3.3	4.3	
118	54	25-Mar-99	8	3	Aluminum	Water	60	-3	-2.2	30	14:09:09	14:10:20	14:10:36	14:13:09	14:14:21	408	1.2	2.6	3.8	FLUID APPL WAS STOPPED(3-4 SEC) TO ADJUST UNIT
119	55	25-Mar-99	903	2	Aluminum	Water	60	-9	-9.2	0	15:41:56	15:42:56	15:43:19	15:45:40	15:46:40	587	1.0	2.4	3.4	23 sec spray, suspect heavy ice deposit while chamber cooled
120	55	25-Mar-99	905	1	Aluminum	Water	60	-9	-9.1	0	15:43:36	15:44:36	15:44:56	15:49:00	15:49:42	510	1.0	4.1	4.8	20 sec spray
121	56	25-Mar-99	904	3	Aluminum	Water	60	-9	-9.2	0	15:41:59	15:43:10	15:43:18	15:44:27	15:47:07	204	1.2	1.2	3.8	regular spray
122	56	25-Mar-99	906	1	Aluminum	Water	60	-9	-9.3	0	16:05:50	16:06:50	16:07:30	16:12:46	16:13:30	1020	1.0	5.3	6.0	40 sec spray
123	56	25-Mar-99	904	2	Aluminum	Water	60	-9	-9.2	0	16:08:02	16:09:02	16:09:15	16:11:42	16:13:00	332	1.0	2.5	3.8	
124	57	25-Mar-99	903	3	Aluminum	Water	60	-9	-9.3	0	16:06:40	16:07:42	16:07:53	16:09:45	16:11:50	281	1.0	1.9	4.0	regular spray
125	57	25-Mar-99	905	3	Aluminum	Water	60	-9	-9.6	0	16:29:50	16:30:50	16:31:10	16:36:10	16:36:22	510	1.0	5.0	5.2	20 sec spray
126	58	25-Mar-99	907	2	Aluminum	T1E-6	60	-9	-9.5	0	16:34:25	16:35:25	16:35:36	16:38:17	16:39:58	281	1.0	2.7	4.4	
127	58	25-Mar-99	908	1	Aluminum	T1E-6	60	-9	-9.5	0	16:35:48	16:36:48	16:36:58	16:38:59	16:40:48	255	1.0	2.0	3.8	
128	59	25-Mar-99	902	C1	Aluminum	Water	60	-9	-9.4	0	16:40:00	16:41:00	16:41:05	16:45:35	16:46:20	500	1.0	4.5	5.3	poured 1/2 liter on contaminated plate; no fluild bottom right corner; C1 sensor used
129	59	25-Mar-99	901	C3	Aluminum	Water	60	-9	-9.8	0		16:58:05	16:58:13	17:01:40	17:02:47	500	0.0	3.5	4.6	pour on bare plate; fluid did not reach left side of plate(dry); c3 sensor used
130	60	25-Mar-99	916	2	Aluminum	T1E-6	60	-9	-9.2	10	17:27:56	17:28:58	17:29:10	17:30:45	17:32:00	306	1.0	1.6	2.8	
131	60	25-Mar-99	910	1	Aluminum	Water	60	-9	-8.8	10	17:34:40	17:35:40	17:35:40	17:37:30	17:38:35	500	1.0	1.8	2.9	pour 1/2 liter on contaminated plate; ignore bottom right edge
132	61	25-Mar-99	911	C1	Aluminum	Water	60	-9	-8.7	10	17:48:50	17:49:55	17:50:08	17:51:53	17:52:20	332	1.1	1.8	2.2	
133	61	25-Mar-99	912	C3	Aluminum	Water	60	-9	-8.8	10	17:50:10	17:52:01	17:52:12	17:53:47	17:54:20	281	1.9	1.6	2.1	
134	62	25-Mar-99	915	3	Aluminum	T1E-6	60	-9	-9.1	10	17:39:15	17:40:15	17:40:30	17:42:48	17:43:37	383	1.0	2.3	3.1	
135	62	25-Mar-99	913	2	Aluminum	Water	60	-9	-8.9	10	17:53:20	17:54:20	17:54:40	17:56:38	17:57:25	510	1.0	2.0	2.8	20 sec spray
136	63	25-Mar-99	917	2	Aluminum	Water	60	-9	-8.9	20	18:15:52	18:16:52	18:17:06	18:17:55	18:18:54	357	1.0	0.8	1.8	
137	63	25-Mar-99	918	3	Aluminum	Water	60	-9	-8.9	20	18:16:05	18:17:14	18:17:26	18:18:02	18:19:10	306	1.2	0.6	1.7	
138	64	25-Mar-99	919	1	Aluminum	T1E-6	60	-9	-8.7	20	18:20:45	18:21:15	18:21:35	18:23:36	18:24:00	510	0.5	2.0	2.4	
139	64	25-Mar-99	920	1	Aluminum	T1E-6	60	-9	-8.7	20	18:21:17	18:22:17	18:22:29	18:24:10	18:24:55	306	1.0	1.7	2.4	

Note: - Fluid type code T1E-3 denotes Type I fluid, ethylene glycol-based, freeze point of -3°C
- All tests were exposed to Freezing Rain Precipitation (25 g/dm²/hr)

Legend:

Aluminum	Al
Aluminum Honeycomb	C1
Carbon Fibre on Honeycomb	C3
Glass Fibre on Honeycomb	C4
Kevlar on Honeycomb	C5

- Spray Start Time & Spray Finish Time – the time difference is the total spray duration, and is used to calculate the amount of fluid applied;
- Time of 1st Freeze – is the time when freezing is first observed anywhere on the test surface. This interval is not equivalent to plate failure calls in holdover trials involving contamination over 1/3 of the plate surface, but corresponds to the *initial fluid failure* time;
- Time of Total Plate Failure – is the time when the plate surface is completely covered with ice;
- Fluid Quantity – is a calculated value based on spray duration and sprayer flow rates;
- Exposure Interval – The time differential between plate exposure time and the spray start time is the total duration of exposure to precipitation prior to testing;
- Interval to 1st Freeze – the elapsed time from spray application to time of 1st freeze;
- Interval to Complete Failure – the elapsed time from spray application until the complete plate surface has been covered with frozen fluid; and
- Comments – describe point of interest or any modifications to test parameters.

4.2 Description of Data Collected and Analysis

The log of tests (Table 4.1) incorporates all-important data recorded. Of prime interest is the time interval until the onset of freezing following spray application.

Concentration of Type I fluid as it progressively dilutes under the freezing rain precipitation is also important. Figure 4.1 provides a sample of a completed form showing progressive Brix values and corresponding time.

Temperature profiles of test plate surfaces is the other key element, and provides a basis of inferring the significance of a fluid freeze point value at any point in time. This data was continuously logged in a database.

Data was analysed by grouping selected tests and presenting them in two main chart types.

FIGURE 4.1

HOT WATER TRIALS

BRIX PROGRESSION

DATE: 23-Mar-99

OAT: -12 °C

	RH (%)	Wind Speed (km/h)			
		Top Left	Top Right	Bottom Left	Bottom Right
Start	-	10	10	10	10
End	-	10	10	10	10

Plate Position: 4

Run #: 62

Surface Type: Aluminum

Fluid Type: T1E (-9)

Fluid Brix: 14 °

Fluid Temperature: 60 °

Plate Exposure Start Time: ______ (hh:mm:ss)

Spray Start Time 14:59:47 (hh:mm:ss)

Spray Finish time 15:00:03 (hh:mm:ss)

	1	2	3	4	5	6	7	8	9	10
Time (min)	15:00:14	15:00:33	15:00:48	15:01:02	15:01:32	15:02:09	15:02:30	15:02:41	15:03:09	
Brix	15	10.5	10.75	10	9.5	7.5	5.75	5.75	5	
	11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Time (min)										
Brix										

Comments on Final Plate Condition:

MEASUREMENTS BY:

HANDWRITTEN BY:

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At: Box
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The first type of chart plots the time interval from fluid application until first freezing, versus OAT. These charts give an indication of the relationship between time intervals and OAT values, and provide an overall appreciation of values of time intervals observed. Figure 4.2 is a sample of that type of chart.

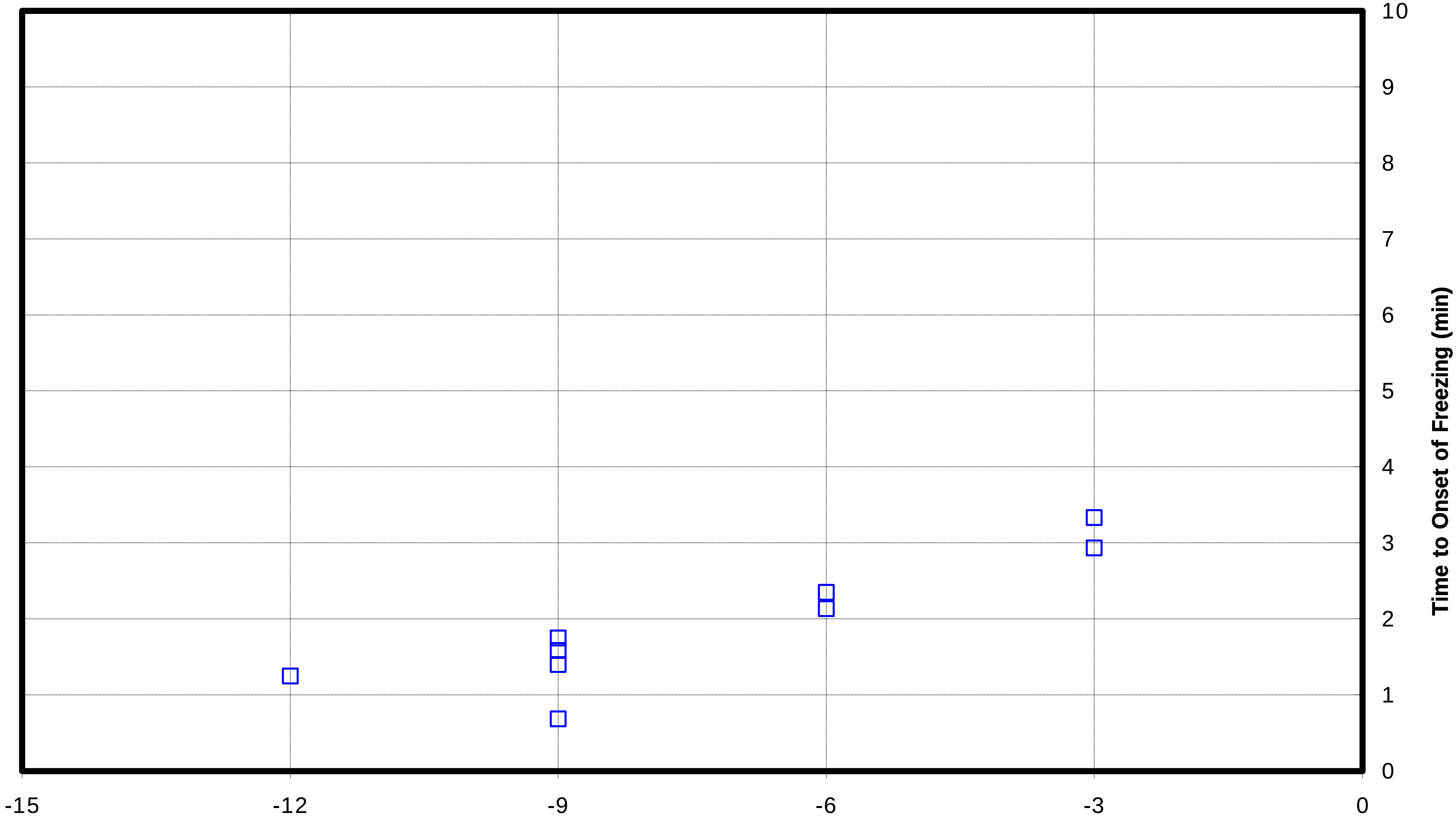
The second type of chart plots temperature and fluid freeze point profiles of selected runs. This chart type enables a better understanding and comparison of the time for test surfaces to cool under various test conditions, and graphically displays the differential between fluid freeze point and surface temperature as it diminishes with time. Figure 4.3 is a sample of that type of chart.

FIGURE 4.2

HOT WATER DEICING TRIALS

ELAPSED TIME TO ONSET OF FREEZING - HOT WATER - WINDS 10 km/h

SIMULATED LIGHT FREEZING RAIN (25 g/dm²/hr)



cm1514/report/hotwater/Hw_w_eff.xls
At: 10 kph (2)
5/21/02, 9:34 AM

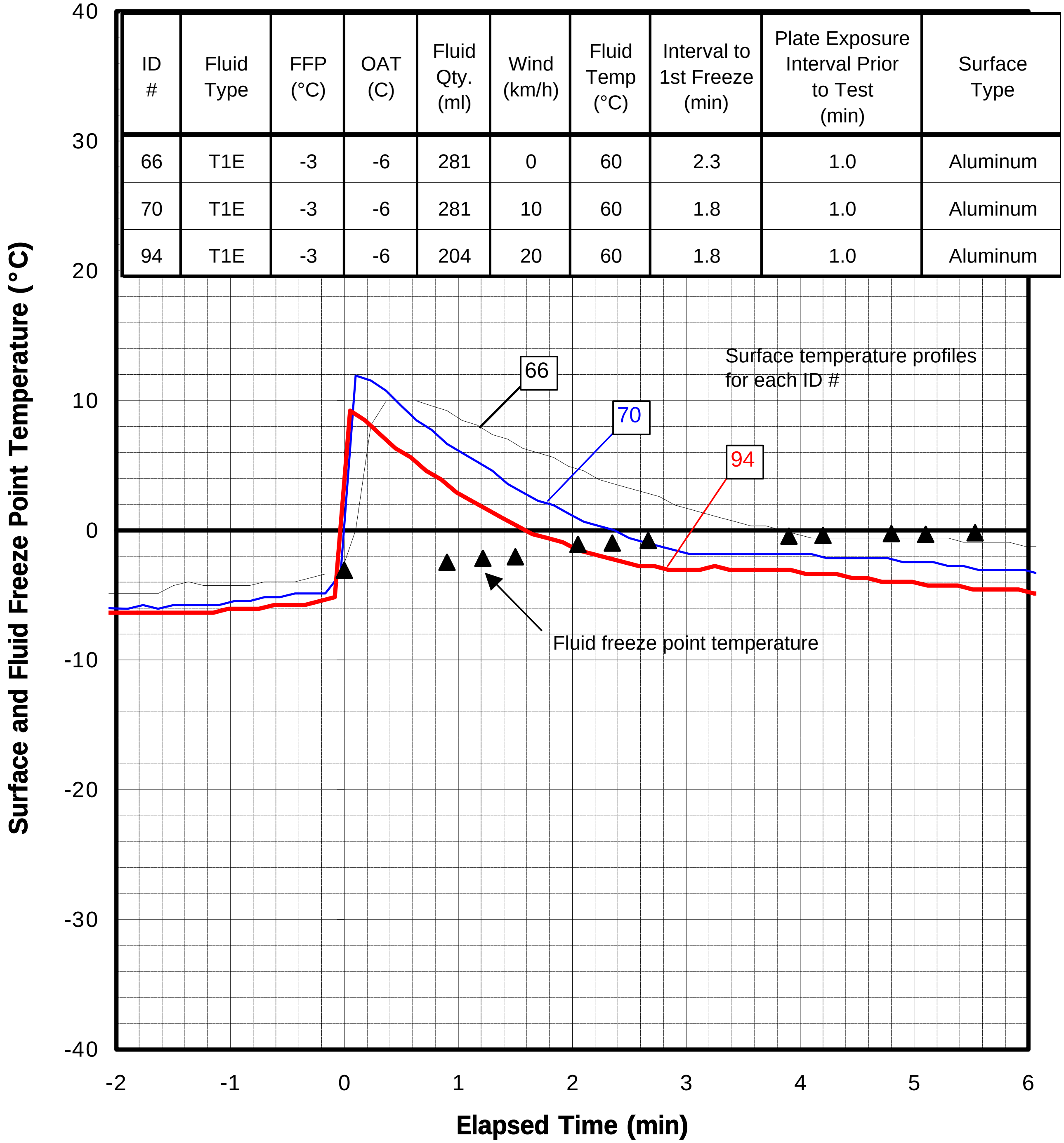
FIGURE 4.3

Effect of Wind at OAT = -6°C, Hot Type I

Simulated Light Freezing Rain (25 g/dm²/hr)

ID# 66, 70, & 94

ID #	Fluid Type	FFP (°C)	OAT (C)	Fluid Qty. (ml)	Wind (km/h)	Fluid Temp (°C)	Interval to 1st Freeze (min)	Plate Exposure Interval Prior to Test (min)	Surface Type
66	T1E	-3	-6	281	0	60	2.3	1.0	Aluminum
70	T1E	-3	-6	281	10	60	1.8	1.0	Aluminum
94	T1E	-3	-6	204	20	60	1.8	1.0	Aluminum



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5. ANALYSIS AND OBSERVATIONS

This section discusses the results of the various test runs. The key measure of performance is the value of the elapsed time from fluid application to the onset of freezing. These values are compared for various test conditions.

The discussion first examines test results from the perspective of constituting a database from which a guideline for application of hot water can be developed. The impacts of OAT, wind speed, and test surface composition are considered. The performance of hot water is compared to hot Type I fluid (both diluted and neat).

Test procedures are then examined to detect whether the test design had any significant influence on test results. This examination considers the extent to which test surfaces were allowed to develop contamination, the duration and amount of fluid sprayed, and the method of fluid application (spray versus pour).

5.1 Elapsed Time to Onset of Freezing

For the application of hot water, the relationship between elapsed time to the onset of freezing and OAT for various wind speeds is charted in Figures 5.1 to 5.4. In Figures 5.5 to 5.7 the corresponding data are presented for dilute Type I fluid, and Figure 5.8 presents the results obtained using neat Type I (XL54) fluid.

5.1.1 Hot Water

Hot water test results at all wind speeds tested show a general trend of declining values for elapsed times as a function of colder ambient temperatures. Some peculiarities apparent in the data require discussion.

A) Repeated tests at all values of OAT for calm wind conditions showed a notable scatter in results. At an OAT of –3°C, elapsed time data values varied from 4.7 to 6.3 minutes. This notable range in values did not appear to the same extent in results for tests in wind conditions. The same observation applies to tests conducted using dilute Type I fluids.

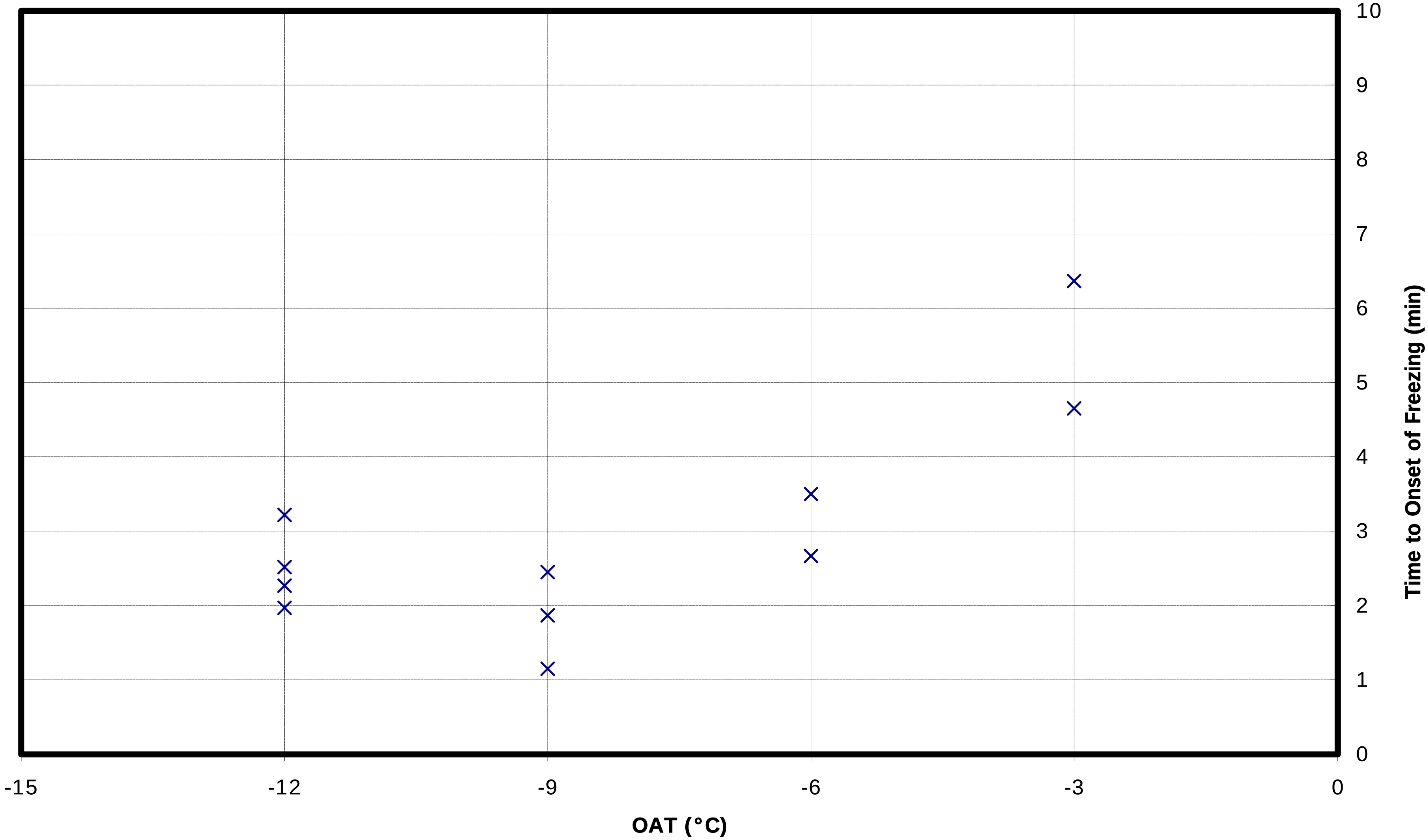
Scatter in test data for elapsed time until onset of freezing was discussed at the previously mentioned August 1998 meeting at the FAA William J. Hughes Technical Center in Atlantic City. That discussion included tabling of a study (see Appendix C)

FIGURE 5.1

HOT WATER DEICING TRIALS

ELAPSED TIME TO ONSET OF FREEZING - HOT WATER - CALM WINDS

SIMULATED LIGHT FREEZING RAIN (25 g/dm²/hr)



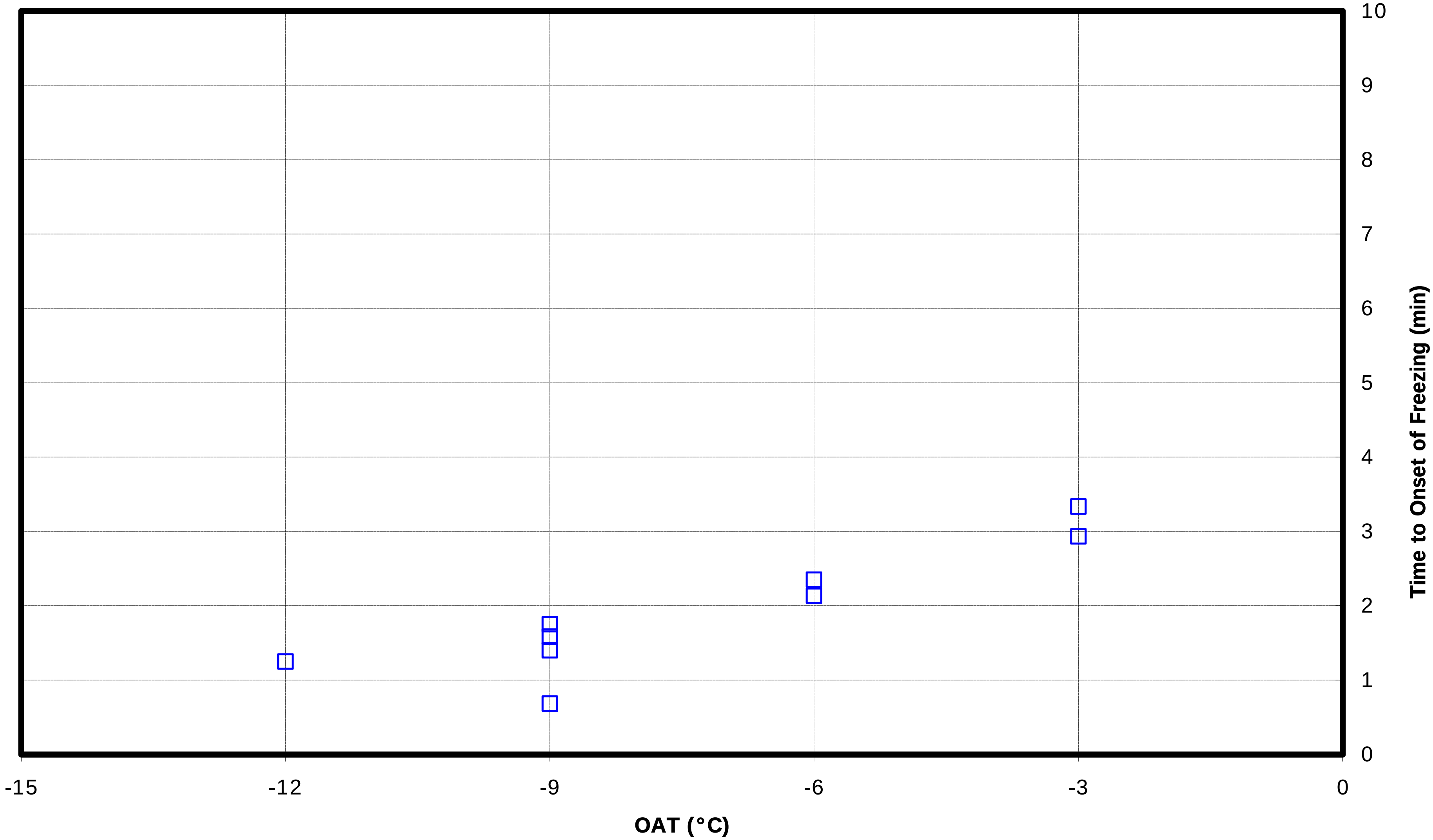
cm1514/report/hotwater/Hw_w_eff.xls
At: 0 kph
5/21/02, 9:35 AM

FIGURE 5.2

HOT WATER DEICING TRIALS

ELAPSED TIME TO ONSET OF FREEZING - HOT WATER - WINDS 10 km/h

SIMULATED LIGHT FREEZING RAIN (25 g/dm²/hr)



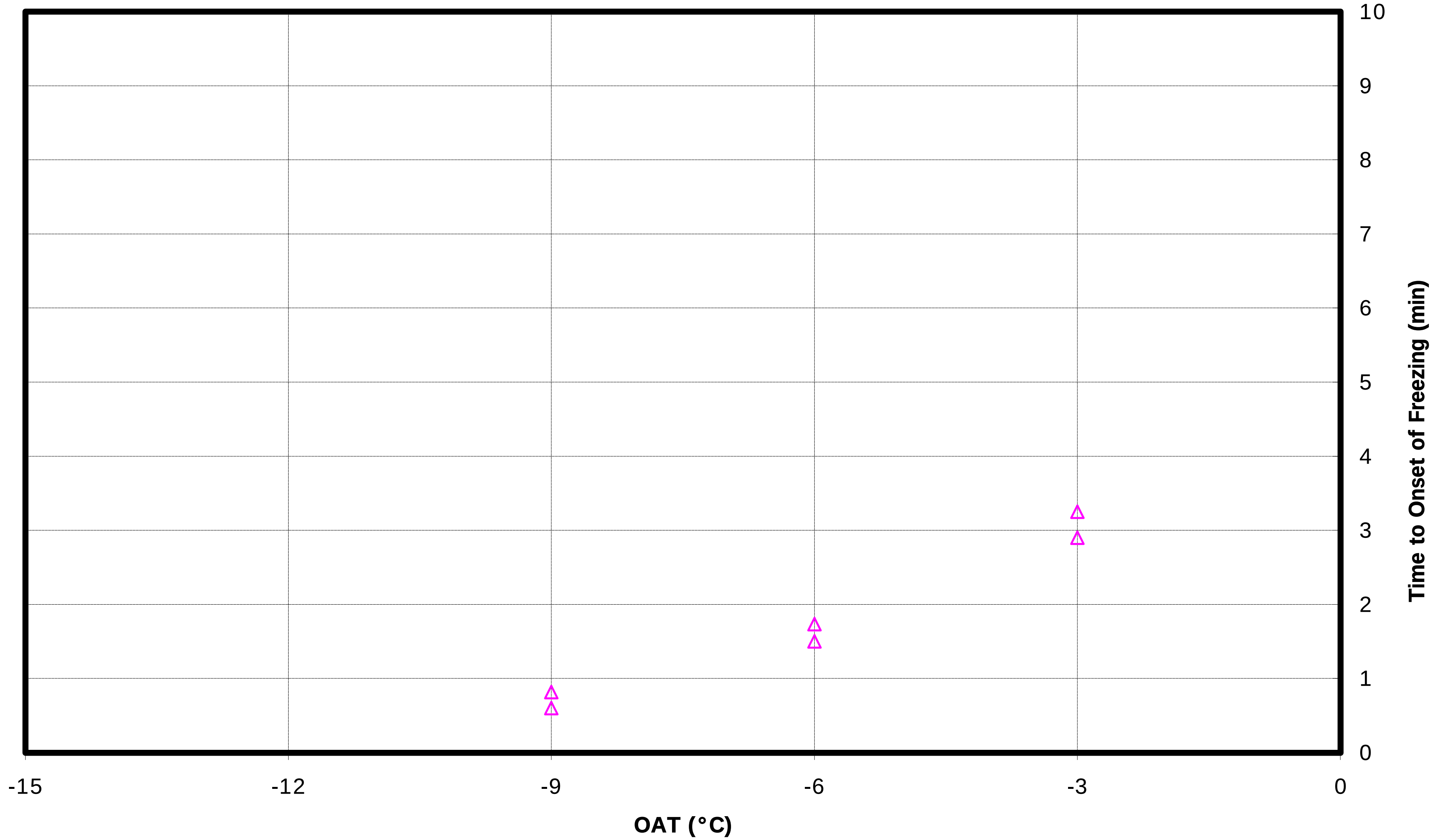
cm1514/report/hotwater/Hw_w_eff.xls
At: 10 kph
5/21/02, 10:42 AM

FIGURE 5.3

HOT WATER DEICING TRIALS

ELAPSED TIME TO ONSET OF FREEZING - HOT WATER - WINDS 20 km/h

SIMULATED LIGHT FREEZING RAIN (25 g/dm²/hr)



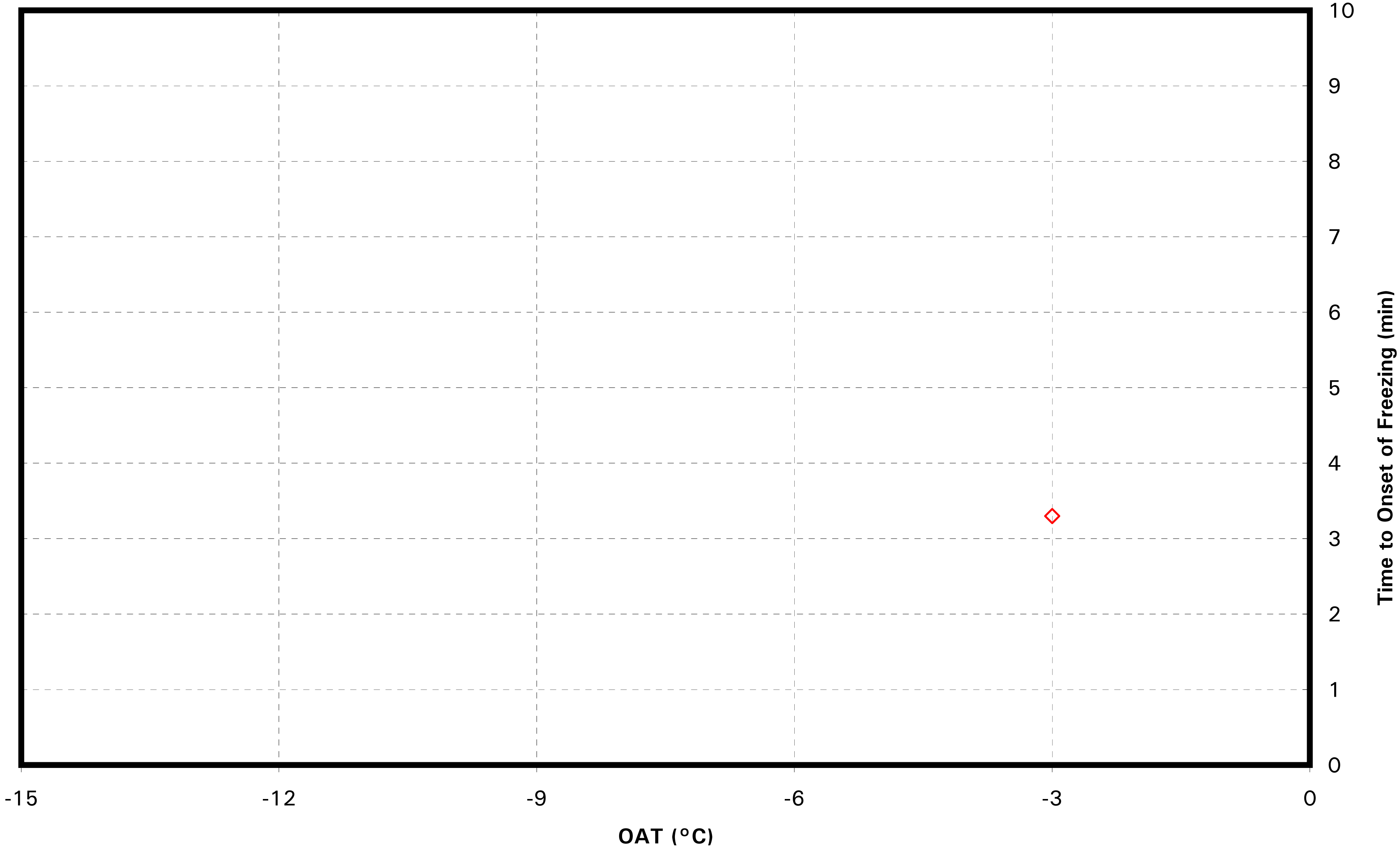
cm1514/report/hotwater/Hw_w_eff.xls
At: 20 kph
5/21/02, 9:36 AM

FIGURE 5.4

HOT WATER DEICING TRIALS

ELAPSED TIME TO ONSET OF FREEZING - HOT WATER - WINDS 30 km/h

SIMULATED LIGHT FREEZING RAIN (25 g/dm²/hr)



cm1514/report/hotwater/HW_W_EFF
At: 30 kph
1/28/2003, 3:56 PM

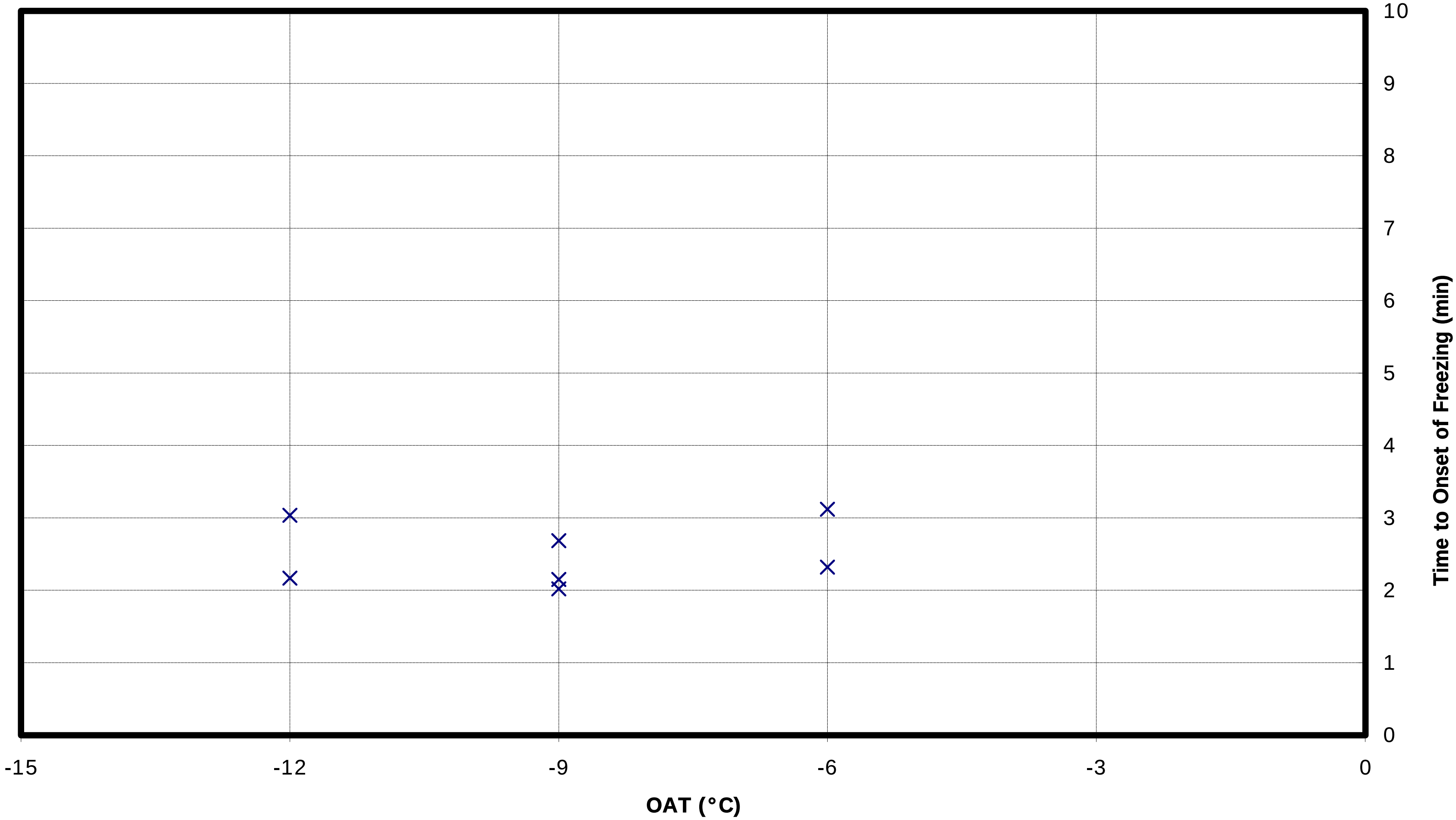
FIGURE 5.5

HOT WATER DEICING TRIALS

ELAPSED TIME TO ONSET OF FREEZING - HOT DILUTE TYPE I - CALM WINDS

SIMULATED LIGHT FREEZING RAIN (25 g/dm²/hr)

(Freeze Point at 3°C Above OAT)



cm1514/report/hotwater/T1d_w_ef.xls
At: 0 kph
5/21/02, 9:37 AM

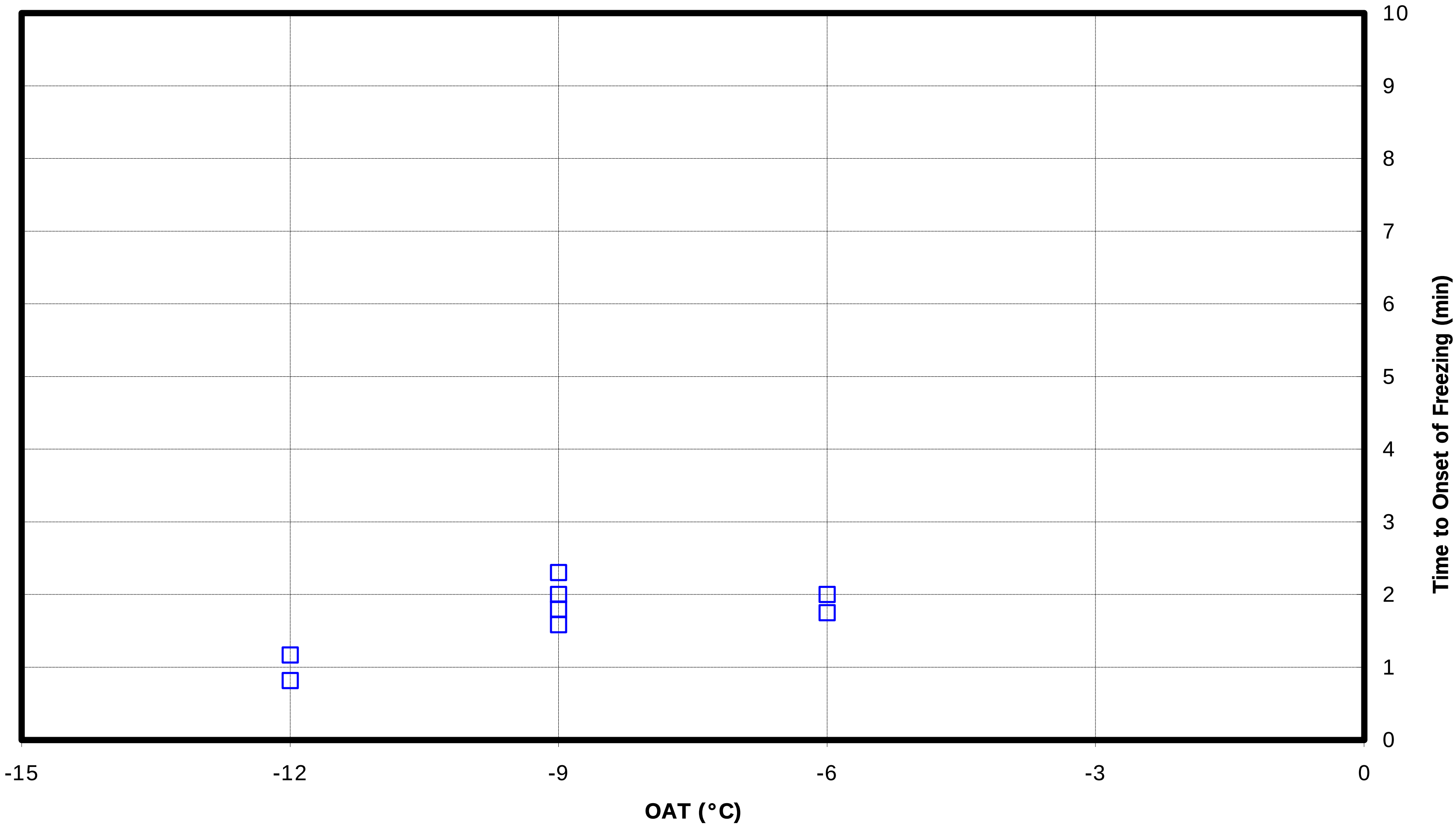
FIGURE 5.6

HOT WATER DEICING TRIALS

ELAPSED TIME TO ONSET OF FREEZING - HOT DILUTE TYPE I - WINDS 10 km/h

SIMULATED LIGHT FREEZING RAIN (25 g/dm²/hr)

(Freeze Point at 3°C Above OAT)



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5/21/02, 10:46 AM

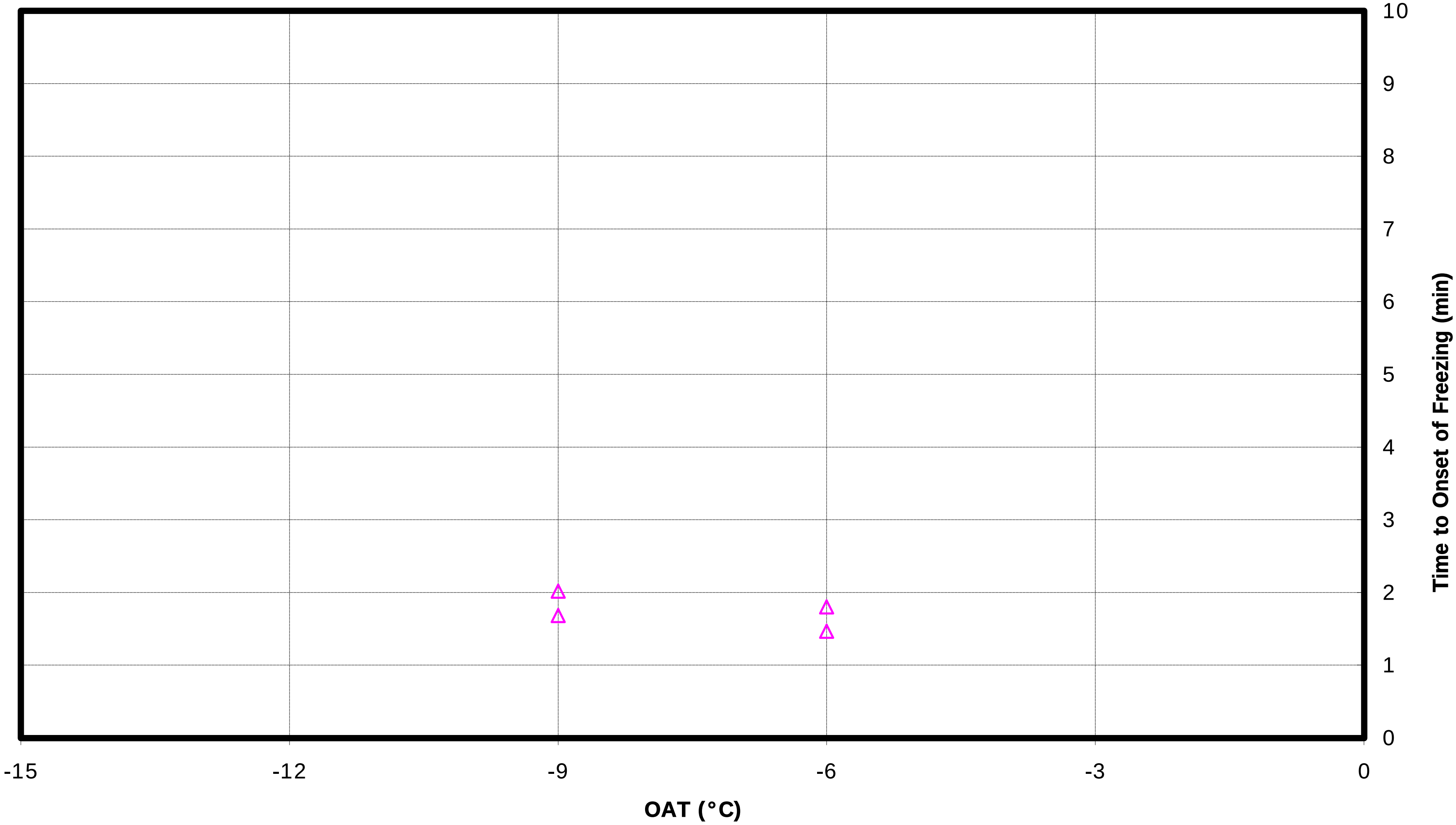
FIGURE 5.7

HOT WATER DEICING TRIALS

ELAPSED TIME TO ONSET OF FREEZING - HOT DILUTE TYPE I WINDS 20 km/h

SIMULATED LIGHT FREEZING RAIN (25 g/dm²/hr)

(Freeze Point at 3°C Above OAT)



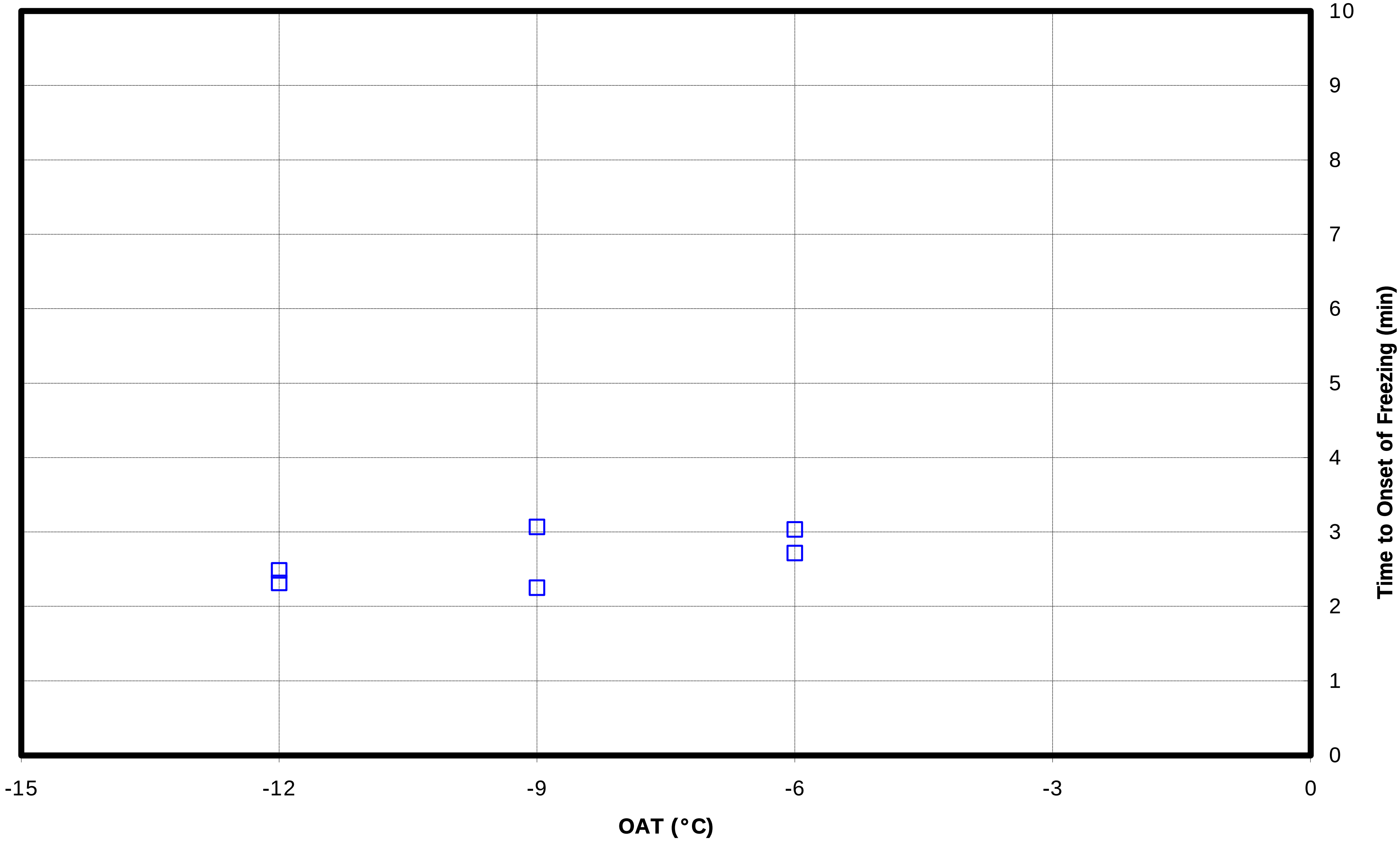
cm1514/report/hotwater/T1d_w_ef.xls
At: 20 kph
5/21/02, 9:38 AM

FIGURE 5.8

HOT WATER DEICING TRIALS

ELAPSED TIME TO ONSET OF FREEZING - HOT XL54 - WINDS 10 km/h

SIMULATED LIGHT FREEZING RAIN (25 g/dm²/hr)



cm1514/report/hotwater/Xl_w_eff.xls
At: 10 kph
5/21/02, 9:38 AM

that reported the variability in times to freeze for hot water on test plate surfaces. It should be noted that the reported study was conducted in calm conditions at an OAT of –7°C. The methods of fluid application and fluid test quantities are not reported. The cause of the variation in freezing time was assigned to nucleation of ice crystals, which may occur earlier in the presence of dust and dirt. The lower limit of the range of values reported was around two minutes, which is in line with the results of this series of tests.

B) In calm conditions, the trend line for elapsed time dropped consistently with a reduction of OAT from –3°C to –9°C, but then turned upward at –12°C. Such a result is counter-intuitive and an explanation was sought. Supplementary tests were conducted at –9°C to confirm results at that temperature. The data from those tests supported previous results. Repeated tests at –12°C in calm conditions also supported previous test data. The additional data points from the repeat tests are included in Figure 5.1. This peculiarity is discussed later in this chapter.

The upturn in trend line at –12°C is not apparent in results for tests conducted in wind conditions.

C) The data values for elapsed time at all ambient temperatures were shorter than those observed in previous tests involving hot water. In Figure 5.9, results from the 1997-98 First Step Fluid trials (reported in Figure 2.4) are compared to current test results. Test procedures for the two tests were different in that the First Step trials involved application of a standard fluid quantity (500ml) by pouring on a clean test surface, whereas, in the current trials, fluid was sprayed onto an iced surface in amounts needed to clean the surface. The impact of these procedural differences is explored in later discussions.

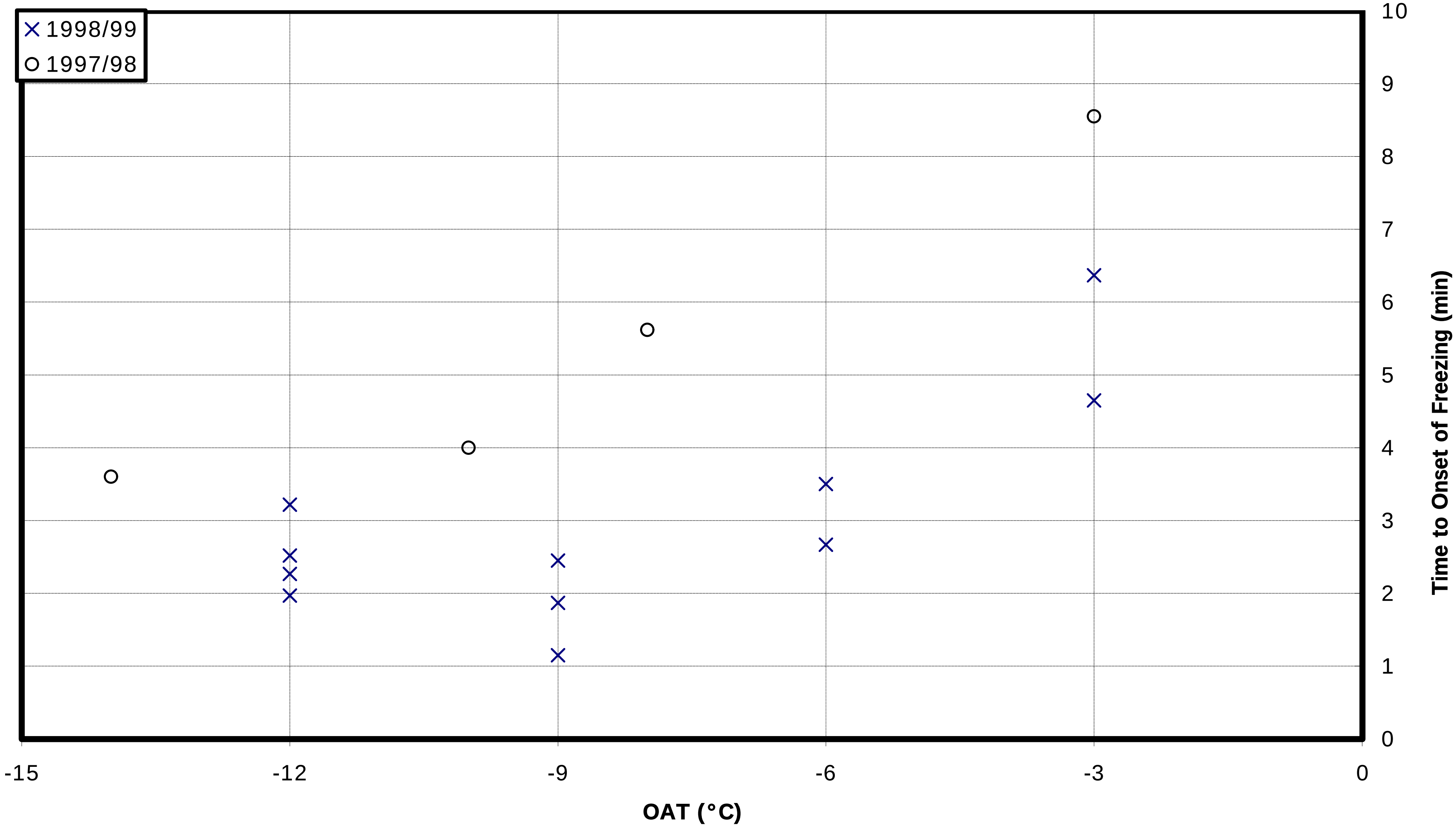
The elapsed times to initial freezing from the current study are also considerably shorter than the results of the field trials on operational aircraft conducted in March-April 1995. The 1995 trials involved spray application on the aircraft by operators experienced in hot water deicing. However, these 1995 tests were conducted in dry conditions. A review of the test record for those trials revealed that the operators sprayed varying amounts, ranging between 20 and 40 gal. (90 to 180 L) per DC-9 wing. This is equivalent to 300 to 600 ml per test plate area, for an average of 450 ml. This indicates that the test quantities in this series of trials were somewhat conservative, which would contribute to shorter elapsed times prior to freezing.

FIGURE 5.9

HOT WATER DEICING TRIALS

COMPARISON OF ELAPSED TIMES RESULTS OF 1997/98 FIRST-STEP FLUID TRIALS - CALM WINDS

SIMULATED LIGHT FREEZING RAIN (25 g/dm²/hr)



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D) Elapsed times to the onset of freezing in calm winds were 3 minutes and greater at ambient test temperatures of –3 and –6°C (Figure 5.1).

With winds of 10 km/h and at an OAT of –6°C, elapsed time dropped to between 2 and 3 minutes (Figure 5.2). The elapsed time at the OAT of –3°C was 3 minutes and above.

At a wind speed of 20 km/h, the only OAT condition producing an elapsed time of 3 minutes was at –3°C (Figure 5.3). The single test reported for wind speeds of 30 km/h (Figure 5.4) gave a similar result of 3 minutes.

Table 5.1 lists elapsed times in minutes for various OAT/wind speed combinations.

Table 5.1
Elapsed Times to Onset of Freezing for Hot Water

Wind Speed	OAT			
	–12ºC	**-9ºC**	**-6ºC**	**-3ºC**
Calm	2 and over	1 and over	2.5 and over	3 and over
10 km/h	1 and over	0.5 and over	2 and over	3 and over
20 km/h		0.5 and over	1.5 and over	3 and over
30 km/h				3 and over

5.1.2 Dilute Type I Fluid

Tests conducted with Type I fluid at the currently approved fluid freeze point limit for first-step fluid deicing (3°C above OAT) produced results very similar to hot water. This fluid was tested at only three OAT conditions, the fluid freeze point at an OAT of –3°C being equivalent to water.

In calm conditions (Figure 5.5), values for elapsed times to the onset of freezing were in the range of 2 to 3 minutes for all ambient temperatures tested. As mentioned, in calm conditions at –12°C the resulting data did not continue the expected downward trend.

At a wind condition of 10 km/h (Figure 5.6), the elapsed times were reduced to 2 minutes or less for all OAT values tested.

At a wind condition of 20 km/h (Figure 5.7), the elapsed times were reduced to less than 2 minutes for all values of OAT tested.

Table 5.2 lists elapsed times for various OAT/wind speed combinations.

Table 5.2
Elapsed Time to Onset of Freezing for Dilute Type I Fluid

Wind Speed	OAT			
	–12°C	**-9°C**	**-6°C**	**-3°C**
Calm	2 and over	1.5 and over	2.5 and over	
10 km/h	0.5 and over	1.5 and over	1.5 and over	
20 km/h		1.5 and over	1.5 and over	
30 km/h				

5.1.3 Type I Fluid Neat (XL54)

A limited number of tests were conducted with this fluid for comparison purposes, and only at wind speeds of 10 km/h (Figure 5.8).

At an OAT of -6°C an elapsed time of 2.5 to 3 minutes resulted (Table 5.3). At colder ambient temperatures, elapsed time reduced slightly to between 2 and 3 minutes.

Table 5.3
Elapsed Time to Onset of Freezing for Type I Fluid Neat

Wind Speed	OAT			
	–12°C	**-9°C**	**-6°C**	**-3°C**
Calm				
10 km/h	2 and over	2 and over	2.5 and over	
20 km/h				
30 km/h				

5.1.4 Comparison of Fluid Types

Figure 5.10 provides a comparison of results produced with wind speeds of 10 km/h by water, dilute Type I, and neat Type I fluid.

This chart demonstrates how little difference there is in the performance of the three fluids in conditions of light freezing rain. As would be expected, the neat Type I fluid performed better than either water or diluted Type I, but only marginally so at any tested OAT. Water generally performed as well or better than dilute Type I fluid. The slight improvement that full strength Type I fluid offered over water and dilute Type I fluid is explained by the rapid dilution of the freeze point depressant fluids when exposed to

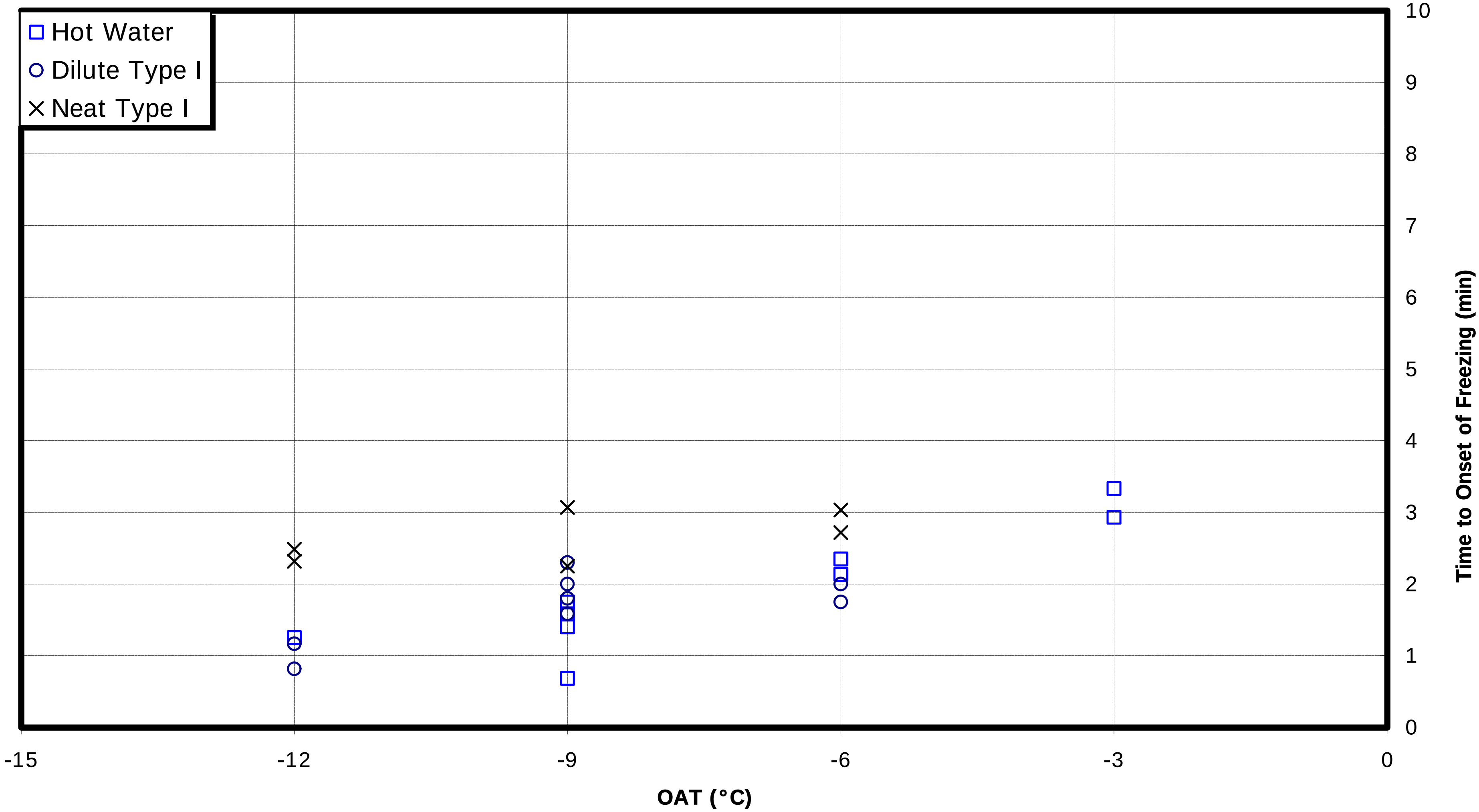
FIGURE 5.10

HOT WATER DEICING TRIALS

COMPARISON OF FLUID TYPE

ELAPSED TIME TO ONSET OF FREEZING - WINDS 10 km/h

SIMULATED LIGHT FREEZING RAIN (25 g/dm²/hr)



cm1514/report/hotwater/Hw_t1.xls
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5/21/02, 9:39 AM

the test precipitation rate (light freezing rain). This feature was discussed in Section 2.2 as part of a review of previous studies on first-step fluid freeze point buffer requirements.

Charts in which time profiles of surface temperatures and fluid freeze points are plotted versus OAT provide a further perspective on test results and are discussed in the following sections.

5.1.5 Effect of OAT

Figures 5.11, 5.12, and 5.13 illustrate the impact of OAT on the rate of cooling of the test surface. The plots of the test surface temperatures can be compared to the freeze point of the test fluid, thereby allowing an estimation of the time to the onset of freezing at the point of intersection of the two lines. It should be noted that this is purely an estimate as only a single temperature probe was installed on each test plate and first freezing usually occurred on some edge of the plate. These locations are significantly remote relative to the locations of the temperature sensors.

Figure 5.11 reports on a water spray in calm wind conditions. Four conditions of OAT are reported. The plate surface temperatures rise instantaneously at the time of fluid application. The surface temperature eventually cools down to ambient. The slope of each of the temperature profiles during the cooling period provides the rate of cooling. On close examination it can be seen that the slope increased with a drop in OAT values. The profile at OAT of –3°C has the shallowest slope and the profile at OAT of -12°C has the steepest. The same observation can be made on the other two figures. The intersection of the surface temperature profiles with the fluid freeze point (0°C) is in all cases significantly later than onset of freezing reported in the chart legend.

Further examination of Figure 5.11 provides additional explanation for the upturn in elapsed time values as the OAT moved from –9 to –12°C (noted in the previous sections). In this figure the temperature profile of the –12°C curve peaked at a value higher than the other curves. When the curves are compared to the fluid amounts reported in the legend, it can be seen that the quantity of fluid applied has a direct bearing on peak temperature value. Recall that the quantity of fluid was determined by the amount required to clean the plate surface in each test. It appears that more fluid was required to clean the surface in the colder temperature. The same observation holds for Figure 5.12. When profiles for –9 and –12°C are compared, it can be seen that the additional heat transferred to the surface in the –12°C case more than compensated for its steeper cooling profile, and resulted in a retarded intersection with the fluid freeze point (0°C).

FIGURE 5.11

Effect of OAT, Wind Calm, Hot Water

Simulated Light Freezing Rain (25 g/dm²/hr)

ID# 97, 65, 59, & 2

ID #	Fluid Type	FFP (°C)	OAT (C)	Fluid Qty. (ml)	Wind (km/h)	Fluid Temp (°C)	Interval to 1st Freeze (min)	Plate Exposure Interval Prior to Test (min)	Surface Type
97	Water	0	-3	281	0	60	4.7	1.0	Aluminum
65	Water	0	-6	230	0	60	2.7	1.0	Aluminum
59	Water	0	-9	204	0	60	1.4	1.0	Aluminum
2	Water	0	-12	306	0	60	2.0	1.0	Aluminum

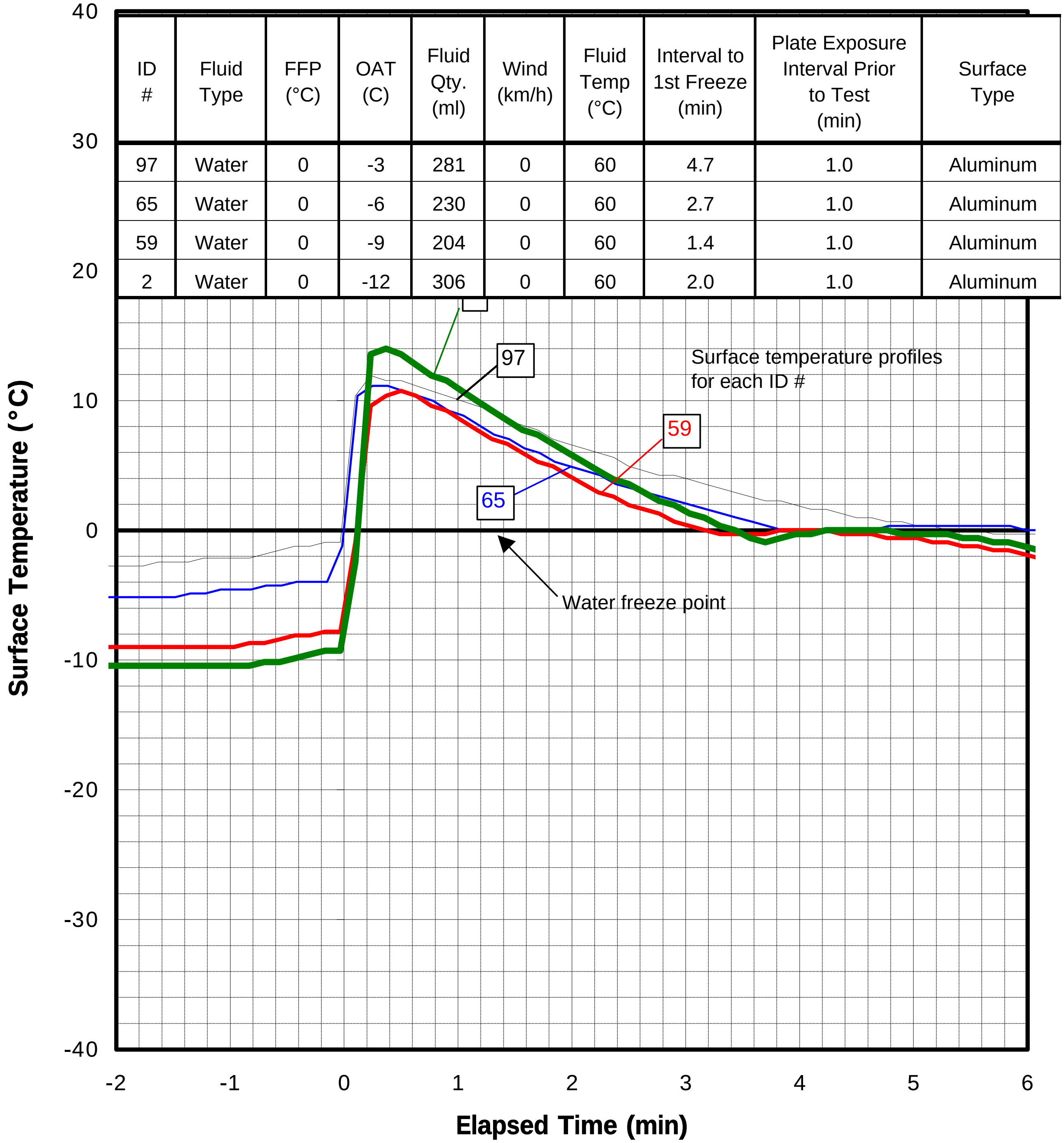

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FIGURE 5.12

Effect of OAT, Wind = 10 kph, Hot Water

Simulated Light Freezing Rain (25 g/dm²/hr)

ID# 103, 73, 34, & 20

ID #	Fluid Type	FFP (°C)	OAT (C)	Fluid Qty. (ml)	Wind (km/h)	Fluid Temp (°C)	Interval to 1st Freeze (min)	Plate Exposure Interval Prior to Test (min)	Surface Type
103	Water	0	-3	281	10	60	2.9	1.0	Aluminum
73	Water	0	-6	306	10	60	2.1	1.0	Aluminum
34	Water	0	-9	281	10	60	0.7	1.0	Aluminum
20	Water	0	-12	306	10	60	1.3	1.1	Aluminum

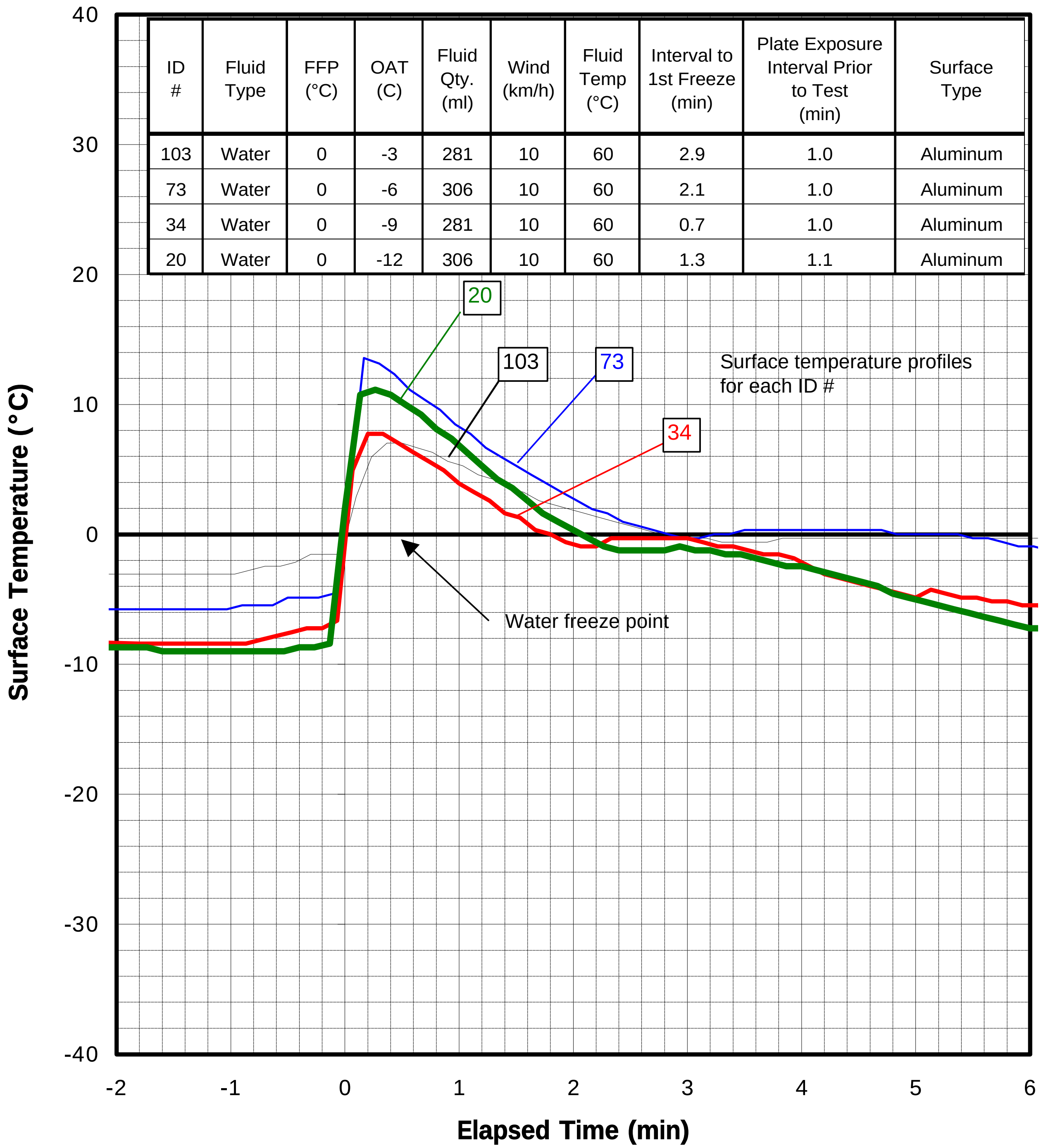
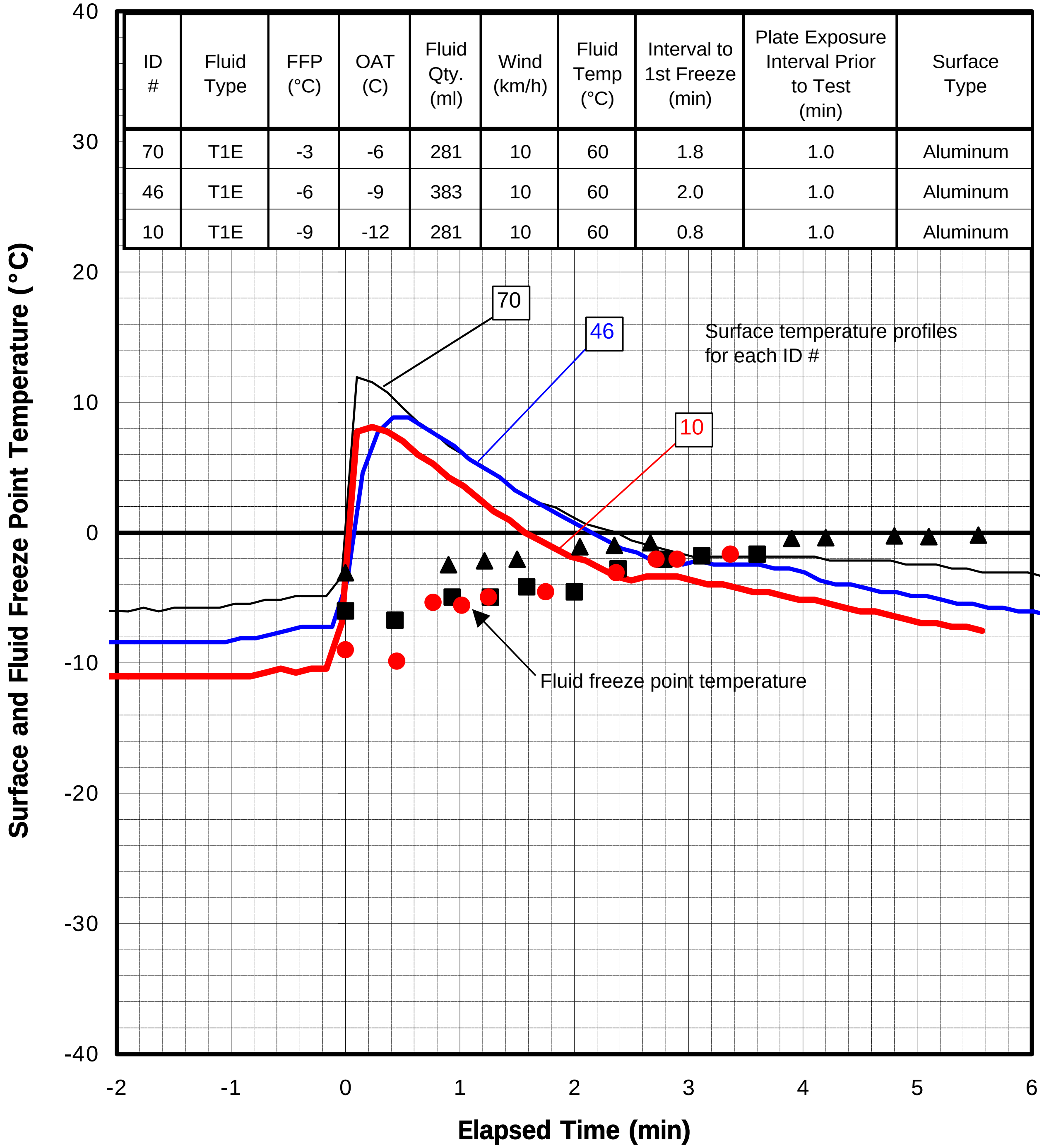


FIGURE 5.13

Effect of OAT, Wind = 10kph, Hot Type I

Simulated Light Freezing Rain (25 g/dm²/hr)

ID# 70, 46, & 10



ID #	Fluid Type	FFP (°C)	OAT (C)	Fluid Qty. (ml)	Wind (km/h)	Fluid Temp (°C)	Interval to 1st Freeze (min)	Plate Exposure Interval Prior to Test (min)	Surface Type
70	T1E	-3	-6	281	10	60	1.8	1.0	Aluminum
46	T1E	-6	-9	383	10	60	2.0	1.0	Aluminum
10	T1E	-9	-12	281	10	60	0.8	1.0	Aluminum

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Why more fluid was required at the colder temperature and whether this phenomenon is representative of operations in the field, is open to conjecture.

Figure 5.13 provides a similar display for a Type I fluid. In this chart, the fluid freeze point progressively rises from its initial value to 0°C. The fluids with freeze points of –6 and –9ºC both show an initial enhancement where the freeze point improves (drops) due to evaporation of water from the thin film on the heated surface. This corresponds to the results of the Deicing Only study (2), except in this case the precipitation quickly overcomes the initial enrichment.

5.1.6 Effect of Wind Speed

Figures 5.14 and 5.15 illustrate the influence of wind on surface cooling rates, and thereby on time interval to the onset of freezing after the application of hot water. In Figure 5.14 the temperature profiles for plates treated with hot water show progressively steeper slopes and more rapid cooling in going from calm wind conditions to winds of 20 km/h. In wind conditions, this translates directly to an earlier intersection with the fluid freeze point curve and an earlier onset of freezing.

Figure 5.15 presents a similar view for an application of dilute Type I fluid. Although the surface temperatures during the cooling periods clearly show the effect of wind speed, it is interesting that the time to onset of first freezing was the same for winds of 10 and 20 km/h.

5.1.7 Effect of Fluid Type

Figure 5.16 provides a further perspective on the comparison of the performance of water versus Type I fluid (mixed to the approved freeze point). The identical profiles for tests 85 (Type I) and 86 (water) reflect completely common test conditions. The other tests shown have some differences in fluid quantities and this is reflected both in the peak values of the temperature profiles and in elapsed time to the initiation of freezing. In these tests, water performed as well or better than Type I fluid.

5.1.8 Effect of Composite Surfaces

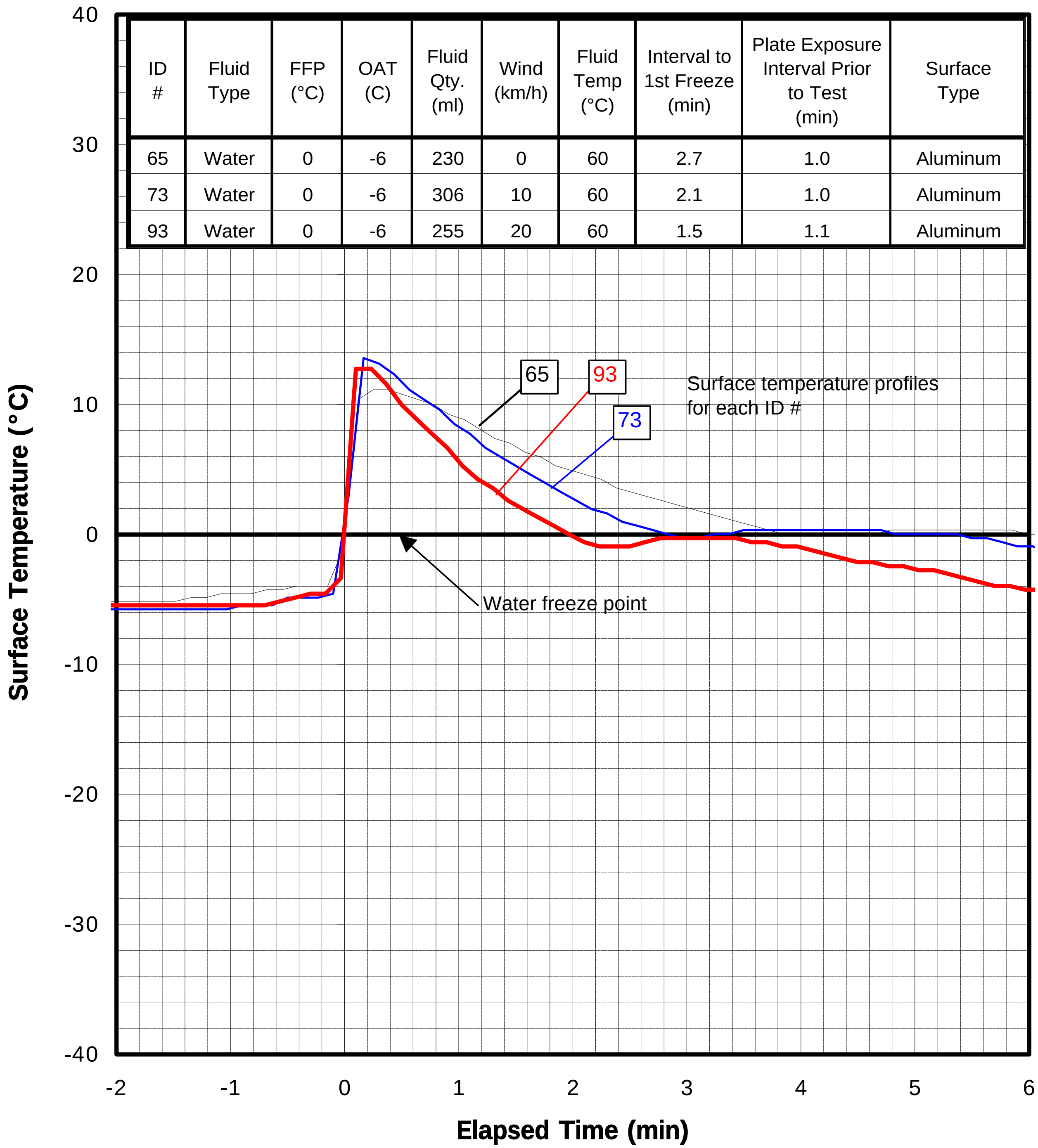
Figures 5.17, 5.18, and 5.19 present the test results of fluid application on surfaces of various composition. In these tests, the various surfaces were all contaminated to the same level, and fluid was sprayed until a clean surface was achieved.

FIGURE 5.14

Effect of Wind at OAT = -6 °C, Hot Water

Simulated Light Freezing Rain (25 g/dm²/hr)

ID# 65, 73, & 93



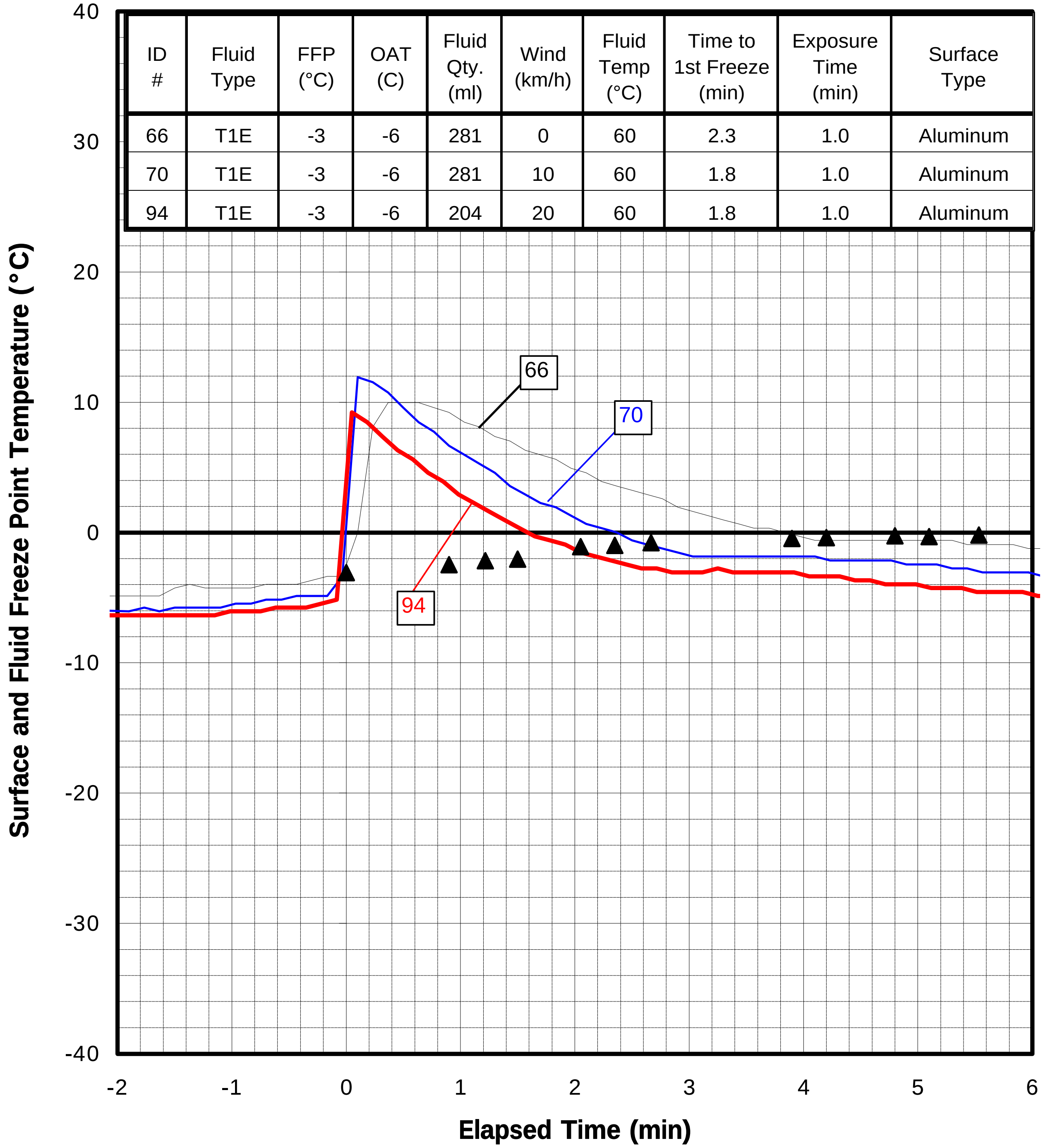
ID #	Fluid Type	FFP (°C)	OAT (C)	Fluid Qty. (ml)	Wind (km/h)	Fluid Temp (°C)	Interval to 1st Freeze (min)	Plate Exposure Interval Prior to Test (min)	Surface Type
65	Water	0	-6	230	0	60	2.7	1.0	Aluminum
73	Water	0	-6	306	10	60	2.1	1.0	Aluminum
93	Water	0	-6	255	20	60	1.5	1.1	Aluminum

FIGURE 5.15

Effect of Wind at OAT = -6 °C, Hot Type I

Simulated Light Freezing Rain (25 g/dm²/hr)

ID# 66, 70, & 94



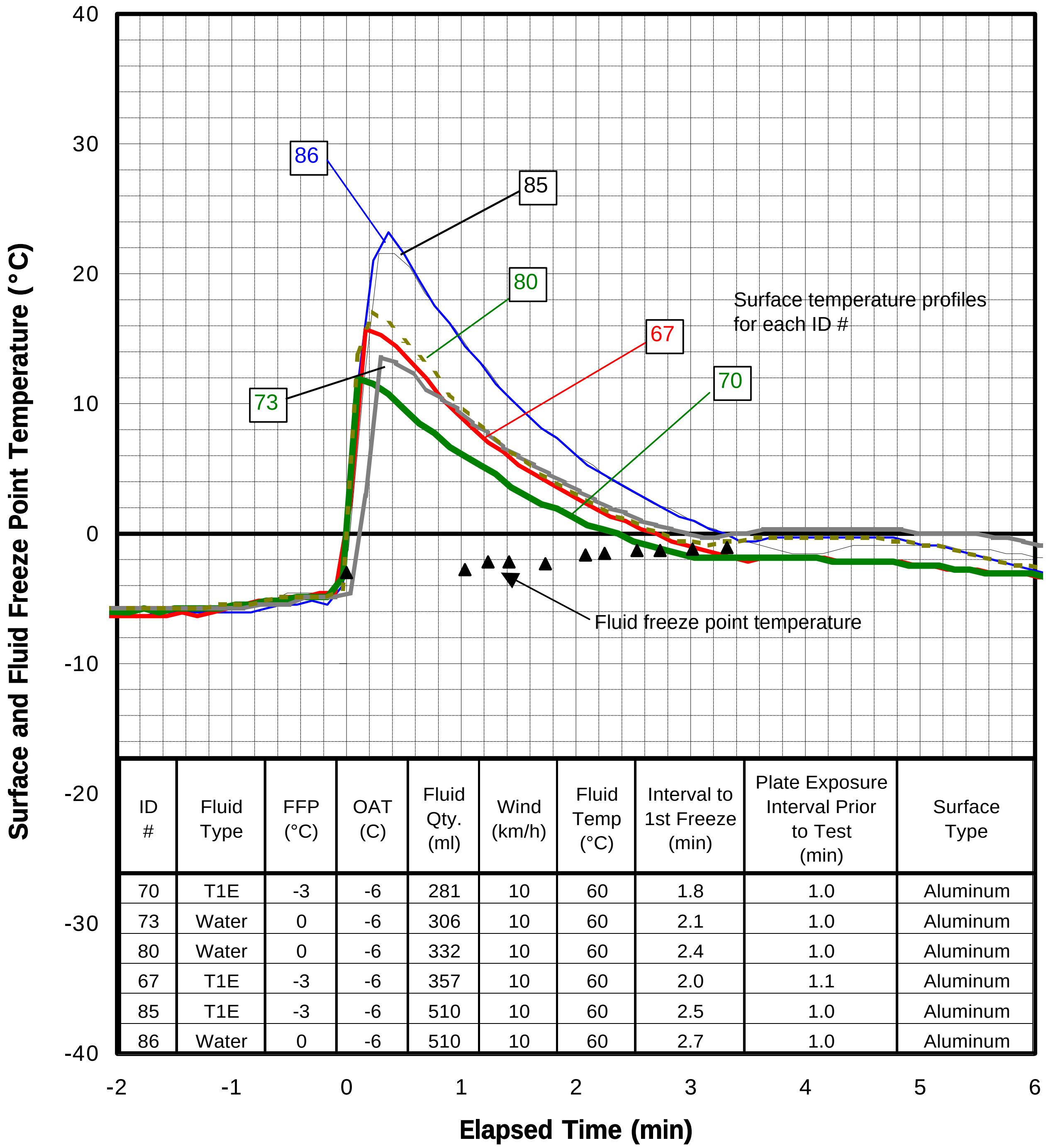
ID #	Fluid Type	FFP (°C)	OAT (C)	Fluid Qty. (ml)	Wind (km/h)	Fluid Temp (°C)	Time to 1st Freeze (min)	Exposure Time (min)	Surface Type
66	T1E	-3	-6	281	0	60	2.3	1.0	Aluminum
70	T1E	-3	-6	281	10	60	1.8	1.0	Aluminum
94	T1E	-3	-6	204	20	60	1.8	1.0	Aluminum

FIGURE 5.16

Examination of Fluid Quantity and Type, Wind = 10km/h, OAT = -6°C

Simulated Light Freezing Rain (25 g/dm²/hr)

ID# 85, 86, 67, 70, 73, & 80



ID #	Fluid Type	FFP (°C)	OAT (C)	Fluid Qty. (ml)	Wind (km/h)	Fluid Temp (°C)	Interval to 1st Freeze (min)	Plate Exposure Interval Prior to Test (min)	Surface Type
70	T1E	-3	-6	281	10	60	1.8	1.0	Aluminum
73	Water	0	-6	306	10	60	2.1	1.0	Aluminum
80	Water	0	-6	332	10	60	2.4	1.0	Aluminum
67	T1E	-3	-6	357	10	60	2.0	1.1	Aluminum
85	T1E	-3	-6	510	10	60	2.5	1.0	Aluminum
86	Water	0	-6	510	10	60	2.7	1.0	Aluminum

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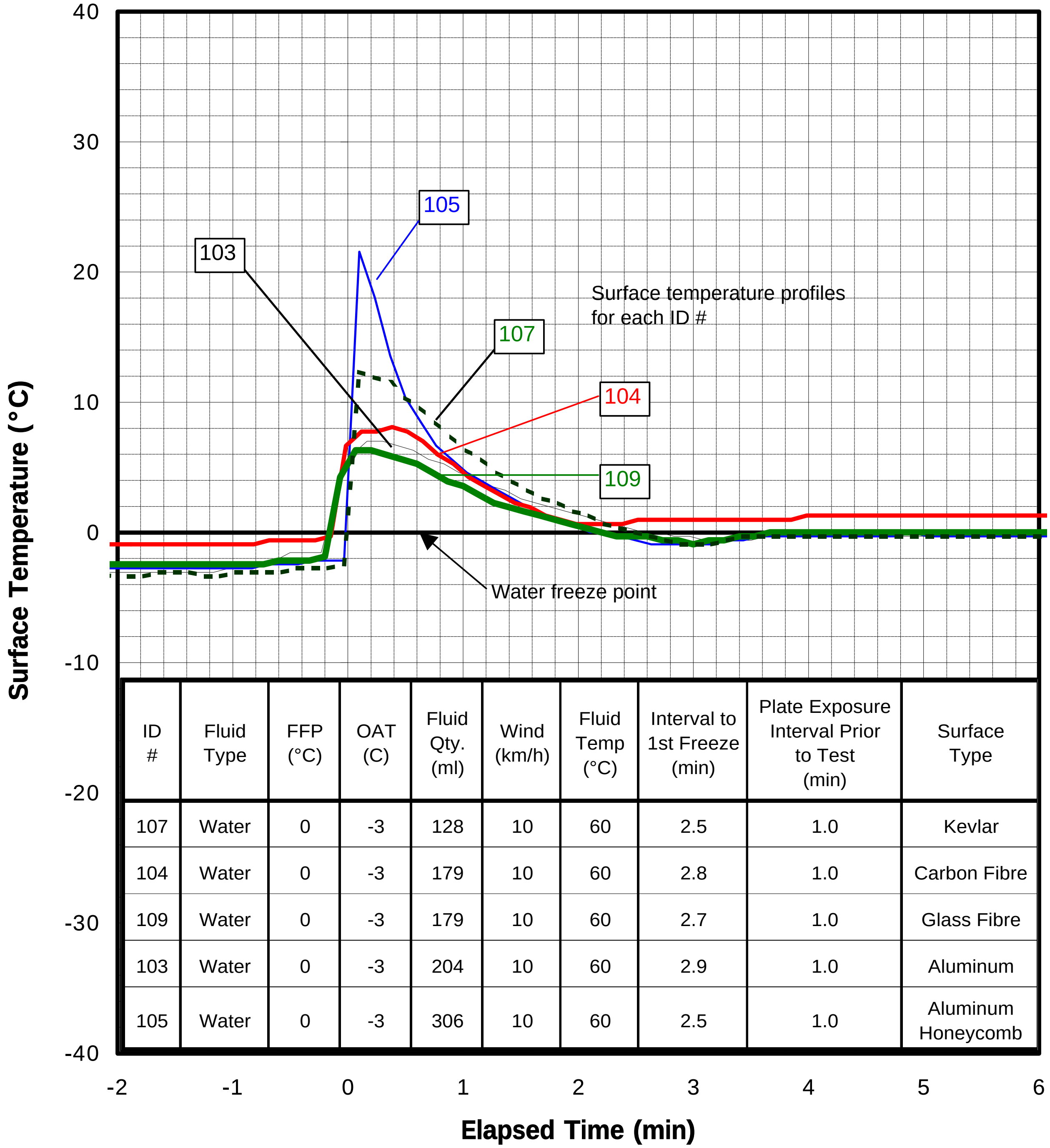
FIGURE 5.17

Effect of Plate Composition, OAT = -3°C, Hot Water

Simulated Light Freezing Rain (25 g/dm²/hr)

ID# 103, 105, 104, 109, & 107



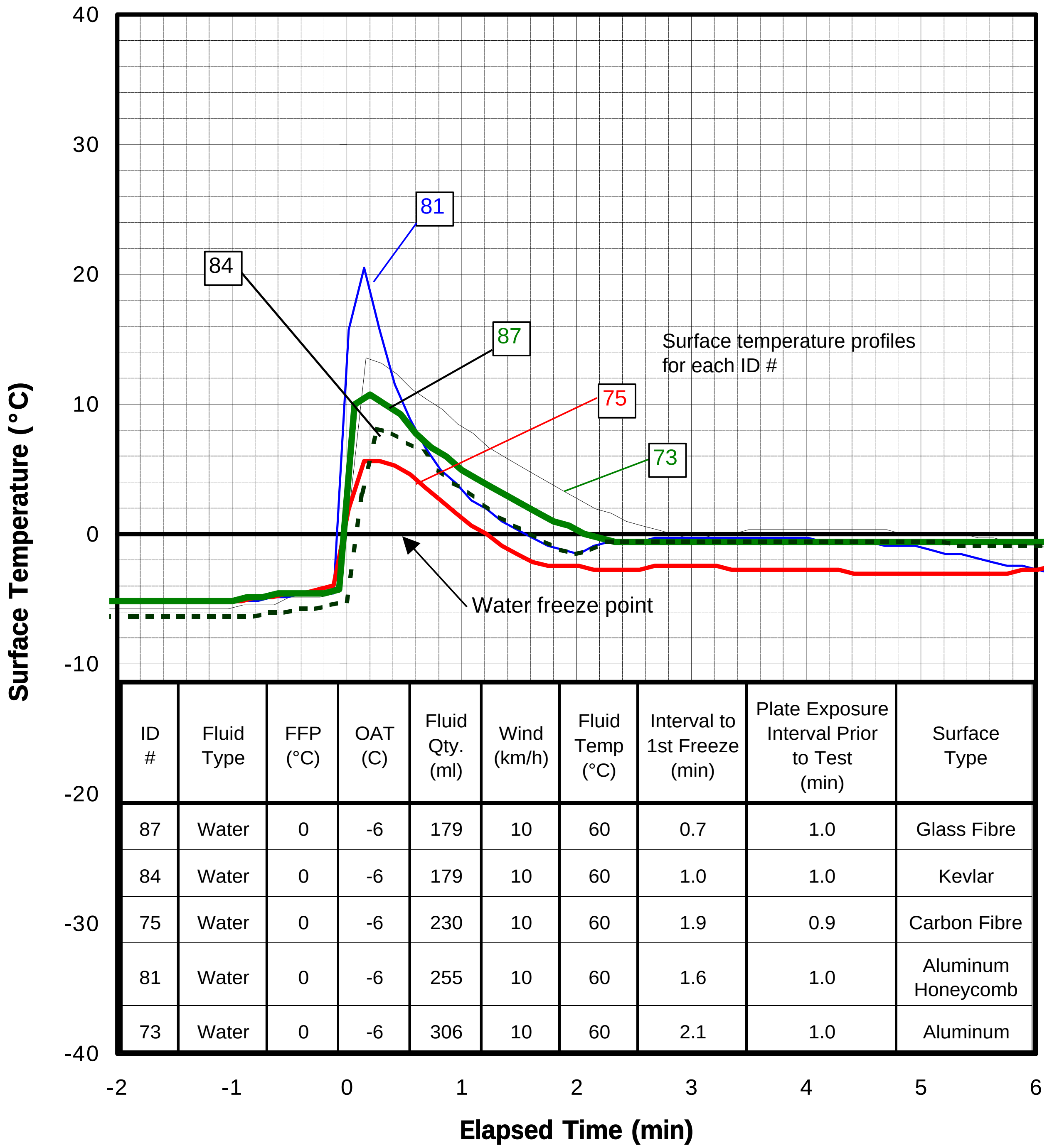
ID #	Fluid Type	FFP (°C)	OAT (C)	Fluid Qty. (ml)	Wind (km/h)	Fluid Temp (°C)	Interval to 1st Freeze (min)	Plate Exposure Interval Prior to Test (min)	Surface Type
107	Water	0	-3	128	10	60	2.5	1.0	Kevlar
104	Water	0	-3	179	10	60	2.8	1.0	Carbon Fibre
109	Water	0	-3	179	10	60	2.7	1.0	Glass Fibre
103	Water	0	-3	204	10	60	2.9	1.0	Aluminum
105	Water	0	-3	306	10	60	2.5	1.0	Aluminum Honeycomb

FIGURE 5.18

Effect of Plate Composition, OAT = -6°C, Hot Water

Simulated Light Freezing Rain (25 g/dm²/hr)

ID# 73, 81, 75, 87, & 84



ID #	Fluid Type	FFP (°C)	OAT (C)	Fluid Qty. (ml)	Wind (km/h)	Fluid Temp (°C)	Interval to 1st Freeze (min)	Plate Exposure Interval Prior to Test (min)	Surface Type
87	Water	0	-6	179	10	60	0.7	1.0	Glass Fibre
84	Water	0	-6	179	10	60	1.0	1.0	Kevlar
75	Water	0	-6	230	10	60	1.9	0.9	Carbon Fibre
81	Water	0	-6	255	10	60	1.6	1.0	Aluminum Honeycomb
73	Water	0	-6	306	10	60	2.1	1.0	Aluminum

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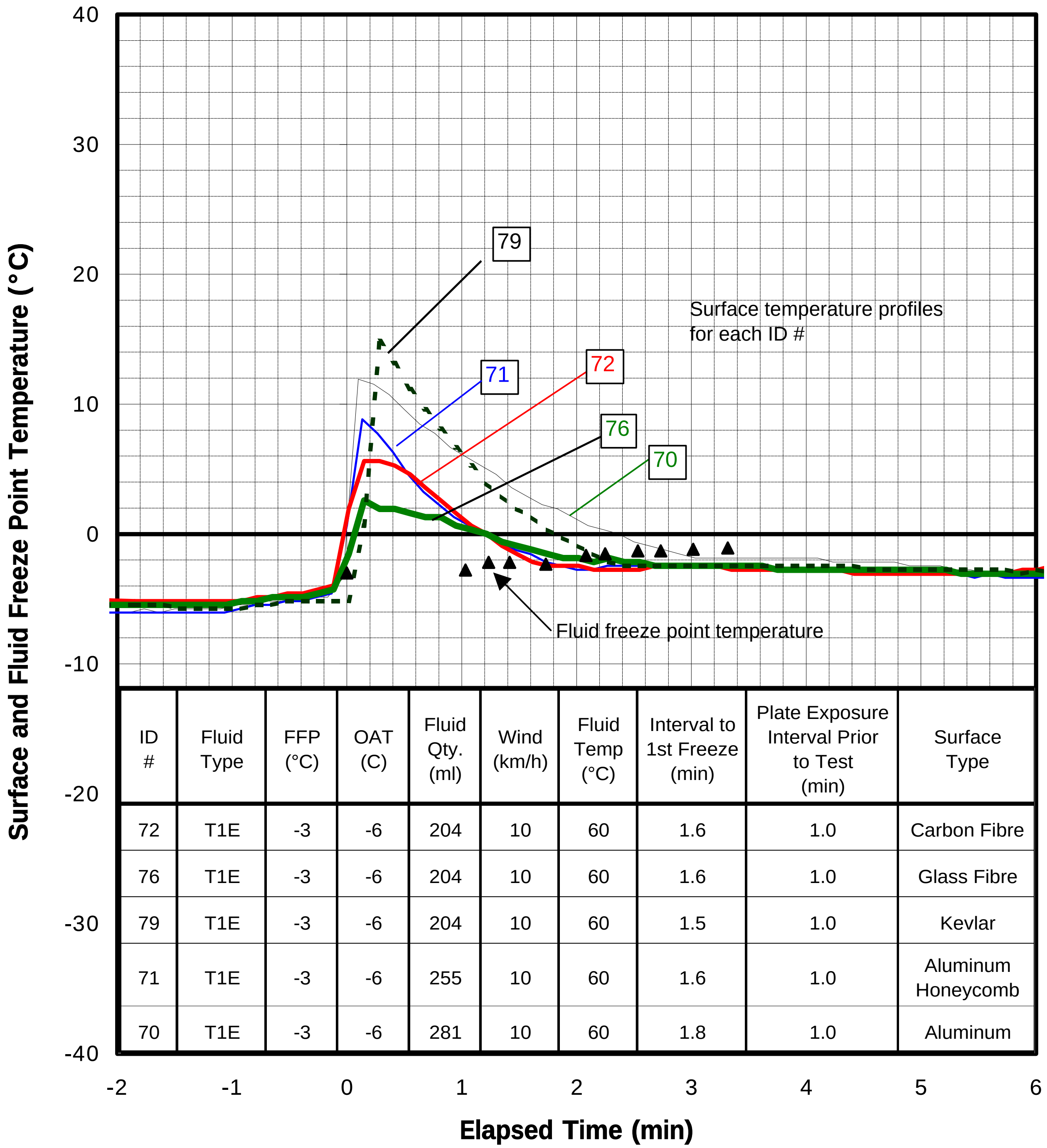
FIGURE 5.19

Effect of Plate Composition, OAT = -6°C, Hot Type I

Simulated Light Freezing Rain (25 g/dm²/hr)

ID# 70, 71, 72, 76, & 79



ID #	Fluid Type	FFP (°C)	OAT (C)	Fluid Qty. (ml)	Wind (km/h)	Fluid Temp (°C)	Interval to 1st Freeze (min)	Plate Exposure Interval Prior to Test (min)	Surface Type
72	T1E	-3	-6	204	10	60	1.6	1.0	Carbon Fibre
76	T1E	-3	-6	204	10	60	1.6	1.0	Glass Fibre
79	T1E	-3	-6	204	10	60	1.5	1.0	Kevlar
71	T1E	-3	-6	255	10	60	1.6	1.0	Aluminum Honeycomb
70	T1E	-3	-6	281	10	60	1.8	1.0	Aluminum

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In each of the three charts, the surface temperatures follow very different profiles, primarily with respect to the peak temperature recorded. Referring to Figure 5.17, the different peak values do not seem to have a direct bearing on the elapsed times. When the fluid quantities shown in the legend box are examined, it is noted that quantities for aluminum and aluminum on honeycomb core are higher than for the other composite surfaces. This feature is common to each of the three conditions charted.

To explore this further, Table 5.4 was devised to examine the relative values of fluid quantities and elapsed times for the different surfaces.

The table illustrates the degree to which fluid quantities for the carbon-fibre, glass-fibre, and Kevlar composite surfaces are lower than for the two types of aluminum surfaces. The elapsed time to freezing generally shows a direct relationship to quantity of applied fluid, except for the aluminum honeycomb case. For aluminum honeycomb, the onset of freezing was within the range for the other materials in this table, however, it did not appear to be commensurate with applied fluid quantity and was shorter than expected. This was most pronounced at an OAT of -3°C and less so at -6°C. The observation on the honey-comb core surface is supported by previous deicing fluid trials on operational aircraft where wing surfaces fabricated of this material were the first to exhibit failure.

The observation that consistently smaller fluid quantities were needed in order to provide a clean surface in the case of the non-aluminum composites is of interest. A potential explanation may lie in the fact that these surfaces were painted, and perhaps the contaminant had a lower level of adhesion than it did on the aluminum surfaces.

Extending the observation to an operational setting is somewhat questionable. Normally the major part of a wing surface is aluminum, with various wing components being fabricated of composite materials, which are painted. In a deicing operation, the operator would tend to apply fluid at the same rate over the entire wing, which is generally performed in a sweeping action encompassing both aluminum and composite surfaces. In such a scenario, the amount of fluid applied would be controlled by the wing surface requiring the greatest amount of fluid, and as a result, the composite surfaces would receive the same rates of application as the aluminum. In other words, the composite surfaces would receive a surplus of fluid over and above that amount needed to achieve a clean surface. The impact of the surplus fluid quantity on the period of protection for the composite surfaces is not known. In this study, the effect of various fluid quantities was explored but associated tests were conducted only on aluminum surfaces. These tests are discussed in later sections.

Table 5.4
Study of Composite Surfaces, Winds 10 km/h, Freezing Rain (25 g/dm²/hr)

Hot water, OAT –3°C

Surface Type	Fluid Quantity (ml)	Comparison of Fluid Quantity to Smallest Fluid Quantity (ratio)	Elapsed Time To Onset of Freezing (min)	Comparison of Elapsed Time to Smallest Value of Elapsed Time (ratio)
Aluminum	204	1.6	2.9	1.2
Aluminum on Honeycomb	306	2.4	2.5	1.0
Carbon Fibre	179	1.4	2.8	1.1
Glass Fibre	179	1.4	2.7	1.1
Kevlar	128	1.0	2.5	1.0

Hot water, OAT –6°C

Surface Type	Fluid Quantity (ml)	Comparison of Fluid Quantity to Smallest Fluid Quantity (ratio)	Elapsed Time To Onset of Freezing (min)	Comparison of Elapsed Time to Smallest Value of Elapsed Time (ratio)
Aluminum	306	1.7	2.1	3.0
Aluminum on Honeycomb	255	1.4	1.6	2.3
Carbon Fibre	230	1.3	1.9	2.7
Glass Fibre	179	1.0	0.7	1.0
Kevlar	179	1.0	1.0	1.4

Hot dilute Type I, OAT –6°C

Surface Type	Fluid Quantity (ml)	Comparison of Fluid Quantity to Smallest Fluid Quantity (ratio)	Elapsed Time To Onset of Freezing (min)	Comparison of Elapsed Time to Smallest Value of Elapsed Time (ratio)
Aluminum	281	1.4	1.8	1.2
Aluminum on Honeycomb	255	1.3	1.6	1.1
Carbon Fibre	204	1.0	1.6	1.1
Glass Fibre	204	1.0	1.6	1.1
Kevlar	204	1.0	1.5	1.0

5.2 Examination of the Influence of Test Parameters on Results

5.2.1 Effect of Fluid Quantity

As discussed in the description of test procedures, the method of fluid application used in these trials was selected in conjunction with a decision to test on contaminated surfaces. The amount of fluid was not prescribed, and the operator was instructed to spray until a clean surface was achieved. This did result in differences in fluid quantities applied. In Figures 5.11 and 5.12, for example, the fluid quantities for the eight tests reported ranged from 204 ml to 306 ml.

Already discussed (Section 5.1.5) was the greater amount of fluid required in the –12°C OAT condition.

In general, the quantities of fluid applied were less than the quantities of fluid employed in previous tests when fluids were applied by pouring on clean plates. A fluid quantity of 500 ml was commonly used in these previous tests.

A number of special tests with varying fluid quantities were conducted to examine the impact fluid quantity has on elapsed time to the onset of freezing. Figure 5.20 graphically illustrates the impact fluid quantity has on peak temperature and on the time interval to first freezing in calm wind conditions. The inset charts the time to the onset of freezing versus quantity of fluid applied. Clearly, the amount of fluid applied in the first step has a direct bearing on the elapsed time before the onset of freezing, or in an operational setting, on the period of safety available to the deicing operator before applying a protective overspray of an anti-icing fluid.

Figure 5.21 (OAT of -12°C and a 10 km/h wind condition) further illustrates the impact of fluid quantity. It is interesting to note that the period of protection provided by a water spray of 1020 ml (three times the required quantity) was 2.7 minutes. This is equivalent to the protection times provided by XL54 trials reported in Figure 5.10. This quantity of fluid (1020 ml on a standard test plate) is equivalent to 300 L (80 US gal.) on a DC-9 wing.

5.2.2 Method of Application

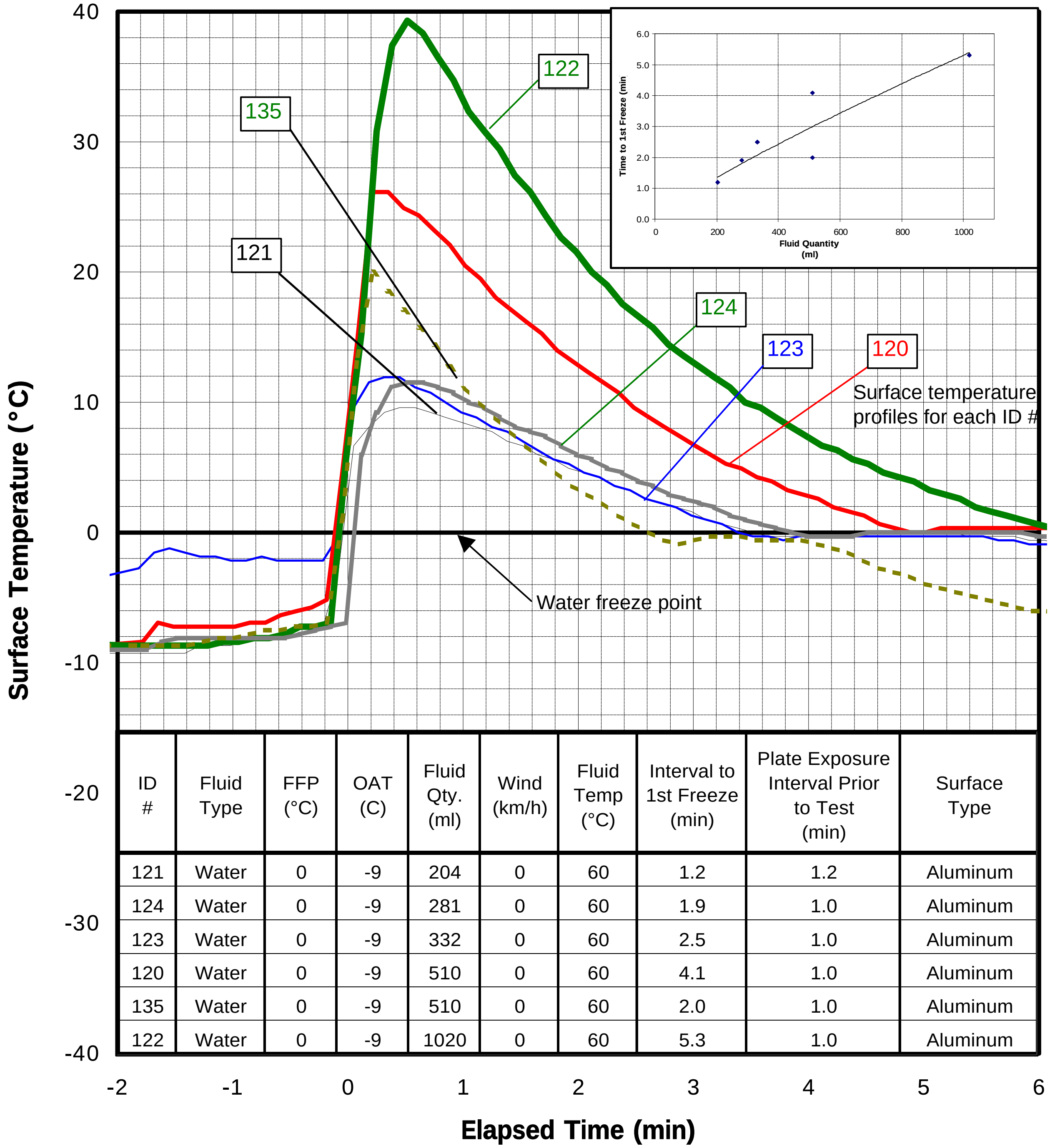
Several special tests were conducted to compare the effect of pouring versus spraying. Figure 5.22 presents the results of tests conducted at an OAT of –9°C, both in calm conditions and with a wind of 10 km/h. In these tests, a common quantity of fluid was applied by spraying and by pouring to plates with a standard degree of contamination (one minute

FIGURE 5.20

Effect of Fluid Amount, Wind Calm, OAT = -9°C, Hot Water

Simulated Light Freezing Rain (25 g/dm²/hr)

ID# 121, 123, 120, 122, 124, & 135



ID #	Fluid Type	FFP (°C)	OAT (C)	Fluid Qty. (ml)	Wind (km/h)	Fluid Temp (°C)	Interval to 1st Freeze (min)	Plate Exposure Interval Prior to Test (min)	Surface Type
121	Water	0	-9	204	0	60	1.2	1.2	Aluminum
124	Water	0	-9	281	0	60	1.9	1.0	Aluminum
123	Water	0	-9	332	0	60	2.5	1.0	Aluminum
120	Water	0	-9	510	0	60	4.1	1.0	Aluminum
135	Water	0	-9	510	0	60	2.0	1.0	Aluminum
122	Water	0	-9	1020	0	60	5.3	1.0	Aluminum

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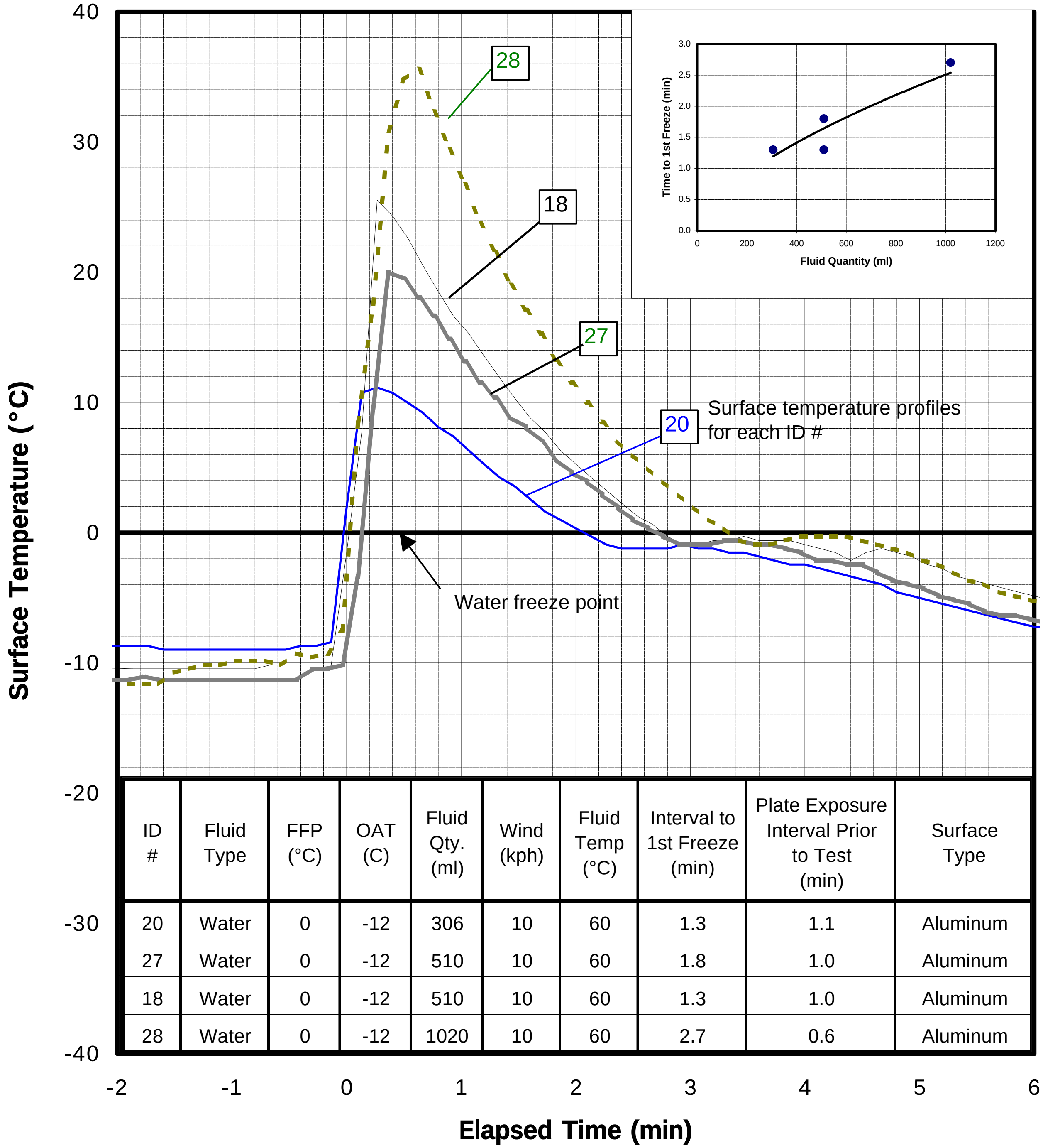
FIGURE 5.21

Effect of Fluid Amount, Wind = 10 km/h, OAT = -12°C, Hot Water

Simulated Light Freezing Rain (25 g/dm²/hr)

ID# 18, 20, 27, & 28



ID #	Fluid Type	FFP (°C)	OAT (C)	Fluid Qty. (ml)	Wind (kph)	Fluid Temp (°C)	Interval to 1st Freeze (min)	Plate Exposure Interval Prior to Test (min)	Surface Type
20	Water	0	-12	306	10	60	1.3	1.1	Aluminum
27	Water	0	-12	510	10	60	1.8	1.0	Aluminum
18	Water	0	-12	510	10	60	1.3	1.0	Aluminum
28	Water	0	-12	1020	10	60	2.7	0.6	Aluminum

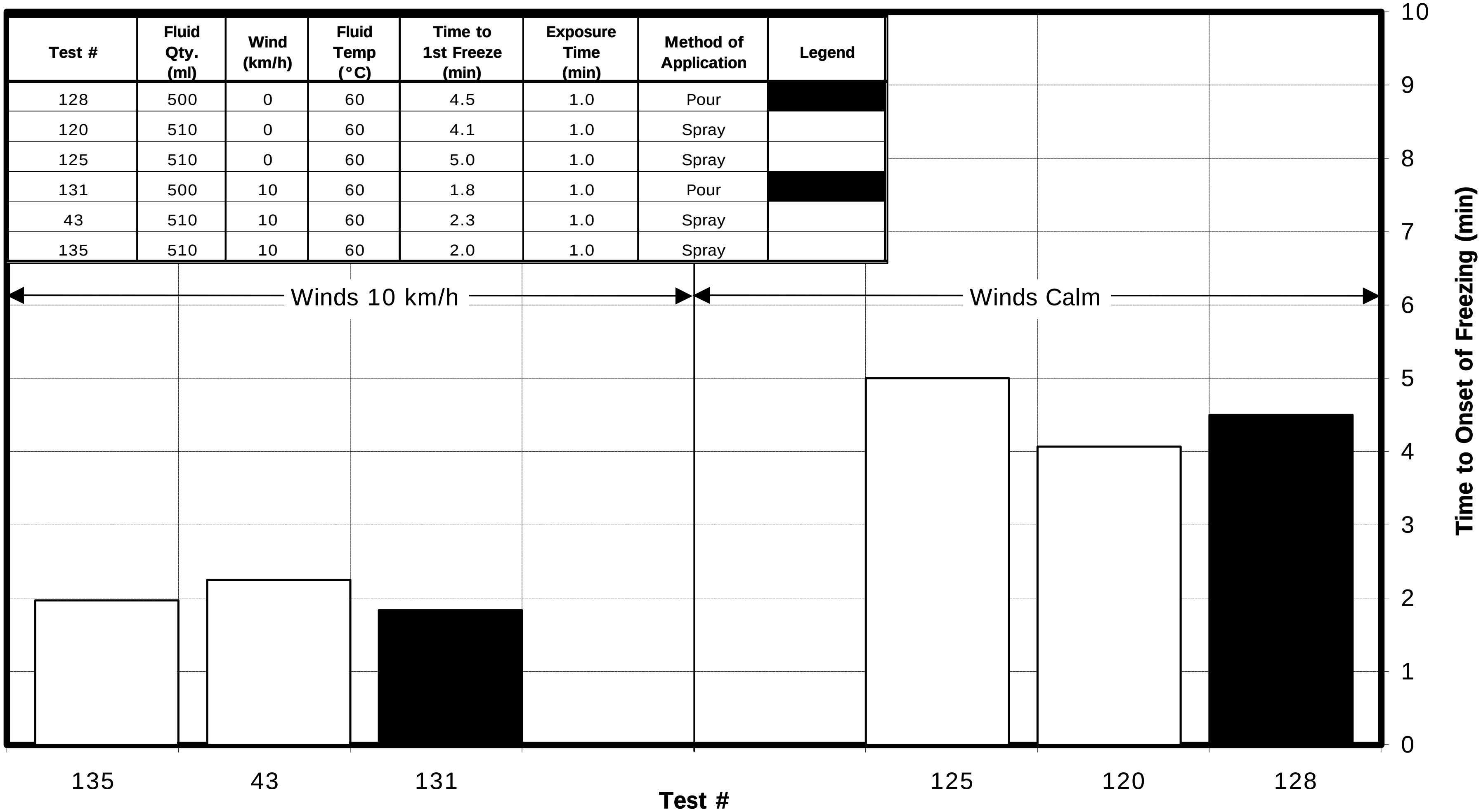
FIGURE 5.22

COMPARISON OF METHOD OF FLUID APPLICATION
SPRAYED vs POURED

HOT WATER, OAT = -9°C, ALUMINUM PLATE

SIMULATED LIGHT FREEZING RAIN (25 g/dm²/hr)

Test #	Fluid Qty. (ml)	Wind (km/h)	Fluid Temp (°C)	Time to 1st Freeze (min)	Exposure Time (min)	Method of Application	Legend
128	500	0	60	4.5	1.0	Pour	
120	510	0	60	4.1	1.0	Spray	
125	510	0	60	5.0	1.0	Spray	
131	500	10	60	1.8	1.0	Pour	
43	510	10	60	2.3	1.0	Spray	
135	510	10	60	2.0	1.0	Spray	



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exposure to freezing rain at 25 g/dm^2/hr). The resulting elapsed times to freezing are not significantly different.

Figure 5.23 compares results for pouring 500 ml of hot water on clean and contaminated test surfaces, and for spraying both 510 ml and amounts as required on contaminated surfaces. The comparison of pouring 500 ml on a clean plate (Tests 102 and 129), versus spraying a quantity as required on a contaminated plate (Tests 97 and 59) is striking. The differences in elapsed time to onset of freezing in this comparison conforms to the variance between current test results and results from previous tests illustrated in Figure 5.9. Figure 5.24 provides a further illustration of the difference in results, in wind speeds of 10 km/h.

It can be concluded that, given the same quantities of fluid applied, similar results are produced by the two methods of fluid application. The principal difference lies with the amounts applied; the current test procedures require the operator to spray until the surface is clean and resulted in the application of considerably less fluid than the standard 500 ml used in the previous sets of tests.

5.2.3 Degree of Test Surface Contamination

As part of the test procedure, ice contamination was allowed to form on the test plates and was then removed by spraying as much fluid as necessary to clean the test surface. The degree of contamination was controlled by the length of time that the test plate was exposed to the freezing rain precipitation prior to application of the heated fluid spray. An exposure time of one minute was used as a standard, with multiples of that interval tested in some runs to examine the impact on results.

At the ambient test temperatures, the freezing rain immediately froze upon striking the plate, and very little if any escaped from the surface. This was confirmed by weighing test plates before and after a timed period of exposure, and then using those values to calculate the rate of precipitation. The calculated rate was virtually the same as that measured through the standard procedures for establishing precipitation rates.

Several tests were conducted to examine the impact of varying the degree of contamination. In these tests, precipitation was allowed to accumulate for longer periods prior to spraying. Figures 5.25 and 5.26 present these test results.

Tests reported in Figure 5.25 were conducted with hot water, at an OAT of –3°C in a calm wind condition. Plate exposure times ranged from 1.4 minutes to 10 minutes. It can be seen that the corresponding elapsed

FIGURE 5.23

INFLUENCE OF TYPE OF APPLICATION AND FLUID QUANTITY

HOT WATER, WINDS CALM

SIMULATED LIGHT FREEZING RAIN (25 g/dm²/hr)

Test #	Comment
102, 129	Poured 500 ml, Clean Plate
101, 128	Poured 500 ml, Contaminated Plate
97, 59	Sprayed as Required (approx. 255 ml), Contaminated Plate
122	Poured 1020 ml, Contaminated Plate
120	Sprayed 510 ml, Contaminated Plate

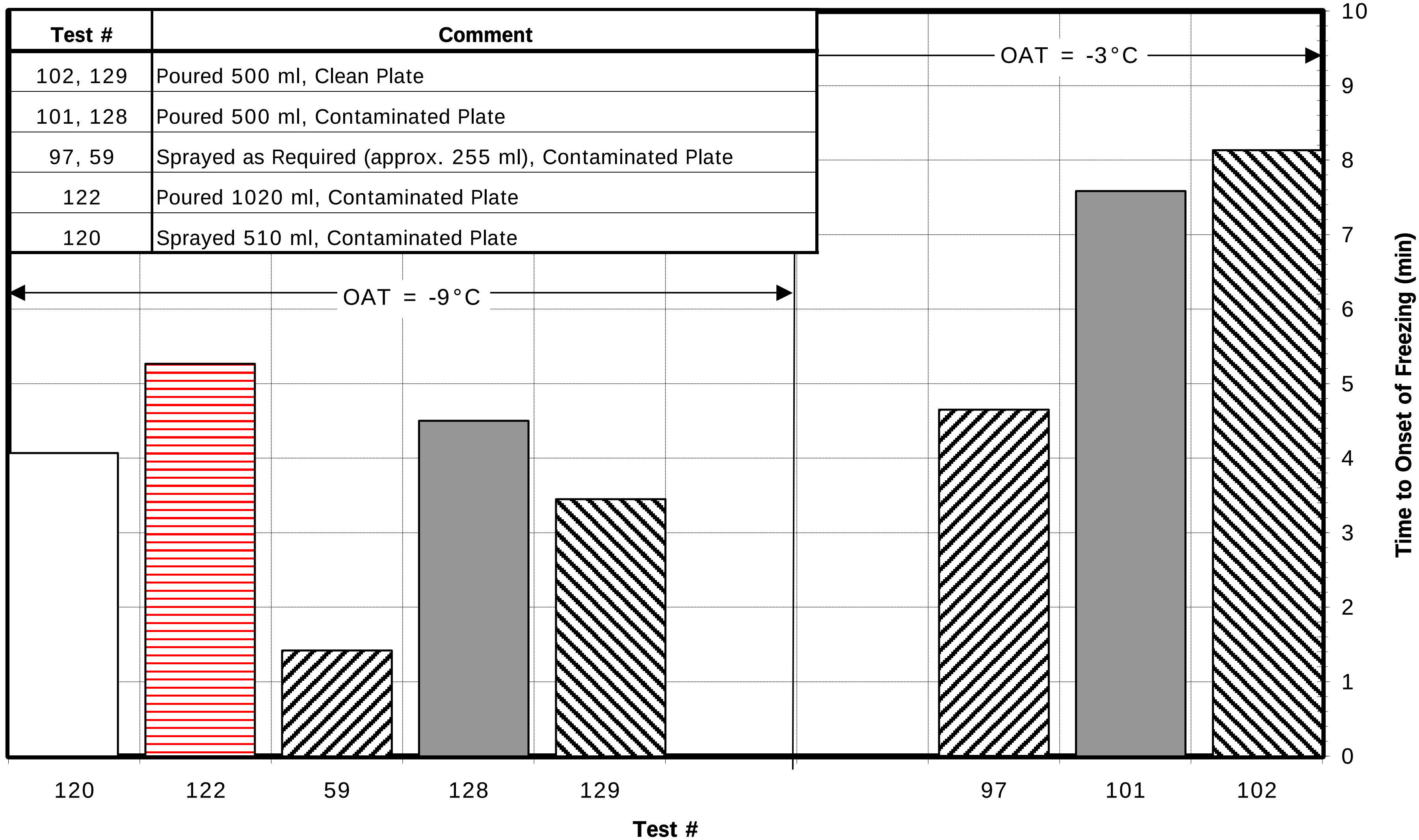

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FIGURE 5.24

INFLUENCE OF TYPE OF APPLICATION AND FLUID QUANTITY

HOT WATER, WIND = 10 km/h

SIMULATED LIGHT FREEZING RAIN (25 g/dm²/hr)

Test #	Comment
111, 40	Poured 500 ml, Clean Plate
108, 131	Poured 500 ml, Contaminated Plate
135	Sprayed 510 ml, Contaminated Plate
103, 34	Sprayed as required (approx. 255 ml) Contaminated Plate

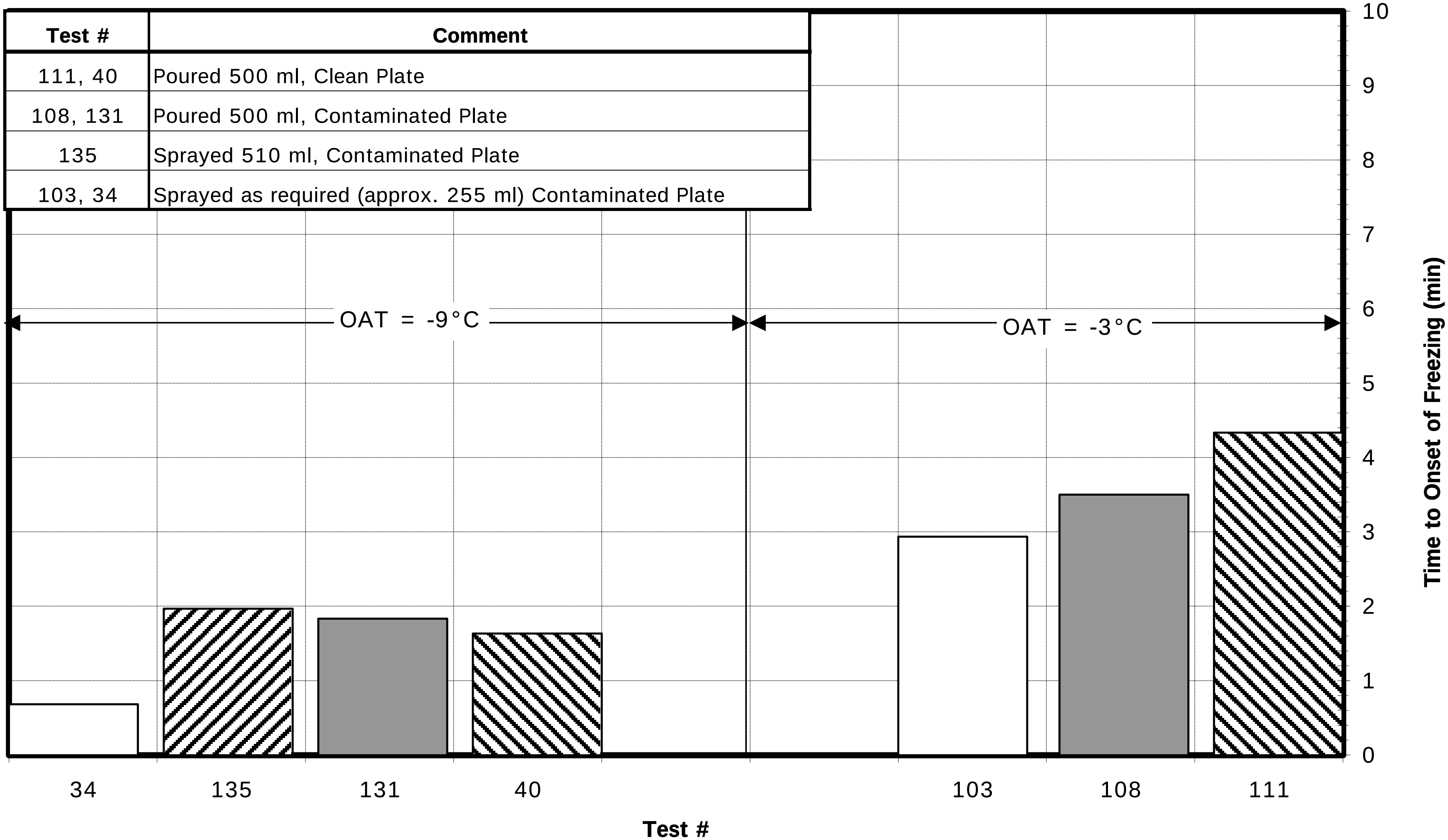

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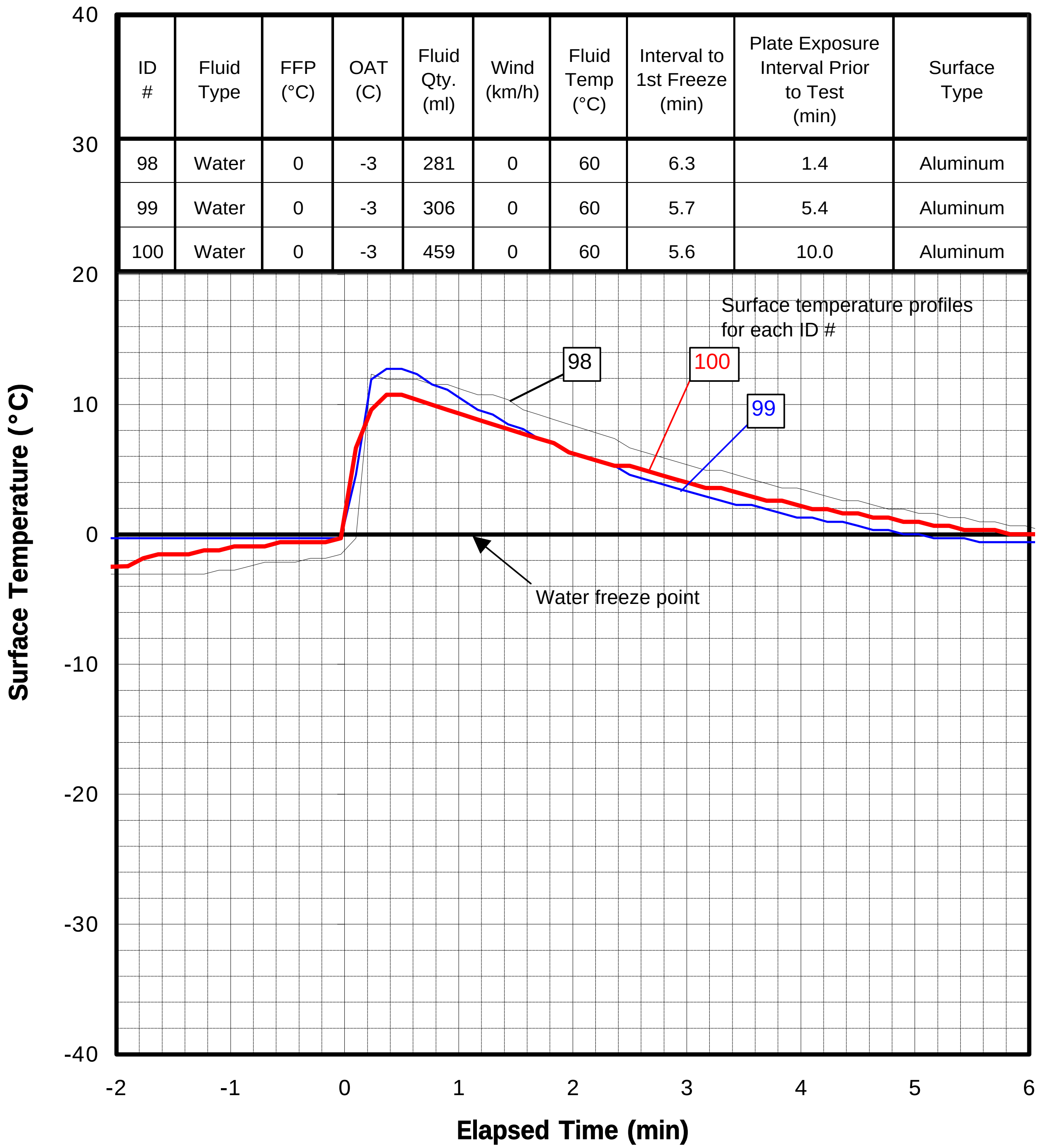
FIGURE 5.25

Effect of Amount of Contaminant - Hot Water Trials

Simulated Light Freezing Rain (25 g/dm²/hr), OAT -3°C, Calm Wind

ID# 98, 99, & 100



ID #	Fluid Type	FFP (°C)	OAT (C)	Fluid Qty. (ml)	Wind (km/h)	Fluid Temp (°C)	Interval to 1st Freeze (min)	Plate Exposure Interval Prior to Test (min)	Surface Type
98	Water	0	-3	281	0	60	6.3	1.4	Aluminum
99	Water	0	-3	306	0	60	5.7	5.4	Aluminum
100	Water	0	-3	459	0	60	5.6	10.0	Aluminum

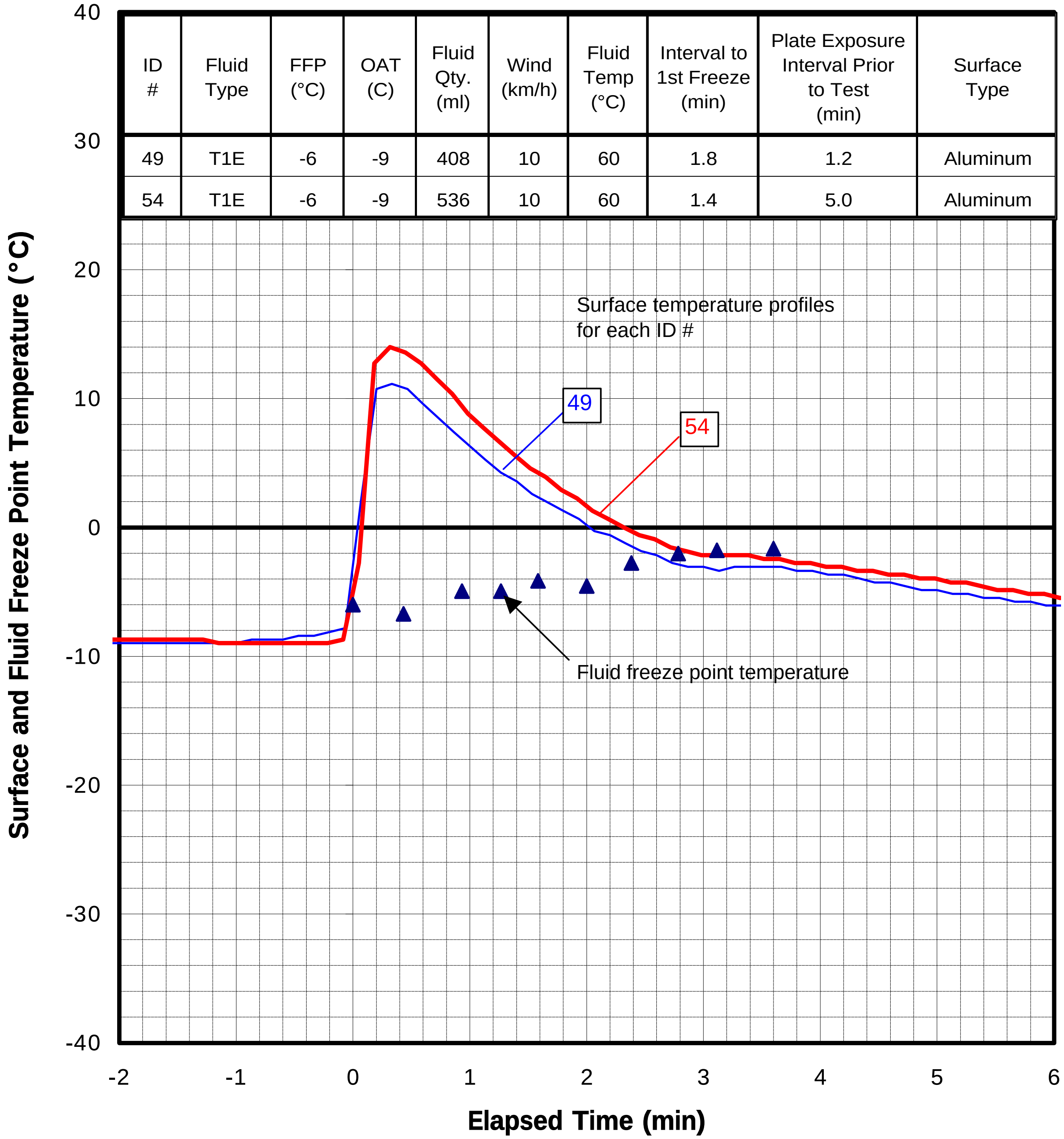
FIGURE 5.26

Effect of Amount of Contaminant - Type I Fluid Trials

Simulated Light Freezing Rain (25 g/dm²/hr), OAT -9°C, 10 km/h Wind

ID# 49 & 54

ID #	Fluid Type	FFP (°C)	OAT (C)	Fluid Qty. (ml)	Wind (km/h)	Fluid Temp (°C)	Interval to 1st Freeze (min)	Plate Exposure Interval Prior to Test (min)	Surface Type
49	T1E	-6	-9	408	10	60	1.8	1.2	Aluminum
54	T1E	-6	-9	536	10	60	1.4	5.0	Aluminum



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times to freezing did vary as a function of the change in level of contamination, but to a minor degree. The fluid quantity however did show a strong correlation. Despite the differences in level of contamination, the plate temperature profiles were very similar. It is concluded that the additional fluid quantities needed to clean a heavily contaminated surface compensated for the heat lost in the ice removal process.

Figure 5.26 reports results from tests conducted with diluted Type I fluid at an OAT of –9°C with winds of 10 km/h. The conclusions are similar with perhaps a slightly stronger correlation between the elapsed time and the duration of contamination interval.

Overall, it can be concluded that extent of contamination does not exert a significant influence on elapsed time to freezing, under the test procedures followed in this study.

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6. CONCLUSIONS

Based on the results of these trials, a number of conclusions can be drawn.

6.1 Period of Protection

The principal conclusion is that hot water provides a period of protection equal to or better than Type I fluid mixed to the approved freeze point in ambient temperatures down to –6°C, at high rates of precipitation and in winds up to 10 km/h (Sections 5.1.1D and 5.1.2). At that limit, the time interval until the onset of freezing for both fluid types (Tables 5.1 and 5.2) is between 2 to 3 minutes. It should be noted that this is a severe condition, where a full strength Type I fluid provides only three minutes of protection.

At –9°C, with winds of 10 km/h, diluted Type I fluid performs slightly better than hot water. A period of protection of two minutes was obtained with diluted Type I fluid, whereas with hot water, the period of protection drops to a value between one and two minutes. In this condition, full strength Type I fluid (XL54) protects for a period between two to three minutes (Table 5.3).

At –3°C, with winds of 20 and 30 km/h, hot water provided a three-minute period of protection before freezing.

6.2 Variations in Test Results

In repeated tests in calm conditions, variable elapsed times occurred before the onset of freezing. This variability was reduced greatly for wind condition tests. As test results during wind conditions are more severe and conservative, they should provide the basis for decision-making, reducing the importance of variable results seen in calm conditions.

6.3 Comparison to Previous Test Results

Values for elapsed time until freezing were significantly lower in these tests than seen previously during the first step fluid trials because of the differences in test procedures. Previous trials required application of a standard fluid amount (500 ml) by pouring on a clean test surface, whereas this series of trials required spraying a contaminated plate until it was clean. A much smaller quantity of applied fluid resulted, with correspondingly shorter periods of protection.

Results were also considerably lower than those of the field trials on operational aircraft conducted in March/April 1995. Those trials involved spray application on the aircraft by operators experienced in hot water deicing. However, those tests were conducted in dry conditions. A review of the test record revealed that the operators sprayed varying amounts of hot water, ranging from 20 to 40 gal. (90 to 180 L) on each DC-9 wing. This is equivalent to 300 to 600 ml on each test plate area, with an average of 450 ml. Thus, the test quantities in this series of trials were conservative.

6.4 Test Results at Cold Temperatures

An increase in protection time noted at –12°C (as compared to –9°C) was achieved as a result of additional fluid spray required to attain a clean surface at that test condition. While this is an interesting observation, the duration of protection offered at that temperature is too short to be considered an operational limit.

6.5 Effect of Composite Surfaces

The fluid quantities needed to produce a clean surface on the painted composite test surfaces were significantly smaller than those required in the case of aluminum surfaces. Elapsed times to the onset of freezing for the glass fibre, carbon fibre, and Kevlar composite surfaces were shorter than for standard aluminum test plates, but equal to or better than the times on the aluminum on honeycomb core test surface. The shorter times are at least partly due to the smaller fluid amounts.

In an operational setting, any composite surfaces in a wing structure would receive the same amount of fluid as the aluminum surface. Therefore, the protection period would be similar.

Aluminum on honeycomb core appears to be the most critical type of surface, giving the lowest rate of increase in period of protection per additional unit of fluid quantity.

6.6 Effect of Fluid Quantity

The amount of fluid applied directly influences the duration of the period of protection before freezing for aluminum surfaces. The three-minute window is possible down to –9ºC at 10 km/h winds if sufficient hot water is applied. Tests to examine the influence of fluid quantity were not conducted on composite surfaces, but it is expected that a similar conclusion would result.

6.7 Method of Application

It can be concluded that, given the same quantities of fluid applied, similar results are produced by the two methods of application (spraying and pouring). The principal difference lies with the amounts applied; the current test procedures required the operator to spray until the surface is clean. This resulted in the application of considerably less fluid than the standard 500ml quantity used in previous tests.

6.8 Degree of Surface Contamination

The degree of contamination does not significantly influence elapsed time to freezing for the test procedures and conditions followed in this study. The loss of fluid heat absorbed in cleaning away the heavier contamination is compensated for by the application of greater amounts of fluid. Additional hot water applied after the removal of frozen contamination can expand the window between the deicing and anti-icing steps.

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7. RECOMMENDATIONS

It is recommended:

- That, based on the results of this study, potential limits for use of hot water as a first-step fluid be considered as follows:
  - to –6°C in wind conditions up to 10km/h
  - to –3°C with no wind restrictions
- That a final series of tests be conducted on operational aircraft to confirm these proposed limits, and to examine the effects on elapsed time until onset of freezing of varying the quantity of hot water. These tests should be conducted during precipitation, and ideally would include an aircraft with composite materials on some wing surfaces. Lacking aircraft availability, the new TDC test wing installation could be considered for these trials.
- That any published guidelines for the application of hot water as a first-step fluid emphasize the benefits of applying generous quantities.
- That the influence on elapsed time to onset of freezing of different quantities of fluids on composite surfaces be examined through further laboratory tests.

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2. Singh, K. R., *Aircraft Ground Operations in Canadian Winter Weather: Tax Times, Wing Temperatures and Hot De-Icing,* Aviation Research Corporation, Vaudreuil, April 1996, Transportation Development Centre report, TP 12735E, 128.

3. Dawson, P., Hanna, M., Chaput, M., *Aircraft Deicing Fluid Freeze Point Buffer Requirements Deicing Only and First Step of Two-Step Deicing,* APS Aviation Inc., Montreal, December 1998, Transportation Development Centre report, TP 13315E, 167.

4. D'Avirro, J., Chaput, M., Hanna, M., Peters, A., *Aircraft Ground De/Anti-icing Fluid Holdover Time Field Testing Program for the 1997-98 Winter,* APS Aviation Inc., Montreal, December 1998, Transportation Development Centre report, TP 13318E, 200.

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APPENDIX A
WORK STATEMENT
AIRCRAFT AND FLUID HOLDOVER TIME TESTS FOR WINTER 1998-99

APPENDIX A

TRANSPORTATION DEVELOPMENT CENTRE

WORK STATEMENT

AIRCRAFT AND FLUID HOLDOVER TIME TESTS FOR WINTER 98/99

(December 1998)

1. INTRODUCTION

Following the crash of a F-28 at Dryden in 1989 and the subsequent recommendations of the Commission of Inquiry, the Dryden Commission Implementation Project (DCIP) of Transport Canada (TC) was set up. Together with many other regulatory activities an intensive research program of field testing of deicing and anti-icing fluids was initiated with guidance from the international air transport sector through the Society of Automotive Engineering (SAE) G-12 Committee on Aircraft Ground De/Anti-icing. As a result of the work performed to date Transport Canada and the US Federal Aviation Administration (the FAA) have been introducing holdover time regulations and the FAA has requested that the SAE, continue its work on substantiating the existing ISO/AEA/SAE Holdover Time (HOT) tables (TC research representing the bulk of the testing).

The times given in HOT Tables were originally established by the Association of European Airlines based on assumptions of fluid properties, and anecdotal data. The extensive testing conducted initially by the DCIP R&D Task Group and subsequently by its successor Transport Canada, Transportation Development Centre (TDC) Aviation Winter Operations R&D (AWORD) Group has been to determine the performance of fluids on standard flat plates in order to substantiate the times or, if warranted, to recommend changes.

TDC has undertaken most of the field research and much other allied research to improve understanding of the fluid HoldOver Times. Most of the HOT table cells been substantiated, however low temperatures have not been adequately explored and further tests are needed.

The development of ULTRA by Union Carbide stimulated all the fluid manufacturers to produce new long lasting anti-icing fluids defined as Type IV. All the Type IV fluids were upgraded in early 1996 and therefore all table conditions need to be re-evaluated and the table revised if necessary. Certain special conditions for which advance planning is particularly difficult such as low temperatures with precipitation, rain or other precipitation on cold soaked surfaces, and precipitation rates as high as 25 gm/dm²/hr need to be included in the data set. All lead to the need for further research.

Although the Holdover tables are widely used in the industry as guides to operating aircraft in winter precipitation the significance of the range of time values given in each cell of the table is obscure. There is a clear need to improve the understanding of the limiting weather conditions to which these values relate.

An important effort was made in the 94/95 and 95/96 seasons to verify that the flat plate data were representative of aircraft wings. Airlines cooperated with DCIP by making aircraft and ground support staff available at night to facilitate the correlation testing of flat plates with performance of fluids on aircraft. An extension of this testing was to observe patterns of fluid failure on aircraft in order to provide data to assist pilots with visual determination of fluid failure, and to provide a data to contamination sensor manufacturers. The few aircraft tests made to validate the flat plate tests were inconclusive and more such tests are needed. Additional tests testing with hot water for special deicing conditions were not completed. All these areas are the subjects for the further research that is planned for the 98/99 winter.

The primary objective of 97/98 testing was the performance evaluation of new and previously qualified Type IV fluids over the entire range of conditions encompassed by the holdover time tables. The effect of different variables on the fluid holdover time, in particular the effect of fluid viscosity, was examined and deemed to be significant. As a result, any future Type IV fluid holdover time testing will be conducted using samples representative of the manufacturers lowest recommended on-wing viscosity. Current methods for establishing holdover times in snow involve outdoor testing, which has been the source of industry concern for some time. It is recommended that a snowmaking device in development need to be evaluated for the future conduct of snow holdover time tests in controlled conditions. The study of fluid buffers was also continued in 97/98 and identified several industry concerns which will be addressed in further research. The adherence of contaminated fluid to aircraft wings was also evaluated in a series of simulated takeoff runs without aircraft rotation. Further research in these areas is needed.

2. PROGRAM OBJECTIVE (MCR 16)

Take an active and participatory role to advance aircraft ground de-icing/anti-icing technology. Develop international standards, guidance material for remote and runway-end de-icing facilities, and more reliable methods of predicting de-icing/anti- icing holdover times.

3. PROGRAM SUB-OBJECTIVES

3.1. Develop reliable holdover time (HOT) guideline material based on test information for a wide range of winter weather operating conditions.

3.2. Substantiate the guideline values in the existing holdover time (HOT) tables for fluids that have been qualified as acceptable on the basis of their impact on aircraft take-off performance.

3.3. Perform tests to establish relationships between laboratory testing and real world experience in protecting aircraft surfaces.

3.4. Support development of improved approaches to protecting aircraft surfaces from winter precipitation.

4. PROJECT OBJECTIVES

4.1. Develop holdover time data for all newly qualified de/anti-icing fluids.
4.2. Develop holdover time data for Type IV fluids using lowest qualifying viscosity samples.
4.3. Develop supplementary data for a reduced buffer ‘de-icing only’ Table.
4.4. Determine whether recycled, recovered fluid can be used as a ‘De-icing only’ fluid.
4.5. Determine whether the extreme precipitation rates used for laboratory testing of de/anti-icing fluids are in fact encountered in practice.
4.6. Obtain equipment for laboratory production of artificial snow which most closely reproduces natural snow.
4.7. Assess the limiting conditions of wind, precipitation and temperature under which water can be used as the first step of a two-step de-icing procedure.
4.8. Determine the patterns of frost formation and of fluid failure initiation and progression on the wings of high-wing turbo-prop and jet commuter aircraft.
4.9. Assess the practicality of using vehicle-mounted remote contamination detection sensors for pre-flight (end-of-runway) inspection.
4.10. Provide base data on the capabilities of remote sensors.
4.11. Provide pilots with reference data for the identification of fluid failure. Quantify pilot capabilities to identify fluid failure
4.12. Provide support services for the conduct of tests to determine under what conditions contaminated fluid adheres to aircraft lifting surfaces.
4.13. Assess whether pre-warming fuel at time of re-fuelling will help to eliminate the ‘cold soaked’ wing problem.
4.14. Develop a low-cost test wing which can be used in the laboratory in lieu of field testing full scale aircraft.
4.15. Establish the safe limits for de-icing truck operation when de-icing aircraft with the engines running.
4.16. Provide general support services.
4.17. Disseminate test findings

5. DETAILED STATEMENT OF WORK

5.1. General

5.1.1. Planning and Control

Develop a detailed work plan, activity schedule, cash flow projection, project management control and documentation procedures (as specified in Section 9,"Project Control") within three weeks of effective commencement date, confirming task priorities, suggesting hardware and software suppliers, broadly identifying data needs and defining the roles of subcontractors, and submit to TDC for review and approval.

5.1.2. Safety and Security

Particular consideration will be given to safety in and around aircraft on the airport and deicing sites In the event of conflict between access for data gathering to obtain required test results and safety considerations, safety shall always govern.

5.2. Holdover Time Testing and Evaluation of De/Anti-icing Fluids

5.2.1. Newly Certified Fluids

Conduct flat plate tests under conditions of natural snow and artificial precipitation to record the holdover times, and to develop individual Holdover Time Tables based on samples of newly certified or re-certified fluids supplied by Fluid Manufacturers under as wide a range of temperature, precipitation rate, precipitation type, and wind conditions as can be experienced. Anticipate tests for one new fluid. Snow tests shall be conducted outdoors, and ZD, ZR-, Zfog, and CSW tests will be performed in the laboratory. All testing shall be performed using the methodology developed in the conduct of similar tests for Transport Canada in past years.

5.2.2. Low Viscosity Type IV Anti-icing Fluids

Fluid holdover time testing of Type IV fluids will be conducted using procedures established during past test seasons but using fluid with the lowest operational use viscosity.

5.2.2.1. Flat Plate Tests for New Type IV Fluids

Conduct flat plate tests under conditions of natural snow and artificial precipitation to record the holdover times, and develop individual Holdover Time Tables based on samples of new Type IV fluids supplied by Fluid Manufacturers under as wide a range of temperature, precipitation rate, precipitation type, and wind conditions as can be experienced. Anticipate for four new fluids using samples with one viscosity. Snow tests shall be conducted outdoors, and ZD, ZR-, Zfog, and CSW tests shall be performed in the laboratory using methodology applied in past years.

5.2.2.2.Effect on Holdover Time of Viscosity

Conduct tests aimed at determining the effect of fluid viscosity on holdover time. Tests shall be conducted in light freezing rain and freezing drizzle conditions at various temperatures in the National Research council (NRC) Climatic Environment facility (CEF) using low and high viscosity samples representing production limits of three anti-icing fluids: a propylene, an ethylene and the Fluid X (which will become the benchmark for laboratory based HOT testing).

Anticipate a total of approximately 100 tests to be conducted under ZR- and ZD at -3 and -10 Celsius at low and high rates.

5.2.3.Recycled Fluids as Type I Fluids

5.2.3.1.Holdover Times

A complete set of holdover time tests shall be conducted using two fluid test samples of recovered glycol based freezing point depressant fluid which have been recycled and exhibit nominal conformance to Type I de-icing fluid performance characteristics. The objective of this series of tests is to establish a sound base of data sufficient to establish valid holdover time tables for these fluids.

5.2.3.2.Compatibility with Type IV Fluids

Fluid compatibilty trials shall be conducted using various combinations of the recycled fluids and commercial Type IV fluids. Determine how the Inland fluids perform when used in conjunction with a Type IV fluid overspray.

5.3. Supplementary Data for Deicing Only Table

Evaluate the test conditions used in establishing the deicing only table by undertaking the following test series at sub zero temperatures but with no precipitation.

5.3.1. Establish Quantity of Fluid for Field Tests.

Conduct a series of comparative laboratory tests with 0.5, 0.25 and 0.1 litre per plate. Consider the case of spraying for frost with a fan shape to cover a wide area with a small amount of fluid compared with a stream as used to remove snow or ice. Examine typical fluid quantities representing frost removal spray. Conduct some tests on aircraft piggybacking on other testing if feasible.

5.3.2.Establish Temperature of Fluid for Field Tests

Laboratory tests will be performed with fluids initial temperatures at the spray nozzle of 60ºC, 50ºC, and 40ºC init ial temperature.

Field tests on aircraft will be designed to measure the loss of fluid temperature and to measure fluid evaporation and enrichment during the air transport phase between spray nozzle and wing surfaces, for various distances and shapes of spray pattern (3 distances; 2 spray patterns).

5.3.2.1.
Examine the effect on the final freeze point of sprayed fluids on the wing, resulting from variations in the temperature of the fluid (60ºC, 50ºC, and 40ºC).
5.3.2.2.
Examine the effect on wing heat and fluid evaporation of removing contaminant from the wing surface. Various degrees of ice depth shall be deposited using a hand-held rainmaker, including a very light coating to simulate frost. The amount of fluid sprayed shall be controlled by the operator, spraying until a clean surface results.

5.3.3. Perform tests at current buffer limit as baseline.
Perform a series of comparative tests using buffers at 3ºC and 10ºC to compare to the new data and the data collected last season with buffers at 0ºC .

5.3.4. Simulate High Wind Conditions
Tests shall be performed using NRC fans producing winds up to 30 kph for comparison with the earlier series of tests with speeds up to 20 kph

5.3.5. High Relative Humidity
Perform a series of plate tests at 90% RH to compare results to those already gathered. Review the condition with weather services to determine typical RH values during deicing only conditions.

5.3.6. Cold Soaked Wings
Perform a series of tests on cold soak boxes to establish whether the natural buffer provided by evaporation would be sufficient to provide protection if the wing were in a cold-soaked condition, with wing temperature several degrees below OAT. These tests can be run in conjunction with high humidity tests when deposition of frost on cold soaked surfaces would normally be expected.

5.3.7. Effect of Snow Removal on Fluid Heat Input
Perform tests to establish whether removal of snow results in extesive amounts of heat being carried away and insufficient heat being transferred to the wing during deicing.
Expose flat plates to snowfall (either natural or as simulated by approved equipment) and protect snow catches of various thicknesses. Tests shall be run in an area protected from further snowfall. Fluid shall be applied with a hand sprayer, until the plate is cleaned, measuring the amount of fluid applied. The final fluid concentration on the plate shall be measured. The heat lost in fluid run off shall be measured. Parallel tests will be conducted on bare surfaces.

A carefully calculated heat balance shall be determined for each experiment based on the temperatures of the applied fluid, the plate and the collected run-off material.

5.3.8. Effect of Composite Surfaces on Evaporation

Evaluate the effects of the use of composite materials in wings on the heat transfer from deicing fluid to the wing. Conduct a series of laboratory comparative tests on a several samples of composite surfaces.

Identify an appropriate aircraft having a wing surface composed of new technology composite material as well as aluminium, determining the thermal pathways connecting the composite surfaces to the main wing structure.

Conduct field tests on a sample aircraft.

5.3.9. Unpowered Flight Control Surfaces

Field trials will be conducted on DC9 aircraft to assess the impact of fluids of various buffers on the freedom of operation of the unpowered elevator control tabs to establish whether the natural buffer provided by evaporation would be sufficient to provide protection if the wing were in a cold-soaked condition, with wing temperature several degrees below OAT

5.3.10. Field Tests on Aircraft

Three overnight test sessions shall be planned for these tests. Tests shall be conducted on aircraft types including the McDonnell Douglas DC-9 and Canadair RJ, with a minimum of one night for each type. Testing on a third aircraft type would be useful to improve confidence and to confirm the universality of the results. Use an ice detector sensor system to provide a separate source of data.

5.3.11. Laboratory Tests

The number of proposed tests shall be controlled by limiting tests to the minimum number of ambient conditions that will support conclusions on the significance of the issues raised while maintaining a good level of confidence. As a minimum, this encompasses about 230 plate tests and would require about 8 days at the NRC CEF Facility or other suitable facility.

5.4. Flow of Contaminated Fluids from Wings during Takeoff

5.4.1. Requirement

Evaluate anti-icing fluids for their influence on adherence, in particular, propylene based Type IV fluids which were observed during fluid failure

A test plan shall be developed jointly with NRC.

Two days of testing at Mirabel Airport shall be planned.

Use an ice contamination sensor to assist in documenting contamination levels to provide valuable assistance in data gathering. A contingency allowance to fund sensor company participation shall be included.

Data collected during these trials shall include:

- type of fluid applied;
- record of contamination level prior to take off runs,;record of level of contamination following takeoff runs;
- observations, photography and video taping, and ice sensor records; and
- specifics on aircraft takeoff runs obtained from NRC personnel.

5.4.2. Conduct of Trials and Assembly of Results

Coordinate all test activities, initiating tests in conjunction with NRC test pilots based on forecast weather. Analyse results and document all findings in a final technical report and in presentation format.

5.5. Aircraft Full-Scale Tests

5.5.1. Purpose of Tests

Conduct full-scale aircraft tests:

- To generate data which can be used to assist pilots with visual identification of fluid failure;
- To generate data to be used to assess a pilot's field of view during adverse conditions of winter precipitation for selected aircraft; (See item 5.11)
- To compare the performance of de/anti-icing fluids on aircraft surfaces with the performance of de/anti-icing fluids on flat plates;
- To examine the pattern of failure using Type IV fluid brands not tested in the past; and
- To further investigate progression of failure on the two wings in crosswind conditions.

5.5.2. Planning and Coordination

Planning and preparation for tests including provision of facilities, personnel selection and training, and test scheduling shall be the same as provided to TDC in previous years

5.5.3. Testing

All tests and dry runs shall be performed using the methodology developed in the conduct of similar tests for Transport Canada in past years.
Test planning will be based on the following aircraft and facilities:

Aircraft	Airline	Test Locn.	Deicing Pad	Deicing Crew
Canadair RJ	Air Canada	Dorval	Central	Aéromag 2000
ATR42	Inter Canadian	Dorval	Central	Aéromag 2000

5.5.4. Test Measurements

Make the following measurements during the conduct of each test:

- Contaminated thickness histories at selected points on the wings. The selection of test points shall be made in cooperation with the Transportation Development Centre,
- Contamination histories at selected points on wings (selected in cooperation with the Transportation Development Centre),
- Location and time of first failure of fluids on the wings,
- Pattern and history of fluid failure progression,
- Time to failure of one third of the wing surface
- Concurrent measurement of time to failure of fluids on flat plates. The plates will be mounted on standard frames and on aircraft wings at agreed locations,
- Wing temperature distributions,
- Amount of fluid applied in each test run and fluid temperature,
- Meteorological conditions, and
- For crosswind tasks, effects of rate of accumulation on each wing.

In the event that there is no precipitation during full-scale tests, the opportunity shall be taken to make measurements of fluid thickness distributions on the wings. These measurements shall be repeated for a number of fluid applications to assess the uniformity of fluid application.

5.5.5. Pilot Observations

Contact airlines and arrange for pilots to be present during the tests to observe fluid failure and failure progression, and to record pilot observations from the cockpit and the cabin for later correlation with aircraft external observations.

5.5.6. Remote Sensor Records

Record the progression of fluid failure on the wing using RVSI and/or Cox remote contamination detection sensors if these sensors are made available.

5.6. Snowmaking Methods and Laboratory Testing for Holdover Times

5.6.1. Evaluation of Winter Weather Data

5.6.1.1. Snow Rates

Collect and evaluate snow weather data (precipitation rate/temperature data) during the winter to ascertain the suitability of the data ranges used to date for evaluation of holdover time limits.

Obtain current data from Environment Canada for three sites in Quebec: Rouyn, Pointe-au-père (Mont-Joli), and Ancienne Lorette (Quebec City), in addition to Dorval (Montreal).

5.6.1.2. Fog Deposition Rates

Devise a procedure and conduct fog deposition measurements outdoors on at least two occasions to determine the range of fog deposition rates which occur in natural conditions.

5.6.1.3. Frost Deposition Rates

Frost deposition rates shall be collected at various temperatures in natural conditions in order to determine a deposition range for this condition. Consideration shall be given to collecting deposition rates in cold temperatures (for example in Thompson, Manitoba). A total of five sessions shall be planned.

5.6.2. Snowmaking Methods

Acquire a version of the new snow generation system recently developed by the National Centre for Atmospheric Research (NCAR).

Evaluate the NCAR system for the future conduct of holdover time testing in simulated snow conditions. Tests shall be conducted in a small climatic chamber at Concordia University, PMG Technologies, or at NRC. Tests shall also be conducted with one Type IV fluid over a range of temperature and snowfall rates to compare the SAE holdover times for this fluid in natural and simulated conditions.

A further series of tests shall be performed with the system in order to assess the holdover time performance of the reference fluid (as described in the proposed SAE test procedures).

A total of 8 days of climatic chamber rental shall be planned for the conduct of the proposed tests.

5.7. Documentation of Appearance of Fluid Failure for Pilots

Current failure documentation deals largely with freezing drizzle and freezing rain conditions

5.7.1. Documentation of Failures

Finalise documentation of failure through limited further research as follows:

5.7.1.1.

provide similar documentation for fluids exposed to snow conditions, taking advantage of the availability of a snow making device for laboratory use;

5.7.1.2.

provide documentation for a propylene based Type IV fluid at typical delivered viscosity, for precipitation conditions tested previously, to determine characteristics at its operational limits and the nature and mechanisms of failure. Conduct selected comparison tests with a second fluid to test commonality of responses. Data from this activity will be cross-analysed with data from proposed research to examine the flow of similar fluids at different levels of contamination from aircraft wings during a simulated takeoff; and

5.7.1.3.

examine and document the appearance and nature of failure of propylene base fluids at cold temperatures (-10 C).

5.7.1.4.

Conduct tests at the National Research Council Climatic Environmental Facility based on last years' procedures, with enhancements as necessary and available. Snow documentation may be conducted in a different laboratory facility. Documentation under outdoor snow conditions will be conducted for comparison purposes to laboratory conditions.

5.7.2. Conduct of trials/assembly of results

Coordinate all test activities, scheduling tests with NRC CEF in conjunction with other test activities. Analyse results and document all findings, recommendations and conclusions in a final technical report and in presentation format. Provide timely updates of schedule revisions to TDC.

5.7.3. Pilot Observations

Contact airlines and arrange for pilots to be present during tests to observe fluid failure and failure progression. Record pilot observations for later correlation with aircraft external observations.

5.8. Feasibility of Performing Wing Inspections at End-of-runway

5.8.1. Requirement

Examine the feasibility of scanning aircraft wings with ice contamination sensors just prior to aircraft entering the departure runway using Dorval airport as an example scenario.

Explore ways of positioning sensors at agreed locations on an airport.

Composition and conduct of tests shall be adapted as information is gained on the practicality of this activity.

5.8.2. Planning

A Project Plan shall be prepared which will include:

a) activities to determine the parameters, operational issues and constraints related to the proposed process, and

b) a test plan for operational trials to examine the capabilities of the contamination sensors to determine the feasibility of their operational use.

The test plan for operational trials (three sessions) shall include:

- establishing test locations with airport authorities,
- establishing operational procedures with airport authorities,
- arranging equipment for scanning; vehicle, sensor installation and radios,
- collecting and coordinating information from the deicing activity at the deicing centre,
- test procedures with detailed responsibilities for all participants,
- control of the confidential data gathered on wing condition, and

- notification to all concerned in the project, including aircraft operators, that scanning activities will take place.

5.8.3. Coordination

Coordination all activites with authorities from Aéroports de Montréal and arrange support from Cox and/or RVSI

5.8.4. Field Trials

Conduct trials to further evaluate the feasibility of integrating such a process within current airport operations management, as well as to gather information on wing condition, just prior to takeoff, during deicing operations. These trials shall be based on the use of mobile equipment currently available. A "truthing" test pannel shall be present at each trial to demonstrate the validity of the wing readings on an ongoing basis

The trials shall be designed to address issues such as:

- equipment positioning versus current runway clearance limitations,
- time delay between inspection and start of take-off
- system capabilityto meet its design objectives in severe weather
- suitability of mobile equipment or fixed facility.
- need for rapid extension and retraction of sensor booms,
- airport support needed, e.g. snow clearance, provision of operating locations,
- accommodating scanner limitations for distance, light, angle of incidence.
- communications needed to support scanning operation,
- recording data from the sensors, and
- communicating results of the scanning to pilots and regulatory authorities.

5.8.5. Test Personnel and Participation

Initiate all tests based on suitable weather conditions. The individual test occasions shall be coordinated with Aéroports de Montréal and Aéromag 2000.

Coordinate the provision of a suitable vehicle and the installation of an ice detection sensor. Monitor the test activity, ensuring the collection and protection of all scanning data, as well as the collection of data related to weather conditions and previous aircraft deicing activities. Ensure that the instrument providers deliver data and an objective measure of wing contamination based on scanner information in a timely and reproducible manner.

5.8.6. Study Results

Results from the feasibility study shall be presented in technical report format which shall include comments pertinent to long term implementation.

Results from the scanner tests shall be provided in technical report format and shall include analysis of wing contamination data cross-referred to the deicing history of individual aircraft scanned.

5.9. Ice Detection Sensor Certification Testing

5.9.1. Minimum Ice Thickness Detectable in Tactile Tests

Prepare procedures and conduct tests to establish human limits in identifying ice through tactile senses. These tests shall use the NRC or equivalent test facilities acceptable to TDC and a test setup equivalent to that planned for sensor certification. Several ice thicknesses and textures shall be tested to establish tactile sensing limiting thickness for smooth ice and for roughened ice.

The experiment shall involve sufficient participants and test conditions such as to provide reliable results usable in approving sensors to replace human tactile testing.

TDC shall assist in the experimental design

Tests shall be conducted with both contractor personnel and a selection of pilots as subjects.

A professional human factors scientist shall be used to establish testing parameters such as:

- what proportion of plates should be bare
- whether subjects should be blindfolded to eliminate visual cues.
- whether the same plate should be judged more than once
- how to ensure that subjects do not compare plates
- what should be the minimum time between plate touching

Results of the tests shall be analysed statistically to establish confidence limits for the findings

5.9.2. Field Tests for Sensor Distance and View Angle Limits

Develop a detailed test plan with a matrix of all test parameters, required coordination of equipment detailing the responsibilities of all participants.

Collect test data, including photo and video records of all tests.

The areas of ice contamination used for sensor evaluation shall be quantified by size, location and thickness. Angles of incidence, sensor heights and distances shall be verified independently. In concert with the sesor manufacturer, data from sensor readings and observer data shall be collated and analysed to reach conclusions on sensor limitations for distance and angle of incidence in various weather conditions.

5.10. Planning a Wing Deicing Test Site

Develop a plan for implementing a deicing test site, centred on an aircraft wing and supported by current fluid and rainmaking sprayers.

The plan shall include the acquisition of a surplus complete wing, from either a scrapped or an accidented moderate sized aircraft or an outboard section of a larger aircraft. The wing section should if possible include ailerons and leading edge slats The design of the test site shall include a test area that could contain and recover sprayed fluids. Installation of the wing should entail a mounting designed to allow the wing to be rotated relative to current winds. The site must be secure yet allow ease of access and ability to install inexpensive solutions to control sprayed fluid.

Costs shall be estimated for the main elements of the development of a wing test bed site including:

wing purchase and delivery,

site lease and development, and

wing mount design and fabrication.

5.11. Evaluation of Hot (and Cold) Water Deicing

Investigate unheated and hot water deicing/defrosting, to determine under what meteorological conditions and temperatures these procedures are safe and practicable.

Unheated water deicing shall be evaluated at air temperatures above 1 degree C(34 degrees F).

Hot water deicing shall be evaluated at air temperatures below 1 degree C and include temperatures below –3 degrees C (27 degrees F).

These experiments shall establish how long it takes for the water to freeze on the surface under these conditions.

This is to be the first step of a two step procedure. From these data, a safe and practical lower limit shall be established considering the three-minute window required for second step anti-icing in the two-step deicing procedure.

Precipitation rates, as utilised in the generation of holdover time tables, shall be considered. Environmental chamber tests shall be correlated with outdoor aircraft tests. All laboratory test procedures and representative test results shall be recorded on videotape, including failure modes where applicable. The video shall depict a recommended full-scale aircraft hot water deicing procedure. A written report shall include the laboratory test results and a recommended aircraft unheated/hot water deicing procedure, including the limitations of precipitation, OAT and wind.

5.12. Evaluation of Warm Refuelling

Conduct a feasibility study of the suitability of refuelling with warm fuel to reduce susceptibility to “cold-soaked wing” icing, and to improve holdover times.

Coordinate activities to support testing the “warm fuel” concept using operational aircraft, including arranging;

- Participation of interested airlines, along with provision of aircraft for test purposes;
- Participation of local refueller;
- Arrangements with the equipment supplier (Polaris) to deliver the equipment to the selected airport along with the required technical support.

Testing will be conducted at Dorval on three occasions, one of which will include snow or freezing precipitation. Test aircraft selected should include a representation of both “wet” and “dry” wings if possible.

Wing surface temperatures of test wings will be monitored at several points over a period of time, to assess the influence thereon of warmed fuel. A reference case based on fuel boarded at the normal local temperature will be conducted.

5.13. Engine Air Velocity Distributions near Deicing Vehicles

Measure air velocity distributions in the vicinity of a de-icing truck when de-icing a large aircraft whose engines are running.

Tests shall be conducted during a period of no precipitation, either frost deicing or following snowfall, on two separate occasions at the Dorval International Airport deicing facility. Aircraft with engines mounted on the wing (e.g. B737) as well as rear engines mounted aircraft (e.g. DC-9 and RJ) will be sampled during live deicing operations, the precise type to be agreed by TDC. The tests shall be coordinated with Aéroport de Montréal and Aéromag 2000.

Wind velocity shall be measured from an Elephant-mu de-icing truck at locations recommended by TDC around the tail of the aircraft at different elevations and distances from the engines depending on the aircraft type, and the de-icing procedure followed by Aéromag 2000.

Photograph and video record the conduct of all tests.

5.14. Provision of Support Services

Provide support services to assist TDC with testing, the reduction of data and presentation of findings in the activites identified below which relate to the content of this work statement, but are not specifically included.

5.14.1. Re-Hydration

Conduct a series of exploratory trials on flat plates at the Dorval site or NRC to observe the behaviour of re-hydrated Type IV fluids and to help determine how re-hydration affects the flow- off characteristics of a Type IV fluid exposed to frost conditions.

5.14.2. Frost Tests on a Regional Jet

Conduct a series of tests to determine the roughness of frost deposition on the wings of a Regional Jet aircraft. Conduct tests on three overnight occasions.

5.14.3. Ice-Phobic Materials Evaluation

Conduct a series of tests on flat plates to determine the effects of ice-phobic materials on the film thickness and on holdover time of de/anti-icing fluids.

5.14.4. Evaluation of Infra-Red Thermometers

Evaluate use of infra-red technology as a method of determining accurate skin and fluid temperatures during operational conditions. Conduct tests in conjunction with full-scale and holdover time testing.

5.14.5. Frost Self-Elimination

Examine the self-elimination of frost on several test surfaces under variable weather conditions. Conduct test in conjunction with frost deposition trials on flat plates.

5.14.6. Environmental Impact Assessment

Assess the environmental issues related to the use of glycol-based products for aircraft de-icing purposes. Examine the waste fluid collection and disposal procedures for several deicing facilities in relation to current and future environmental legislation.

5.14.7. An Approach to Establish Wing Contamination

Document an approach to determining operational limits for levels of contamination on aircraft wings. This approach will include consideration of the location of contamination on the wings and the area contaminated. The levels of contamination on aircraft wings prior to takeoff as determined during the scanning trials prior to takeoff will be factored in.

The approach will discuss how the limits (when defined) could be used in software routines to enable sensor systems to provide Go/No-Go indications to the aircraft pilot and regulatory authorities.

5.14.8. Accident/incident Database Analysis

Provision of database manipulation and support aimed at establishing problem areas and their significance.

5.14.9. Other activities

Other activities, such as the evaluation of forced air technology, the evaluation of alternate (zero glycol) deicing methods, and the evaluation of frost removal equipment at gates, or others may emerge as issues during the course of the winter season.

APPENDIX B
EXPERIMENTAL PROGRAM
LABORATORY TRIALS TO ESTABLISH ENVIRONMENTAL LIMITS FOR HOT WATER DEICING

CM1514.001

EXPERIMENTAL PROGRAM
LABORATORY TRIALS TO ESTABLISH ENVIRONMENTAL LIMITS FOR HOT WATER DEICING

Winter 1998/99

APS AVIATION INC.

March 12, 1999
Version 2.2
Revised July 19, 2002

EXPERIMENTAL PROGRAM
LABORATORY TRIALS FOR HOT WATER DEICING
Winter 1997/98

APS will conduct a series of tests on flat plates in the National Research Council controlled environment laboratory facility at Ottawa Airport. This document provides the detailed procedures and equipment required for the conduct of these tests.

1. OBJECTIVE

The objective of this series of tests is to examine environmental limits (OAT, wind) for the application of hot water as the first step fluid in a two-step deicing procedure.

2. BACKGROUND

The current limitation for application of hot water (SAE ARP4737) as the first step deicing fluid is -3ºC. This limitation is intended to ensure that a minimum three minute window before freezing of the applied water occurs, is available to the deicing operator for the purpose of applying the overspray of the second step anti-icing fluid.

Previous related studies include Hot Water Deicing Trials conducted on aircraft during the Winter 1994/95 season, and a project during the Winter 1997/98 season to determine fluid dilution limitations for the deicing fluid applied during Deicing Only conditions, and for the first step fluid of a two-step deicing operation.

The 1994/95 study examined whether the OAT limitation for the application of hot water could safely be lowered beyond -3ºC. That study, conducted primarily on aircraft, indicated that hot water deicing is feasible at OATs below -3ºC, depending on wind speed and operator disciplines. Earliest occurence of freezing occurred on flight control surfaces at the rear of the wing, as opposed to the main wing surface. It was recommended that any further tests should consider examination of composite materials frequently used in the fabrication of these surfaces. Tests in a controlled environment laboratory confirmed the major influence that high winds exert on shortening the time until freezing initiates. Field operators experienced in hot water deicing indicated that a cautious approach is necessary even at moderate temperatures during conditions of high wind.

The 1997/98 study on First Step Fluids examined application of Type I deicing fluids, as well as water, and determined the resultant interval until freezing initiated. Trials were conducted at a range of temperatures, under freezing rain and freezing drizzle precipitation. Later in the study, a test procedure for combining wind and precipitation conditions was devised, and a small number of trials at one OAT were conducted. This study included an examination of the rate of dilution of the applied Type I fluids under the test levels of precipitation. Test results demonstrated that the heat transferred to the test surface from the heated first step fluid accounted for the major part of the safe period until freezing initiated. Type I fluids experienced rapid dilution after application on the surface, and provided a further extension to the safe period until initiation of freezing. The value of this extended safe period provided by the Type I fluids, was relatively more significant in high wind conditions when the surface temperature dropped more rapidly.

The 1997/98 Deicing Only study examined the use of very dilute fluids to remove any contamination following termination of precipitation. This study included measurement of the rate of cooling of the test surface for different wind and OAT combinations, but under conditions of no precipitation. This information is useful for providing an indication of the time interval from application of the deicing fluid, until the surface temperature reaches 0ºC, for various OAT/wind combinations.

The findings from these previous studies have been considered in the design of the current experiment.

3. TEST REQUIREMENTS

Tests will be scheduled at the NRC CEF facility over a 3 day period. Test variables will include air temperature and wind speed. A precipitation condition of freezing rain at a rate of 25 $g/dm^2/hr$ will be established.

Fluids will be applied by spraying. An controlled level of contamination will be allowed to collect on the plates prior to test and between test runs, by exposing the plate to precipitation for a predetermined time interval. This exposure time interval will be re-established for each temperature condition with the objective of standardizing the degree of plate contamination for all conditions as much as possible.

The resulting layer of ice contamination will then be removed by spraying as much fluid as is required to provide a clean plate. The time interval until freezing

initiates will then be measured.
In certain of the trials that demonstrate times shorter than, 3 minutes, the test will be re-run with additional fluid sprayed, with the objective of determining how much additional sprayed water would be necessary to achieve a 3 minute time to freezing.

For tests involving Type I fluid, a duplicate test plate will be run to enable measurement of dilution rates of the fluid. The test procedure is described in Attachment I.

4. EQUIPMENT AND FLUIDS

Equipment to be employed is listed in detail in Attachment II.

Water, heated to 60ºC, will be the primary fluid applied in these trials. A reference fluid consisting of Type I deicing fluid mixed to the current -3ºC buffer limit for first step fluids will be tested as well. The rate of dilution of this fluid will be measured during the trials.

5. PERSONNEL

A test team of three personnel will conduct these trials. The team will normally conduct tests on two test plate surfaces simultaneously, while a third plate (duplicate for Type I fluid tests) will enable ongoing fluid strength sampling without disturbing the experiment.

A support team of two personnel will be responsible for the provision of accurately prepared test fluids to support ongoing testing in the most efficient manner.

An overall coordinator will be present.
Duties of each team member is shown in Attachment III.

6. TEST PLAN

A test matrix of fluid types and concentrations, ambient temperatures, wind speeds, relative humidity and test surfaces is shown in Figure 1.

A detailed test plan is provided in Attachment IV.

7. DATA FORMS

The following data forms are required:

- Data form for Hot Water Trials (see Figure 2);
- Brix Progression for Hot Water Trials (see Figure 3);
- Precipitation Rate Measurement (see Figure 4); and
- Continuous Precipitation Rate Measurement (see Figure 5).

FIGURE 1
TEST PLAN FOR HOT WATER TRIALS

OAT (°C)	FLUID	WIND (kph)	TEST SURFACE
-3	Water	Calm	Standard test plate for all conditions
		10	Composite surfaces for selected conditions
		20	
		30	
-6	Water	Calm	
	Type I ADF	10	
		20	
		30	
-9	Water	Calm	
	Type I ADF	10	
		20	
		30	
-12	Water	Calm	
	Type I ADF	10	
		20	
		30	

NOTES

Precipitation Rate - Light Freezing Rain 25 g/dm²/hr
Fluids heated to 60°C
Fluids applied by spraying
Type I ADF mixed to -3°C buffer

FIGURE 2

DATA FORM FOR HOT WATER TRIALS (LIGHT FREEZING RAIN)

REMEMBER TO SYNCHRONIZE TIME 1998/99

LOCATION: CEF (Ottawa) **DATE: March ,1999** **AMBIENT TEMPERATURE: °C**

	RH	Wind Speed (kph)			
	(%)	Top Left	Top Right	Bottom Left	Bottom Right
Start					
End					

Run #:	______	______	______
Surface Type:	__________	__________	__________
Fluid Type:	__________	__________	__________
Fluid Brix:	______ °	______ °	______ °
Fluid Temperature:	______ °C	______ °C	______ °C
Plate Exposure Start Time:	__________ (hh:mm:ss:)	__________ (hh:mm:ss:)	__________ (hh:mm:ss:)
Spray Start Time:	__________ (hh:mm:ss:)	__________ (hh:mm:ss:)	__________ (hh:mm:ss:)
Spray Finish Time:	__________ (hh:mm:ss:)	__________ (hh:mm:ss:)	__________ (hh:mm:ss:)

Plate #

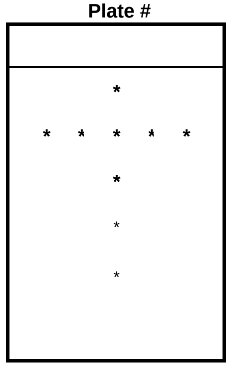


Plate #

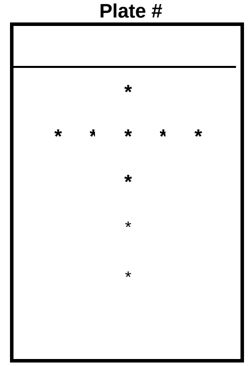
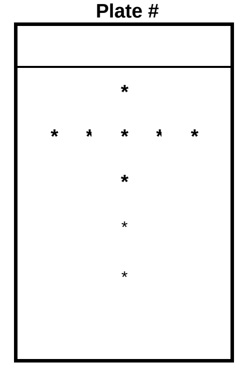


Plate #



Time to 1st Freezing:	__________	__________	__________
Time to Failure (6" Line):	__________	__________	__________
Time to complete Failure (15" Line):	__________	__________	__________

COMMENTS: ____

HAND WRITTEN BY : __________

LEADER: __________

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FIGURE 3

HOT WATER TRIALS

BRIX PROGRESSION

DATE: March , 1999

OAT: ________ **°C**

	RH (%)	Wind Speed (kph) Top Left	Top Right	Bottom Left	Bottom Right
Start					
End					

Plate Position: ________ °

Fluid Temperature: ________ °

Run #: ________

Plate Exposure Start Time: ________ (hh:mm:ss)

Surface Type: ________

Spray Start Time ________ (hh:mm:ss)

Fluid Type: ________

Spray Finish time ________ (hh:mm:ss)

Fluid Brix: ________ °

	1	2	3	4	5	6	7	8	9	10
Time (min)										
Brix										
	11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Time (min)										
Brix										

Comments on Final Plate Condition: ________

Plate Position: ________ °

Fluid Temperature: ________ °

Run #: ________

Plate Exposure Start Time: ________ (hh:mm:ss)

Surface Type: ________

Spray Start Time ________ (hh:mm:ss)

Fluid Type: ________

Spray Finish time ________ (hh:mm:ss)

Fluid Brix: ________ °

	1	2	3	4	5	6	7	8	9	10
Time (min)										
Brix										
	11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Time (min)										
Brix										

Comments on Final Plate Condition: ________

MEASUREMENTS BY: ________

HAND WRITTEN BY: ________

FIGURE 4

PRECIPITATION RATE MEASUREMENT AT CEF IN OTTAWA

Date: ____________________

Start Time: ____________________ am/pm

Run # : ____________________

Precip Type: ____________________ (ZD, ZR-)

Pan Location:

1	**2**	**3**	**4**	**5**	**6**
7	**8**	**9**	**10**	**11**	**12**

Collection Pan:

Pan/ Cup #	Area of Pan (dm^2)	Location		Weight of Pan (g) Before	After	Collection Time (min) Start	End
1		1	=				
2		2	=				
3		3	=				
4		4	=				
5		5	=				
6		6	=				
7		7	=				
8		8	=				
9		9	=				
10		10	=				
11		11	=				
12		12	=				

Comments: ____________________

Handwritten by: ____________________

Measured by: ____________________

Precipitation Rate = Δg/area (dm^2)/hr

FIGURE 5

CONTINUOUS PRECIPITATION RATE MEASUREMENT AT CEF IN OTTAWA

Date: ____________________

Start Time: ____________________

Run # : ____________________

Precip Type: ____________________ (ZD, ZR-)

Pan Location:

1	**2**	**3**	**4**	**5**	**6**
7	**8**	**9**	**10**	**11**	**12**

Collection Pan:

Pan/ Cup #	Area of Pan (dm²)	Location	Weight of Pan (g)		Collection Time		Rate
			Before	After	Start	End	
1							
2							
1							
2							
1							
2							
1							
2							
1							
2							
1							
2							
1							
2							
1							
2							

Comments:

Handwritten by: ____________________

Measured by: ____________________

Precipitation Rate = Δg/area (dm²)/hr

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ATTACHMENT I
HOT WATER TRIALS
DETAIL TEST PROCEDURE

1. PREPARATION

- Prepare test surfaces prior to transporting to Ottawa;
- Buff any existing plates planned for use, removing all traces of markings;
- Prepare sufficient test surfaces to enable assigning two surfaces to each fluid mix. Mark plate identifier on each plate, not on top surface; and
- Do not put grid marks on top surface.

Prepare fluid mixes in advance.

Calibrate fluid sprayers to determine rate of fluid sprayed over time using a fixed nozzle setting and fixed pressure.

Prepare equipment for transport to the National Research Council.

2. PRE TEST SET-UP AT SITE

- Establish initial temperature in chamber;
- Conduct calibration procedure on droplet size and precipitation rate:
- Set up equipment for test support, including fluid heating equipment;
- Install thermistor system and confirm operation of thermistors and temperature loggers; and
- Establish required interval for exposure of plates to precipitation to develop standard thickness of ice layer at all test conditions.

3. PROCEDURES

Precipitation rates will be measured over the entire stand at beginning of test session and every three hours, as well as on a continuing basis every 20 minutes using two pans.

Standard general test procedures for conducting tests at the National Research Council apply:

- Synchronizing watches and logging equipment apply; and
- Cleaning test surfaces prior to application of fluids.

Fluids are to be heated to 60ºC at time of application. Temperature and Brix values of fluids are to be measured. Fluids are to be applied using sprayers designed for this purpose. Plates will be exposed to precipitation for a standard predetermined interval to develop a layer of ice. The test fluid will then be sprayed to remove the ice layer, and the duration of spray recorded. The sprayers will be pre-calibrated to enable calculation of fluid quantity sprayed based on records of spray duration.

Tests will be run until complete plate failure, and times of initial appearance of freezing and plate failure will be recorded.

Plate temperatures will be monitored throughout by means of installed thermistor probes and data loggers. Temperature of test surfaces will be allowed to return to ambient laboratory temperature prior to proceeding with the next test.

Brix values will be measured on duplicate plates throughout the test run. Measurements will be taken at a frequency sufficient to produce data points sufficient to construct a fluid freeze point temperature profile over time. The procedure for lifting fluid samples for Brix measurement will attempt to collect a mix of fluid by running the fluid sampler the full length of the plate, from bottom to top, but avoiding picking up fluid from the drip line.

A video and photographic record of the test setup will be maintained.

ATTACHMENT II

NATIONAL RESEARCH COUNCIL COLD CHAMBER TESTS
HOT WATER TRIALS
TEST EQUIPMENT CHECKLIST

TASK	***NRC Cold Chamber***	
	Resp.	**Status**
Logistics for Every Test		
Make Hotel reservations		
Rent Van/Car		
Call Site Personnel		
Test Equipment		
Stand x 1		
Still Photo Camera		
Weigh Scale		
Stand Video Camera		
Pole for Video Camera		
Video Camera X 1 (Surf & Snow) + Access		
Plates (standard & composite) x 6		
Data Forms		
Precipitation rate Data Forms		
Reports + Tables		
Cake Pans x 12		
Video Tapes		
Type I Fluids		
Clipboards x 3		
Pencils + Space pens x 4		
Paper Towels		
Rubber squeegees		
Plastic Refills for Fluids and funnels		
Electrical Extension Cords		
Lighting x 2		
Tools		
Stop watches x 3		
Storage bins for small equipment		
Thermistor Probes		
Speed tape		
Protective clothing		
Brixometer x 3		
Tie wraps		
Tags (Labels) for Fluid designation on stand		
2.0 Litre Containers		
Fluid heating apparatus		
Thermos containers		
Wet/dry shop vaccum		
RH Vaisala meter		
PC or laptop		
Fluid sprayer		
Compressor		
Protective clothing		
Fans (NRC)		
Wind Gauge		
Scrapers		
Heat guns		
Fluid spreader		
Tub for spreaders		

ATTACHMENT III
PERSONNEL ASSIGNMENT

Overall Coordinator

- Assists team leaders as required; and
- Discusses and approves any changes to test procedures as determined necessary from test results or circumstances.

Test Team Leader & 2 Assistants

- Coordinates team member activities;
- Ensures experiments conducted in accordance with procedures;
- Advises Test Centre staff regarding tests requirements;
- Ensures data forms are completed fully;
- Calls end of test on each plate;
- Records general test data for each run;
- Directs installation of thermistor system. Ensures ongoing logging of temperature profiles of each test surface;
- Directs equipment setup for different wind conditions. Ensures wind distribution over test stand is measured and recorded at the start and end of each run;
- Measures precipitation rates; and
- With assistant, measures and records Brix values for Type I fluid tests.

Fluids Manager & 1 Assistant

- Fully knowledgeable of fluid requirements for tests. Must anticipate fluid requirements in advance of need, to avoid down time awaiting fluid for test purposes;
- Responsible for preparing accurate fluid mixes in accordance with plan, and labelling fluid containers for easy identification and to eliminate potential for errors;
- Responsible for heating fluids and maintaining them at required temperature ready for testing;
- Responsible for applying fluids when directed by team leader;
- Ensures fluid temperature and Brix is measured and recorded at time of fluid application;

Photographer (Duty performed by Test Team Member)

- Responsible to photograph and videotape test setup, conduct of tests, and any special results on test surfaces

Attachment IV
HOT WATER TRIALS
TEST SCHEDULING AND CONTROL SHEET

PRECIPITATION:	Freezing Rain at 25 g/dm²/hr	
FLUID TEMPERATURE:	60°C at the Nozzle	
TEST SURFACE TYPES:	Aluminum	Al
	Aluminum Honey Comb	C1
	Carbon Fibre on Honey Comb	C3
	Glass Fibre on Honey Comb	C4
	Kevlar on Honey Comb	C5

Note: for selected tests where time to freezing is less than 3 minutes, the test will be rerun with additional spray quantity to determine whether 3 minute lag can be delivered with additional spray quantity. These repetitions will be decided during the course of testing.

Proposed Test Period	Time Fluid Needed	Test Team	Run #	Test Objective	OAT (°C)	Fluid Type	Wind (kph)	Surface Type	Plate Exposure Time
			1	Initial Ice	-3	Water	Calm	Al	
			2	Initial Ice	-3	Water	10	Al	
			3	Initial Ice	-3	Water	10	C1	
			4	Initial Ice	-3	Water	10	C3	
			5	Initial Ice	-3	Water	10	C4	
			6	Initial Ice	-3	Water	10	C5	
			7	Initial Ice	-3	Water	20	Al	
			8	Initial Ice	-3	Water	30	Al	
			9	Initial Ice	-6	Water	Calm	Al	
			10	Initial Ice	-6	T1E -3	Calm	Al	
			11	Brix	-6	T1E -3	Calm	Al	
			12	Initial Ice	-6	Water	10	Al	
			13	Initial Ice	-6	Water	10	C1	
			14	Initial Ice	-6	Water	10	C3	
			15	Initial Ice	-6	Water	10	C4	
			16	Initial Ice	-6	Water	10	C5	
			17	Initial Ice	-6	T1E -3	10	Al	
			18	Initial Ice	-6	T1E -3	10	C1	
			19	Initial Ice	-6	T1E -3	10	C3	
			20	Initial Ice	-6	T1E -3	10	C4	
			21	Initial Ice	-6	T1E -3	10	C5	
			22	Brix	-6	T1E -3	10	Al	
			23	Initial Ice	-6	Water	20	Al	
			24	Initial Ice	-6	T1E -3	20	Al	
			25	Brix	-6	T1E -3	20	Al	
			26	Initial Ice	-6	Water	30	Al	
			27	Initial Ice	-6	T1E -3	30	Al	
			28	Brix	-6	T1E -3	30	Al	
			29	Initial Ice	-9	Water	Calm	Al	
			30	Initial Ice	-9	T1E -6	Calm	Al	
			31	Brix	-9	T1E -6	Calm	Al	
			32	Initial Ice	-9	Water	10	Al	
			33	Initial Ice	-9	Water	10	C1	
			34	Initial Ice	-9	Water	10	C3	
			35	Initial Ice	-9	Water	10	C4	

Attachment IV
HOT WATER TRIALS
TEST SCHEDULING AND CONTROL SHEET

PRECIPITATION:	Freezing Rain at 25 g/dm²/hr	
FLUID TEMPERATURE:	60°C at the Nozzle	
TEST SURFACE TYPES:	Aluminum	Al
	Aluminum Honey Comb	C1
	Carbon Fibre on Honey Comb	C3
	Glass Fibre on Honey Comb	C4
	Kevlar on Honey Comb	C5

Note: for selected tests where time to freezing is less than 3 minutes, the test will be rerun with additional spray quantity to determine whether 3 minute lag can be delivered with additional spray quantity. These repetitions will be decided during the course of testing.

Proposed Test Period	Time Fluid Needed	Test Team	Run #	Test Objective	OAT (°C)	Fluid Type	Wind (kph)	Surface Type	Plate Exposure Time
			36	Initial Ice	-9	Water	10	C5	
			37	Initial Ice	-9	T1E -6	10	Al	
			38	Initial Ice	-9	T1E -6	10	C1	
			39	Initial Ice	-9	T1E -6	10	C3	
			40	Initial Ice	-9	T1E -6	10	C4	
			41	Initial Ice	-9	T1E -6	10	C5	
			42	Brix	-9	T1E -6	10	Al	
			43	Initial Ice	-9	Water	20	Al	
			44	Initial Ice	-9	T1E -6	20	Al	
			45	Brix	-9	T1E -6	20	Al	
			46	Initial Ice	-9	Water	30	Al	
			47	Initial Ice	-9	T1E -6	30	Al	
			48	Brix	-9	T1E -6	30	Al	
			49	Initial Ice	-12	Water	Calm	Al	
			50	Initial Ice	-12	T1E -9	Calm	Al	
			51	Brix	-12	T1E -9	Calm	Al	
			52	Initial Ice	-12	Water	10	Al	
			53	Initial Ice	-12	Water	10	C1	
			54	Initial Ice	-12	Water	10	C3	
			55	Initial Ice	-12	Water	10	C4	
			56	Initial Ice	-12	Water	10	C5	
			57	Initial Ice	-12	T1E -9	10	Al	
			58	Initial Ice	-12	T1E -9	10	C1	
			59	Initial Ice	-12	T1E -9	10	C3	
			60	Initial Ice	-12	T1E -9	10	C4	
			61	Initial Ice	-12	T1E -9	10	C5	
			62	Brix	-12	T1E -9	10	Al	
			63	Initial Ice	-12	Water	20	Al	
			64	Initial Ice	-12	T1E -9	20	Al	
			65	Brix	-12	T1E -9	20	Al	
			66	Initial Ice	-12	Water	30	Al	
			67	Initial Ice	-12	T1E -9	30	Al	
			68	Brix	-12	T1E -9	30	Al	

APPENDIX C
REPORT
HOT WATER DEICING STUDY IN THE CLIMATIC CHAMBER FOR AIR CANADA

UNION CARBIDE

UNION CARBIDE CANADA INC.
7400 LES GALERIES D'ANJOU BLVD., SUITE 360, ANJOU, QUÉBEC H1M 3M2

June 26, 1998

FAX TRANSMISSION
(11 pages)

Mr. Charles O. Masters

Aircraft Safety Branch, AAR-420

Mr. Charles O. Masters
Aircraft Safety Branch, AAR-420
FAA Technical Center
Atlantic City, New Jersey
<u>U.S.A.</u>

Mr. Masters,

In preparation for the August 3-4 meeting on Deicing Only Table/Low-Glycol First Step Deicing Procedures, please find enclosed appended a report entitled *Hot Water Deicing Simulation Study in the Climatic Chamber for Air Canada*, authored by Dr. Y. Boluk and issued on March 13, 1991. Also find the copy of 5 slides summarizing this report, which had been included in the Minutes of the SAE Ground De-icing ad hod Committee held in Atlanta on June 18-19, 1991.

These documents establish that the freezing of super-cooled water can occur within a very wide range of times. The times can be as short as 2 minute. Two minutes is generally considered not enough time to proceed with the second step (ARP 4737-suggests 3 minutes). After ice is formed, application of unheated (20°C) anti-icing fluid is unable to melt this ice. The presence of an anti-icing fluid over the ice may mask the presence of ice, unless a careful examination is made. Dispatching an aircraft with ice underneath anti-icing fluid would be dangerous

In the past, I understand that first step deicing has been successfully done with fluids having a freezing point above OAT (Outside Ambient Temperature), but the second step was done with hot fluid, which eliminated any ice which might have formed. If the second step is accomplished with unheated anti-icing fluid, the experiments of Dr. Boluk show that the ice may not melt, thus, the danger.

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Product Safety (514) 493-2868
Sales (514) 493-2610

Faxes:
Distribution (514) 493-2618
Product Safety (514) 493-2628
Sales (514) 493-2619

Responsible Care: A Total Commitment®

Please make sure that during the meeting, the data of this report is considered. It is important to be certain that recommended procedures arising from this meeting eliminate the possibility of having ice underneath anti-icing fluid.

Should you have any questions, please call.

Yours very truly,

J. Leroux

Jacques Leroux
Senior Account Manager
- Chemicals

JL/fc

Enclosures

cc: Mr. C.H. Carder, Union Carbide
Mr. W.H. Hoppmeyer, Union Carbide
Mr. A.P. Manzo, Air Canada
Mr. Paul Boris, FAA
Mr. B.B. Myers, Transport Canada

HOT WATER DEICING SIMULATION STUDY IN THE CLIMATIC CHAMBER

FOR

AIR CANADA

Prepared by:

Y. Boluk

March 13, 1991

Technology Department
Union Carbide Canada Limited
Montreal, Quebec, Canada
(514) 640-6400

SUMMARY

The freezing time of wet test plates after hot water application has been investigated in the climatic chamber. Preliminary studies show that wet test plates freeze in 2 to 10 minutes at -7 °C. The freezing time depends on the water application temperature and impurities in the water and on the surface. Once a surface is frozen, application of an unheated anti-icing fluid does not melt the ice. Freezing times of water wet test plates at other subzero temperatures are under investigation.

I. INTRODUCTION

The purpose of deicing is the removal of frost, snow, and ice accumulations from aircraft surfaces to give an aerodynamically clean aircraft. The deicing of aircraft is typically achieved by applying a high-pressure stream of a hot fluid onto the surface. The thermal and mechanical energies of the hot fluid melt, dislodge and flush away frozen accumulations. The use of hot water can be an effective mechanical and thermal means to melt and remove frozen deposits. However this method leaves surfaces wet, and the water remaining on the aircraft freeze at subzero conditions. The freezing time of water wet surfaces depends on the application temperature and temperatures of air and surface.

The anti-icing of an aircraft is done to provide extended protection (holdover time) against hoar frost, snow and freezing rain. It is achieved by applying undiluted and unheated anti-icing fluid on an ice free aircraft surface(1). Therefore if the wet aircraft surface freezes after hot water deicing, the anti-icing fluid must not be applied. The objective of this study was to investigate the freezing of cold and wet surfaces after hot water application. Hot water deicing conditions were simulated using an inclined plane in the climatic chamber.

II. EXPERIMENTAL

Tests were performed in the climatic chamber at -7 °C. The plate surface was also kept at -7 °C. Water was heated to 40, 50, 60, and 70 °C and applied onto the 10 ° inclined test plate surfaces. The freezing time of hot water on test plates was recorded. Each test involved two test plates. Unheated UCAR® Aircraft Anti-icing Fluid (AAF) 250-3 was applied on the frozen test plates and its ice melt capability was also investigated.

III. RESULTS AND DISCUSSION

Part I. Hot water application

Figure I and Table I show the freezing time of wet test plates as a function of hot water application temperature. The freezing time was between 2 and 10 minutes when the water was applied at 70 °C. The variation in the freezing time was due to the nucleation of ice crystals. For real outside conditions, the presence of dust and dirt would help nucleation and shorten the freezing time close to 2 minutes. The freezing time decreased to 2-3½ minutes when the water was applied at 40 °C.

In a typical deicer truck operation the fluid temperature is controlled in the tank. However when hot water is sprayed, the large surface to volume ratio of water droplets causes a significant heat loss to the cold air. The water temperature drops between 10-15 °C before the spray impinges on the aircraft surface. The temperature drop in the water stream is the function of spraying distance, air temperature and wind factor. If the temperature is 60 °C in the deicer tank it would not be unrealistic to estimate the water temperature to be 50 °C at the wing surface. The freezing time of wet wing would be close to 3 minutes.

Part II. Anti-icing fluid application

In Part II, the anti-icing fluid at 20 °C was applied to the test plates which were frozen after the hot water application. The ice on the test plates was not melted by applying unheated anti-icing fluid. This confirms the validity of precautions given in UCAR® AAF 250-3 product literature(1).

IV. CONCLUDING REMARKS

The freezing time of a water wet surface depends on the water application temperature and purity of water at constant air and surface temperatures.

The freezing time can be as low as 2 minutes at -7 °C surface and air temperatures and for deicing water at 70°C.

An unheated anti-icing fluid did not melt the ice on frozen surfaces.

Further study is needed to measure the freezing time at other subzero air and surface temperatures.

V. REFERENCE

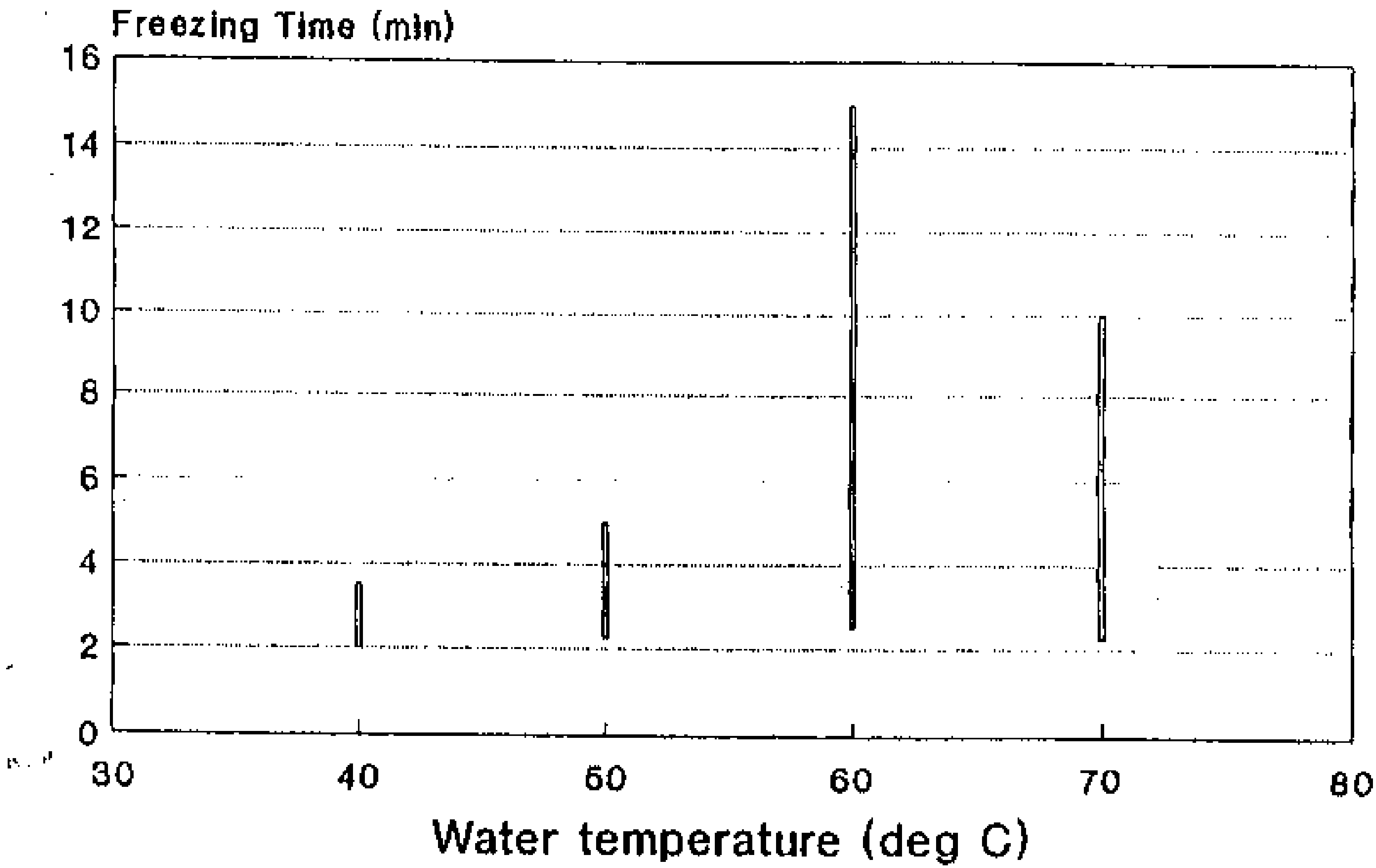
1. UCAR® Aircraft Anti-icing Fluid 250-3 Literature.

Table I. Freezing Time on Test Plates

Hot Water Application Temperature (°C)	Freezing Time (minutes)
40	2 - 3 ½
50	2 ¼ - 5
60	2 ½ - 15
70	2 ¼ - 10

Figure I. Freezing Time on Test Plates

Air and substrate temperatures= -7 deg C



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HOT WATER DEIGING
A SIMULATION IN THE CLIMATIC CHAMBER

SAE AD HOC COMITTEE MEETING
ATLANTA
JUNE 19, 1991

YAMAN BOLUK

DEICING

The removal of frost, snow and ice accumulation aircraft surfaces.

ANTI-ICING

- Provides extended protection
- Apply on a clean (ice free) aircraft

EXPERIMENTAL
COLD CHAMBER

- Air Temperature : - 7 deg C
- Skin Temperature : - 7 deg C
- Water Temperature : 40, 50, 60 and 70 deg C
- Substrate : 10 deg inclined flat plate

CONCLUSION

- Freezing time depends on the water application temperature and purity of air water.
- The freezing time can be as low as 2 minutes - 7 deg C surface and air temperature and for deicing water at 70 deg C.
- An unheated anti-icing fluid does not melt the ice on the frozen surfaces.

APPENDIX D
SAE AEROSPACE RECOMMENDED PRACTICE
ARP 4737
AIRCRAFT DEICING/ANTI-ICING METHODS WITH FLUIDS

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AEROSPACE RECOMMENDED PRACTICE

SAE ARP4737 REV. C

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Superseding ARP4737B

AIRCRAFT DEICING/ANTI-ICING METHODS WITH FLUIDS

FOREWORD

The purpose of this document is to provide guidelines for the methods and procedures used in performing the maintenance operations and services necessary for proper deicing and anti-icing of aircraft on the ground.

Exposure to weather conditions, on the ground, that are conducive to ice formation, can cause accumulation of frost, snow, slush, or ice on aircraft surfaces and components that can adversely affect aircraft performance, stability, and control and operation of mechanical devices such as control surfaces, sensors, flaps, and landing gear. If frozen deposits are present, other than those considered in the certification process, the airworthiness of the aircraft may be invalid and no attempt should be made to fly the aircraft until it has been restored to the clean configuration.

Regulations governing aircraft operations in icing conditions shall be followed. Specific rules for aircraft are set forth in United States Federal Aviation Regulations (FAR), Joint Aviation Regulations (JAR), Canadian Air Regulations, and others. Paraphrased, these rules relate that NO ONE SHOULD DISPATCH OR TAKE OFF AN AIRCRAFT WITH FROZEN DEPOSITS ON COMPONENTS OF THE AIRCRAFT THAT ARE CRITICAL TO SAFE FLIGHT. A critical component is one which could adversely affect the mechanical or aerodynamic function of an aircraft. The intent of these rules is to assure that no one attempts to dispatch or operate an aircraft with frozen deposits that were not approved by the regulatory authorities.

The ultimate responsibility for the determination that the aircraft is clean and meets airworthiness requirements rests with the pilot in command of the aircraft.

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Outside Air Temperature OAT	One-Step Procedure see 6.3.3.1 Deicing/Anti-icing	Two-Step Procedure see 6.3.3.2	
		First Step: Deicing	Second Step: Anti-icing[1]
-3 °C (27 °F) and above	FP of heated fluid[2] mixture shall be at least 10 °C (18 °F) below OAT	Water heated to 60 °C (140 °F) minimum at the nozzle or a heated mix of fluid and water.	FP of fluid mixture shall be at least 10 °C (18 °F) below actual OAT
Below -3 °C (27 °F)		FP of heated fluid mixture shall not be more than 3 °C (5 °F) above OAT	

NOTE: For heated fluids, a fluid temperature not less than 60° C (140° F) at the nozzle is desirable. Upper temperature limit shall not exceed fluid and aircraft manufacturer's recommendations.

CAUTION: Wing skin temperatures may differ and in some cases may be lower than OAT. A stonger mix (more glycol) can be used under the latter conditions.

1 To be applied before first step fluid freezes, typically within 3 min.
2 Clean aircraft may be anti-iced with *unheated* fluid

FIGURE 1 - Guidelines for the Application of SAE Type I Fluid Mixtures (Minimum Concentrations) as a Function of Outside Air Temperature (OAT)

Outside Air Temperature OAT	One-Step Procedure see 6.3.3.1 Deicing/Anti-icing	Two-Step Procedure see 6.3.3.2	
		First Step: Deicing	Second Step: Anti-icing[1]
-3 °C (27 °F) and above	50/50 Heated[2] Type II/IV	Water heated to 60 °C (140 °F) minimum at the nozzle or a heated mix of Type I, II or IV with water.	50/50 Type II/IV
Below -3 °C (27 °F) to -14 °C (7 °F)	75/25 Heated[2] Type II/IV	*Heated suitable mix of Type I, II or IV with FP not more than 3 °C (5 °F) above actual OAT.*	75/25 Type II/IV
Below -14° C (7° F) to -25 °C (-13 °F)	100/0 Heated[2] Type II/IV		100/0 Type II/IV
Below -25 °C (-13 °F)	SAE Type II/IV fluid may be used below -25 °C (-13 °F) provided that the freezing point of the fluid is at least a 7 °C (13 °F) below OAT and that aerodynamic acceptance criteria are met. Consider the use of SAE Type I when Type II/IV fluid cannot be used (see Figure 1).		

NOTE: For heated fluids, a fluid temperature not less than 60° C (140° F) at the nozzle is desirable. Upper temperature limit shall not exceed fluid and aircraft manufacturer's recommendations.

CAUTION: Wing skin temperatures may differ and in some cases may be lower than OAT. A stronger mix *(more glycol)* can be used under the latter conditions.

1 To be applied before first step fluid freezes, typically within 3 min.
2 Clean aircraft may be anti-iced with *unheated* fluid

CAUTION: An insufficient amount of anti-icing fluid, especially in the second step of a two step procedure may cause *a* substantial loss of holdover time; *particularly when using a Type I fluid mixture for the first step (deicing).*

FIGURE 3 - Guidelines for the Application of SAE Type II and Type IV Fluid Mixtures (Minimum Concentrations) as a Function of Outside Air Temperature (OAT)

2.2 U.S. Government Publications:

Available from DODSSP, Subscription Services Desk, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.

AC 20-117 Hazards Following Ground Deicing and Ground Operations in Conditions Conducive to Aircraft Icing

3. DEFINITIONS:

3.1 Abbreviations:

C = Celsius
F = Fahrenheit
OAT = Outside Air Temperature
FP = Freezing point
h = Hours
min = Minutes

3.2 Buffer/Freezing Points:

The difference between OAT and the freezing point of the fluids used.

3.3 Fluids:

CAUTION: SAE Type I fluids supplied as concentrates for dilution with water prior to use shall not be used undiluted, unless they meet aerodynamic performance and freezing point buffer requirement (reference AMS 1424).

3.3.1 Deicing fluids are:

a. Heated water
b. SAE Type I (see caution)
c. Heated concentrates or mixtures of water and SAE Type I fluid
d. Heated concentrates or mixtures of water and SAE Type II fluid
e. Heated concentrates or mixtures of water and SAE Type III fluid
f. Heated concentrates or mixtures of water and SAE Type IV fluid

Deicing fluid is normally applied heated to assure maximum deicing efficiency.